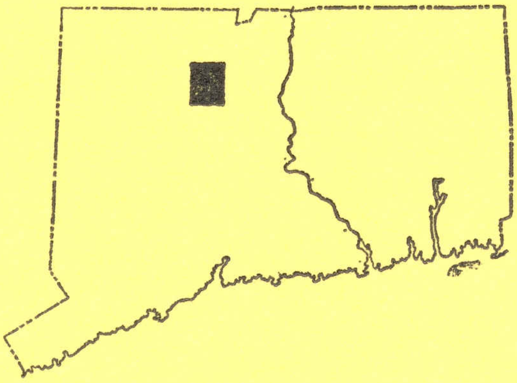
The Bedrock Geology of the Collinsville Quadrangle

WITH MAP

Open Plate 1
Open Plate 2
Open Plate 3

BY ROLFE S. STANLEY



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

A DIVISION OF THE DEPARTMENT OF AGRICULTURE
AND NATURAL RESOURCES

1964

QUADRANGLE REPORT NO. 16

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The Bedrock Geology of the Collinsville Quadrangle

by

Rolfe S. Stanley

ABSTRACT

Mapping of twelve stratigraphic units outlines two en echelon gneiss domes separated by an isoclinal synform and flanked on the west by a series of isoclinal folds that trend northeastward and culminate over a southeastward-plunging cross axis. A small reverse fault near the western margin of these folds cuts out approximately 1,000 ft of section and may mark the eastern edge of the Berkshire Highlands. Rocks of Triassic age are down faulted against the metamorphic rocks along the eastern margin of the quadrangle and on a separate fault along the eastern side of Cherry Brook Valley.

A maximum thickness of 12,000 ft of metamorphic rock is subdivided into two groups comprising six formations or twelve members. The lower group, restricted to the Collinsville and Bristol domes, is divided into the Taine Mountain Formation and the Collinsville Formation. The schist and gneiss of the Taine Mountain Formation are further subdivided into the Wildcat Member, the Scranton Mountain Member, and the Whigville Member. In the Collinsville Formation the Bristol Member consists primarily of plagioclase gneiss and amphibolite that grades upward into the schist of the Sweetheart Mountain Member, rich in biotite and plagioclase. West of the domes the Hartland Formation is divided into four formations and is, therefore, raised to group rank. From oldest to youngest they are: The Straits Schist, Rattlesnake Hill Formation, Satan's Kingdom Formation, and the Slashers Ledges Formation. The Rattlesnake Hill Formation is divided into two informal members — the lower contains nonrusty-weathering schist, amphibolite, and calc-silicate gneiss, and the upper contains rusty-weathering schist interlayered with thin beds of mica quartzite. The Satan's Kingdom Formation is formally subdivided into the Ratlum Mountain Member, which contains a mixed group of rocks, and the Breezy Hill Member, primarily a staurolite-garnet schist. The Slashers Ledges Formation is informally divided into the kyanite schist and the rusty schist members.

The Hartland Group is correlated tentatively with the Cambrian and Ordovician rocks of eastern Vermont, although it may be equivalent only to the Cambrian rocks (up to the basal part of the Ottauquechee Formation). In both hypotheses the lower group is correlated with the Mount Holly Complex (Precambrian) or Cavendish Formation (Cambrian?) of eastern Vermont.

The stratigraphic sequence in the domes is based on structural position, with the lowest, and presumably the oldest, rocks forming the core of the Bristol dome. In the northeastward-trending folds, the sequence — although determined according to structural position — is inverted, with the oldest rocks in the center of the synforms and the youngest rocks in the cores of the antiforms. Top sense, determined from graded beds found at one locality only, is consistent with this interpretation. Mineral assemblages, including kyanite, staurolite, garnet, hornblende, cummingtonite, anthophyllite, diopside, epidote, and plagioclase (more calcic than An 20), place these rocks in the middle of the amphibolite facies. The metamorphic subfacies is possibly higher in the domes than in the major folds to the west.

Spatial analysis of structural elements and the style of noncrenulate folds show fundamentally different patterns in the domes and the northeastward-trending folds. In the domes π poles to foliation girdles, noncrenulate fold axes, mullions, and rods are parallel ($\pm 10°$) to mineral lineation in any given locality, but together form a girdle which is better approximated by a small circle than by a great circle in spherical projection. In the northeastward-trending folds most π poles to foliation girdles, noncrenulate fold axes, and mullions plunge to the northeast or southwest at an angle to mineral lineation which plunges to the northwest. The axes of the major folds range from 20° to 90° degrees to the statistical center of mineral lineation. Furthermore, the axes of these folds and this center are orientated on the same great circle. Small-scale crenulate folds deform the axial-surface foliation of the major folds and, in places, deform mineral lineation. These structures are found in schist throughout the quadrangle, but are more fully developed in structural depressions than in culminations and domes.

The northeastward-trending folds presumably evolved during the Acadian Orogeny when the domes and the Berkshire Highlands rose, causing the overlying rocks of the Hartland Group to cascade into the intervening area, producing a complex synclinorium resembling an inverted mushroom. Alternatively, the northeastward-trending folds may represent part of a nappe configuration that was deformed by the domes and the Berkshire Highlands. Recrystallization outlasted deformation and presumably ceased 280 ± 30 million years B. P.

INTRODUCTION

Location and accessibility

The Collinsville quadrangle is located on the border of Litchfield and Hartford Counties, 12 mi. west of Hartford, Connecticut (fig. 1). It

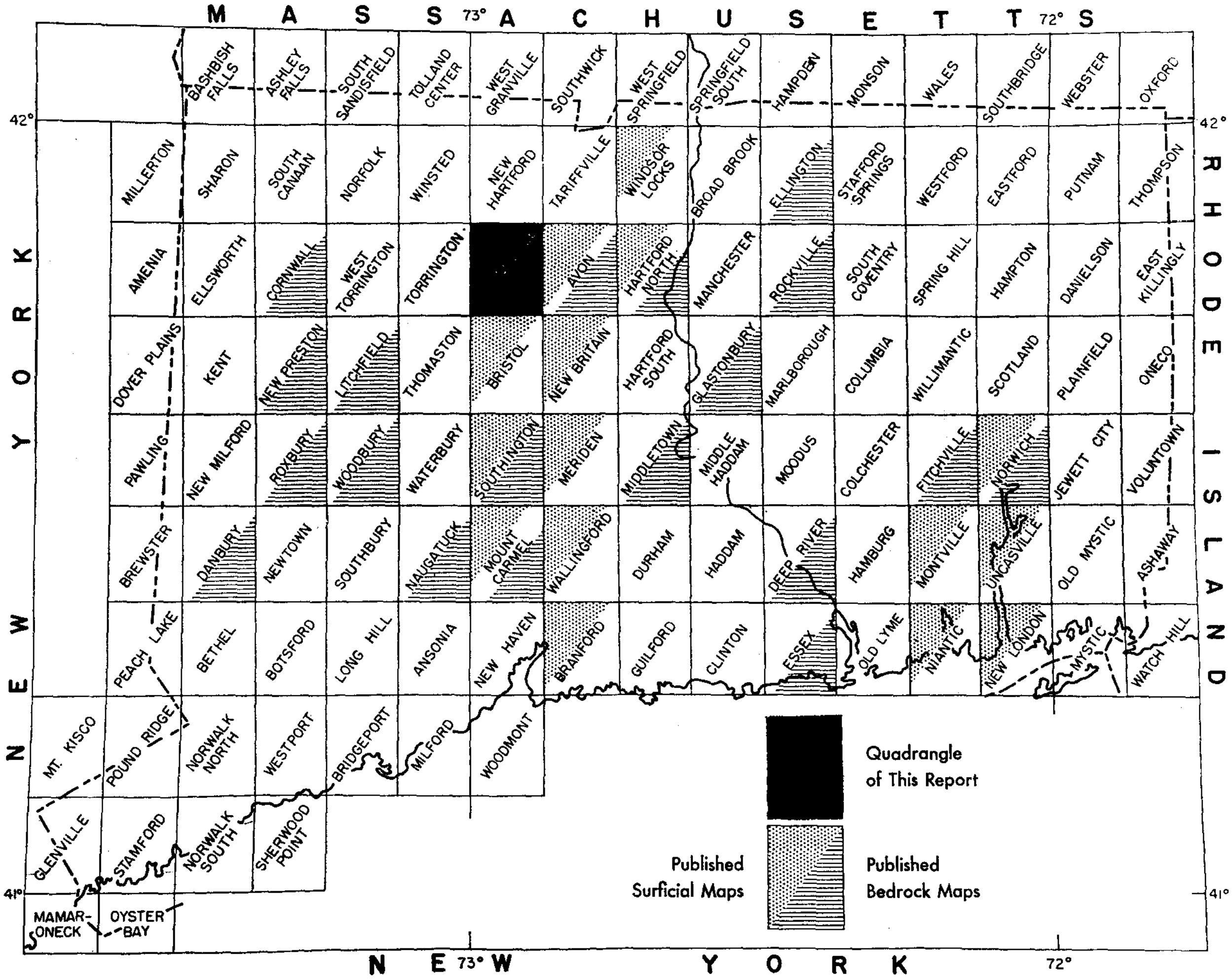

Fig. 1. Index map of Connecticut showing the location of the Collinsville quadrangle, and of other published quadrangle maps. See Appendix for list of published maps.

covers approximately 55 sq. mi. and is bounded by latitudes 41°45′ N and 41°52′30″ N and longitudes 73°00′W and 72°52′30″ W. Principal population centers in the quadrangle are Canton, Collinsville, Unionville, Burlington, Nepaug, and Pine Meadow.

The quadrangle is readily accessible by such routes as U. S. 44 and State routes 4, 177, and 116. A network of minor paved and dirt roads provides convenient access to most parts of the quadrangle. The Tunxis Trail and other trails are invaluable for access to the densely wooded hills and mountains.

Topography and drainage

The map area is located mainly in the crystalline uplands of western Connecticut, but includes a narrow strip of the Connecticut Valley lowlands to the east. Within the quadrangle the irregular terrain ranges from a minimum altitude of 200 ft near Unionville to a maximum of 1,150 ft on top of Johnnycake Mountain. Although maximum relief near Satan's Kingdom is 750 ft, the common relief is around 200 ft. Tops of mountains underlain by similar rock types form a surface that slopes gently toward the Farmington and Nepaug Rivers.

The topographic features of this area are the result of differential erosion modified by glacial deposition. High areas such as Mount Horr, Taine Mountain, Rattlesnake Hill, Breezy Hill, Jones Mountain, Bee Mountain, and Johnnycake Mountain are underlain by quartz-rich rocks and amphibolite, whereas low areas such as those near Canton and east of Burlington are underlain by plagioclase-rich rocks.

The trend of major hills and valleys closely reflects major structures of the quadrangle. In the eastern part of the quadrangle, the hills that surround the basins between Canton and Collinsville and east of Burlington outline the Collinsville and Bristol domes. West of the Nepaug Reservoir and Cherry Brook, all hills and valleys other than the valleys of the Farmington and Nepaug Rivers trend northeastward and reflect the major northeastward-trending folds.

The Farmington River, the principal drainage of the area, flows southeastward across the quadrangle and eventually joins the Connecticut River east of Tariffville. All other streams, such as the Nepaug River, Burlington Brook, and Cherry Brook, drain into the Farmington River and flow either along valleys paralleling the strike of erodible bedrock or along joints oriented at a steep angle to foliation. The course of the Farmington River is adjusted to the major structures of the area. West of Cherry Brook it flows across strike on the northern side of a major culmination in the northeastward-trending folds and presumably follows abundant joints such as those found on hills on either side of the river. East of Cherry Brook the Farmington parallels the margin of the Collinsville dome from Collinsville to Unionville.

Glacial deposits are present throughout the quadrangle. Till commonly covers parts of hills and is particularly abundant on northern slopes. Examples of stratified glacial deposits are found east of Burlington, northwest of Nepaug Reservoir, and west of Schoolhouse Hill. Perennial swamps are found along most brooks.

Previous and present work

Percival (1842) divided the rocks of the area into four map units; one of them, the Canton granitic basin, now occupies most of the Collinsville dome. Since 1842 little work has been done on the bedrock geology of the Collinsville quadrangle. Rice and Gregory (1906) published a report and a map on the geology of Connecticut in which the rocks of the quadrangle were divided into three units: the Collinsville Granite Gneiss, the Hartland Formation, and the Becket Gneiss. Gregory suggested an igneous origin for the Collinsville Granite Gneiss and the amphibolites of the Hartland Formation. In addition, he described four soapstone localities, one of which is located south of Slashers Ledges and the others in nearby quadrangles. The soapstone is important in several hypotheses of correlation discussed in this report. Agar (1929) published a detailed report on the Becket Gneiss of northwestern Connecticut, in which he also described the Hartland Formation along the southern and eastern borders of the Berkshire Highlands.

Wheeler (1937) described the contact between the sedimentary rocks of Triassic age and the crystalline rocks along the eastern margin of the Western Highlands. In the Collinsville quadrangle this contact was considered, in part, a fault, and in part, an unconformity. Platt (1957) discovered sedimentary rocks of Triassic age along Cherry Brook on the border of the Collinsville and New Hartford quadrangles; he suggested that this small outlier had been downdropped along a fault east of Cherry Brook.

In 1955 I spent six days mapping one contact around the Collinsville dome. This contact is shown on the Preliminary Geological Map of Connecticut (1956). Field work was resumed in April 1959 and carried on for about ten months during the period 1959-1961. All areas of abundant outcrop were mapped in detail in order to determine a stratigraphic sequence and to reveal any structures present. The stratigraphy and structure defined in these areas were then extended into areas of poor outcrop. About 85 percent of the outcrop in the quadrangle was examined.

Acknowledgments

Financial support for this study was generously provided by the Connecticut Geological and Natural History Survey. I wish to acknowledge the help and advice given by the Director of the Survey, Joe Webb Peoples. John Lucke, who was Director until 1960, greatly facilitated the initiation of field work in 1959. Since 1962 a National Science Foundation Postdoctoral Fellowship has supported field work to the north in southern Massachusetts and has enabled further study of my earlier work in Connecticut. The study of this particular quadrangle, Collinsville, was suggested by John Rodgers of Yale University who, along with Matt Walton, continually encouraged and guided my doctorate dissertation on the metamorphic stratigraphy and structural geometry in the quadrangle.

Discussions and field conferences with C. E. Fritts, Howard E. Simpson, Robert Schnable, Alan Randall, and other members of the United States Geological Survey, generated a friendly spirit of cooperation that has

helped to solve our mutual problems and advanced the work in western Connecticut. Many of the ideas and techniques in this study have developed from seminars and informal discussion with my associates at Yale University. Among these, special thanks are extended to Edward Hansen, George Myer, William Scott, Kenneth Perry, and Charles Shaw. Richard Armstrong kindly determined a K/Ar age from a schist in the center of the quadrangle. Ernst Bolter generously analyzed several samples. Mary Ann Doolittle drafted many of the figures. John Rodgers, Edward Hansen, Philip Orville, and Howard E. Simpson critically read preliminary drafts of this report. Their comments have added immeasurable value and clarity to the manuscript. To all these people I extend my deepest appreciation.

Regional setting

The crystalline uplands of western Connecticut consist of three northeastward-trending belts of metamorphic rocks – a western belt of high grade gneiss and schist in and between the Hudson, Housatonic, and Berkshire Highlands; a central belt of medium-grade rocks considered together as the Hartland Formation; and an eastern belt of low to medium-grade rock west of New Haven (fig. 2). A chain of en echelon gneiss domes forms the eastern margin of the central belt. Sedimentary and igneous rocks of Triassic age, which underlie the Connecticut River valley of Connecticut and Massachusetts, rest either unconformably or in fault contact with the rocks of the eastern and central belt. The contact is marked by the rather abrupt change in topography that forms a lineament trending north by east, cutting across the central and eastern belts in the crystalline rocks.

The central and western belts of metamorphic rock can be traced northward into eastern Vermont where detailed work during the last twenty years has given stratigraphic and structural coherence to an area of complex geologic history. Moreover, the sequence deciphered in this area can be traced northward to southern Quebec and thence to the fossiliferous rocks of Cambrian and Ordovician age in the Champlain Valley (Osberg, 1956; Cady, 1960).

Although a very generalized correlation between Connecticut and Vermont is possible, a detailed correlation can be made only after the stratigraphy and structure have been deciphered in western Connecticut and western Massachusetts. Current mapping by the United States Geological Survey and the Connecticut Geological and Natural History Survey is hurdling this barrier.

The Collinsville quadrangle is critically located across the narrowest part of the Hartland Formation where it is pinched between the Berkshire Highlands to the west and the Collinsville and Bristol domes to the east. This area was selected specifically in order to study the tectonic history of a typical New England gneiss dome environment. However, in order to delineate structures larger than outcrop size, a detailed understanding of the stratigraphy was first required.

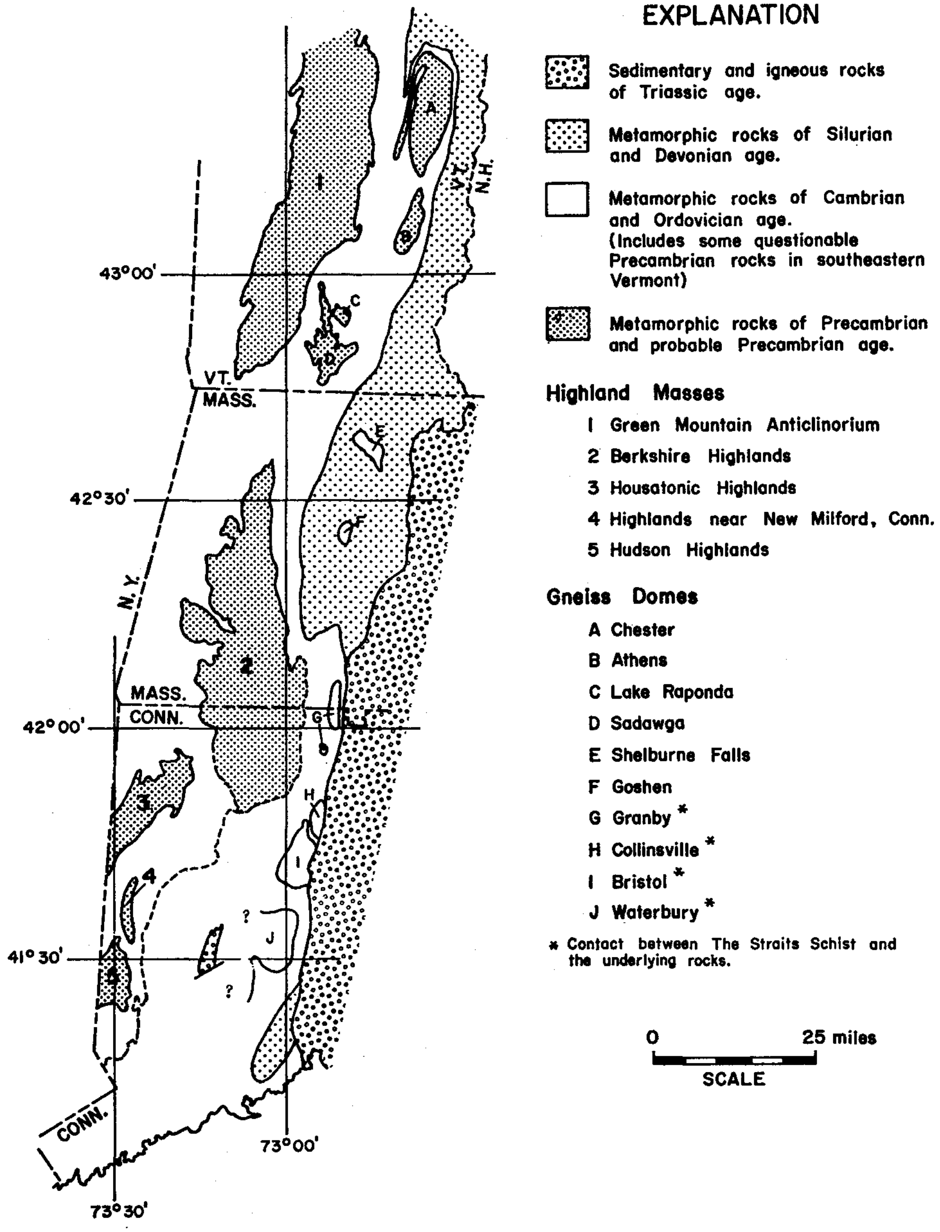

Fig. 2. Generalized geologic map of southeastern Vermont, western Massachusetts, and western Connecticut

METAMORPHIC STRATIGRAPHY

Introduction

It has long been recognized that rocks in a sedimentary terrain can be divided into distinct units, each characterized by specific features which enable a geologist to identify them from place to place. The succession of rock units established for such an area constitutes the stratigraphic section and is based on such criteria as the age of fossils in the rocks, sedimentary features with top sense (such as cross-bedding and graded bedding), or the position that a unit may have in a structure such as an anticline in an area of simple folding.

