STRUCTURE OF THE SAURATOWN MOUNTAINS WINDOW, NORTH CAROLINA

edited by

Robert D. Hatcher, Jr.

CAROLINA GEOLOGICAL SOCIETY

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CAROLINA GEOLOGICAL SOCIETY
FIELD TRIP GUIDEBOOK

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NORTH CAROLINA

Edited by

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Front cover: sketch of Pilot Mountain
by Donald G. McClanahan

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FOREWORD

In 1968 a field trip to the Sauratown Mountains was conducted by David Dunn, Bob Butler, Gerry Stirewalt, and Barry Centini related to the Geological Society of America Southeastern Section meeting in Durham, North Carolina. This field trip and meeting were memorable for several reasons. We were intensely debating the nature of the Brevard fault zone and, because at that time most of the field work had been conducted in the area of the Grandfather Mountain window and the Sauratown Mountains, most of the arguments focused on geologic relationships derived from this area. At that time many of us did not accept the strike-slip fault interpretation of Reed and Bryant or the root zone hypothesis of Burchfiel and Livingston (1967, American Journal of Science) for this structure. We also did not yet know about the Smith River allochthon and were just beginning to study the well exposed segments of the Brevard fault zone and adjacent Blue Ridge and Piedmont in South Carolina and nearby Georgia and North Carolina. The Sauratown Mountains became a focus for part of the debate on the Brevard fault because of relationships between folding and faulting thought to exist in the Sauratown Mountains (see for example, Stirewalt and Dunn, 1973, GSA Bulletin). Bruce Bryant and Jack Reed had earlier suggested the quartzites in the Sauratown Mountains occur in a window. The other event that made the Southeastern Section meeting in 1968 memorable was Martin Luther King was assassinated during the meeting.

This field trip has the purpose of presenting some of the data and ideas from our recent work in the Sauratown Mountains and adjacent Piedmont. We believe that we have shown that the insights of Bryant and Reed are correct, that the Brevard fault is unrelated to the Sauratown Mountains, the Stony Ridge fault is a relatively minor structure — despite the impressive cataclasite that occurs along it — and that the Inner Piedmont stratigraphy is the same as that in the Blue Ridge and probably the Smith River allochthon. Major faults exist here, but they have different ages determined by their relationships to the metamorphic peak, and they juxtapose contrasting stratigraphic packages or basement units.

The four papers in this guidebook were written independently and represent somewhat divergent views on the interpretation of details of the structure of the Sauratown Mountains. We decided to present our conclusions in this form so that questions could be asked during the field trip that might bring out the reasons for the differences in interpretations.

We hope you will enjoy the field trip.

Bob Hatcher
Keith McConnell
Tony Heyn

October 7, 1988

ACKNOWLEDGMENTS

We wish to acknowledge the cooperation and interest of the local residents of this area during the time we worked here. Particularly, we wish to thank Danny Minton and his family, and Mrs. Clara Wall Minton for their kindness. We are also grateful for the cooperation of the rangers at Pilot Mountain State Park, particularly Eric Nygard and Andy Whitaker for their assistance.

Many hours spent in typing, drafting, and formatting the field guide by Nancy L. Meadows and Donald G. McClanahan at the University of Tennessee are very much appreciated. We also thank Leonard S. Wiener for providing some information on county roads at a critical time.

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Guidebook for 1988 Annual Meeting
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SAURATOWN MOUNTAINS WINDOW - PROBLEMS AND REGIONAL PERSPECTIVE

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ABSTRACT

The Sauratown Mountains window is a large structure located northeast of the Inner Piedmont, southeast of the Smith River allochthon, and northwest of the Carolina terrane composed of the Charlotte and Milton belts. This structure has been studied by a number of geologists who have interpreted it as an anticlinorium, a window, or a recumbent fold. Our studies confirm that the Sauratown Mountains is a complex window made up of an inner window of basement and cover (Sauratown formation) framed by a post-metamorphic thrust (Danbury fault) surrounded by an outer window of a different suite of basement and cover (Hogan Creek Formation) that is framed by a pre- to synmetamorphic thrust (Forbush fault) that transported rocks of the Ashe Formation. The Yadkin fault, mapped previously by several geologists as the boundary between the Inner Piedmont and the Sauratown Mountains, appears to be a metamorphic gradient, from lower grade toward the east to higher grade toward the west and, therefore, is not a fault. Our data also indicate the Stony Ridge fault has little or no displacement, and appears to be only a silicified and multiply reactivated Triassic-Jurassic fissure.

The geologic history of this area began with deposition of the Hogan Creek and Sauratown formations on the late Proterozoic outer rifted continental margin of North America, with the Ashe representing coeval or slightly younger sedimentation. These rocks were then deeply buried, metamorphosed and isoclinally folded, and juxtaposed along the Forbush thrust, a likely portion of the Hayesville-Gossan Lead thrust, during the Taconic event. Suturing of the Carolina terrane to North America also took place during this event, or slightly later. Overthrusting of the continental margin along the Danbury thrust occurred after the rocks had cooled to greenschist facies conditions, or lower grade, possibly during the Alleghanian when the basal Blue Ridge-Piedmont thrust sheet was emplaced. Formation of the broad anticlinorium may be related to duplexing of platform rocks beneath the Blue Ridge-Piedmont thrust sheet.

The Mesozoic history of rifting and emplacement of diabase dikes was accompanied by fracturing and hydrothermal alteration producing the siliceous cataclasite bodies of the Stony Ridge fracture zone.

INTRODUCTION

The Sauratown Mountains window is located in North Carolina and Virginia at the northeast end of the Inner Piedmont (Fig. 1). The guidebook provides an introduction to the geology of the western end of the Sauratown Mountains window (Fig. 2) and is based on detailed geologic mapping by Heyn (1984), McConnell (in progress), and myself, and on geochronologic studies conducted here during the 1980s by McConnell and others (1986, 1988) and by Fullagar and Butler (1980). The present studies were undertaken to determine the role of basement massifs in the mountain building process.

One of the first descriptions of the geology of the Sauratown Mountains was that of Kerr (1875) in which he described a quartzite of "Huronian" age surrounded by Laurentian gneisses.

The Sauratown Mountains area was first demonstrated to be a large antiformal structure by Mundorff (1948) during the course of regional geologic mapping. The area was first suggested to be a window by Bryant and Reed (1961) when they noted the similarity between the clean Pilot Mountain quartzite of the Sauratown Mountains and quartzite of the Chilhowee Group exposed in Grandfather Mountain window and the Unaka belt of the western Blue Ridge (Fig. 1). They also noted the association of complexly deformed, probably much older gneisses with quartzites in each of these areas.

Studies of this area in a more modern context began in the 1960s with D. E. Dunn, J. R. Butler, and their graduate students. These studies almost immediately resulted in several products (Centini, 1968, 1969; Butler and Dunn, 1968) and an indication that the Sauratown Mountains may be part of a recumbent fold system that also involved the Brevard fault zone (Dunn and others, 1965; Stirewalt and Dunn,

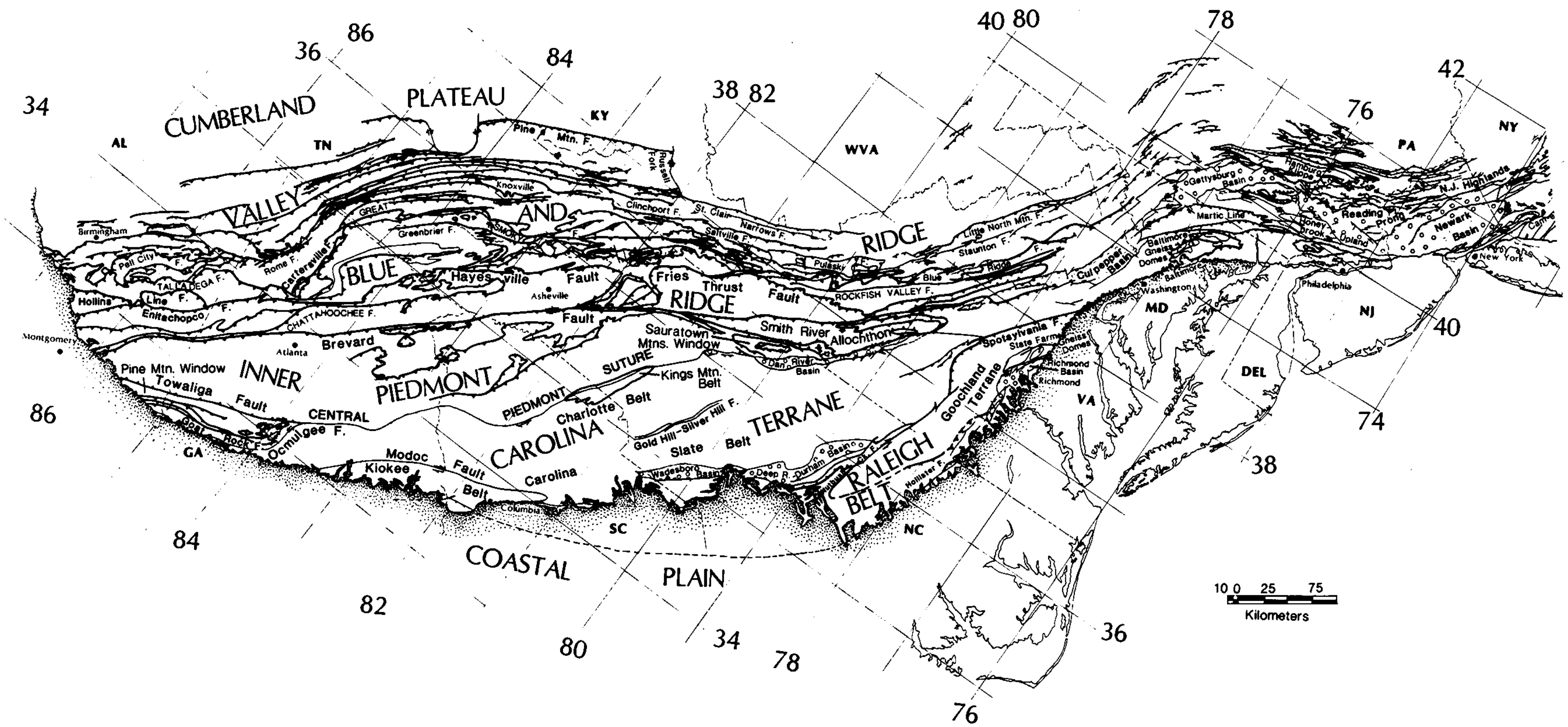

Figure 1. Location of the Sauratown Mountains window in the southern Appalachians.

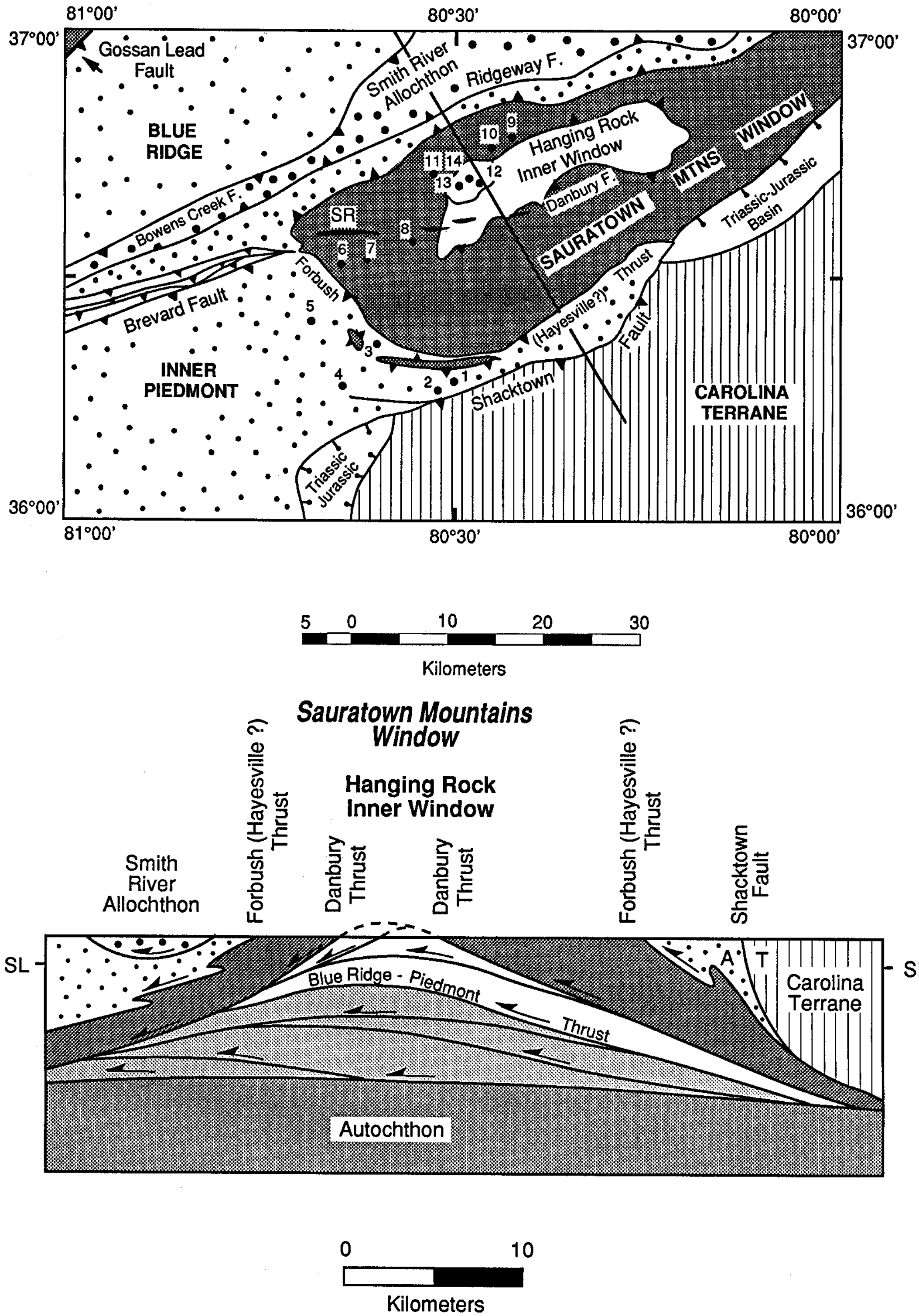

Figure 2. A. Simplified tectonic map of the southwestern Sauratown Mountains window showing locations of field trip stops. B. Cross-section through the Sauratown Mountains window (location shown in Figure 2A). SRA - Smith River allochthon. FF - Forbush fault. HRIW - Hanging Rock inner window.

1971, 1973). Butler and Dunn (1968) were the first to suggest Mesozoic reactivation of the Brevard fault resulted in the Stony Ridge fault. Reconnaissance geologic mapping by Rankin and others (1973) and Espenshade and others (1975) served to outline several major rock units of this area as well as delineate several major tectonic boundaries. Subdivisions within the basement rocks of the Sauratown Mountains were also recognized.

The discovery of the Smith River allochthon by Conley and Henika (1973) added an exciting wrinkle to the problem of the Brevard fault zone and the relationships of Piedmont to Blue Ridge rocks (Fig. 1). The Smith River allochthon consists of a group of rocks originally described as having Piedmont affinities that rest between rocks of the Sauratown Mountains - with Blue Ridge affinities - and the Blue Ridge. Rocks of the Smith River allochthon appear to have passed over the Sauratown Mountains anticlinorium to reach their present position. Lewis (1980) studied the structural relationships in the region where the projected southwestern end of the Smith River allochthon joins the Brevard fault zone and concluded the allochthon is a far-travelled Inner Piedmont nappe.

REGIONAL SETTING OF THE SAURATOWN MOUNTAINS WINDOW

Discovery of the Smith River allochthon brought forth some interesting possibilities for the kinematics of emplacement of tectonic units in the Blue Ridge and western Piedmont. This thrust sheet may be considered, like others in the region, to be part of the post-metamorphic group of thrust sheets: the Linville Falls and Fries thrusts, faults of the frontal Blue Ridge, the Chattahoochee-Soque River thrust of the central Blue Ridge in southern North Carolina and Georgia (See Hatcher and Goldberg, in press), and several thrust sheets like the Alto (Hatcher, 1978; Hopson and Hatcher, 1988) and Six Mile (Griffin, 1969, 1974) in the Inner Piedmont. Although it is possible that the Smith River allochthon is correlative with the Six Mile and Alto sheets, data presented herein indicate the Smith River allochthon is related to an eroded remnant of a fault separating the Sauratown Mountains window from the Inner Piedmont, as indicated by Espenshade and others (1975) and Lewis (1980), that they called the Yadkin fault. A major difference between the Inner Piedmont thrust sheets, the Smith River allochthon, and the post-metamorphic thrusts of the western Blue Ridge is that all of the western Blue Ridge post-metamorphic thrusts transport basement rocks. Grenville basement rocks are unknown in the Inner Piedmont and Smith River allochthon, but are likely to be present in the Inner Piedmont.

The Greenbrier, Chunky Gal Mountain-Shope Fork, and Hayesville-Gossan Lead thrust sheets comprise the known pre-metamorphic thrust complexes of the Blue Ridge. These characteristically do not contain large amounts of Grenville basement rocks, but instead (with the exception of the Greenbrier) transport most of the mafic and ultramafic rocks of the Blue Ridge and contain all of the granitoid plutons of appreciable size (>1 km^2). The Hayesville-Gossan Lead thrust is considered a suture that separates North American margin and ocean-floor sedimentary-volcanic assemblages from the North American rifted-margin, probably represent-

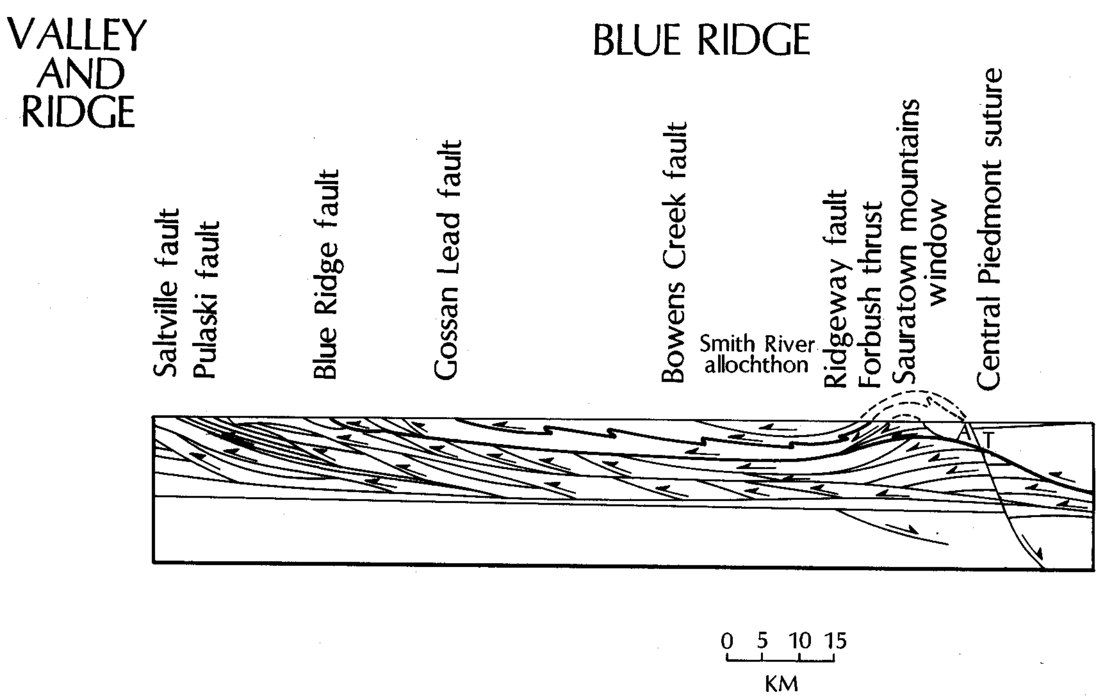

Figure 3. Cross-section through the western half of the southern Appalachians.

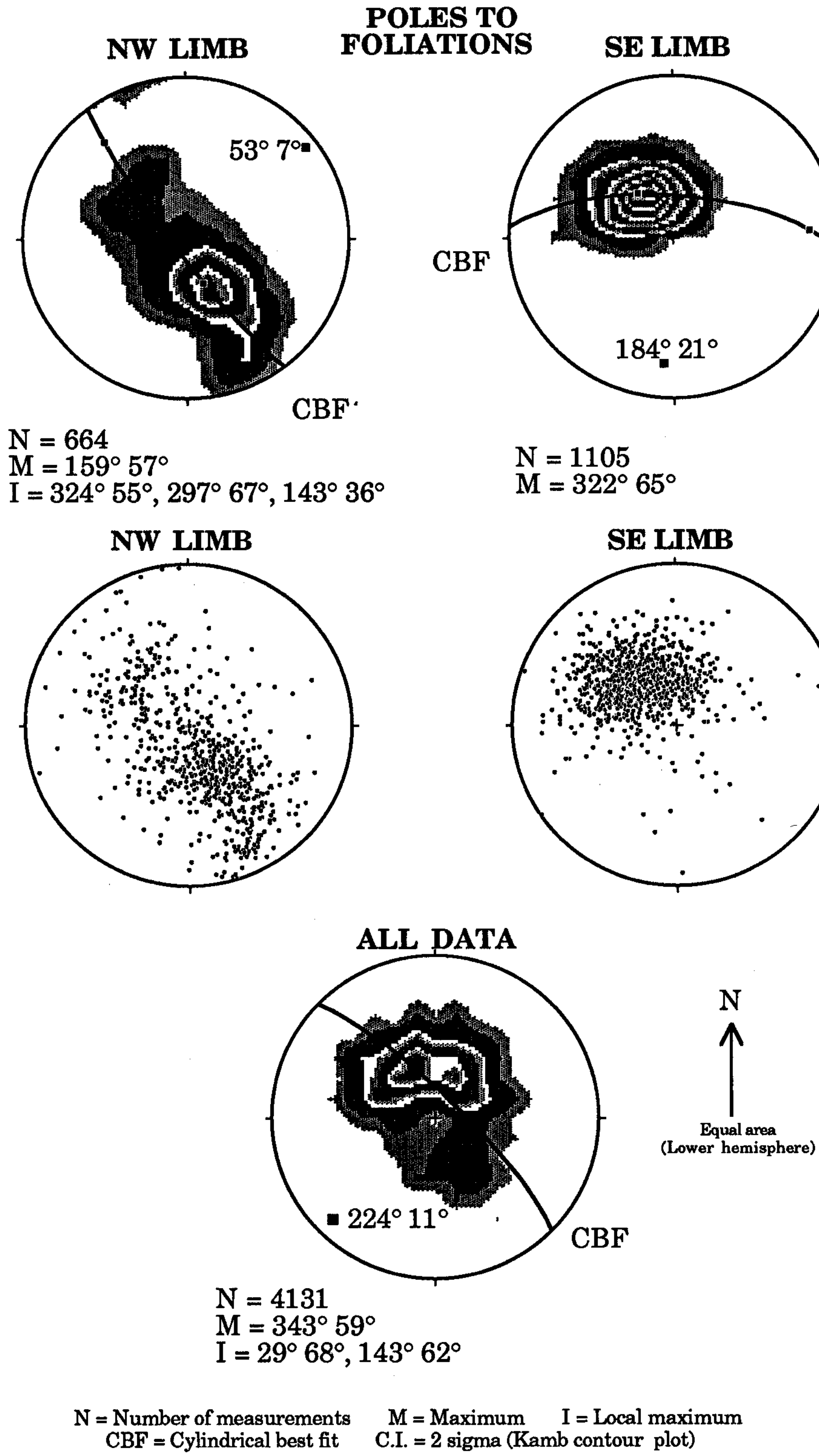

Figure 4. A. Fabric diagrams of poles to dominant foliation diagrams for the northwest and southeast flanks, and a diagram with all foliations in the area of Plate 1. The data illustrate that the anticlinorium is not perfectly symmetrical, but documentthe anticlinorium has a northwest vergence. Much of the data collected by Heyn (this guidebook; Fig. 12) in the hinge zone are included in the lower stereonet diagram (i.e., all data), but were not included in the stereonet diagrams for the limbs of the anticlinorium.

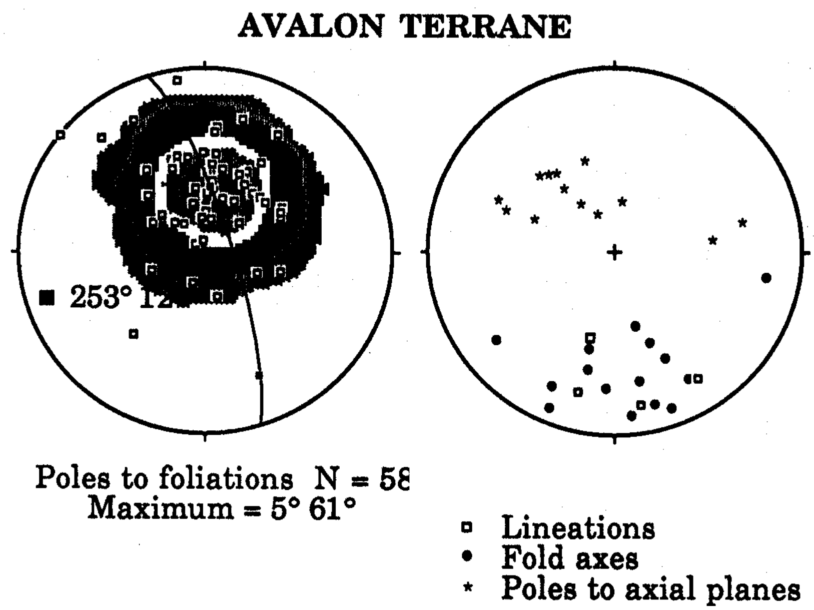

Figure 4. B. Fabric diagram of poles to dominant foliation for Carolina terrane rocks. (Diagrams were compiled and plotted by T. Heyn.)

ing accretion during the Taconic event (Hatcher, 1978; Hatcher and Goldberg, in press). Our studies indicate the presence of a major boundary framing the Sauratown Mountains window, the Forbush thrust. This thrust separates basement and cover assemblages inside the window from a stratigraphy identical to that in the eastern Blue Ridge - belonging to the Ashe-Tallulah Falls Formation - but residing in the Inner Piedmont. This fault, because of the similarities of the stratigraphy it transported and its timing relationships to the regional metamorphic peak, may be the Hayesville-Gossan Lead thrust. These relationships will be discussed more below.

South and southwest of the Sauratown Mountains window is a narrow strip of Inner Piedmont rocks that is truncated to the southeast by another fault (Shacktown fault in Fig. 1). This fault is the central Piedmont suture of Hatcher and Zietz (1980) separating rocks of North American affinity from Carolina terrane (Secor and others, 1983) rocks of European and African affinity (Armorica of Van der Voo, 1982).

Figure 3 is a simplified cross-section summarizing the relationships between major tectonic units from the Valley and Ridge to the Carolina terrane.

STRATIGRAPHIC UNITS

Several large stratigraphic units are present in the Sauratown Mountains window. These include the Ashe Formation, the Hogan Creek Formation, and the Sauratown formation. The Ashe Formation consists of metasandstone, aluminous schist, mafic, and ultramafic rocks, and is located outside the outer window in the Inner Piedmont. The Hogan Creek Formation consists of metasandstone, pelitic schist, quartzite, and minor mafic/ultramafic rocks, and is located in the outer window. The Sauratown formation contains the Pilot Mountain quartzite, arkose, and pelitic schist located inside the inner window. The Hogan Creek and Sauratown formations were probably both deposited on Middle Proterozoic basement, while the Ashe Formation was probably deposited on oceanic crust and possibly rifted fragments of North American continental basement (See Fig. 13 of Heyn). Several basement units are defined herein by McConnell based on bulk composition and tectonic association of each unit. These include the Forbush gneiss, the Miller Creek complex, the Pilot Mountain gneiss, the Grassy Creek gneiss, and the Volunteer gneiss (See McConnell, this guidebook).

METAMORPHIC GRADE

Metamorphic grade of major rock units provided the basis for identification of several faults, as well as evidence for the timing of faulting. The uniform decrease in metamorphic grade northeastward through the Ashe Formation outcrop belt and into the Hogan creek Formation provided evidence that Forbush thrust is either overprinted or moved at a time when the rocks there were almost at the same temperature toward the end of the principal metamorphic event. In contrast, the rocks of the inner window(s) are lower grade than those of the Hogan Creek belt. This provides evidence for juxtaposition of tectonic units along a major post-metamorphic boundary.

Migmatitic pods in the Hogan Creek Formation suggest

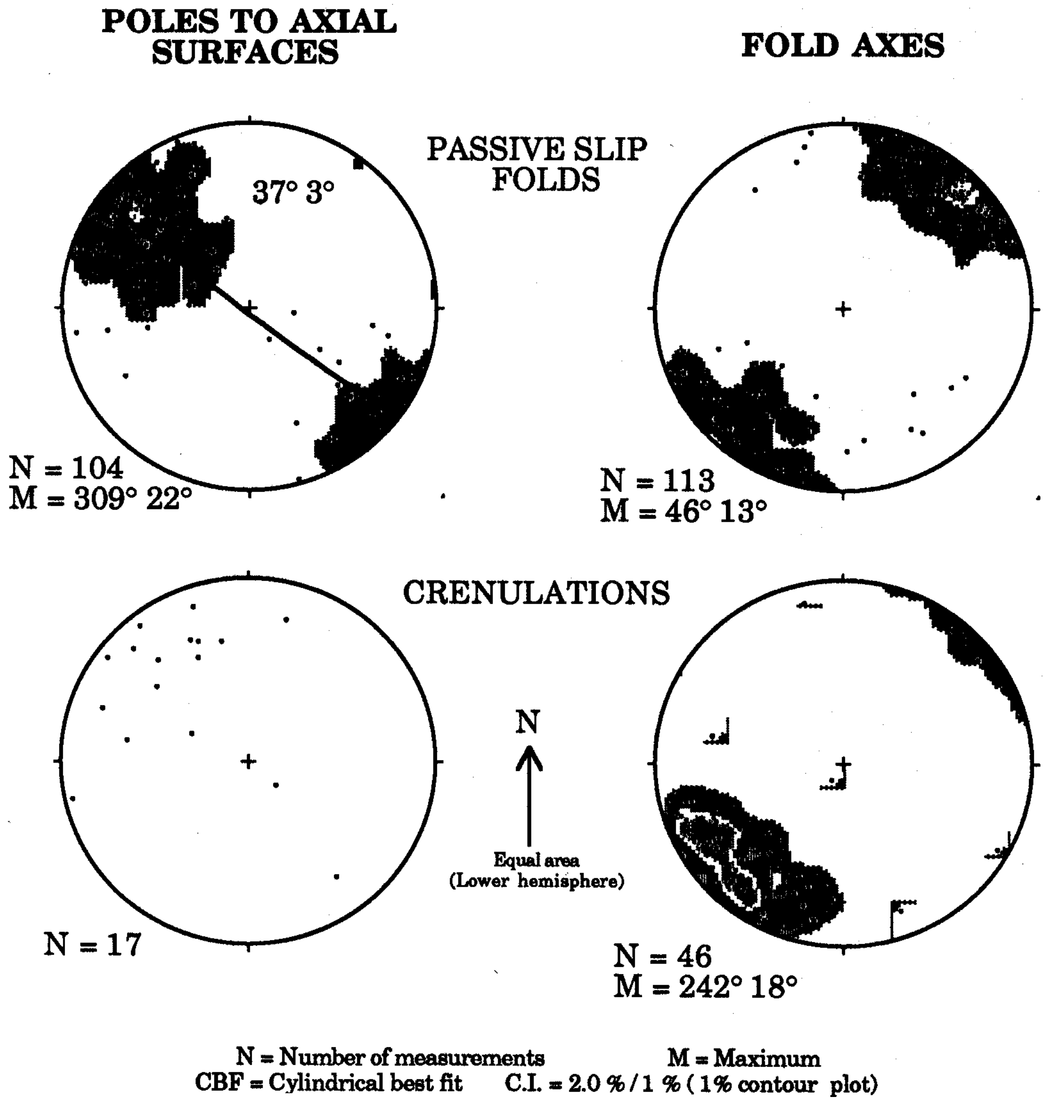

Figure 5. Fabric diagrams for all crenulation and "passive-slip" folds for the area of Plate 1. (Compiled and plotted by T. Heyn.

these rocks were metamorphosed to high grade, but the prograde equilibrium mineral assemblage present suggests the grade is no higher than garnet. These pods may have formed by metamorphic differentiation, rather than by higher grade anatectic processes, as has been suggested for the migmatites of the Ashe Formation farther west. The latter formed in the upper part of the kyanite zone and the sillimanite zone. The local high-grade appearance of the Hogan Creek Formation rocks may have led Bartholomew and Lewis (1984) to associate these rocks with Middle Proterozoic basement. All Middle Proterozoic rocks of the Appalachians contain either granulite or upper amphibolite facies mineral assemblages. The local migmatitic character is the only reason we could find to associate these rocks with other basement units like the Cranberry Gneiss, but find no other similarities.

Retrograde metamorphism is present throughout much of the Sauratown Mountains anticlinorium, but appears to be concentrated in particular zones, possibly related to intense crenulation folding (see discussion by Heyn).

MESOSCOPIC FABRIC ELEMENTS

The dominant foliation in the Sauratown Mountains anticlinorium is defined by parallel orientation of layer silicates, amphiboles, and elongate feldspar or quartz aggregates. Compositional layering and this foliation are generally parallel. Basement fabrics, both S-surfaces and folds, are indistinguishable from those in the cover, so it is impossible to distinguish basement from cover on tectonic grounds alone.

We interpreted the dominant S-surface here (Fig. 4) as S_2, because of relationships to earlier truncated foliations

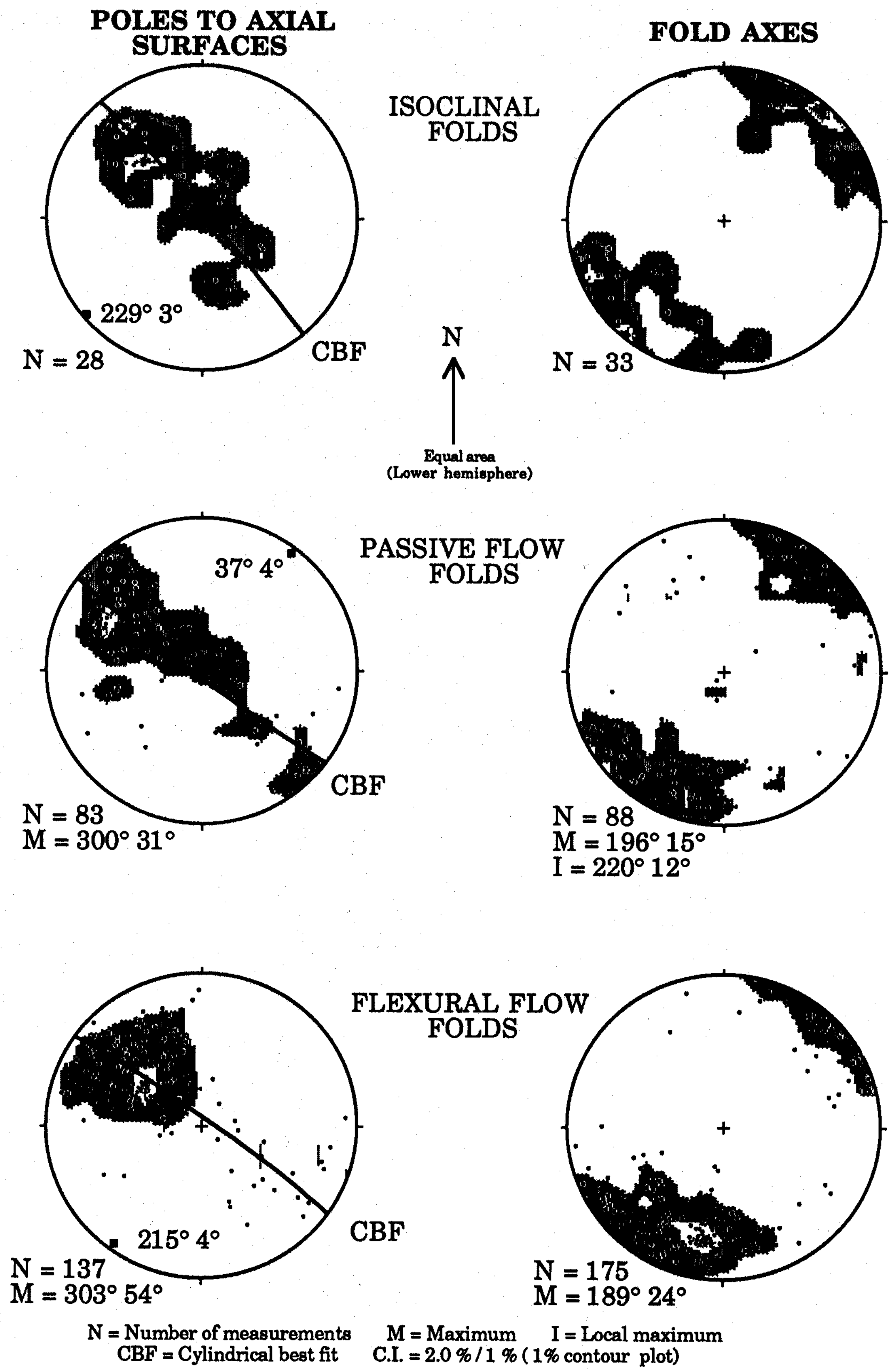

Figure 6. Fabric diagram for all early folds of different kinds for the area of Plate 1. (Compiled and plotted by T. Heyn.)

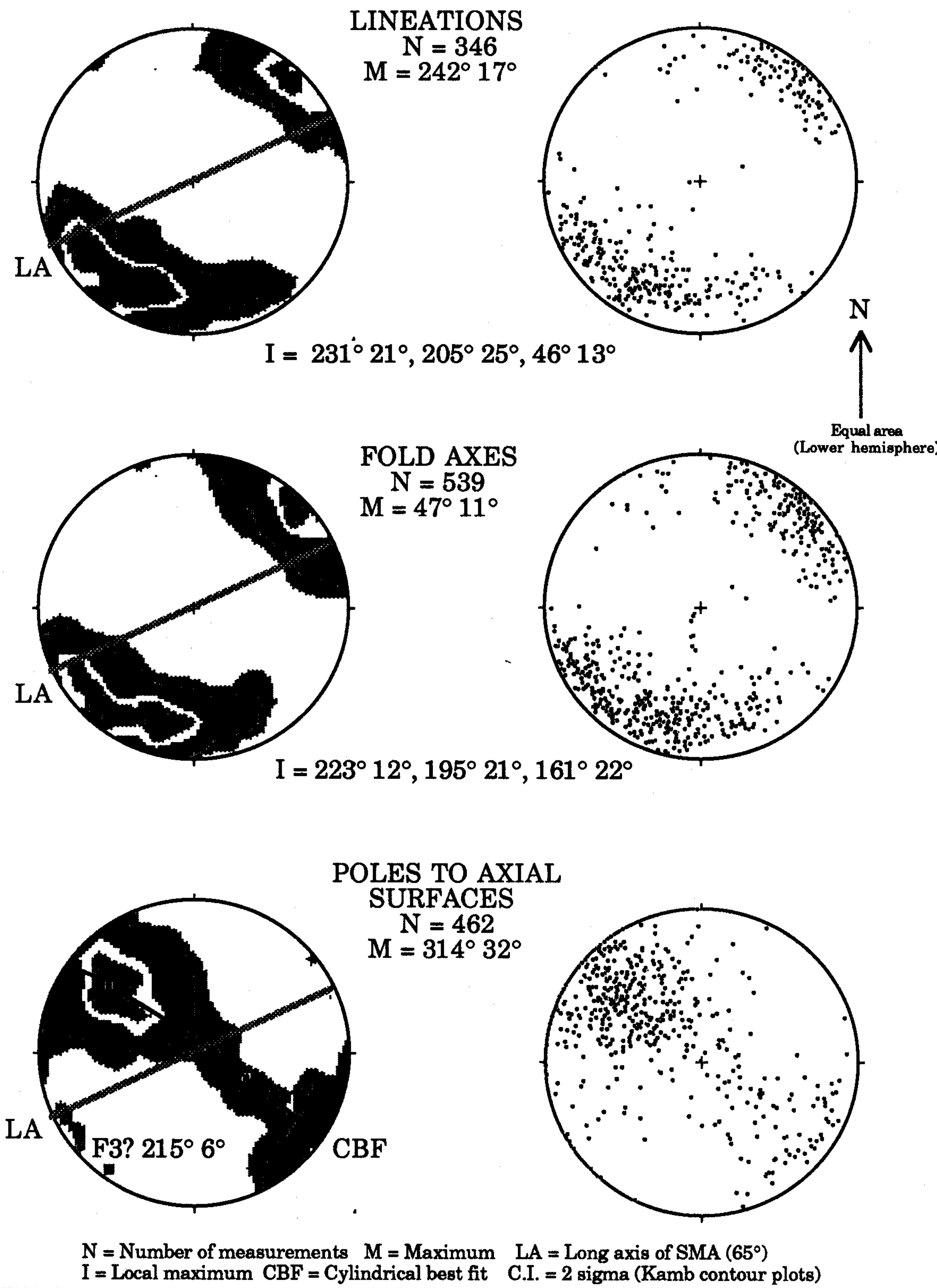

Figure 7. Fabric diagram of linear fabrics for all the area of Plate 1. (Compiled and plotted by T. Heyn.)

