Major Tectonic Features and Structural Elements in the Northwest Part of the Greenville Quadrangle, Georgia

U.S. GEOLOGICAL SURVEY BULLETIN 1643

Major Tectonic Features and Structural Elements in the Northwest Part of The Greenville Quadrangle, Georgia

By ARTHUR E. NELSON

A study of major structural features, tectonic fabrics, and fold analyses of polydeformed metamorphic rocks comprising three major thrust sheets that together form a large part of the southern Appalachian Mountains in northeast Georgia

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DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1985

For sale by the Distribution Branch, U.S. Geological Survey,
604 South Pickett Street, Alexandria, VA 22304

Library of Congress Cataloging in Publication Data

Nelson, Arthur E. (Arthur Edward), 1922–
Major tectonic features and structural elements in the northwest part of the Greenville quadrangle, Ga.

(U.S. Geological Survey bulletin ; 1643)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1643
1. Geology—Georgia—Greenville region. 2. Geology, structural. I. Title. II. Series: Geological Survey bulletin ; 1643.
QE75.B9 no. 1643 557.3 s [557.58'455] 85-600011 [QE102.G73]

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Major Tectonic Features and Structural Elements in the Northwest Part of the Greenville Quadrangle, Georgia

By Arthur E. Nelson

Abstract

The rocks underlying the northwest part of the Greenville 2-degree quadrangle form parts of three lithotectonic units. From northwest to southeast, they are the Great Smoky thrust sheet, the Hayesville thrust sheet, and the Helen-Coweeta terrane, which divides the Hayesville sheet diagonally southwest to northeast. The Hayesville thrust sheet was transported westward over the Great Smoky thrust sheet along the Hayesville thrust fault. The Hayesville fault is part of a major fault system in the southern Appalachian Mountains; in the study area, the Hayesville fault also forms the contact around several windows of the Great Smoky thrust sheet through the Hayesville thrust sheet.

Landsat images show that each lithotectonic unit is characterized by lineaments with distinct trends. The lineaments probably represent fracture zones. They suggest that rocks of each lithotectonic unit yielded differently to stress or that lineaments were present before thrust emplacement, and they imply different prethrust tectonic histories for the different thrust sheets.

Rocks in the study area were deformed by at least four phases of folding; the second generation folds (F_2) form the dominant folds and have northeast-trending axes. Northwest of the Hayesville fault, the F_2 fold axial surfaces are upright to steeply inclined; southeast of the fault, the F_2 axial surfaces range from recumbent to steeply inclined. A set of conjugate folds (F_3) whose axes trend north-northeast and west-northwest refolds the F_2 folds. The F_3 fold axial surfaces are upright to steeply inclined.

Analysis of conjugate folds (F_3) shows that the direction of maximum compression during F_3 folding was northeast-southwest, almost parallel to the regional (S_1) foliation trend. This direction is nearly normal to the maximum compression direction during F_2 folding. The F_3 maximum compression direction probably is due to a relaxation of compressive stress or due to elastic rebound after F_2 folding.

INTRODUCTION

This report describes and interprets the general structure and deformation chronology of polydeformed metamorphic rocks underlying the northwest part of the Greenville 2-degree quadrangle in northeast Georgia (fig. 1). Because most earlier geologic investigations of the area were of a reconnaissance nature and because many remote sections were not previously mapped, the geologic detail of much of the study area has not been well understood. My investigation indicates that the rocks underlying the report area are allochthonous. They have been folded during at least four and possibly six folding phases, and they have been locally deformed by ductile and brittle faulting.

Previous work

Yeates and McCallie (1896) and Park (1953) described some of the gold deposits and mining properties of Georgia. One of the major gold producing zones, the Dahlonega gold belt, extends northeast from Dahlonega and forms part of the Helen-Coweeta terrane, defined later in this report (see p. 4). Hopkins (1914) described soapstone, and Furcron and Teague (1943) reported on the mica-bearing pegmatites within the study area. Crickmay (1952) and Hurst (1973) described rocks in this area as part of their general descriptions of the Blue Ridge crystalline rocks. Hartley (1973) reported on the ultramafic rocks present in the north part of the area, and Hatcher (1971) described the geology of Rabun and Habersham Counties, Ga. Hatcher also reported on the various aspects of the tectonic history of northern Georgia and surrounding areas (1974, 1976, 1978a, c). The general geology of the area is shown on the Geologic Map of Georgia (Georgia Geological Survey, 1976). Dupuis (1975) and Wooten (1980) mapped adjoining areas to the west and north, respectively, of the report area, and Shellebarger (1980) and Gillon (1982) mapped parts of the study area as part of the U.S. Geological Survey Greenville 2-degree quadrangle mapping project.

GENERAL GEOLOGY

Three lithotectonic units underlie the northwest part of the Greenville 2-degree quadrangle in northeast Georgia. From northwest to southeast, these units are the Great Smoky thrust sheet, the Hayesville thrust sheet, and the Helen-Coweeta terrane. The Hayesville sheet was transported westward over the Great Smoky sheet along the Hayesville fault, a major Appalachian tectonic feature (Williams, 1978). Rocks of the Great Smoky sheet underlie the Hayesville fault and are exposed in several windows through the Hayesville sheet. The Helen Group (informal usage of Gillon, 1982) and the Coweeta Group of Hatcher (1979) form a long narrow lithotectonic unit herein called the Helen-Coweeta terrane that divides diagonally from southwest to northeast the Hayesville sheet in northeast Georgia and adjacent North Carolina.

Great Smoky thrust sheet

Rocks of the Great Smoky thrust sheet consist chiefly of interbedded feldspathic and argillaceous metasandstone, metaconglomerate, muscovite schist, and calc-silicate granofels that together form various groups and formations of the Ocoee Supergroup (Higgins and Zietz, 1975) of Late Proterozoic age. Although the Great Smoky sheet rocks have been metamorphosed and polydeformed, original bedding, even at sillimanite grade, is preserved locally. Middle Proterozoic plutonic rocks and variably layered paragneisses form the basement rocks in parts of the Great Smoky thrust sheet, but they are not exposed in the report area.

Hayesville thrust sheet

Two formations make up the Hayesville thrust sheet in the report area; (1) the Tallulah Falls Formation (Hatcher, 1971; Bell and Luce, 1983), which occupies most of the eastern part, and (2) the Richard Russell Formation (informal usage of Gillon, 1982), which occupies the western part. The Richard Russell Formation probably is equivalent to the Tallulah Falls Formation of probable late Precambrian age (Hatcher, 1971; Bell and Luce, 1983).

The Richard Russell Formation consists primarily of biotite gneiss and lesser amounts of mica schist, fine-grained feldspar gneiss, metasandstone, quartzite, hornblende gneiss, amphibolite, and some calc-silicate layers. Granitic and granodiorite gneisses are interlayered with these rocks. Numerous discontinuous pegmatite veins and pods of various sizes are dispersed widely throughout the Hayesville sheet, and migmatitic biotite gneiss and granitic gneiss are abundant. In the Hayesville thrust sheet near the Hayesville fault, some diamictite is exposed. Although the diamictite is not widespread, its presence suggests that it probably formed as the Hayesville sheet advanced northwesterly. Some Grenville (Middle Proterozoic) basement rocks are exposed east of the report area (in the eastern part of the Hayesville thrust sheet), but they have not been observed in the study area.

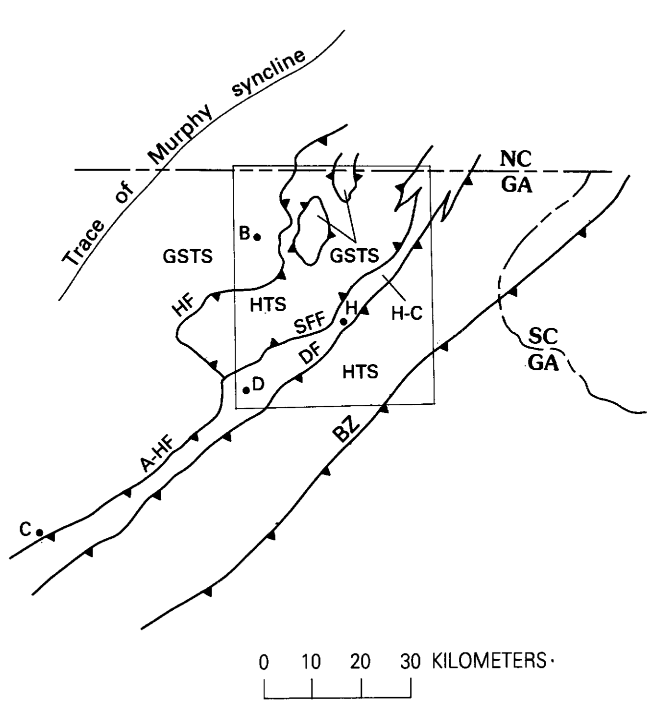


Figure 1*A*. Location of report area and generalized tectonic map of northeast Georgia. B, Blairsville; C, Canton; D, Dahlonega; H, Helen; GSTS, Great Smoky thrust sheet; HTS, Hayesville thrust sheet; H-C, Helen-Cowetta terrane; DF, Dahlonega fault; SFF, Shope Fork fault; HF, Hayesville fault; A-HF, Allatoona-Hayesville fault; BZ, Brevard zone.

Rocks of the Hayesville sheet, particularly units of biotite gneiss, mica schist, and metasandstone, are variably layered. Compositional layering, which results from metamorphic differentiation and transposition of bedding into the regional foliation, is widespread in the report area. Hatcher (1976) described similar transposed bedding farther east in the Hayesville sheet. The transposition and metamorphic differentiation probably destroyed most of the primary sedimentary features that may have existed in the rocks. Layers in most of the rocks range from 2 to 15 cm in thickness; rarely are rock layers greater than 1 m thick. As a result of interlayering, metamorphic differentiation, and transposition of rock units, contacts between mapped units in the Hayesville thrust sheet are commonly gradational (Nelson, 1982, 1983a and b; Nelson and Koeppen, 1984).