In a metamorphic terrain the same principles of subdivision apply. However, recognizing the rock units in an area of discontinuous outcrop is commonly a problem because of structural complexities, variation in metamorphic intensity, and possible stratigraphic facies changes which are known to be present in unmetamorphosed areas along strike. Because fossils and many sedimentary criteria for determining original tops are largely destroyed or questionable, the stratigraphic succession for a specific metamorphic area must be based on structural position. Such a succession tells us only that unit *A,* found in the center of an antiform, is below unit *C,* in the trough of the adjacent synform. The succession tells us nothing about relative age because the antiform may actually be a syncline that was turned upside down during deformation. The age and chronological sequence of the units can be determined best by tracing them to unmetamorphosed, fossiliferous rocks, as was done between eastern Vermont and Quebec (Osberg, 1956; Cady, 1960).

The rocks in the Collinsville quadrangle have been subdivided into as many units as were practical to map on the scale of 1:24,000. For each of the domes and major folds the sequence of rock units was established on the basis of structural position. For example, in the Bristol dome the lowest unit (not necessarily the oldest) is found in the core of the dome and the highest unit is found outside the dome. In the major folds west of the domes, the lowest unit is found along the crest of an antiform and the highest unit in the trough of the adjacent synform. Although fossils were not found that could establish the relative age among the rock units, a stratigraphic sequence is proposed for the quadrangle on the postulate that the oldest rocks form the core of the Bristol dome. This postulate is known to be correct for the domes of eastern Vermont which are on line with the domes of western Connecticut. In the major folds west of the domes, the stratigraphic sequence and rock types are quite different from the sequence and rock types in the Collinsville and Bristol domes. In the major folds, however, the sequence is thought to be upside down and to overlie the domal sequence. Evidence supporting this hypothesis will be discussed in later sections of this report.

The stratigraphic section in the quadrangle is composed primarily of schist with subordinate amounts of quartz gneiss, plagioclase gneiss, amphibolite, quartzite, calc-silicate gneiss, and garnet-quartz gneiss and granulite. The many variations in physical appearance and mineral composition of the schist provide ample criteria for stratigraphic subdivision.

Geographically, the quadrangle can be divided into three broad areas on the basis of rock type. As shown on the geologic map (pl. 1, in pocket), gneiss rich in plagioclase and quartz interbedded with amphibolite and hornblende gneiss underlie most of the quadrangle east of the north-south portion of Farmington River, whereas gneiss rich in quartz and subordinate schist rich in mica underlie the quadrangle south of Nepaug Reservoir and west of Farmington River. Schist interbedded with minor amounts of quartzite, plagioclase gneiss, calc-silicate gneiss, and amphibolite underlie most of the quadrangle northwest of a line connecting Nepaug Reservoir with Canton Center. This schist differs from place to place in relative proportions of essential minerals and commonly contains large porphyroblasts of staurolite, garnet, kyanite, and plagioclase.

Major subdivisions

Twelve mappable units are here defined for the Collinsville quadrangle. These units are grouped into six formations; two crop out in the domes and four are subdivisions of the old Hartland Formation, shown on the Preliminary Geological Map of Connecticut (Rodgers and others, 1956). All of these formations are formally defined in this report except The Straits Schist which was originally defined as a member of the Hartland Formation (Rodgers and others, 1959). Recent work by Fritts (1962) has raised this unit to formation rank.

These six formations are placed into two groups – the lower group, which includes the Taine Mountain Formation and the Collinsville Formation, and the Hartland Group, which includes The Straits Schist, the Rattlesnake Hill Formation, the Satan's Kingdom Formation, and the Slashers Ledges Formation. The contact between these groups is placed below the graphitic two-mica schist recognized as The Straits Schist and above the feldspathic biotite-rich schist of the Sweetheart Mountain Member of the Collinsville Formation. This contact has been mapped from Long Hill (north of Bridgeport) to just south of the Little River (about 6 mi. west of Westfield) in southern Massachusetts. In the Collinsville and the southern part of the Bristol quadrangles, it corresponds fairly closely to the contact drawn by Percival (1842) and by Rice and Gregory (1906) between the Collinsville and Bristol Granite Gneiss and the Hartland Formation. Consequently, with a slight adjustment of this old line and its extension around the northern parts of the Bristol dome into the Collinsville quadrangle, a mappable contact with historical precedent separates conveniently two major rock units in the eastern part of western Connecticut. Because members of the Taine Mountain Formation, previously mapped as Hartland, clearly underlie rocks mapped as the Bristol and Collinsville Granite Gneiss by Rice and Gregory, confusion will be avoided if the old Hartland Formation is restricted to rocks overlying the Collinsville Formation of this report. Although the Hartland Group contains only four formations in the Collinsville quadrangle, future work in other areas may discover formations overlying the Slashers Ledges Formation. Consequently the upper contact of this group is not defined.

Field methods

Map units in the Collinsville quadrangle are based on differences in rock type and in the weathered appearance of the rocks. Field methods used in this study are familiar to any field geologist, particularly to one who has mapped sedimentary rocks. Early in the project it was found easier to map at least three units simultaneously than to follow a single contact throughout a given area. This procedure facilitated the recognition of facies changes in an early stage of mapping and thus reduced the need to revisit complicated areas. Spatial analysis of structural elements plotted on an equal-area projection at the end of each field day helped portray the geometry of major structures in three dimensions and, coupled with stratigraphic mapping, formed a guide for the next day's work.

Basis for stratigraphic sequence

Before discussing the stratigraphy in the Collinsville quadrangle it is necessary to justify the stratigraphic sequence used in this report. This is always a basic problem in areas of unfossiliferous rocks, and becomes even more difficult in an area of metamorphic rocks where the structure is complicated by inverted folds and superposed structures. No *major* superposed folds are recognized in the quadrangle, but the major folds west of the domes are believed to be inverted. In the domes, however, the sequence is thought to be right side up. Although the stratigraphic sequences in both of these areas are based on structural position, the solution to the fundamental problem of which end of the two sequences represents the original stratigraphic "tops" must be found in the broad geologic relations within and outside the quadrangle.

In the gneiss domes of eastern Vermont, rocks of Precambrian age are mantled by rocks of Cambrian to Devonian age (see Geologic Map of Vermont, Doll and others, 1961). This age relationship is based on rare fossils found in eastern Vermont and adjacent Quebec and on correlation with fossiliferous rocks in the Champlain Valley. Because the domes of western Connecticut and western Massachusetts are on line with the domes in Vermont, the oldest rocks are assumed to form the core of the Bristol dome. Therefore, *east* of Cherry Brook and the Nepaug Reservoir the oldest unit is the Taine Mountain Formation and the youngest is the Rattlesnake Hill Formation.

West of Cherry Brook and the Nepaug Reservoir detailed stratigraphic and structural mapping revealed six major northeastward-trending folds which culminate across a southeastward-plunging cross axis in the area of the Nepaug State Forest. Abundant outcrop in the areas around Satan's Kingdom and north of the Farmington River provided excellent control for subdividing the old Hartland Formation. Although glacial deposits cover much of the center of the quadrangle, abundant outcrop on Bee Mountain, Garrett Mountain, and along the Nepaug River provided ample control for extending along strike the major folds mapped north of the Nepaug State Forest.

Based on structural position, therefore, a succession of mappable units was defined in which the upper member of the Rattlesnake Hill Formation formed the top of the sequence and the Slashers Ledges Formation the base. Here no regional relationship was available to suggest whether the sequence was right side up or inverted. Fortunately, the stratigraphic relationship between the rock sequence of the northeastward-trending folds and that of the Collinsville and Bristol domes provides a likely answer to this problem. The critical link in establishing this relationship is the upper member of the Rattlesnake Hill Formation. This unit crops out in belts on either side of Cherry Brook Valley and south and east of Phelps Brook (see pl. 1). Although outcrops of the member are not strictly continuous between these belts, the striking similarity of rock type, together with the map pattern and the structure on Garrett Mountain, suggests that the rocks in these two belts are equivalent. The map units that structurally underlie the upper member of the Rattlesnake Hill Formation in the Ratlum Mountain-Garrett Mountain fold system and those that underlie it in the domes are quite different. *East* of Cherry Brook Valley and the Nepaug Reservoir the upper member overlies a thick sequence of two-mica schists (including the unique The Straits Schist) conformable to rocks of the Collinsville and Bristol domes. On the other hand, *west* of Cherry Brook Valley and the Nepaug Reservoir this member overlies a thick sequence of mica-plagioclase-quartz schist and gneiss (Satan's Kingdom and Slashers Ledges Formations) which commonly contain large porphyroblasts of staurolite, garnet, kyanite, and plagioclase. In this sequence there is no unit identical to either The Straits Schist or the Collinsville Formation, both of whom are easily recognized. Thus, the upper member of the Rattlesnake Hill Formation is found to overlie two totally different stratigraphic sequences.

At least three solutions to this stratigraphic problem are possible. In the first two hypotheses the sequence west of the domes is right side up; in the third it is inverted.

1) According to the first hypothesis the rocks west of Cherry Brook in the major folds could have been down faulted against the Collinsville and Bristol domes, presumably along a northwestward-dipping surface. This is quite unlikely, however, because the upper member of the Rattlesnake Hill Formation not only forms the top of the sequence *east* of Cherry Brook, but also occupies the trough of synforms in the Ratlum Mountain-Garrett Mountain fold system to the west and, therefore, "caps" the sequence *west* of Cherry Brook.

2) According to a second hypothesis, the rock sequence in the major folds is right side up. The units below the upper member of the Rattlesnake Hill Formation are, therefore, facies equivalents of those underlying this member in the domes.

Several arguments make this arrangement unlikely: a) The stratigraphic succession below the upper member of the Rattlesnake Hill Formation in the domes is totally different from that in the major folds to the west, and no individual member can be recognized in these two successions. If the relationship were facies change, then one would expect that at least some units other than the upper member should be present in both successions. b) Structurally, the facies hypothesis requires a syncline between the Cherry Brook antiform and the domes. Geologic mapping does not reveal a syncline here; analysis of planar and linear elements on the east side of Cherry Brook Valley and Garrett Mountain shows only fold axes plunging northwestward. The major fold axes calculated from foliation measurements around their hinges plunge either northeastward or southwestward, not northwestward.

3) According to the third hypothesis, all strata in the Ratlum Mountain-Garrett Mountain fold system are overturned so that stratigraphically older units crop out in the troughs of synforms, whereas stratigraphically younger units crop out in the cores of antiforms. The resulting structural configuration and stratigraphic sequence of this fold system are shown in the geologic sections A-A‴ and B-B‴ (pl. 2).

The relationship between bedding foliation and axial-surface foliation, the orientation of major-fold axes, and a sedimentary structure with "top sense" such as graded bedding, form a basis for either accepting or rejecting the third hypothesis. To illustrate how sedimentary features and

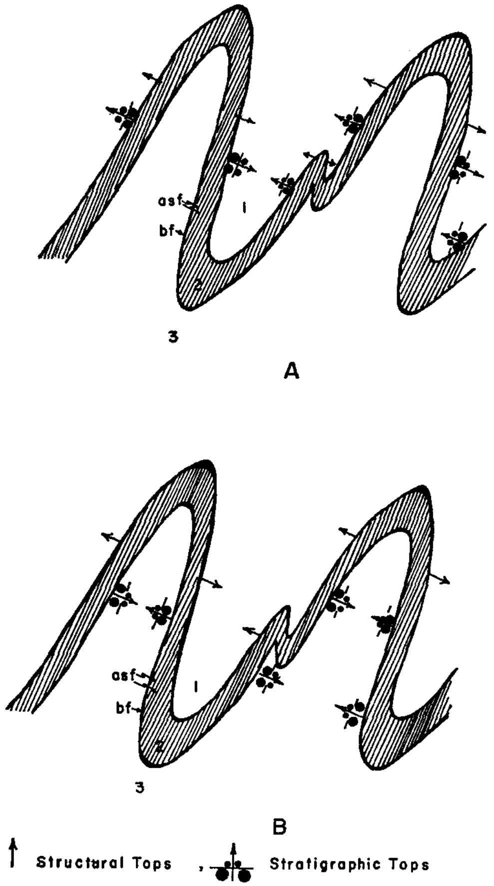

Fig. 3. Profile diagram of a hypothetical series of folds showing the relation between bedding foliation (bf), axial-surface foliation (asf), and graded bedding.

structure may be of help in solving the fundamental problem of which end of the stratigraphic sequence was originally the top, let us take a hypothetical series of folds mappable on the scale of 1:24,000 (fig. 3). We will assume that the axes of the folds do not parallel the dip of the axial-surface foliation, because in this position the distinction between antiform and synform becomes arbitrary and the problem of whether the overall stratigraphic sequence is inverted or right side up becomes meaningless. If the sedimentary structure and the relation between bedding foliation and axial-surface foliation *both* indicate either a normal position or an overturned position (depending upon the limb of the fold), then the overall stratigraphic sequence is right side up with *1* the youngest bed and 3 the oldest (fig. 3A). If, however, these criteria are consistently opposite on each limb of the fold, no matter what the size, then the overall sequence is upside down with *3* the youngest bed and *1* the oldest. (fig. 3B). Separately, the sedimentary and structural criteria tell only part of the story, and neither alone solves the fundamental problem of stratigraphic "tops" for an area of discontinuous outcrop deformed into a series of folds. The relation among bedding foliation, axial-surface foliation, and the orientation of the major fold axis will indicate the limb of the fold on which the outcrop is located, but not the original stratigraphic "tops," although a definite sequence can be established (*3, 2, 1,* in both A and B of fig. 3). On the other hand, if only graded bedding is present, then the "top" direction at that outcrop is known, but the location on the major fold is not known. If the fold is fully exposed the problem of location is solved, but if the fold is larger than the area of continuous outcrop, then one can locate the limb by the relation between bedding foliation and axial-surface foliation, provided that the foliation cutting the bedding is essentially parallel to the axial surface of the major fold. Together these criteria are valuable in solving the problem of whether or not the stratigraphic sequence is right side up.

In the Collinsville quadrangle one outcrop along the Nepaug River west of the Nepaug Dam (*G* on the geologic map, pl. 1) contains features that are interpreted as graded bedding. In other places in the quadrangle, features were seen that resemble relic cross-bedding, but they are so unclear that I cannot be sure how much of the structure is truly cross-bedding. However, in the outcrop along the Nepaug River, a consistent direction of stratigraphic "tops" has been confirmed independently by several geologists. Here a schist rich in large staurolite and plagioclase porphyroblasts alternates with a medium-grained, mica-quartz gneiss in beds several feet thick. The dip of both the bedding foliation and a second foliation is to the northwest. In each bed of gneiss the *lower* contact with the schist is gradational whereas the *upper* contact is sharp. This pattern is repeated four times in the outcrop and is diagrammed in figure 4. The quartz gneiss presumably represents a shaly sandstone that originally graded upward into a shale that now contains large porphyroblasts of staurolite and plagioclase. Note that the present distribution of grain size is just opposite to that of the original sedimentary grain size, yet the direction of stratigraphic "tops" is revealed by the physical contacts and the compositional difference. Therefore, the stratigraphic sequence is upside down in this outcrop. But the position of the outcrop on the major folds must be determined before a conclusion can be drawn as to whether the overall sequence in the major folds is right side up or upside down. If the outcrop is located on the overturned limb, then the overall sequence would be right side up (fig. 3A). If the outcrop is located on the normal limb, the opposite would be true (fig. 3B).

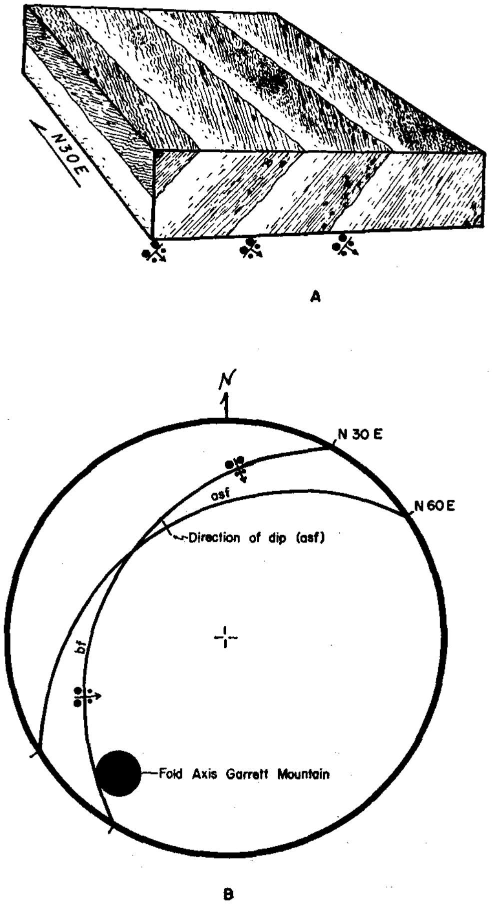

Fig. 4. Graded bedding showing two foliations, in an outcrop along Nepaug River. Beds shown blank in *A* represent gneiss; beds of schist are shown by closely spaced lines representing axial-surface foliation; black spots represent porphyroblasts. The orientation of bedding foliation (bf) and axial-surface foliation (asf) is shown in the equal-area projection (lower hemisphere). The dip direction of axial-surface foliation is indicated by a tick mark. The fold axis from Garrett Mountain was calculated from forty foliation measurements.

As shown in figure 4 and plate 1, the second foliation strikes to the east of the bedding foliation and is presumably axial surface to the major folds. The foliations shown here are based on five measurements of each type of foliation. The five poles to the bedding foliation, measured along the contact between gneiss and schist, form a point maximum; the corresponding plane is shown on figure 4B. The five poles to the axial-surface foliation, measured only in schist, form a 30° spread along a great circle. A small maximum in the center of the spread corresponds to the plane shown in figure 4B. All the axial-surface foliations strike to the east (N 35° E to N 74° E) of the bedding foliation and they intersect the bedding foliation very near the point shown in the spherical projection. If the foliation in the schist is indeed axial surface to the major folds, then the fold axis defined by the intersection of the two planes in figure 4b is southwest of the dip direction of the axial-surface foliation. Therefore the outcrop is on the normal limb of an antiform. This conclusion agrees with information on Garrett Mountain where the attitude of the major fold axis, computed from poles to bedding foliation, plunges gently to the southwest. Furthermore, as shown by the line of dots on the geologic map (pl. 1) the outcrop on the Nepaug River is on strike with the zone of garnet amphibolite that crops out on the normal or western limb of the antiform on Ratlum Mountain. Here a bedding foliation is cut by one other foliation, a situation similar to that found along the Nepaug River. This second foliation is indeed axial surface to minor folds and, therefore, to the major fold. Thus the outcrop shown in figure 4 is located on the normal limb of a major antiform and the stratigraphic "tops" point toward the core of the fold. These data indicate that the overall stratigraphic sequence in the Ratlum Mountain-Garrett Mountain fold system is inverted as in figure 3B. This conclusion is consistent with the third hypothesis. Admittedly, several outcrops like the one along Nepaug River would verify this hypothesis far better than one, but the very fact that this single example agrees with the third hypothesis does make it more probable than the other two. Therefore, the hypothesis for the major folds west of the domes, together with the assumption that the oldest rocks crop out in the core of the Bristol dome, constitutes the basis for the stratigraphic column in the Collinsville quadrangle.

General procedure in description of formations

On the following pages, name, type locality, distribution, topographic expression, rock type, and petrographic features, including modal analyses of rocks typical of each map unit, are discussed for each formation and member. Although approximately 210 thin sections have been studied, the map units are based solely on megascopic features such as color, rock type, and mineral composition. Stratigraphic nomenclature and procedure, as described in the 1961 edition of the "Code of Stratigraphic Nomenclature," is followed as closely as possible in this report. Formations are distinguished solely on the basis of rock type and mappability on the scale of 1:24,000. Members are defined in five of the six formations and are distinguished because they represent a significant mappable variation of the formation to which they belong. In several members distinctive rock types, such as amphibolite, calc-silicate gneiss, garnet-quartz granulite, and quartzite, serve as useful marker horizons and are identified by separate symbols on the geologic map. Five of the six formations are new and, therefore, are formally defined. For each of these, type localities are designated and located on the geologic map. Type localities or reference localities for the eleven members are either located in the type locality for the particular formation or in other areas where their salient features are better displayed. Seven of the eleven members are given formal names, of which two — the Bristol and Whigville Members — are named for geographic localities outside the quadrangle. These will be formally defined by Simpson in a forthcoming quadrangle report of the U. S. Geological Survey. Because all but the lower two formations are part of the old Hartland Formation, this unit is raised to group rank. The lower two formations are combined informally in the lower group.

The lithologic descriptions consist only of textural designations such as schist, gneiss, or granulite, preceded by mineralogical modifiers arranged in order of increasing abundance—the name of the most abundant mineral placed next to the textural term (for instance, biotite-plagioclase-muscovite-quartz schist). The terminology of Ingram (1954) is used to describe the thickness of gneiss and quartzite in outcrops where they are interlayered with schist. All textural and petrographic terminology in this report conforms as closely as possible to definitions by Williams, Turner, and Gilbert (1954). Certain terms used to describe grain contacts are taken from Niggli (1954). Winchell and Winchell (1956) and Tröger (1956) were constantly used for mineral identification and nomenclature.