Figure 8. Crenulated and rodded quartz-feldspar layer in the State quarry (Stop 8).

present in boudins that are wrapped by this foliation. Most folds fold this foliation, except rarely observed folds having sheared and attenuated limbs. $_2$ is superposed by a younger foliation in the hinges of some flexural-flow folds, and partly transposed by later crenulation folds (Fig. 5), particularly in pelitic rocks. Early folds formed by either passive or flexural flow (Fig. 6); the latter are buckles. These folds and crenulations were warped by open flexural folds.

Linear structures other than folds are common in this area (Fig. 7). Planes of crenulations form an intersection lineation; intersection of S_2 with the weakly developed axial-plane foliation of pre-crenulation tight folds also forms an intersection expressed as elongate quartz, micas and feldspar parallel to the hinges of folds (Fig. 8). This lineation is easily mistaken for a "stretching" lineation: difficult to confirm without independent evidence (such as microboudins of feldspar elongate parallel to the lineation).

SAURATOWN MOUNTAINS TECTONIC UNITS

Several major tectonic units have been recognized in and around the Sauratown Mountains window (Plate 1, Fig. 2). This is a composite window framed on the outside by the pre-metamorphic Forbush thrust and on the inside by the post-metamorphic Danbury fault originally recognized by Simons (1982) at the east end of Hanging Rock Mountain. The central part of the Sauratown Mountains window comprises an antiformal basement massif with a core of 1.0 to 1.2 Ga basement rocks (Rankin and others, 1973; McConnell and others, 1986, 1988), with a cover of Late Proterozoic (?) metasedimentary rocks. The innermost window in the complex is a tectonic unit recognized by McConnell (Plate 1, Fig. 2) that exposes basement (Volunteer gneiss) unlike that in other thrust sheets in the central part of the anticlinorium. This inner window is also framed by a post-metamorphic thrust, the Volunteer thrust.

Framing the innermost late thrust assemblage in the window is a sequence of basement (Pilot Mountain gneiss) and metasedimentary cover (Plate 1). The cover consists of a sequence of graywacke, metasandstone, and pelitic schist called the Hogan Creek Formation (Hatcher and others, 1988) from exposures along Hogan Creek that traverses the widest part of the outcrop belt in the Siloam quadrangle. This unit corresponds to the "layered mesogneisses" considered Grenville-age country rocks in the Sauras massif of Bartholomew and Lewis (1984), and the Low Water Bridge gneiss of Lewis (1983). The Hogan Creek Formation is also in contact farther south with the Forbush orthogneiss.

Because of the S-C fabric present in the orthogneiss and the more pronounced mylonitic character of the contacts of the Forbush gneiss with the Hogan Creek Formation, it could be argued that the contact is a fault (see Heyn, this guidebook), albeit an early one, possibly related to the Forbush fault.

The Forbush thrust is a very important boundary because it could be correlative with the Hayesville-Gossan Lead thrust of the Blue Ridge. Almost identical stratigraphic sequences and possibly ophiolitic basement occur in both thrust sheets; both have similar timing relationships to the thermal-metamorphic peak affecting the region. Continental basement is rare in both thrust sheets, but abundant in footwall sequences, and both thrust sheets contain Paleozoic granitoids that are rare in footwall rocks.

TECTONIC PROBLEMS

A difference of opinion exists among the field trip leaders about the location of both the earlier Forbush fault and the later fault that frames the western end of the inner window (A and B, plate 1). McConnell prefers to locate the Forbush thrust northwest of the most extensive body of Forbush orthogneiss, thereby making it basement to the Ashe Formation outside the window. Hatcher and Heyn would prefer to locate the fault along the northern contact of Ashe Formation aluminous schist. Both alternatives have some merit. McConnell's alternative requires correlating the amphibolite-poor graywacke-metasandstone-pelitic schist south and west of the Forbush orthogneiss with the Ashe. This is an acceptable correlation except that this unit should be the uppermost part of the Ashe Formation (if the same relationships prevail here as where details of the Tallulah Falls stratigraphy are known). McConnell's interpretation would place Grenville basement at the top of the stratigraphic section; but if either interpretation is correct, the Ashe (or Tallulah Falls) stratigraphy must be inverted here. Presence of the lengthy outcrop belt of Forbush orthogneiss cannot be a limiting factor for location of the Forbush thrust because other smaller outcrop belts of the gneiss occur in the northern part of the Vienna quadrangle. As a compromise, both alternative fault traces are indicated in Plate 1.

The overturned sequence of Ashe Formation rocks in this area is consistent with existence of a large recumbent syn-metamorphic antiformal nappe in the Inner Piedmont southwest of the Sauratown Mountains window. This raises an additional question about the timing of the Forbush thrust, for it must have formed later than or coeval with the dominant structures in the Inner Piedmont, but is still considered here to have formed before or during the metamorphic-thermal peak.

The problem of the location of the brittle fault around the west end of the inner window presents another problem. Marked stratigraphic contrasts are not present, as with the location of the Forbush thrust, but the association of the Pilot Mountain quartzite with possibly the same or different metasandstone and pelitic schist units, is a variable that must be considered. McConnell prefers to map the fault into the mass of Hogan Creek Formation, then southwestward to envelope the southwest end of one of the bodies of Pilot Mountain gneiss. Evidence for this fault in the Hogan Creek Formation or along the contact with the basement is lacking except at one place (Stop 11), where the basement gneiss is mylonitic but the cover rocks nearby do not appear mylonitic. I prefer to map the fault along the southeast contact of the narrow linear body of Sauratown formation-Pilot Mountain quartzite member that forms a semicircle about 1 to 5 km to the north and west of the main body of Sauratown formation-Pilot Mountain quartzite member. Both McConnell and Hatcher observed a brittle fault on this contact immediately northwest of Pilot Mountain, but the displacement of this fault is unknown. If it is a major fault, as preferred by Hatcher, the relationship between the narrow linear belt of Pilot Mountain quartzite and the main body at Pilot Mountain could be explained either by thinning by faulting of the narrow belt, or thinning by change of depositional environment. The Pilot Mountain quartzite was an obviously mature, well-sorted quartz sand deposited where other components could have been winnowed away. Similar quartzite occurs on the Tallulah Falls dome in northeastern Georgia. Additional discussion of the depositional processes related to the Pilot Mountain quartzite may be found in the article by D. Walker in this guidebook.

An additional difference of opinion is related to the basement Forbush gneiss and possible correlatives. Heyn and Hatcher prefer to associate all bodies of Forbush gneiss with the tectonic unit containing the Hogan Creek Formation, even if the contacts are all tectonic. McConnell does not see the need to always associate the Forbush gneiss with the Danbury thrust sheet. The body of unnamed augen gneiss in the Ashe Formation belt may or may not be correlative with Forbush gneiss. If it is, Heyn and Hatcher would conclude it is exposed in a window through the Forbush thrust. Additional high-quality age dating would resolve the correlation problem.

A third correlation problem involves the existence of the Yadkin fault. There is no difference of opinion among the field trip leaders here. Heyn could find no evidence for a fault along the projected trace mapped by both Espenshade and others (1975) and Lewis (1980, 1983). The same rock unit - the Ashe Formation - is present on both sides of the projected contact, and a metamorphic gradient is present. Metamorphic grade increases from kyanite grade toward the east to sillimanite grade toward the southwest, consistent with the sequence here being overturned. Additional discussion of this problem may be found in Heyn's paper in the field guide.

Out interpretation of the Stony Ridge "fault" conflicts with previous geologists' work. We were unable to demonstrate the necessary "appreciable displacement" anywhere in the area of Plate 1 - certainly not enough to demonstrate that this zone is faulted. We all have mapped extensive linear sub-parallel zones of siliceous cataclasite in this area. The aluminous schist in the Ashe Formation, probably the most easily traced unit in the entire area, was mapped by T. Heyn across the projected trace of the Stony Ridge "fault" at the west end of the Sauratown Mountains without apparent displacement, although some additional fracturing and folding was noted here. Other contacts along demonstrable zones of siliceous cataclasite mapped by McConnell farther east are also not displaced. The Stony Ridge siliceous cataclasite zone is similar to others, like the Warwoman lineament, mapped or otherwise observed by myself in the southern Appalachian Blue Ridge and Piedmont. These are commonly Late Triassic to Early Jurassic fracture zones emplaced roughly at the same time as the diabase dikes. Contacts are not significantly displaced and recurrent motion along them appears from detailed mapping to be predominantly normal to the fracture zone.

TECTONIC HISTORY OF THE SAURATOWN MOUNTAINS WINDOW AREA

The Sauratown Mountains window formed as a product of compressional events that began affecting the rocks here in the early Paleozoic and continued episodically throughout the remainder of the Paleozoic and into the Mesozoic. Deposition of the Hogan Creek Formation and correlative units (the Pilot Mountain quartzite and basal arkose) occurred on Middle Proterozoic basement in a rifted-margin setting during the Late Proterozoic. Rocks of the Ashe Formation were probably deposited coevally along the continental slope and rise, and on the adjacent newly formed ocean floor, seaward from the same rifted-margin (Fig. 9; Hatcher, 1978).

Compressional activity began sometime in the Early or Middle Ordovician with recumbent folding, metamorphism, then overthrusting of the deep-water Ashe Formation sedimentary and volcanic rocks and ophiolitic basement onto the rifted margin continental basement succession along the Forbush thrust. These rocks were then tightly folded again producing the refolded-fold pattern in the southwestern part of Plate 1. These events were completed by the end of the Acadian event(s), and possibly earlier.

The Shacktown fault is probably the Taconic suture, if it is the boundary between rocks of North American affinity and Carolina terrane rocks. Regional relationships that provide information on timing of metamorphism and plutonism suggest the Shacktown fault formed during or near the end of the Taconic event (Hatcher, in press). Following accretion of the Carolina terrane to North America, construction of the orogen was completed during the Alleghanian by formation of thrusts that transported the accreted mass over the foreland forming the Danbury family of thrusts that would be

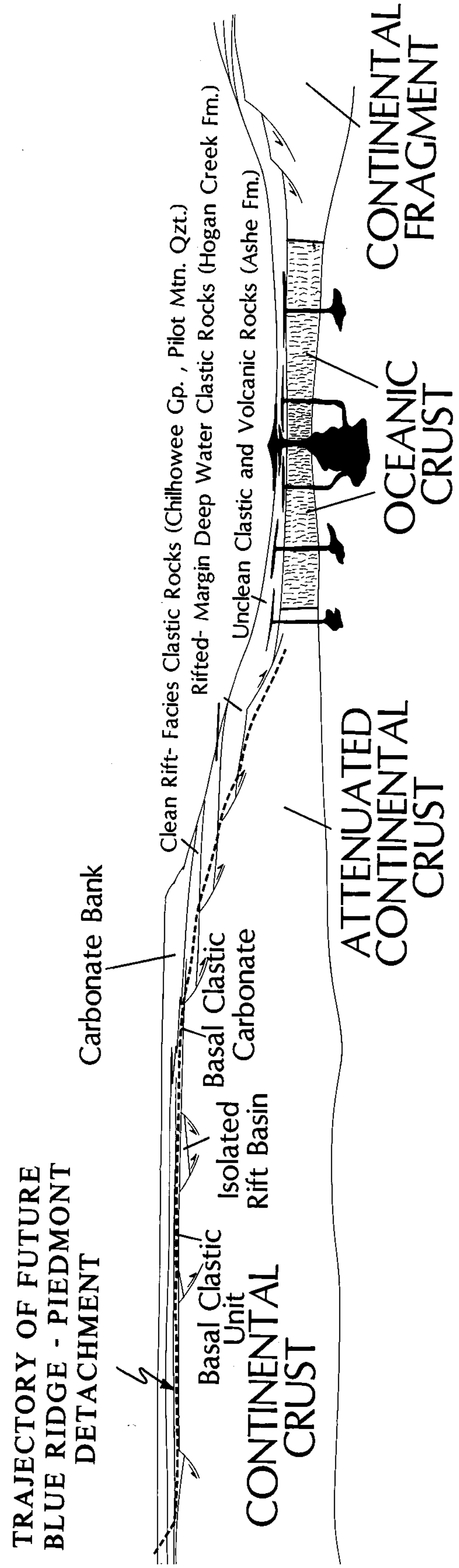

Figure 9. North American rifted-margin showing possible relationships between the different stratigraphic and tectonic units prior to Paleozoic thrusting.

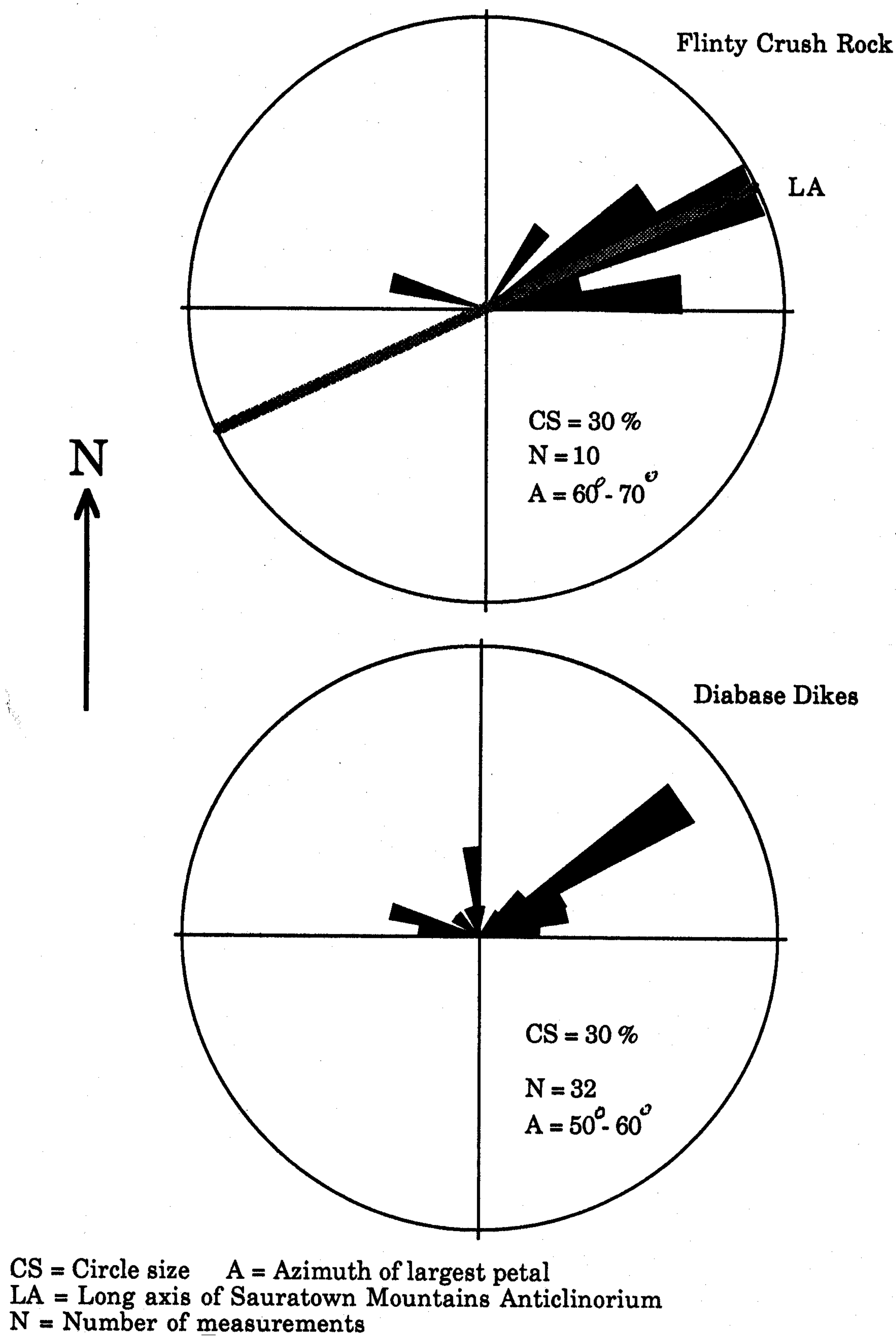

Figure 10. Rose diagrams of orientations of siliceous cataclasite (top) and diabase (bottom) dikes. (Compiled and plotted by T. Heyn.)

exposed later in the inner window. The Blue Ridge thrust beneath the exposed complex probably was arched by duplexing of platform carbonate and clastic rocks forming the Sauratown Mountains anticlinorium (Fig. 3).

Rifting and crustal extension occurred during the Late Triassic and Early Jurassic forming the Dan River and Davie County basins that flank the anticlinorium along suitable oriented segments of the earlier suture. Siliceous cataclasite and diabase dikes formed at this time (Fig. 10). Crustal extension (and possibly hydrofracturing) produced conduits for intrusion of diabase in several orientations here and elsewhere in the Piedmont (Ragland and others, 1983). Fractures that may not have penetrated the entire crust could have become sites for hydrothermal alteration under zeolitic facies conditions forming the siliceous cataclasite zones like the Stony Ridge.

ACKNOWLEDGMENTS

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GEOLOGY OF THE HINGE ZONE OF THE SAURATOWN MOUNTAIN ANTICLINORIUM, NORTH CAROLINA

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ABSTRACT

Rocks along the southwestern flank of the Sauratown Mountains anticlinorium are mostly metasedimentary rocks, and belong to the Hogan Creek and the Ashe Formations. The Hogan Creek Formation was previously interpreted as Middle Proterozoic basement, but may have been deposited on continental basement during the Late Proterozoic. The Ashe Formation might be correlative with the Hogan Creek Formation, and was probably deposited on oceanic crust. The Ashe Formation presently occurs above the Hogan Creek Formation. Two metamorphosed igneous rock units, the Forbush gneiss and an unnamed augen gneiss, were also mapped. The Forbush gneiss (as defined in this guidebook) is Middle Proterozoic basement and occurs below the Hogan Creek Formation. Its contact with the Hogan Creek Formation is probably a folded shear zone. The augen gneiss may also be basement; it occurs along the Shacktown fault, but also along the hinge zone of the anticlinorium in contact with the Ashe Formation. Rocks previously included in the Inner Piedmont appear to be continuous with the Ashe Formation.

Prograde and retrograde metamorphism affected rocks of the anticlinorium during the Paleozoic. The boundary between high-grade and medium-grade rocks in the Ashe Formation formed during prograde metamorphism. It trends subparellel to the strike of the dominant tectonic surface and the compositional layering. Prograde amphibolite-facies mineral assemblages are preserved in the Ashe Formation. Rocks of the Hogan Creek Formation attained at least epidote-amphibolite facies conditions. The lense-shape of many rock units at the map-scale is attributed to isoclinal folding. Isoclinal folds formed during prograde metamorphism. The dominant tectonic surface is parallel to the axial planes of isoclinal folds and is generally parallel to compositional layering. Retrograde mineral phases are best developed where F_3 folding was intense. Open F_4 and F_5 flexural-slip folds may have developed during the formation of the anticlinorium. The anticlinorium may also contain a set of non-cylindrical folds that formed during D_3. Cataclasites occur where the North Stony Ridge fault was previously mapped. Rocks have mylonitic fabrics where the South Stony Ridge fault had been mapped in previous studies; these fabrics are thought to have formed when S_3 surfaces developed. The distribution of the Stony Ridge cataclasites trend across to the strike of the S_3.

INTRODUCTION

The Sauratown Mountains anticlinorium (SMA) contains allochthonous basement massifs that were complexly folded during the Paleozoic. The SMA is located southeast of the Smith River allochthon, and northeast of the Charlotte belt and the Dan River Mesozoic basin in northern central North Carolina. Rocks of the SMA were studied in order to establish the spatial distribution of basement massifs within the hinge zone of the anticlinorium, and to determine the metamorphic and structural evolution of the SMA. Another aspect of the study was to determine the mechanisms and timing of movement along faults bounding the SMA. The region studied along the southwestern flank of the SMA contains the hinge zone of the SMA (Fig. 1).

The Sauratown Mountains anticlinorium has a northeast trending long axis, and is bounded on the northwest by the Smith River allochthon. The Smith River allochthon is thought to be an Inner Piedmont thrust sheet that was transported over the anticlinorium (Conley and Henika, 1973; Rankin, 1975). The Ashe Formation occurs along the margins of the SMA, and flanks the Hogan Creek Formation (Heyn, 1984). The Hogan Creek Formation occurs within the SMA, and was originally mapped as a basement unit (Rankin and others, 1973; Espenshade and others, 1975; Lewis, 1980; Bartholomew and Lewis, 1984); the Hogan Creek Formation was thought to be equivalent to rocks located at the center of the SMA that were intruded by Middle Proterozoic rocks. Rocks of the center of the SMA plunge to the southwest, beneath the Hogan Creek Formation.

The core of the SMA has generally been thought to be a single basement massif. This interpretation was based on comparisons of rocks of the Hogan Creek Formation with rocks of basement massifs elsewhere in the Appalachians, and on the intrusive relationship of Middle Proterozoic rocks into rocks similar to the Hogan Creek Formation (Bartholomew and Lewis, 1984). Data in this paper, however, indicate that the Hogan Creek Formation may be Late Proterozoic cover.

Espenshade and others (1975) and Lewis (1980) originally mapped rocks located along the southwestern flank of the SMA as Henderson Gneiss in the Inner Piedmont. Espenshade and others (1975) and Lewis (1980) also interpreted the contact of the Ashe Formation with the Inner Piedmont

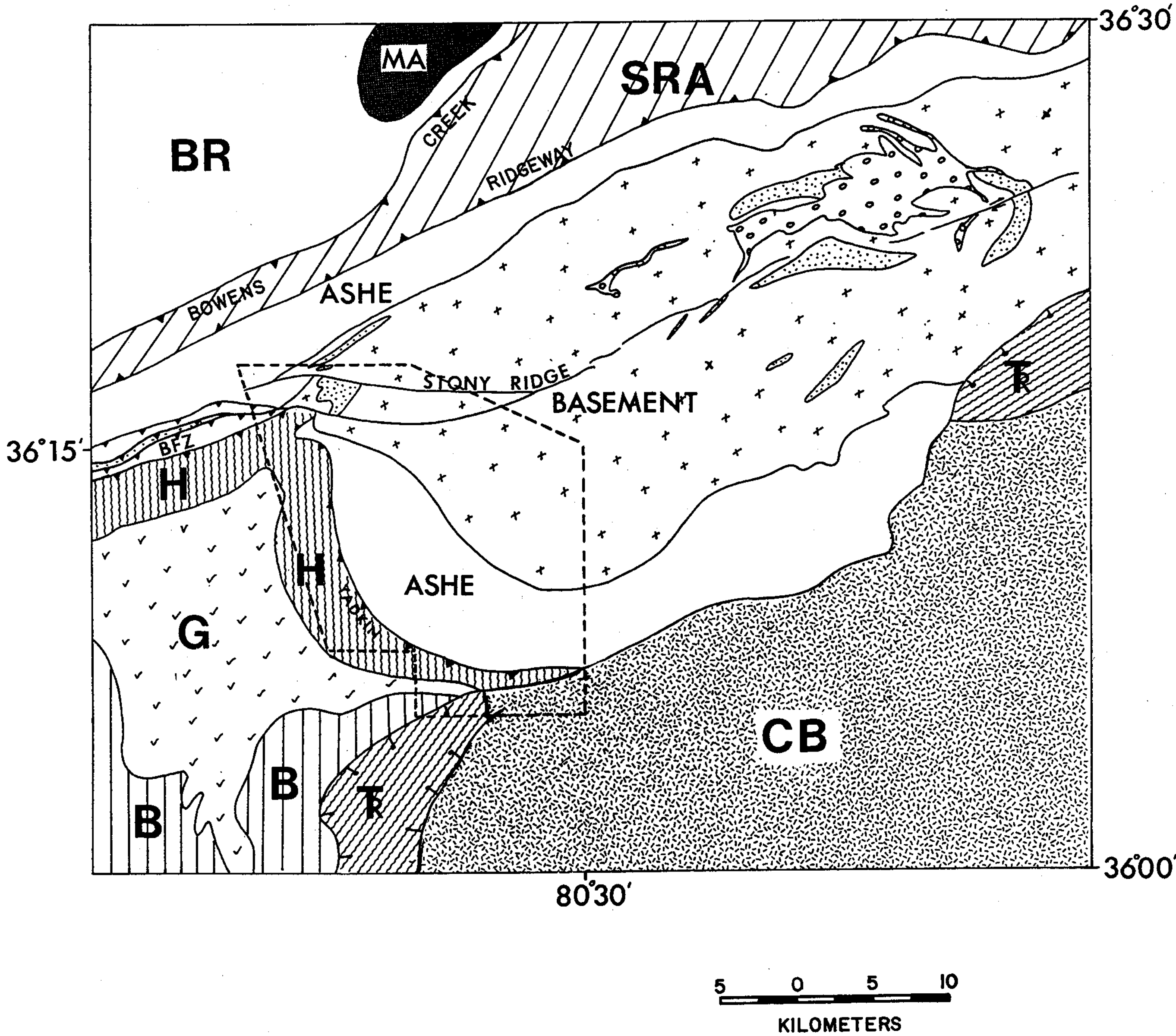

Figure 1. Geologic map of the Sauratown Mountains anticlinorium (from Espenshade and others, 1975). The box is the study area. The Yadkin fault was not mapped in the study area (see Fig. 2). Espenshade and others (1975) thought that basement (cross pattern) occupied a very large area at the center of the anticlinorium; I was able to outline only small pockets of basement (see Fig. 2). Rocks labelled as basement by Espenshade and others (1975) in the study area belong to the Hogan Creek Formation. Quartzite in the core of the anticlinorium is represented by a circle pattern. TR - Mesozoic basins. SRA - Smith River allochthon. MA - Mount Airy granite. BR - Blue Ridge. CB - Carolina terrane. G - high-grade granitic gneisses of the Inner Piedmont. B - Biotite gneisses of the Inner Piedmont. H - Rocks previously mapped as Henderson gneiss. BFZ - Brevard fault zone.

as a thrust fault. Although fabrics indicating high-strain exist in rocks along the southwestern flank of the SMA, many data from this study indicate that rocks previously mapped as Henderson Gneiss are part of the Ashe Formation of the SMA.

ROCK UNITS

Rocks of the SMA comprise unmetamorphosed and metamorphosed intrusive rocks, a mafic-rich and a mafic-poor metasedimentary sequence, and retrograded Middle Proterozoic basement (Fig. 2).

Hogan Creek Formation

The mafic-poor sequence was named the Hogan Creek Formation (Hatcher and others, 1988). The Hogan Creek Formation comprises muscovite biotite gneiss (q-o-b-m-e;

TABLE 1. Prograde mineral assemblages of the hinge zone of the SMA.

Medium grade non-migmatitic rock o the kyanite zone (Lower kyanite grade	***High grade*** Migmatitic rocks of the kyanite and sillimanite zones (Upper kyanite and sillimanite grade)
	Metabasite
HCF h-o(or a)-e-q-(+d)-(+b)	ne
GAS h-o(or a)-q-(+e)	ns
GSA h-a-e-	h-a-q-(+e
	Metacarbonate
HCF c-cl-d-q-t-p	ne
	Metapelite
HCF b-m-q-p	ns
GAS m-q-o-b-g-k-(+st	b-q-o-m-g-k or s-(+st)
GSA n	b-q-m-pl
	Meta-arkose?
HCF q-o-mi-b-m-(+e)	ne?
	Metagraywacke
HCF q-o-b-m-e-	ns
GAS q-o-b-m-	ns
GSA n	q-o(or a)-b-(+m)-(+mi)-(+e

Assemblages are grouped by protolith. The formation or member that contain these assemblages are shown.

HCF - Hogan Creek Formation. GAS - Garnet-aluminous schist member of the Ashe Formation. GSA - Graywacke-schist-amphibolite member of the Ashe Formation. Other abbreviations used in the table and text: a-andesine. am-amphibole. ac-actinolite. ant-anthophyllite. b-biotite. c-calcite. ch-chlorite. cl-clinozoisite. cpx-clinopyroxene. d-diopside. e-epidote. g-garnet. h-hornblende. k-kyanite. la-labradorite. m-muscovite. mi-microcline. my-myrmekitic plagioclase. ne-non-existent. ns-not sampled. o-oligoclase. opx-orthopyroxene. op-opaque. p-phlogopite. pl-plagioclase. q-quartz. s-sillimanite. st-staurolite. t-tremolite. ta-talc.

see Table 1 for abbreviations), biotite schist (b-m-q-pl), and quartzo-feldspathic gneiss (o-mi-q-b-m). Minor amounts of impure marble (c-cl-d-q-t-p), amphibolite (h-o-e-q-b-d), amphibole gneiss, altered ultramafic rocks (ta-ch-ant-ac-h), and feldspathic quartzite (q-o-mi-b-m) are also present. Espenshade and others (1975) grouped the Hogan Creek Formation together with various metamorphosed igneous rocks in a partly differentiated basement unit. Some rocks of the Hogan Creek Formation were formerly considered a basement unit called the Low Water Bridge gneiss by Lewis (1983) and Bartholomew and Lewis (1984).

Ashe Formation

Rocks of the mafic sequence may be correlated with rocks of the mafic-rich Ashe Formation in its type area in Ashe County, North Carolina (Rankin and others, 1973; Espenshade and others, 1975; Lewis, 1980; Hatcher and others, 1988). Heyn (1984) and McConnell (this guidebook) consider all rocks of the mafic-rich sequence to be equivalent to the Ashe Formation. Rocks of the Ashe Formation were mapped in areas previously designated as Inner Piedmont, and in areas previously designated as the Ashe Formation by Espenshade and others (1975). The Ashe Formation, as mapped by Heyn (1984), comprises garnet-aluminous schist

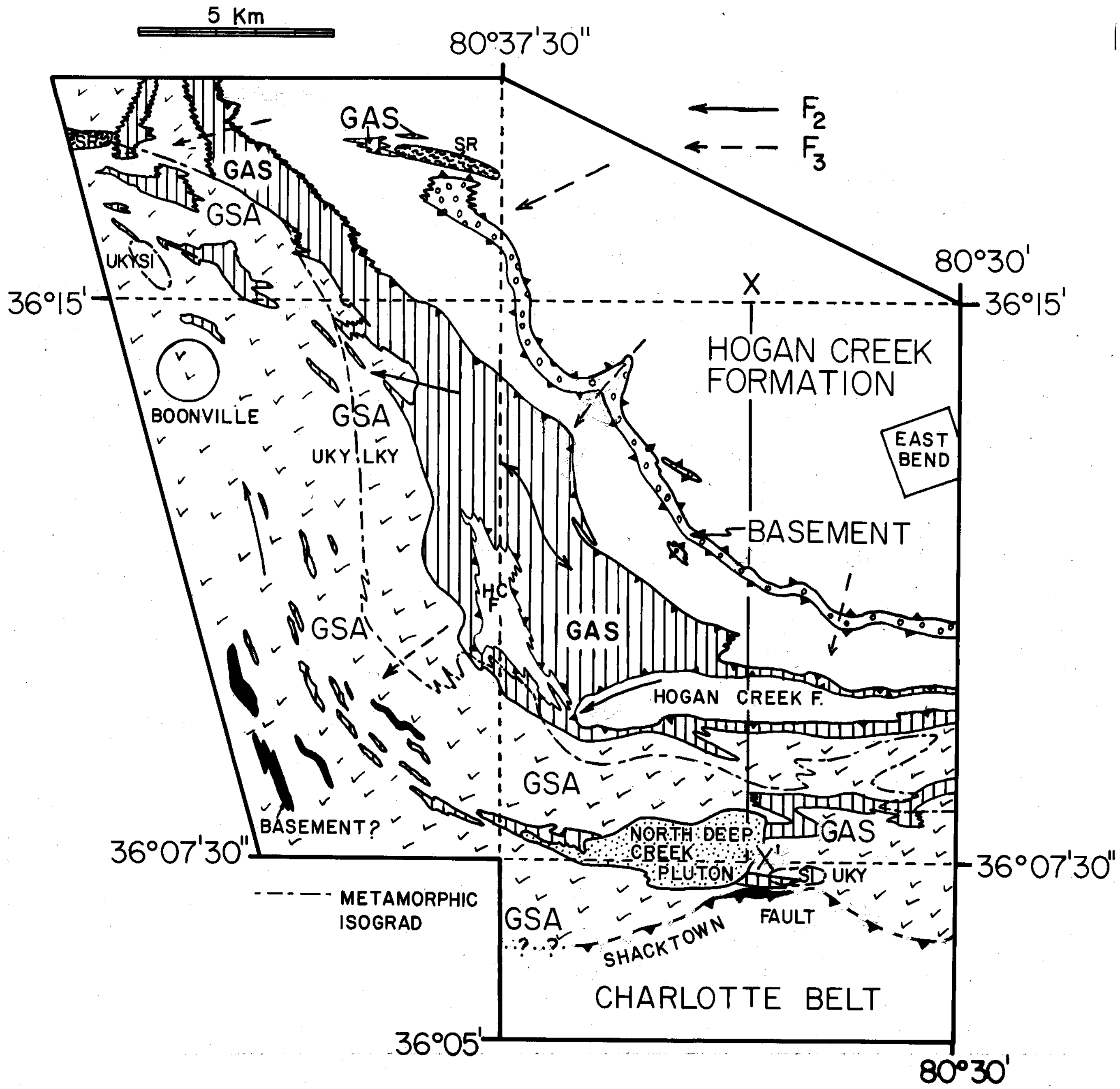

Figure 2. Simplified geologic map of the study area. The area studied includes the East Bend, and portions of the Yadkinville, Farmington, Copeland, and Siloam 7.5 minute quadrangles. The Forbush gneiss (circle pattern) is basement. The augen gneiss (black pattern) could be basement. GSA - Graywacke-schist-amphibolite member (check pattern). GAS - Garnet-aluminous schist member (vertical line pattern). UKY - High grade rocks of the kyanite zone (upper kyanite grade). LKY - Medium grade rocks of the kyanite zone (lower kyanite grade). SI - High grade rocks of the sillimanite zone (sillimanite grade). HCF - Hogan Creek Formation. SR - Stony Ridge cataclasite (wavy line pattern). There may be a change of deformational mechanism across the UKY-LKY boundary from one involving passive folding (on UKY side) to one that involves flexural-flow folding (on LKY side); compositional layering is considerably transposed south of the boundary. Solid lines with sawteeth may be premetamorphic faults.

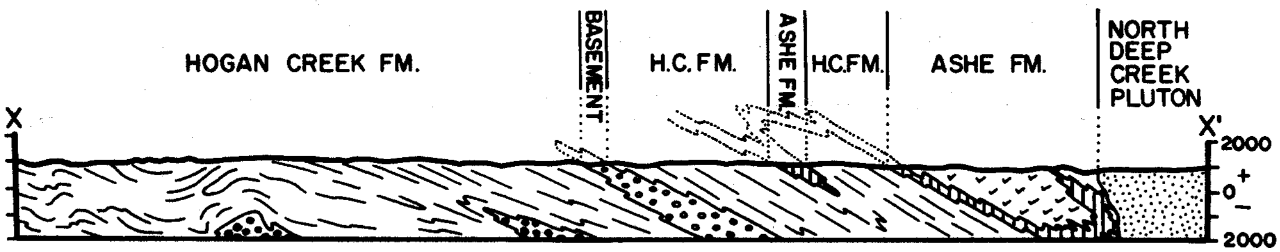

Figure 3. Simplified cross-section along X-X' in Figure 2. The graywacke-schist-amphibolite member is represented with a check pattern. The garnet-aluminous schist member is represented with a vertical line pattern.

and graywacke-schist-amphibolite units (Fig. 2 and 3). The garnet-aluminous schist member of the Ashe Formation consists of aluminous schist (m-q-o-b-g-k or s) interlayered with lesser amounts of biotite muscovite gneiss (q-o-b-m-e) and amphibolite (h-an-g-q). The garnet-aluminous schist member outcrops in two broad bands separated by rocks of the graywacke-schist-amphibolite member (Fig. 2). McConnell (this guidebook) showed that the two belts of garnet-aluminous schist member rocks are connected at the surface east of my study area (Plate 1). The belt of garnet-aluminous schist member rocks that occurs immediately south of the Hogan Creek Formation (Fig. 2) was traced from south of East Bend, North Carolina, northwestward across the Stony Ridge fault of Espenshade and others (1975) and Lewis (1980). Garnet-aluminous schist exposed just south of the Hogan Creek Formation can be traced into the graphitic garnet-mica schist unit of Lewis (1980). Espenshade and others (1975) mapped this unit 70 km around the northwestern flank of the SMA.

The graywacke-schist-amphibolite member of the Ashe Formation extends from the Shacktown fault to the northwestern flank of the SMA (Fig. 2). The graywacke-schist-amphibolite member can be traced across the Stony Ridge faults into a rock unit mapped by Lewis (1980) that contains biotite gneiss and ultramafic-rocks, even though the continuity of this unit has been obscured to some extent due to fold interference (Fig. 2). The graywacke-schist-amphibolite member contains biotite-muscovite schist (b-q-m-pl), amphibolite (h-a-e-q), and a variety of biotite gneisses (o-b-q-m-mi). Some layers of hornblende gneiss were mapped among high-grade biotite gneisses of the graywacke-schist-amphibolite member. Ultramafic rocks (opx-cpx-ch) and altered ultramafic rocks (ta-ch-ant-ac) were also mapped among amphibolites of the graywacke-schist-amphibolite member.

McConnell (this guidebook) includes a belt of rocks (predominantly biotite-muscovite gneiss) located between the garnet-aluminous schist member and a metamorphosed igneous rock here called the Forbush gneiss, with the Ashe Formation (Fig. 2); this belt of rock is, in this guidebook, included with the Hogan Creek Formation because it contains metadiorite, feldspathic quartzite, and other rocks typical of the Hogan Creek Formation.

Forbush Gneiss

The Forbush gneiss (o-q-mi-b-m-my-e) is a metamorphosed adamellite, and occurs as an elongate belt between outcrops of the Hogan Creek Formation (Fig. 2). The mylonitic fabric of the Forbush gneiss is similar to the fabric of rocks that formed by dynamic recrystallization and grain size reduction. Radiometric-U-Pb-age dating of the Forbush gneiss yielded a Middle Proterozoic age (McConnell and others, 1988). The Forbush gneiss was mapped across the trace of the South Stony Ridge fault of Espenshade and others (1975), but was not found north of the North Stony Ridge fault. Lewis (1980) indicated that Forbush gneiss is truncated along the North Stony Ridge fault. (Ironically, contacts in the Ashe Formation are neither truncated nor displaced at the scale of mapping.) McConnell (this guidebook) mapped several other lense-shaped bodies of the Forbush gneiss to the east of the area studied (Plate 1).