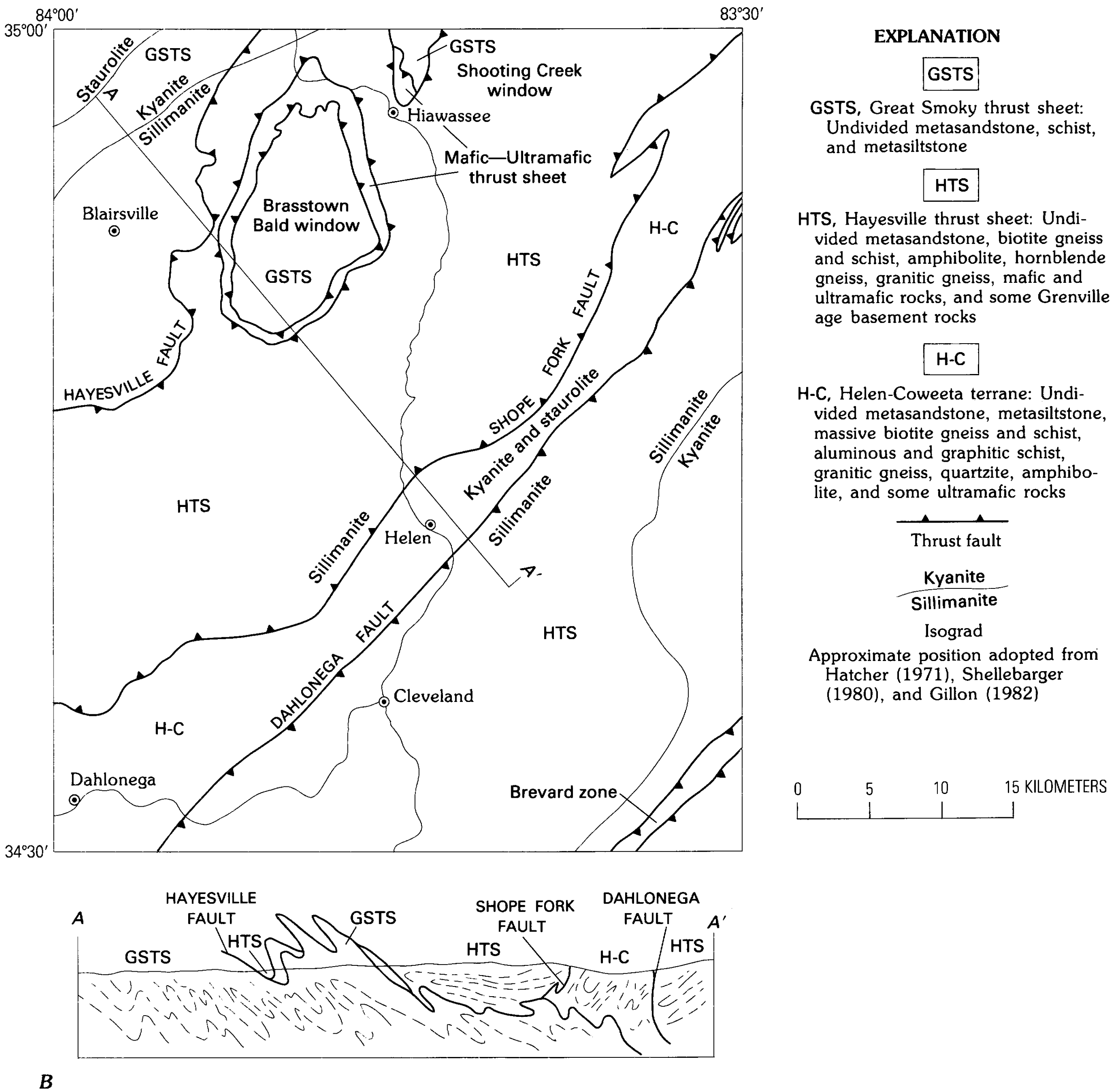


Figure 1*B*. Generalized lithotectonic map of the northwest part of the Greenville 2-degree quadrangle, Georgia.

Mafic and ultramafic rocks

A wide variety of ultramafic and mafic rocks is present in the Hayesville sheet, some as small discontinuous pods, some as large mappable units (Hadley and Nelson, 1971; Nelson, 1982, 1983a and b). These rocks are chiefly serpentinite, dunite, pyroxenite, gabbro, and amphibolite (Hartley, 1973). Locally, some of these rocks are magnetite rich. The relation of the ultramafic rocks to the Hayesville sheet is uncertain. The ultramafic rocks have chemical affinities with mantle rocks (Hartley, 1973, p. 59) and, as such, may represent fragments of oceanic crust caught up in the Hayesville sheet during or before westward emplacement of the Hayesville sheet. Some ultramafic rocks are believed to represent small separate thrust slices of oceanic crust underlying the Hayesville sheet.

Ultramafic and mafic rocks that surround the Brasstown Bald window (in the north-central portion of the study area) are believed to form a separate thrust slice of oceanic crust between the Hayesville and Great Smoky thrust sheets (fig. 1*B*). Some ultramafic and mafic rock bodies high in the thrust sheet may represent diapirs or small intrusives. Other ultramafic and mafic rocks are exposed along strike northeast of the report area, and some ultramafic bodies are probably present locally but concealed within the Hayesville sheet elsewhere in the study area.

Helen-Coweeta Terrane

Rocks of the Helen Group (informal usage of Gillon, 1982) and the overlying Coweeta Group (Hatcher, 1979) form the Helen-Coweeta terrane (fig. 1*B*) that extends northeastward from Dahlonega, Ga. This terrane varies in width and divides the Hayesville thrust sheet diagonally into almost equal areas (fig. 1*B*). The Helen Group contains numerous rock types, including metagraywacke, quartzite, graphite-bearing garnet-muscovite-biotite schist, metasiltstone, phyllite, and impure feldspathic metasandstone that is locally conglomeratic and interlayered with thin muscovite schist beds. Thin to thick layers of amphibolite also are present, as are some granitic gneiss and ultramafic bodies. Rocks of the Helen-Coweeta terrane range from garnet(?)-staurolite to kyanite grade; locally they are retrograded.

The Coweeta Group includes feldspar quartz-biotite-epidote gneiss, metasandstone, granofels, quartzite, aluminous schist, garnetiferous biotite schist, and minor amphibolite. Granitic gneiss and some ultra mafic rocks also are present. Rocks of the Coweeta Group overlie the Helen Group and range from staurolite-kyanite to sillimanite grade; locally they are retrograded.

Although some rock types in both the Coweeta and Helen Groups are similar, their overall lithology differs significantly. Rocks in the Coweeta Group commonly contain numerous thin layers of calc-silicate granofels, which is rarely seen in rocks of the Helen Group. The Helen Group contains relatively thick units of amphibolite, graphite schist, and metasiltstone units, all of which are much less abundant or are absent in the Coweeta Group.

Correlations of rock units in the Helen-Coweeta terrane with mapped units along strike in the vicinity of Canton, Ga. (McConnell and Costello, 1980), are somewhat tenuous. The Canton area is about 45 km southwest of the study area; the area between Canton and the Helen-Coweeta terrane is unmapped. No one-to-one correlation of mapped units between the Helen-Coweeta terrane and the Canton area exists, and the Helen-Coweeta terrane has been deformed by faulting. Nevertheless, recent investigations by K. I. McConnell and J. O. Costello (1981, oral commun.) indicate that some units in the terrane do correlate with units of the New Georgia Group to the southwest (Abrams and McConnell, 1981).

While some rock assemblages of the Helen-Coweeta terrane appear to correlate with rocks of the Canton area, part of the terrane resembles Ocoee rocks of the Great Smoky thrust sheet. Incomplete studies by me suggest that some Ocoee rocks may be present in the terrane, either as a window or as a tectonically emplaced unit. Ocoee rocks are exposed in the Brasstown Bald and Shooting Creek windows to the northwest in the Hayesville sheet; the Brasstown Bald window is about 12 km northwest of the Helen-Coweeta terrane. Because the Helen-Coweeta terrane has been deformed by faulting, some Ocoee rock units may have been tectonically emplaced. This emplacement is plausible because part of the Great Smoky thrust sheet is exposed along the trend of the Helen-Coweeta terrane just west and southwest of Dahlonega (fig. 1*A*). Rocks of the Great Smoky sheet are in this location because of a southerly bend of the Hayesville fault (Williams, 1978) in the adjoining Rome 2-degree quadrangle (fig. 1*A*). Current field studies should help resolve this problem.

Metamorphism

A Paleozoic Barrovian-type prograde regional metamorphism affected the southern Blue Ridge rocks (Hadley and Goldsmith, 1963; Carpenter 1970; Butler 1972; Dallmeyer 1975). This metamorphic event probably occurred during the Taconic orogeny about 450 m.y. to 480 m.y. ago (Butler, 1972; Dallmeyer 1975). Much of the report area is within a large, elongate, northeast-trending sillimanite-grade metamorphic zone (fig. 1*B*). However, lower grade rocks (staurolite-kyanite) border the higher grade sillimanite zone in the northwest part of the area. Lower grade rocks also are present in the southeast part of the area, especially near the Brevard zone (fig. 1*B*). The southern part of the Helen-Coweeta terrane, which ranges from garnet(?)-staurolite to kyanite grade, is bordered on both sides by sillimanite-grade rocks of the Hayesville thrust sheet.

Within the sillimanite zone, the effects of metamorphic differentiation and anatectic melting are particularly noticeable. Biotite gneiss, mica schist, and metasandstone units of the Hayesville sheet have been variably migmatized and have been differentiated to form gneisses of banded leucosomes and melanosomes. Quartz, which is highly mobile, also has been segregated into variably sized veins and pods that are widespread. Veins and irregular bodies of quartzofeldspathic segregations and anatectic melt materials and irregular granite bodies also are common. The migmatized and differentiated rocks of the Hayesville sheet contrast strongly with rocks of the Great Smoky sheet, which are only slightly migmatitic and do not have an abundance of feldspathic differentiates, even though they are at the same metamorphic grade as the Hayesville sheet rocks. Rocks in the study area at kyanite grade are essentially nonmigmatitic; they do not have an abundance of feldspathic differentiates, and the effects of metamorphic differentiation are rare.

Sillimanite is distributed widely in most pelitic rocks within the sillimanite zone and is commonly present in rocks with a moderate quartz content and a moderate to low muscovite content. Sillimanite lies in and most probably grew in the regional foliation planes (S_1) during the high temperature peak of regional metamorphism. The foliation formed during the 450- to 480-m.y. regional metamorphic event but before the high temperature peak. The foliation planes were later deformed during regional folding (F_2) that probably occurred slightly after the high temperature peak.

Temperatures probably remained elevated in the study area through an episode of deformation that occurred after the regional F_2 folding. The apparent growth of biotite along planes parallel to the third fold generation (F_3) axial surfaces supports this hypothesis. Therefore, I believe that temperatures remained elevated in the study area at least until after the F_3 folding event.

In some places, prograde metamorphic minerals have been retrogressively altered. Some, but not all, of the altered areas appear to be related to shear zones. The alteration is not intense, nor is it widespread. Sillimanite alters to sericite or sericitic clusters, and garnet and biotite alter to chlorite. Some plagioclase is saussuritized. Most of the ultramafic rocks are extensively chloritized, are serpentinized, and are altered locally to talc schists. The age of retrogression is uncertain, and several estimates have been proposed for the time of retrograde alteration in the southern Appalachian Mountains. Hatcher (1972) and Butler (1973) suggested that the alteration was due to a Permian thermal event, probably related to late Paleozoic thrusting. Shellebarger (1980) believes that the alteration resulted from uplift and cooling after the last deformation and thus does not necessarily imply a separate thermal event.

STRUCTURAL GEOLOGY

Faults, joints, and lineament trends

Numerous thrust faults characterize the southern Appalachian Mountains (Rodgers, 1953; King, 1964; Hadley and Goldsmith, 1963; Hadley and Nelson, 1971; Hatcher, 1971, 1972). The Hayesville thrust sheet was pushed westward over the Great Smoky thrust sheet along the Hayesville fault. I believe this fault is premetamorphic to early synmetamorphic. The fault does not offset the sillimanite isograd (fig. 1), and the foliation (S_1) attitudes in rocks on either side of the fault do not appear to be deflected in the Greenville quadrangle or in the area to the north (Wooten, 1980).