Modal analyses and pertinent optical and compositional data are listed on tables 2 to 14. Each mode is based on approximately 1,000 counts on a standard (4 cm by 2 cm) thin section. No analysis of error was made, but duplicate runs on an amphibolite by the same operator showed a deviation of from 1.4 to 2.0 percent, whereas duplicate runs on a schist by two operators showed a deviation of from 0.4 to 4.7 percent. In the table footnotes, after the name of each analyzed sample, optical data are listed for amphibole, plagioclase, and pyroxene. All compositions are based on optical data measured either on the universal and flat stage or in liquids of known index. The $Z \wedge C$ angles of the amphibole grains measured on the universal stage were consistently closer to the average than to the maximum of several such values measured in grains showing only one cleavage on the flat stage. For this reason, the average $Z \wedge C$ is given for those amphiboles measured on the flat stage. The twelve $Z \wedge C$ values measured on the universal stage represent all the varieties of monoclinic amphiboles identified in the quadrangle. For each of these, the characteristic colors in plane-polarized light are listed. In the hornblendic rocks, for which no color or $Z \wedge C$ is given, the hornblende is identical to that in either sample Cb21 (table 5) or SLrs3 (table 13). The color of biotite in plane-polarized light is discussed in the petrography section of the table footnotes.

The optical determination of the anorthite content in plagioclase on the flat stage is somewhat ambiguous, from An 0 to An 35. Such determinations were made by measuring the extinction angle of the fast-vibration direction in adjacent twin lamellae in grains cut perpendicular to (010). All such measurements were made on grains showing multiple lamellae presumably twinned according to the albite law. Commonly as many as ten grains were measured in a single thin section — the results are then given as an average, along with the range of recorded values (see tables 1, 2). In order to determine if the extinction is positive or negative, all three features were checked: the optic sign measured only in sections with a centered optic axis figure, the index of refraction with adjacent quartz grains by the Becke line test, and the extinction position relative to the composition plane of the twins and the (001) cleavage. Although these tests removed any ambiguity as to the extinction sign in many samples, enough doubtful measurements remained to warrant study on the universal stage. Forty measurements were made on 35 samples on the universal stage using the method described by Turner (1947). Here the anorthite content can be determined to within about ±3 percent. Of these 35 samples, only four determinations gave an anorthite value that corresponded to an extinction sign *opposite* to that determined on the flat stage. Furthermore, this study showed several very interesting results. First, many of the grains are twinned, not according to the albite law but according to the albite-ala law — a complex law in which the composition plane is (010) and the twinning axis lies in the composition plane perpendicular [100]. Other laws such as the pericline law are found in amphibolite and calc-silicate rocks. Secondly — and most important — it showed that the anorthite content correlated with rock type. Thus the plagioclase is albite or sodic oligoclase in granitic rocks, calcic oligoclase in aluminous schist and plagioclase gneiss, andesine in amphibolite, and andesine to anorthite in calc-silicate gneiss.

The anorthite composition was also determined from the index of refraction of glass fused from cleavage fragments of about thirty samples of medium- and coarse-grained granitic rocks, according to the method given by Schairer and others (1956). This method was only successful for pure samples of coarse-grained rocks.

Lower group

TAINE MOUNTAIN FORMATION

General discussion. The name Taine Mountain Formation is assigned to rocks cropping out along the Tunxis Trail on the southwestern end of Taine Mountain east of Washington Turnpike. This area is designated the type locality for the formation.

Three members are recognized in this formation — the Wildcat Member, the Scranton Mountain Member, and the Whigville Member. The Wildcat Member is best exposed south of the Tunxis Trail in the type locality for the formation, in outcrops east of Case Cemetery, and on Wildcat Mountain in the Collinsville and Bristol quadrangles. The type locality for the Scranton Mountain Member is on the western side of Scranton Mountain along the Tunxis Trail, where a more complete section crops out than in the type locality of the formation. The type locality of the Whigville Member is located near Whigville in the Bristol quadrangle and will be formally described by Simpson in the report on that quadrangle to be published by the U. S. Geological Survey. In the Collinsville quadrangle this member is exposed best along a trail south of Taine Mountain Road on Taine Mountain.

The Taine Mountain Formation crops out only in the northern part of the Bristol dome, where the lower two members are principally confined to the Collinsville quadrangle, whereas the Whigville Member is mostly restricted to the Bristol quadrangle. The formation is well exposed on the southwestern side of Taine Mountain, the eastern side of

Table 1. Explanation of abbreviations and symbols used in tables 2 to 14

Mineral abbreviations

Amph = amphibole
A = anthophyllite
Ap = apatite
Bi = biotite
Calc = calcite
Chl = chlorite
Clz = clinozoisite
C = cummingtonite
Di = diopside
Ep = epidote
G = graphite
Gt = garnet
Hbl = hornblende
Ky = kyanite
Mg = magnetite
Mi = microcline
Ms = muscovite
P = pistacite
Pl = plagioclase
Px = pyroxene
Q = quartz
R = rutile
Sph = sphene
Stau = staurolite
Tm = tourmaline
Z = zircon

Other abbreviations used in body of tables

T = trace amount (less than 0.5 percent)
f = foliate
fg = fine grained (<1 mm)
mg=medium grained (1 to 5 mm)
cg=coarse grained (5 mm to 3 cm)
vcg=very coarse grained (>3 cm)

Abbreviations and symbols used in description of samples (footnote 2, tables 2 to 13), and in the last two columns of table 14

Overlining of abbreviations and symbols indicates average values.

Plagioclase in a sample is described in terms of its anorthite (An) content; the extinction angle is given for amphiboles and pyroxenes.

$\overline{\text{An}}$ (or other mineral abbreviation) with overlining indicates that the determination which follows it is an average of several measurements made on the flat stage — for $\overline{\text{An}}$, using the extinction angle of the fast vibration direction in a section cut perpendicular to (010).

An* (or other mineral abbreviation or symbol) followed by * indicates that the measurement was made on the universal stage — for An*, according to the method given by Turner (1947).

An° indicates that the anorthite percentage was determined from the index of refraction of glasses fused from cleavage fragments of the plagioclase, according to the method given by Schairer and others (1956).

Numerals immediately following $\overline{\text{An}}$, An*, or An° indicate the percent of anorthite in the plagioclase.

Numeral(s) in parentheses indicate number of grains measured in a single thin section.

Numerals separated by a hyphen indicate range in percent of anorthite in the plagioclase.

2V = optic angle; subscript (x, z) indicates vibration direction along which measurement was made; figure following it gives value of this angle in degrees.

$Z \wedge C$ = extinction angle, determined on the flat stage unless otherwise noted; figure following it gives value of this angle in degrees.

X, Y, Z, with color indicated after each letter indicates color in plane-polarized light.

Examples

$\overline{\text{An}}$ 26 (4); 23-28 describes a plogioclase containing 26 percent anorthite, the average of four measurements on the flat stage. The range of anorthite given by these measurements is 23 to 28 percent.

An* 23 (1), $2V_x83$ describes a plagioclase containing 23 percent anorthite, as determined by one measurement on the universal stage. The optic angle, in the x-vibration direction is 83°.

$\overline{\text{Amph}}$ $\overline{Z \wedge C}$ 22 (3) describes an amphibole with average extinction angle of 22°, as determined by three measurements on the flat stage.

Wildcat Mountain, Scranton Mountain, Two Buck Ring, and the eastern side of Barnes Hill.

The Whigville Member, the Scranton Mountain Member, and the upper part of the Wildcat Member form a topographic rim surrounding a central basin. The rocks underlying this basin may contain more plagioclase than the exposed part of the Wildcat Member because many of the outcrops in other topographic lows, such as the basin west of Canton, contain rocks that are rich in plagioclase. However, the character of these lowest rocks can only be inferred because much of the basin is covered by ice-contact stratified drift of Pleistocene age. Drainage in this formation is controlled by foliation and steeply dipping joints oriented nearly perpendicular to foliation.

Wildcat Member. The Wildcat Member of the Taine Mountain Formation is a fairly homogenous unit composed of biotite-plagioclase-quartz gneiss, with subordinate biotite - plagioclase - muscovite - quartz schist, kyanite-plagioclase-biotite-quartz schist, and a few lenses of amphibolite. All the rocks are nonrusty-weathering and range in grain size from fine to medium. Biotite-rich folia in the gneiss are commonly very much thinner than the folia rich in quartz and plagioclase.

Biotite-plagioclase-quartz gneiss is by far the most common rock on Taine Mountain and Wildcat Mountain, but north of Punch Brook Road the member is more schistose.

Table 2. Modal analyses of the Wildcat Member of the Taine Mountain Formation[1]

Twc sample no.[2]	Q	Pl	Ms	Bi	Hbl	Ep	Gt	Ky	Stau	Mg	Chl	Ap
1	28.3	24.3	25.3	19.4	......	......	....	0.7	....	2.0	....	....
2	50.8	34.9	......	11.9	......	......	T	......	....	2.1	....	T
3	38.0	38.4	7.2	13.8	......	......	0.6	......	....	1.4	0.6	....
4	42.5	10.5	4.1	18.2	......	......	1.5	21.4	0.9	0.9	....	....
5	41.4	21.6	13.3	21.1	......	......	1.5	....	......	0.9	....	T
6	16.6	27.0	......	7.0	40.4	0.9^{P}	T	....	......	6.8	1.1	....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Biotite-plagioclase-muscovite-quartz schist; fg
2. Biotite-plagioclase-quartz gneiss; fg; $\overline{\mathrm{An}}$ 25(2), 22-28
3. Biotite-plagioclase-quartz gneiss; fg; An*23, $2V_x85$
4. Plagioclase-biotite-kyanite-quartz schist; mg
5. Muscovite-biotite-plagioclase-quartz gneiss; fg; $\overline{\mathrm{An}}$ 24 (3), 23-25
6. Amphibolite; fg

PETROGRAPHY OF MEMBER

TEXTURE: Foliate north of Punch Brook Road; more granular to the south. Grain contacts mosaic and ungranulated. Implicate contacts rare.

MINERAL FEATURES: *Quartz:* Uniform extinction common; mosaic and undulatory extinction rare. Fractures present. *Plagioclase* partly altered to sericite. *Biotite:* X very light olive, YZ dark olive to black. Partly altered to chlorite (optically negative). *Garnet* contains abundant quartz inclusions. *Kyanite* fine grained and free of inclusions.

The upper contact of this member is placed above the highest nonrusty-weathering biotite-plagioclase-quartz gneiss of the Wildcat Member and below the rusty-weathering schist and gneiss of the Scranton Mountain Member. The contact is apparently not gradational and can be located within a zone 10 to 20 ft thick. Good exposures of the contact are found in the type locality of the formation and on Belden Road southeast of Two Buck Ring.

Modal analyses of six rocks typical of the Wildcat Member are shown in table 2. Except in the amphibolite, the quartz-plagioclase ratios are all higher than 1.0 and range as high as 4.0. The muscovite-biotite ratios are commonly lower than 1.0 except in sample Twcl.

Scranton Mountain Member. This member is a fairly homogeneous unit composed of medium-grained garnet-plagioclase-quartz-biotite-muscovite schist, with subordinate mica-plagioclase-quartz gneiss and thin calc-silicate gneiss. Characteristically, these rocks are rusty weathering, and many outcrops of the schist contain kyanite. Commonly, muscovite and biotite are about equal in abundance, whereas quartz is more abundant than plagioclase. A few fine-grained, nonrusty-weathering garnet-muscovite-quartz-plagioclase granulites, resembling granodiorites in composition, crop out as layers parallel, or at low angles to, foliation of adjacent metasedimentary rocks.

The proportion of schist to gneiss is the only lateral variation observed in the Scranton Mountain Member. Rusty schist with only a few beds of gneiss crops out on Scranton Mountain, Two Buck Ring, the eastern side of Barnes Hill, and a hill south of Route 116, whereas beds of rusty-weathering schist and gneiss, in about equal proportions, are found along the southwestern part of Taine Mountain near Washington Turnpike.

As shown on the geologic map (pl. 1), the Scranton Mountain Member is in contact with either the overlying Whigville Member or the Bristol Member of the Collinsville Formation. This relationship can be interpreted either as an unconformity or as a conformable sequence in which the Scranton Mountain and Whigville Members are facies equivalents overlain by the Bristol Member. Although the map relation at this contact suggests an unconformity, the gradational contacts between the Bristol Member and underlying member of the Taine Mountain Formation support the conformable interpretation. Admittedly, a horizontal gradation between the Scranton Mountain and Whigville Members would be difficult to prove in metamorphic rocks, particularly in a glaciated terrain such as New England, but the presence of bedding foliation striking across the contact between these members, suggests a stratigraphic facies change. The Scranton Mountain Member is interpreted therefore as a facies equivalent of the Whigville Member.

The contact of the Scranton Mountain Member with the overlying Whigville Member is placed at the level where (ascending in the sequence) the rusty schist and gneiss compose less than 50 percent of outcrops larger than 5 ft measured across bedding foliation. The contact can be located within 50 to 75 ft; the rocks on either side of the contact zone are typical of the appropriate member.

The contact of the Scranton Mountain Member with the Bristol Member is placed below the lowest amphibolite of the Bristol Member, and is well exposed in the type locality of the Taine Mountain Formation. Furthermore, this contact is marked by a fairly abrupt change from the rusty schist with several beds of gneiss to nonrusty, light olive-gray gneiss which generally exhibits coarse, compositional layering and is interbedded with amphibolite.

Listed in table 3 are modes of the typical rocks of the Scranton Mountain Member. The quartz-plagioclase ratios are all greater than 1, whereas most muscovite-biotite ratios are near or less than 1, thus confirming the impression given by outcrops.

Table 3. Modal analyses of the Scranton Mountain Member of the Taine Mountain Formation[1]

Tsm sample no.[2]	Q	Pl	Ms	Bi	Hbl	Clz	Gt	Sph	Ky	Mg	Chl	Ap
1	25.7	8.3	30.5	25.6	......	....	6.9	....	2.7	....	....	T
2	23.1	13.7	27.4	28.6	......	....	5.1	....	1.8	....	T	T
3	37.0	29.5	5.9	25.1	......	....	2.5	....	....	....	....	....
4	49.2	28.0	......	......	14.6	T	4.6	3.1	....	T	....	T

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Garnet-biotite-quartz-muscovite schist; mg; An 24 (1)
2. Garnet-quartz-muscovite-biotite schist; mg; An*24 (1), $2V_x$ 88
3. Muscovite-biotite-plagioclase-quartz gneiss; fg; $\overline{\text{An}23}$ (4) 23-24
4. Garnet-hornblende-plagioclase-quartz gneiss; fg; An*74 (1), $2V_x$84;
   Hbl* $\overline{Z \wedge C}=13$ (3), $2V_x$ 85; X colorless, Y light olive, Z blue gray

PETROGRAPHY OF MEMBER:

TEXTURE: Foliate; quartz and feldspar elongate in the foliation. In calc-silicate gneiss, quartz and plagioclase are granoblastically interlocked; hornblende, garnet, and sphene are either poikiloblastic or are present as fine grains in clusters. Grain contacts in all rocks are ungranulated and simple; implicate contacts rare.

MINERAL FEATURES: *Quartz*: Uniform extinction common; mosaic and undulatory extinction rare. Fractures present in most thin sections. *Plagioclase*: Calcic oligoclase in aluminous rocks; bytownite with blebs of quartz in calc-silicate rocks. Moderate sericitization in all rocks. About 50 percent of grains show twinning. *Biotite*: X colorless, YZ dark red brown. Chlorite occurs either as an alteration of biotite or separately in stellate clusters. *Garnet* porphyroblastic, and contains abundant inclusions of quartz, muscovite, and biotite. *Kyanite*: Porphyroblastic and free of inclusions. In some samples sericite sheaths and crosscuts fragments of kyanite which are in optical continuity. *Magnetite* subhedral and skeletal.

Whigville Member. This member consists of medium-grained plagioclase-mica-quartz schist containing garnet and less commonly, kyanite. The schist is nonrusty weathering and is normally layered. Thin micaceous layers (less than 1 cm thick) alternate with slightly thicker layers rich in quartz and plagioclase and together they form slabby outcrops. This feature is reflected particularly well in the topography north of Whigville in the Bristol quadrangle. In overall aspect, this member looks much like the more schistose rocks in the Wildcat Member, and the two would probably be mapped as one unit if they were not separated by the rusty-weathering rocks of the Scranton Mountain Member.

The upper contact of the Whigville Member is placed below the lowest amphibolite of the Bristol Member. Commonly the mica schist of the

Whigville becomes gneissic just below the lowest amphibolite and gradually takes on aspects more characteristic of gneiss of the Bristol Member. The only outcrop of the contact between these two members is found on a trail south of the old Taine Mountain Road on the western side of Taine Mountain.

Modal analyses of two samples typical of the Whigville Member are listed in table 4. Both the quartz-plagioclase and muscovite-biotite ratios are more than 1.

Table 4. Modal analyses of the Whigville Member of the Taine Mountain Formation[1]

Tw sample no.[2]	Q	Pl	Ms	Bi	Gt	Ky	Mg	Chl	Ap
1	29.2	10.6	27.0	24.8	T	7.9	T	T	....
2	24.2	19.6	24.1	24.8	4.0	2.1	....	....	1.2

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Kyanite-plagioclase-biotite-muscovite-quartz schist; fg
2. Plagioclase-muscovite-quartz-biotite schist; fg; An 23 (2), both values the same

PETROGRAPHY OF MEMBER

TEXTURE: Foliate; thin laminae of mica (some garnet and kyanite) alternate with thicker laminae of quartz and plagioclase.

MINERAL FEATURES: *Quartz*: Uniform extinction; a few grains, however, show mosaic extinction. Fractured in most thin sections. *Plagioclase* sericitized to varying degrees in all samples. *Biotite*: X light yellow brown, YZ black to dark olive brown. *Garnet* contains abundant inclusions of quartz. *Kyanite* fine grained and partly altered to sericite in some samples.

COLLINSVILLE FORMATION

General discussion. To the Collinsville Formation, named by Rice and Gregory (1906) for the village of Collinsville in the town of Canton, are assigned the rocks cropping out on the southern face of Sweetheart Mounttain between the top of that face and the lowest water level of Nepaug Reservoir. This area is hereby designated the type locality. The outcrop here can best be seen during the fall months when the water level in the reservoir is lowest. For reference, another locality is designated on the western side of Route 4 in Collinsville, where a continuous section is exposed in a cut made in 1961 from the upper part of the Bristol Member to the lower part of The Straits Schist. Unfortunately, in this locality amphibolite and hornblende gneiss form most of the Bristol Member, which elsewhere normally consists of quartz-plagioclase gneiss interbedded with subordinate amounts of amphibolite.

The Collinsville Formation is subdivided into two members – the Bristol Member (Rice and Gregory, 1906) and the Sweetheart Mountain Member. The Bristol Member (originally entitled "Bristol Granite Gneiss" by Rice and Gregory, 1906) was made for the city of Bristol where the sequence of plagioclase gneiss, quartz gneiss, hornblende gneiss, amphibolite, and garnet-quartz gneiss is exposed. Although no type locality has yet been designated for this unit, in the Bristol quadrangle excellent exposures are found adjacent to the Pequabuck River in Bristol. This unit can be traced to the type locality for the Collinsville Formation in the Collinsville quadrangle. The Sweetheart Mountain Member is named for Sweetheart Mountain where it crops out in the type locality of the Collinsville Formation.

The names Collinsville and Bristol were both originally used by Gregory (Rice and Gregory, 1906) for bodies of rock cropping out around Collinsville and Bristol. Earlier, Percival (1842) had used the names Canton granitic basin and Bristol granitic basin. Although both authors realized that these rocks were very much alike, they did not propose a correlation; Gregory at least believed both bodies to be intrusive. The present work and that of Simpson in the Bristol quadrangle establishes the correlation of the Bristol and Collinsville Granite Gneisses of Gregory. In order to preserve these names, already in the literature, Simpson and I propose to use Bristol Member and Collinsville Formation as defined above.

The Collinsville Formation has been mapped as such only in the Bristol and Collinsville domes in the Bristol and Collinsville quadrangles. Identical rock types have been seen, however, in both the Granby domes in the New Hartford and Southwick quadrangles, near Reynolds Bridge in the Thomaston quadrangle, in the Waterbury dome, and just north of the Housatonic River in the Southbury quadrangle.

The Bristol Member underlies basins and many minor valleys in the Bristol and Collinsville domes. Such hills as Mount Horr and the small hill northeast of Canton are underlain mostly by amphibolite. The plagioclase gneiss of the member forms basins and valleys, which are largely covered by glacial deposits; for example, the valleys of small brooks on Taine Mountain and along the western side of Scranton Mountain. In contrast to the Bristol Member, the Sweetheart Mountain Member and The Straits Schist form prominent hills and mountains rimming both the Collinsville and Bristol domes.