Although the Forbush gneiss is part of the basement in the SMA, its modal composition differs from the 1.2 Ga Pilot Mountain Gneiss, a basement unit near the center of the SMA (Rankin and others, 1973). The Forbush gneiss does not contain perthite and contains more microcline than the Pilot Mountain Gneiss. Forbush gneiss is metamorphosed adamellite whereas the Pilot Mountain Gneiss is metagranodiorite (Heyn, 1984).

Unnamed Augen Gneiss

An unnamed metamorphosed adamellite augen gneiss (mi-q-an-b-m-my-g-e) occurs as elongate bodies that are concordant with foliation and layering within the enclosing Ashe Formation. McConnell (this guidebook) included these rocks augen gneisses in the Forbush gneiss. Clasts in the augen gneiss are mostly microcline, but it also contains plagioclase clasts. The unnamed augen gneiss occurs mainly in areas previously mapped as Henderson Gneiss by Espenshade and others (1975). The augen gneiss also occurs along the Shacktown fault where it has a pronounced mylonitic fabric (see Shacktown fault). Northwest of the Shacktown fault the augen gneiss contains many subhedral feldspar megacrysts, and has a granoblastic texture. The augen gneiss has more biotite and less plagioclase than typical Henderson Gneiss studied by Hatcher (1971) and Lemmon (1973), but matches the modal mineral composition of rocks mapped closer to the SMA as Henderson Gneiss by Bryant and Reed (1970).

Intrusive Rocks and Metamorphosed Intrusive Rocks

Several intrusive and metamorphosed intrusive bodies occur in the SMA, including metadiorite, Crossnore Complex gneiss, a variety of granitic gneisses, the North Deep Creek gabbro, and Mesozoic diabase dikes. Amphibolite, and ultramafic rocks of the SMA, may be intrusive or have an ophiolitic origin, and are described with the Hogan Creek and Ashe Formations. The unnamed augen gneiss could also be intrusive, but has been described separately because it could be Middle Proterozoic basement.

The North Deep Creek gabbro (la-o-am-cpx-b) intruded the Ashe Formation after the dominant tectonic surface (S_2) formed (Fig. 2). The gabbro is porphyritic and occupies an area of approximately 15 km^2 just north of the Shacktown fault. Chlorite may have formed in the gabbro during retrograde metamorphism of the SMA. The gabbro does not have a visible foliation in hand sample, and a contact aureole was not found. A faint alignment of biotite, and undulatory extinction of some minerals in thin-section, indicate that the rock was deformed slightly.

A variety of light-colored metamorphosed igneous rock

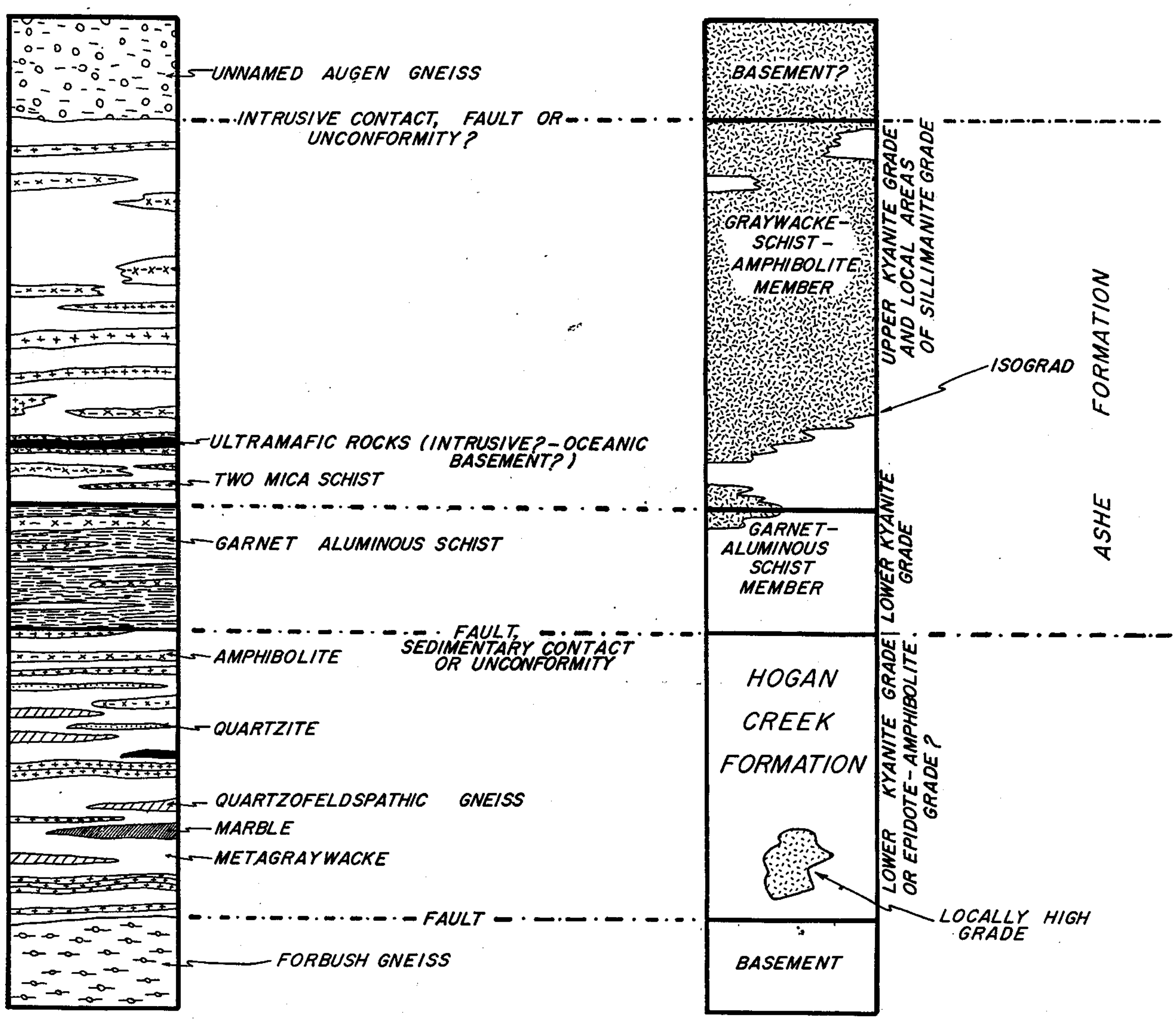

Figure 4. Lithostratigraphic sequence of the southwestern flank of the Sauratown Mountains anticlinorium. The shaded region of the right column indicates what sections of the column were affected by migmatization. Granitic leucosomes are restricted to upper kyanite and sillimanite grade rocks.

with a small grain size was mapped. Bodies are equigranular, range in composition from tonalite to adamellite, and generally are elongate parallel to the compositional layering of the Ashe and Hogan Creek Formations. Rocks of the Crossnore Complex (metamorphosed granite first outlined by Espenshade and others, 1975) were distinguished from these light-colored rocks by their texture and mineralogy. Crossnore metagranite (mi-q-pl-m-b-e-my) mapped by Espenshade and others (1975), Lewis (1980), and Heyn (1984) has more microcline, and contains large relict feldspar megacrysts. Crossnore Complex rocks were mapped in contact with rocks of the Ashe and Hogan Creek Formations (Lewis, 1980; Heyn, 1984); it is not clear if Crossnore complex rocks intruded the Ashe or if they are exposed in a window in the Ashe Formation. Crossnore Complex rocks are thought to have an age of 700-600 Ma. (Odom and Fullagar, 1984).

Small bodies of metadiorite (h-a-b-q-op) have also been mapped throughout the Hogan Creek Formation (Heyn, 1984; McConnell, unpublished data). These metadiorites only occur in the Hogan Creek Formation, and were intruded discordantly before the peak of metamorphism (Heyn, 1984).

LITHOSTRATIGRAPHIC SEQUENCE

The Hogan Creek Formation, Ashe Formation, and Forbush gneiss are lithostratigraphic units (as defined by the International Subcommission on Stratigraphic Classification, 1987). These units constitute a lithostratigraphic sequence based on their position prior to folding (Fig. 4). The Ashe Formation occurs above the Hogan Creek Formation, and the Hogan Creek Formation is interpreted to occur above the Forbush and Pilot Mountain gneiss. Folds inferred from map patterns, and structural data obtained at the outcrop scale were taken into account to reconstruct the sequence. Words such as “above” and “overlying” describe the location of a particular lithostratigraphic unit prior to folding.

The Forbush gneiss occurs below the Hogan Creek Formation and is interpreted as the lowermost unit in the study area (Fig. 4). The distribution of Forbush gneiss outcrops, structural data obtained at the outcrop, and a lithologic correlation between rocks located north and south of the Forbush gneiss indicate that the Forbush gneiss may occupy an elongate window in the core of an isoclinal antiform (Heyn, 1984). The Forbush gneiss does not intrude the Hogan Creek Formation. The contact of the Forbush gneiss with the Hogan Creek Formation is interpreted as a shear zone that accommodated displacement during metamorphism, and perhaps before metamorphism, because a soapstone body encountered in the Hogan Creek Formation appears to be truncated along the northern and southern contact, and Forbush gneiss is finer-grained near the northern contact.

Mylonitic fabrics in the Forbush gneiss are similar to rocks that experienced grain-size reduction by dynamic recrystallization. The Forbush gneiss is most intensely strained near the northern contact, and appears to be more intensely strained throughout than rocks of the Hogan creek Formation (Heyn, 1984). Many outcrops along the center of the unit have asymmetric feldspar clasts with recrystallized tails, but augen have experienced relatively little grain-size reduction. Near the northern contact with the Hogan Creek Formation, the size and number of the augen decrease considerably. The Forbush gneiss generally has small, equidimensional grains near the northern contact with the Hogan Creek Formation.

McConnell (this guidebook) mapped a calcsilicate unit in contact with rocks of the Hogan Creek Formation and interpreted these rocks as the basement on which the Hogan Formation was deposited. It is not clear whether or not this calcsilicate is part of the same basement massif as the Forbush gneiss, but McConnell noted the presence of interlayered pyroxene-bearing gneiss. McConnell attributes the outcrop pattern of the Forbush gneiss to preservation in the cores of F_2 folds but prefers to include the Forbush gneiss in the same tectonic unit as the Ashe formation above the Hogan Creek Formation. In this interpretation, the northern contact of the Forbush gneiss with the Hogan Creek Formation is a premetamorphic fault.

Amphibolites are tentatively shown to increase in abundance near the top of the Hogan Creek Formation in Figure 4, because several outcrops contain amphibolite interlayered with Hogan Creek Formation metagraywacke. Outcrops composed entirely of amphibolite or ultramafic rock occur in the Hogan Creek Formation outcrop belt near the contact with the overlying Ashe Formation. These may represent klippes of the Ashe Formation (basement?) rocks preserved in the troughs of synforms.

Ashe Formation occurs above the Hogan Creek Formation (Fig. 4). The contact of the garnet-aluminous schist member with the Hogan Creek Formation could be a fault that formed before metamorphism, or a depositional contact. If fault-related textures existed in rocks near this contact, they did not survive Paleozoic metamorphism. The belt of garnet-aluminous schist member rocks exposed just south of the Hogan Creek Formation (Fig. 2) occurs in a set of isoclinal antiforms and synforms. Rocks of the garnet-aluminous schist member exposed just north of the Shacktown fault (Plate 1, Fig. 2) are interpreted to occur in the core of a simple isoclinal antiform; this belt is thought to plunge northwest, under the graywacke-schist-amphibolite member of the Ashe Formation to the west of the North Deep Creek pluton (Fig. 2). This interpretation is based mainly on the occurrence of a layer of ultramafic rock that appears repeated at the surface due to this antiform; ultramafic rocks occur both north and south of the garnet-aluminous schist member near the North Deep Creek pluton (Plate 1).

The graywacke-schist-amphibolite member of the Ashe Formation is exposed along a south west plunging isoclinal synform (Fig. 3), and occurs above the garnet-aluminous schist member. A unique feature of this unit is that it contains a continuously mappable horizon composed of ultramafic rocks and amphibolite near its base (Fig. 4).

The augen gneiss, previously correlated with the Henderson Gneiss (Espenshade and others, 1975), could be a fourth lithostratigraphic unit situated above the Ashe Formation. The augen gneiss occurs as lense-shaped bodies within the graywacke-schist-amphibolite member outcrop belt of the Ashe Formation. West of the North Deep Creek pluton, it occurs both north and south of the garnet-aluminous schist member (Fig. 2). The outcrop distribution and location, relative to map-scale folds, indicate that the augen gneiss could be exposed in the cores of isoclinal synforms, and may, therefore, represent a lithostratigraphic unit, perhaps situated in fault (premetamorphic?) contact, above the graywacke-schist-amphibolite member. Alternatively, the augen gneiss may be intrusive into Ashe Formation. If the augen gneiss is dated as Grenville basement, the contact must be a fault or an uncomformity

METAMORPHISM

Prograde metamorphis

Rocks of the Sauratown Mountains anticlinorium are high- and medium-grade metamorphic rocks. Prograde mineral assemblages are grouped by protolith and metamorphic grade in Table 2. Prograde regional metamorphism probably occurred during the Taconic orogeny (Glover and others, 1983).

Metapelites of the Ashe Formation contain either kyanite or sillimanite. These minerals and the presence or absence of pervasive migmatite were used to define isograds between lower kyanite, upper kyanite, and sillimanite grade rocks (Fig. 2; terminology defined by Hatcher, 1973). Migmatization occurred during progressive regional metamorphism in the sillimanite zone, and in a large portion of the kyanite zone. The lower kyanite-upper kyanite boundary was drawn at the first appearance of pervasive migmatitic features (Hatcher, 1973).

The P-T conditions of medium-grade metamorphism in the Ashe Formation (field A of Fig. 5) are bracketed by the following data. Medium-grade metapelites of the Ashe Formation contain both staurolite and kyanite, but do not display migmatitic features, and oligoclase is the stable plagioclase. The “staurolite-in” isograd defines the onset of the medium-grade metamorphism (Winkler, 1979). The P-T conditions for the formation of staurolite (curve M of Figure 5; determined by Hoschek, 1969) bounds field A where it overlaps the stability field of kyanite. The Al_2SiO_5 equilibrium lines, determined by Richardson and others (1969), bound field A at the low pressure margin. Curve Q (Fig. 5) is the upper temperature boundary for field A, and approximates the P-T conditions at the onset of migmatization in rocks such as those of the Ashe Formation (where $PH_2O=P_{total}$; Winkler 1979). The migmatites in the Ashe Formation probably did not form in the absence of water because solidus curves for dry rock do not cross the kyanite stability field at less than 10 kilobars.

Medium grade gneisses (metagraywackes) of the Ashe Formation contain biotite, muscovite, quartz, and oligoclase, and minor K-feldspar. The granitic fractions of the migmatites contain abundant K-feldspar, quartz, and oligoclase (or andesine), and much less biotite and muscovite. The K-feldspar necessary for initiation of melting along curve Q may have formed as a result of a reaction which occurs at the same P-T conditions as curve Q (von Platen and Holler, 1966). This reaction is:

(1) muscovite + SiO_2 + oligoclase $\rightarrow$ K-spar/plagioclase/SiO_2 component in melt + andesine or quartz + Al_2SiO_5 + H_2O

Field observations and modal analyses of rocks fro near the medium grade-high grade boundary indicate that wherever microcline becomes abundant, it formed at the expense of muscovite (Heyn, 1984). Quartz is also less abundant in melanosomes next to microcline-rich leucosomes. The absence of kyanite in the leucosomes suggests that Al_2SiO_5 may have been removed from the system, or that it crystallized elsewhere in the melanosome. Indeed, two generations of kyanite have been observed in high-grade metapelite. The P-T field of high-grade kyanite-zone rocks of the Ashe Formation (Area B; Fig. 5) is bounded on the high-temperature side by a “staurolite-out” reaction because migmatitic metapelites contain staurolite; curve X of Richardson (1968) is an estimate of the upper temperature boundary of field B.

Rocks containing sillimanite are limited to small isolated areas (Fig. 2), but are pervasive southwest of the study area (Espenshade and others, 1975). High-grade metapelites with sillimanite contain feldspar, muscovite, biotite, quartz, and staurolite, and are interlayered with migmatitic metagraywacke. It follows that the P-T conditions of metamorphism of sillimanite grade rocks are confined to area C (Fig. 5). Presence of sillimanite may reflect a decrease in pressure, but metamorphic assemblages of the Ashe Formation probably indicate a simple P-T path that is typical of progressive Barrovian metamorphism (path H; Fig. 5). The outcrop pattern of sillimanite bearing rocks could be the manifestation of local fluid migration, but probably represents the effect of F_3 folding (see section on Structural Geology).

The P-T conditions of prograde metamorphism which affected the Hogan Creek Formation are not well constrained. The mineral assemblages of rocks studied in thin section indicate that the metamorphic grade of the Hogan Creek Formation belongs to the epidote-amphibolite facies. High-grade conditions were probably also attained locally in

Table 2. Summary of structural features. D_{Gren}? = Potential deformational episode of the Grenville orogeny. D_{1-5} are Paleozoic deformational phases. D_6 may be a Mesozoic deformational episode.

EVENT	FOLDS			S-SURFACES		SHEAR ZONE/FAULT
	Designation	Style	Average orientation of fold axis	Designation	Description or comment	
D_{Gren}?	—	—	—	—	Possibly manifested in high-strain fabrics of augen and Forbush gneisses	—
—	—	—	—	S_0	Compositional layering (commonly transpose)	—
D_1	—	—	—	—	—	Premetamorphic faults?
D_2	F_1	Isoclinal FF, PF	Variable	S_1	Axial plane foliation	Shacktown?
	F_2	Isoclinal recumbent PF, FF	Variable	S_2	Dominant tectonic surface	Shacktown Grain-size reduction of many tectonites; high-grade shearing along SW flank of SMA
D_3	F_3	Tight, open similar FF, FS overturned upright	SW	S_3	Penetrative in schists Crenulation cleavage	Shacktown; mylonitization along zones parallel to S_3
D_3 or D_4?	F_4	Open, FS Upright	SW	—	Possibly equivalent to F_3	—
D_3 or D_5?	F_5	Open, FS Upright	SE	—	Possibly due to non-cylindrical geometry of F_3	—
D_6 ?	—	—	—	—	—	Stony Ridge

Abbreviations: FS = Flexural-slip FF = Flexural-flow PF = Passive-flow

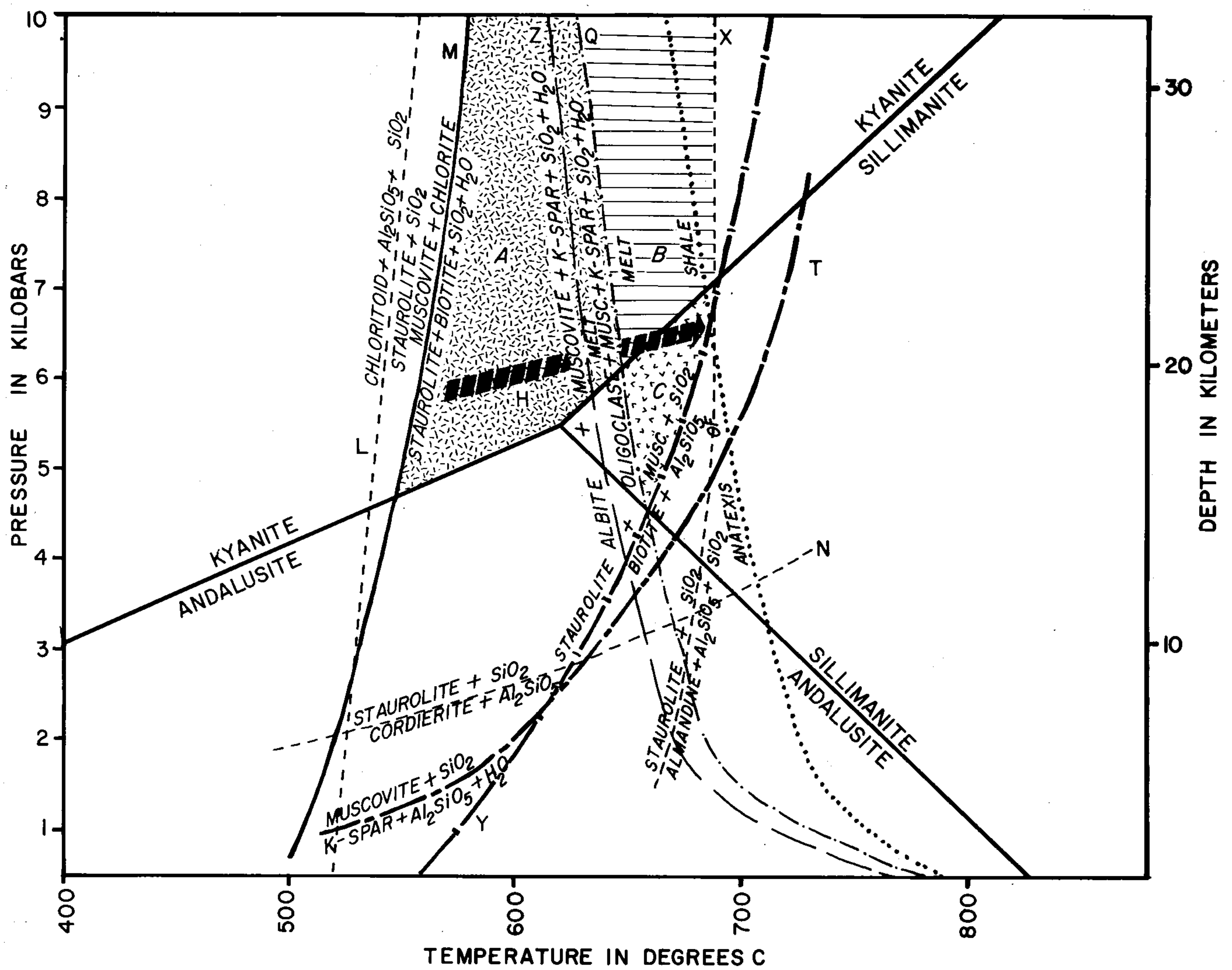

Figure 5. The stability fields of the Ashe Formation exposed along the hinge zone of the Sauratown Mountains anticlinorium. The temperatures attained during Barrovian metamorphism were between 550°C and 700°C. The rocks were buried to depths of 20 km. A - The stability field of medium grade rocks. B - The stability field of high grade rocks of the kyanite zone. C - The stability field of high grade rocks of the sillimanite zone. The thick black arrow (H) represents a possible path for metamorphism. Al_2SiO_5 lines are from Richardson and others (1969). Curve Z is from Winkler (1979). Curves L, N, and X are from Richardson (1968). Curve M is from Hoscheck (1969). Curve T is from Evans (1965). Curve Y is from Hoscheck (1968). The curve for anatexis of shale is from Wyllie and Tuttle (1969). Curve Q is the same as Z, but is shifted 15 °C to the right.

the Hogan creek Formation as indicated by the existence of migmatitic features. Migmatites of the Hogan Creek Formation were not delineated on the map scale, so isograds are not shown in Figure 2.

The minerals of metabasic rocks encountered in the Hogan Creek outcrop belt indicate that the rocks of the northern portion of the study area belong to the garnet zone. Samples studied can have garnet, and usually contain oligoclase (~An_{25}), and either blue-green or pale-green pleochroic hornblende. The disappearance of albite in metabasite marks the lower boundary of rocks of the amphibolite facies according to Cooper and Lovering (1970). Miyashiro (1973), however, considered amphibolites with albite, epidote, and hornblende (blue-green pleochroic) to be characteristic of the epidote-amphibolite facies. Ramberg (1952) considered the boundary between the epidote-amphibolite and the amphibolite facies to be coincident with the first appearance of andesine in equilibrium with epidote. Thus, the mineral assemblage of metabasites of the Hogan Creek Formation is consistent with at least the epidote-amphibolite facies (low grade) and probably the amphibolite facies (medium grade).

The presence of diopside in amphibolite that is interlayered with gneiss of the Hogan Creek Formation indicates that these rocks belong to the amphibolite facies. Diopside forms roughly in the lower part of the amphibolite facies in the medium pressure series of metamorphism (Miyashiro, 1973). The exact temperature at which diopside forms depends mainly on the bulk rock composition. Diopside also forms near the lower boundary of the amphibolite facies in marble (Miyashiro, 1973), and marble of the Hogan Creek Formation contains diopside.

Many rocks studied in thin-section indicate that the mineral assemblages of the Hogan Creek Formation may have formed at P-T conditions lower than medium-grade rocks of the Ashe Formation. Metabasite of Ashe Formation contains hornblende with light green rather than blue-green pleochroism, and generally contains andesine. Prograde epidote is also less abundant in Ashe Formation amphibolite. Miyashiro (1973) indicated that with increasing metamorphic grade, epidote becomes less abundant, plagioclase more Ca-rich, and hornblende changes pleochroic-color from blue-green to green-brown. It is not clear if quartzo-feldspathic gneisses of the Hogan Creek Formation were partial melts, formed by metamorphic differentiation, or represent metamorphosed sedimentary layers. It is clear that some outcrops in the Hogan Creek Formation were affected by high-grade conditions because these outcrops contain coarse granitic leucosomes.

Retrograde metamorphism

Greenschist-facies minerals formed mainly where $_3$ folding was intense (see section on Structural Geology). Retrograde minerals are well-developed on trend with several northeast trending faults located just west of the SMA (interpreted as the Brevard fault zone by Espenshade and others, 1975) in areas of the SMA where D_3 was particularly intense. Rocks along the Shacktown fault were also affected by retrograde metamorphism. Retrograde metamorphism also occurred, to a lesser degree, elsewhere in the SMA. Retrograde minerals might have formed in the SMA when lo grade metamorphism, dated at approximately 360-390 m.y. (Odom and Fullagar, 1973; Sinha and Glover, 1978), occurred along the Brevard fault zone. The northeast trending faults that occur immediately west of the SMA were affected by retrograde metamorphism (Espenshade and others, 1975).

Retrograde metamorphism of the SMA is manifested in the following incomplete reactions. Aluminum silicate is rimmed by white mica. This assemblage may have formed according to the reaction:

(2) $3SiO_2 + 3Al_2SiO_5 + H_2O + 2K \rightarrow 2KAl_2AlSi_3O_{10}(OH)_2$

Fractured garnet porphyroclasts are altered to chlorite, probably as a result of the following retrograde reaction:

(3) garnet + $H_2O \rightarrow$ chlorite + quartz +/- hematite

Irregular rims of chlorite around garnet porphyroblasts may also be produced according to reaction (3). Plagioclase is typically sericitized and altered to epidote as a result of the following retrograde reaction:

(4) $SiO_2 + H_2O$ + K + plagioclase $\rightarrow$ sericite + epidote (+/- clinozoisite)

Since epidote forms at the expense of Ca-plagioclase, rocks with considerable retrograde epidote commonly contain albite. Other changes include:

(5) biotite $\rightarrow$ chlorite

(6) amphibole $\rightarrow$ chlorite

Chloritoid occurs in Hogan Creek Formation gneiss on trend with the northeast-trending faults located west of the anticlinorium. It is interpreted to have formed during retrograde metamorphism (Espenshade and others, 1975). Chloritoid first forms in the biotite zone, reaches its maximu development in the garnet zone, and rapidly diminishes in the staurolite zone (Fig. 5). Retrograde minerals involved in the development of $_3$ are described in the structure section. Retrograde reactions could have occurred during a separate M_2 metamorphic event, or could be related to fluid migration during the waning stages of regional metamorphism. Local alteration due to fluids associated with an intrusion or faulting may also have initiated many of these reactions.

Proterozoic Metamorphism

Relict granulite mineral assemblages were not found in rocks previously interpreted as basement in the study area. McConnell (this guidebook) has recognized granulite-facies metamorphism in a lithostratigraphic unit interpreted to be located at the base of the Hogan Creek Formation (Plate 1).

STRUCTURAL GEOLOGY

Structural elements of the SMA are summarized in Table 2 and in Figures 6 through 10. Some structure is also expressed in the aeromagnetic data for this area (Fig. 11). The orientation of fabric elements such as foliations and lineations are represented on equal-area (lower hemisphere) diagrams; most of the diagrams are contoured following the method of Kamb (1959). Most rocks of the hinge zone of the SMA are thought to have been deformed during the Paleozoic, and were affected by up to five phases of folding. Fine-grained mylonitic fabrics of the Forbush gneiss may partly be the result of a Middle Proterozoic deformational event.

Folds and foliation

Two phases of isoclinal folds (F_1 and F_2) developed during prograde metamorphism. The dominant tectonic surface developed during isoclinal folding, and is defined by a high-grade or a medium-grade mineral assemblage. This tectonic surface generally dips 30^o to 40^o towards the southwest (Fig. 12a). Isoclinal folds have geometries consistent with the flexural-flow buckling and passive-flow folding mechanisms

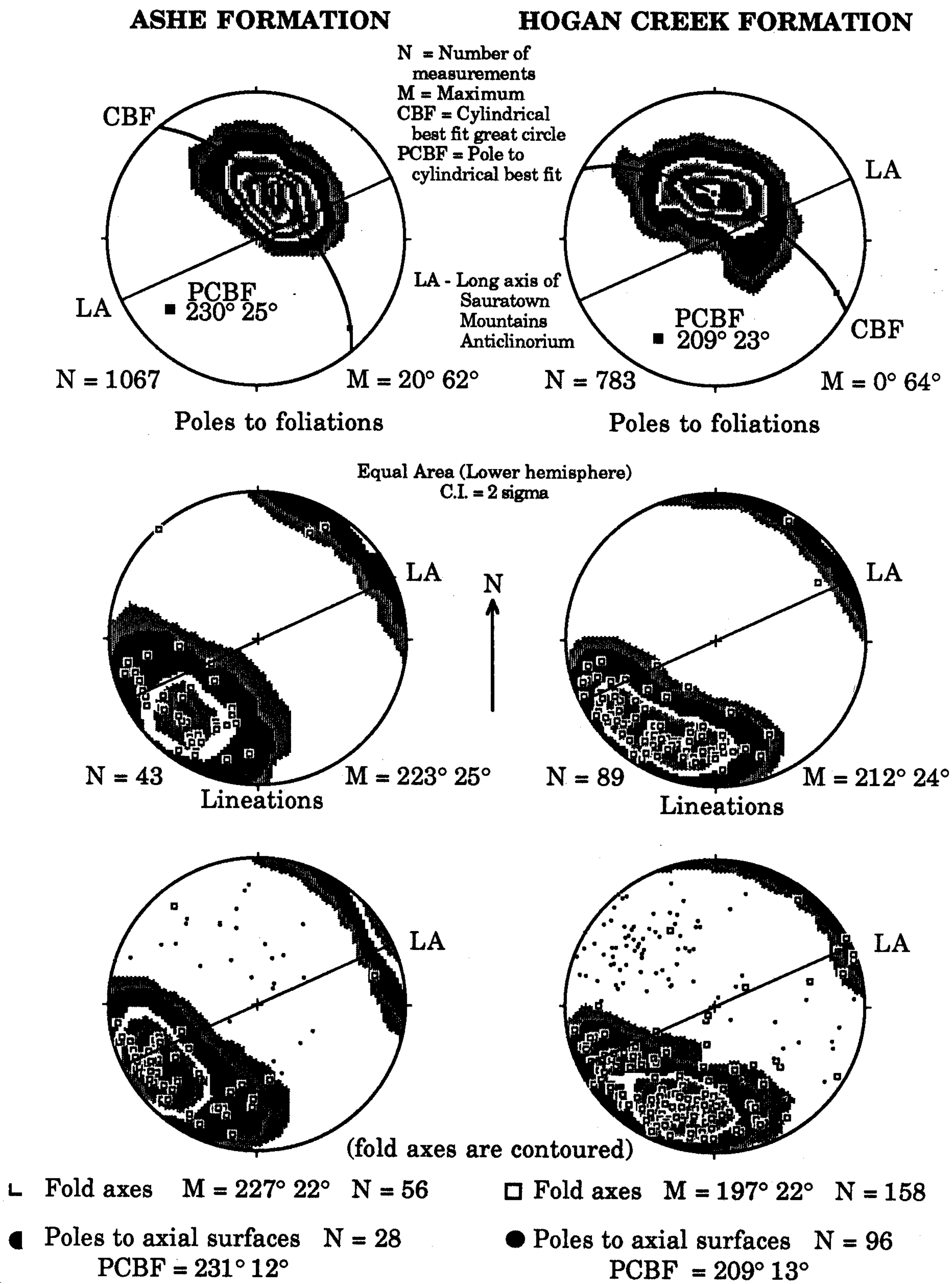

Figure 6. Stereonet diagrams of structural data from the Ashe and Hogan Creek Formations. The long axis of the Sauratown Mountains anticlinorium was determined from Espenshade and others (1975) map. The Hogan creek Formation was generally interpreted as basement. Fabric elements of the Hogan Creek Formation have the same orientation as those of other rocks in the area studied. The Hogan Creek Formation could be correlative with the Ashe Formation.

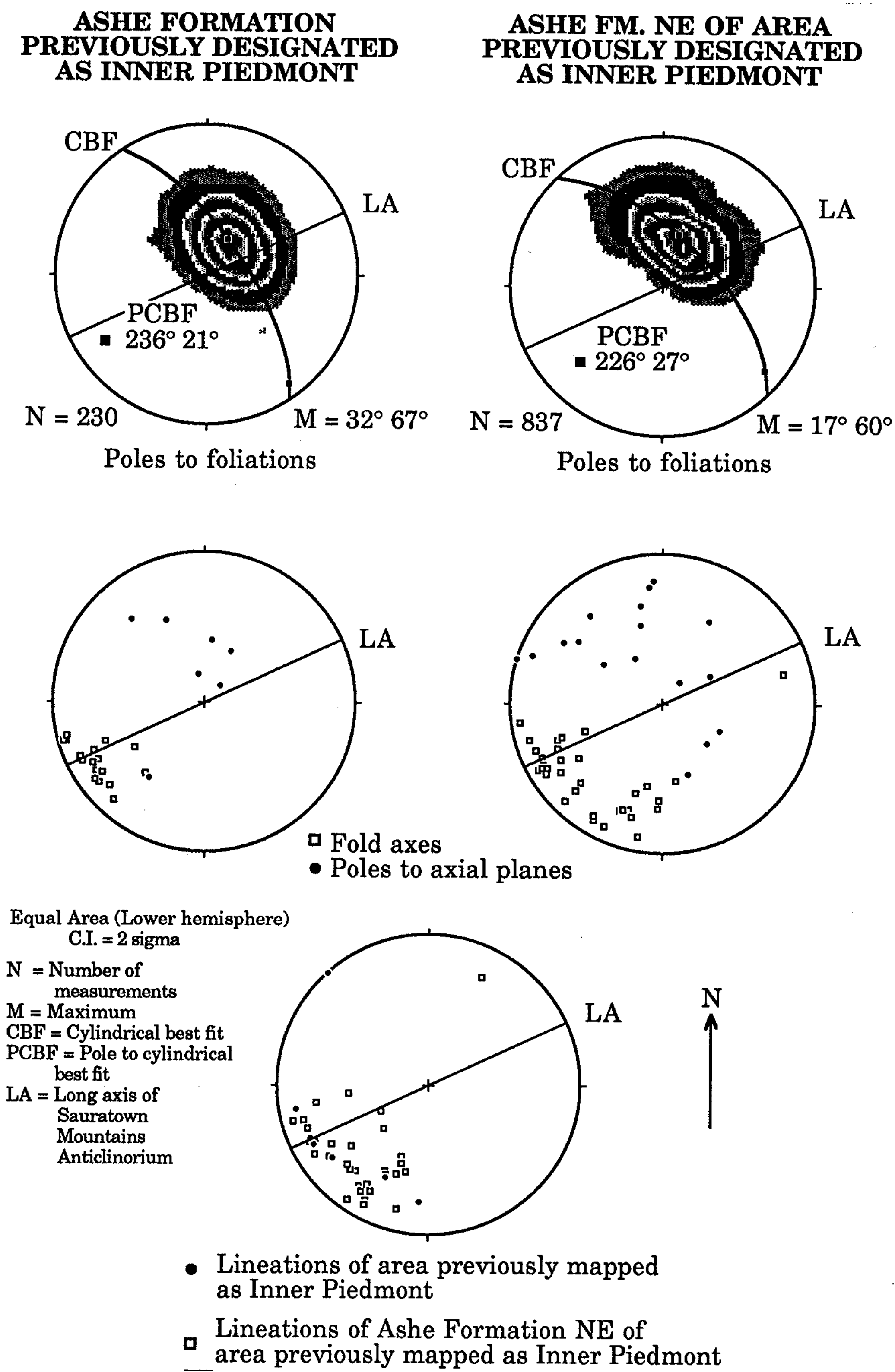

Figure 7. Stereonet diagrams of structural data from the area previously designated as the Inner Piedmont and from the Ashe Formation north of area previously designated as the Inner Piedmont by Espenshade and others (1975). The similarity in the data ofthe two domains, geophysical data, and field observations indicate that the "Yadkin fault" does not bound the SMA in the area studie d, and that the Ashe Formation extends into the area delineated as the Inner Piedmont by Espenshade and others (1975).

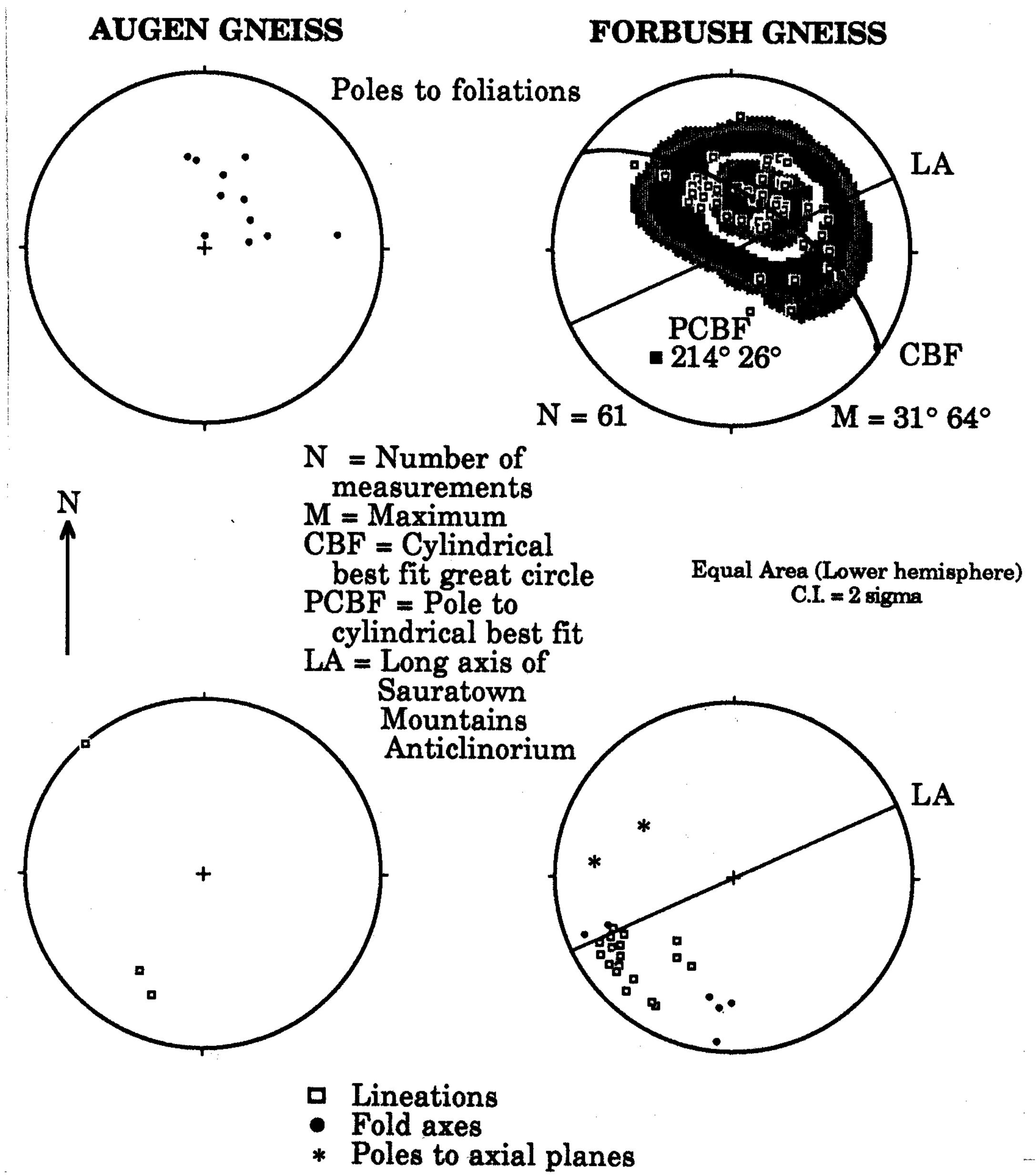

Figure 8. Stereonet diagrams of structural data from the Forbush gneiss (basement) and from the augen gneiss. The orientations of fabrics elements of the Forbush gneiss are not distinguishable from those of other rocks of the SMA. The augen gneiss may have been intruded into the Ashe Formation, it may also be basement. The Forbush gneiss is unique because it has a mylonitic fabric.

described by Donath and Parker (1964). Isoclinal folds have a variable orientation (Fig. 9). This variation is attributed to later refolding, but may, in part, exist because isoclinal folds are non-cylindrical. The axial surfaces of isoclinal folds are parallel to the dominant foliation (compare the maxima of Fig. 12a with Fig. 9a and 9f).