Shellebarger (1980) described the Hayesville fault and summarized evidence that supports its occurrence in the northwestern part of the Greenville quadrangle. He indicated that the fault juxtaposes rocks of different lithologies and structural style. Southeast of this fault, the Hayesville thrust sheet contains most of the known ultramafic rocks and intrusive plutons and volcanic rocks. In addition, the metasandstones are more garnetiferous, and the schists more mafic, than similar rock types occurring in the Great Smoky thrust sheet. In places along the Hayesville fault, competent rock types of the Hayesville sheet have been changed to blastomylonite and mylonite gneiss. Southeast of the Hayesville fault, the rocks are recumbently folded, whereas the rocks northwest of the fault are folded into upright folds or are only slightly overturned.

Many smaller faults also are present in the study area; they include both thrust and normal faults, as well as ductile shear zones that are present in individual outcrops. These small faults and shear zones are not shown in figure 1 of this report because the paucity of exposures precludes mapping them.

Both brittle and ductile faulting have deformed the southern part of the Helen-Coweeta terrane. The southeast side of the terrane near Dahlonega (fig. 1) is bounded by a fault, and the Geologic Map of Georgia (Georgia Geological Survey, 1976) shows a discontinuous fault and a shear zone along the terrane's southeast side. This fault and the shear zone have been referred to as the Dahlonega shear zone (Crickmay, 1952, p. 48, and Fairly, 1973, p. 693). The northwest side of the terrane is bounded by the Shope Fork fault, which was mapped by Hatcher (1976), near the Georgia-North Carolina boundary. The Shope Fork fault is folded by what appears to be F_2 folds, and Hatcher (1976) suggests that the fault is pre- or synmetamorphic. However, a discordance of foliation attitudes between the Helen-Coweeta terrane and the Hayesville sheet indicates that later movement along the Shope Fork fault is post-S_1. Recent geologic mapping shows that the Shope Fork fault, which is probably a fault zone, locally extends southwestward toward Dahlonega (Gillon, 1982); the Shope Fork fault appears to join the Hayesville fault west of the Greenville quadrangle.

Reconnaissance mapping in the Helen-Coweeta terrane shows that shear zones are present along several prominent northeast-trending topographic lineaments. The shear zone boundaries appear to be gradational, and rocks from these zones include button schist, mylonite, blastomylonite, and mylonite gneiss. These rocks exhibit deformed fabrics that range from microscopic to mesoscopic in size; the rocks display a prominent mylonitic foliation. The sheared rocks in the Helen-Coweeta terrane are probably the northeast continuation of sheared rocks described by Bowen (1961) in Dawson County, just west and southwest of Dahlonega.

Jointing is present throughout the study area, but joint patterns have not been studied in detail. Most joints are steeply inclined and do not seem to have well-defined preferred strike orientations. Less commonly, joints are shallow dipping or are horizontal. Some thin pegmatite and quartz veins occupy early joint sets.

Figure 2 is a Landsat image (Georgia Geologic and Water Resources Division, 1977) of the northwest part of the Greenville quadrangle; outlines of the major lithotectonic units are superimposed on the image. Distinct image patterns and lineament trends show a close correlation with the major lithotectonic units. The lineaments follow topographic and geologic features, such as aligned stream valleys or some distinct lithologic units, and many lineaments are believed to reflect prominent fracture zones.

Several sets of lineament patterns, which do not follow the regional trends of mapped lithologic units, are present in the Hayesville sheet but are not evident in the adjoining lithotectonic units. A north-trending set appears to end along the Hayesville fault, especially in the Brasstown Bald window area. The same set ends along the Shope Fork fault to the south and does not appear in the Helen-Coweeta terrane. The same set continues, however, in the Hayesville sheet, south of the Helen-Coweeta terrane. A west-southwest-trending set also is present in both the eastern and western parts of the Hayesville sheet but is not present in the Helen-Coweeta terrane.

A faint east-southeast lineament trend is present in the Helen-Coweeta terrane and in part of the Great Smoky sheet but is not present in the Hayesville sheet. The principal lineament trends in the Inner Piedmont, southeast of the Brevard zone, do not have strikes parallel to lineaments in the Hayesville sheet.

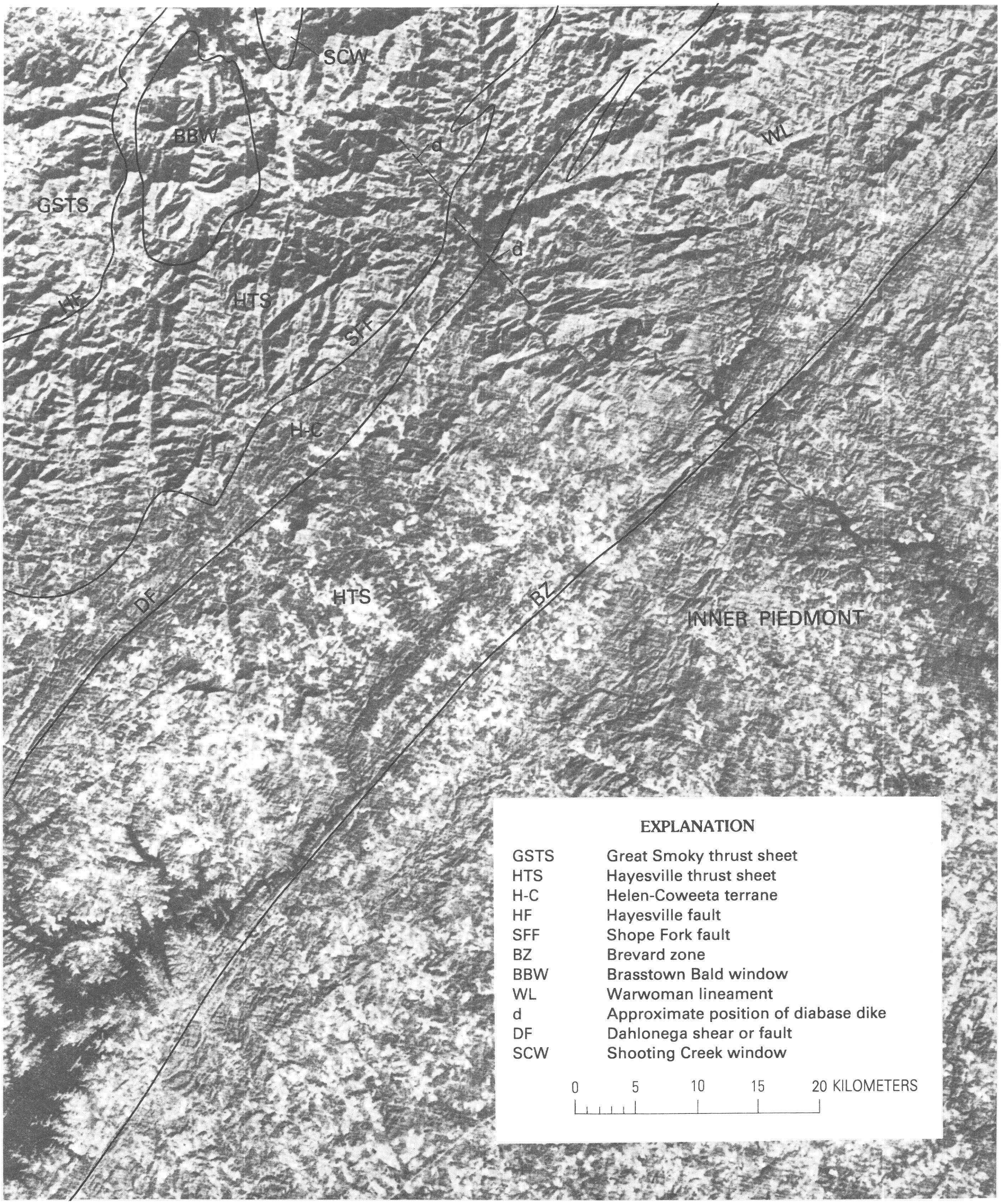
The contrasting lineament patterns among adjacent major lithotectonic units suggest that each unit was subjected to a different history of fracturing before emplacement along thrust faults. Alternatively, the physical makeup of each unit may have caused the units to yield differently to stress.

The gently curving west-southwest-trending Warwoman lineament (Hatcher, 1974) forms a prominent Landsat feature (fig. 2). Although bedrock is concealed by surficial materials in valleys that form most of the lineament, a siliceous flinty crush rock is exposed along part of it west of Clayton, Ga. Hatcher (1974) reports that the lineament is a late feature—probably post-Paleozoic—and indicates that lithologic contacts cross the lineament without being offset.

On the Landsat image (fig. 2), the Warwoman lineament appears to cross the Dahlonega shear zone, which bounds the southeast side of the Helen-Coweeta terrane. A similarly trending, prominent lineament almost on strike with that of the Warwoman lies in the Hayesville sheet, west of the Helen-Coweeta terrane. Because the lineament's trace is indistinct near the Shope Fork fault, we cannot be certain that the Warwoman is present west of the fault. If the Warwoman is present to the west, it appears to be displaced about 1.6 km to the right, along the Shope Fork fault. A few kilometers northeast of this locality, reconnaissance mapping shows a small unmetamorphosed diabase dike of probable Triassic-Jurassic age that also appears to be offset about 1.6 km to the right, along the Shope Fork fault. The apparent similar displacements of the dike and the Warwoman lineament suggest post-Triassic-Jurassic movement along the Shope Fork fault.

Folding and related deformation

In the southern Blue Ridge, the major folds trend northeast, and their axes plunge gently northeast or southwest. These folds vary from upright to inclined to recumbent, and, although some of them verge southeast, most verge northwest. Evidence for polyphase folding is widespread, and the present outcrop patterns of many large structural features have resulted from superposed folding (Dallmeyer and others, 1978; Hatcher, 1974, 1978b; Wooten, 1980; Shellebarger, 1980). The superposed later fold phases have formed large-scale interference patterns of



Base from Georgia Department of Natural Resources, Blue Ridge Mountains sheet, 1977.

Figure 2. Landsat image of the northwest part of the Greenville 2-degree quadrangle and approximate boundaries of the major lithotectonic units of the area.

domes and basins, such as the Tallulah Falls dome (Hatcher, 1971) and other similar structures within and adjacent to the study area (Shellebarger, 1980).