Bristol Member. This member is a heterogeneous unit composed of medium-grained biotite-muscovite-plagioclase-quartz gneiss, biotite-quartz-plagioclase gneiss, and amphibolite, with subordinate layers of amphibole-biotite-quartz-plagioclase gneiss and distinctive quartz-garnet granulite. Near granitic rocks, which commonly contain pink feldspar, microcline is an essential phase in the gneiss. All the rocks of the Bristol Member are nonrusty weathering and range in color from white through shades of gray to shades of greenish gray. Commonly the gneiss consists of alternating layers rich in light or in dark minerals, or it contains thin, discontinuous folia rich in dark minerals evenly distributed through the rock. Garnet is present in most of the rocks and is normally associated with biotite and chlorite, particularly in the Collinsville dome. Amphibolite containing distinctive greenish-gray patches rich in epidote is found throughout that dome and along Nepaug Reservoir in the Bristol dome. Amphibolite of this type was also observed in the city of Bristol. In all areas of both domes, the amphibolite commonly contains garnet and grades vertically into hornblende-plagioclase gneiss and biotite-plagioclase gneiss. In outcrops containing more than one rock type, the amphibolite is present only as layers and lenses which are concordant to the foliation in the other rocks. Although a single amphibolite layer could not be recognized from place to place, most of the outcrops containing amphibolite are identified on the geologic map (pl. 1) by a separate symbol.

Near the top of the member a zone rich in thin (less than 5 cm) layers of pale-red quartz-garnet granulite is found consistently near the borders of the Bristol and Collinsville domes. Quite commonly such granulite grades vertically into biotite-quartz-garnet gneiss.

The upper part of the Bristol Member grades into a schist typical of the Sweetheart Mountain Member, and the contact is placed where the rock changes from predominately gneiss to predominately schist. This contact, commonly within 50 to 100 ft of the zone rich in quartz-garnet granulite, is very well exposed in the roadcut on Route 4 in Collinsville, mentioned above as the reference locality for the formation.

Modal analyses of rocks typical of the Bristol Member are shown in table 5. Because this unit is a mixture of different rock types, an attempt was made to sample all rock types from the major outcrop areas. The 32 modes fall into approximately four compositional groups: binary mica-quartz gneiss and schist, biotite-quartz-plagioclase gneiss, hornblende and/or cummingtonite gneiss, and amphibolite. The binary mica-quartz rocks are more abundant in the northern part of the Bristol dome than the plagioclase gneiss, where both are always interstratified with amphibolite. Here the quartz-plagioclase ratio ranges from 1.1 to 3.6, and

Table 5. Modal analyses of the Bristol Member of the Collinsville Formation[1]

Collinsville Dome													
Cb sample no.[2]	Q	Pl	Mi	Ms	Bi	Amph	Di	Ep	Gt	Sph	Mg	Chl	Ap
1	29.6	24.0	....	29.0	15.5	....	....	....	1.2	.....	0.7	.....	....
2	48.2	45.3	....	....	5.4	....	....	....	....	.....	0.7	T	....
3	32.0	49.5	....	....	16.8	....	....	....	T	.....	T	1.0	....
4	29.7	54.2	....	....	3.9	....	....	....	5.2	.....	1.4	5.6	....
5	41.5	51.6	....	....	5.1	....	....	T^{P}	....	.....	.....	1.7	....
6	33.8	56.8	....	T	5.1	....	....	....	3.5	.....	0.8	.....	....
7	31.5	57.1	....	....	6.6	....	....	....	3.5	.....	1.0	.....	T
8	27.2	50.3	8.4	1.0	11.7	....	....	1.3^{P}	....	T	.....	.....	T
9	35.8	32.5	14.3	12.2	5.0	....	....	....	....	.....	T	.....	T
10	18.2	40.2	31.1	1.2	9.3	....	....	....	....	.....	.....	.....	....
11	36.0	37.1	21.4	0.6	4.7	....	....	T^{P}	....	.....	.....	.....	....
12	....	60.0	....	....	26.8	8.0^{C} 5.1^{Hbl}	....	....	....	.....	.....	T	....
13	34.4	60.0	....	....	0.8	9.3^{C}	....	....	....	.....	0.5	.....	....
14	10.2	46.8	....	....	11.9	18.1^{C}	....	....	10.3	.....	0.5	2.2	....
15	24.3	53.0	....	....	17.1	T^{Hbl}	....	0.9^{P}	2.7	.....	0.8	T	T
16	31.0	46.0	....	....	14.6	6.4^{Hbl}	....	1.6^{P}	....	.....	T	.....	....
17	6.5	44.5	....	....	13.7	26.0^{Hbl}	....	....	8.9	.....	.....	0.4	....
18	1.1	23.0	....	....	....	75.5^{Hbl}	....	....	T	.....	.....	.....	....
19	3.7	25.0	....	....	....	69.6^{Hbl}	....	1.0^{P}	....	.....	0.7	.....	....
20	5.6	17.2	....	....	T	70.6^{Hbl}	....	6.3^{P}	....	.....	.....	.....	....
21a	36.8	26.5	....	....	....	2.8^{Hbl}	26.4	5.3^{Clz}	1.4	0.8	.....	.....	....
21b	17.8	14.5	....	....	....	52.0^{Hbl}	....	....	....	T	.....	.....	....
22	17.0	7.7	T	....	....	19.7^{Hbl}	28.6	25.8^{P}	....	0.7	.....	.....	....
23	....	2.8	T	....	....	22.8^{Hbl}	25.1	49.0^{P}	....	0.9	.....	.....	....

Cb sample no.[2]	Q	Pl	Ms	Bi	Amph	Ep	Gt	Sph	Mg	Chl	Ap
					Bristol Dome						
24	35.6	....	43.4	10.5	....	.....	10.0	....	.....	....	0.5
25	43.1	13.5	17.5	25.1	....	.....	0.5	....	T	T	T
26	55.6	18.8	24.2	0.8	....	.....	0.6	....	.....	....	.....
27	54.7	15.0	30.1	....	....	.....	....	....	.....	....	.....
28	57.2	24.0	9.3	8.3	....	.....	0.9	....	T	....	.....
29	39.6	48.0	....	10.1	....	.....	2.1	....	T	T	.....
30	18.3	35.0	....	42.7	....	.....	4.0	....	.....	....	.....
31	10.7	13.4	....	....	67.2^{Hbl}	.....	8.3	T	T	....	.....
32	13.6	13.2	....	....	66.5^{Hbl}	2.3^{P}	....	T	4.2	....	.....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

COLLINSVILLE DOME

1. Biotite-plagioclase-muscovite-quartz gneiss; mg
2. Plagioclase-quartz gneiss; fg; $\overline{\text{An}}$ 25 (7), 24-27
3. Biotite-quartz-plagioclase gneiss; mg
4. Quartz-plagioclase gneiss; fg; $\overline{\text{An}}$*9 (4), $\overline{2V_z}$ 83 (4), An° 10 and 12
5. Biotite-quartz-plagioclase gneiss; fg; $\overline{\text{An}}$ 24 (3), 23-24
6. Biotite-quartz-plagioclase-gneiss; mg; An*23 (2), $2V_x$ 87
7. Biotite-quartz-plagioclase-gneiss; mg; An*29 (1), $2V_x$ 85
8. Microcline-biotite-quartz-plagioclase gneiss; fg; $\overline{\text{An}}$ 26(6), 25-27
9. Muscovite-microcline-plagioclase-quartz gneiss; fg; $\overline{\text{An}}$ 24(3), 23-26
10. Biotite-quartz-microcline-plagioclase gneiss; fg

    Plagioclase in contact with microcline is zoned — Core An*27 (1), $2V_x$ 84; Rim An*32 (1), $2V_x$ 86. Sample is from gneiss which is crosscut by a granite dike.
11. Microcline-quartz-plagioclase gneiss; fg; $\overline{\text{An}}$ 24(7), 23-27
12. Hornblende-cummingtonite-biotite-plagioclase gneiss; fg; An 27(1)

    C* $\overline{Z \wedge C}$ 20 (4), $\overline{2V_z}$ 77 (4); non-pleochroic

    Hbl* $\overline{Z \wedge C}$ 22 (2), $\overline{2V_x}$ 73 (2); X colorless, Y green, Z blue green to very pale green
13. Cummingtonite-quartz-plagioclase gneiss; fg; An 22(1)

    C* $\overline{Z \wedge C}$ 22 (2), $\overline{2V_z}$ 82 (2), non-pleochroic
14. Quartz-biotite-cummingtonite-plagioclase gneiss; mg; An*31 (1), $2V_x$ 84,

    C* $\overline{Z \wedge C}$ max 18 (8), $2V_z$ non-pleochroic
15. Biotite-quartz-plagioclase gneiss; mg; $\overline{\text{An}}$ 23 (3), 22-24
16. Hornblende-biotite-quartz-plagiocase gneiss; fg; An*33 (1), $2V_x$80
17. Garnet-biotite-hornblende-plagioclase gneiss; mg; An*31 (1), $2V_x$87
18. Amphibolite; fg; An*47 (2), $2V_z$ 83 (2)
19. Amphibolite; fg; An*35 (1), $2V_x$ 83
20. Amphibolite; mg; $\overline{\text{An}}$ 35 (3), 34-36
21. Calc-silicate lens (a) in an amphibolite (b)

    (a) Lens: mg; An*48 (1), $2V_z$ 85; Di* $\overline{Z \wedge C}$ 41 (2), $\overline{2V_z}$ *60 (2)

    (b) Amphibolite: fg; $\overline{\text{An}}$ 30 (3), 24-34; Hbl $\overline{Z \wedge C}$ 17 (2), $\overline{2V_x}$ 82 (2), X colorless, Y olive green, Z blue gray
22. Calc-silicate lens in amphibolite; mg; An*9 (1), $\overline{2V_z}$ 84
23. Calc-silicate lens in amphibolite; mg; An*35 (1), $2V_x$ 87

BRISTOL DOME

24. Garnet-biotite-quartz-muscovite schist; mg; An 28 (1)
25. Plagioclase-muscovite-biotite-quartz gneiss; fg; An*12 (1), $2V_z$ 83
26. Plagioclase-muscovite-quartz gneiss; mg; An*23 (1), $2V_x$ 90
27. Plagioclase-muscovite-quartz gneiss; fg
28. Biotite-muscovite-plagioclase-quartz gneiss; fg; An*24 (1), $2V_x$ 85
29. Biotite-quartz-plagioclase gneiss; fg; $\overline{\text{An}}$ 25 (2), 24-26

30. Quartz-plagioclase-biotite gneiss; mg; $\overline{\text{An}}$ 23 (2), 22-24
31. Garnet amphibolite; fg; An 30 (1)
32. Amphibolite; fg; An 38 (2), both values the same

PETROGRAPHY OF MEMBER

TEXTURE: *Felsic gneiss and schist*: Foliate in the mica-rich rocks but more granular in the mica-poor rocks. Essential minerals evenly distributed throughout. Grain contacts of quartz and plagioclase ungranulated even near the fault on east side of Collinsville dome. Mica and amphibole varying from subhedral to euhedral. *Amphibolite*: Foliate with little compositional layering. Axes of amphibole not preferentially oriented except in outcrops near border of Collinsville dome along Farmington River. Grain contacts vary from mosaic to simple implicate patterns; grains commonly subhedral and free of inclusions. Hornblende porphyroblasts and glomeroblasts abundant in some outcrops on top of Horr Mountain near hinge of a mappable fold; biotite sparse and intergrown with hornblende; streaks of small epidote grains present in plagioclase-rich bands. *Calc-silicate lenses*: Most of the essential minerals poikiloblastic and complexly intergrown. Plagioclase greatly altered to sericite, epidote, and unidentifiable material. Epidote grains in some lenses show regular zoning in which the birefringence increases toward the center of an individual grain (the opposite was observed in sample Cb23); epidote grains with irregular birefringence common. Euhedral grains of sphene more abundant than in the surrounding amphibolite.

MINERAL FEATURES: *Quartz*: Uniform and mosaic extinction common in all rocks. Planes of inclusions abundant in some rocks. Fractures present in every thin section. *Plagioclase*: Twinning more abundant in this member than in any other stratigraphic unit in the quadrangle; twin laws identified from charts in Turner (1947) are the albite-ala and the albite laws in the felsic rocks, and the pericline, albite-ala, and albite laws in the amphibolite and amphibole gneiss; average composition of grains measured on universal stage is An 26 (seven samples) in the felsic rocks, An 32 (three samples) in the amphibole gneiss, and An 41 (two samples) in the amphibolite. Extinction irregular or zonal in the amphibolite, amphibole gneiss, and microcline gneiss. Reverse compositional zoning present in a microcline gneiss (sample Cb10) crosscut by a granite. Bent twin lamellae rare. Most grains weakly sericitized; along a fault on the east side of the Collinsville dome the plagioclase grains are strongly altered and cut by veinlets of calcite. *Microcline*: Appears to replace plagioclase; amoebic grain contacts with plagioclase which commonly show zonal extinction. Not altered to sericite. *Biotite*: In binary-mica-quartz rocks X colorless to light yellow brown, YZ red brown; in hornblende gneiss and plagioclase gneiss X colorless to light yellow, YZ dark olive brown to black; in amphibole gneiss X colorless, YZ brown to dark brown. *Amphibole*: See description of sample CB21b for optical data on common hornblende; in Cb12 cummingtonite and common hornblende coexist both as separate and composite phases; in composite grains pleochroic hornblende is intergrown with cummingtonite in strict optical and physical continuity; these phases are interleaved in some grains as thin lamellae paralleling (001) and (100). *Epidote*: Andehral and fine grained. Normal and reverse zoning common; irregular extinction present in some samples. *Garnet*: Commonly porphyroblastic and filled with inclusions of quartz, biotite, and chlorite; in some samples inclusions are restricted to the center of the porphyroblast. "Bleached" halos devoid of mafic minerals found around garnets in some samples of plagioclase gneiss and amphibolite, suggesting that garnet formed from the mafic minerals — the formation of garnet may be a source for the additional water needed to alter biotite to chlorite. *Chlorite*: More abundant in the Bristol Member than in any other stratigraphic unit in the quadrangle; more common with dark-brown and black biotite than with red-brown biotite; also occurs separately in stellate clusters. *Magnetite* subhedral and skeletal.

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the muscovite-biotite ratio averages 7.5 from five samples. In the Collinsville and the southern part of the Bristol dome, the plagioclase gneiss with interstratified amphibolite is prevalent and contains from 35 percent to 57 percent plagioclase with no muscovite. The quartz-plagioclase ratio ranges from 0.5 to 0.8. Compared to the other stratigraphic units in the quadrangle chlorite is quite common in the felsic rocks, particularly the plagioclase gneiss where magnetite and garnet are also generally plentiful. Garnet forms over 50 percent of the essential minerals in the thin layers of quartz-garnet granulite and gneiss near the top of the member. Microcline is locally present where the felsic gneiss is cut by granitic rocks, many of which contain pink feldspars in the Collinsville and southern part of the Bristol domes. Furthermore, muscovite is always associated with microcline in all the gneisses, even in the plagioclase gneiss which normally contains only biotite.

With the addition of epidote and hornblende the plagioclase gneiss characteristically grades into amphibolite, although megascopically the contact between gneiss and amphibolite is sharp. The amphibolite is generally uniform, with hornblende ranging from 66 to 77 percent, plagioclase from 13 to 25 percent, and quartz from 1 to 13 percent. Together, epidote, sphene, garnet, and magnetite constitute less than 10 percent of each thin section. As shown by the modes in table 5, not all the amphibolites contain garnet. In those that do, the garnet is commonly surrounded by a small rim of plagioclase and locally the garnets "cap" small rods of quartz and plagioclase, as along the Farmington River south of Collinsville. In many outcrops in both the Collinsville dome and the southern part of the Bristol dome small green lenses are found in the amphibolite. These contain diopside, hornblende, pistacite, clinozosite, quartz, and altered plagioclase as essential minerals, with sphene, garnet, and microcline as accessory minerals (Cb21 through Cb23). Diopside and clinozoisite, which are typical of the lenses, are never present in the amphibolite. These rocks are richer in calcium and possibly poorer in iron than the surrounding amphibolite and because of this are called calc-silicate lenses. A mode from an amphibolite in contact with such a lens is given as Cb21, both counted from the same thin section.

A cummingtonite-plagioclase gneiss (Cb12 to 14) was found in two localities toward the upper part of the member, both at about the same stratigraphic level below the quart-garnet granulite. In one such locality just west of Unionville along Route 4, cummingtonite and hornblende occur both as separate phases and as composite grains. This gneiss was found only in the Collinsville dome, but a careful search would probably reveal its presence in the Bristol dome.

Sweetheart Mountain Member. This member is a homogeneous unit composed of medium- to coarse-grained muscovite-biotite-plagioclase-quartz schist which contains garnet (5 to 15 mm) and, in some outcrops, kyanite crystals (5 to 10 cm long) randomly oriented on foliation surfaces. The schist is nonrusty weathering and contains abundant quartz-plagioclase stringers and clots that tend to form irregular porphyroblastic masses. Amphibolite is found as concordant podlike bodies throughout the schist, tending to be abundant near the top of the member. Excellent outcrops of the Sweetheart Mountain Member are exposed in the type locality of the formation, where all of these characteristics are found. A small outcrop of serpentine was found south of Taine Mountain on the western limb of the synform separating the Collinsville and Bristol domes.

The upper contact of the Sweetheart Mountain Member is the contact separating the lower group from the Hartland Group and is readily mapped in many quadrangles on the eastern side of western Connecticut from the Long Hill quadrangle to southwestern Massachusetts. In the Collinsville quadrangle, it is marked by the change from nonrusty-weathering schist rich in plagioclase and biotite (Sweetheart Mountain Member) to rusty-weathering, graphitic schist rich in quartz and muscovite. Commonly the contact is also marked by amphibolite. Although exposed in the roadcut on Route 4 in Collinsville, it is recognized best in weathered outcrops such as those on Clear Brook Road east of Phelps Dam, those west of Taine Mountain Road about 3,000 ft north of the

Collinsville-Bristol quadrangle line, and those on a small hill west of Dyer Avenue in Collinsville.

Modal analyses of rocks of the Sweetheart Mountain Member are shown in table 6. Sample Cs1 is fairly typical of the most common rock type, although staurolite, *not* kyanite, is present in the thin section. In outcrop, however, kyanite is normally present, whereas staurolite was never found. The quartz-plagioclase ratio is 1.9, and the muscovite-biotite ratio is 0.5, both ratios consistent with the overall field impression. Sample Cs2 is typical of a schist found in several localities near the contact with the underlying Bristol Member.

Table 6. Modal analyses of the Sweetheart Mountain Member of the Collinsville Formation[1]

Cs sample no.[2]	Q	Pl	Ms	Bi	Hbl	Ep	Gt	Sph	Ky	Stau	Chl
1	51.4	27.1	5.1	11.2	....	.....	5.0	.....	T	T	....
2	49.7	32.1	11.7	4.2	....	.....	2.2	.....	....	....	T
3	3.9	19.1	....	....	70.3	5.3^{P}	.....	1.4	....	....	....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Garnet-biotite-plagioclase-quartz schist; mg; An*29 (1), $2V_x$88
2. Muscovite-plagioclase-quartz schist; mg; An*33 (1), $2V_x$ 87
3. Amphibolite; fg; An*35 (1), $2V_x$ 86

PETROGRAPHY OF MEMBER

TEXTURE: Foliate. Grain contacts implicate.

MINERAL FEATURES: *Quartz*: With uniform and mosaic extinction. *Plagioclase*: Irregular and zonal extinction common. Anorthite composition higher in the amphibolite than in the schist. *Biotite*: X colorless to very light brown, YZ dark red brown to olive brown. Chloritized in some grains.

Hartland Group

As originally used by Rice and Gregory (1906), the Hartland was considered a formation and named for rocks cropping out near the town of Hartland about 10 mi. north of New Hartford, Connecticut. The Hartland Formation is raised to group rank in the present report because four formations are recognized in what was previously considered part of one formation by Rice and Gregory. This group includes rocks stratigraphically above the Collinsville Formation and is divided into The Straits Schist, the Rattlesnake Hill Formation, the Satan's Kingdom Formation, and the Slashers Ledges Formation.

THE STRAITS SCHIST

General discussion. The Straits Schist was originally defined as a member of the Hartland Formation by Rodgers (1959) who designated a gorge, formerly known as The Straits, along Connecticut Route 63 east of Straitsville as the type locality. Since that time, this unit has been recognized by many workers throughout the eastern part of western Connecticut and clearly deserves formational status. Fritts (1962, 1963b) has raised The Straits to formational rank, but has picked a slightly different upper contact than that described by Rodgers (Rodgers and others, 1959). Although the upper contact of The Straits Schist mapped in this report differs somewhat from that described by Fritts, the same stratigraphic nomenclature is used in order not to confuse the terminology in western Connecticut by proposing a different name for essentially the same formation. Fritts, Simpson, and I have mapped an identical lower contact of The Straits Schist and have traced this formation from southeast of the Waterbury dome to the Collinsville quadrangle where it is best exposed on Rattlesnake Hill and in roadcuts along Route 4 between Unionville and Collinsville. These areas are designated reference localities.