It is not clear if F_1 folding was penetrative throughout the entire area because F_1 folds are rarely observed. F_1 folds appear to be the first structures that modified compositional layering (S_0) in both the Ashe and Hogan Creek Formations, and have an S_1 axial-plane foliation. Compositional layering and the axial surfaces of F_2 folds are parallel to the axial surfaces of F_1 folds except in the hinge zones of F_2 folds. S_1 is sometimes preserved at the hinge zones of F_2 isoclines in medium-grade rocks. S_1 is also preserved in amphibolite boudins and is inclined to the foliation (S_2) that wraps around the boudins. The S_1 surface is also preserved as straight inclusion trails in prekinematic garnets wrapped by S_2. Sigmoidally-shaped inclusion trails in garnets from the limb of an F_2 fold, may indicate that isoclinal folds developed during a single long-lasting deformational event. The inclusion trails are continuous with the S_2 foliation of the

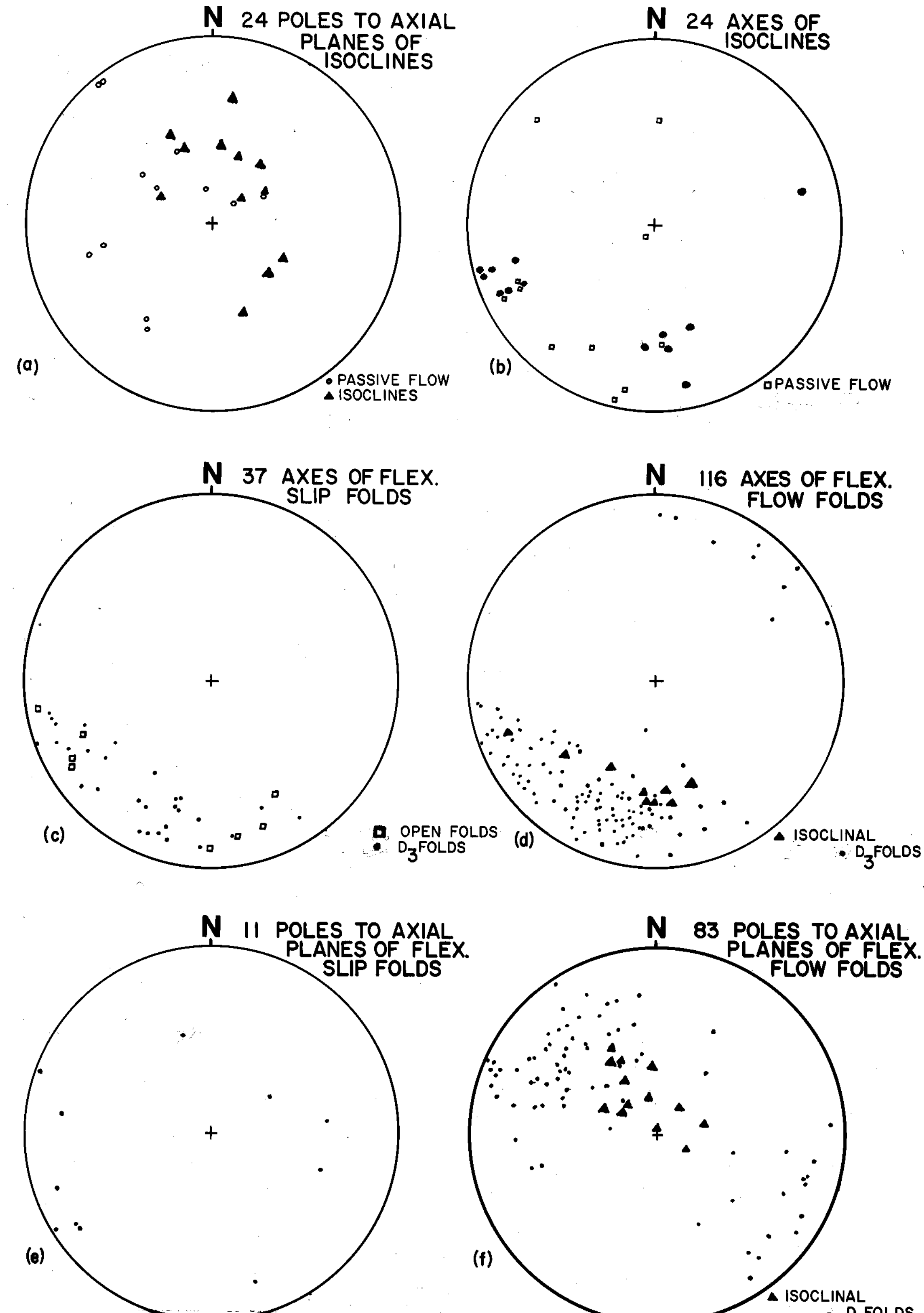

Figure 9. Stereonet diagrams of (a) poles to axial planes of isoclinal folds, (b) isoclinal fold axes, (c) flexural-slip fold axes, (d) flexural-flow fold axes, (e) poles to D_3 flexural-slip fold axial planes, and (f) poles to D_3 flexural-flow fold axial planes. Isoclines plotted in (a) and (b) include both passive- and flexural-flow isoclines. Some F_2 isoclines that formed by the passive-flow mechanism are distinguished in (a) and (b). The axes of some flexural-flow isoclines are plotted with F_3 flexural-flow folds in (d). This complexity can be accounted for in the model of Figure 11b.

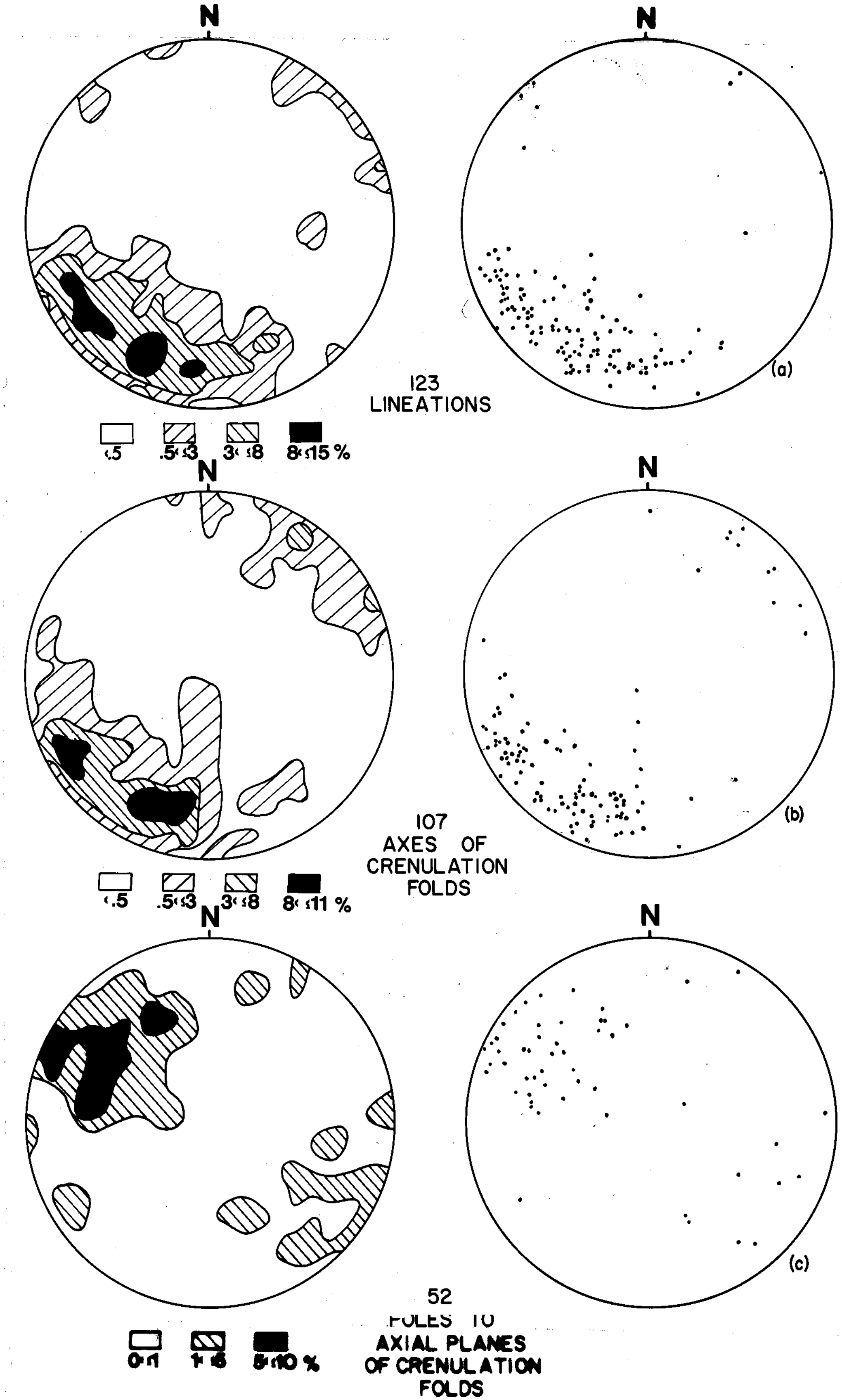

Figure 10. Equal-area stereonet diagrams of (a) lineations, (b) axes to crenulation folds, and (c) poles to axial planes of S_3 crenulation folds.

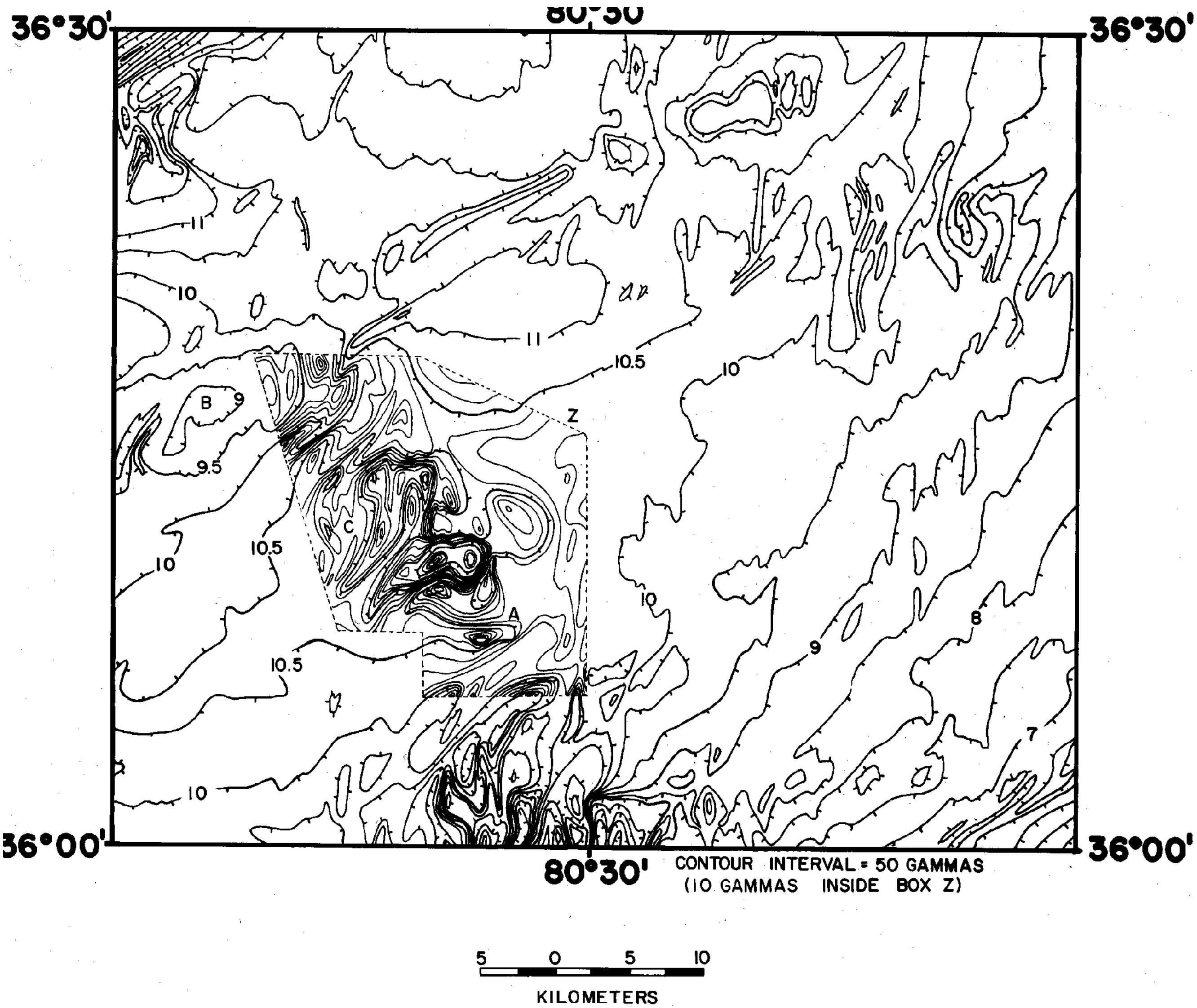

Figure 11. Aeromagnetic map of the Sauratown Mountains anticlinorium (U.S. Geological Survey, 1976b), Box Z delineates the study area. Feature A corresponds with the North Deep Creek pluton. Feature B coincides with the lineament labelled the Brevard fault zone in Espenshade and others (1975) map. The magnetic highs in the vicinity of C correspond to the surface location and down-dip projection of amphibolites. Large amplitude-high frequency magnetic anomalies to the south of the study area correspond with features in the Avalon terrane.

rock, and are typical of porphyroblasts that grew when the matrix schistosity was progressively rotated.

An S_2 surface sometimes occurs as an axial planar foliation to outcrop-scale F_2 folds. Other F_2 folds have a foliation (S_1) subparallel with the compositional layering, even in their hinge zones. Because F_1 folds are so rare, the dominant tectonic surface is interpreted to be $_2$ that developed during second phase isoclinal folding. The outcrop pattern of most rock units is controlled by F_2 folds. Lense-shaped bodies such as those of the garnet-aluminous schist member shown in Figure 2 are thought to be present at the crests of F_2 antiforms. Extensive transposition of compositional layering occurred during D_2 in high-grade rocks of the Ashe Formation (see Yadkin fault problem). F_2 isoclines verge northward.

The medium grade-high grade boundary in the Ashe Formation is oblique to the dominant tectonic surface (Fig. 2). This may indicate that isoclinal folding ceased before the end of prograde metamorphism. Some metamorphic textures observed in thin section (e.g., postkinematic kyanite porphyroblasts that grew oblique to, and across, the S_2 plane) support his observation. Crosscutting relationships in some migmatites also suggest that prograde metamorphism continued after isoclinal folding (e.g., leucosomes formed parallel

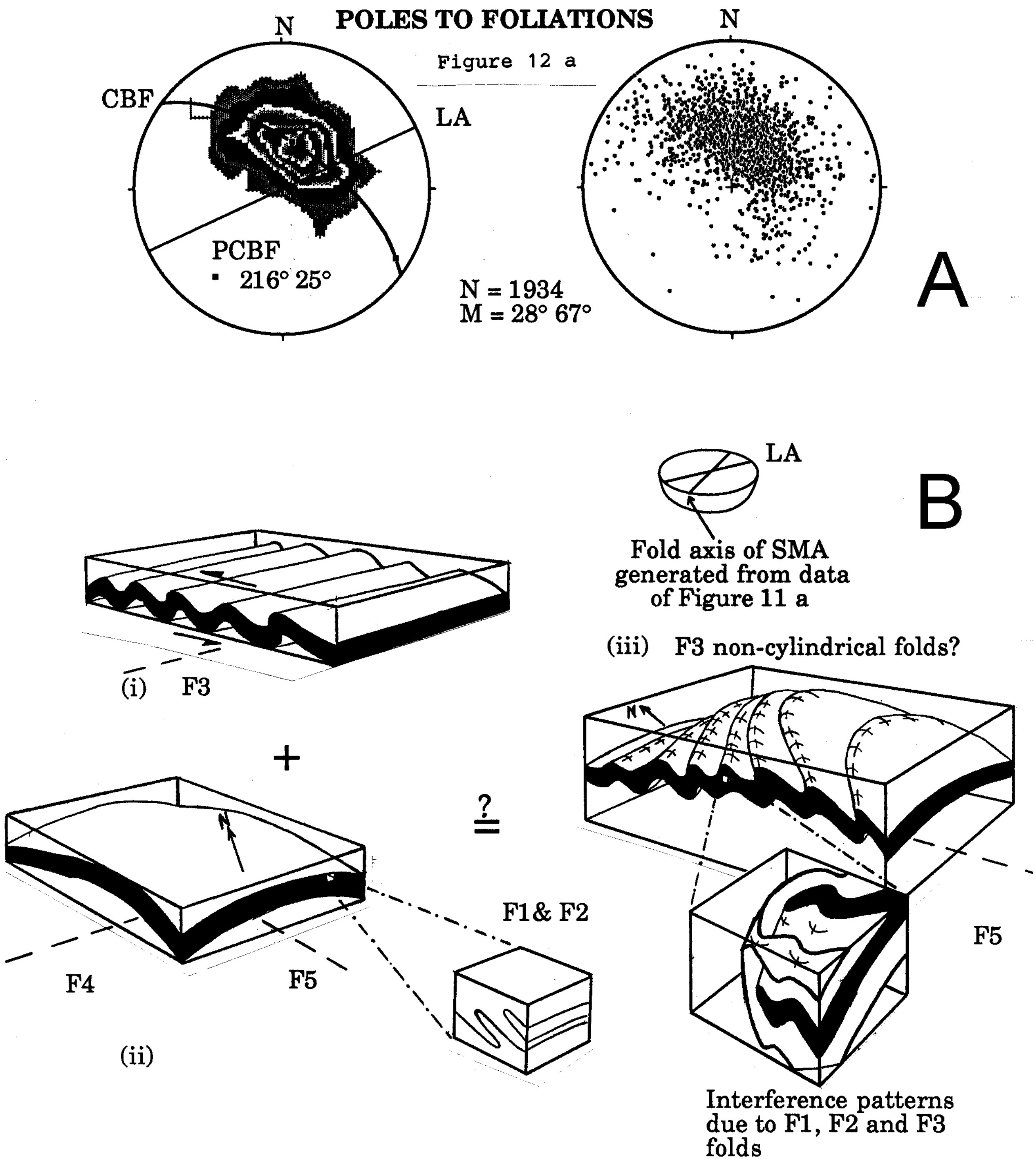

Figure 12. (a) Equal-area stereonet diagrams of poles to foliations measured in the area studied, and (b) schematic block diagrams for the structural development of the Sauratown Mountains anticlinorium. CBF - Cylindrical best fit of the data. PCBF - Pole to cylindrical best fit. N - Number of measurements. M - Maximum. F_1 and F_2 isoclinal folds formed during prograde metamorphism. The anticlinorium may have developed when open and tight, but non-cylindrical F_3 folds formed; i.e., the geometry of block diagram (iii) formed during one episode of folding. Alternatively, the anticlinorium may have developed due to the cumulative effects of cylindrical F_3 folds followed by open F_4 and F_5 folds (i + ii = iii). It is not clear whether or not data F_5 folds are simply an expression of the non-cylindrical geometry of F_3 folds. The long axis of the anticlinorium (LA) is not coincident with the fold axis generated by the data of (b); this may be the manifestation of where the data was collected relative to the crest of the anticlinorium.

to S_2). In many places, however, leucosomes were folded or extensively disrupted during isoclinal folding (see Yadkin fault problem). Migmatization probably ceased before $_3$ folding in most of the study area because greenschist facies minerals have typically developed where D_3 was intense, and granitic leucosomes are usually folded by F_3 folds.

Flexural-flow and flexural-slip buckling mechanisms operated during a third deformational phase (D_3) (Heyn, 1984). The S_3 foliation developed mainly in schist where $_3$ folding was intense. The east-northeast trend of compositional layering in the northern portion of the study area is related to intense F_3 folding. F_3 flexural-flow folds are similar or tight, and their axial surfaces are upright or overturned to the northwest. The axial surfaces of F_3 flow folds dip more steeply than S_2 and parallel S_3. Axes of tighter F_3 flexural-slip folds span a range of orientation; their axes fan through a west-southwest trend in the northwestern portion of the study area to a south-southeast trend in the southwestern portion of the study area. $_3$ flow folds grade into F_3 flexural-slip folds along strike. F_3 crenulation folds are typically asymmetric and have an S_3 crenulation cleavage; such folds are best developed in schists of the Ashe Formation in the northwestern portion of the area studied on trend with a fault zone interpreted as the Brevard fault zone by Espenshade and others (1975). F_3 crenulation folds have the same orientation as F_3 flow folds (Fig. 9d and 10b). An S_3 axial plane foliation occasionally developed in gneisses of northern portion of the study area where large F_3 folds dominate. The plunge of F_3 fold axes changes to near horizontal at the center of the SMA (Fig. 6, Hatcher, this guidebook).

Many isoclinal fold axes have orientations that are similar to the orientations of F_3 fold axes (Fig. 9b and 9d), but subtle differences exist between the orientations of the axial-planes of F_3 folds and isoclines (Fig. 9f). This similarity might exist because some F_3 folds are isoclinal, but most isoclinal folds are interpreted to have formed before D_3 because they have the highest-grade mineral assemblages preserved parallel to their axial surfaces, and their geometries are consistent with a more ductile environment than flexural-flow and flexural-slip F_3 folds. It is likely that many isoclinal folds plunge southwest because they were rotated during D_3.

S_3 is an axial-plane foliation and is usually present as a crenulation cleavage in schist. Sometimes narrow zones (~0.01-1 m) with mylonitic fabrics parallel $_3$ in schist. S_2 mica occurs in schists in microlithons delineated by S_3. This mica is commonly bent or rotated into parallelism with the S_3 surface near the edge of the microlithons. S_3 in these schists is characterized by sericite and retrograde phases, such as chlorite and epidote. Muscovite that once formed $_2$ was grain-size reduced parallel to S_3, and exists as randomly-oriented sericite. Bent retrograde sericite and chlorite also occur along the hinge zones of crenulation folds, and were strained when S_3 accommodated slip. Chlorite has also grown obliquely across S_3.

S_3 is rarely penetrative in gneisses, but single grains of postkinematic chlorite grew across S_2 in gneisses where F_3 folding was intense. Some biotite-muscovite gneisses in the northern portion of the area studied are intensely crenulated, but lack retrograde mineral phases. These rocks have textures typical of dynamic-recrystallization and have polygonized biotite along the hinge zones of crenulation folds.

The above observations indicate that retrograde metamorphism, relative to D_3 deformation, was diachronous throughout the hinge zone of the SMA. Most metamorphic textures studied in thin section, however, indicate that retrograde phases formed before the end of $_3$ deformation but after D_2 deformation (phase associated with isoclinal folding), and retrograde minerals are best developed where F_3 folding was most intense. This may indicate that retrograde metamorphism generally occurred during D_3 deformation. Retrograde minerals that overprint S_3 probably indicate that retrograde metamorphism lasted longer than the D_3 deformation phase in some areas. Also, occurrences of crenulated biotite-muscovite gneiss completely lacking retrograde minerals, and the presence of mineral (e.g., hornblende) lineations parallel to F_3 fold axes indicate that D_3 probably began during prograde metamorphism.

Two open fold sets affected the hinge zone of the SMA (Fig. 9c). These folds formed by flexural slip (Heyn, 1984). The axes of one phase (F_4) plunge southwest, and the axes of the second phase (F_5) plunge south-southeast. Their axial surfaces are usually near vertical. The broad open fold that forms the hinge zone of the SMA (Fig. 1 and Fig. 2a of Hatcher, this guidebook) developed when $_2$ folds were warped by F_4 folds. The two sets of open-folds may have formed during doming of the SMA, but it is also possible that most southwest plunging, open folds formed during D_3, because F_4 and F_3 fold axes have similar orientations (Fig. 9c), and several southwest plunging, tight folds were traced into open folds. If F_3 folds and the open folds formed at the same time, they might define a single, non-cylindrical fold set (this idea is illustrated in Fig. 12b); i.e., F_3 folds may have been folded by two younger generations of open slip folds, or the SMA formed during a single D_3 event after isoclinal folding. The broad girdle of Figure 12a outlines the axis of the open fold that forms the hinge zone of the SMA.

Lineations

Mineral lineations parallel to isoclinal fold axes (L_2), stretching lineations (L_2; elongate clusters of recrystallized feldspar grains in S_2), intersection lineations (L_{2x3}), and mineral lineations parallel to F_3 fold axes (L_3) are plotted in Figure 10a. These lineations span a range of orientations in the hinge zone of the SMA (Fig. 7 of Hatcher, this guidebook). Their orientations are similar to the orientations of F_3 fold axes (compare Fig. 10a, 9c, and 9d). Even the stretching lineations in the S_2 plane of mylonitic Forbush gneiss plunge southwest, and are oriented at a high angle to the axis of the isoclinal antiform along which this unit is exposed. Many of these L_2 lineations are interpreted to have been rotated during D_3 into near-parallelism with L_3. Alternatively, the stretching lineations formed during D_3. This is not likely because the tectonic transport direction inferred from $_3$ folds is to the northwest (stretching lineations in L-S tectonites such as the Forbush gneiss are usually parallel with the transport direction). Most lineations are interpreted as L_3 and L_{2x3} lineations. The range of orientations of these lineations and of F_3 fold axes may be the product of late F_4 and F5 open folding. It is also possible that their geometry defines the Sauratown Mountains anticlinorium as a set of non-cylindrical F_3 folds (Fig. 12b).

Samples of Forbush mylonite studied contain spectacular quartz ribbons that parallel the schistosity. The ribbons consist of rectangular quartz grains with wavy extinction, straight to gently curved grain boundaries, and a weak preferred lattice orientation. Feldspar clasts with recrystallized tails were rotated in a fine-grained matrix. The feldspar grains have textures typical of dynamic recrystallization (e.g., curved grain boundaries, and rotated subgrains). These fabrics are interpreted to have formed during synmetamorphic plastic deformation, followed by a period of incomplete post-tectonic recrystallization, or a period of deformation with a lower strain rate. Only the grain boundaries of the more ductile phases (e.g., quartz) were reoriented during this period of recrystallization. Other rocks studied along the Shacktown fault contain retrograde minerals, and planar discontinuities that appear to have formed at a later time, possibly when the crust was thinner.

Shacktown Fault

The Shacktown fault truncates the southeastern limb of the SMA; it consists of a narrow zone of rocks between the Charlotte (or Milton) belt and the SMA that has been intensely deformed (Fig. 2; Heyn, 1984). Rocks along the Shacktown fault contain many planar discontinuities, and have pronounced mylonitic fabrics. High-angle planar discontinuities occur between Forbush mylonite and phyllonite. The foliation in rocks on either side of these discontinuities is both parallel and non-parallel to the discontinuities. The axial planes of isoclinal folds are parallel to low-angle discontinuities, and the orientations of these isoclinal folds are roughly consistent with those of the SMA. Crinkle lineations in chlorite schist located along the Shacktown fault have the same orientations as the crenulation folds in the SMA.

The mineral assemblages in these mylonites and the orientation of fabric elements along the Shacktown fault indicate that movement occurred during prograde metamorphism and continued after the peak. Undeformed diabase dikes that cross the fault indicate that movement ceased before the end of the Jurassic. The Shacktown fault may correspond to the central Piedmont suture of Hatcher and Zietz (1980), which separates the Avalon terrane from North American rocks. The Kings Mountain shear zone, which accommodated displacement approximately 350 m.y. ago (Kish, 1977), could be a reactivated fault zone near the suture.

Stony Ridge Cataclasites

Siliceous cataclasite occurs in places along the trace of the North Stony Ridge fault. Mylonitic fabrics occur in rock where the South Stony Ridge fault had been mapped in previous studies. These fabrics are thought to have formed coeval with S_3. The distribution of siliceous cataclasite trends across the strike of the S_3. Breccia from the Stony Ridge fault yielded a $^{87}Sr/^{86}Sr$ isotopic age of 180 m.y. (Fullagar and Butler, 1980). Stony Ridge cataclasite is thought to have accommodated mappable displacement (Butler and Dunn, 1968; Lewis, 1980; Simons, 1982), but displacement could not be documented at the scale of mapping for this study. The Stony Ridge structure was, therefore, interpreted as a Mesozoic fissure with little displacement (Hatcher and others, 1983).

The Yadkin Fault Problem

Espenshade and others (1975) named the Yadkin fault for part of the narrow zone of highly strained rocks termed the Shacktown fault by Heyn (1984), and for part of a “fault” located along the southwestern flank of the SMA. Espenshade and others (1975) also interpreted a set of northeast trending faults located west of the SMA as eastward segments of the Brevard fault zone; they connected two of these faults with the Yadkin fault. Espenshade and others (1975) indicated that the Yadkin fault is an “approximately located or inferred thrust fault” and is depicted on their map as a line with an open fold geometry. Even though compositional layering has been disrupted, and rocks with high-strain fabrics exist along the southwestern flank of the SMA, a narrow fault zone does not appear at their contact of the “Inner Piedmont” with the SMA. Metasedimentary rocks previously included in the Inner Piedmont belt by Espenshade and others (1975), south of the “Yadkin fault,” are here interpreted to be part of the Ashe Formation.

Rocks along the southwestern flank of the SMA are not cut by high-angle discontinuities, and do not have fabrics like those in the Shacktown fault zone. The outcrop distribution of rocks with high-strain fabrics, and the presence of Ashe lithologies in the area previously designated as “Inner Piedmont” (southwest of the “Yadkin fault”), are not consistent with offset along a narrow fault. The distribution of these rocks is consistent with a wide zone of shearing that is traceable from the lower kyanite-upper kyanite boundary westward to the edge of the area mapped.

High-grade rocks flanking the SMA are strained, but this deformation appears to have involved a thick package of rocks. Partial melting, metamorphic differentiation, and/or solid-state grain growth resulted in coarse granitic leucosomes in high-grade metasedimentary rocks of the southwestern flank of the SMA. This process accompanied shearing, and resulted at some locations in the formation of distinctive porphyroclastic gneiss and schist. These rocks contain large feldspar porphyroclasts that are surrounded by a fine-grained, biotite-rich matrix. Because this porphyroclastic gneiss gradually changes laterally into medium grade metagraywackes of the Ashe Formation, Heyn (1984) attributed the textures to grain growth during migmatization. Lewis (1983) recognized their unusual textures, and correlated them with mylonitic Henderson Gneiss.

Even though the porphyroclastic rocks do not have typical mylonitic fabrics, their fabrics are clearly associated with large strain at high metamorphic grade. This interpretation is based on several observations; the mineral assemblage of these rocks belongs to the amphibolite facies (Heyn, 1984), and feldspar porphyroclasts are derived from disrupted granitic migmatite leucosomes. Furthermore, these clasts were grain-size reduced. In thin-section, the clasts are mantled by small subgrains with curved grain boundaries and wavy extinction. The crystallographic orientation of these subgrains indicates that they were progressively reoriented; this process appears to have formed many grains in the matrix. In rocks with a mica-poor matrix, a uniform recrystallized grain-size was established, and straight to gently curved grain boundaries formed. Rocks with a biotite-rich matrix are finer-grained, and have more complex grain boundaries. Quartz and feldspar of the matrix do not have grain-shape fabrics, and do not have preferred lattice orientations (two characteristics that are typical of mylonite). Only the mica in the rock has a strong preferred orientation, defining the foliation. Many aspects of such a fabric are commonly attributed to dynamic recrystallization (e.g., Borradaile, 1982), and other aspects are attributed to grain boundary migration after deformation (e.g., Bouchez, 1982). Regardless of the origin of these fabrics, the distribution of these rocks is not consistent with offset along a narrow fault. The porphyroclastic rocks occur as widely scattered outcrops among granoblastic gneisses rich in leucosomes.

Grain-size reduced augen gneiss, also mapped along the southwestern flank of the SMA occurs as widely scattered lenses (Fig. 2). This augen gneiss has a granoblastic texture and is not nearly as deformed as rocks along the Shacktown fault; augen gneiss has a pronounced mylonitic fabric along the Shacktown fault. Furthermore, the area conventionally designated as the "Inner Piedmont" also contains the same rock units as the Ashe formation of the SMA. Aluminous schists, amphibolite and other rocks typical of the Ashe Formation occur well southwest of the "Yadkin fault." Minor differences between these rocks and those of the Ashe Formation are probably the result of differences in P-T conditions. For instance, the decrease of muscovite in "Inner Piedmont" aluminous schists is attributed to metamorphic reactions (Table 1).

Contrary to Goldsmith's (1981) findings, there is no discordance of structures across the "Yadkin fault". Rocks previously interpreted as the "Inner Piedmont" record the same fabric elements as rocks of the SMA, and the orientation of these fabric elements are the same on both sides of the "Yadkin fault" (Fig. 6 and 7). Aeromagnetic data also indicate that the Ashe Formation extends southwest of the area delineated as the SMA by Espenshade and others (1975). An aeromagnetic map of the SMA (U.S. Geological Survey map, 1976b; Fig. 11) outlines shallow and surface geological features. For instance, the magnetic high anomaly designated A (Fig. 11) corresponds with the North Deep Creek pluton. A series of magnetic highs in the vicinity of C correspond to the surface location and the down-dip projection of amphibolite in the Ashe Formation. If the "Yadkin fault", which is unaffected by tight fold phases, is the contact between two different terranes in the southwestern portion of the study area, one would expect an expression on the aeromagnetic map (Fig. 11); however, no such expression has been detected.

Compositional layering was transposed in the Ashe Formation on a map scale (Fig. 1), and individual unit boundaries in the graywacke-schist-amphibolite member are not traceable for long distances south of the upper kyanite-lower kyanite boundary. Several outcrops show that compositional layering was considerably transposed in the Ashe formation during high-grade deformation without involving distinct discontinuities. These field relations, and others described above, are attributed to shearing and extensive migmatization during early isoclinal folding without formation of the Yadkin fault.

The boundary between medium grade rocks and high grade rocks may coincide with Espenshade and others' (1975) "Inner Piedmont" boundary. The transposition of layering south of the boundary may reflect a change in fold mechanism from flexural-flow buckling to passive-flow folding. The high-grade conditions that existed during D_2 deformation south of the boundary probably promoted transposition and passive folding.

DISCUSSION

The contact between the Ashe and Hogan Creek Formation is potentially a premetamorphic fault, the Forbush fault of Hatcher and others (1988). The mafic-rich sequence of the Sauratown Mountains anticlinorium (SMA) is correlated with the Ashe Formation, and a narrow thrust fault was not mapped along the southwestern flank in the SMA. These observations indicate that rocks of the SMA outside the trace of the Forbush thrust are part of the Inner Piedmont, and that rocks in the eastern Blue Ridge may have equivalents in the

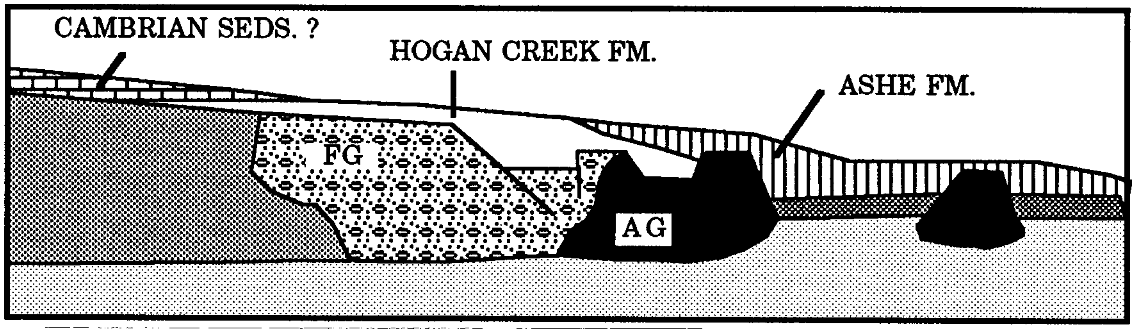

Figure 13. Schematic diagram of a likely geological setting for the various lithostratigraphic units before closing of the proto-Atlantic ocean. In this model the Ashe Formation was deposited on oceanic crust, and the Hogan Creek Formation was deposited on older continental crust. The basement in this model is a composite terrain made of several rock types with perhaps various Proterozoic ages. The basement may have had Middle Proterozoic deformation fabrics. Quartzites that comprise the Sauratown Mountains may have been deposited on basement and on Late Proterozoic cover. AG - Unnamed augengneiss. FG - Forbush gneiss.

Inner Piedmont.

Several northeast trending thrust faults were mapped just west of the SMA, and have been correlated with Brevard faults by Espenshade and others (1975). Several of these faults, including the Ridgeway fault, were determined to extend northwest of the SMA, and are thought to have formed during emplacement of the Smith River allochthon (Conley and Henika, 1973; Lewis, 1980). Lewis (1980) interpreted two of these northeast trending faults as brittle structures and correlated then with the Stony Ridge fault of the SMA. If the SMA is part of the Inner Piedmont, the Bowens Creek fault (northern boundary of the Smith River allochthon) could be continuous with the Brevard fault zone as Conley and Henika (1973) primarily suggested.

Many of the northeast trending faults located west of the SMA appear to gradually change near the SMA into complex F_3 folds. These tight northeast-trending F_3 folds appear to grade into more open folds near the center of the anticlinorium (see Fig. 5 and 6, Hatcher, this guidebook). Mylonitic textures of rocks within these folds indicate that considerable strain was accommodated on trend with the northeast trending faults during D_3 deformation. In addition, retrograde metamorphism in both the folds and the northeast trending faults implies that they are related.