Within the report area, mesoscopic structures at some exposures show that the rocks have been deformed by folding at least four times (fig. 3). Hatcher (1976 and oral commun., 1979) reports six phases of folding in similar rocks exposed farther east in the Hayesville sheet. Fold interference patterns are commonly seen at rock exposures; most of these patterns are similar to types 2 and 3 of Ramsay (1967) (fig. 4). The first generation folds (F_1) (fig. 5) are represented as intrafolial, rootless, recumbent isoclinal folds in transposed layers. Second generation folds (F_2), which form the major folds, are steeply inclined to recumbent isoclinal folds, with hinges generally plunging gently northeast or southwest (fig. 6). The limbs of F_2 folds have been folded locally into two sets of tight to open, upright to overturned flexural folds or crenulations. The axes of one set trends north-northeast, and the axes of the other set trends west to northwest. Whether these folds represent separate fold phases F_3 and F_4 or whether they form part of a conjugate fold pair (Johnson, 1956) is uncertain. Evidence presented below (pg. 18) favors the latter interpretation. Hereafter, the two sets of folds will be referred to collectively as F_3 folds and individually as F_3 (northeasterly) and F_3 (northwesterly). Generally, the axial surfaces of the F_2 folds are less steep than those of the later folds, but some F_2 folds in the northwest part of the report area have steeply dipping axial surfaces. Statistical analyses of folds suggest that the flanks of some F_3 folds were gently folded by a later folding event or events, but axial plane cleavages have not been identified with these later folds or flexures. Post-F_3 folding appears to be around an east-west axis and a less well defined north-to-northeast axis. A late episode of folding along northeast-trending axes in an area east of the study area (Hatcher, 1978b) may correspond to post-F_3 folding along a northeast-trending axis. Flowage folds characterize the F_1 and F_2 folds, and flexure folds are the dominant fold type for the F_3 folds in the report area.

Bedding (S_0), metamorphic layering, regional foliation (S_1), foliation axial planar to F_2 folds (S_2), and crenulation cleavage (S_3) form the principal planar structures in the report area. Bedding can be identified in most rock units of the Great Smoky sheet northwest of the Hayesville fault. Farther to the southeast, however, most of the bedding in rock units within the study area appears to be transposed into the regional foliation.

Except for a diabase dike and some small pegmatite and quartz veins, all rocks in the study area have a pervasive planar foliation (S_1). This foliation

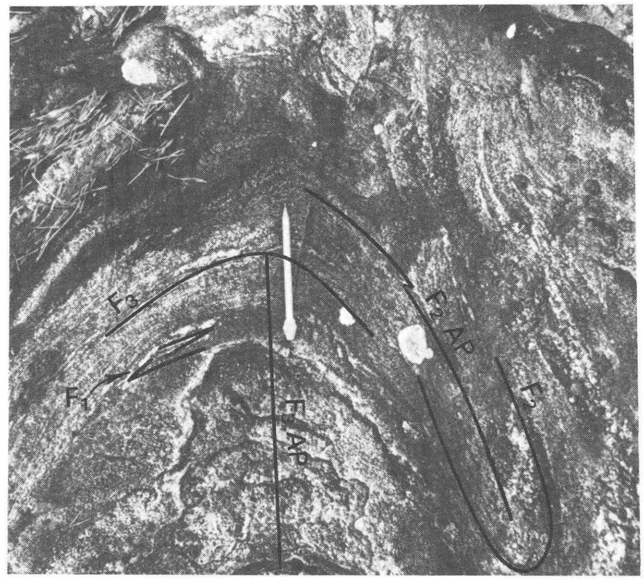


Figure 3. Three fold phases at an exposure in Brasstown Creek 2.2 km east-southeast of U.S. Route 76 and south of Young Harris. F_1 is present as small rootless isoclines; F_2 is overturned and is tight to isoclinal; F_3 is an upright fold with an almost vertical axial plane (AP). Pencil for scale.

is axial planar to the first generation folds (F_1) (fig. 5); subsequent phases of deformation refold the regional foliation into later fold generations (F_2 and F_3). The second generation folds appear to have a poorly developed axial plane schistosity (S_2), but the later F_3 fold generation locally displays a strong axial plane crenulation cleavage (fig. 7). In this report, these surfaces (S_1, S_2, S_3) correspond to the fold phases (F_1, F_2, F_3). Foliated clasts are present in some host metasedimentary rocks in the Hayesville sheet, and their foliation is across the S_1 foliation in the host gneiss. I interpret this foliation as showing that the clasts were probably deformed prior to their incorporation into the host rocks before the regional foliation S_1 formed and, as such, may represent a pre-S_1 deformation fabric.

Crenulation cleavage (slip cleavage), although common, is not uniformly well developed except where it locally masks the earlier regional foliation (fig. 7). Crenulation cleavage is the most recent planar structure associated with folding. This cleavage is present in many pelitic units, and, where observed, it is axial planar to either the northwest or northeast F_3 folds (fig. 8). Where the cleavage is well developed, F_3 folds deform the layering and the regional foliation. Two principal crenulation cleavage sets are present. One set is associated with the northeast-trending F_3 folds; the other set is related to the northwest-trending F_3 folds. The northeast-striking set is much more common and widespread than is the northwest set.

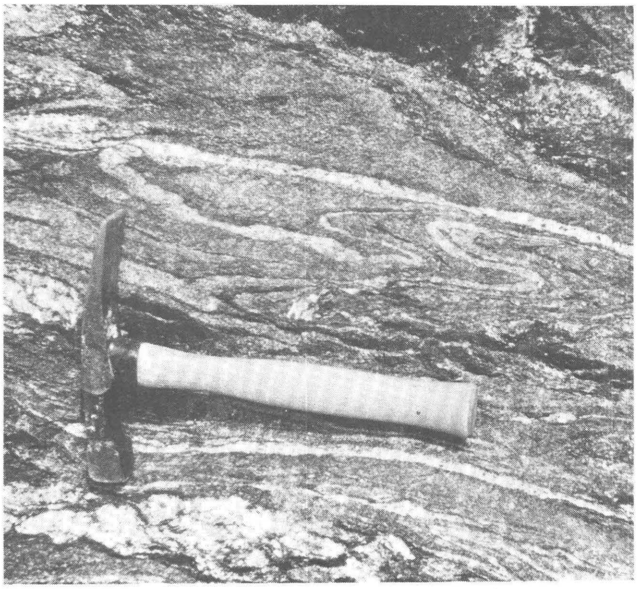


Figure 4. Type 3 fold interference pattern (Ramsay, 1967) at an outcrop along the Richard Russell Highway about 0.3 km west of Hogpen Gap. F_2 folds are refolded by F_3 folds. Hammer for scale.

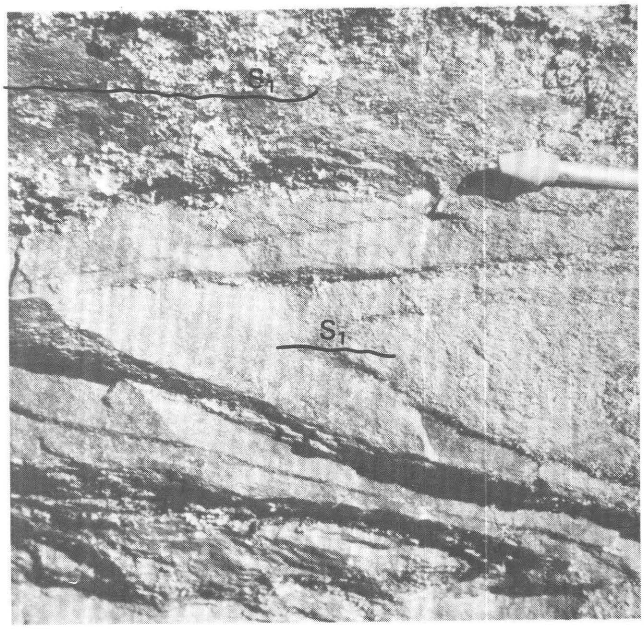


Figure 5. Outcrop showing hinge of an F_1 isoclinal fold in siliceous metasandstone and schist in the Hayesville thrust sheet and also showing trend of foliation (S_1). View is northwestward along the shore of Lake Sidney Lanier just south of Highway 369 at Browns Bridge. Pencil for scale.

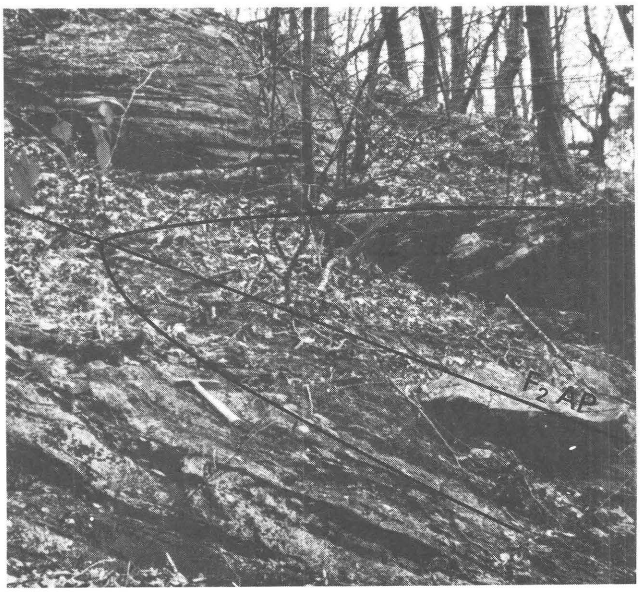


Figure 6. An F_2 fold (axial plane (AP) dipping gently southeast) that is overturned to the northwest. View is northeastward near the Appalachian Trail in western Union County at an exposure 0.25 km north of Puncheon Gap. Hammer for scale.

Locally, small crenulations associated with the two cleavage sets form a conjugate fold pair (fig. 9). These conjugate folds are rare, but they and their related crenulation cleavages suggest that the northwest-striking folds and the northeast-striking folds probably formed together as a conjugate F_3 fold pair. As such, the F_3 folds probably represent one of the later sets of compressive structures to form during the waning stages of regional metamorphism and deformation that affected the southern Appalachians.

Throughout most of the study area and elsewhere in the Hayesville thrust sheet, satisfactorily defining the chronology and the details of the macroscopic folding is difficult. The principal reasons for this difficulty are that (1) the original bedding (S_0) is transposed into the regional foliation (S_1); (2) no easily distinguished marker beds exist; (3) a thick forest cover conceals much of the bedrock; and (4) original primary sedimentary features, such as graded bedding, are not well preserved. In the Hayesville sheet, the compositional layering is almost everywhere parallel to the pervasive foliation (S_1), and this foliation is axial planar to F_1 folds (fig. 5). On figure 5, foliation form lines (constructed from foliation (S_1) attitudes) were drawn to depict the general form of the post-F_1 folds.