Topographically, The Straits Schist stands in sharp relief to the underlying more erodible Collinsville Formation and forms prominent mountains such as Taine Mountain, Rattlesnake Hill, Barnes Hill, and Johnnycake Mountain. Strike valleys are uncommon and all the brooks follow steep joints. South of Collinsville, however, the Farmington River follows the strike of The Straits Schist, flowing along the contact with the underlying Collinsville Formation.

Lithology. The Straits Schist is one of the most distinctive schists in western Connecticut. It characteristically consists of medium- to coarse-grained graphite-garnet-plagioclase-biotite-muscovite-quartz schist that normally contains small porphyroblasts of kyanite and segregations of quartz or quartz-plagioclase of varying size. The schist is always rusty weathering, generally contains more muscovite than biotite, and many foliation surfaces are covered with films of graphite. Concordant bodies of amphibolite, several feet thick, are found throughout the formation, being most numerous in the lower part.

A few very thin beds of graphitic mica-quartz gneiss are present in many outcrops in the lower and middle portions of the formation; toward the top they are more common, alternating with the typical graphitic schist. In the Southington and Mount Carmel quadrangles, Fritts (1963b, 1963c) does not find these beds of gneiss in the lowest part of the Hartland Group and, on this basis, divides The Straits Schist from the overlying Southington Mountain Formation, placing the contact below the beds of gneiss. To the north, however, in the Collinsville quadrangle, these beds are scattered throughout The Straits Schist and, therefore, cease to be good mapping criteria. Consequently, another definition of the upper contact has been selected for this report. Easily identified in most parts of the quadrangle, this contact is placed below the beds of calc-silicate gneiss which are found at the base of the Rattlesnake Hill Formation. At this same stratigraphic level the graphitic, rusty-weathering schist of The Straits changes to a nonrusty-weathering and nongraphitic schist typical of the overlying formation, and this change provides a reliable criterion for stratigraphic subdivision where the calc-silicate gneiss is not present. A clear exposure of this contact is seen in the upper reaches of a small intermittent brook just east of Bahre-Johnson Road on Rattlesnake Hill. Another fine exposure is found along a dirt road south of Nepaug River approximately 1,000 ft east of the dam at the northern end of Nepaug Reservoir.

Modal analyses of rocks typical of The Straits Schist are listed in table 7. Samples S1 to S3 are the dominant rock type and come from either the middle or upper parts of the formation. The quartz-plagioclase ratios of S1 and S3 average 3.0, and the muscovite-biotite ratios of the first three modes average 2.8. Both of these ratios are much higher than in the underlying Sweetheart Mountain Member or in the overlying lower member of the Rattlesnake Hill Formation. Several thin sections from the lower part of The Straits Schist, not listed in table 7, are even richer in muscovite and contain smaller percentages of quartz and plagioclase. Sample S4 was counted from a thin gneiss of a type found in several outcrops near the top of the formation.

Table 7. Modal analyses of The Straits Schist[1]

S sample no.[2]	Q	Pl	Ms	Bi	Hbl	Gt	Sph	Ky	Mg	Chl	Ap	G
1	39.9	15.1	19.5	18.0	....	3.4	....	2.9	.....	.....	....	1.2
2	37.4	11.4	31.5	10.5	....	5.2	....	3.8	.....	0.4	T	T
3	41.9	....	41.9	9.6	....	6.4	....	T	.....	.....	....	T
4	56.2	31.6	....	10.8	....	1.1	....	.....	T	.....	....	.....
5	17.9	16.0	....	....	46.7	16.7	T	.....	2.4	.....	....	.....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Graphite-plagioclase-biotite-muscovite-quartz schist; mg; An*30 (1), $2V_x$ 83
2. Graphite-garnet-plagioclase-biotite-muscovite-quartz schist; mg; An*21 (1), $2V_x$ 87
3. Graphite-garnet-muscovite-quartz schist; mg
4. Graphite-biotite-plagioclase-quartz gneiss; mg; $\overline{An}$ 24 (2), 23-25
5. Garnet amphibolite; mg; $\overline{An}$ 32 (4), 26-40

PETROGRAPHY OF MEMBER

TEXTURE: Foliate. Contacts between quartz and plagioclase implicate. Muscovite and biotite interleaved, forming discrete layers alternating with quartz and plagioclase in some samples. Graphite commonly elongate parallel to (001) of muscovite.

MINERAL FEATURES: *Quartz*: Uniform extinction common; mosaic and undulatory extinction present. In sample S2 quartz with strong undulatory extinction is associated with micas containing kink bands. *Plagioclase*: Anorthite content higher in the amphibolite than in the schist. Sericite present in most grains. *Biotite*: X colorless to light yellow brown, YZ dark red brown. In sample S2 chlorite alters biotite. *Garnet*: Porphyroblastic. Abundant inclusions of quartz restricted to center of the garnet in some samples. In sample S5 a thin "bleached" halo devoid of mafic minerals surrounds the garnet. *Kyanite*: Porphyroblastic. Commonly associated with muscovite and biotite. In thin sections containing chloritized biotite, the kyanite grains are sheathed and penetrated by sericite.

RATTLESNAKE HILL FORMATION

General discussion. The name, Rattlesnake Hill Formation, is here formally assigned to rocks cropping out on the northern part of Rattlesnake Hill which is hereby designated the type locality. The formation is divided informally into two members. The lower member is best displayed east and west of Bahre-Johnson Road in the type locality of the formation. The upper member crops out in many places in the quadrangle; particularly clear outcrops are found on the northern side of

Ratlum Mountain, east of Bee Mountain along Spencer Road, and just north of the junction of Bunker Hill and Barbourtown Roads. This is the member that is so important in clarifying the stratigraphic relationship between the rocks involved in major northeastward-trending folds and the rocks in the domes.

Altough the Rattlesnake Hill Formation commonly rims basins and minor valleys of the Collinsville and Bristol domes, it generally is lower topographically than The Straits Schist. Rivers and streams flowing across this formation follow well developed joints oriented nearly perpendicular to foliation. Strike valleys are not common.

Lower member. The lower member is a heterogenous unit composed of medium-grained biotite-plagioclase-muscovite-quartz schist and amphibolite. Thinly to thickly bedded calc-silicate gneiss is common at the base. The schist is nonrusty weathering, contains approximately equal proportions of muscovite and biotite, and commonly contains more plagioclase than The Straits Schist. Garnet and kyanite are present in most of the schist, and large quartz-kyanite segregations (6 to 12 in. long) garnish many outcrops, especially along the western side of Rattlesnake Hill. Several concordant amphibolite bodies are found in the middle of the member. The calc-silicate gneiss ranges in composition from a calcite-plagioclase-quartz gneiss to a plagioclase-quartz-hornblende-microcline gneiss with varying amounts of diopside and clinozoisite. North of Woodchuck Road pegmatite crosscuts and is interlayered with the calcite-plagioclase-quartz gneiss. This relationship can best be seen in the spillway to the Simsbury Reservoir in the Tariffville quadrangle.

Several lateral variations are found in this member. North of North Mountain Road the schist commonly contains more feldspar than along the western side of Rattlesnake Hill.. Abundant pegmatites in this area suggest that part of this feldspar may be introduced. Schist found in scattered outcrops northeast of the Collinsville dome is finer grained and contains more muscovite and quartz than does the schist on Rattlesnake Hill. Although calc-silicate gneiss is always found at the base of the lower member north of the Nepaug Reservoir, none was found in the two outcrops of the member south of the reservoir. Here the member is quite thin, but the common nonrusty schist does crop out northeast of the junction between Foote and Smith Roads and just north of Rock Road (pl. 1).

The upper contact of the lower member is placed above nonrusty-weathering, medium-grained, mica-plagioclase-quartz schist with garnet and kyanite, and below rusty-weathering, fine- to medium-grained mica-quartz schist of the upper member. Commonly the latter schist is graphitic and contains little, if any, garnet and kyanite. This contact is best exposed along North Mountain Road where outcrops typical of the two members occur within 150 ft of each other. It is less well exposed along the western end of Bahre-Johnson Road and along a dirt road east of Nepaug Reservoir.

Modal analyses of rocks typical of the lower member are listed in table 8. The proportion of the different rock types analyzed for the table is not representative of the member as a whole. A single sample, RH11, is by far the most abundant type, whereas five samples (RH13 to 7) represent the calc-silicate gneiss common only at the base of the member. The quartz-plagioclase and muscovite-biotite ratios in RH11 are consistent with the overall field impression: commonly biotite and plagioclase are more plentiful than in the underlying The Straits Schist. The samples of calc-silicate gneiss were taken from the four main outcrop localities (RH13 and 7 are from the same locality) and reflect the variation in mineralogy and relative percentages suggested in outcrop. Microcline, instead of muscovite, is the dominant potassium-bearing phase and is considered native to the calc-silicate gneiss, although locally where pegmatite is abundant (such as north of Woodchuck Road) much of this phase may be an introduced one.

Table 8. Modal analyses of the lower member of the Rattlesnake Hill Formation[1]

RHl sample no.[2]	Q	Pl	Mi	Ms	Bi	Amph	Di	Calc	Clz	Gt	Sph	Ky	Chl	Ap
1	34.0	19.4	....	26.2	17.2	....	....	....	.....	2.3	.....	T	T	....
2	44.6	22.0	....	12.1	18.8	....	....	....	.....	2.5	.....	....	....	T
3	54.0	7.0	16.0	....	....	1.1	18.3	....	2.9	.....	0.6	....	....	....
4	40.2	10.6	....	....	....	1.1	47.4	....	0.8	.....	0.5	....	....	....
5	17.5	7.9	9.3	....	4.5	12.9	47.5	....	.....	.....	T	....	....	....
6	46.7	31.6	1.9	....	4.5	....	....	15.3	.....	.....	.....	....	....	....
7	12.8	10.8	51.8	....	....	20.3	....	....	2.5	.....	2.0	....	....	....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Biotite-plagioclase-muscovite-quartz schist; mg; An 27 (2), both values the same.
2. Muscovite-biotite-plagioclase-quartz gneiss; fg
3. Calc-silicate gneiss; mg; An*46 (1), $2V_z$ 81; Hbl $\overline{Z \wedge C}$ 21 (4), $2V_x$, non-pleochroic
4. Calc-silicate gneiss; mg; An*45 (1), $2V_z$ 83; Hbl $\overline{Z \wedge C}$ 19 (3), $2V_x$, non-pleochroic
5. Calc-silicate gneiss; mg; Hbl* $\overline{Z \wedge C}$ 15 (2), $\overline{2V_x}$ 88, non-pleochroic
   Di* $\overline{Z \wedge C}$ 41 (3), $\overline{2V_z}$ 55
6. Calcite-plagioclase-quartz gneiss; fg; An*35 (1), $2V_x$ 88
7. Plagioclase-quartz-hornblende-microcline gneiss; fg; Hbl $2V_x$, X colorless, Y green gray, Z gray

PETROGRAPHY OF MEMBER

TEXTURE: Foliate in schist. Compositional layering in calc-silicate gneiss consists of quartz-plagioclase layers alternating with calc-silicate layers. The (001) of biotite and the C-axes of hornblende parallel the layering. Grain contacts mosaic in quartz-rich layers, and in complicated implicate patterns in diopside-rich layers.

MINERAL FEATURES: *Quartz* shows uniform extinction; strong undulatory extinction in samples from Rattlesnake Hill. *Plagioclase* in calc-silicate gneiss contains very abundant sericite and clinozoisite. *Microcline* fresh, with mosaic to amoeboid grain boundaries. *Biotite*: X colorless, YZ light brown (phlogopite?) in calc-silicate gneiss. *Hornblende* non-pleochroic; grains subhedral to anhedral and inclusion free. *Diopside*: Porphyroblastic. Abundant inclusions of quartz, hornblende, and microcline.

POSTCRYSTALLINE STRAIN FEATURES: Common in all the samples collected from Rattlesnake Hill. The quartz always shows strong undulatory extinction and even contains deformation lamellae in some of the pegmatites just east of Bahre-Johnson Road, where the plagioclase lamellae are deformed by shear fractures and kink bands oriented at a high angle to the twin planes. Cleavage in some diopside grains in a nearby calc-silicate gneiss is also bent. Kink bands are common features in mica grains collected in the same area and along North Mountain Road. The above features suggest that strain, although local in extent, either postdated or escaped recrystallization which locally chloritized biotite and sericitized plagioclase. It seems unlikely that these features are related to Triassic deformation because no samples from the Eastern Border Fault or Cherry Brook Fault contain these strain features; instead the quartz extinguishes uniformly and the micas, although altered, are not kinked.

Upper member. The upper member is a fairly homogeneous unit composed of rusty-weathering, fine- to medium-grained mica-quartz schist interbedded with thinly to thickly bedded mica quartzite and mica-plagioclase-quartz gneiss. In some localities a distinctive quartz-garnet granulite accompanies the quartzite and gneiss. Analyses by X-ray fluorescence (by Bolter in 1962) showed garnets from the granulite to be rich in manganese, giving the rock a distinctive pale-red color. The schist of this member is everywhere intensely weathered, commonly contains graphite and, rarely, noticeable amounts of garnet and kyanite. Thin- to medium-bedded mica quartzite is characteristically dark gray on fresh surfaces and contains small amounts of graphite; thin sections reveal clinozoisite and nonpleochroic hornblende (tremolite-ferrotremolite) – as, for example, in samples from Ratlum Mountain. The thickly bedded quartzite is light colored both on weathered and fresh surfaces. On the eastern side of Bee Mountain a thinly bedded cummingtonite-plagioclase gneiss crops out with the typical mica quartzite and fine-grained schist. Although this member is one of four rusty-weathering units in the quadrangle, the interbedded quartzite beds make it lithologically unique and the presence of andesine and epidote, coupled with the absence of kyanite and staurolite, make it mineralogically distinct.

The lower part of the member is mostly schist with minor beds of thinly bedded quartzite. In the upper part, mica quartzite and schist, in beds of varying thickness up ot three feet are interlayered, commonly in about equal proportions. Thickly bedded quartzite is also typical of the upper part. The best outcrops of the lower part are found along North Mountain Road just west of the contact with the lower member. Excellent outcrops of the upper part occur at the junction of Bunker Hill and Barbourtown Roads and along the eastern side of Ratlum Mountain.

The rocks on Jones and Yellow Mountains in the northwestern part of the quadrangle are similar in many respects to the rocks of the upper member on Ratlum Mountain and are tentatively correlated with them. Detailed mapping has shown that the rocks of Jones and Yellow Mountains are in contact with the schist of the Satan's Kingdom Formation that stratigraphically overlies the upper member of the Rattlesnake Hill Formation on Ratlum Mountain. However, a reverse fault may extend southward from Ratlum Brook and separate these units along part of Jones Mountain. If this structure is indeed present, then the rocks of Jones and Yellow Mountains are either stratigraphically much lower than the Satan's Kingdom Formation, having been brought to their present position by major movement along this fault, or they are equivalent to at least part of the upper member of the Rattlesnake Hill Formation – movement along the fault being small and possibly local.

Rusty-weathering schist and mica-quartz gneiss, some containing nonpleochroic hornblende similar to that found in schist and gneiss on Ratlum Mountain, occur throughout the eastern part of Jones and Yellow Mountains (see table 9). In addition, quartz-garnet granulite like that present in a few outcrops of the upper member of the Rattlesnake Hill Formation is common in many outcrops of rusty schist and gneiss on Jones and Yellow Mountains. Analysis by Bolter in 1962 showed that

Table 9. Modal analyses of the upper member of the Rattlesnake Hill Formation[1]

RHu sample no.[2]	Q	Pl	Ms	Bi	Amph	Ep	Gt	Sph	Ky	Mg	Chl	G
1	39.5	23.6	0.9	36.3	.....	.....	....	....	....	....	.....	T
2	46.3	16.6	16.2	19.6	.....	1.1^{P}	....	T	....	....	.....	T
3	83.5	7.1	....	7.6	0.8	0.8^{P}	....	T	....	....	.....	T
4	38.0	1.6	....	T	.....	.....	57.2	....	....	....	.....	....
5[3]	61.2	....	....	....	2.9	T^{Clz}	35.8	....	....	....	.....	....
6[3]	72.5	....	17.7	9.2	.....	.....	T	....	....	....	0.6	....
7[3]	12.4	0.7	30.6	26.8	.....	.....	5.9	....	22.4	T	.....	....
8[3]	59.1	19.9	15.5	5.7	.....	.....	T	....	....	....	.....	....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Graphite-plagioclase-biotite-quartz schist; mg; An*34 (1), $2V_x$ 86
2. Graphite-muscovite-plagioclase-biotite-quartz gneiss; fg; An 38 (3), all values the same.
3. Graphite-biotite quartzite; fg; Hbl $\overline{Z \wedge C}$ 12 (3), $\overline{2V_x}$ 78, non-pleochroic (ferro-tremolite?)
4. Garnet-quartz granulite (garnet-spessartite); mg
5. Garnet-quartz granulite; mg; Hbl* $\overline{Z \wedge C}$ 18 (2), $\overline{2V_x}$ 86 (2), non-pleochdoic (tremolite?)
6. Biotite-plagioclase-quartz gneiss; mg
7. Quartz-kyanite-biotite-muscovite schist; mg; An 26 (1)
8. Muscovite-plagioclase-quartz gneiss; fg; An 27 (3), all values the same.

PETROGRAPHY OF MEMBER

TEXTURE: Foliate. Grain contacts mosaic and ungranulated. In some samples microscopic folds outlined by micas and graphite are sealed in undeformed porphyroblasts of plagioclase and biotite.

MINERAL FEATURES: *Quartz* with uniform extinction common. *Plagioclase*: Irregular and zonal extinction present in only a few samples. Sericite common. *Biotite*: X light yellow brown, YZ red brown. Some grains partly chloritized. Biotite porphyroblasts oriented at high angle to foliation in some samples.

POSTCRYSTALLINE STRAIN FEATURES: Uncommon in quartz and mica, except on top of Ratlum Mountain, where kink bands in biotite and deformation lamellae in quartz are found in samples collected along contact between Rattlesnake Hill and Satan's Kingdom Formations.

[3] Samples RHu 5,6,7, and 8 are from rocks underlying Jones Mountain and Yellow Mountain.

garnets from both of these areas are rich in manganese and contain approximately similar amounts of TiO_2. Identical rocks on strike with these on Jones Mountain crop out in the spillway of the Compensating Reservoir, just to the north in the New Hartford quadrangle. Here the rocks apparently grade eastward into rocks exposed on a small hill southeast of the spillway that are *identical* to those of the upper member in the center of the quadrangle. West of this hill and south of Pine Grove Cemetery (south of the spillway) the rocks are typical of the Ratlum Mountain Member of the Satan's Kingdom Formation and are assigned to that formation. The contact between these stratigraphic units and the dips and strikes within them outline an antiform plunging north on the upper block of the reverse fault, which presumably follows Ratlum Brook in the Collinsville and New Hartford quadrangles. Thus the relationship between the rocks south of the Compensating Reservoir and the distinct similarities in rock type suggest that the rocks on Jones and Yellow Mountains are equivalent to those of the upper member of the Rattlesnake Hill Formation in the center of the quadrangle.

On the other hand, the rocks on Jones and Yellow Mountains contain a higher proportion of quartz gneiss relative to rusty schist than does the upper member where it crops out to the east. Furthermore, the quartz-garnet granulite is far more abundant in the western part of the quadrangle than in the center. Both of these differences are reflected in the modal analyses in table 9. On Yellow Mountain just south of Town Hill, near the border of the Collinsville and Torrington quadrangles, a nonrusty-weathering, biotite-quartz gneiss crops out that is quite different from the rocks just to the east. Because of its limited extent in the Collinsville quadrangle this rock is included with the Rattlesnake Hill Formation. Future mapping to the west and north may show, however, that this rock type is widespread enough to justify mapping it as a separate unit.

If the distinct similarities and structural relationships south of the Compensating Reservoir are accepted as evidence of the stratigraphic equivalence of the rocks on Jones and Yellow Mountains to the upper member of the Rattlesnake Hill Formation in the center of the quadrangle, then the lithologic differences can be interpreted as an east-west stratigraphic facies change. This would require that displacement on the reverse fault be small and presumably local. Furthermore, this leads to the speculation that some of the rocks to the west in what is now called the Berkshire Highlands may, in fact, be stratigraphically equivalent to rocks below the upper member of the Rattlesnake Hill Formation such as The Straits Schist and the Collinsville and Taine Mountain Formations. Because of the gradual change in facies to the west, perhaps such characteristic rocks as The Straits Schist cannot be recognized in the western part of western Connecticut. Careful mapping in the Torrington and Winsted quadrangles to the west may, however, reveal mappable units that are like those of the domes and thus provide a clue to the character of these speculative facies changes.