The origin of several bodies of grain-size reduced augen gneiss that occur in the Ashe Formation outcrop belt is not clear. Although the augen gneiss is not nearly as grain-size reduced as the Forbush gneiss, this augen gneiss may also be basement. Alternatively, the location of these rocks relative to several map-scale folds, indicates that the augen gneiss may be preserved at the troughs of isoclinal folds, forming a lithostratigraphic unit located above the Ashe Formation, but the Ashe sequence is probably inverted here. Perhaps the augen gneiss was thrust on top of the Ashe Formation before isoclinal folding. It is also possible that the augen gneiss is a Paleozoic intrusive, as indicated by Espenshade and others (1975). However, Harper and Fullagar (1981) suggest that rocks designated as Henderson Gneiss by Espenshade and others (1975) are substantially younger than Henderson Gneiss exposed farther southwest along the Brevard fault zone.

The Forbush gneiss and augen gneiss do not appear to record a greater number of deformations, and fabric elements do not have orientations that are different than those of other rocks of the SMA (compare Fig. 8 with Fig. 6). This indicates that basement may not be distinguishable from cover rocks by the number, or orientation of fabric elements. It is possible that Paleozoic deformation has obliterated Middle Proterozoic fabrics, or that not all basement rocks that were deformed during the Paleozoic had Middle Proterozoic deformation fabrics (many Proterozoic rocks of the Grenville province do not have a deformation fabric). Although the mylonitic S_2 foliation of the Forbush gneiss formed in response to dynamic recrystallization, the small grain size of the Forbush gneiss matrix may exist partly because it was deformed both during the Middle Proterozoic and Paleozoic, and this fabric element may be the only manifestation of Middle Proterozoic deformation.

Rocks of the Hogan Creek Formation were thought to be part of the basement in the SMA (Espenshade and others, 1975; Lewis, 1983; Bartholomew and Lewis, 1984), but it may be Late Proterozoic cover because the contact of the Hogan Creek Formation with the Forbush gneiss (basement) is not intrusive, and it cannot be demonstrated that the Hogan Creek Formation recorded more deformations or is more intensely strained than the Ashe Formation (Fig. 6). It is possible that Middle Proterozoic fabric elements were destroyed during the Paleozoic. Like the Hogan Creek Formation, the Forbush gneiss cannot be differentiated from other rocks of the SMA on the basis of fabric orientation (Fig. 8), but it does have a mylonitic fabric. Other criteria exist that indicate the Hogan Creek Formation may not be basement.

Contact relationships of the Pilot Mountain Gneiss with surrounding rocks are different. Xenoliths indicate the Pilot Mountain Gneiss intruded metasedimentary rocks (Butler and Dunn, 1968), and is unconformably overlain by younger metasedimentary rocks (McConnell, this guidebook). The Forbush gneiss appears to be in fault contact with the Hogan Creek Formation. All known Middle Proterozoic rocks of the Appalachians contain either granulite or upper amphibolite facies relict mineral assemblages or textures, and acquired a lower grade overprint during the Paleozoic (Bartholomew and Lewis, 1984). Field relationships indicate that local migmatization in the Hogan Creek Formation is probably the result of prograde metamorphism during the Paleozoic.

Broad lithologic similarities between the Hogan Creek Formation and basement gneisses such as the Cranberry gneiss have, in part, been the basis for interpreting rocks such as the Hogan creek Formation as basement (Lewis, 1980; Bartholomew and Lewis, 1984). This lithologic correlation in the SMA is suspect because the Hogan Creek Formation contains marble and quartzite, two lithologies not recognized in the Elk Park complex. Correlations based on broad lithologic similarities between potential basement rocks such as the Hogan Creek Formation, and basement complexes elsewhere in the Appalachians, should be used to identify basement only in conjunction with other more concrete evidence.

Evidence indicating the Hogan Creek is basement does not exist in the SMA. Thus, it is likely that the Hogan Creek Formation is Late Proterozoic cover. The mafic-poor Hogan Creek Formation may have been deposited on continental crust, while the mafic-rich Ashe Formation was deposited on oceanic crust in deeper water (Fig. 13). In this context, the Hogan Creek Formation may be a time equivalent of the Ashe Formation, and the contact presently separating them could be a premetamorphic thrust or a sedimentary contact. Mafic rocks of the Ashe Formation may represent metamorphosed basalt and pieces of ophiolite. Forbush gneiss and granulite situated below the Hogan creek Formation may represent continental basement on which the Hogan creek Formation was deposited (McConnell, this guidebook). Heyn (1984) interpreted the biotite-muscovite gneisses and biotite gneisses of the Ashe Formation and Hogan Creek Formation as metagraywackes because they are interlayered with schists and other rocks that are clearly metasedimentary rocks. Feldspathic quartzite of the Hogan Creek Formation may represent nearshore sediment, and marble may represent shallow marine carbonate. If the unnamed augen gneiss is basement, it may have been separated from other basement by younger oceanic crust.

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GEOLOGY OF THE SAURATOWN MOUNTAINS ANTICLINORIUM: VIENNA AND PINNACLE 7.5 MINUTE QUADRANGLES

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ABSTRACT

Detailed geologic mapping of the Vienna and Pinnacle 7.5 minute quadrangles in the Sauratown Mountains anticlinorium and associated radiometric dating of basement gneisses in those quadrangles indicate that multiple Middle Proterozoic basement-cover rock sequences are exposed in the eroded crest of a deformed multi-level structural window resembling an anticlinal stack duplex. The window is defined on the apparent juxtaposition of rocks of higher metamorphic grade over those of lower metamorphic grade along a series of pre- and post-metamorphic thrust faults. Within the window and the duplex are four thrust imbricates which document considerable crustal shortening by thrust imbrication. Each thrust imbricate, respectively termed the Flint Hill, Little Yadkin, Pinnacle, and Volunteer thrust sheets, generally contains a sequence of Middle Proterozoic basement and Late Proterozoic-aged intrusive rocks (i.e., Crossnore Complex) overlain nonconformably(?) by a sequence of metamorphosed sedimentary and volcanic rocks. Nonconformable relationships are demonstrable in one of the thrust sheets but are inferred in the other thrust sheets.

Radiometric dating of two gneiss units in the Sauratown Mountains window by U-Pb methods has documented the presence of pre-Grenville, Middle Proterozoic basement rocks. A U-Pb discordia upper intercept age of 1230 +/- 6 m.y. for the Forbush and Grassy Creek gneisses is interpreted to suggest the presence of an intrusive event in the pre-Grenville crust. Rb-Sr isotopic dating of the Grassy Creek and Pilot Mountain gneisses in the Sauratown Mountains window has given ages of 1173 +/- 33 m.y. Comparis with the U-Pb age of the Grassy Creek gneiss indicates that isotopic homogenization of strontium isotopes occurred at approximately 1170 m.y., pin-pointing the timing of Grenville metamorphism in rocks of the Sauratown Mountains anticlinorium.

INTRODUCTION

The Sauratown Mountains anticlinorium (SMA) lies at the junction of the Blue Ridge, Inner Piedmont, and Milton belts of the Central Piedmont in western North Carolina and southwestern Virginia (Fig. 1). The anticlinorium is a northeast-trending arch characterized by nearly symmetrically distributed basement-cover rock sequences and inverted metamorphic isograds.

Exposed in the eroded crest of the Sauratown Mountains anticlinorium are portions of four imbricate and stacked thrust sheets, which document considerable shortening by thrust imbrication. Following their emplacement, the thrust sheets were domed by deformation associated with the formation of the SMA, and subsequent erosion has exposed a complex window (Fig. 2).

Each thrust sheet contains an intact stratigraphic sequence composed of Middle Proterozoic basement and a nonconformably overlying cover sequence of Upper Proterozoic-Lower Cambrian metasedimentary and metaigneous rocks. While some subtle and some not so subtle differences exist between both the basement and cover sequences within separate thrust sheets, these differences are believed to represent lateral facies variations within a continuous, although broken, sequence of rocks.

BASEMENT COMPLEX

Historically, the presence, areal extent, and specific ages of basement gneisses within the Sauratown Mountains anticlinorium (SMA) have been based on comparisons with other basement-bearing terranes in the southern Appalachian orogen and on intrusive relationships and isotopic age of the Pilot Mountain gneiss (Fig. 1). The three published ages for the Pilot Mountain gneiss (Rankin and others, 1973; Kish and others, 1982; McConnell and others, 1986) document the presence of Middle Proterozoic basement in the Sauratown Mountains, but do not place constraints on the age of Proterozoic basement or allow for determination of the areal extent of basement rocks except by using lithologic comparisons with other units in the SMA or with basement in other terranes. Correlations between units in the anticlinoriu based solely on lithology can fail, however, if basement is lithologically complex and comparison with other terranes is believed to be tenuous because the Sauratown Mountains anticlinorium is separated from other basement massifs in the Blue Ridge anticlinorium and Piedmont by major faults (i.e., Bowens Creek and Shacktown faults).

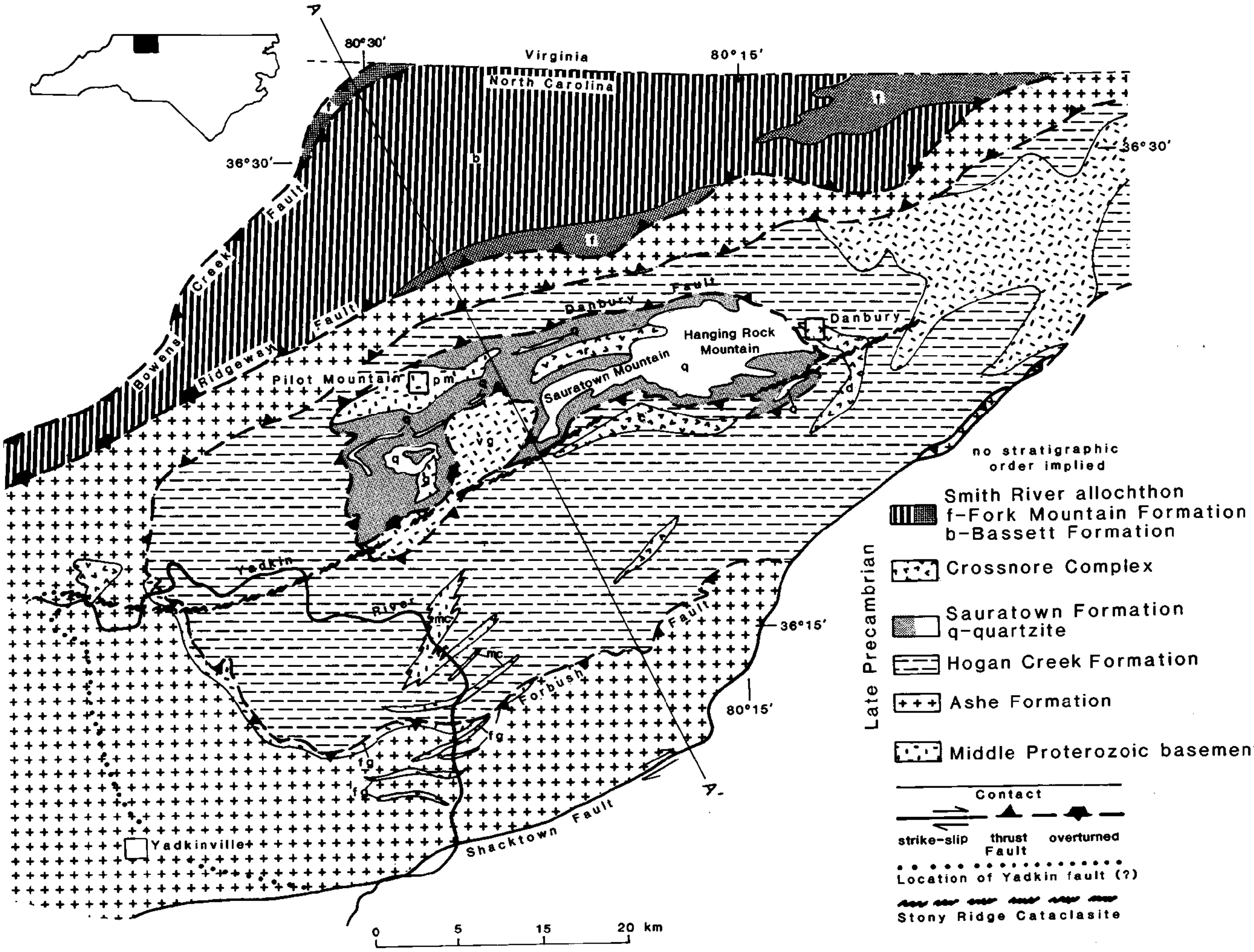

Figure 1. Generalized geologic map of the Sauratown Mountains anticlinorium (modified after Espenshade and others, 1975).

Recent detailed mapping and isotopic dating of basement units in the SMA have provided a basis for reinterpreting the character and areal extent of basement based solely on relationships observed in the SMA. In this reinterpretation, the distribution of basement units is significantly revised from the interpretations presented by Espenshade and others (1975) and Lewis (1980). In particular, Rankin and others (1973) and Espenshade and others (1975) used the ages of the Pilot Mountain gneiss (near the center of the anticlinorium) and apparent intrusive relationships with the surrounding country rocks to interpret much of the country rock in the SMA to be "older" Precambrian. Lewis (1980) and Bartholomew and Lewis (1984) also used the intrusive relationships of the Pilot Mountain gneiss and similarities with layered basement gneisses in the Lovingston massif and central Virginia to propose the term Low Water Bridge Gneiss (Pre-Grenville to early Grenville in age) for much of the rock exposed in the core of the eroded anticlinorium. Rb-Sr data from the Grassy Creek gneiss (similar to and south of the Pilot Mountain gneiss) and contact relationships between the Grassy Creek gneiss and the overlying quartzite cast doubt on the basis for Espenshade and others' (1975) and Bartholomew and Lewis's (1984) interpretation of basement in the SMA.

The Grassy Creek gneiss is approximately 1230 m.y. old (McConnell and others, 1988) and occurs nonconformably beneath quartzites exposed on Pilot Mountain (McConnell and others, 1986). Butler and Dunn (1968) indicated that the quartzites exposed on Pilot Mountain grade into the surrounding schist and gneiss that can be traced to the contact with the Pilot Mountain gneiss with no evidence for major faulting. If the quartzite, which is a lithostratigraphic equivalent to the schists and gneisses surrounding the Pilot Mountain gneiss, rests noncomformbabofficially on the Precambrian Grassy Creek gneiss, then it is unlikely that a gneiss of probable similar age (i.e., Pilot Mountain gneiss) is intrusive into the same sequence. Because of these relationships, the "older" Precambrian designation for rocks around the Pilot

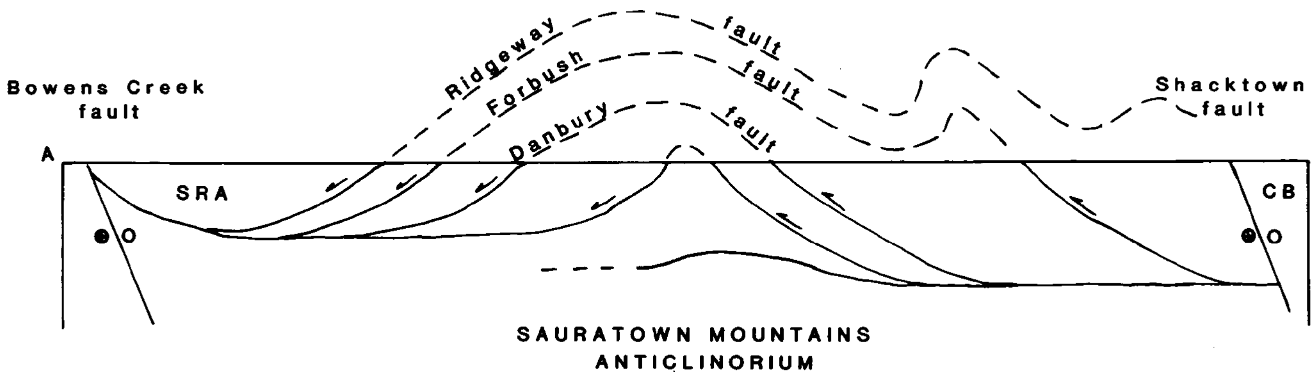

Figure 2. Diagrammatic cross-section through the Sauratown Mountains anticlinorium.

Mountain gneiss is not retained and these rocks are no longer included in the basement complex.

Precambrian basement in the SMA is separated into five distinct units, with each thrust sheet in the anticlinorium containing a characteristic basement sequence (from outermost thrust sheet to innermost thrust sheet the basement sequences are termed - Forbush gneiss, Miller Creek complex, Pilot Mountain gneiss, Grassy Creek gneiss, and Volunteer gneiss). Biotite-augen gneisses, including the Pilot Mountain gneiss exposed near the small town of Pilot Mountain, the Grassy Creek gneiss exposed just east of Pilot Mountain, and the Forbush gneiss (Heyn, 1984) present in the southern parts of the anticlinorium, dominate the lithologies in the Precambrian basement of the Sauratown Mountains anticlinorium. All of these gneisses have been isotopically dated as being Middle Proterozoic basement (Rankin and others, 1973; Kish and others, 1982; McConnell and others, 1986; McConnell and others, 1988). Other parts of the basement sequence are lithologically more complex. For example, near the Yadkin River in eastern Surry County, interlayered calc-silicate gneiss, biotite-augen gneiss, magnetite-quartz feldspar gneiss, epidosite, and amphibolite comprise the Miller Creek complex (McConnell, unpublished data). Members of this complex have not been radiometrically dated but, based on relict granulite facies mineral assemblages, are defined as part of the basement complex.

Forbush Gneiss

In the outermost part of the SMA and overlain by rocks of the Ashe Formation, Middle Proterozoic basement is characterized by a biotite-augen gneiss termed the Forbush gneiss. Heyn (1984) originally used the term Forbush orthogneiss for small exposures of biotite-augen gneiss in the southwestern part of the SMA and BAG for exposures of biotite-augen gneiss farther north in the SMA. McConnell (unpublished thesis) redefined the augen gneisses in this part of the SMA including both the units termed Forbush orthogneiss and BAG in the Forbush gneiss. For the most part, these rocks were not recognized by Espenshade and others (1975) but may have been, at least partially, included in their Elk Park Plutonic Group and/or Henderson Gneiss. Using U-Pb methods, the Forbush gneiss has been isotopically dated at 1230 Ma. (McConnell and others, 1988). Discontinuous linear outcrop belts of biotite-augen gneiss are commonly surrounded by the basal metagraywacke-schist-amphibolite member of the Ashe Formation. The outcrop pattern suggests that the Forbush is exposed in erosion-breached crests of northeast-trending antiforms.

Mineralogically, the Forbush gneiss is composed of large porphyroclasts of microcline and plagioclase surrounded by a groundmass of plagioclase (oligoclase), quartz, biotite, muscovite, garnet, and epidote group minerals. Heyn (1984) described minor mineralogic and textural variations between the Forbush gneiss and the Pilot Mountain gneiss. The mineralogical variations between the Forbush gneiss and the Grassy Creek and Pilot Mountain gneisses are reflected in the strontium concentrations of the Forbush, which are substantially different (i.e., ca. 450 ppm vs. 175 ppm), perhaps outlining chemical complexity within the basement augen gneisses.

Miller Creek Complex

The Miller Creek complex is present along a small tributary to the Yadkin River near the center of the SMA (Fig. 1). Espenshade and others (1975) included these rocks and most of the surrounding country rock in the Cranberry Gneiss. No members of the Miller Creek complex have been isotopically dated; categorization as basement is based on similarities with other basement units in the SMA and the presence of relict granulite facies mineral assemblages.

Rock types present in the Miller Creek complex include magnetite-quartz-feldspar granofels, calc-silicate rock, epidosite (meta-anorthosite?), amphibolite, pyroxene-bearing granitic gneiss, biotite-augen gneiss, and metadiorite. Pyroxene-bearing granitic gneiss is a key unit in the interpretation of these units as part of the Middle Proterozoic basement and in assessing the grade of metamorphism attained during the Grenville event. This gneiss is composed of quartz, microcline, plagioclase, biotite, amphibole, and pyroxene with accessory, epidote, chlorite, and muscovite. Amphibole grains generally surround and appear to be alteration products of pyroxene. The pyroxenes are extensively altered but appear to be both clino- and orthopyroxene forms. Pyroxene in these granitic rocks suggests that granulite facies temperatures and pressures were at least locally reached within rocks of the SMA.

Calc-silicate granofels is the dominant lithology in the Miller Creek complex and is commonly interlayered (tectonically?) with other members of the complex. The calc-silicate granofels is composed of bladed amphibole, quartz, feldspar, chlorite, and epidote with minor amounts of biotite, sphene, and opaque minerals. This unit's predominance in the Miller Creek complex suggests that the protolith, possibly a siliceous carbonate rock, was fairly extensive in the Middle Proterozoic basement of this area.

Epidosite also is present within the Miller Creek complex. Composed largely of epidote group minerals with accessory actinolite, plagioclase, sphene, pyroxene, and chlorite, this rock has a sugary appearance with a light greenish tint and lacks a distinct foliation. The mineralogy of this unit resembles altered anorthosite described in the Roseland Anorthosite by Herz (1984). in altered anorthosites, andesine alters to epidote group minerals and pyroxene alters to amphibole.

Pilot Mountain Gneiss

The town of Pilot Mountain (not to be confused with the topographic feature named Pilot Mountain which occurs approximately 2 km to the south) (Fig. 1) is partially underlain by exposures of biotite-augen gneiss termed the Pilot Mountain gneiss. A sample of the Pilot Mountain gneiss yielded an isotopic date of 1172 Ma. (Pb-Pb age, Rankin and others, 1983, after Rankin and others, 1973) using the uranium-lead zircon method. Somewhat later Kish and others (1982) collected samples from the same locality used by Rankin and others (1973) and reported a Rb-Sr age of 1250 +/- 100 Ma. McConnell and others (1986) also collected samples from this locality and reported a Rb-Sr age of 1172 +/- 33 Ma. with an initial ratio of .70334 +/- .0007 for the Pilot Mountain gneiss.

The Pilot Mountain gneiss is composed of medium-grained muscovite-biotite-quartz-feldspar gneiss with minor amounts of garnet, calcite, and epidote. Associated with the Pilot Mountain gneiss are aplite, biotite gneiss enclaves, and quartz-veins. The aplites are intrusive into the Pilot Mountain gneiss and are composed of microcline, perthite, quartz, and plagioclase. Enclaves are composed of biotite, plagioclase, quartz, and epidote with accessory calcite, hornblende, perthite, garnet, and muscovite. The mineralogy and appearance suggests a metagraywacke protolith.

Butler and Dunn (1968) first noted the presence of enclaves in the Pilot Mountain gneiss and indicated that the schistosity in the xenoliths was concordant with that in the orthogneiss but was strongly discordant to the contact with the enclave implying an intrusive relationship. The age of the Pilot Mountain gneiss and this apparent intrusive relationship were the basis for Espenshade and others' (1975) interpretation of the "older" Precambrian unit. Based on field relationships (see discussion in introduction), however, these enclaves are now thought to represent relicts from a pre-Grenville terrane no longer exposed in the SMA.

Along the contact between the Pilot Mountain gneis and the country rock, there is no evidence for contact metamorphism nor do any dikes or apophyses from the Pilot Mountain gneiss intrude the country rocks. The contact between the Pilot Mountain gneiss and the country rock could, therefore, be interpreted either as a metamorphosed nonconformity or a premetamorphic fault.

Grassy Creek Gneiss

Exposures of ductilely deformed biotite-augen gneis near Pilot Mountain in northwestern Surry County (Fig. 1) are termed the Grassy Creek gneiss (McConnell and others, 1986). Augen gneisses of the Grassy Creek gneiss yielded a Rb-Sr age of 1173 +/- 33 Ma. (McConnell and others, 1986) and are lithologically similar to and believed to be equivalent to the Pilot Mountain gneiss exposed approximately 2 km to the north.

The Grassy Creek gneiss contains bands of coarser-grained material separated by finer-grained bands of intense grain size reduction. Quartz, plagioclase, and alkali feldspar occur in approximately equal amounts in the Grassy creek gneiss with accessory biotite, epidote, muscovite, and opaques. Trace amounts of garnet, calcite, chlorite, and allanite are also present.

As stated previously, the age of the Grassy Creek gneiss combined with the relationship between the gneiss and quartzite on Pilot Mountain are key to defining the stratigraphic sequence in the SMA. Mapping of the overturned contact between the Grassy Creek gneiss and quartzite indicates that the contact is an erosional unconformity. Conglomeratic meta-arkose above the Grassy Creek gneiss grade upward into quartzite on Pilot Mountain. Northeast of Pilot Mountain, in the Hanging Rock Mountain area, Simons (1982) noted the presence of augen gneiss unconformably beneath quartzite, A basal conglomerate similar to that observed at the contact between quartzite and the Grassy Creek gneiss near Pilot Mountain was also observed at this locality. These data suggest that the unconformity between basement and cover rock is regionally extensive.

Volunteer Gneiss

The lowermost thrust sheet in the SMA contains rocks termed the Volunteer gneiss. Rocks comprising the Volunteer gneiss are generally variations of granitic gneiss with minor augen gneiss and biotite granite gneiss which were included largely in Espenshade and others' (1975) "older" Precambrian unit with a part included in the Elk Park Plutonic Group. Mineralogically, the felsic gneisses are composed essentially of equal amounts of plagioclase, quartz, and alkali feldspar with accessory biotite, epidote, and muscovite.

Little evidence is available to support designating these rocks as Middle Proterozoic basement in that no isotopic dating has been performed on these rocks and no relict granulite facies minerals have been recognized. Classification of the volunteer gneiss as basement results from the presence of epidosite similar to that observed in the Miller Creek complex, which resembles altered anorthosite. Anorthosite is commonly found in Grenville terranes (Herz and Force, 1984). Paleozoic anorthosite in the Arden pluton in Delaware indicates, however, that Appalachian anorthosites are not restricted to the Precambrian (Foland and Muessign, 1978).

COVER ROCKS

Units overlying basement in the SMA are composed of interlayered metasedimentary and metaigneous rocks and several distinct metamorphosed intrusive granitic gneiss units. From outermost to innermost thrust sheet in the SMA, the cover sequences have either been named or correlated with: the Ashe Formation, the Hogan Creek Formation (Heyn, 1984; Hatcher and others, 1988) and the Sauratown formation (McConnell, unpublished thesis). Cover rocks are generally absent over the Volunteer gneiss. Lithologic similarities between cover sequences in three of the thrust sheets suggest that they may be lithostratigraphic equivalents. The most noticeable difference between cover sequences present in the various thrust sheets is a decrease in amphibolite and other mafic rocks in the inner parts of the SMA. The Ashe Formation contains numerous layers and lenses of amphibolite and metagabbro, the Hogan Creek formation has lesser amounts of these rocks, and the Sauratown formation contains only minor lenses of amphibolite. This decrease is suggested to represent a transition in depositional environment from eugeoclinal to miogeoclinal within the stacked thrust sheets of the SMA.

Ashe Formation

Rankin (1970) used the term Ashe Formation for fine-grained, thinly layered sulfidic biotite-muscovite gneiss interlayered with mica schist and amphibolite in central Ashe County, North Carolina. Rankin and others (1973) and Espenshade and others (1975) extended the term Ashe Formation into the SMA area. More detailed mapping by Lewis (1980), Heyn (1984) and McConnell (unpublished thesis) also resulted in correlation of rocks, in the northern, southwestern and eastern part of the SMA, with the Ashe Formation (Fig. 1). Although the definition of the Ashe Formation has recently been modified by Rankin (1988), at least part (i.e., the Jefferson terrane) is present in the SMA.

The Ashe Formation in the SMA is characterized by a basal unit of interlayered metagraywacke, garnet-muscovite schist +/- kyanite, amphibolite, felsic gneiss, and metamorphosed gabbroic and ultramafic rocks overlain by garnet-kyanite-staurolite-muscovite schist and amphibolite. The basal unit is similar to the graywacke-schist-amphibolite basal unit in the Tallulah Falls Formation and Sandy Springs Group rocks found in south Carolina and Georgia (Hatcher, 1974; Higgins and McConnell, 1978). The graywacke-schist-amphibolite member overlies the Forbush gneiss along the limbs of antiforms in which the orthogneiss is exposed. The contact between the Forbush gneiss and the graywacke-schist-amphibolite member could be interpreted as either an unconformity or a fault. Rankin (1970) and Rankin and others (1973) have postulated the existence of a nonconformity between the Ashe Formation and basement elsewhere in the southern Appalachians; however, Abbot and Raymond (1984) have indicated that the contact between the Ashe Formation and the Cranberry Gneiss in the locality where Rankin (1970) identified an unconformity, is a fault. They note the presence of porphyroclastic texture at the contact and juxtaposition of metamorphic isograds across the contact.

Hogan Creek Formation

The northern boundary of the thrust sheet containing Ashe Formation rocks is noted by lithologic changes, and the local faulting out of the Forbush gneiss (Fig. 1). The location of the Forbush fault is substantially different from that presented by Hatcher (this guidebook) and Heyn (this guidebook). North and east of the Forbush fault as defined in this report, metagraywacke and minor amounts of mica schist and quartzite dominate the sequence within cover rocks which are termed the Hogan Creek Formation (Heyn, 1984; Hatcher and others, 1988). The major differences between the Hogan creek and the Ashe Formation are the absence of an aluminous schist facies, the decrease in the amount of amphibolite and metagabbro, the presence of marble, and an increase in the amount of quartzite in the Hogan Creek Formation. Otherwise, the sequences and lithologies appear very similar. Because of the lithologic similarities with the Ashe Formation, the Hogan Creek Formation is interpreted here to be equivalent to the Ashe Formation.

As defined, the Hogan Creek Formation includes parts of the Low Water Bridge Gneiss of Bartholomew and Lewis

(1984), non-basement parts of the "older" Precambrian designated rocks of Rankin and others (1973) and Espenshade and others (1975). The contact between the Hogan Creek Formation and Precambrian basement (i.e., Miller Creek complex) is not exposed.

The Hogan Creek Formation is composed of a muscovite-biotite gneiss (metagraywacke) interlayered with muscovite schist, biotite schist, biotite-hornblende-quartz-feldspar gneiss, granitic gneiss, amphibolite, marble, and quartzite and minor amounts of metamorphosed ultramafic rocks. Marble is unique to the Hogan Creek Formation in the SMA. Isolated lenses of marble occur sporadically in the southern limb of the SMA extending from the Yadkin River on the southwest, northeastward to northeast of Danbury (Fig. 1). The best exposure of marble is in the old Lime Rock quarry (Stop 8) near the small community of Siloam on the Yadkin River in Yadkin County where the marble is believed to be at least 20 m thick (Conrad, 1960). At this locality, the marble is composed of calcite, diopside, quartz, zoisite, clinozoisite, tremolite, sphene, and phlogopite.

Sauratown Formation

The northern boundary of the thrust sheet containing the Hogan Creek Formation is marked by a zone of intense ductile deformation and the shearing out of limbs of $_2$ isoclines. This boundary trends northwestward along the southeastern side of the Sauratown Mountains and was termed the Danbury fault by Simons (1982) in the Hanging Rock Mountain area. This bounding fault juxtaposes Hogan Creek Formation rocks against rocks of the Sauratown formation, except locally where the thrust sheet containing the Sauratown formation was overthrust by the upper thrust and Hogan Creek Formation rocks are in contact with rocks of the Volunteer gneiss (Fig. 1).

The Sauratown formation is named for exposures of quartzite on Sauratown Mountain and includes exposures of quartzite on the Pinnacle, and a metagraywacke and schist on the slopes of Pilot and Sauratown Mountain. Psammitic gneiss and schist of Simons (1982) near Hanging Rock Mountain are included within the Sauratown formation.

Butler and Dunn (1968) mapped the quartzite on Pilot Mountain into a muscovite-quartz schist in the surrounding rocks and a similar relationship was observed by Simons further to the northeast. This indicated to Butler and Dunn (1968) that the quartzites exposed on Pilot, Sauratown, and Hanging Rock Mountains were part of the metasedimentary package surrounding the mountains and that they are not exposed in structural window as proposed by Bryant and Reed (1961).

The Sauratown formation rests nonconformably on top of the Precambrian Grassy Creek gneiss. At Pilot Mountain the basal part of the quartzite member is composed of a medium-grained, well-foliated conglomeratic meta-arkose. Mechanically rounded clasts of quartz and microcline up to 1 cm in diameter are present in a matrix of quartz (locally blue), plagioclase, muscovite, and microcline with accessory tourmaline, epidote, and opaque minerals. This metaconglomerate grades stratigraphically upward, but structurally downward, into a thick sequence of massively-bedded quartzite with thin interlayers of muscovite (phengite?) schist locally containing high concentrations of magnetite. The thickness of the quartzite in the Sauratown formation at Pilot Mountain has been estimated to be approximately 65 to 75 m (Butler and Dunn, 1968; Stirewalt, 1969), but tight folding apparent on the mountain suggests that this thickness is exaggerated and the actual thickness may be substantially less than 65 m.

The nonconformity between basement and quartzite at Pilot Mountain has been an attractive target for correlation with the Chilhowee-basement contact observed in the Unaka belt and Grandfather Mountain window (Bryant and Reed, 1961; Simons, 1982), but the distance of separation fro known exposures of Chilhowee Group rocks, the relatively thin character of the quartzite present in the SMA, and questionable relationships with intrusive rocks of the Crossnore Complex (Goldsmith and others, 1988) do not, at the present state of knowledge, allow for direct correlation with the Chilhowee (see Walker, this guidebook).

Intrusive Rocks

Small metagabbroic and metadioritic bodies are not uncommon in rocks of the Hogan Creek and Ashe Formations, but conspicuous by their size are five relatively large occurrences of granitoid gneiss scattered throughout the SMA and apparently intrusive into rocks of the Ashe, Hogan Creek, and Sauratown Formations. The three largest gneiss bodies, bordering the Sauratown and Hanging Rock Mountains on the northwest, east, and southeast, have been termed: the Rock House, Danbury, and Capella gneisses (Fullagar and Butler, 1980) respectively (Fig. 1). Rankin and others (1973) and Espenshade and others (1975) indicated that these rocks were part of their rift-related Crossnore Complex (after Goldsmith and others, 1988) believed to be approximately 820 m.y. old. Simons (1982), after recognizing fluorite, aegirine, and sodic amphibole in the Danbury Gneiss and Capella gneiss, also included those gneisses in the Crossnore Complex. Fullagar and Butler (1980) suggested that the Capella, Rock House, and Danbury gneisses rocks had Rb-Sr ages of between 710 and 650 m.y., younger than the age commonly given for rocks of the Crossnore Complex, but in line with the results of Odom and Fullagar (1984) who have indicated that most of the rocks included in the Crossnore Complex by Rankin and others (1973) have ages between approximately 710 and 680 m.y. with one unit possibly as young as 580 m.y.

Rocks of the Crossnore Complex occur in the Hogan

Creek, Sauratown, and Ashe Formations, and in three of the four thrust sheets in the SMA. Therefore, these gneisses could provide an upper limit on the age of the cover sequences and the age of the quartzite exposed in the SMA if intrusive relationships can be documented. Simons (1982) noted the presence of xenoliths in the Danbury gneiss and suggested that they were from the surrounding country rock but the contacts were not observed. In addition, Centini (1968), Lewis (1980) and Heyn (1984) suggested that rocks of the Crossnore Complex are intrusive into the country rock, but again, contact relationships are lacking. Without further evidence, it cannot be said with complete certainty whether the rocks termed Crossnore in the SMA are intrusive into the cover sequence of if enclaves present within the Danbury and Rock House gneisses represent pieces of a Grenville terrane no longer exposed.

Mesozoic Diabase

Mesozoic diabase dikes are common in the southern part of the SMA near the boundary with the Charlotte belt. Dikes trend in an arc from approximately N 40^{o} W to N 60^{o} E, with most dikes trending approximately N 60^{o} E. The prominent trend of the diabase dikes roughly parallels the trend of the Shacktown fault which on the northeast is on trend with the Chatham fault (Conley, 1978) that forms the northern boundary of the Danville Triassic-Jurassic basin. Raglan and others (1983) included dikes in this area in a group that is chemically similar to oceanic tholeiites with lower concentrations of LIL elements than diabase dikes found elsewhere in the southern Appalachians.

METAMORPHISM

Mineral assemblages and isotopic ages of basement rocks in the Sauratown Mountains anticlinorium (SMA) indicate that portions of the anticlinorium have undergone at least two prograde metamorphic events, one associated with the Grenville orogeny and a second, mid-Paleozoic event. Cover rocks within the anticlinorium contain mineral assemblages indicative of only the latter (mid-Paleozoic event) of the two events. Widespread alteration of prograde mineral assemblages (e.g., biotite to chlorite, etc.) in both basement and cover rocks suggests that most of the sequence has been affected by late-stage retrogression.

Grenville Metamorphism

Metamorphic grade in Middle Proterozoic basement in the Sauratown Mountains anticlinorium generally is characterized by lower amphibolite to upper greenschist facies mineral assemblages. These assemblages probably reflect the prograde Grenville metamorphic event and also retrogression by mid-Paleozoic metamorphism and subsequent shearing.

Basement units within the SMA have been compared to the Elk River and Globe massifs in western North Carolina based on the apparent absence (except locally in the Elk River massif) of granulite facies metamorphism (Bartholomew and Lewis, 1984). Recent mapping and thin section analysis has determined that, at least locally, granulite facies conditions were attained in rocks of the SMA during the Grenville event. Granitoid gneiss of the Miller Creek complex contains amphibole and pyroxene (both ortho- and clinopyroxene forms) as the major mafic phases. Pyroxene-bearing granites are generally restricted to the Precambrian basement in the southern Appalachians and denote the occurrence of granulite facies metamorphism. These data suggest the correlation of basement based on apparent metamorphic grade attained during the Grenville is unreliable.

No structural fabrics associated with the Grenville orogenic event have been identified in this study or other detailed investigations (Lewis, 1980; Heyn, 1984). The absence of any relict structural fabrics and the only rare occurrence of possible granulite facies mineral assemblages implies that evidence for the Grenville event has been almost completely overprinted by later metamorphic events. Because of overprinting by later events, the areal extent of granulite facies metamorphism in the SMA during the Grenville cannot be determined.

The timing of the Grenville metamorphic event in the SMA can be approximated using Rb-Sr isotopic data. Rb-Sr ages for the Pilot Mountain and Grassy Creek gneisses (1173 +/- 33 m.y.) are considered to represent metamorphic ages documenting the re-equilibration of Strontium isotopes during the Grenville metamorphic event (McConnell and others, 1988). While the Grenville event is commonly estimated to have occurred approximately 1 billion years ago, these data suggest that in the Sauratown Mountains, the timing is somewhat older than 1000 m.y. at approximately 1170 m.y. ago.

Mid-Paleozoic Metamorphism

Mineral assemblages in the cover sequence within the SMA display a pattern of decreasing metamorphic grade towards the center of the structural window thus outlining an inverted metamorphic sequence. Metamorphic grade decreases from upper amphibolite facies (sillimanite grade) on the northern (Smith River allochthon; Conley, 1978; Espenshade and others, 1975) and southeastern boundaries (Ashe Formation rocks) of the anticlinorium to greenschist facies assemblages in the Sauratown formation in the center of the window. The inversion and symmetry of metamorphic isograds about the anticlinorium, in part, documents the presence of a tectonic window.

Isolated occurrences of sillimanite are present in Ashe Formation rocks in the southern part of the massif near the Shacktown fault and in the western part of the massif in rocks interpreted as Ashe equivalents by Heyn (1984). The Ashe Formation equivalents were formerly included in the

Inner Piedmont but as outlined by Heyn (this guidebook) the Yadkin fault, defined by Espenshade and others (1975) as separating Inner Piedmont and Ashe Formation rocks, is not distinct and the feature is interpreted as the upper kyanite to lower kyanite grade transition and the onset of incipient migmatization. Espenshade and others (1975) interpreted the Yadkin fault to conform to lithologic contacts and indicated that the fault coincided with the kyanite-sillimanite isograd.