Figure 10 shows the foliation (S_1) form line trends for the report area. The two major regional structures are outlined; they are (1) the west part of

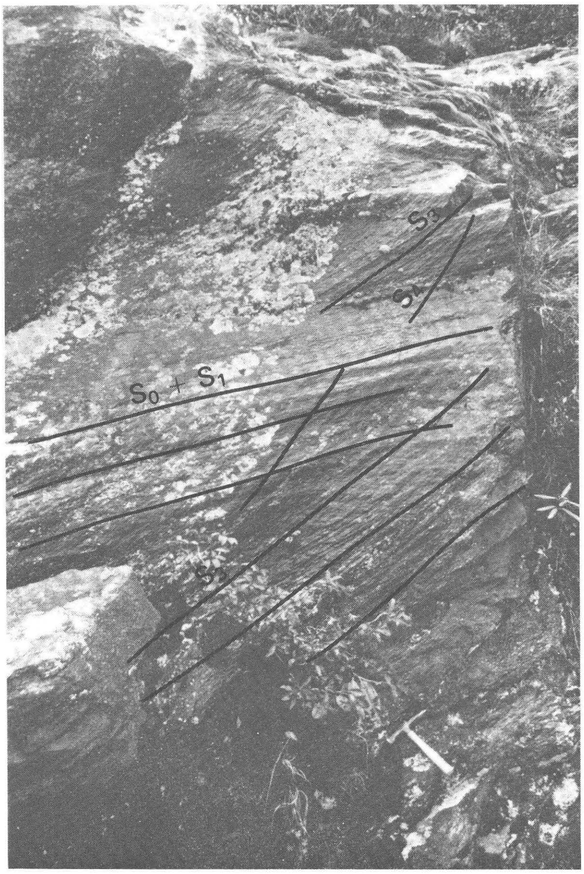


Figure 7. Exposure showing S_0, S_1, and S_3 foliation. The S_3 foliation is the dominant planar feature and almost masks the earlier foliations. A faint S_4(?) crenulation cleavage is also present. View is northwestward, just southeast of the crest of Brasstown Bald. Hammer for scale.

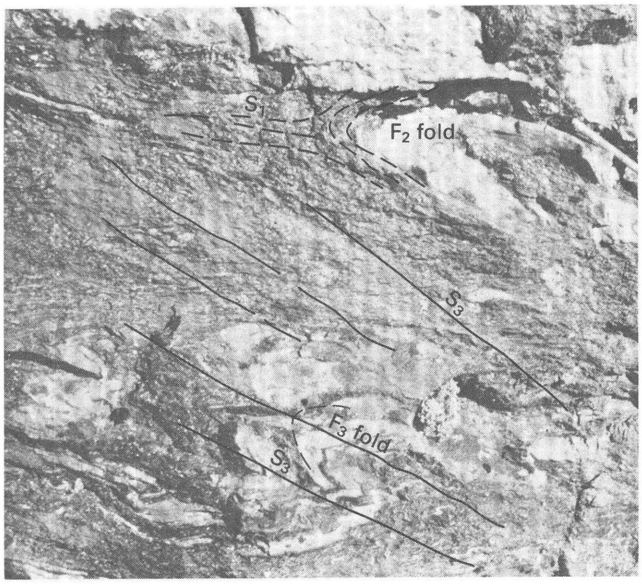


Figure 8. Exposure showing a rootless F_2 fold and an F_3 fold with an axial planar crenulation cleavage S_3. View is northwestward 0.35 km west-southwest of Chimney Top about 5 km southeast of Young Harris. Pencil for scale.

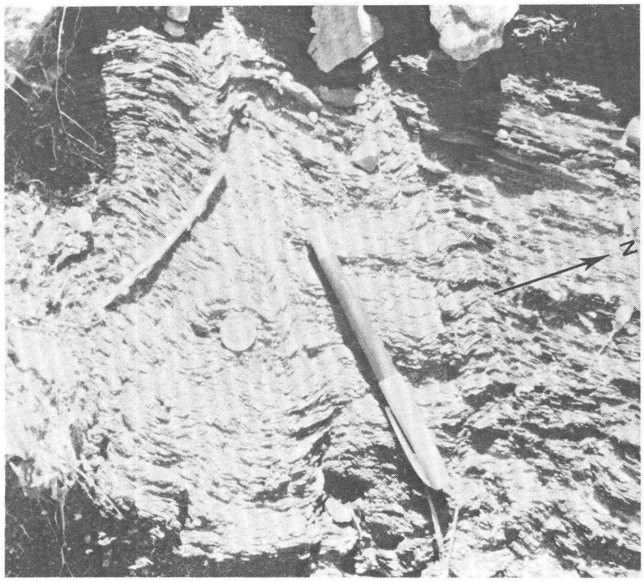


Figure 9. Gently inclined saprolite exposure showing a small conjugate F_3 fold pair. Exposure is located in a ditch next to Smyrna Road 0.15 km north of Ebenezer Church, in the northwest part of the Greenville quadrangle. Felt pen for scale.

the Tallulah Falls dome (Hatcher, 1971), which is east of the Helen-Coweeta terrane, and (2) the Chattahoochee basin and synform, which occupies much of the western part of the Hayesville sheet. The Chattahoochee basin is a broad, shallow-dipping, complex structure with a central, shallow-dipping basin that merges to the northeast into a synform with a northeast-trending axis. Numerous small folds with several distinct trends also are present. Exposures within the Chattahoochee basin and synform commonly show fold interference patterns, and in places as many as four and possibly five episodes of folding are recorded in the rocks. In and near the Chattahoochee basin, one fold set trends west-northwest, and other sets trend north-northeast.

Folds in the Helen-Coweeta terrane east of the Chattahoochee synform trend northeast.

The previously mentioned limitations (see p. 9) to fold analysis on a macroscopic scale required equal area projections to make generalized interpretations of the fold chronology. Insofar as possible, the

Figure 10. Generalized structure of the report area shown by foliation S_1 form lines. Regional Appalachian fold structures trend northeast, and later folds are superposed upon them. B, Blairsville; D, Dahlonega; H, Helen; HF, Hayesville fault; SFF, Shope Fork fault; DF, Dahlonega fault; BZ, Brevard zone; GSTS, Great Smoky thrust sheet; HTS, Hayesville thrust sheet; H-C, Helen Coweeta terrane; BBW, Brasstown Bald window; SCW, Shooting Creek window; TFD, Tallulah Falls dome.

study area was divided into structurally homogeneous areas (fig. 11), and the linear and planar fabric elements for each area were statistically analyzed by using an equal area net. In the fold analyses that follow, the S_1 attitudes are represented by a five-digit numeral. The bearing of the strike of fabric elements is given by the first three digits, and the dip or plunge value by the next two digits. The symbol "πS" refers to a great circle of best fit through poles of measured S surface segments. The normal to πS is represented by βS_1 which is the statistically defined axes of folding (Turner and Weiss, 1963).

Fold Analyses

Area I

This area (see fig. 11) occupies the southwest part of the Hayesville sheet northwest of the Helen-Coweeta terrane. Here the S_1 foliation attitudes generally strike east-west and have moderate north dips that reflect the structural attitudes along the southern boundary area of the Chattahoochee basin (fig. 10). I observed few F_2 folds; they are overturned to the southeast and are reclined to recumbent. Their axes trend northeast. Figure 12*A* is an S_1 pole diagram for area I and shows projections of F_2 fold axes. The concentrations of poles to S_1 suggest a weak S_1 girdle with a βS_1 of 060/16°. The single S_1 pole maxima concentration is interpreted to show that significant post-F_2 deformation did not noticeably affect the rocks in area I. Together with the observed F_2 folds, the concentration suggests that the S_1 surface in this area was deformed by F_2 folds that are overturned to the southeast. The plotted fold axes are close to the statistical axial plane 086/33°; this proximity suggests that F_2 folds are overturned to the southeast.

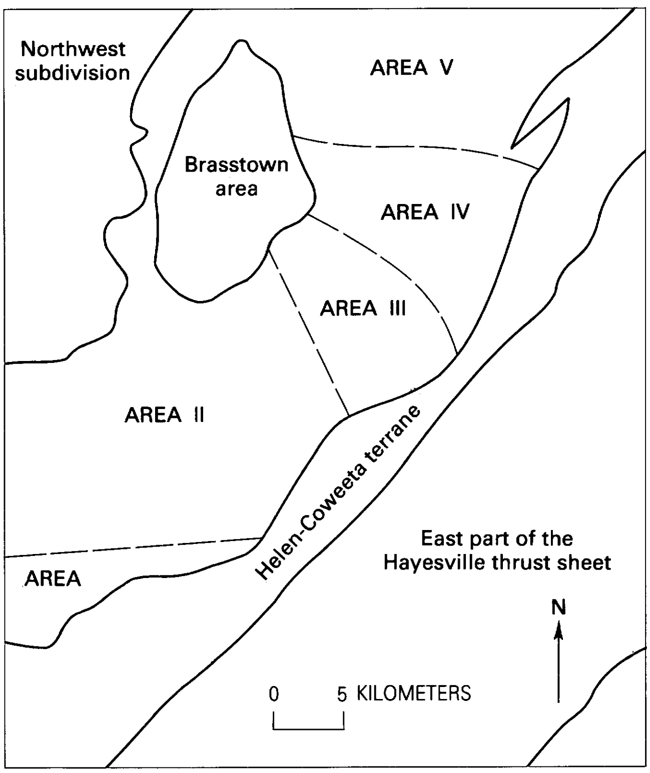


Figure 11. Structural areas in northwest Greenville quadrangle that were used for statistical analyses of fold events.

Area II

Area II (see fig. 11) lies just north of area I in the Hayesville thrust sheet. The wide dispersal of S_1 poles along a broad girdle (fig. 12*B*) suggests that area II probably has undergone considerably more post-F_2 deformation than has adjacent area I and that a single βS_1 probably does not characterize this area. Besides the F_2 regional folds whose axes trend northeast, there are also F_3 folds with northwest- and northeast-trending axes. I interpret an S_1 pole diagram for area II (fig. 12*B*) as showing a trimodal distribution for S_1 pole concentrations. This distribution resulted from a spread of a maxima for northwest-dipping surfaces into two submaxima, possibly during F_3 (northwest) folding. The 313/10° βS_1 is close to the plotted mean attitude for axes of 17 northwest-trending F_3 folds (fig. 12*B*). The projections of the mean attitude for axes of 15 southwest- and northeast-plunging F_3 fold axes have different orientations than does the βS_1 072/10°. However, the 217/05° βS_1 strike is close to the average strike for the axes of northeast-trending F_2 and F_3 folds, except it plunges gently southwest instead of northeast; note that some measured F_3 folds plunge southwest and that others plunge northeast. The βS_1 positions for the southeast- and northwest-dipping S_1 surfaces suggest that the segment of the Chattahoochee synform in area II is folded into upright folds along northeast-trending axes. The general northeast-southwest strike of S_1 contrasts strongly with the east-west S_1 trend in area 1.