The upper contact of the Rattlesnake Hill Formation is placed above fine- to medium-grained, rusty-weathering schist interbedded with thinly bedded mica quartzite and below medium-grained, nonrusty-weathering, light-colored mica-plagioclase-quartz schist, typical of the Ratlum Mountain Member. This latter schist contains small garnets (2 to 3 mm), kyanite, and commonly staurolite. Biotite crystals are larger than muscovite and are either oriented at an angle to foliation or scattered over foliation surfaces, giving the rock a salt and pepper aspect. In some localities the contact is gradational and is arbitrarily placed above the last outcrop containing more than 75 percent rusty schist and mica quartzite; thickly bedded quartzite is commonly found near and along it. Exposures of the contact are found along Barbourtown Road and on top of Ratlum Mountain.

In table 9 are listed modal analyses of the typical rocks in the upper member that crop out both in the center and northwestern parts of the quadrangle. The presence of clinozoisite and andesine, together with the absence of kyanite and staurolite, indicate a higher CaO-Al_2O_3 ratio in the center of the quadrangle than in the more aluminous rocks both on either side of the upper member and on Jones and Yellow Mountains — all of which contain oligoclase, kyanite, sillimanite, and garnet. Furthermore, the quartz-plagioclase and muscovite-biotite ratios are higher in the rocks in the northwestern part than in the center of the quadrangle and reflect the field observations mentioned in a preceding paragraph.

SATAN'S KINGDOM FORMATION

General discussion. The name Satan's Kindom Formation is here formally assigned to rocks cropping out in Satan's Kingdom, in the Nepaug State Forest west of the Farmington River. This area is hereby designated the type locality.

Two members are formally proposed for this formation – the Ratlum Mountain Member and the Breezy Hill Member. The type locality of the Ratlum Mountain Member is north of Diters Road on Ratlum Mountain. Other reference localities are located in Satan's Kingdom and along the gorge of the Farmington River south of Route 44 (Satan's Kingdom Access Area). The type locality for the Breezy Hill Member is located on top of Breezy Hill east and west of Breezy Hill Road. Other reference localities are found in Satan's Kingdom and along the transmission line crossing Bee Mountain south of Route 4 near Nepaug.

The Satan's Kingdom Formation constitutes much of the outcrop between Cherry Brook Valley and Jones Mountain and underlies most of the hills, such as Ratlum Mountain, Garrett Mountain, and Bee Mountain in the center of the quadrangle. The Breezy Hill Member underlies the highest of these hills, such as Breezy Hill and the western portions of Satan's Kingdom and Bee Mountain. This line of hills forms a local drainage divide; from it intermittent brooks flow westward into the Farmington River or Beckwith Brook and eastward into brooks draining Ratlum Mountain, Satan's Kingdom, and Bee Mountain. All brooks flowing across the strike of the Breezy Hill Member follow steeply dipping joints. In contrast, the Ratlum Mountain Member underlies lower hills such as Ratlum Mountain, Garrett Mountain, and a hill north of the Nepaug Reservoir. In Satan's Kingdom and on the eastern side of Bee Mountain, the Ratlum Mountain Member forms gentle slopes leading down from high areas underlain by the Breezy Hill Member. In areas underlain by the Ratlum Mountain Member, topography is well adjusted to rock type; minor hills and knolls are underlain by amphibolite and rocks rich in quartz, whereas small valleys are underlain by rocks rich in plagioclase. This relationship is illustrated on Ratlum Mountain where brooks flow parallel to the strike between knolls of amphibolite.

Ratlum Mountain Member. This member is a heterogeneous assemblage of medium-grained, nonrusty-weathering, garnet-biotite-muscovite-plagioclase-quartz schist, garnet-biotite-plagioclase-quartz gneiss, amphibole-biotite-plagioclase gneiss, and calc-silicate gneiss, and includes a zone of garnet amphibolite which is locally overlain by garnet-anthophyllite rock.

Biotite porphyroblasts in the schist and the gneiss are commonly at an angle to the foliation and form "cross biotites" like those described in some of the rocks in eastern Vermont (Skehan, 1962, p. 84). Furthermore, the biotite grains are speckled over the light gray foliation surface as isolated porphyroblasts and clusters forming a distinct splatter pattern resembling "salt and pepper" sands. Small red garnets, 2 to 3 mm in size, stand out like BB shot on the weathered surfaces and are a characteristic feature of this member. The schist normally contains either garnet, staurolite, and kyanite, or garnet and staurolite, or garnet and kyanite. In three localities on Ratlum Mountain microscopic sillimanite was found with garnet and staurolite, and in a thin section from one of the localities kyanite is also present (SKrm1, table 10). With the exception of sillimanite these minerals generally occur as porphyroblasts of different size. In one outcrop along the Nepaug River staurolite porphyroblasts up to 10 cm in length garnish an outcrop of silvery schist and gneiss.

Large porphyroblasts of plagioclase (2 to 4 cm) are striking features in some of the schist and apparently are not related to the intrusion of any granitic body, but instead appear to maintain a single stratigraphic position. This zone, together with a garnet amphibolite that is commonly sandwiched between the layers of porphyroblastic schist, forms a distinctive marker in the middle of the Ratlum Mountain Member (see pl. 1). Although the amphibolite – which may be two beds in some localities – is not always present, the same zone of plagioclase porphyroblasts is normally found along strike from their common outcrops. On Ratlum Mountain an anthophyllite-biotite-plagioclase gneiss stratigraphically overlies (but structurally underlies) the garnet amphibolite. In one locality a pod of garnet and anthophyllite, 20 ft wide, crops out between these two beds.

The upper contact of the Ratlum Mountain Member is gradational and, locally, difficult to delineate. In all areas, however, it can be limited to a stratigraphic thickness of 50 to 75 ft. Where best shown, as in Satan's Kingdom and on the northern part of Ratlum Mountain, the contact is placed where the light gray "salt and pepper," garnet-kyanite-staurolite schist with "cross biotites" changes to grayish-blue, garnet-staurolite schist of the Breezy Hill Member. Characteristically, "cross biotites" and "salt and pepper" foliation surfaces are absent in the Breezy Hill Member in which quartz-rich layers (1 to 2 cm thick) alternate with mica-rich layers. Although the contact is gradational, schists typical of the two members are not commonly interbedded – instead, the change is gradual and the contact is arbitrarily placed below outcrops containing more than 50 percent of rock typical of the Breezy Hill Member.

Modal analyses of rocks typical of the Ratlum Mountain Member are listed in table 10. Most of the member is made up of aluminous rocks represented by samples SKrm1 through 9, whereas the amphibole-plagioclase gneiss (SKrm10 and 11) is only found on Ratlum Mountain. SKrm12 to 14 are characteristic of the calc-silicate gneiss found in thin beds in the lower part of the member. In these rocks the modal percentage of each of the essential minerals varies considerably from sample to sample, although the same minerals are normally always present. In the aluminous rocks, the quartz-plagioclase ratios range from 0.4 in SKrm9 to very high values such as SKrm1. Similarly, the muscovite-biotite ratios are variable and are evenly distributed above and below the value of one. The presence of sillimanite along with kyanite, garnet, and staurolite is rare in the Collinsville quadrangle, but this association more than any other may shed an important light on the physical-chemical conditions of metamorphism and deformation.

Table 10. Modal analyses of the Ratlum Mountain Member of the Satan's Kingdom Formation[1]

SKrm sample no.[2]	Q	Pl	Ms	Bi	Amph	Ep	Gt	Sph	Ky	Stau	Mg	Chl	Ap	G	Tm	Z	R
1	42.0	T	13.2	17.1	....	....	11.5	.....	12.5	3.3	.....	.....	T	....	....	T	....
2	32.4	26.9	15.4	22.4	....	....	T	.....	....	2.1	T	.....	....	....	T	....	....
3	29.0	18.5	20.8	13.0	....	....	12.8	.....	3.4	.....	.....	2.5	.....	....	....	....	....
4	19.7	16.9	27.0	32.8	....	....	2.1	.....	1.5	.....	.....	.....	.....	....	....	....	....
5	55.1	7.2	18.3	14.4	....	....	4.8	.....	....	.....	T	.....	.....	....	....	....	....
6	53.3	29.2	T	4.5	....	....	8.7	.....	....	.....	.....	4.0	.....	....	....	....	....
7	14.5	27.6	24.0	29.8	....	....	4.1	.....	T	.....	.....	.....	.....	....	....	....	....
8	20.5	23.0	30.5	25.7	....	....	T	.....	....	.....	T	.....	.....	....	....	....	....
9	14.4	38.0	10.5	25.4	....	....	11.4	.....	....	.....	.....	.....	T	....	....	....	....
10	....	68.4	....	18.0	4.0^{A}	T^{Cls}	7.9	.....	....	.....	T	0.8	.....	....	....	....	T
11	T	71.2	....	12.3	10.2^{Hbl}	....	2.5	.....	....	.....	2.1	0.9	.....	T	T	....	....
12	16.4	30.1	....	....	17.8^{Hbl}	12.4^{Cls}	22.2	1.0	....	.....	.....	T	.....	....	....	....	....
13	29.0	33.1	....	4.8	20.8^{Hbl}	2.0^{P}	6.4	2.8	....	.....	.....	1.1	.....	....	....	....	....
14	13.8	....	....	....	17.6^{Hbl}	40.6^{Cls}	26.3	1.7	....	.....	.....	.....	.....	....	....	....	....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Garnet-kyanite-muscovite-biotite-quartz schist; mg; (sillimanite)
2. Muscovite-biotite-plagioclase-quartz schist; mg; An 24 (1); (sillimanite)
3. Garnet-biotite-plagioclase-muscovite-quartz schist; mg; An 24 (1)
4. Plagioclase-quartz-muscovite-biotite schist; mg; An*27 (1), $2V_x$ 85
5. Biotite-muscovite-quartz schist; fg
6. Garnet-biotite-plagioclase-quartz gneiss; mg; An 28 (1)
7. Quartz-muscovite-plagioclase-biotite schist; mg
8. Quartz-plagioclase-biotite-muscovite schist; mg; An 34 (1)
9. Muscovite-garnet-quartz-biotite-plagioclase schist; mg
10. Garnet-biotite-plagioclase gneiss; fg; An 27 (2)
11. Hornblende-biotite-plagioclase gneiss; mg; An*36 (1), 2V 90; Hbl*, $\overline{Z\wedge C}$ 15 (2), $\overline{2V_x}$ 77 X colorless, Y green, Z blue green
12. Clinozoisite-hornblende-garnet-plagioclase gneiss (calc-silicate); mg; An*92 (2), $2V_x$ 79 (2); Hbl* $\overline{Z\wedge C}$ 17 (3), $\overline{2V_x}$ 80, X colorless, Y light brownish yellow, Z light green
13. Garnet-hornblende-plagioclase gneiss (calc-silicate); mg; Hbl $\overline{Z\wedge C}$ 24 (3), $2V_x$, pleochroic formula similar to SKrm12
14. Calc-silicate gneiss; mg; Hbl $\overline{Z\wedge C}$ 21 (10), non-pleochroic

PETROGRAPHY OF MEMBER

TEXTURE: Foliate in aluminous schist and gneiss. Porphyroblasts of garnet, kyanite, staurolite, and biotite are common. Granoblastic with some compositional layering in the calc-silicate gneiss, and weakly foliate in the amphibole-plagioclase gneiss. Grain contacts simple in aluminous rocks, but very complicated in calc-silicate gneiss and amphibole-plagioclase gneiss.

MINERAL FEATURES: *Quartz* with uniform extinction common; mosaic and undulatory extinction less so. *Plagioclase*: Calcic oligoclase or sodic andesine in aluminous schist and gneiss, andesine in the amphibole-plagioclase gneiss, and anorthite in calc-silicate gneiss. Sericitization weak in aluminous rocks to intense in calc-silicate rocks. Plagioclase porphyroblasts contain inclusions of quartz, mica, and garnet, and encase folds outlined by mica; rotated porphyroblasts common in the schist on either side of the amphibolite zone in the middle of the member. *Biotite*: X colorless, YZ dark red brown in aluminous rocks. Porphyroblasts, oriented at a high angle to foliation, are common in most schists. Biotite is partly altered to chlorite in about 40 percent of samples. *Clinozoisite*: Irregular and zonal patterns displayed in both interference colors and extinction. In normally zoned grains, the inner zone is more birefringent than outer zone, suggesting decrease in Fe from center to edge of grain. One sample of calc-silicate gneiss in contact with light-gray quartz gneiss contains clinozoisite normally zoned in the middle of the bed, whereas in outer portion of bed the zoning is reversed. *Garnet*: Porphyroblastic, with inclusions of quartz and some mica. A few rotated grains present. *Kyanite*: Commonly porphyroblastic and free of inclusions. In some samples kyanite is partly sericitized. *Sillimanite:* Rare. Is present as nebulitic clusters of very fine needles commonly associated with biotite; needles appear to develop parallel to (001) cleavage of biotite.

POSTCRYSTALLINE STRAIN FEATURES: Restricted to top of Ratlum Mountain near those described in the upper member of the Rattlesnake Hill Formation (table 9). Undulatory extinction strongly developed in quartz; in some grains deformation lamellae are present. Many of the micas are bent, and kink bands are present in some — in one thin section kink bands are present in kyanite, oriented at a high angle to the cleavage.

Breezy Hill Member. This member generally consists of nonrusty-weathering, medium-grained, plagioclase-mica-quartz schist containing garnet, staurolite, and small (less than 5 mm) plagioclase porphyroblasts. Commonly, quartz-rich layers (less than 2 cm thick) alternate with mica-rich bands and the schist is grayish blue in color. Thin beds of quartz-rich gneiss are locally present. Toward the base of the member, the schist is, in places, light in color and contains kyanite, garnet, and staurolite. Throughout the quadrangle, the top 50 to 100 ft contain large (1 to 4 cm) porphyroblasts of staurolite, which are particularly abundant east of Satan's benchmark on Slashers Ledges. Although this zone is always present, no sharp line can be placed between it and the stratigraphically lower schists which are relatively poor in large staurolite porphyroblasts.

Three narrow belts of rusty-weathering, plagioclase-mica-quartz schist crop out on the south slope of Breezy Hill (see pl. 1). These rocks, found only in this locality, are interbedded with nonrusty-weathering rocks typical of the member and contain kyanite in addition to the garnet and staurolite which is common in nearby nonrusty schist.

These belts can be interpreted in at least two ways. First, they could represent one continuous layer that had been repeated by folding. This could account for the increase in map width of the member on Breezy Hill, where the dip of the foliation is about the same as south of the Farmington River. Second, they could simply represent three separate lenses interbedded with the nonrusty schist. Tectonic thinning could then account for the decrease in map width south of Breezy Hill. Folding, however, seems unlikely. On Ratlum Mountain, just to the east, where folding does account for the repetition of rock type, minor folds are quite plentiful and statistically plunge northeastward. On Breezy Hill, however, only ten minor folds are found, and of these only *two* crop out near or in the rusty schist. Furthermore, most of the fold axes plunge steeply at diverse angles to the northwest. To be sure, minor folds are often difficult to identify in a schist, particularly if a penetrative axial-surface foliation has been developed, but there are enough thin layers of binary-mica quartz gneiss in the member so that if folding repeated the rusty schist, minor folds should be abundant. Consequently, it seems more reasonable to consider these three belts as lenses, particularly because outcrop, which could further clarify the geologic relations, is absent just south of Breezy Hill.

The contact of the Satan's Kingdom Formation with the overlying kyanite schist member of the Slashers Ledges Formation is placed above garnet-staurolite schist rich in staurolite porphyroblasts and below magnetite-kyanite-muscovite-quartz schist rich in kyanite porphyroblasts, some of which are 10 to 15 cm long. This contact is indeed striking and can best be seen east of Slashers Ledges and along the upper reaches of Beckwith Brook.

Table 11 lists modal analyses of several samples typical of the Breezy Hill Member. In all these samples the quartz-plagioclase ratio is greater than 2 and the muscovite-biotite ratio greater than 1. These ratios are consistent with field observations. Normally garnet and staurolite are present and form porphyroblasts filled with inclusions of quartz, mica, and, in places, plagioclase. Kyanite is present in some layers both in the rusty and nonrusty schist. As in the underlying member, sillimanite again is present with staurolite and garnet, but none was found with kyanite.

Table 11. Modal analyses of the Breezy Hill Member of the Satan's Kingdom Formation[1]

SKbh sample no.[2]	Q	Pl	Ms	Bi	Gt	Ky	Stau
1	21.6	9.3	38.3	28.0	2.8	.....	....
2	31.0	15.3	33.3	17.6	2.7	.....	T
3	25.4	12.2	27.0	28.2	4.9	1.9	T

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Quartz-biotite-muscovite schist; mg
2. Plagioclase-biotite-quartz-muscovite schist; mg
3. Plagioclase-quartz-muscovite-biotite schist; mg

PETROGRAPHY OF MEMBER

TEXTURE: Foliate. Quartz-plagioclase laminae alternate with mica-rich laminae in some samples. Grain contacts ungranulated and mosaic.

MINERAL FEATURES: *Quartz*: Uniform extinction. Fractures plentiful in some samples. *Plagioclase* untwinned and mildly sericitized. *Biotite*: X colorless, YZ red brown, in both rusty and nonrusty schist, although grains with YZ dark olive brown were found in the nonrusty schist. Partly chloritized biotite present in only a few samples. *Kyanite* clear; partly altered to sericite in only a few samples.

SLASHERS LEDGES FORMATION

General discussion. The name, Slashers Ledges Formation, is assigned to rocks cropping out east and south of Slashers Ledges, which are located west of Route 44 and southeast of Jones Mountain. Because this formation is exposed in the hinge areas of plunging folds, many excellent localities are available at and south of Slashers Ledges. The type locality is on the eastern limb of the northward-plunging synform just south of Slashers Ledges and extends northwest from a point marked "550" on the 550-ft contour line (pl. 1), perpendicular to stratigraphic contacts. A reference locality is located on the west limb of the northward-plunging antiform and extends northwestward from where the contact between the rusty schist and the kyanite schist members crosses the antiform.

The Slashers Ledges Formation is informally divided into two members — the kyanite schist member and the rusty schist member. Both are well exposed in the type locality of the formation. A more convenient exposure of the rusty schist member is located at the junction of the 400-ft contour line and a small brook flowing northeastward to the Farmington River from the outcrop area of the Slashers Ledges Formation. This outcrop forms a small waterfall at the break in slope at the western edge of a river terrace on the western side of the Farmington River.

The Slashers Ledges Formation trends northeastward from Nepaug to the western side of Breezy Hill along a belt varying in width from 1,500 to 4,000 ft. Most outcrops of the formation are found east and south of Slashers Ledges where topography and drainage are delicately adjusted to structure and rock type. The rusty schist member and schist rich in kyanite form hills, whereas the talc-chlorite schist and quartz-plagioclase gneiss form strike valleys along which many brooks flow. On the resistant rocks, streams follow steeply dipping joints oriented perpendicular to the foliation.

Kyanite schist member. This member is a fairly homogeneous unit composed of nonrusty-weathering, kyanite-biotite-plagioclase-quartz-muscovite schist with small porphyroblasts of magnetite, garnet, and plagioclase. Kyanite — which varies in amount — is very striking on most outcrops because it occurs as long (10 to 20 cm) blades randomly arranged on the foliation. On steep joint faces these porphyroblasts protrude as jagged blades and may be the source of the name "Slashers Ledges." In the middle of the member a laminate amphibolite, 5 to 10 ft thick, crops out between a rock that apparently grades across strike from a biotite-quartz-plagioclase gneiss into a quartz-mica-plagioclase schist with small porphyroblasts of garnet and staurolite. This amphibolite is quite distinct from the more massive amphibolite in the lower formations because it is well laminated and in places grades into a hornblende schist. In gross composition, therefore, the member resembles a giant sandwich in which the "bread"is the kyanite schist, and the "filling" — thin though it may be — is the more basic rock rich in calcium, iron, and magnesium, and comparatively poor in aluminum.

The upper contact of the kyanite schist member is placed above nonrusty-weathering kyanite-rich schist and below rusty-weathering mica-plagioclase-quartz schist containing garnet, staurolite, and kyanite in accessory amounts.

Modal analyses of each of the distinctive rock types in the kyanite schist member are listed in table 12. SLksl was counted from a large (9 cm by 3 cm) glomeroblast and is made up of a dense cloud of small randomly oriented kyanite grains.

Rusty schist member. This member is composed of rusty-weathering, medium-grained, muscovite-biotite-plagioclase quartz schist containing garnet, staurolite, and kyanite in accessory amounts. Throughout its extent it is homogeneous and strikingly different from the kyanite schist member. Outcrops of serpentine were observed at nine localities at or near the base of the member. This rock varies in composition from a steatite to an epidote-pyroxene-hornblende gneiss, which locally could be called an amphibolite. The steatite is light olive gray in color (5Y6/1 on the Rock Color Chart distributed by the Geological Society of America) on fresh surfaces and whitish gray on weathered surfaces. Stellate clusters of talc are a conspicuous feature in this rock. The serpentine is black on fresh surfaces, but buff with white patches on weathered outcrops. The pyroxene-hornblende gneiss is black and distinctly layered. All gradations between the steatite and the serpentine can be found, but the gneiss was only found in one locality, along with some serpentine, in the upper reaches of Beckwith Brook just below the second swamp along its course. An excellent outcrop of the steatite is found in an old open-pit mine just west of Steele Road southeast of Atwood Swamp. Most of the nine localities are marked by excavations around old mines.