The majority of Ashe Formation rocks in the study area contain mineral assemblages indicative of middle amphibolite facies. Kyanite and staurolite are observed in aluminous members of the Ashe Formation on both limbs of the SMA (Espenshade and others, 1975). Heyn (1984) working to the west of the study area was able to define the upper kyanite to lower kyanite grade transition based on the onset of migmatization to the south and southwest. This transition and incipient migmatization occurs in the extreme southwestern part of the study area but is unmapped on the northwestern limb of the SMA.

Towards the core of the anticlinorium and inward into the window, metamorphic grade decreases to lower amphibolite to upper greenschist facies in the Little Yadkin thrust sheet. Rocks generally contain garnet-oligoclase-biotite with no apparent kyanite or staurolite present. Plagioclase composition locally decreases to albite. The absence of aluminous rocks in the Hogan Creek Formation prohibits exact determination of metamorphic grade in this part of the massif; however, the majority of the mineral assemblages observed indicate that rocks were metamorphosed to lower amphibolite facies (Heyn, 1984; this guidebook).

In the Pinnacle thrust sheet metamorphic grade decreases toward lower greenschist facies with albite present instead of oligoclase (Centini, 1968; Butler and Dunn, 1968; Simons, 1982; Heyn, this guidebook). Garnet locally occurs but is not widespread. Butler and Dunn (1968) noted the local occurrence of garnet and the apparent absence of mineral assemblages suggestive of lower greenschist facies metamorphism, concluding that metamorphic grade in this area was in the quartz-albite-epidote-almandine subfacies. Although Simons (1982), working in the eastern part of the Sauratown Mountains, implied that stilpnomelane was present, it has not been recognized in this part of the SMA and metamorphic grade in this part of the anticlinorium is believed to be upper greenschist facies.

The timing of the mid-Paleozoic metamorphic event is not as easily documented as the age of the Grenville event. Metamorphic grade in the inner parts of the window during the mid-Paleozoic event were not of sufficient intensity to reset the Rb-Sr system. Attempts to isotopically date rocks in the outer parts of the window using the Rb/Sr method were unsuccessful, prohibiting the determination of the timing of middle amphibolite facies metamorphism in those rocks. Interpretations on the timing of Paleozoic metamorphism in the SMA must rely on data collected from outside the window

Odom and Russell (1975) presented Rb/Sr data on the Henderson Gneiss and rocks of the Smith River allochthon that suggest an age of approximately 450 m.y. for the age of metamorphism in the area of the SMA. Sinha and Glover (1978) using U/Pb zircon data from the Henderson Gneiss also derived a 450 m.y. age for the mid-Paleozoic metamorphic event. They interpreted the mylonitization of the Henderson Gneiss to have occurred in association with this metamorphic event. Harper and Fullagar (1981), studying granitic gneisses southwest of the study area, indicated that Rb-Sr ages clustered in the 460-420 m.y. range suggesting that this could represent mid-Paleozoic metamorphism or an intrusive event. Harper and Fullagar (1981) preferred the latter interpretation because they doubted that isotopic homogenization could occur over the large area from which their samples were obtained (100 km^2). Conley (1978) interpreted the Leatherwood Granite as intruding rocks of the Smith River allochthon subsequent to the peak of metamorphism. The Leatherwood Granite was radiometrically dated as 462 +/- 20 m.y. (Rb/Sr whole rock age, Odom and Russell, 1975) or 450 m.y. (Rankin, 1975). The evidence currently available suggests that Paleozoic regional metamorphism occurred at approximately 450 Ma.

Retrogressive Metamorphism

Retrograde mineral assemblages are common in rocks of the SMA. Generally, this retrogression takes the form of alteration of kyanite and staurolite to sericite and biotite, and amphibole to chlorite. The retrogression is so widespread that it is difficult to attribute the alteration to a particular fault or set of faults. Heyn (1984) was able to determine that retrograde metamorphism is best developed where D_3 deformation produced steeply-dipping S_3 cleavage or F_3 reoriented S_d completely. Retrogressive metamorphism related to the D_3 event is believed to reflect final stacking of thrust sheets within the Sauratown Mountains window. Mylonitic textures in rocks of the anticlinorium confirm that major faulting occurred within the massif following the peak of metamorphism. This ductile shearing may be related to the event that formed mylonites in the Brevard fault zone to the southwest.

Sinha and Glover (1978) have indicated that retrogressive metamorphism in the Henderson Gneiss occurred approximately 280-300 m.y. ago based on K-Ar ages obtained by Stonebraker and Harper (1973). This retrogressive event was believed to have followed a second Paleozoic metamorphism associated with mylonitization in the Brevard fault zone and is attributed to the Acadian orogeny. No evidence was obtained in this investigation to suggest that a second Paleozoic prograde metamorphic event has occurred in the Sauratown Mountains anticlinorium. One line of speculation would suggest that the mylonitization observed in rocks of the Sauratown Mountains anticlinorium and Henderson Gneiss occurred coincidently at approximately 360 m.y. ago and that the K/Ar ages reflect cooling ages from this faulting event.

CHARACTER AND TIMING OF DEFORMA TIONAL EVENTS

Although the re-equilibration of strontium isotopes in basement gneisses dates the Grenville orogeny in the SMA, no fabric elements have been identified in the basement which can be definitely associated with the Grenville orogeny. All textures currently recognized in rocks of the SMA are believed to have resulted from later metamorphic and deformational events.

The internal structure of the SMA is complex with multiple episodes of folding and faulting (Table 1). Rocks in each thrust sheet seem to have undergone all of the recognized deformational and metamorphic events suggesting that the prefaulting geographic separation on the thrusts was not large enough to record different deformational and/or metamorphic histories.

Mid-Paleozoic deformation in the SMA is characterized by two episodes of isoclinal flow folding that occurred coincident with the major episode of prograde regional metamorphism. Northeast-trending, northwest-vergent F_1 isoclines are folded by F_2 tight to isoclinal folds. Heyn (1984) noted that F_1 isoclines are folded by coaxial F_2 folds and that the axial-planar foliation associated with the early folds has been transposed by the second folding event which makes separating F_1 and F_2 folds difficult. The regionally extensive S-surface recognized in the SMA is believed to be the axial-planar foliation to $_2$ folds. Heyn (1984) indicated that both of these folding events preceded the peak of mid-Paleozoic metamorphism, as indicated by the growth of aluminum-silicate minerals across the S_2 surface and the distribution of metamorphic isograds at an oblique angle to s_2.

The timing of the mid-Paleozoic deformational events can be constrained based on the timing of the Taconic metamorphic event. Odom and Russell (1975) presented Rb-Sr data on the Henderson Gneiss and rocks of the Smith River allochthon that suggested an age of approximately 450 Ma. for the timing of prograde metamorphism in the SMA area. Sinha and Glover (1978) using U-Pb zircon data from the Henderson Gneiss derived an approximately 460 m.y. age for the mid-Paleozoic event in the Rosman, North Carolina, area. They interpret the mylonitization of the Henderson Gneiss to be associated with this metamorphic event. Therefore, the timing of the major episode of isoclinal flow folding in the SMA is believed to have occurred at approximately 450 Ma.

The emplacement of the Smith River allochthon over the SMA is tied to the age of mid-Paleozoic metamorphism. Rankin (1975) indicated that major movement on the Ridgeway fault and emplacement of the Smith River allochthon occurred prior to the peak of metamorphism. He suggested that a maximum age of emplacement was 450 Ma. based on an unpublished age for a granitic gneiss in the allochthon. Conley (1978), however, indicates that the Smith River allochthon was emplaced after the intrusion of the Martinsville complex which he believes is unmetamorphosed and 450 m.y. old based on the age of the Leatherwood granite. The coincidence of the assumed age of metamorphism (i.e, approximately 450 Ma.) and the maximum/minimum age of emplacement of the Smith River allochthon suggests that the allochthon was emplaced in association with or shortly after the peak of mid-Paleozoic metamorphism.

In the SMA, major thrusting and imbrication, perhaps related to the emplacement of the Smith River allochthon, is believed to have occurred coincident with and following mid-Paleozoic metamorphism. This timing is based on the shearing out of synmetamorphic F_2 folds and the presence of mylonites along the borders of the imbricates, as well as the juxtaposition of high-grade metamorphic mineral assemblages over low-grade assemblages. These relationships suggest that thrusting began prior to the peak of metamorphis and continued past the point where deformation outlasted recrystallization associated with regional metamorphism.

Neither metamorphism nor the extensive thrusting associated with the mid-Paleozoic event reset Rb-Sr ages in the basement gneisses. This suggests that either basement slices were carried passively in the thrust sheets now observed in the SMA or the absence of a major fluid phase during metamorphism and deformation was not conducive to the large scale re-equilibration of isotopes.

Following major thrusting and emplacement of the Smith River allochthon, deformation associated with third generation folds (F_3) took place. Generally, F_3 folds are northeast-trending, flexural-slip to flexural-flow folds which are upright to slightly vergent to the northwest. These folds are observed on both a mesoscopic and megascopic scale with an example of the latter being the Sauratown Mountains anticlinorium. Parasitic folds related to this deformational event fold the Ridgeway fault (Conley, 1978) and faults bounding the major thrust sheets within the SMA. $_3$ folds also are responsible for the lense-like exposures of the Forbush gneiss in the thrust sheet containing the Ashe Formation (Fig. 1). Generally the timing of $_3$ folds may coincide with the episode of deformation and low-grade metamorphism noted along the Brevard fault zone which is dated at approximately 360-390 Ma. (Odum and Fullagar, 1973; Sinha and Glover, 1978).

Following or perhaps coincident with F_3 folding, late-stage shearing occurred in rocks along the southern margin of the SMA (i.e., the Shacktown fault). The southern margin of the SMA is marked by the development of a shear cleavage in metagraywackes and intense retrogression of amphibolite facies mineral assemblages. This episode of shearing and retrogression may be related to Acadian deformation, as noted in the Brevard zone by Odom and Fullagar (1973), or result from an episode of Alleghanian dextral shear that has reset Rb-Sr whole-rock ages near the Bowens Creek fault (Gates and Mose, 1987).

Fourth and fifth generation folds are broad, open, cross folds that interfere with each other and with other folding events resulting in the development of dome and basin interference patterns. Interference between these two fold events is particularly well expressed near Pilot Mountain where the quartzite defines a broad domal structure (Fig. 1). Folds of these generations trend northeast-southwest and northwest-southeast and are flexural-slip folds.

Late-stage brittle deformation characterized by flinty crush rock overprints mylonitic features along the Shacktown fault. The northeast and southwest extensions of the Shacktown fault form the boundaries of Dan River-Danville and Davie County Triassic basins and brittle deformation observed along the Shacktown fault is possibly an indication of reactivation of the Shacktown fault during Mesozoic rifting. Mesozoic deformation is noted along the Stony Ridge cataclasite near the center of the SMA. Fullagar and Butler (1980) used Rb-Sr methods to suggest an age of 180 m.y. for the re-equilibration of isotopes on the Stony Ridge cataclasite.

SUMMARY AND CONCLUSIONS

The geologic mapping presented in this guidebook are summarized as follows:

1. Structural and lithologic data indicate that erosion through the crest of the Sauratown Mountains anticlinorium has exposed a complex, multi-tiered structural window. While the interpretation that the SMA area represents a window is not new (i.e., Bryant and Reed, 1961), the complexity of the window and the probable presence of anticlinal stack duplex in the window were not suggested in previous reports.
2. U/Pb isotopic dating documents the presence of Middle Proterozoic basement in the Sauratown Mountains anticlinorium. The age of basement and the relationship between basement and quartzite of the Sauratown formation provide a firm basis for placing constraints on stratigraphic interpretations in the SMA.
3. Rb-Sr ages of the Grassy Creek and Pilot Mountain gneisses pinpoint the timing of Grenville metamorphism in rocks of the SMA at 1170 m.y. Ages for the peak of Grenville metamorphism elsewhere in the southern Appalachian orogen are geographically variable.
4. Each trust sheet in the Sauratown Mountains window appears to contain a sequence consisting of Middle Proterozoic basement overlain non-conformably by late Proterozoic to early Paleozoic cover rocks.
5. Analysis of thrust sheet boundaries indicates that thrusting in the SMA area began prior to the peak of Paleozoic metamorphism and concluded after the peak.
6. Crossnore Complex rocks in the SMA area, if they truly are related to the Crossnore, appear to be intrusive into three of the four thrust sheets in the SMA and therefore must predate the thrusting episode and suggest that the thrust sheets were not substantially separated when intrusion occurred. By inference from isotopic studies of the Crossnore Complex outside of the SMA area, the age of the cover sequences intruded by the Crossnore would have to be older than 680 m.y.
7. No evidence is available to support the widespread presence of a sequence of “older” Precambrian rocks as proposed by Rankin and others (1973) and Espenshade and others (1975). Enclaves in Middle Proterozoic basement are interpreted as remnants from terranes no longer exposed in the SMA area.

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PALEOGEOGRAPHIC SIGNIFICANCE OF THE QUARTZITE ON PILOT MOUNTAIN, SURRY COUNTY, NORTH CAROLINA

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ABSTRACT

Recent mapping in the metamorphic core of the southern Appalachians has led to identification of several internal basement massifs interpreted as windows exposing parauthochthonous basement beneath the Danbury thrust sheet. In many instances this parauthochthonous basement possesses a sedimentary cover sequence. One such internal massif is exposed in he Piedmont of North Carolina by the Sauratown Mountains window. Here, the 1.2 Ga basement is overlain by a cover sequence of metaarkose, schist, and quartzite of the Sauratown formation (McConnell, this guidebook). The westernmost of the large quartzite bodies is exposed at Pilot Mountain State Park, Surry County, North Carolina. Lithologic and stratigraphic similarities between the sedimentary sequence at Pilot Mountain and the Chilhowee Group of the Grandfather Mountain Window and Unaka Belts to the west have prompted some to propose stratigraphic equivalence.

Detailed examination of the primary cross-stratification types preserved within the quartzite at Pilot Mountain resulted in the delineation of three facies: 1) a low-angle, planar-tabular cross-stratified facies (foreshore); 2) a small-scale, trough cross-stratified facies (upper shoreface); and 3) an interbedded sandstone and shale (phyllite) facies (lower shoreface to inner shelf). Deposits of similar origin within the Chilhowee Group appear to thin west to east, from 80 m at the Chilhowee Group type locality at Chilhowee Mountain (300 km west-southwest of Pilot Mountain) to 40 m within the Unaka Belt (150 km west of Pilot Mountain). The quartzite at Pilot Mountain possesses a stratigraphic thickness exceeding 40 m, and therefore does not appear to represent a distal portion of this passive-margin sequence. Assuming that the sedimentary sequences exposed in the Sauratown Mountains Window and the Unaka Belt occupy the same relative positions with respect to the North American continental margin today as they did when they were deposited, two possible paleogeographic-paleotectonic interpretations seem plausible: 1) the quartzites of Stokes and Surry Counties, North Carolina, represent Upper Proterozoic, Ashe Formation-equivalent deposition along a sea-floor high associated with the partially or fully rifted basement terrane. In this case subsequent orogenic activity would have resulted in the overthrusting of the massif and its cover by the finer grained, offshore deposits of the Ashe Formation; 2) the quartzites of Stokes and Surry Counties, North Carolina, represent Upper Proterozoic to Lower Cambrian (Chilhowee and Evington Group time-equivalent) deposition on an isolated, rifted continental fragment. Bathymetric shallowing along the flanks of basement block would result in the deposition of shallow water sediments derived primarily from the rifted Middle Proterozoic-age basement block.

INTRODUCTION

The quartzite strata exposed in the Sauratown formation at Pilot Mountain, Surry County, North Carolina, represent the westernmost exposure of a locally extensive quartzite body that is part of a sedimentary sequence resting on Precambrian (1.0 to 1.2 Ga.) basement (Rankin and others, 1973; McConnell and others, 1986). This basement and associated cover sequence are exposed in the Piedmont by the Sauratown Mountains window (Hatcher, 1987; Hatcher and others, 1988) and along with the Pine Mountain Belt of Alabama and Georgia and the State Farm Gneiss of Virginia, constitute the easternmost internal basement massifs of the southern Appalachians (Fig. 1; Hatcher, 1984). These basement massifs occur immediately west of the low (west) to high (east) gravity gradient inferred to represent the eastern edge of Grenville crust (Williams, 1978; Haworth and others, 1981; Hatcher, 1984). As such, these massifs probably represent parauthochthonous basement exposed under the main thrust sheet (Hatcher, 1984).

Quartzites in Stokes and Surry Counties, North Carolina, have been the source of much geologic debate since their original assignment by Kerr (1875) to the Huronian age, and therefore stratigraphically equivalent to the Kings Mountain group. Subsequent mapping by Mundorff (1948) outlined an area of “quartzite and schist” with boundaries essentially the same as the Huronian age rocks shown by Kerr (1875). The Geologic Map of North Carolina, published in 1958 by the North Carolina Department of Conservation and Development, likewise assigned the quartzites to the Kings Mountain Group. The first suggestion that these quartzites and the underlying basement were exposed within a structural window through the Piedmont belt was put forth by Bryant and Reed (1961), based on lithologic and stratigraphic similarities to Chilhowee Group (Upper Proterozoic to Lower Cambrian) rocks of the Grandfather Mountain window in western North Carolina and the Unaka Belt in northeasternmost Tennessee. Butler and Dunn (1968) disputed the

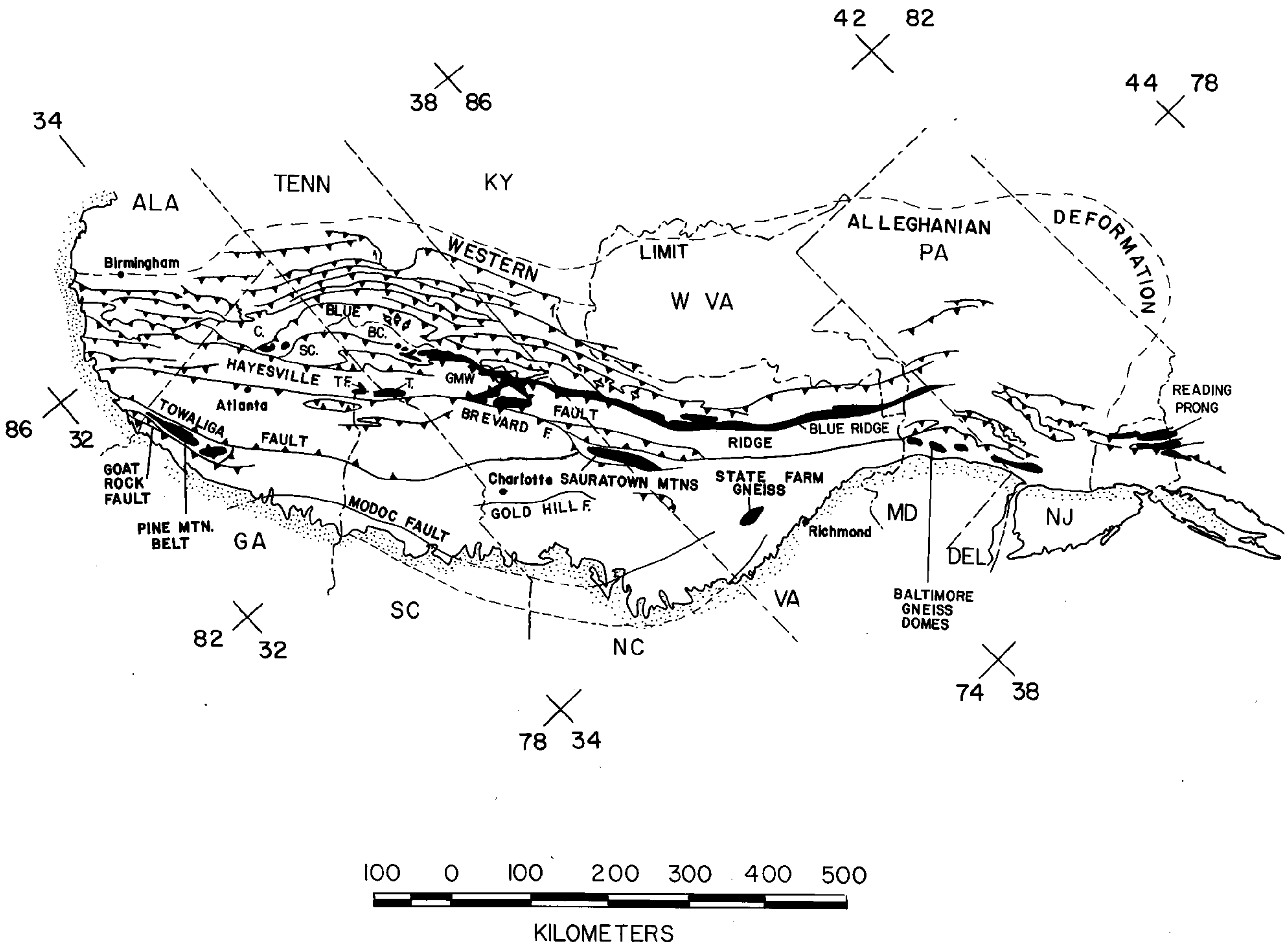

Figure 1. Map of the southern and central Appalachians showing the main subdivisions and the distribution of Grenville basement rocks (black) (from Hatcher, 1984).

existence of the window and suggested that the quartzites represented a facies change within the Inner Piedmont belt protoliths, and were therefore equivalent to the Upper Proterozoic Ashe Formation. Rankin and others (1973) assigned the quartzites an Upper Proterozoic to lower Paleozoic age, citing the conspicuous preservation of primary bedding within the quartzites as evidence against their correlation with the older Ashe Formation. Recognition of the thrust faults that form the Sauratown Mountain window and Hanging Rock Inner window by Hatcher and others (1988) has resulted in renewed interest in the possibility of the quartzites being stratigraphically equivalent to the Chilhowee Group of the western Blue Ridge, as originally proposed by Bryant and Reed (1961). While the quartzite and associated lithologies have been shown to be structurally isolated from the Ashe Formation, lack of fossil or radiometric dating from the quartzites precludes any definitive stratigraphic assignment. The purpose of this investigation was to determine the depositional setting of the quartzite exposed at Pilot Mountain, Surry County, North Carolina, and to compare this setting to that proposed for the Hampton and Unicoi Formations of the Chilhowee Group of Unaka Belt (Cudzil and Driese, 1987; Walker and others, 1988).

METHODS

The nature of exposure at Pilot Mountain dictates that examination of the quartzite body be limited to traverses along the cliff base, with few vertical sections observable. The Ledge Spring Trail runs along the base of the cliff face and provides access to varying stratigraphic levels within the quartzite body (Fig. 2). Regional deformation in the area has resulted in varying degrees of recrystallization and penetrative deformation. Consequently, some portions of the quartzite body are devoid of primary sedimentary structures and attempts to measure and describe an accurate stratigraphic section were severely hampered. As a result of numerous traverses, over 25 m of the estimated 45-75 m of quartzite

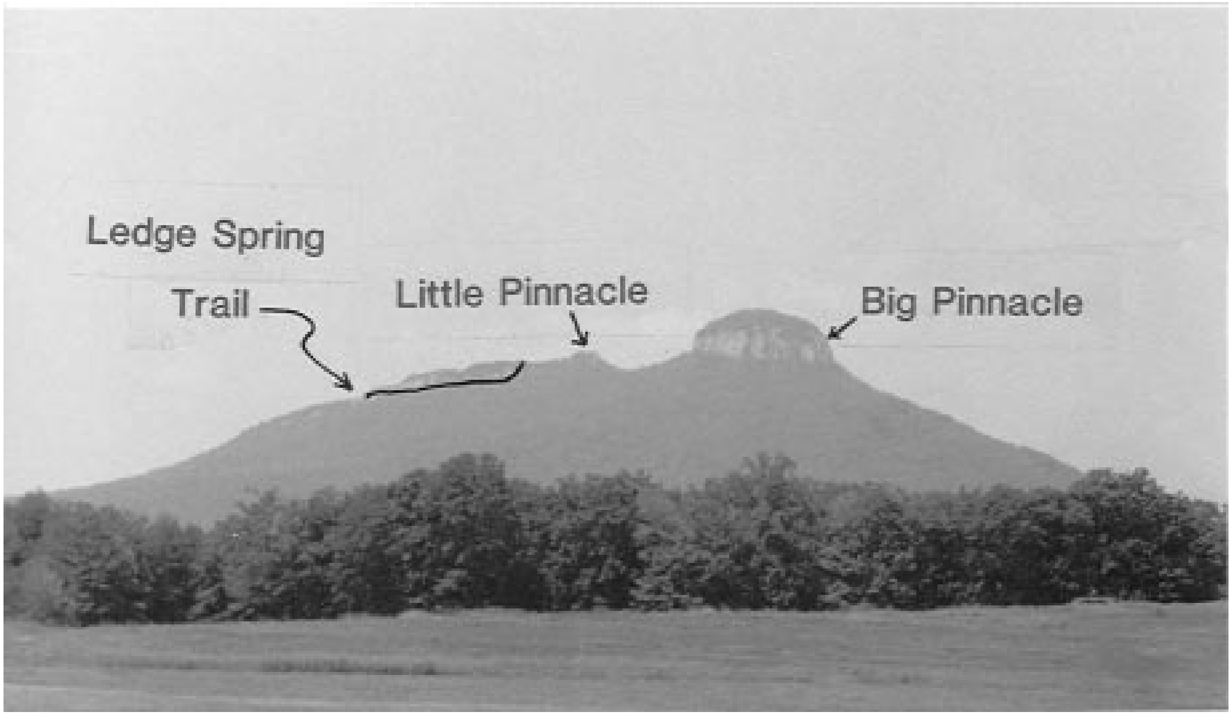

Figure 2. Pilot Mountain as seen from approximately 1.2 km south.

were examined. The section described here therefore represents a somewhat "piecemeal" vertical sequence based upon the relative position of various sedimentary structures and suites of structures observed along the trail from the base to the top of the Little Pinnacle quartzite body

DEPOSITIONAL SETTING

The vast majority of the quartzite can be characterised as well-sorted, mineralogically mature, fine- to medium-grained quartz sandstone, with laminations within individual beds well-defined by heavy mineral concentrations. Consequently, examination of exposures at Pilot Mountain resulted in identification of a broad range of primary sedimentary structures and cross-stratification types. Facies definitions are based on the suite of primary sedimentary structures and stratification types present, as well as the stratigraphic occurrence of these features. Three facies were defined and include: 1) a low-angle, planar tabular cross-stratified sandstone facies; 2) a trough cross-stratified sandstone facies; and finally 3) an interbedded sandstone and shale (phyllite) facies.

The textural and mineralogic maturity of the deposits of these facies, as well as the concentrations of heavy minerals, suggest a high degree of reworking within a fairly high energy environment. Several of the cross-stratification types observed are indicative of deposition by oscillatory flow, suggesting subaqueous deposition. These two broad features indicate deposition occurred in a relatively shallow, marine environment. The overall distribution of primary features further suggests that the bedforms were formed under varying components of unidirectional (current) and oscillatory (wave) flow.

Low-angle, Planar-tabular Cross-stratified Sandstone Facies

This facies is characterized by 0.1 to 0.3 m thick, low-angle, planar-tabular cross-stratification, in which the 2 to 10^{o} dipping laminal dip in a variety of directions resulting in the characteristic wedge-shaped cross-sets (Fig. 3A). This facies is vertically and laterally restricted, and hence is defined as an individual facies because of its uniqueness and interpretational significance. The lone example of this facies occurred within a thick sequence of rocks dominated by the trough cross-stratified sandstone facies.

Interpretation

The occurrence of heavy mineral laminated, low-angle, planar-tabular "wedge" cross-stratification is interpreted to have resulted from swash and backswash in the foreshore zone (Clifton, 1969; Reineck and Singh, 1980). The wedge-shaped sets are attributed to deposition on the changing slope of the beachface (McCubbin, 1981). Consequently this facies represents the shallowest deposition recorded within the quartzite at Pilot Mountain.

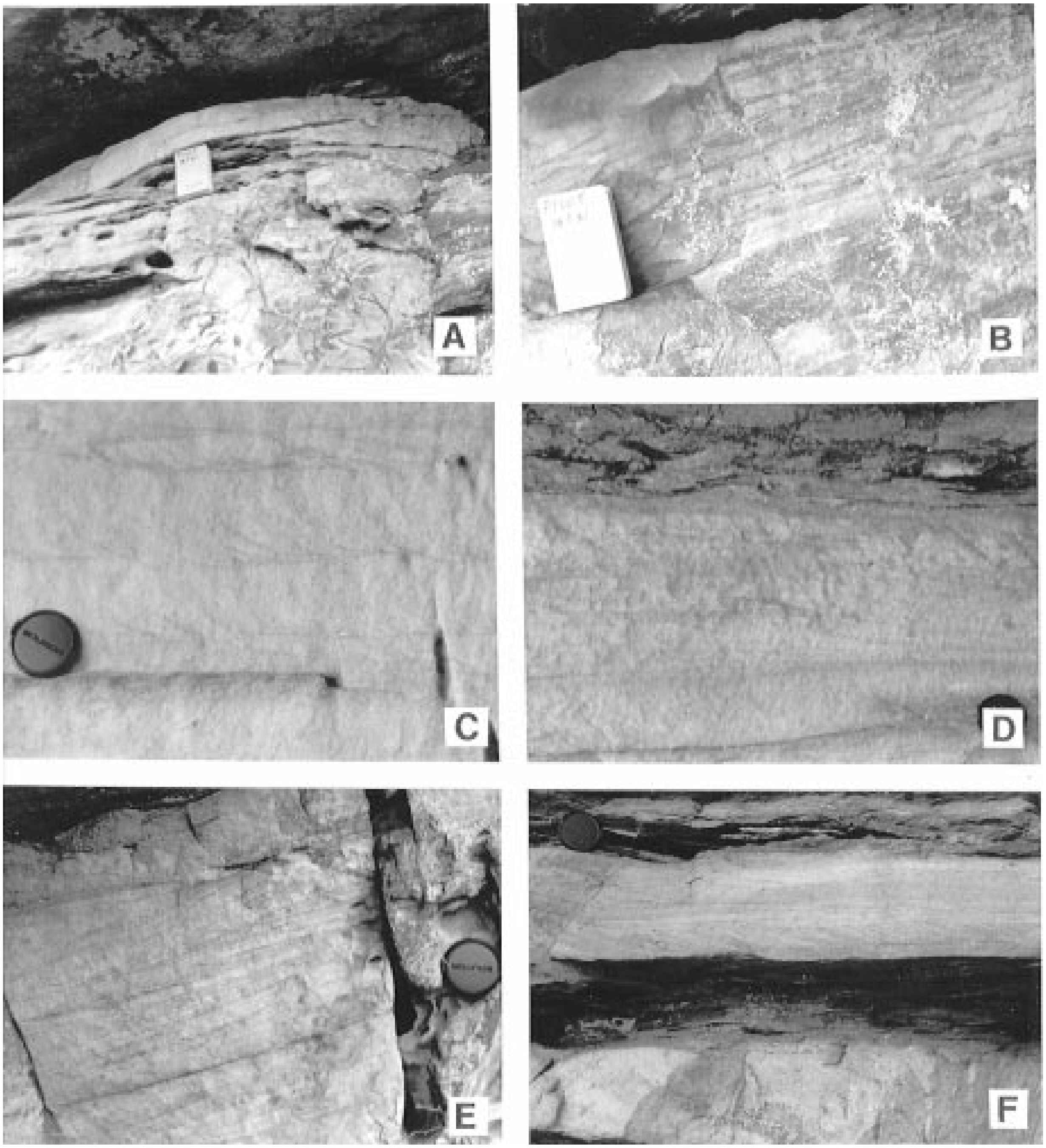

Figure 3. Field photos of the diverse array of primary cross-stratification types observed within the quartzite at Pilot Mountain, Surry County, North Carolina. A = low-angle, planar-tabular cross-stratification. B = small-scale, trough cross-stratification. C = small scale, high-angle, planar-tabular cross-stratification. Note "pseudo-piperock" texture in right margin of photo. D = Composite cross-stratification composed of horizontal lamination (base), small-scale trough-hummocky cross-stratification intermediate (middle), and asymmetric ripple cross-stratification (top) (See text for explanation). E = small-scale trough-hummocky intermediate cross-stratification. F = composite bed composed on small scale, high-angle, planar-tabular cross-stratification (base) and small-scale trough-hummocky cross-stratification intermediate (top).

Trough Cross-stratified Sandstone Facies

This facies is actually characterized by the occurrence of small-scale, trough cross-stratification (Fig. 3B) as well as rare occurrences of small scale, high-angle, planar-tabular cross-stratification (Fig. 3C). In both instances the deposits are thickly to very thickly bedded (.3 to >1 m) and display planar bases and tops. In some occurrences, the trough cross-sets appear to represent an intermediate between, or som combination of, hummocky and trough cross-stratification (Fig. 3E). This facies is the most widespread, constituting as much as 70% of the sandstone still retaining primary cross-stratification. Near-vertical incipient fracture or cleavage planes within some beds of this facies, result in a distinctive pattern similar to the "piperock" lithology commonly attributed to the Late Proterozoic to Recent trace fossil Skolithos (Crimes, 1987; Fig. 3C). Unfortunately, no unequivocal examples of Skolithos were observed, but recent work completed in the Upper Proterozoic to Lower Cambrian Chilhowee Group of East Tennessee (Cudzil and Driese, 1987; Walker and others, 1988; Driese and Walker, in prep) indicates that although Skolithos may be somewhat restricted to shallow-water, high-energy facies, its distribution is non-uniform. Consequently, its apparent absence at Pilot Mountain need not be construed as being indicative of a pre-Late Proterozoic (Pre-Vendian) time of deposition.

Interpretation

Trough cross-stratification and high-angle, planar-tabular cross-stratification results from migration of 3-D and 2-D (respectively) ripples or dunes under unidirectional flow (Harms and others, 1982). The interstratification of rocks displaying these cross-stratification types with rocks of the low-angle, planar-tabular cross-stratified facies suggests that this facies represents deposition by wave surge and wave-generated currents (McCubbin, 1981) in environments adjacent to the foreshore. The cross-stratification described as being intermediate between trough and hummocky, might then represent deposition in which some component of oscillatory flow occurred. Such combined-flow conditions would be consistent with deposition in slightly deeper water, where unidirectional current flow is reduced in significance and the increased influence of oscillatory flow felt. Overall, the rocks of this facies are interpreted as representing deposition along the upper shoreface.

Interbedded Sandstone and Shale Facies

The interbedded sandstone and shale facies occurs exclusively in the lower 5 to 10 m of the section examined. This facies is characterized by the occurrence of shale interbedded with sandstone beds that possess combinations of two or more of these features (Fig. 3D). In this instance the bed displays from base to top: horizontal lamination; low-angle, small-scale trough cross-stratification; and finally asymmetric ripples. In other instances beds display distinct changes in cross-stratification (Fig. 3F), where small scale, high angle, planar-tabular cross-stratification is directly overlain by broad, shallow, trough cross-stratification.

Interpretation

The occurrence of interbedded shale and sandstone displaying composite cross-stratification is interpreted as resulting from fluctuations in flow regime consistent with stor sedimentation. In this interpretation, deposition was probably below fair-weather wave base and is represented by the shale intervals. Storm events resulted in the introduction of sand by storm-generated currents, possibly represented by the small-scale planar-tabular sets. The close association of these sandstones to those of the trough cross-stratified facies suggests that sand may have been supplied by erosion of the adjacent, shallower environments, as observed in the North Sea and described by Johnson (1978). These storm sand beds could then have been reworked during waning stages of the storm by combined oscillatory and unidirectional flow. The resulting deposit (Fig. 3D) may resemble the ideal hummocky sequence as documented by Dott and Bourgeois (1982) or some composite bed containing cross-stratification indicative of purely unidirectional (current) and combined flow (Fig. 3F). These processes would then have differed slightly from deposition observed in inner shelf settings below fairweather wave base by Swift and others (1983) in that a larger degree of unidirectional flow may have resulted in the "mixed" nature of the small-scale trough-hummocky cross-stratification intermediate. Recent, yet-unpublished experimental flume work conducted by Myrow and Southard (in prep) suggests that hummocky and trough cross-stratification may represent single bedform types out of a continuum of bedforms produced by combined unidirectional and oscillatory flow. Overall, rocks of this facies are interpreted to have been deposited in a lower shoreface to inner shelf setting.

Depositional Model

As can be seen in Figure 4, the apparent stratigraphic arrangement of these facies as exposed at Pilot Mountain would indicate deposition in a shallow shelf to foreshore (beach) setting during some fluctuation of relative sea-level. The quartzite can then be separated into two depositional phases, the lower phase representing a typical progradational sequence, and the upper representing sedimentation during transgression. Because the upper phase seems to have resulted only in deposition of rocks assigned to the trough cross-stratified facies, it may be inferred that this transgressive event was gradual and of a minor magnitude.

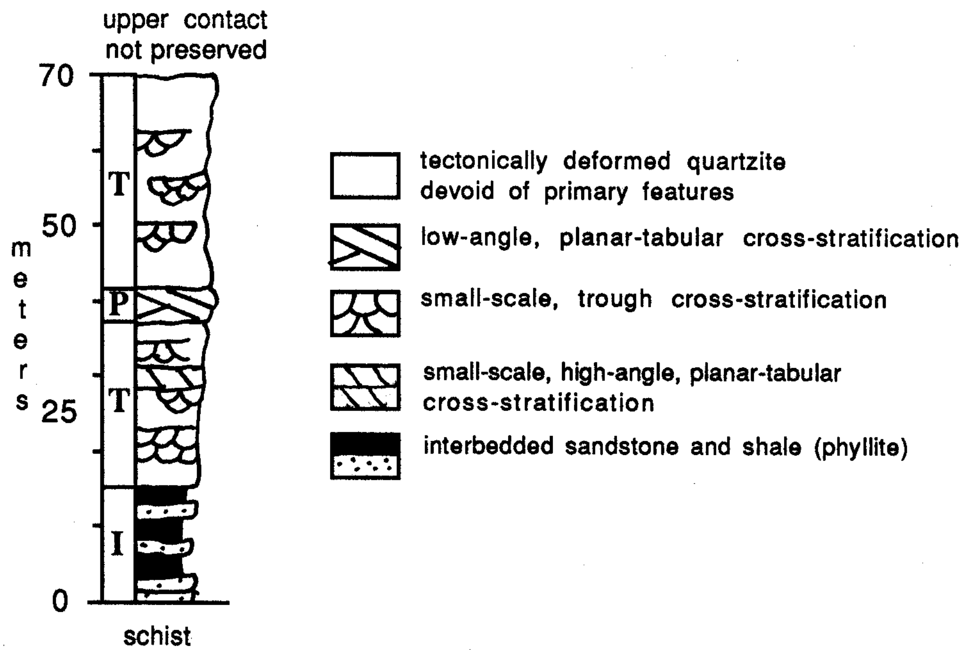

Figure 4. Composite (see text for explanation) stratigraphic section for the quartzite at Pilot Mountain, Surry County, North Carolina. Facies are labelled as follows: I = Interbedded Sandstone and Shale (Phyllite) Facies; P = Low-angle, Planar-tabular Cross-stratified Sandstone Facies; T = Trough Cross-stratified Sandstone Facies.

COMPARISON WITH CHILHOWEE GROUP OF THE UNAKA BELT

The Chilhowee Group as exposed within the Unaka Belt of northeasternmost Tennessee, is a nearly 1000 m thick siliciclastic sequence deposited within a diverse suite of terrigenous environments. This sequence has been assigned a threefold stratigraphy which includes, from base to top: 1) the Unicoi Formation, approximately 400 m of feldspar- and quartz-rich pebbly sandstone to conglomerate; 2) the Hampton Formation, approximately 280 m of interbedded shale and quartz sandstone; and 3) the Erwin Formation, approximately 250 m of interbedded shale and quartz sandstone (King and Ferguson, 1960; Cudzil, 1985; Cudzil and Driese, 1987).