Area III

In area III (see fig. 11), the regional schistosity (S_1) strikes northeast and dips primarily to the northwest, but some other attitudes are also present. Besides the generally northeast-striking major F_2 fold axes, both northeast- and northwest-trending F_3 folds are present. In places throughout the report area, F_2 and the northeast-trending F_3 folds have almost par-

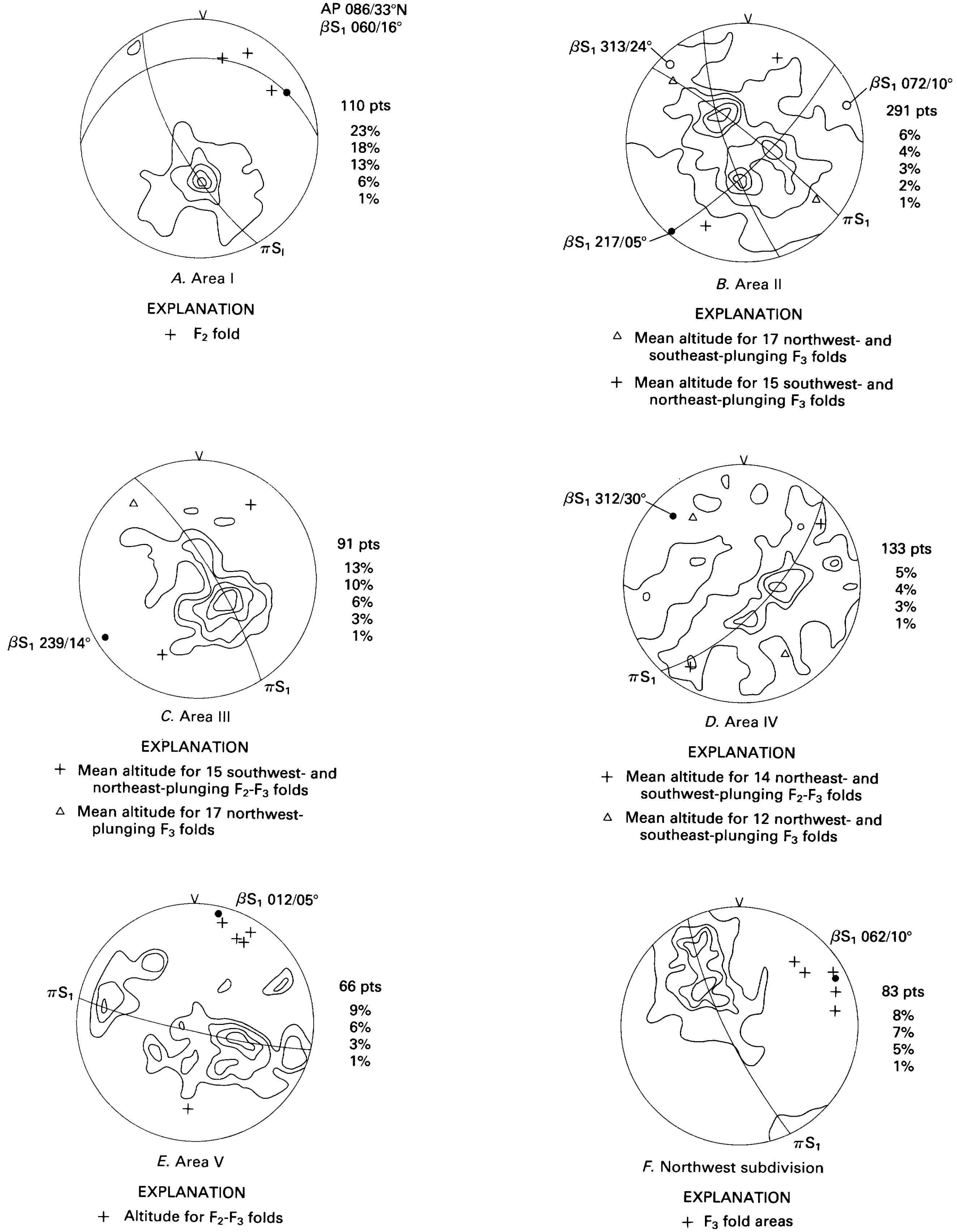


Figure 12. Contoured equal area projections of poles to S_1 and F_2 and F_3 fold attitudes for areas shown in figure 11.

allel axes, and, depending on the rock exposure, one cannot always differentiate an F_2 from an F_3 fold. Figure 12*C* is an S_1 pole diagram that also gives the mean attitudes of undifferentiated F_2 and F_3 folds in area III. The S_1 pole maxima concentrations are somewhat elongate and define a πS_1 girdle with a βS_1 of 239/14°. The pole concentrations are locally dispersed away from the girdle, especially near the maximum pole density. I believe that the maximum density for S_1 poles approximates S_1 attitudes prior to F_3 strain, but the dispersal of the pole concentrations at several points along the girdle may reflect post-F_2 deformation that is related to the F_3 strain. The effects of post-F_2 strain in area III, however, do not seem to be as widespread as in area II. Figure 12*C* shows that, although some surfaces dip southeastward, most of the surfaces in area III dip to the northwest. This northwest dip suggests that, in this part of the Chattahoochee synform, the northeast-trending folds are overturned to the southeast.

Area IV

Area IV (see fig. 11) contains a wide variety of S_1 orientations. Figure 12*D* contains plots of poles to S_1 that form a πS_1 girdle with a βS_1 of 312/20°. The poles to S_1 are widespread in the diagram, but a bimodal distribution is indicated by two maxima. Also shown in the diagram are the mean trends of fold axes and their plunges for the undivided F_2 and northeast-trending (F_3) folds, as well as the northwest-trending (F_3) folds.

The bimodal spread of the πS_1 girdle appears to be the result of post-F_2 deformation. Because the βS_1 and the mean fold projections for the northwest-striking F_3 folds are similar, I interpret the post-F_2 strain as resulting from deformation associated with F_3 (northwest-trending) folds.

Area V

The regional schistosity in area V (see fig. 11) almost uniformly strikes northeast and dips primarily to the northwest, but in some areas it dips to the southeast. The rocks in this area have been folded several times. I observed some type 2 and 3 interference patterns (Ramsay, 1967) in the field within area V. The F_1 folds are small rootless isoclinal folds in the foliation; F_2 folds plunge to the southwest. These F_2 folds, which appear to form part of the major folds with northeast-trending axes, are reclined and overturned to the southeast. A few asymmetric northeast-trending (F_3) folds also were observed.

The S_1 pole concentrations in area V (fig. 12*E*) define a πS_1 girdle with a βS_1 of 012/05°. One high density pole maxima, which plots together with a less dense point maxima, forms a bimodal S_1 pole distribution along the girdle. Figure 12*E* also shows the projections of axes of northeast undivided F_2 and F_3 folds that plunge either to the northeast or southwest. The F_2 and F_3 fold axes have very similar trends. I interpret the bimodal distribution as reflecting F_2 folding. The irregular scatter from the πS_1 girdle may be a result of F_3 (northwest) folding. However, I did not observe F_3 northwest-trending folds within area V.

The northwest subdivision

The northwest subdivision (see fig. 11) is north and west of the Hayesville fault and southeast of the Murphy syncline (fig. 1*A*). Rocks of the Great Smoky thrust sheet underlie the subdivision. Structurally, the rocks of this area are overturned. Most of the rock units and the included foliations (S_1) dip variably southeast, but some rock units dip northwest. Fold interference patterns (Shellebarger, 1980) show the rocks have been multiply folded. Figure 12*F*, which gives the orientations for S_1 in the northwest area, shows a πS_1 girdle with a closely spaced bimodal maxima distribution and a βS_1 of 062/10 °. The main concentration of points containing the two maxima probably represents the least deformed S_1 surfaces on the southeast flank of the Murphy syncline. The spread of the maxima, as well as the distribution of points away from the girdle, probably represents late stage or post-F_2 folding. The plots for northeast-plunging F_2 folds are widely dispersed, also possibly due to post-F_2 deformation.

Shellebarger (1980) reported that rocks in the study area northwest of the Hayesville fault have been folded several times. Wooten (1980) also indicated that rocks northwest of the Hayesville fault just north of the report area are multiply deformed. Both Wooten and Shellebarger report that folds equivalent to the F_2 folds of this report have steeply inclined axial surfaces and are overturned to the northwest.

The Helen-Coweeta terrane

The Helen-Coweeta terrane area (see fig. 11) is underlain by rocks whose foliation (S_1) trends northeast, parallel to the strike of the terrane. After the formation of foliation during F_1, the rocks were folded around northeast-trending axes, and the foliation now dips either northwest or southeast. Within the terrane, differentiating between F_2 and F_3 folds is difficult. Both F_2 and F_3 folds have axes that strike northeast and plunge gently northeast, and some F_2 folds also plunge south-southwest.

Figure 13*A* illustrates the S_1 orientations within the Helen-Coweeta terrane. Plots of S_1 pole concen-

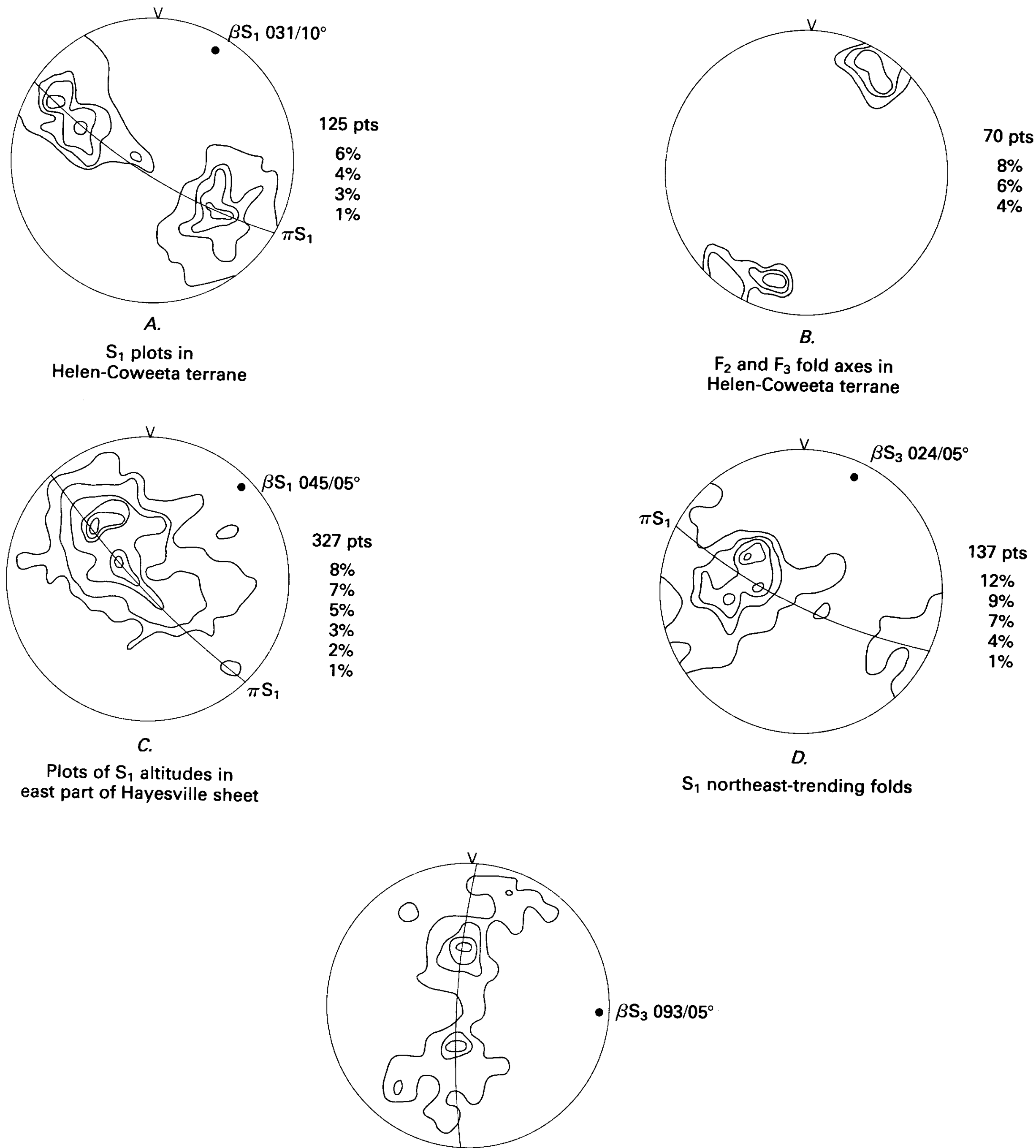


Figure 13. Contoured equal area projections of various planar and linear features in northwest Greenville quadrangle.

trations have a bimodal distribution and form a πS_1 girdle whose βS_1 is 031/10°. Figure 13*B* shows the bimodal distribution of undivided F_2 and F_3 fold axes. The βS_1 of figure 13*A* would plot within the northeast maxima for the fold axes. I interpreted this as showing that the bimodal S_1 pole distribution probably resulted from either F_2 or F_3 deformation or, more probably, from both. Additionally, the northeast maxima is close to the F_2 and F_3 (northeast-trending) plots elsewhere in the study area.