Table 12. Modal analyses of the kyanite schist member of the Slashers Ledges Formation[1]

SLks sample no.[2]	Q	Pl	Ms	Bi	Hbl	Ep	Gt	Ky	Mg	Chl
1	28.2	3.3	3.4	7.2	....	....	.....	52.6	5.3	.....
2	27.2	18.0	34.0	9.7	....	....	1.2	6.0	3.9	.....
3	22.6	27.6	27.6	22.1	....	....	1.6	....	.....	.....
4	9.6	58.1	....	29.5	....	T^P	.....	....	T	2.4
5	3.5	30.2	....	4.1	55.1	....	.....	....	7.2	.....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Magnetite-quartz-kyanite porphyroblast (9 cm by 3 cm); fg; An 26 (1)
2. Kyanite-plagioclase-quartz-muscovite schist;mg
3. Biotite-quartz-plagioclase-muscovite schist; mg; $\overline{\mathrm{An}}$ 24 (3), 23-25
4. Biotite-plagioclase gneiss; mg; An 27 (1)
5. Plagioclase-hornblende schist; mg; An 24 (1); Hbl $\overline{Z \wedge C}$ 17 (6), $2V_x$; X colorless to buff, Y olive green, Z blue gray

PETROGRAPHY OF MEMBER

TEXTURE: Foliate in schist. C-axes of hornblende lineated in the foliation. Porphyroblasts of plagioclase and kyanite commonly contain undulating trails of fine mica, magnetite, and quartz that cut across undeformed twin lamellae and cleavage.

MINERAL FEATURES: *Quartz*: Uniform extinction. Some grains fractured. *Plagioclase*: Commonly untwinned. Mildly sericitized. *Biotite*: X colorless, YZ red brown. A few grains chloritized. *Kyanite*: A few grains partly sericitized.

Unlike many of the serpentine bodies of eastern Vermont and western Massachusetts, this serpentine is concordant with the foliation in the surrounding rocks and shows no zoning. Instead, individual outcrops seem to be a mixture of serpentine and steatite with intermediate varieties. In some of these outcrops serpentine appears as pseudomorphs of hornblende. Presumably the parent to the serpentine and steatite is represented by the hornblende-pyroxene gneiss, because serpentine cuts and is interlayered with the gneiss in the outcrop along Beckwith Brook. In none of the nine localities is the kyanite or rusty schist altered near or in contact with the serpentine. Although these bodies now appear as discontinuous lenses, they may well have once been continuous and subsequently pulled apart during deformation. Modes of some of the typical rocks in the rusty schist member are listed on table 13. In the rusty schist, quartz and muscovite, respectively, are more abundant than plagioclase and biotite. In both thin sections, porphyroblasts of garnet, staurolite, and kyanite are present, and in one they are actually touching. Only modes from the pyroxene-hornblende gneiss are listed on table 13; they show that the percentage or hornblende or pyroxene can vary considerably, but together they form about 70 percent of the rock, whereas the other minerals constitute the remaining 30 percent. In the altered rocks the percentage of talc and chlorite is quite variable with talc ranging as high as 80 percent in the steatite, but forming only about 15 percent in the serpentine. Normally at least two chlorite minerals are present along with such opaque minerals as magnetite and pyrite. A small percentage of carbonate generally is present in the steatite.

The upper contact of the rusty schist member is not exposed in the Collinsville quadrangle.

Table 13. Modal analyses of the rusty schist member of the Slashers Ledges Formation[1]

SLrs sample no.[2]	Q	Pl	Ms	Bi	Hbl	Px	Ep	Gt	Sph	Ky	Stau	Ap
1	32.0	4.9	31.5	18.1	....	....	....	9.2	.....	0.9	3.4	....
2	20.9	6.1	35.5	28.5	....	....	....	4.8	.....	2.0	2.2	....
3	T	14.3	....	....	53.7	17.6	12.8^P	.....	1.3	.....	.....	T
4	....	7.6	....	0.8	16.0	56.5	17.1^P	.....	2.0	.....	.....	....

[1] For explanation of abbreviations used in this table, see table 1.

[2] DESCRIPTION OF SAMPLES

1. Biotite-muscovite-quartz schist; mg
2. Quartz-biotite-muscovite schist; mg
3. Epidote-plagioclase-pyroxene-hornblende gneiss; mg; An*38 (1) $2V_x$ 86; Px* $Z \wedge C$ 48 (1), $2V_z$ 64 (1) (hedenbergite); Hbl* $\overline{Z \wedge C}$ 21 (3), $2V_x$ 74 (3); X colorless or buff, Y olive green, Z blue gray
4. Hornblende-epidote-pyroxene gneiss; mg; Px* $\overline{Z \wedge C}$ 45 (4), $2V_z$ 64 (4) (hedenbergite); Hbl* $Z \wedge C$ 24 (1), $2V_x$ 64 (1); pleochroic formula as in SLrs 3

PETROGRAPHY OF MEMBER

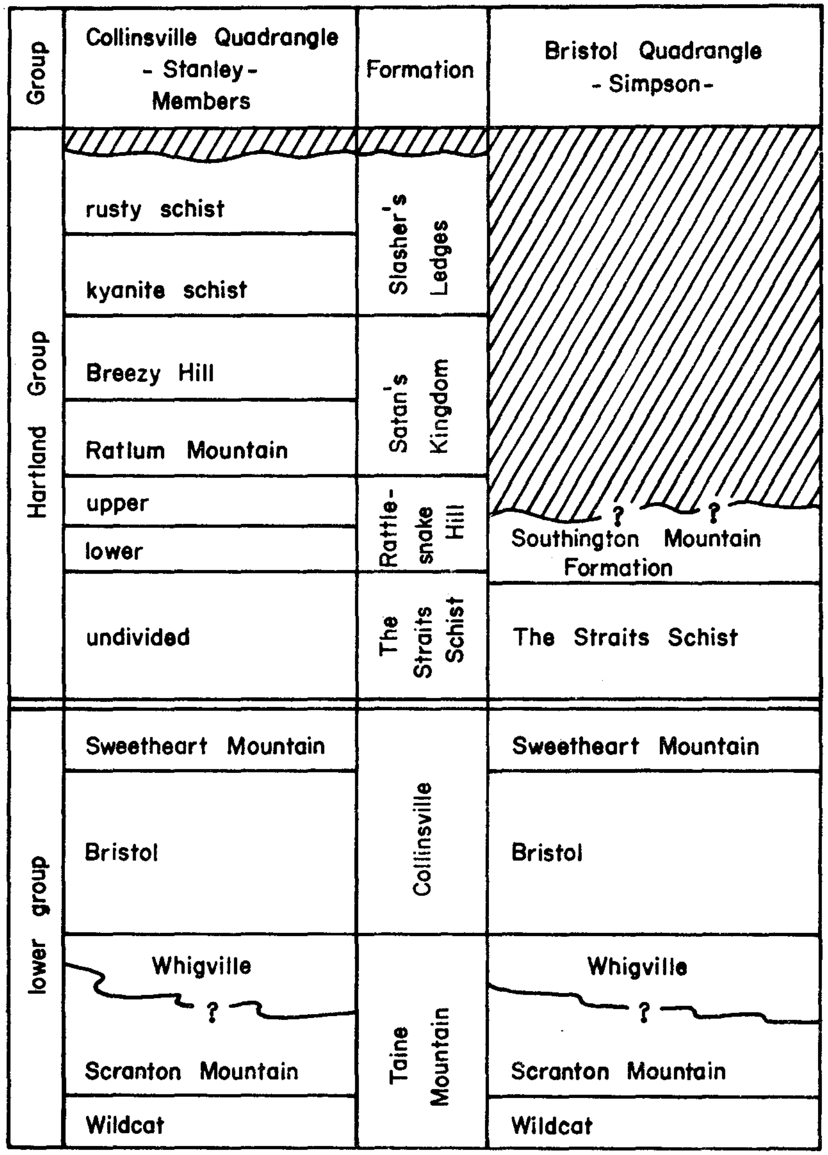
TEXTURE: *Schist* foliate, with porphyroblasts of garnet, staurolite, and kyanite. *Pyroxene-hornblende gneiss* with very complicated texture, consisting of large poikiloblastic grains of hornblende and pyroxene together with smaller grains of plagioclase, epidote, and sphene. *Serpentine and steatite:* A plexus of talc and two species of chlorite which are consistently different in grain size. Magnetite and pyrite abundant, whereas carbonate is minor and present only in the steatite.

MINERAL FEATURES: *Plagioclase*: Commonly porphyroblastic, untwinned, and partly sericitized in the schist. In the pyroxene-hornblende gneiss extinction is zonal or irregular. Anorthite compositions range from An 28 to An 47. *Biotite*: X colorless, YZ red brown in the schist. *Pyroxene*: $2V_z$ measurements are in the range of hedenbergite, according to Winchell (1951, figs. 289, 306). *Epidote*: Many grains contain normal zoning with material of high birefringence surrounded by material of low birefringence. Reverse zoning present in some samples. *Chlorite*: Two species are present in the serpentine and steatite. One is nonpleochroic, optically positive, and light gray in birefringence; the other is pleochroic, with X very light yellow and YZ light yellow green, optically negative, and first-order blue in birefringence.

Correlation and age of the metamorphic rocks

The correlation of metamorphic formations of the Collinsville quadrangle with others defined in western Connecticut is certainly not final. Even more doubtful is a detailed correlation with the formations of Vermont. One of the prime goals of current mapping in western New England is a synthesis commensurate with detailed mapping. Such a synthesis can only be made with confidence when the various stratigraphic sections throughout this part of New England are fitted together into a coherent framework. At present this is not possible, but different correlation schemes suggested by workers in the region certainly will provide guides for the future. In the following paragraphs several schemes are suggested for correlation with other areas in western Connecticut and with eastern Vermont, where the stratigraphic section is more fully documented. The main key to all the schemes is The Straits Schist which can now be traced from Long Hill in south-central Connecticut to just south of Little River in southern Massachusetts. The detailed correlation of the Hartland Group is the chief problem in all of the schemes.

Correlation of the rock units in the eastern margin of the Western Highlands is shown in figures 5 and 6 and is based on recent unpublished



Group	Collinsville Quadrangle - Stanley - Members	Formation	Bristol Quadrangle - Simpson -
Hartland Group	rusty schist	Slasher's Ledges	
	kyanite schist		
	Breezy Hill	Satan's Kingdom	
	Ratlum Mountain		? ?
	upper	Rattle-snake Hill	Southington Mountain Formation
	lower		
	undivided	The Straits Schist	The Straits Schist
lower group	Sweetheart Mountain	Collinsville	Sweetheart Mountain
	Bristol		Bristol
	Whigville ? Scranton Mountain	Taine Mountain	Whigville ? Scranton Mountain
	Wildcat		Wildcat

Fig. 5. Correlation of the stratigraphic sections in the Collinsville and Bristol quadrangles, Connecticut.

work by Fritts and Simpson, and on material contained in this report. The Straits Schist can easily be traced throughout this area and, therefore, is fundamental to any hypothesis. Although the correlation of the Taine Mountain and Collinsville Formations within the Collinsville and Bristol quadrangles is very clear, these units have not as yet been recognized as such in the Waterbury and Oxford domes. Reconnaissance work in the Waterbury and Southbury quadrangles, however, has shown that rocks identical to the Collinsville and Taine Mountain Formations are present. Even though an unconformity is mapped at the base of The Straits Schist in the Mount Carmel and Southington quadrangles and in the southern part of the Bristol quadrangle, no unconformity was found along the correlative stratigraphic horizon in the Collinsville quadrangle.

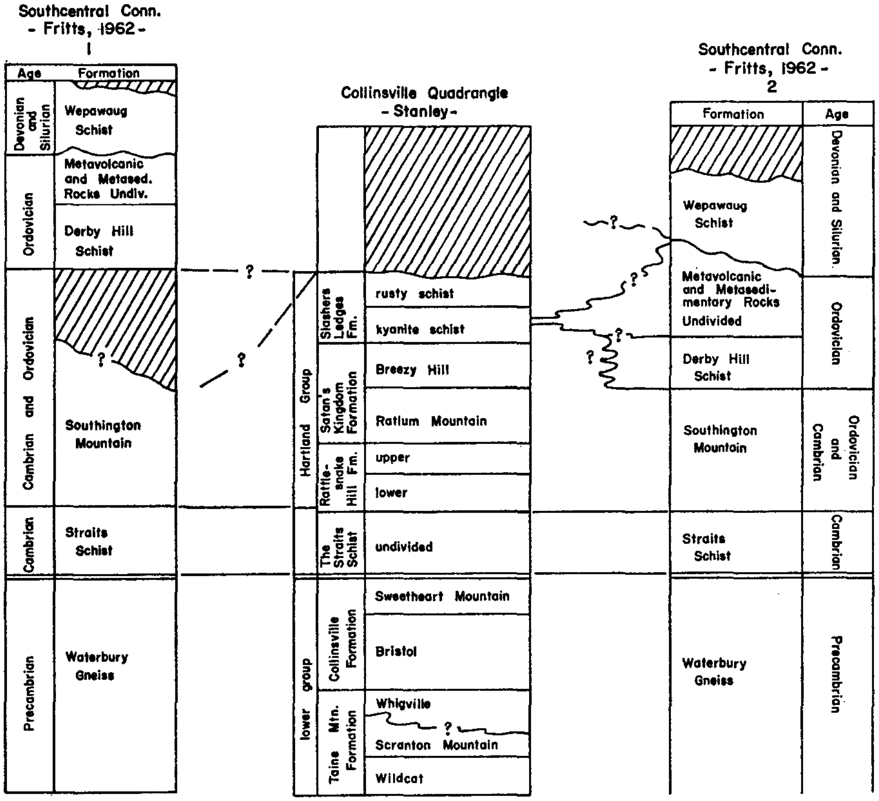


Fig. 6. Correlation schemes for the stratigraphic sections in the Collinsville quadrangle and in south-central Connecticut.

Correlation of the Rattlesnake Hill, Satan's Kingdom, and Slashers Ledges Formations with the rocks above The Straits Schist east and south of the Waterbury dome is a problem, and although no clear-cut solution can be presented, certain limitations can be proposed. Rocks belonging to the Derby Hill Schist through the Wepawaug Schist are not present *as such* in the Collinsville quadrangle. It is likely that rocks above The Straits Schist in the Hartland Group are in part equivalent to the Southington Mountain Formation and underlie the Derby Hill Schist. Whether the Southington Mountain Formation includes all the formations above The Straits Schist is debatable. Descriptions and outcrops of the Southington Mountain Formation (Fritts, 1963b, 1963c) fit only the Rattlesnake Hill Formation and possibly some of the Satan's Kingdom Formation. It is quite possible that the Derby Hill Schist may unconformably overlie the Southington Mountain Formation, thus cutting out much of the section present in the Collinsville quadrangle (solution 1, fig. 6). Such an unconformity has not been mapped by Fritts. The need for a pre-Derby Hill unconformity, however, could easily vanish if future mapping in the Southington Mountain Formation reveals all the Collinsville section above The Straits Schist.

Another solution to this problem is shown in figure 6 (solution 2). Here the Derby Hill Schist is considered a facies equivalent of the Breezy Hill Member of the Satan's Kingdom Formation because the two are somewhat similar. This scheme, however, creates an additional problem. Where in the Collinsville section are the rocks above the Derby Hill Schist? One can easily see how the Wepawaug Schist could be missing, because it rests unconformably on lower rocks, thus allowing formations to be added or subtracted below the unconformity (Fritts, 1962). It is not present in the Collinsville quadrangle and presumably was removed during post-Acadian erosion. The metavolcanics that overlie the Derby Hill Schist are correlated with the Barnard Volcanic Member of the Missisquoi Formation (Fritts, 1962). These rocks are not present in the Collinsville quadrangle, but it is quite possible that the volcanics could pinch out to the north and west, and, therefore, not be present on the western side of the Collinsville quadrangle. The rusty schist of the Slashers Ledges Formation could then be equivalent to the Cram Hill Member of the Missisquoi Formation which is also rusty weathering.

The Cram Hill Member is not recognized as such in south-central Connecticut and presumably was removed by pre-Wepawaug erosion, if it was ever present. Admittedly, both of these solutions have difficulties. The second scheme, however, is more consistent with the correlation with the Vermont section, which I prefer, although it does involve several facies changes in Connecticut. On the other hand, the first scheme is simpler and is unhampered by hypothetical facies changes.

Turning now to Vermont, one finds several schemes possible (see fig. 7). Currently our knowledge of the detailed stratigraphy of western Massachusetts is mainly based on the broad mapping of Emerson (1898, 1917). Detailed mapping is just beginning in the northern and southern parts of the state so that any correlation from Connecticut to Vermont must jump the gap with only the aid of Emerson's map. The ages of the formations in Vermont are determined in part by fossils found in eastern Vermont and adjacent Quebec and, in part, on correlation to rocks cropping out on the Green Mountain axis in southern Quebec, where, according to Osberg (1956) and Cady (1960), they interfinger with the fossiliferous carbonate-quartzite assemblage of the Champlain Valley.

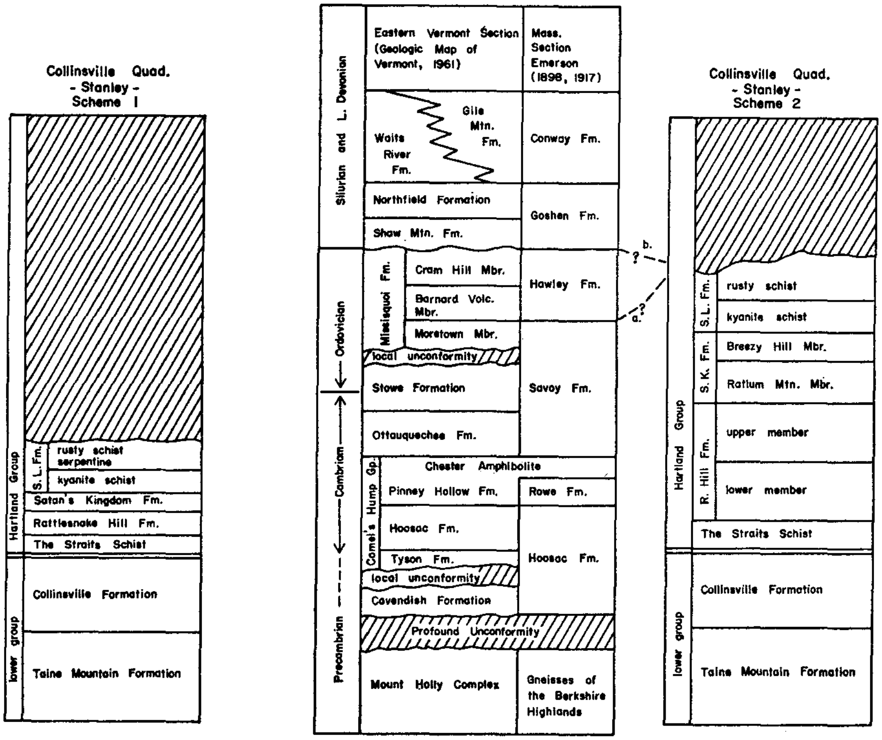


Fig. 7. Schemes for correlation of the stratigraphic sections in the Collinsville quadrangle and in eastern Vermont.

Such evidence forms the basis of the stratigraphic column shown on the Geologic Map of Vermont (Doll and others, 1961) where rocks below the Shaw Mountain Formation are considered Cambrian and Ordovician. Precambrian rocks are shown in the Green Mountain anticlinorium and in gneiss domes such as the Chester and Lake Raponda domes. The formations from the base of the Hoosac Formation up to and including the Waits River Formation can be traced with comparative ease to the southern part of Massachusetts where, according to Emerson (1917), they strike southeastward under the Triassic in the vicinity of Granville (fig. 2). Structurally, the pattern appears simple in most of western Massachusetts, but becomes complex north of Blandford where the formations are thrown into a series of tight folds before diving under the Triassic rocks (see Emerson, 1917). In 1898 Emerson stated that the Hoosac continued into northwestern Connecticut and formed what Gregory in 1906-1907 assigned to the Hartland Formation. Rodgers (Rodgers and others, 1959) considered The Straits Schist the base of the Hartland Formation and equivalent to at least part of the Hoosac Formation.