A process-oriented sedimentologic study was conducted on the Chilhowee Group of the Unaka Belt at the Doe River Gorge, by Cudzil (1985) along U.S. Highway 19E southeast of Elizabethton, Tennessee. This section occupies a present day position nearly 150 km west of Pilot Mountain, North Carolina. That study resulted in the identification of four facies (Fig. 4) which were interpreted as representing deposition within environments ranging from coastal, alluvial braided plain to outer shelf. The shallowest of the marine environments was represented by super-mature quartz arenites possessing low-angle cross-stratification and large-scale planar-tabular cross-stratification similar to that observed in the quartzite of Pilot Mountain. At the Doe River, the thickest mature, marine quartz sandstone body within the Chilhowee Group measures less than 40 m. In contrast, similar bodies within the Chilhowee Group at its type locality at Chilhowee Mountain (located to the southwest of the Unaka Belt) exceed 80 m thick, possibly suggesting the Chilhowee Group at Chilhowee Mountain occupied a more proximal position with respect to the craton, than that of equivalent sedimentary rocks exposed in the Doe River Gorge. If this observed change in thickness does truly represent thinning of sand bodies to the east, the apparent 45 m thickness of the quartzite at Pilot Mountain, over 150 km to the east, can be regarded as somewhat anomalous. The shallow-water nature of the quartzite at Pilot Mountain and its substantial thickness further suggests that it does not represent a distal equivalent of the Chilhowee Group as exposed in the Doe River Gorge. Process sedimentology has yet to be conducted on the Chilhowee Group in the Grandfather Mountain window; therefore a similar comparison would be premature.

DISCUSSION

Comparison of depositional processes and stratigraphic thicknesses of similar lithologies observed at Pilot Mountain and the Doe River Gorge do not appear to be consistent with the interpretation of the quartzite of Pilot Mountain as representing some eastern equivalent of the Chilhowee Group of the Unaka belt. The observed litho-stratigraphic similarity between these two sequences may be a manifestation of similarities of source rock and depositional setting. While chrono-stratigraphic equivalence may not be applicable, this type of similarity would be consistent with interpretation of the quartzite at Pilot Mountain as representing deposition along an offshore, rifted microcontinent or similar terrane.

Because the entire Pilot Mountain sedimentary sequence lies on Middle Proterozoic basement (McConnell and others, 1988), its North American affinity appears certain. Assuming that the sedimentary sequences exposed in the Sauratown Mountain window, the Grandfather Mountain window, and the Unaka belt occupy the same relative positions (with respect to the North American continental margin) today as they did when they were first deposited, two possible paleogeographic-paleotectonic interpretations seem plausible: 1) the quartzites of Stokes and Surry Counties, North Carolina, represent Upper Proterozoic (Ashe Formation-equivalent) deposition along a sea-floor high associated with the partially or fully rifted basement terrane. In this case subsequent orogenic activity would have resulted in the overthrusting of the massif and its cover by the finer-grained, offshore deposits of the Ashe Formation; 2) the quartzites of Stokes and Surry Counties, North Carolina, represent Upper Proterozoic to Lower Cambrian (Chilhowee or Evington Group time equivalent) deposition on an isolated, rifted continental fragment. Bathymetric shallowing along the flanks of basement block would result in the deposition of shallow-water sediments derived primarily from the rifted Grenville-age basement block.

ACKNOWLEDGMENTS

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CAROLINA GEOLOGICAL SOCIETY FIELD TRIP STOPS FOR 1988

Note: All field trip stops are located on the Copeland, East Bend, Farmington, Pilot Mountain, Pinnacle, Siloam Vienna, and Yadkinville, North Carolina, 7 1/2 minute quadrangles.

DAY 1

Depart Pilot Mountain Inn at 8 AM, Saturday, November 12, 1988. Drive west on N.C. 268 and take a left on Surry County Road 2038, then a second left in about 2000 feet on Surry County Road 2080. Continue on County Road 2080 for about 4 miles, then turn right onto Surry County Road 2082. Follow this road to the "T" intersection in Siloam (please observe traffic warnings and be prepared for the Saturday morning rush hour). Turn Left (south) onto Surry County Road 1003, cross the railroad tracks, and the Yadkin River and continue southward on Siloam Road to Smithtown. (Observe the same cautions as above as you approach Smithtown.) Turn left (east) at the "T" intersection, then bear right at a fork (~1500 feet) onto Smithtown Road (Yadkin County Road 1541). Continue southeastward to the stop sign at N.C. 67. Cross N.C. 67 and continue for about 2000 feet on Smithtown Road, then turn right (south) onto Yadkin County Road 1580. Follow 1580 for about 3 miles to a "T" intersection, then turn left (south) onto Forbush Road (Yadkin County Road 1570) and continue for about one mile. Bear right (south) onto Yadkin County Road 1600. Continue to a "T" intersection at old U.S. 421(Yadkin County Road 1605). This is Stop 1.

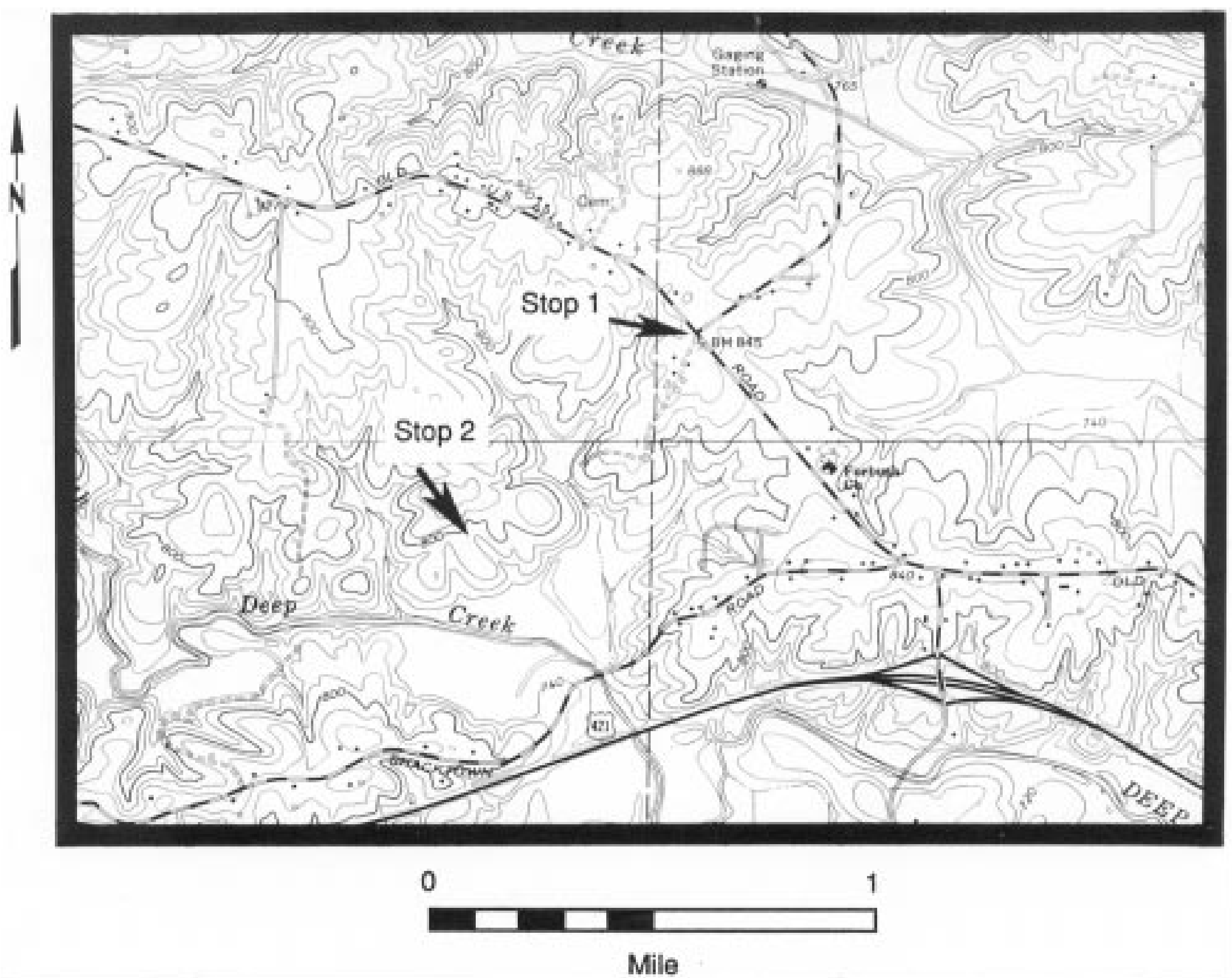

Figure S1. Parts of the Farmington and East Bend, North Carolina, 7 1/2 minute quadrangles showing the locations of Stops 1 and2.

STOP 1. FORBUSH "OPHIOLITE" AT OLD U.S. 421-COUNTY ROAD INTERSECTIO

The exposure here consists of boulders of soapstone (talc-chlorite-anthophyllite) with float and saprolite of amphibolite (hornblende-plagioclase-epidote) exposed in the ditch beside the road (Fig. S1). This exposure is typical of exposures of ultramafic and mafic rocks in this area; ultramafic rocks commonly resist weathering and form bouldery exposures that are covered by a starved vegetation, because of the general lack of certain nutrients in these rocks and possible blocking of other nutrients by the abundance of certain other constituents (e.g., Mg). (Should someone inform the landowner(s) of this problem?) Mafic rocks commonly form a red, clay-rich soil.

The basis for suggesting this is part of an ophiloite is the association of deformed mafic and ultramafic rocks, and the possible association of these rocks with the Forbush thrust (Plate 1). Note that these rocks were intruded by the North Deep Creek gabbro, and are not likely to be associated in time with the gabbro.

Turn west onto old U.S. 421 (Yadkin County Road 1605) and drive about a mile. Turn left into a new subdivision (Yadkin County Road 1705), then make another left. We are now in the North Deep Creek pluton and gabbro boulders are abundantly included in the landscaping for most residences. Stop 2 is located on one of the subdivision roads near the creek.

STOP 2. NORTH DEEP CREEK GABBRO

The North Deep Creek gabbro, located north of the Shacktown fault (Fig. S1; Plate 1, and Fig. 2 of Heyn, this guidebook), and intruded the Ashe Formation after isoclinal folding. The gabbro does not have a megascopic foliation (Fig. S2), but in thin-section biotite appears to be faintly aligned, and some minerals exhibit undulatory extinction. This suggests that the rock was slightly deformed. The rock contains (in order of decreasing abundance), plagioclase, amphibole (deep green pleochroism), pyroxene, and biotite (Table S1). Accessory minerals include quartz, myrmekite, apatite, zircon, sphene, and an opaque mineral. Chlorite occurs as an alteration product of biotite, and sericite and clinozoisite are secondary alteration products after plagioclase. Plagioclase ranges in composition from labradorite to oligoclase (determined by Michel-Levy method) and occurs both in the groundmass and as large phenocrysts. Plagioclase phenocrysts are most abundant in gabbro with a fine-grained

Figure S2. North Deep Creek gabbro exhibiting almost an ophitic texture with laths of plagioclase in a groundmass of mafic and felsic components. Knife is 10 cm long.

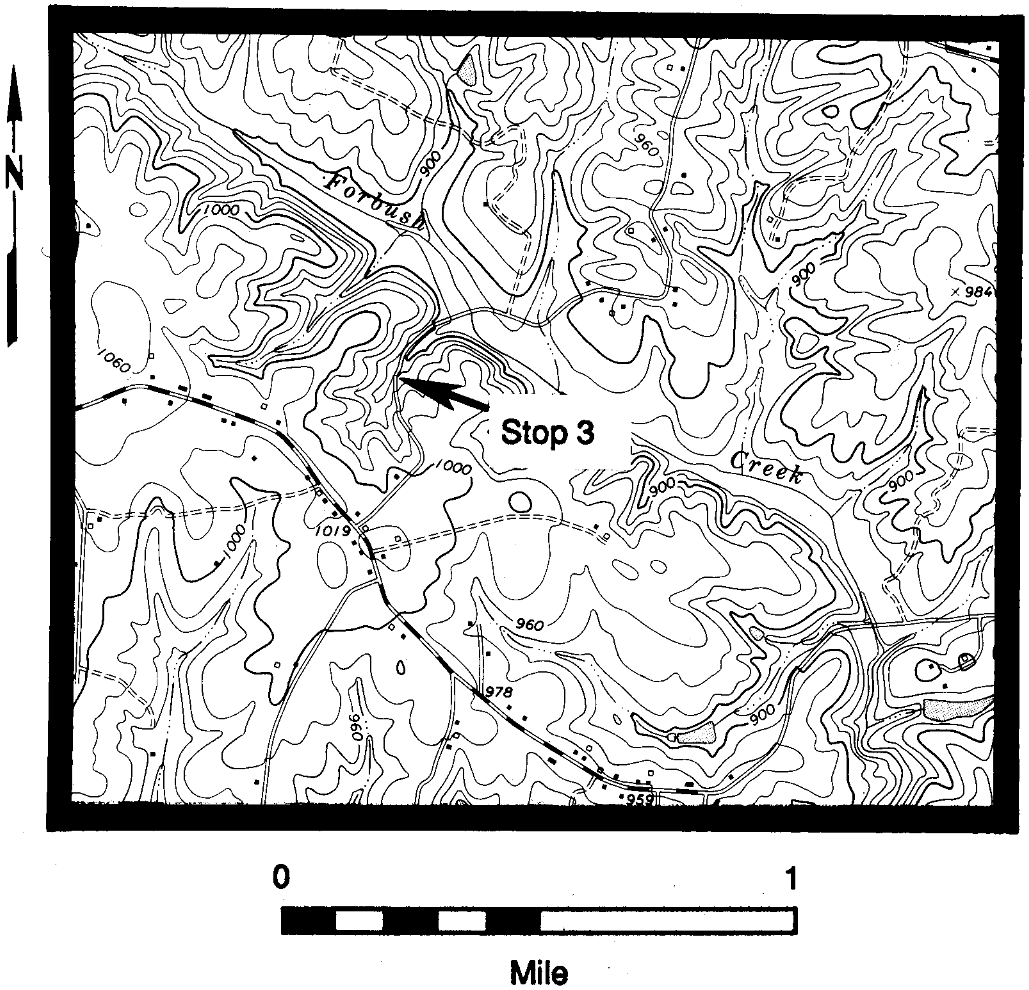

Figure S3. Portion of the East Bend, North Carolina, 7 1/2 minute quadrangle showing the location of Stop 3.

matrix exposed along the contact with the Ashe Formation. Near the center of the pluton, the rock is generally more

Table S1. Model percentages of samples from the North Deep Creek pluton.

Sample	1	2
Plagioclase	54.4	53.3
Amphibole	21.5	33.1
Pyroxene	14.5	6.0
Biotite	8.1	5.7
Myrmekite	0.3	-
Quartz	1.2	-
Epidote	-	1.2
Chlorite	Tr	Tr
Apatite	0.3	-
Opaque	Tr	0.7
Points Counted	420	510

Tr - Trace amounts.

equigranular, and plagioclase phenocrysts are less abundant. Pyroxene grains have inclined extinction, a faint green-brown pleochroism, and are biaxial negative with a maximum birefringence of 0.03. Hornblende grains sometimes completely surround pyroxene, opaque minerals, and/or biotite. The apatite, plagioclase, amphibole and biotite of this rock are well suited for dating by the Rb-Sr mineral isochron technique. This pluton may have been emplaced during the Acadian or Alleghanian orogenies, or could be associated with Mesozoic rifting.

Return to County Road 1509, then turn right (east) and backtrack eastward on old U.S. 421 to Stop 1. Turn left (north) onto Yadkin County Road 1600, drive about 2.8 miles to the "T" intersection with Forbush Road (Yadkin County Road 1570) and turn left (north). Drive north about 1.3 miles to Yadkin County Road 1584 and turn left (west). Continue on County Road 1584 to the intersection with Yadkin County Road 1509 and bear right (northwest). Drive about one mile northwest, then turn right (northeast) onto Yadkin County Road 1596.

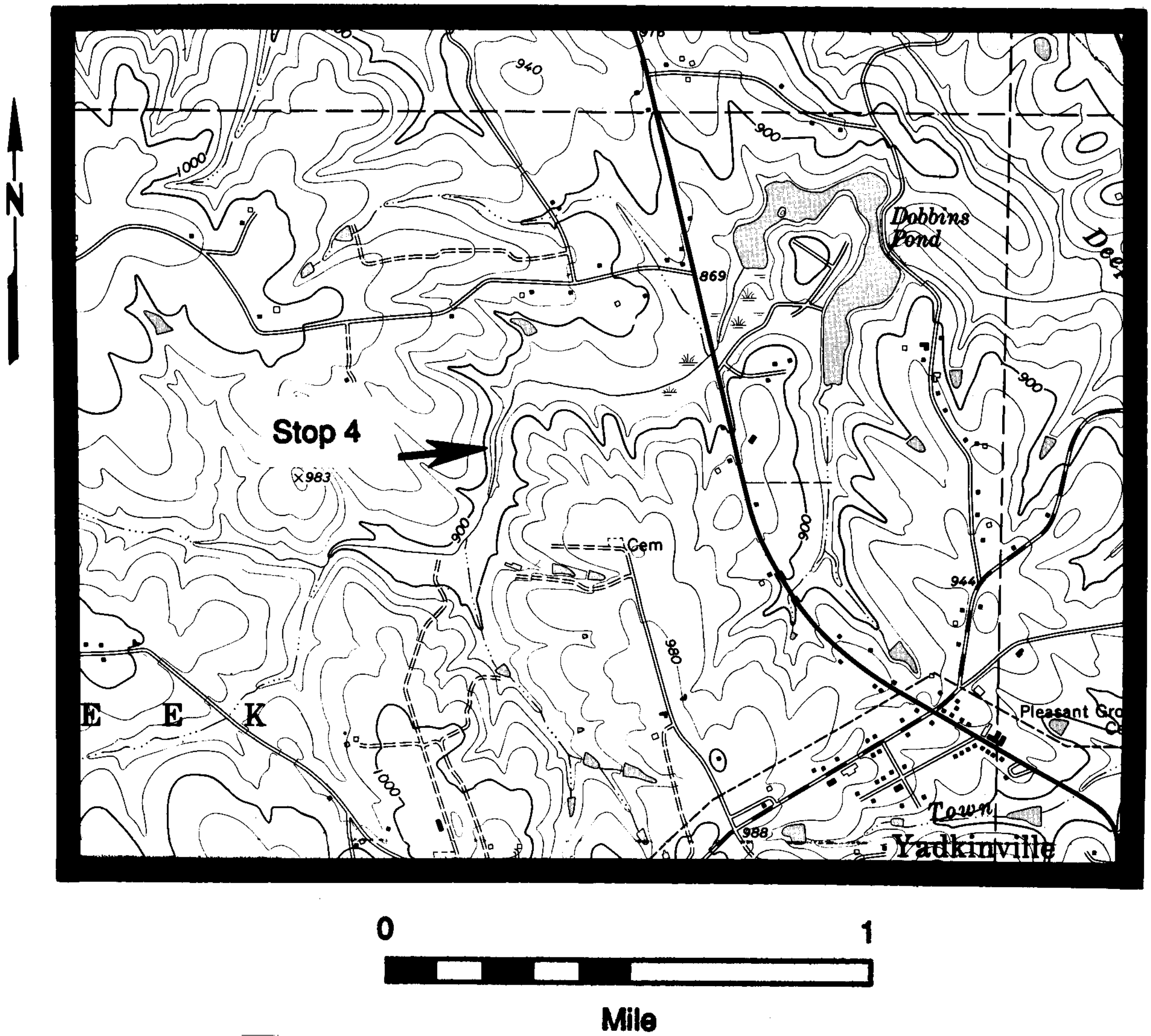

Figure S4. Portion of the Yadkinville, North Carolina, 7 1/2 minute quadrangle showing the location of Stop 4.

Drive about 1000 feet northeast, stop, and continue walking down the road. This is Stop 3.

STOP 3. ASHE FORMATION ALUMINOUS SCHIST

The aluminous schist unit in the Ashe Formation here (Fig. S3) consists mostly of white muscovite-quartz-garnet-biotite-plagioclase + kyanite schist interlayered with smaller amounts of quartz-plagioclase-biotite + epidote metagraywacke, and amphibolite. Sillimanite is the dominant aluminum silicate mineral at higher grade, but here it is kyanite. Staurolite and kyanite have been found in an aluminous schist nearby. Note the characteristics of the soil and saprolite. Much of this unit was mapped by identifying garnet and kyanite in the soil. You should be able to find abundant garnets and kyanite in the soil here, particularly along the shoulders of the road. A foliation can still be measured in the saprolitic outcrop. The contact between the Ashe Formation and Hogan Creek Formation is located along the base of the hill. Although fault-related textures have not been observed near this contact, it is possible that it is a fault. Hatcher and others (1988) suggested it may be a premetamorphic fault, the Forbush fault.

Return to Siloam Road (County Road 1509), then turn left (west) and continue southward to old U.S. 421 (County Road 1605) via Siloam Road. Turn left (west) and drive into Yadkinville (~2 miles). Turn right (north) at the stop light onto U.S. 601 and drive north about two miles to Yadkin County Road 1380. Turn left and drive west about 0.3 mi. Buses will park along the road near a gravel road and driveway. We will walk to the end of the

Figure S5. Unnamed augen gneiss exposed at Stop 4. The porphyroclasts are composed mostly of coarse microcline, but many are composite. This is a likely candidate for Grenville basement.

driveway past a new home, through a gate, and into the creek bottom. Stop 4 is located up the creek about 150 m south of the house.

STOP 4. AUGEN GNEISS (BASEMENT?) IN ASHE FORMATION OUTCROP BELT

This unnamed augen gneiss occurs as lens-shape bodies surrounded by high-grade rocks of the Ashe Formation (Plate 1, and Fig. 2 of Heyn, this guidebook; Fig. S4 and S5). Rocks of the Ashe Formation encountered nearby include aluminous schist, a variety of biotite gneiss, and amphibolite. The augen gneiss, a metamorphosed adamellite, occurs mainly in an area previously designated as Henderson Gneiss by Espenshade and others (1975). The foliation (strike: 345, dip: 17^{o} SW) in this outcrop is parallel with the dominant tectonic surface observed in migmatites of this area, and is interpreted to have formed during high-grade metamorphism when isoclinal folds developed. The lineation (trend: 217, plunge: 15^{o} SW) of this outcrop is contained in the plane of foliation, and may be a stretching lineation. The foliation and lineation are thought to have developed when many minerals (e.g., microcline) in the rock were grain-size reduced.

In thin-section the augen gneiss has a granoblastic texture with curved grain boundaries. Feldspar clasts are rimmed with small grains of dynamically recrystallized feldspar. The straight grain boundaries of some quartz grains may have formed during a period of grain boundary migration after the development of the foliation. Farther southeast along the Forbush fault the unnamed augen gneiss has a pronounced mylonitic fabric (see Shacktown fault of Heyn, this guidebook).

The augen gneiss could be a Paleozoic intrusive rock or Precambrian basement. It has been correlated with the Henderson Gneiss (Espenshade and others, 1975). The location of the augen gneiss, relative to several map-scale folds, suggests that it is preserved in the troughs of isoclinal folds, and forms a separate lithostratigraphic unit located above the Ashe Formation. Although a Middle Proterozoic foliation and/or granulite facies minerals have not been observed in the augen gneiss, it is possible that this rock is basement because it is a metamorphosed adamellite. Fine-grained orthogneiss located northeast of this outcrop is a metamorphosed adamellite, and has been interpreted as Middle Proterozoic basement (McConnell and others, 1988).

Table S2.

Sample	UNNAMED AUGEN GNEISS (basement ?) 1	2	FORBUSH GNEISS (basement) 3	4
Quartz	25.6	25.1	24.8	22.9
Plagioclase	18.3	21.9	35.6	32.5
Microcline	30.4	25.7	19.2	18.7
Myrmekite	Tr	1.2	2.9	Tr
Muscovite	3.0	4.1	3.2	4,1
Biotite	20.9	19.9	9.1	18.5
Epidote	-	0.1	2.4	2.4
Chlorite	-	-	1.7	Tr
Apatite	-	-	-	0.4
Sphene	-	0.7	0.8	0.72
Garnet	Tr	2.0	-	-
Zircon	Tr	Tr	Tr	-
Points Counted	265	512	509	459

Tr. - Trace amounts.

Modal percentages of the unnamed augen gneiss, and the Forbush gneiss are shown in Table S2. Sample 1 is an analysis of a sample collected at Stop 4. Sample 2 was collected along the Shacktown fault. Samples 3 and 4 were collected in the East Bend and Siloam Quadrangles

Return to the buses on County Road 1380, then drive eastward to U.S. 601. Turn left (north) onto U.S. 601 and drive about 4 miles. Turn right (east) onto Yadkin County Road 1513 and drive about 1000 feet to a new road cut on the west side of one of the headwaters tributaries of North Deep Creek. This is Stop 5 (Fig. S6).

STOP 5. MIGMATITIC ASHE FORMATION ROCKS NEAR BOONVILLE

These unusual porphyroclastic gneisses and schists are restricted to areas of the Ashe Formation that experienced extensive migmatization, and are thought to be highly strained, high-grade metasedimentary rocks that belong to this unit. These rocks are thought to have developed because granitic leucosomes of migmatites were dismembered under high temperature conditions. Petrographic studies have shown that grain-size reduction played an important role in the development of the fabric (see Yadkin fault problem of Heyn, this guidebook). If this interpretation is correct, the angular fragments of hornblende gneiss that are present in the outcrop must have an origin similar to boudins (Fig. S7 and S8). It is also possible that these rocks are deformed and metamorphosed diamictite, or metamorphosed igneous rocks. The foliation (strike: 325, dip: 25^{o} SW) is thought to have developed during isoclinal folding. Amphibolite and hornblende gneiss are also present in this exposure.

This outcrop of porphyroclastic rock occurs in areas previously designated as Henderson Gneiss by Espenshade and others (1975) just west of the projected trace of the Yadkin fault. The outcrop distribution of these highly strained rocks, the presence of rocks typical of the Ashe Formation (e.g., aluminous schists) west of this outcrop, and other data indicate that the “Yadkin thrust fault” does not occur along the southwestern flank of the anticlinorium (see Yadkin fault

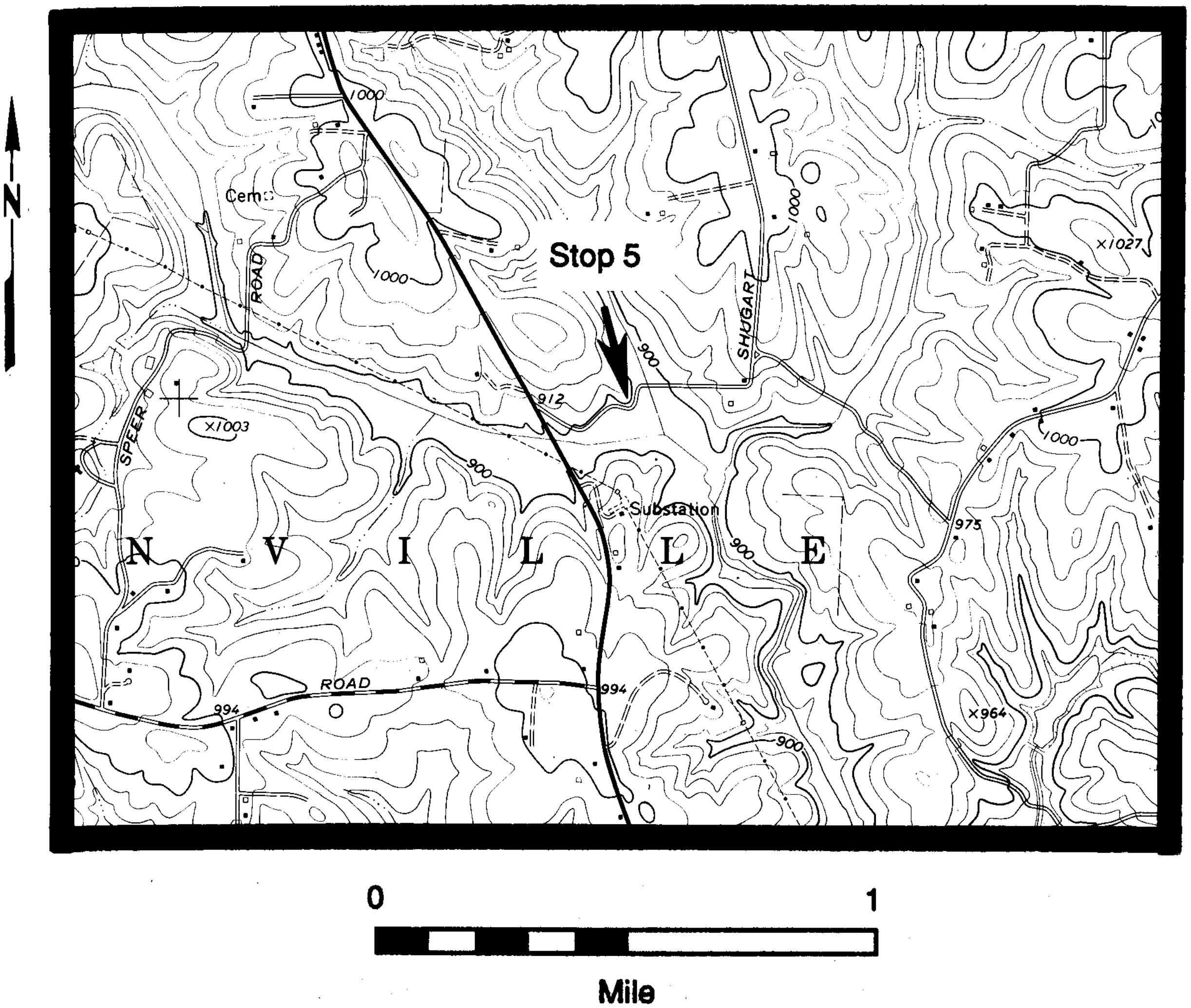

Figure S6. Portion of the Yadkinville, North Carolina, 7 1/2 minute quadrangle showing the location of Stop 5.

problem of Heyn, this guidebook). The outcrop distribution of these rocks is consistent with a wide zone of shearing that starts approximately at the lower kyanite-upper kyanite boundary in the Ashe Formation, and continues beyond the western limit of mapping (Plate 1; Fig. 2 of Heyn, this guidebook).

Thin sections were made by T. Heyn from these rocks. Espenshade and others (1975) included these outcrops in their hg unit (this unit includes various metasedimentary rocks, amphibolite and Henderson Gneiss) just west of their "Yadkin fault". Heyn (1984) interpreted these textures to be the product of migmatization; however, it seems clear from these thin-sections and rock slabs that the textures developed because granitic leucosomes were extensively dismembered in a process analogous to mylonitization, but, perhaps, at conditions close to the melting temperature of the rock. We would argue that the fabric in this outcrop is a product of extensive deformation, perhaps even more extensive than the deformation accommodated by the rocks we have called mylonitic gneiss. The outcrop distribution of this lithology, and the presence of aluminous schist and amphibolite, are not consistent with offset along a distinct "yadkin fault"; they are consistent with a wide zone of translation that starts, approximately, at the lower kyanite-upper kyanite isograd, and continues beyond the western limit of Heyn's mapping. The "xenolith" in such an interpretation has an origin similar to a boudin. Such an interpretation may be difficult to defend at the outcrop, but the rock certainly is not a metamorphosed diamictite, or a metamorphosed igneous rock. Lewis (1983; Fig. 6) recognized rocks similar to these in the Copeland quadrangle, and interpreted the rocks as mylonitic Henderson Gneiss. The presence of such rocks may be the justification for Lewis' (1980) "Yadkin thrust sheet".

Continue east on Yadkin County Road 1513 for about 1000 feet to the intersection with Shugart Road (County Road 1512) and turn left (north). Drive north

Figure S7. Migmatitic Ashe Formation rocks at Stop 5. Note abundant porphyroclasts and inclusions showing earlier layering, as well as migmatitic layering in this exposure.

about 1.6 miles to the stop sign at N.C. 67 and turn right (east) onto N.C. 67. Drive about 1.8 miles east to the intersection of Rockford Road (Yadkin County Road 1510) with N.C. 67 and turn left (north). Drive about 2.2 miles northward on Rockford Road, turn left onto Yadkin County Road 1527, and park near the bridge. This is Stop 6 (Fig. S9).

STOP 6. ASHE FORMATION (OR HOGAN CREEK FORMATION) ROCKS NORTHEAST OF BOONVILLE

This amphibole gneiss is thought to be a lithology of the Hogan Creek Formation (Heyn, this guidebook). This outcrop occurs just northeast of the Ashe Formation, and southwest of the Forbush gneiss (Plate 1). McConnell (this guidebook) included these rocks, and metagraywacke located south of the Forbush gneiss, with the Ashe Formation. These rocks were previously interpreted as basement by

Figure S8. Close up of area to lower right of hammer in Figure S7 showing several porphyroclasts of diverse kinds. Could this exposure be part of an olistostrome, or does it have a different origin?

Espenshade and others (1975) and Lewis (1980). The mafic rocks of this outcrop contain (in order of decreasing abundance) blue-green hornblende, epidote, chlorite, quartz, plagioclase, biotite, and muscovite. Small amounts of garnet, apatite, and opaque minerals are also present. Many of these minerals are thought to have formed during F_3 folding (see structural geology section of Heyn, this guidebook). Most folds in this outcrop are F_3 folds overturned toward the northwest. Compositional layering is probably transposed bedding (orientation: 295^o, 30^o SW), and parallels the dominant tectonic surface in the Ashe Formation. Mineral lineations are parallel to F_3 fold axes at this outcrop (average orientation of F_3 fold axes: 240^o, 25^o SW). Retrograde chlorite occurs as cross-mica and occurs parallel to compositional layering.

Continue northwestward on Rockford Road (County Road 1527; may change to 2221 at the Surry County line) for about 1.2 miles and turn right (northeast) onto Surry County Road 2230 just beyond the railroad tracks. Drive about 0.4 miles and park in the cleared area beside the road and tracks. Walk northeast along the tracks about 250 m to Stop 7 (Fig. S9).

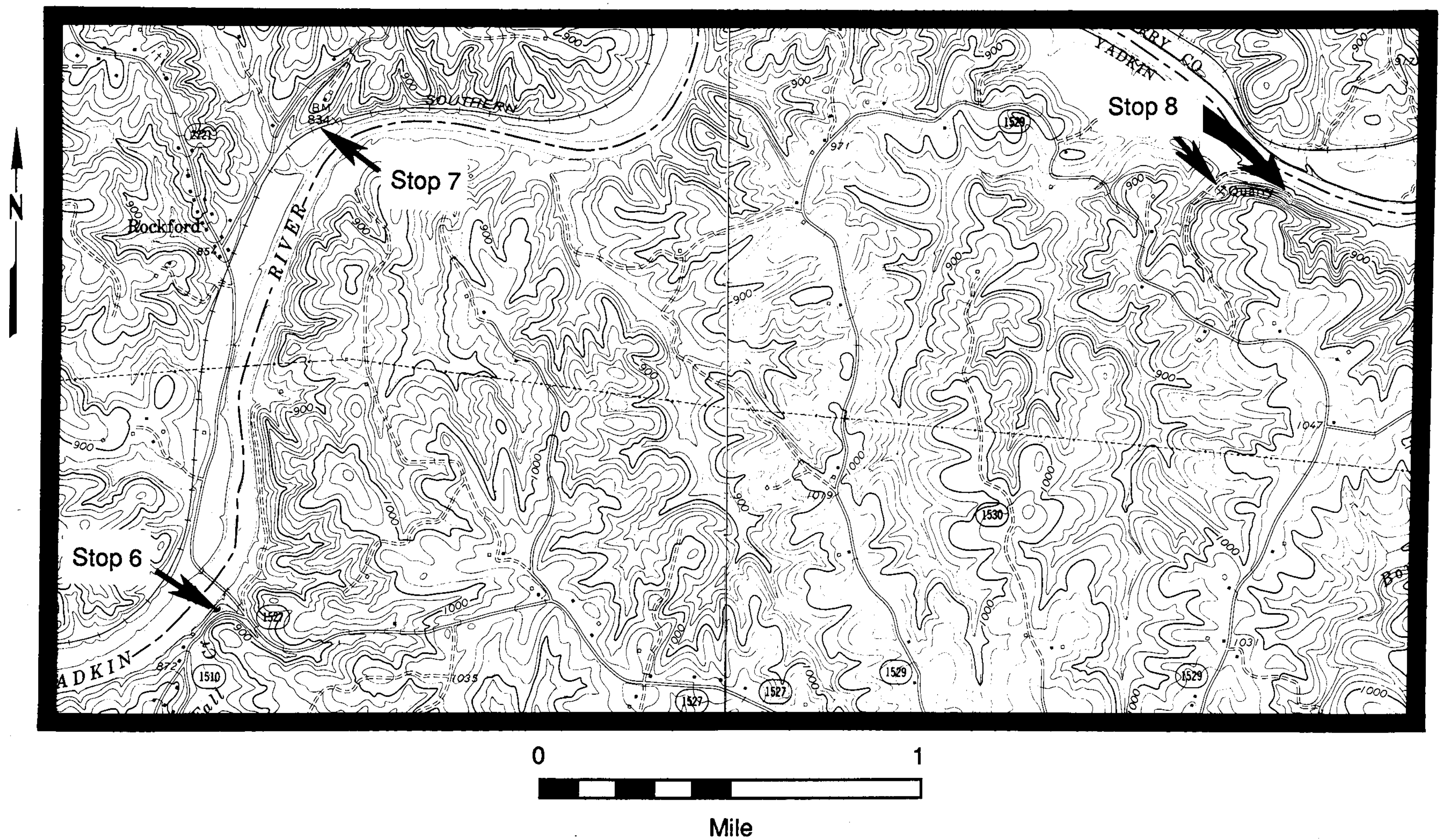

Figure S9. Portion of the Copeland and Siloam, North Carolina, 7 1/2 minute quadrangles showing the locations of Stops 6, 7, and 8.