East part of the Hayesville sheet

The east part of the Hayesville sheet lies just east of the Helen-Coweeta terrane (see fig. 11) and covers that part of the Hayesville sheet southwest of the Tallulah Falls structural dome (Hatcher, 1971) where the rock units and S_1 surfaces strike primarily northeast. Most of the dips are to the southeast, but northwest-dipping foliation is not uncommon. An orientation for poles to S_1 is shown in figure 13*C*. The poles form a distinct πS_1 girdle with a bimodal maxima distribution and a βS_1 of 045/05°. The orientation of the girdle and the position of the πS_1 are similar to those of the Helen-Coweeta terrane (fig. 11), where the maximum density concentrations are more widely dispersed along the πS_1 girdle. Because fabric orientations in both the Helen-Coweeta terrane and Hayesville sheet (east) are similar, I believe that the S_1 surfaces in both areas have a similar post-S_1 deformation history.

Brasstown Bald window

Hartley and Penley (1974) and Shellebarger (1980) described parts of the Brasstown Bald area (see fig. 11). Within the Brasstown window, the regional foliation has been deformed by F_2, F_3, and later folding. Fabric element diagrams (fig. 14*A–D*) were made for this area; these include S-pole diagrams, as well as plots of other fabric elements from rocks along a ridge northwest of Brasstown Bald.

An S_1 pole orientation for the entire window is shown in figure 14*A*. Here the S_1 pole plots define a πS_1 girdle with a βS_1 of 037/24° and define a statistical axial plane that contains the βS_1. Figure 14*B* shows the axial plane of a representative F_2 fold, its axis, and the axes of several other F_2 and F_3 folds. The βS_1 (fig. 14*A*) for the window is reasonably similar to the F_2 fold axes. The βS_1 and F_2 fold axes, together with the axial plane and the S_1 pole maxima, suggest that the F_2 folds are overturned to the west-northwest.

Crenulation cleavage (S_3)

Figure 13*D* shows the orientations of crenulation cleavage for the northeast-trending (F_3) folds throughout the study area. Pole concentrations show a somewhat dispersed maxima within a broad zone of low pole concentrations that define a questionable girdle. The distribution of poles to S_3 surfaces (axial planar to the northeast-trending folds) represents a wide variety of S_3 attitudes. The majority of these S_3 surfaces, however, dip to the southeast and suggest that most of the axial planes of the northeast-trending folds have similar orientations. The spread of the maxima away from the girdle may represent post-F_3 folding about an east-west axis or may be due to cleavage fans about F_3 axes.

Figure 13*E* shows the S_3 crenulation cleavage orientations for the northwest-trending (F_3) folds for the entire study area. Pole plots to S_3 give a πS_3 girdle with a βS_3 of 093/05°. The pole concentrations along the girdle have a bimodal distribution and probably reflect post- F_3 folding about an east-west axis.

Figure 14*C* illustrates the S_3 cleavage pole concentrations in the Brasstown Bald area for the F_3 northwest-trending (F_3) folds that define a πS_3 girdle with a βS_3 of 119/30°. The pole density concentrations form a bimodal distribution, and their separation suggests post-F_3 deformation, possibly along a west-trending axis.

Figure 14*D* shows the poles to S_3 cleavage associated with northeast-trending (F_3) folds in the Brasstown Bald area; these plots of S_3 cleavage define a statistical axial plane at 033/34°for the maximum S_3 pole concentration. The βS_1 position for the window plots on the edge of a cluster of several F_2 and F_3 fold axes (fig. 14*B*) that are close to the plotted axial plane. The maxima concentration, together with the axial plane and F_3 fold axes plots, suggests that here the northeast-trending F_3 folds plunge northeast and are overturned to the northwest. The well-defined S_3 maxima density suggests minimal post-S_3 deformation.

The bimodal distribution of poles to S_3 crenulation cleavage for northwest-trending (F_3) folds (figs. 14*C* and 13*E*) suggests post-F_3 folding along east-west axes. The pole concentrations (fig. 14*D*) for F_3 northeast-trending fold cleavages in the Brasstown Bald area, however, do not suggest significant post-F_3 deformation, even though post-F_3 folding of similar cleavages along west-trending axes throughout the study area is suggested by figure 13*D*. This lack of agreement presents a problem. If both the northwest- and northeast-trending (F_3) folds form a conjugate pair, their associated rocks also should show evidences of similar post-F_3 deformation. Several explanations for this apparent difficulty are possible. (1) The measured S_3 surfaces of northeast-trending folds in the Brasstown Bald area might have been taken from a position or positions on a relatively undeformed part of a fold that would have similar attitudes. (2) The measured crenulation cleavages might be associated with a fold that is younger than the northwest-trending (F_3) folds; that is, a fold that has not been previously recognized. (3) The number of plotted measured surfaces was insufficient and did not indicate the post-F_3 folding.

In summary, the post-F_1 fold analyses show orientations of the principal folds within specific areas of the report region. In the Great Smoky thrust sheet

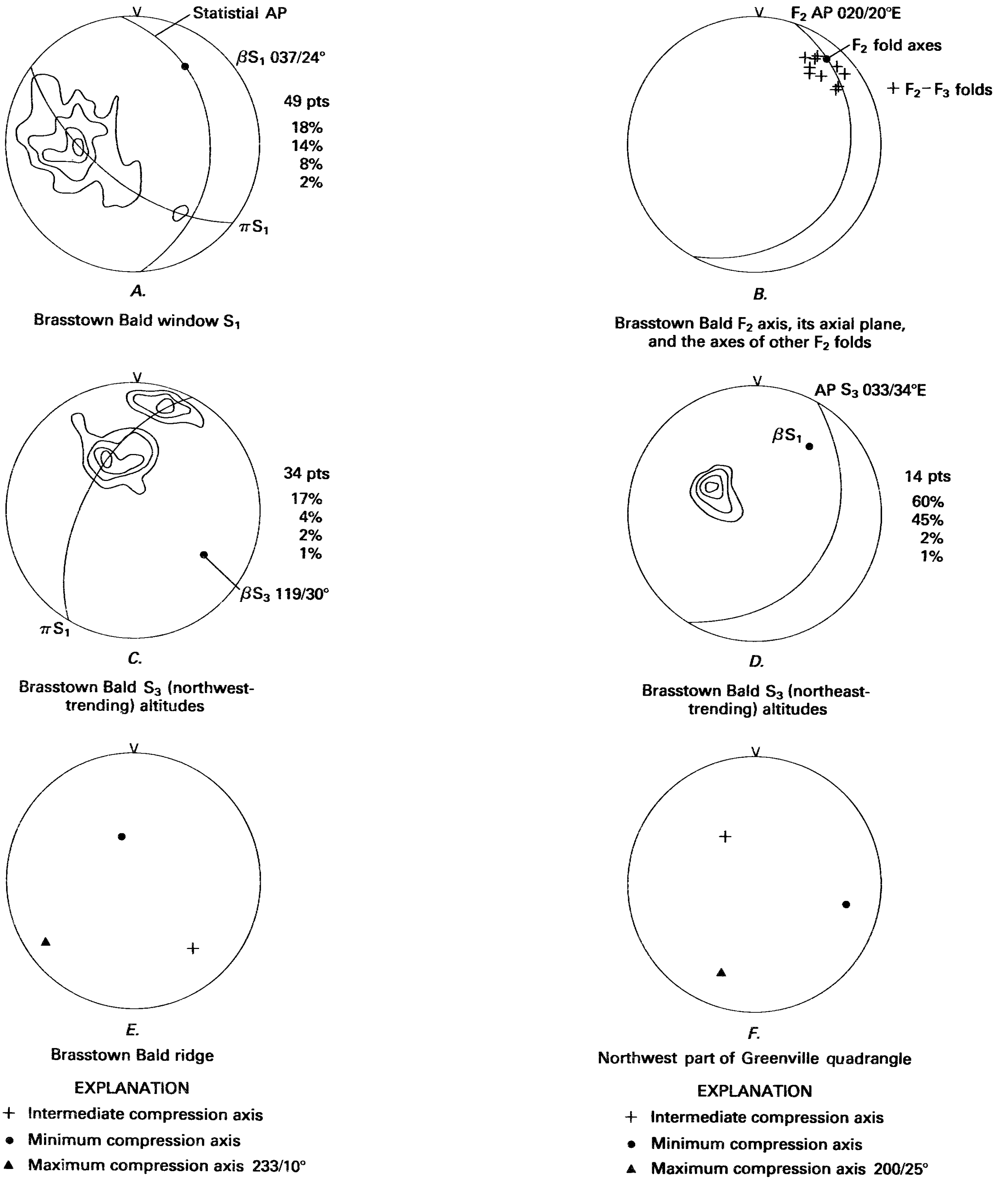


Figure 14. Contoured equal area projections of various planar and linear features in the Brasstown Bald area and northwest Greenville quadrangle.

northwest of or beneath the Hayesville fault, the regional F_2 folds are mostly overturned to the northwest, and their axial surfaces are steeply inclined. The F_3 strain appears to be reflected in the varied distribution of F_2 fold axes and in the diverse attitudes of S_1 surfaces.

In the Hayesville thrust sheet southeast of the Hayesville fault, the F_2 folds are reclined to recumbent and, depending on their location with reference to the Chattahoochee basin (fig. 10), have variable orientations that reflect considerable F_3 (northwest- and northeastward) strain. S_1 attitudes vary widely. In contrast, in both the Helen-Coweeta terrane and the southeastern part of the Hayesville thrust sheet, the F_2 fold axes generally strike northeast and have steeply dipping axial surfaces. These terranes also appear to have been subjected to post-F_2 deformation that did not change the orientation of F_2 fold axes greatly. Throughout the report area, F_3 fold axes strike west to northwest and north to northeast, and their axial surfaces range from gently to steeply inclined. Although statistical evidence suggests post-F_3 folding about east-west axes, field observations indicate only gentle warping about east-west axes. I recognize no significant post-F_3 folding in the study area.

F_3 fold analysis

Ramsay (1962) used some structural elements of conjugate folds to determine the principal stress directions in the formation of a conjugate fold system. He discussed a procedure to determine the three principal stress axes for the deforming forces responsible for conjugate folds. Tobisch and Fiske (1976) made regional structural interpretations of the central Sierra Nevada from maximum compression directions (maximum stress of Ramsay) of conjugate folds. Ramsay and Tobisch and Fiske indicated that the maximum compression directions probably lie parallel or subparallel to the surfaces being folded.

Several crenulation cleavage sets are exposed along a ridge north of Brasstown Bald in the Brasstown Bald window. Orientations of the axial planes of both sets of crenulation folds were plotted on a stereonet. These data were used to obtain a statistical orientation for the principal compression directions (Ramsay, 1962). Figure 14*E* shows the statistical compression axes for the conjugate (F_3) folds in the Brasstown Bald window. The maximum compression direction is 233/10° and is subparallel to the regional foliation on the ridge north of Brasstown Bald. A similar study was made of conjugate folds near Ebenezer Church, which is 8 km northwest of Blairsville and 1 km east of the quadrangle boundary in the northwest part of the study area. Figure 14*F* shows a statistical maximum compression direction for the northwest area at 200/25°. This direction almost lies in the regional foliation for that area. These southwest-striking compression directions are not exactly parallel, and the slight angular discordances between them are probably due to preconjugate deformation that gave the rock units varying orientations. The southwest trend of the maximum compressive stress axis for the conjugate folds is almost parallel to the trends of the regional F_2 and F_3 fold hinges in the report area (see figs. 12, 13, and 14).

In the southern Appalachian Blue Ridge Mountains, the regional folds trend northeast-southwest. This trend suggests that the maximum compression axes of the stress ellipsoid had a northwest-southeast orientation during regional deformation. It has previously been shown that the maximum compression direction for the conjugate folds in part of the report area was to the southwest. This orientation suggests that the stress field during conjugate folding was oriented almost normal to that which was prevalent during regional deformation. Tobisch and Fiske (1976) reported on a similar situation in the central Sierra Nevada. To explain this anomaly, they suggested a model where the conjugate structures resulted from forces that developed during an elastic recovery stage that occurred after the main folding event. This necessitated shortening parallel to the regional structural trends. Therefore, applying the Tobisch-Fiske model in the report area, the stress field that produced the regional northeast-trending structures was not rotated almost 90° to obtain the conjugate folding maximum compression. Instead, the compression direction for conjugate folding probably resulted from forces that developed during elastic recovery after the main deformation.

SUMMARY AND CONCLUSIONS

The rocks underlying the northwest part of the Greenville 2-degree quadrangle form parts of three major lithotectonic units. They are the Great Smoky thrust sheet, the Hayesville thrust sheet, and the Helen-Coweeta terrane. Each of these lithotectonic units is characterized by lineaments with distinct trends; each is allochthonous and bounded by faults.

The Hayesville fault and its northern continuation separate two major terranes in the Appalachian

Mountain chain—the Great Smoky thrust sheet and the Hayesville thrust sheet (Rankin, 1975; Hatcher, 1976, 1978; Williams, 1979). The Hayesville fault is pre- or synmetamorphic and is folded. The fault forms the contact around several windows in the Hayesville sheet.

The Shope Fork fault is probably a pre- or synmetamorphic feature, but some evidence indicates a late episode of movement along part of the fault. Patterns on Landsat imagery suggest possible right lateral offset of the Warwoman lineament along the Shope Fork fault. Mapping suggests that a post-metamorphic diabase dike of probable Triassic-Jurassic age(?) is similarly offset along the Shope Fork.

The Helen-Coweeta terrane is bounded by faults, and numerous topographic lineaments within the terrane are associated locally with mylonitic rocks. These lineaments correspond with aeromagnetic lineaments in rocks of the Helen Group that extend southwest beyond the study area. Bowen (1961) also described a band of sheared rocks that are on strike with the Helen Group a few miles to the southwest, in Dawson County. Therefore, shear zones in the Helen Group may be part of a larger shear zone; that is, the Dahlonega shear zone in northeast Georgia.

Several major lithotectonic units in the study area are characterized by distinctive lineament trends on Landsat images. These lineaments, which are not the northeast-trending lineaments seen on topographic maps, are believed to reflect prominent fracture zones in the lithotectonic units. Two interpretations of the lineament trends are possible: (1) each major lithotectonic unit had different physical characteristics that caused the unit to yield differently to stress or (2) the lineaments were present in each thrust sheet prior to emplacement into their present positions.

The majority of folds in the terrane northwest of (below) the Hayesville fault are F_2 folds with northeast-trending axes. These folds are overturned to the northwest, and their axial surfaces are steeply inclined. F_1 folds are not apparent northwest of the Hayesville fault, but F_3 folds are present and superimposed upon the F_2 folds.

Southeast of the Hayesville fault, most F_2 folds have northeast-trending axes. In this area, the F_2 folds are overturned, but their axial surfaces are either gently inclined or nearly horizontal. The imprint of later folding has variably deformed F_2 axial surfaces. The F_3 (northeast- and northwest-trending) folds are well developed locally, and their axial surfaces range from steeply to gently inclined. In places, rocks show type 2 and 3 fold interference patterns. These patterns result from F_3 folds deforming the almost flat-lying F_2 and F_1 folds. Figure 15 is a schematic diagram of a folded regional foliation surface between the Hayesville fault and the Helen-Coweeta terrane; the diagram shows the generalized form of the F_2 and F_3 folds.

In the report area, the relations between the directions of maximum compression for the conjugate and regional folds seem to agree with the structural requirements of the conjugate folding model of Tobisch and Fiske (1976). The analysis of conjugate folds shows that maximum compression directions for conjugate folding nearly parallel the regional foliation, as shown in figure 12*E* and *F*.

If all the northeast- and northwest-trending F_3 folds in the report area are part of a conjugate fold pair, then one less folding event is required to explain the fold structures present. This simplifies structural interpretation and eliminates the need for an almost 90° rotation of the force field after regional F_2 deformation. Further work is necessary to determine whether conjugate folding extends beyond the report area.

With the inclusion of the conjugate folds, the following fold phases occur in the report area:

F_1—Rootless recumbent to reclined isoclinal folds that trend northeast. F_1 folds lie in the regional foliation and may be coplanar with F_2 folds.

F_2—Steep to recumbent isoclinal folds that form major folds. F_2 folds deformed S_1 regional foliation, probably occurred after peak metamorphism, and rarely have well-developed axial plane foliations (S_2).

F_3—Upright to slightly inclined conjugate fold sets that trend northeast and northwest. F_3 fold sets have planar crenulation cleavage in pelitic units and probably are late metamorphic.

F_4—Post-F_3 folding about east-west and north-northeast axes, as suggested by statistical fold analyses. Field studies, however, have not identified axial planar cleavages associated with these later folds.

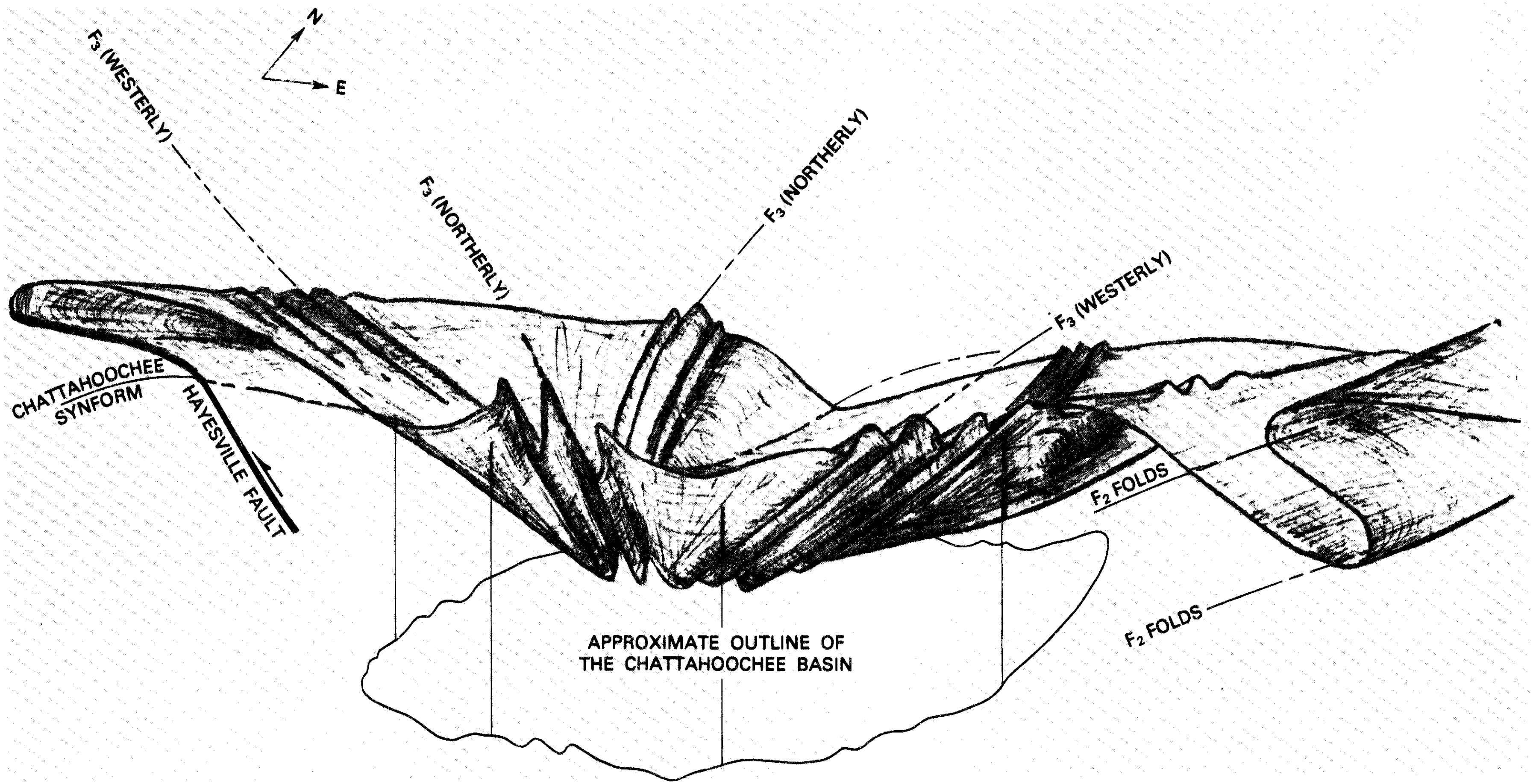


Figure 15. A deformed S_1 surface in part of the Hayesville thrust sheet between the Hayesville fault and the Helen terrane. The generalized form of the F_2 and F_3 folds is indicated.

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