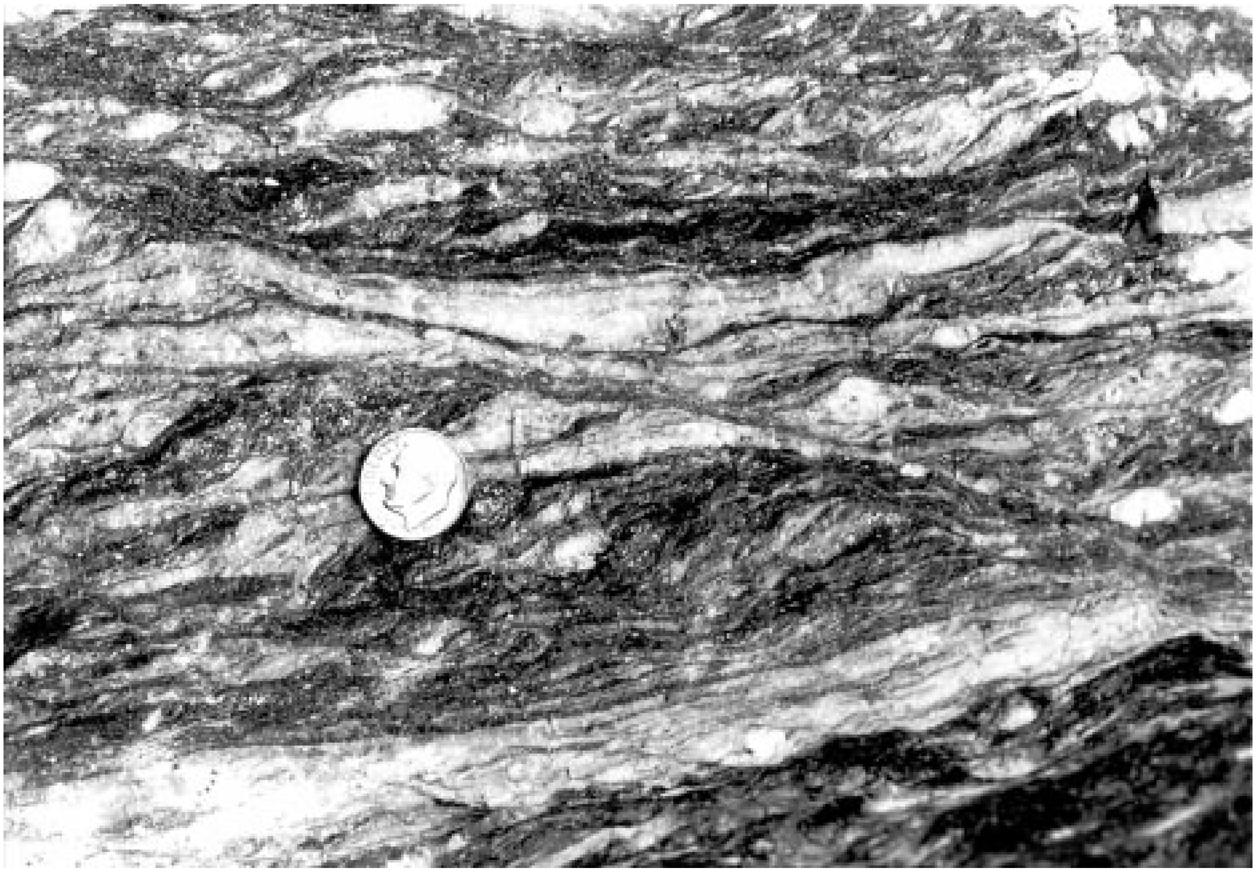

Figure S10. A. Hogan Creek Formation metasandstone at abandoned quarry on Yadkin River at Stop 8 showing a small ductile shear zone and the overall S-C fabric of the rock mass.

STOP 7. FORBUSH GNEISS AT ROCKFORD

The Forbush gneiss consists of biotite augen gneiss that contains a strong foliation generally parallel to that of the enclosing rocks. There is also another foliation in the augen gneiss inclined to the dominant foliation that may, in combination with the dominant foliation, define an S-C fabric. The apparent flattening of augen near the contacts could be interpreted as increased dominance of C-surfaces if the contacts are faulted. This rock unit of all in this area most closely resembles the Henderson Gneiss mapped farther southwest, but the Forbush gneiss is Grenville basement (See McConnell, this guidebook), and the Henderson Gneiss has a Cambrian age. The Forbush gneiss is composed of a groundmass of plagioclase, microcline, quartz, and biotite with microcline porphyroclasts (assumed to be derived from phenocrysts in a protolith megacrystic granite or adamellite).

Retrace route to Rockford and bridge at Stop 6, then continue east on Yadkin County Road 1527 to Richmond Hill. Road 1527 joins County Road 1529 at the church in Richmond Hill. Continue eastward, then northward on Road 1529. Note that 1529 bears left (north) at a fork about 0.2 mi. east of the junction with Road 1527. Richmond Hill Road continues southeast from here toward Smithtown. About two miles north on 1529 from this fork is a gravel road that bears right (northeast) called State Quarry Road (it does not appear to have a county road number). Turn right and follow this road about 1/2 mile to the abandoned quarry. This is the first part of Stop 8 (Fig. S9). Once we have looked at the rocks here, we can walk to the end of the road and to the exposures along the hill side. The buses will be waiting for us there.

STOP 8. LIME ROCK QUARRY IN HOGAN CREEK FORMATION ON THE YADKIN RIVER

Please stay away from the quarry high wall!!!

This stop consists of a series of exposures beginning with the State aggregate quarry, where Hogan Creek Formation rocks are exposed, and continuing with an exposure of Hogan Creek marble and metasandstone in an old Lime Rock Quarry(?) farther east along the Yadkin River.

Rocks in the State quarry consist of Hogan Creek Formation metasandstone and schist, along with quartz-feldspar+/-muscovite pods and irregular veins. Pods and irregular veins of this type are common throughout the Hogan Creek outcrop belt. A few of the feldspars were

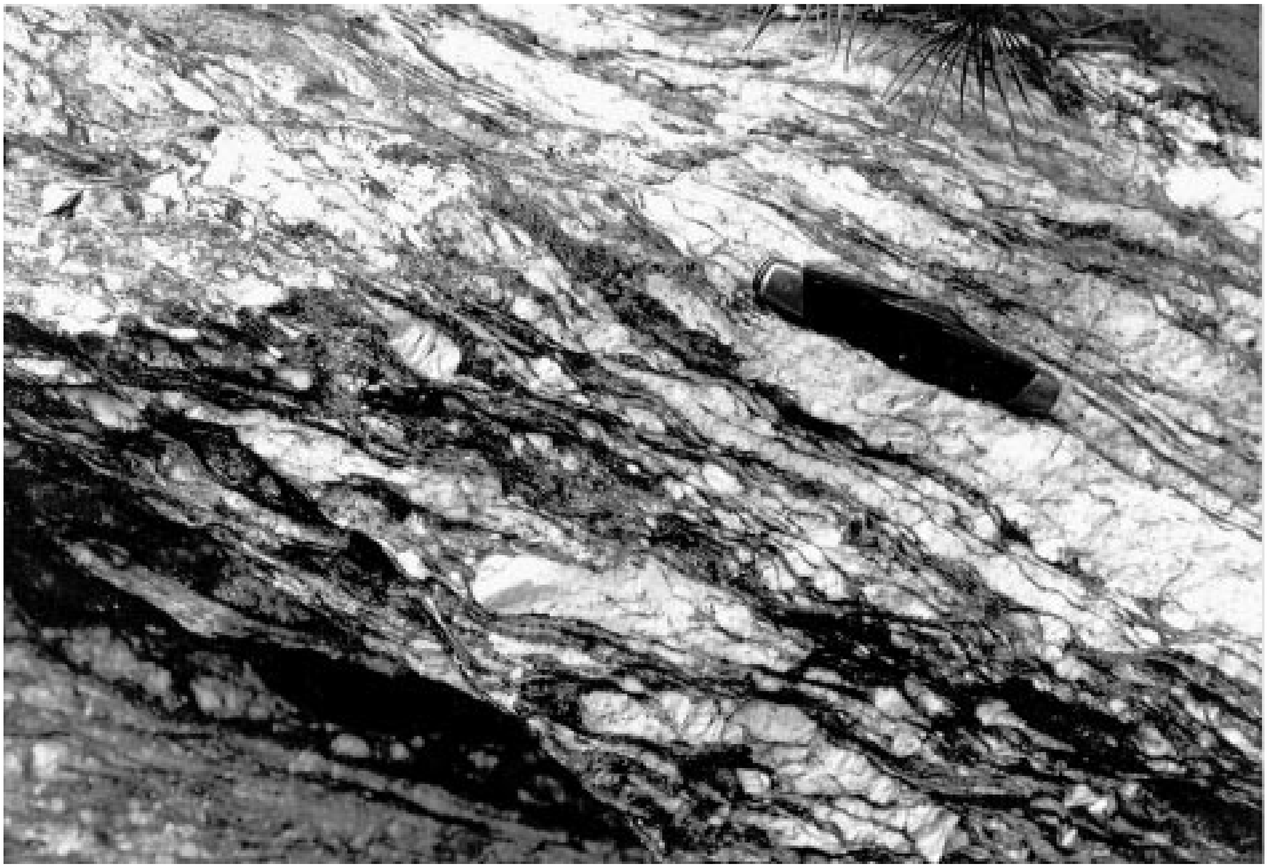

Figure S10. B. Deformed feldspar porphyroclasts and feldspar-rich layers in Hogan Creek Formation rocks at abandoned quarry at Stop 8. Note porphyroclast indicating a sinistral shear sense in the center to the left of the knife.

deformed into spectacular shear-sense indicators (Fig. S10) and occur in metasandstone with an annealed mylonitic texture. Unfortunately, all we have seen to date are in unattached blocks. Both S and Z flexural-flow buckle folds are present in place. Some thin quartz-feldspar layers are tightly folded and produce almost a rodding lineation parallel to the hinges of folds.

The feldspar pods here give the impression that these rocks are true migmatite, suggesting a high metamorphic grade. Mineral assemblages in the Hogan Creek Formation (see Heyn, this guidebook) suggest that the metamorphic grade reached no higher than the garnet zone. Anatectic migmatites commonly form in the upper part of the kyanite zone or at higher grade. They probably formed by metamorphic differentiation.

The exposure farther downstream about 180 m east of the end of the road contains marble and calc-silicate boudins and amphibolite boudins in Hogan creek metasandstone. The maximum thickness of this zone is 5 to 8 m. A thin quartz layer is folded into a west-vergent isoclinal recumbent fold (trend N72^{o}E, plunge 18^{o} SW; axial surface N45^{o}W, 22^{o}SE).

Return to buses and retrace route to Richmond Hill. Turn left onto Smithtown Road, drive to Smithtown, th turn left onto Siloam Road (County Road 1003). Retrace route to N.C. 67, then to Pilot Mountain. End of Day 1.

DAY 2

Depart motel 8 AM and drive west on N.C. 268 to the bridge on the Ararat River. Park on right or left, as convenient, on the west side of bridge. Stop 9 is downstream in the river (Fig. S11).

STOP 9. BASEMENT-COVER CONTACT AT N.C. 268 BRIDGE ON ARARAT RIVER

The rocks exposed here consist of basement orthogneiss, mylonite, and cover metasandstone of the Hogan Creek formation. Basement is exposed below the bridge in two large (for this area) masses that jut into the river from the west bank and several smaller exposures in the woods and along the highway. The cover rocks are exposed at river level immediately above the bridge and as weathered rocks along the highway. The contact can be located to within a few meters west of the bridge using exposures along the highway and in the cleared area on the south side of the highway.

Figure S10. C. Close up of sinistral shear-sense indicator shown in B.

The exposure of mylonitic basement (the largest here) contains some obvious orthogneiss, then a layered mass of mylonitic rock. Was this layered mass derived from the orthogneiss, or is it a separate unit? If it is a separate unit, the contact is exposed here (Fig. S12). Transposition of early layering in some of the more felsic material into the dominant foliation in the mylonite is evident here. Shear-sense indicators are not obvious in the mylonite, but may ultimately be found here. One reason is the almost complete dynamic recrystallization of the microfabric in the rock, but larger porphyroclast shear-sense indicators should have survived.

A classic Type 3 (jellyroll) interference fold is present in the mylonite and orthogneiss in the large exposure (Fig. S13). Single folds here are flexural-flow buckle and passive-flow folds over printed by crenulations (Fig. S14). Some early folds and crenulations verge southeast while one of the early passive-flow folds verges northwest. Are these folds and mylonite products of Middle Proterozoic (Grenville) deformation, or are they Paleozoic structures? The contact with the cover rocks may be faulted, and the mapped trace of the Forbush thrust is close by, about 200 m upstream from the bridge. Ironically, the cover rocks exhibit little evidence of mylonitic fabric. There are some S-C structures in the schists of the cover assemblage, but these fabrics (or apparent S-C fabrics - actually crenulations) are present in many parts of the Hogan Creek and Ashe Formation outcrop belts. A thin-section was made by T. Heyn from the Arrarat River exposure. The fabric is typical of a dynamically recrystallized high-grade tectonite. There are several feldspar clasts with recrystallized rims that indicate the rock has experienced considerable grain-size reduction (visible at outcrop scale). The interpretation of the fabric does not help answer the question: “Is the dark mylonitic rock more grain-size reduced than the light colored tectonite, or is the rock a metamorphosed porphyritic aphanitic igneous rock?” Whether or not the dark mylonitic rock is associated with a fault remains a matter of interpretation. It may be difficult to justify the presence of a fault from data collected at the outcrop only. Mylonitic rocks such as these develop in wide zones of noncoaxial ductile deformation in the Adirondacks and elsewhere.

Retrace route to Pilot Mountain Inn and continue east on N.C. 268 through Pilot Mountain town. Drive about 1.6 miles east and turn right onto Stokes County Road 1180 and follow to a “T” intersection. Turn right (south) onto County Road 1136. Drive about 0.4 miles south and turn left (east) onto County Road 1182. Turn

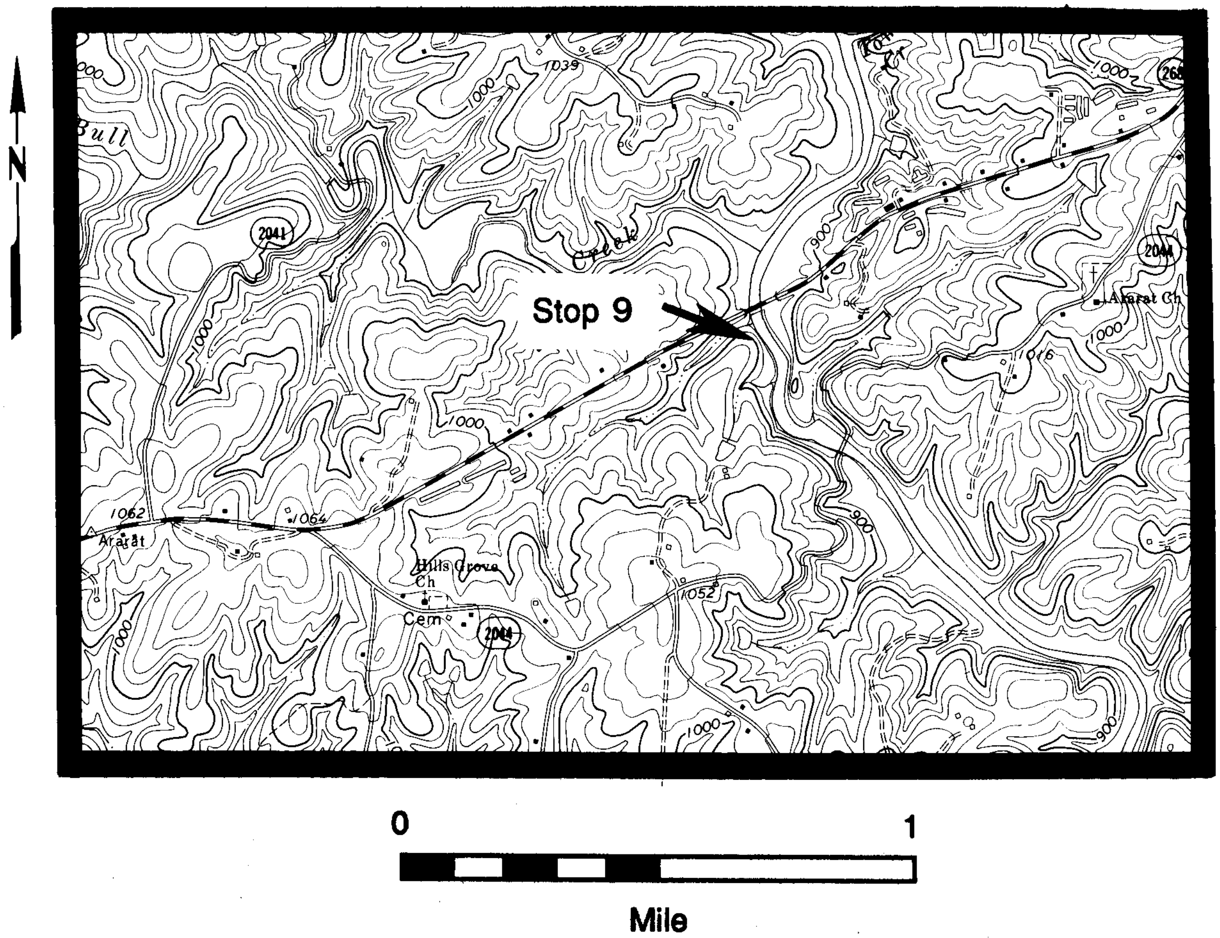

Figure S11. Portion of the Siloam, North Carolina, 7 1/2 minute quadrangle showing the location of Stop 9.

right in about 0.5 miles onto an unnumbered(?) county road and continue about 0.75 mi to "T" intersection. Turn left onto County Road 1175 and park. This is Stop 10 (Fig. S15).

STOP 10: THE ROCK HOUSE GNEISS NEAR FLAT ROCK (ALTERNATE STOP)

This locality is near the type locality of the Rock House gneiss (Fullagar and Butler, 1980). This unit was originally suspected to be part of the Middle Proterozoic basement but is now known to have distinct chemical similarities to other units in the Sauratown Mountains anticlinorium that have been identified based on mineralogy as part of the Crossnore Complex. Fullagar and Butler have suggested that the Rock House gneiss and other members of the Crossnore Complex in the Sauratown Mountains anticlinorium have ages between 710 and 650 Ma.

The Rock House gneiss is a medium-grained biotite-quartz-feldspar gneiss with a well-developed tightly folded foliation. This gneiss generally outcrops in broad flatrock exposures and, like the Pilot Mountain gneiss, is surrounded by rocks of the Sauratown formation. A small abandoned quarry to the northeast of this locality has exposures of the Rock House gneiss that contain numerous biotite schist enclaves. The relationship of these enclaves to rocks of the Sauratown formation is uncertain but contact relationships on the northern border of the Rock House gneiss suggest that the unit is intrusive into the surrounding rocks.

Retrace route to N.C. 268 and turn left (southwest). Continue for approximately 0.8 mi and bear left onto a county road that appears unnumbered. Continue for about 0.2 mi along this road and park. Stop 11 is on the left (Fig S16). We have permission from the owner to enter the abandoned quarry, but neither the owner nor the Carolina Geological Society claims any responsibility for accidents.

STOP 11. PILOT MOUNTAIN GNEISS AT PILOT MOUNTAIN QUARRY

Please Stay Clear of Ledges and Highwalls

The Pilot Mountain gneiss exhibits a complex array of lithologies and intrusive relationships. The dominant rock

Figure S12. A. Layered gneiss (below) in contact with porphyroclastic orthogneiss (above) at Stop 9. Is the strongly layered darker rock a mylonitized equivalent of the porphyroclastic gneiss, or are we seeing a nontectonic lithologic contact?

type present at this stop is a medium-grained, muscovite-biotite-quartz-feldspar gneiss (Table 1) with lesser amounts of aplite, quartz veins, and metagraywacke enclaves. Biotite content in the augen gneiss varies considerably as does the corresponding color index. This variation is believed to represent varying degrees of enclave consumption. Garnet, calcite, and apatite are common accessory minerals. The Pilot Mountain gneiss is mineralogically similar to the Grassy Creek gneiss, but contains distinctly less opaque minerals (pyrite), and more calcite and garnet.

Aplite in the Pilot Mountain gneiss contains only four major minerals, microcline, perthite, quartz, and plagioclase with little mafic material present. This mineralogy gives the rock a sugary “quartzite” appearance.

Samples from this abandoned quarry were isotopically dated using the uranium-lead Zircon methods with a resulting U-Pb age of 1190 Ma. (Rankin and others, 1971); subsequently revised to 1172 Ma. by Rankin and others (1983). Kish and others (1982) reported an age of 1250 Ma. +/- 100 from samples also collected in the abandoned quarry. Rb-Sr analyses of the Pilot Mountain gneiss from this study (McConnell and others, 1986) provide data that define an isochron of 1173 +/- 33 Ma. (MSRS=3.239) with an initial ratio of 0.70334 +/- .00007. Similar to the results from the Grassy Creek gneiss, the Rb-Sr age of the Pilot Mountain gneiss is interpreted as representing a metamorphic age and the homogenization of isotopes during the Grenville orogeny.

Zircons from the Pilot Mountain gneiss display a mixed population of small and large euhedral zircons and numerous subhedral zircons with rounded terminations. Rounded zircons are present in all size fractions suggesting that xenocrystic zircons are a significant component of the zircon population. Due to the large xenocrystic component, no further U-Pb zircon work was performed on samples from the Pilot Mountain gneiss.

Return to NC 268 into the town of Pilot Mountain and turn left (south) onto old U.S. 52 and follow this road about 0.4 mi to where Surry County Road 2051 bears to the right. Surry County Road 2051 becomes Stokes County Road1152 at the county line (about 1.4 mi from the point in Pilot Mountain where it bears off old 52). Continue on Stokes County Road 1152 about 1.8 mi to County Road 2053 (this is the Surry County Road number). follow County Road 2053 about 1.2 mi to where it crosses a stream. This is Stop 12 (Fig. S16). It will be nec-

Figure S12. B. Closer view of relationships in A. Note what could be interpreted as deformed xenoliths to the lower right of thehammer.

essary to park and walk into this area.

STOP 12. NONCONFORMITY BETWEEN LATE PROTEROZOIC BASEMENT AND COVER SEQUENCE (ALONG GRASSY CREEK BETWEEN COUNTY ROADS 2097 AND 2053 - ALTERNATE STOP)

At an abandoned lake along Grassy Creek, relationships between meta-arkose of the Sauratown formation and Middle Proterozoic basement (Grassy Creek gneiss) can be examined. Exposures along the spillway of the lake are intensely deformed biotite-augen Grassy Creek gneiss. Augen gneisses of the Grassy Creek gneiss contain textures characterized by medium-grained zones separated by finer-grained bands of intense grain size reduction. Fractured porphyroclasts of microcline and unrecovered strain in quartz attest to a strong mylonitic overprint on the Grassy Creek gneiss possibly related to the border of the gneiss. Quartz, plagioclase, and alkali felspar occur in approximately equal amounts in the Grassy Creek gneiss with accessory amounts of biotite, epidote, muscovite, and pyrite (Table S3). Trace

Figure S13. A. Type 3 (hook or jellyroll) fold interference pattern involving dark mylonitic layers and light felsic layers at Stop 9. Dark layer that terminates in a hinge beneath the hammer connects with dark material that intersects the hammer handle above. The microfabric of the dark material is annealed. Is the dark mylonitic rock here derived from the felsic orthogneiss? Are these Grenville or Paleozoic structures?

amounts of garnet, calcite, chlorite, and allanite also are present. The Grassy Creek gneiss is similar to other augen gneisses in the Sauratown Mountains anticlinorium but is distinguished by higher concentrations of pyrite.

Augen gneisses of the Grassy Creek gneiss have been isotopically dated using both U-Pb zircon and Rb-Sr whole-rock methods. Whole-rock samples of Grassy Creek gneiss and Pilot Mountain gneiss to the north yield an isochron Rb-Sr age of 1173 +/- 33 Ma. Based on data from the U-Pb analyses, this age is interpreted to be a metamorphic age.

Zircons from the Grassy Creek gneiss are euhedral with no apparent rounding in the two smaller size fractions. The large fraction (>100) did, however, contain zircons with rounded terminations, suggesting the presence of xenocrystic zircons. The results of isotopic analyses of the three size fractions, therefore, not surprisingly indicate the inclusion of xenocrystic zircons. The three size fractions from the Grassy Creek gneiss do not define a single chord. The intermediate-

Figure S13. B. Strongly transposed felsic orthogneiss layer in the hinge of an isoclinal fold "suspended" in dark mylonitic material. This fold is located about 3 m NE of that in A.

size fraction (<100) falls close to the chord defined by samples of the Forbush gneiss (upper intercept age of 1230 Ma.) and yields a U-Pb age of 1178 Ma. Due to the similarity in U-Pb ages of zircons from the Forbush gneiss and that of the <100 fraction, the Grassy Creek gneiss is speculated to be approximately 1230 Ma. U-Pb ages from the other two size fractions of zircons from the Grassy Creek gneiss are 1520 and 1265 Ma. denoting the inclusion of xenocrystic zircons from substantially older rock units.

West of the Grassy Creek gneiss are exposures of the Sauratown formation that at this locality dip beneath the Grassy Creek gneiss. The basal part of the Pilot Mountain quartzite member of the Sauratown formation is composed of a medium-grained, well-foliated conglomeratic meta-arkose. Mechanically rounded clasts of quartz and microcline up to 1 cm in diameter are present in a matrix of quartz (locally blue), plagioclase, muscovite, and microcline with accessory tourmaline, epidote, and opaque minerals. Microcline makes up approximately 6% of the mode of the meta-arkose. The relationships observed at this stop are similar to gneiss and quartzite on Pilot Mountain. The meta-arkose grades stratigraphically-up but structurally-down in sequence into the massively-bedded quartzite with thin interlayers of muscovite schist observed at Stop 13.

Continue on County Road 2053 about one mile to the entrance to Pilot Mountain State Park and drive to the parking area on top of Pilot Mountain. This is Stop 13 (Fig. S16).

STOP 13. PILOT MOUNTAIN QUARTZITE IN THE SAURATOWN FORMATION AT PILOT MOUNTAIN STATE PARK.

At this stop the Pilot Mountain quartzite member of the Sauratown formation is majestically exposed. The term Sauratown formation is modified after Mundorff's (1948) Sauratown Mountain group and is named for exposures of quartzite on Sauratown Mountain. It includes quartzite, metagraywacke, and schist exposed on the slopes of Pilot Mountain. Butler and Dunn (1968) mapped quartzite on Pilot Mountain into a muscovite-quartz schist in the surrounding rocks and because of this gradational relationship concluded that quartzite on Pilot Mountain was part of the enclosing sedimentary package.

Quartzite exposed at this stop displays well-developed cross-bedding and locally contains thin beds of blue quartz

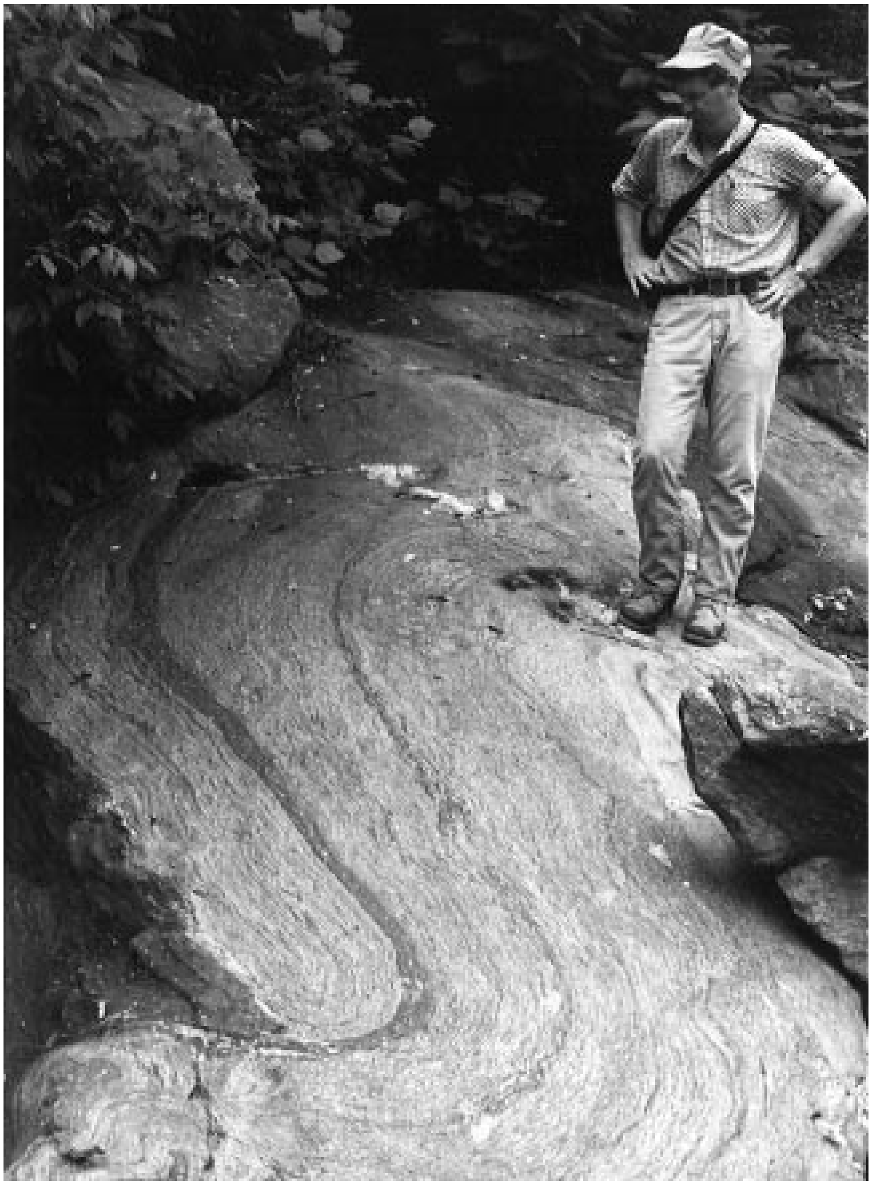

Figure S14. A. Portion of the fold at Stop 9 shown in Figure S13A showing part of the hinge and a long limb overprinted by crenulations.

bearing conglomerate. Quartzite layers are generally 0.5 to 3 m thick and are interbedded with muscovite schist less that 15 cm thick (Stirewalt, 1969). Quartz comprises 90-95% of the rock with accessory tourmaline, epidote, and zircon also present. The thickness of the Pilot Mountain quartzite exposed on Pilot Mountain has been estimated to vary from approximately 30 to 67 m (Stirewalt, 1969; Butler and Dunn, 1968), but folding apparent at this stop suggests that this thickness is exaggerated. Cross-bedding (both festoon and planar types, Stirewalt, 1969; Walker, this guidebook) is best developed on the Pinnacle and in all cases observed indicates that in this area the section is upright. Stirewalt (1969) indicated paleocurrent directions of S53^{o}E and S36^{o}E. The presence, however, of overturned folds on the west side of Pilot Mountain casts doubt on the usefulness of these paleocurrent directions as well as the cross-bedding indicators.

Deformation visible in the rocks exposed at this stop includes large-scale F_2 folds apparent in exposures on the traverse along the western slope of Pilot Mountain. Smaller scale F_3 folds association with deformation that produced the Sauratown Mountains anticlinorium are also visible and generally trend northeast with shallow plunges. F_3 folds are flexural-slip to flexural-flow folds that are upright to slightly vergent to the northwest. A locally well-developed axial-pla-

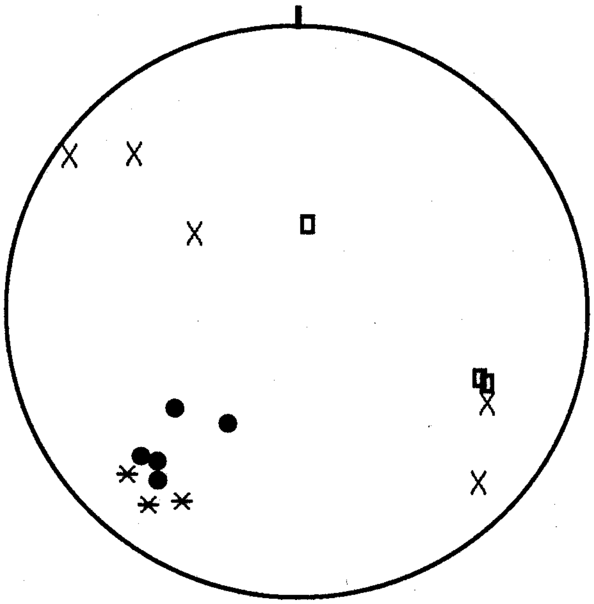

Figure S14. B. Lower hemisphere equal-area plot of the orientations of five earlier fold hinges (dots) and axial surfaces (x's), and the orientations of hinges (asterisks) and axial surfaces (small squares) of three crenulation folds at Stop 9.

nar cleavage (S_3) is present as well as an intersection lineation between S_2 and S_3. Late-stage flexural-slip warping ($_4$ and F $_5$) has resulted in the development of a megascopic dome and basin interference pattern defined by quartzite of the Sauratown formation (Plate 1).

Return down the mountain about 1.2 mi from the parking area at Stop 13 and pull into a turnout. The ledges exposed in the woods immediately above the road comprise Stop 14 (Fig. S16).

STOP 14. DIAMICTITE (?) MEMBER OF THE SAURATOWN FORMATION (PILOT MOUNTAIN STATE PARK)

Quartzite on Pilot Mountain grades into a chloritic biotite-muscovite-quartz schist with accessory plagioclase, garnet, and epidote. This rock type is best exposed just beneath the massive ledge of quartzite on the pinnacle where it forms the core of the dome. Intensely deformed quartzofeldspathic lithic clasts that vary in size from centimeters to over 3 m are characteristic of this unit. The clasts may represent basement clasts eroded and deposited in a diamictite facies of the Sauratown formation; however, the clasts do not resemble the Grassy Creek gneiss and must have had a separate source, but still may be derived from the basement.

Return to Pilot Mountain Inn. End of field trip.

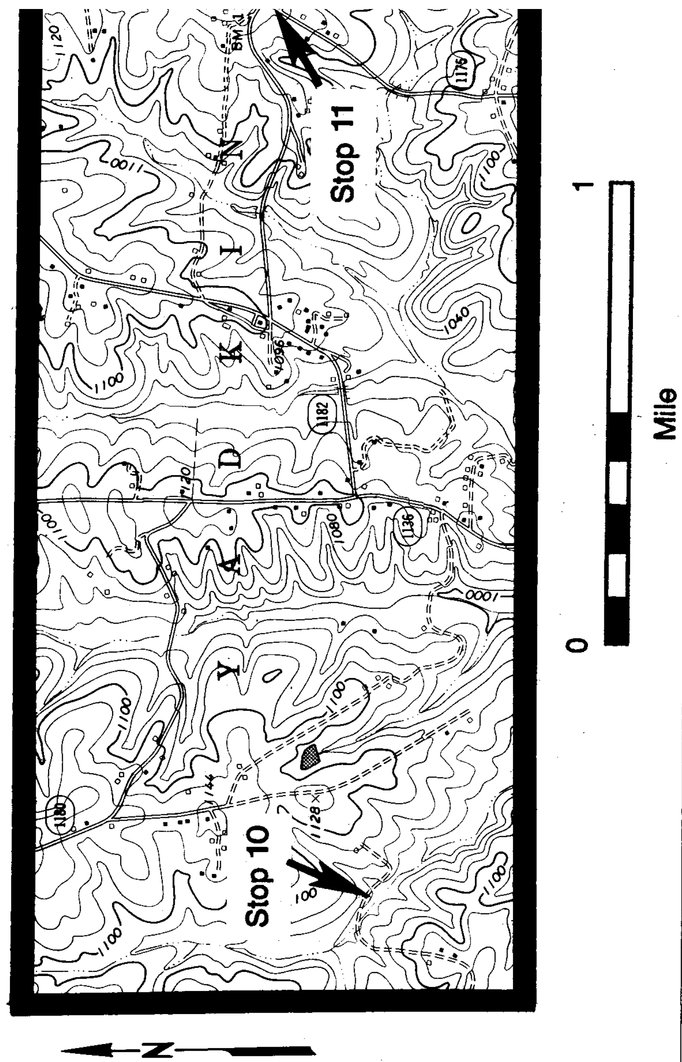

Figure S15. Portion of the Pilot Mountain, North Carolina, 7 1/2 minute quadrangle showing the locations of Stops 10 and 11.

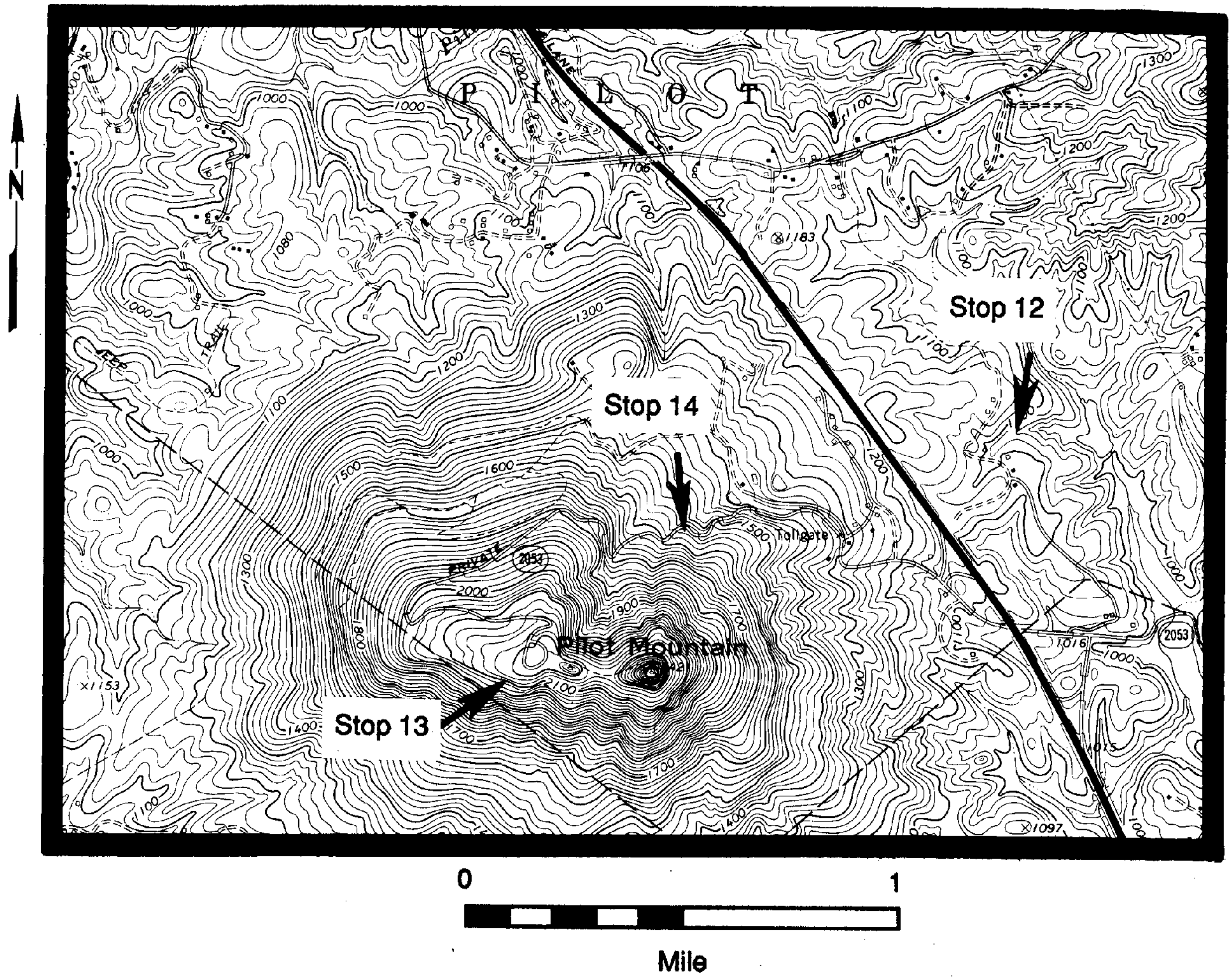

Figure S16. Portion of the Pinnacle, North Carolina, 7 1/2 minute quadrangle showing the locations of Stops 12, 13, and 14.

Table S3. Modal Analyses of Basement Gneisses in the Pinnacle Thrust Sheet.

Sample #	T1*	P. 52	PMQ	PMO
Quartz	25.9	24.1	27.6	26.9
Plagioclase	21.5	23.7	41.0	20.5
Microcline	——	17.7	3.8	10.3
Perthite	6.0	12.4	——	18.8
Myrmekite	——	——	——	——
Muscovite	1.1	4.0	4.1	7.7
Biotite	20.7	10.0	14.4	9.1
Epidote	——	5.8	7.7	3.7
Clinozoisite	22.5	——	——	——
Allanite	——	0.1	——	——
Chlorite	——	0.3	——	——
Apatite	——	——	0.3	0.1
Opaques	——	1.6	——	——
Garnet	——	0.1	0.4	——
Calcite	1.1	0.7	0.7	1.8
Sphene	0.7	——	——	1.1
% Total	100.0	100.0	100.0	100.0
Counts	550	1071	1062	640

* from Heyn (1984)

(T1, PMO and PMQ = Pilot Mountain gneiss; P. 52 = Grassy Creek gneiss).