On the assumption that the stratigraphic succession adapted for the Collinsville quadrangle is correct, two general schemes of correlation with

Massachusetts and southeastern Vermont are proposed. Admittedly, other schemes are possible, but these appear most likely on the basis of our current knowledge. Key to both hypotheses is The Straits Schist. With only a small break just east of the Waterbury dome, this formation can be traced throughout the eastern portion of western Connecticut. North of the Collinsville dome The Straits Schist plunges under the Rattlesnake Hill Formation, but reappears around the two Granby domes (Schnabel, personal communications, 1962). Just south of the Little River in Massachusetts The Straits Schist finally disappears and is covered by higher formations including the Goshen and Conway Formations of Silurian and Devonian age. In Massachusetts The Straits Schist forms part of the area mapped as the Hoosac Formation by Emerson (1917). In my work along Little River northwest of the North Granby dome a succession of map units above The Straits Schist has been separated. One of these units is filled with small porphyroblasts of feldspar and, according to available descriptions, is similar to the Hoosac Formation, thereby substantiating the correlation of The Straits Schist with at least part of the Hoosac Formation (Rodgers and others, 1959). Consequently, both the Collinsville and Taine Mountain Formations would be older than Hoosac Formation which is considered Lower Cambrian and Cambrian (?) by Cady (1960) and listed as Cambrian on the Geologic Map of Vermont (Doll and others, 1961). The lower group in the Collinsville section would then be equivalent to the Mount Holly complex of Precambrian age or to the Cavendish Formation of Cambrian (?) age. This correlation is identical in both the schemes shown on figure 7 and is considered a likely possibility based on the relations around the North Granby dome.

In both schemes (fig. 7) the Rattlesnake Hill, Satan's Kingdom, and Slashers Ledges Formations are correlated with the rocks below the Silurian and Devonian rocks of eastern Vermont. Although the rusty schist of the Slashers Ledges Formation and the Northfield Formation are both rusty weathering, they are quite different in other important aspects. The Northfield Formation includes thin beds of brown-weathering, impure limestone that is interlayered with dark-gray slate (Skehan, 1961) and is correlative with the Goshen Formation or Massachusetts. Near Blandford, in southern Massachusetts, the Goshen has been metamorphosed to the amphibolite facies and is very different from the rusty schist of the Slashers Ledges Formation which is devoid of calc-silicate rocks. Furthermore, the rusty schist contains lenses of serpentine which are reported only from the Cambrian and Ordovician rocks of Vermont. Therefore, it is unlikely that any of the Hartland Group in the Collinsville quadrangle is equivalent to the Silurian and Devonian rocks of Vermont. The two schemes shown in figure 7, therefore, differ only in the degree to which the upper three formations of the Hartland Group are stretched out or compressed relative to the Cambrian and Ordovician rocks of eastern Vermont.

According to scheme 1 (fig. 7), the Hartland Group is equivalent with the Hoosac, Rowe, Chester Amphibolite, and basal Savoy Formations of Massachusetts, which correspond to the Tyson, Hoosac, Pinney Hollow, and Ottauquechee Formations of Cambrian age in eastern Vermont. This correlation is based on the following evidence:

1) The serpentine and steatite lenses in the base of the rusty schist of

the Slashers Ledges Formation are similar to rocks in the Chester Amphibolite described by Emerson (1898, 1917), whose map shows serpentine and steatite in ten localities along the formation in Massachusetts. At one of these, near West Granville, a kyanite schist comparable to the kyanite schist of the Slashers Ledges Formation crops out near a steatite. In this same general area, the Chester Amphibolite outlines a system of major folds that plunge to the north (Emerson, 1917). The western syncline in the Chester Amphibolite is on line with Slashers Ledges in the Collinsille quadrangle where steatite and serpentine are found in a complex synclinal structure that separates the folds of Slashers Ledges from those of Ratlum Mountain. Folds plunging at gentle angles to the north are found along the eastern border of the Berkshire Highlands in Connecticut and in southern Massachusetts and suggest that the major folds in the Collinsville quadrangle continue northward to West Granville. In this scheme, the rusty schist, the highest unit in the Collinsville quadrangle, would be equal to the basal part of the Savoy Formation of Massachusetts or to the Ottauquechee Formation of Vermont.

2) Available descriptions indicate that the Satan's Kingdom Formation is somewhat similar to parts of the Hoosac Formation. According to Emerson (1917), Cady (1960), and Doll and his coworkers (1961), schist with albite porphyroblasts is characteristic of parts of this formation from Massachusetts to the northern part of Vermont. In the Collinsville quadrangle large plagioclase porphyroblasts are abundant near the amphibolite in the Ratlum Mountain Member, whereas small plagioclase porphyroblasts are typical in many parts of the Breezy Hill Member.

This scheme appears quite feasible when one studies Emerson's geologic map, but recent detailed work both in northern and southern Massachusetts indicates that Emerson mapped as the Chester Amphibolite serpentines that are found in formations ranging from the Hoosac to the Missisquoi of Vermont (Chidester, personal communications, 1962). Therefore, any correlation scheme based solely on the Chester Amphibolite is misleading. Consequently, the presence of serpentines and steatites in the highest unit of the Collinsville quadrangle suggests only that the section is equivalent to the Cambrian and Ordovician section of eastern Vermont, because there serpentines are found only in that part of the section.

According to the second scheme, the Hartland Group is correlated with the Hoosac, Rowe, Chester Amphibolite, and Savoy Formations of Massachusetts, which correspond to the Cambrian and Ordovician section below the Barnard Volcanic Member of the Missisquoi Formation in Vermont. As shown on figure 7, the upper two members of the Missisquoi Formation are equivalent to the Hawley Formation in Massachusetts and are in part composed of interlayered acid and basic volcanics, although the Cram Hill Member of the Missisquoi Formation is in large part a rusty-weathering, carbonaceous mica schist. Because the upper part of the section in the Collinsville quadrangle contains only a few beds of amphibolite and plagioclase gneiss — both presumed to be of volcanic origin — equivalents of the Hawley Formation are probably not present (fig. 7, scheme 2a). It is quite possible, however, that the volcanics could pinch out to the south and west and that the rusty schist of the Slashers Ledges Formation could be equivalent to the Cram Hill Member (fig. 7, scheme 2b).

The formations below the Hawley Formation show definite similarities to those of the Hartland Group. The correlation of The Straits Schist with at least part of the Hoosac Formation has already been discussed. The lower member of the Rattlesnake Hill Formation can also be recognized along Little River in Massachusetts where it directly overlies The Straits Schist as it does in the Collinsville quadrangle. It is overlain by a schist with small plagioclase porphyroblasts typical of the Hoosac Formation, which indicates that this lower member of the Rattlesnake Hill Formation is probably part of the Hoosac Formation. In eastern Vermont and northern Massachusetts the Ottauquechee Formation consists of thinly bedded, dark-colored quartzite interbedded with rusty-weathering, carbonaceous schist comparable to that in the upper member of the Rattlesnake Hill Formation. If these correlations are valid, the Pinney Hollow Formation, as well as part of the Hoosac Formation, may decrease in thickness toward Connecticut and, if present at all in the Collinsville quadrangle, may be included in the Rattlesnake Hill Formation. Current mapping along Little River in Massachusetts suggests that the Rattlesnake Hill Formation does indeed thicken to the north where it includes map units that are not present in the Collinsville quadrangle. The Ratlum Mountain Member of the Satan's Kingdom Formation and the Stowe Formation of Vermont are similar in that they both contain aluminous rocks and porphyroblasts of plagioclase, garnet, kyanite, and staurolite (chloritoid in Vermont); furthermore, both contain beds of amphibolite. Near Blandford, just northwest of the Little River, rocks comparable to the Ratlum Mountain Member crop out adjacent to rocks that are tentatively considered to be the Moretown Member of the Missisquoi Formation of Vermont. Finally, there are parts of the Breezy Hill Member that consist of well banded, nonrusty-weathering schist in which quartz-rich layers (2 cm thick) alternate with mica-rich layers. This feature is common in the Moretown Member.

Admittedly, there are weaknesses in both of the schemes shown in figure 7. Of the two, the second seems currently to fit the facts better. Whether the rusty schist of the Slashers Ledges Formation is equivalent to part of the Moretown or Cram Hill Members of the Missisquoi Formation is debatable. The second scheme is deficient in that it requires part of the lower section in Vermont to pinch out toward Connecticut. Furthermore, the similarities between the Stowe-Moretown and the Ratlum Mountain-Breezy Hill units are only suggestive at best and must await the completion of detailed work in northern Connecticut and southern Massachusetts. At present, however, it seems reasonable to correlate The Straits Schist with the Hoosac Formation, which would then make the Collinsville and Taine Mountain Formations equivalent possibly to the Mount Holly Complex. In addition, it is unlikely that any of the Silurian and Devonian rocks of Vermont are present in the Collinsville quadrangle. The most doubtful correlation, then, is the upper three formations of the Hartland Group with specific formations in the Vermont section, although it seems quite likely that they must fit somewhere in the Cambrian and Ordovician section.

GRANITIC ROCKS

The granitic rocks in the Collinsville quadrangle include pegmatite, medium-to coarse-grained rocks of granitic composition, and aplite. They are commonly light colored, unfoliated, in bodies of varying size and shape, and contain different proportions of plagioclase, quartz, microcline, and muscovite. Garnet is a common accessory in rocks below the Rattlesnake Hill Formation. Tourmaline is found only in bodies associated with schist. Biotite is most prominent in pegmatites associated with calc-silicate gneiss, although it is also found in pegmatites in the Satan's Kingdom Formation. Grain size is normally quite variable, ranging from fine to very coarse; in the coarsest varieties crystals of feldspar commonly reach a foot in length. Typically the pegmatites are not zoned and the grain size does not change systematically toward the border. The contacts are extremely irregular and interdigitate with the adjacent schist, especially in discordant bodies. In most outcrops it is impossible to obtain an acccurate picture of the shape of individual bodies because of insufficient three-dimensional exposure, but sills and dikes — both with nonparallel contacts — are plentiful. Generally, small pegmatites are present along boudin lines. Most granitic rocks are not folded, but several small folded bodies were found on Ratlum Mountain and in the domes. In several large outcrops, dikes of "granite" cut other granitic bodies and indicate, at least locally, more than one pulse of intrusion in the overall event of deformation and metamorphism in the area.

Although no systematic effort was made to subdivide the granitic rocks, several conspicuous variations were mapped and are shown by distinct symbols on the geologic map (pl. 1). In the Collinsville dome, about 50 percent of the granitic rocks normally contain pink feldspar, particularly those associated with amphibolite and chlorite-bearing plagioclase gneiss.

Pegmatites devoid of pink feldspar appear to be more abundant in the outer portion of the Collinsville dome than in the inner portion, and are well displayed along the roadcut on Route 4 in Collinsville. In the southwestern part of the Bristol dome, in a large outcrop of pegmatite on both sides of Milford Road, there are large grains of feldspar with graphic intergrowths of quartz. This type of pegmatite is rare in the quadrangle and is identical to the "plum-pudding" Nonewaug granite in the Woodbury quadrangle (Gates, 1954). A foliated granitic rock with small (10 to 15 mm) porphyroblasts of microcline is found only along a narrow belt which extends northeastward from Nepaug along the eastern side of Jones Mountain and is on strike with the reverse fault, located along Ratlum Brook just east of the East Branch of Farmington River. Just north of Woodchuck Road a biotite pegmatite with red feldspars intrudes a slabby calc-silicate gneiss in lit-par-lit fashion. This distinctive association is best seen in an outcrop along the spillway to Simsbury Reservoir in the Tariffville quadrangle. The large bodies of granitic rock are more resistant to erosion than is the surrounding country rock and form rounded knobs commonly elongate parallel to the dominant foliation in the adjacent country rock. In contrast, the plagioclase gneiss, normally containing as much quartz as do the granitic rocks but lacking microcline, forms such topographic lows as the Canton basin. This suggests that microline may be an important factor in determining the relative erodibility of these two groups of rocks. Despite their topographic expression, a thin veneer of weathered material is found on most of the granitic outcrops.

The distribution of the granitic rocks is controlled primarily by major structures, although the composition of the country rock appears to exert some control. As shown on the geologic map (pl. 1), these rocks are particularly abundant in the Scranton Mountain Member of the Taine Mountain Formation, the Collinsville Formation, the Ratlum Mountain Member of the Satan's Kingdom Formation, and the rusty schist member of the Slashers Ledges Formation. In each of these units, however, the granitic rocks are most abundant in particular structural positions such as the hinge line of the major folds. In the Collinsville dome they strike northeastward at a high angle to the predominant lineation (mineral lineation and minor fold axes) which plunges northwestward. Although it is practically impossible to measure the dip of many of these discordant bodies, this relationship suggests that they may be perpendicular to the lineations, as is commonly reported in other metamorphic areas. A similar relationship is also found in the northern part of the Bristol dome on Sweetheart Mountain. In this same dome, however, the granitic rocks are elongate parallel to the foliation on Scranton and Wildcat Mountains. Here they are very abundant in an area where the strike of the foliation changes from the northwest to the northeast in a distance of about 2,000 ft. In the major folds west of the domes, the bodies of granitic rock are commonly elongate parallel to the foliation and are very abundant along the hinges of the major folds, such as on Ratlum Mountain. Where well exposed, these bodies form irregular sills with amoeboid appendages which crosscut the foliation or join with other sills at different levels in the outcrop. Dikes oriented nearly perpendicular to the fold axes of the major folds are far less common.

In table 14 are listed modal analyses of 26 samples, randomly selected from the fine or medium portions of the granitic rocks shown on plate 1. Thirteen of the samples were collected from the lower group in the Collinsville and Bristol domes. Three of the samples are foliate. It is not claimed that these samples are modally representative of each granitic body. An indication of the amount of variation within one body is shown by samples 1681a, b and P6a, b. In all the samples quartz ranges from 21 percent to 45 percent, whereas the percentage of plagioclase to total feldspar ranges from 20 percent to 100 percent. In those samples that contain only plagioclase, muscovite is on the average about 10 percent greater than in samples containing microcline. Biotite is more common in the granitic rocks from the Hartland Group than in those from the lower group and is generally less than 3 percent, except in sample 486 where it makes up about 8 percent of the rock. This sample is from the outcrop of a 5-ft sill that is in turn cut by a muscovite pegmatite.

Table 14. Modal analyses of the granitic rocks[1]

Stratigraphic unit[2]	Sample no.[3]	Q	Pl	Mi	Ms	Bi	Gt	Misc	Grain Size	Flat Stage	Index of Refraction or Universal Stage
SLrs	70	31.3	36.8	24.8	6.3	0.6	.....	......	mg	$\overline{\text{An}}$ 15 (7); 12-18	An*17 (1), $2V_x$ 87
	385	31.2	36.0	26.8	6.3	0.7	.....	......	mg	$\overline{\text{An}}$ 16 (7); 13-18	$\overline{\text{An}}$°13 (2)
SKrm	486	30.4	47.9	9.8	3.9	7.9	.....	T^{Z}	fg	An 17 (1)	—
	P-1	43.7	30.8	....	25.5	.....	.....	......	mg	—	—
	P-4	43.0	40.5	....	16.4	T	.....	......	mg	$\overline{\text{An}}$ 14 (7); 12-19	$\overline{\text{An}}$°12 (4)
	1681 (a)	35.9	44.9	....	19.1	T	.....	......	mg	$\overline{\text{An}}$ 12 (8); 10-13	An*18, $2V_x$ 83
	1681 (b)	34.3	46.8	....	15.7	3.1	.....	T^{Ap}	mg	$\overline{\text{An}}$ 13 (8); 10-19	—
	P6a	30.9	59.5	T	7.1	2.1	.....	......	mg	$\overline{\text{An}}$ 16 (9); 15-18	$\overline{\text{An}}$°18 (2)
	P6b	41.3	36.8	....	19.8	2.1	.....	......	mg	$\overline{\text{An}}$ 14 (9); 12-18	—
RHum	2160f	32.9	32.0	22.5	8.1	4.1	T	......	mg	—	—
RHlm	590 (2)	29.1	45.1	17.0	8.5	T	.....	......	mg	—	An*13 (1), 2V 90
S	270	38.7	40.6	4.2	15.7	.....	0.8	......	mg	$\overline{\text{An}}$ 12 (8); 10-13	—
	789	27.5	44.0	25.5	1.5	1.5	.....	......	mg	$\overline{\text{An}}$ 14 (8); 7-17	An°7 (1)
Cb	1053	30.9	34.3	24.4	8.8	.....	1.5	T^{Ap}	mg	$\overline{\text{An}}$ 11 (8); 1-14	—
	1467 (3)	32.4	44.5	10.6	11.8	0.6	.....	T^{Ap}	mg	$\overline{\text{An}}$ 11 (10); 7-13	—
	1117f	40.5	29.0	....	28.5	.....	2.0	......	fg	$\overline{\text{An}}$ 11 (10); 7-14	—
	1278	35.5	38.7	18.5	6.6	.....	0.7	......	mg	$\overline{\text{An}}$ 13 (6); 10-17	—
	1581	23.8	37.7	29.8	6.3	2.4	.....	......	mg	$\overline{\text{An}}$ 13 (6); 10-18	An*14 (1), $2V_x$ 87
Tsm	65	40.8	40.2	....	18.7	.....	T	......	mg	$\overline{\text{An}}$ 10 (6); 7-13	—
	1293f	43.2	19.8	....	36.7	.....	T	......	fg	$\overline{\text{An}}$ 13 (3); 13-19	—
	1121	38.8	48.5	....	12.4	T	T	......	fg	$\overline{\text{An}}$ 15 (6); 12-14	—
	1205	32.4	49.4	6.4	11.8	.....	.....	......	mg	$\overline{\text{An}}$ 7 (8); 3-12	An*7 (1), $2V_x$ 85
	1055	21.2	15.3	63.1	T	.....	.....	......	mg	$\overline{\text{An}}$ 6 (6); 0-10	An°5 (2)
	1295	41.1	45.2	3.6	10.1	.....	.....	......	mg	$\overline{\text{An}}$ 10 (6); 7-17	—
Twc	1071	32.5	20.0	39.4	4.3	.....	2.8	......	mg	$\overline{\text{An}}$ 6 (5); 2-11	An*9 (1), $2V_x$ 81
	1072	45.1	32.6	17.1	5.3	T	.....	......	fg	$\overline{\text{An}}$ 12 (8); 10-17	—

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[1] For explanation of abbreviations used in this table, see table 1.

[2] For stratigraphic unit names see Explanation of plate 1.

[3] PETROGRAPHY OF GRANITIC SAMPLES

TEXTURE: Xenomorphic granular with only the micas approaching subhedral form. In foliated rocks the micas form the foliation, whereas the quartz and feldspar are granoblastically interlocked. Grain contacts are either mosaic or simple implicate patterns in which small lobate peninsulas of adjacent material interdigitate.

MINERAL FEATURES: *Quartz*: Uniform extinction the rule; mosaic and undulatory extinction rare. In addition to single grains, quartz occurs as droplets and wormlike inclusions in feldspar and muscovite. *Plagioclase*: Commonly twinned according to albite law or albite-ala law. Anorthite content ranges from albite to sodic oligoclase. Sericite is present in most grains, but is most abundant in the rocks surrounded by calc-silicate gneiss and granulite. Extinction uniform except in samples 486 and 1121, where thin rims are present in plagioclase grains in contact with microcline or muscovite. *Microcline*: Appears to replace plagioclase. Typically not sericitized; interstitial to the other essential minerals with narrow digitations commonly penetrating adjacent plagioclase grains. Inclusions of quartz and muscovite common; inclusions of plagioclase less common and normally contain a thin clear rim free of sericite surrounding a core of sericitized plagioclase.

METAMORPHISM

General statement

The rocks in the Collinsville quadrangle represent a variety of compositions that include aluminous schists, quartzo-feldspathic rocks, amphibolite or basic schist, and calc-silicate gneiss. Iron and magnesium rocks are represented by cummingtonite and anthophyllite gneiss found in minor amounts in both the lower and Hartland Groups. With such compositional coverage it is relatively easy to assign the rocks to the almandine-amphibolite facies of Turner and Verhoogen (1960), *but* the subfacies designation becomes more of a problem when one considers the phases present in the aluminous schists, the most sensitive indicators of grade in the facies.

Partial alteration of biotite, plagioclase, and kyanite, as well as the formation of randomly oriented porphyroblasts, sheds some light on recrystallization during the waning stages of metamorphism subsequent to much of the deformational activity. More intense retrograde alteration is found in the crystalline rocks adjacent to the border fault of Triassic age and is presumably due to the influx of solutions along this fault.

Facies assignment

Mineral assemblages of the greenschist facies are found in the serpentine lenses in both the Collinsville and Slashers Ledges Formations. Except for these lenses of serpentine and the altered rocks adjacent to the eastern border fault, the rocks in the quadrangle have been metamorphosed to phase assemblages of the lower and middle parts of the almandine-amphibolite facies, which correspond to the staurolite and kyanite zones of the Barrovian sequence. The occurrence of microscopic sillimanite (fibrolite) scattered in some of the rocks in the quadrangle does suggest

Table 15. Representative mineral assemblages in the Collinsville quadrangle.

Facies	Mineral assemblages
Greenschist	Serpentine-talc-carbonate (calcite?)
Almandine-Amphibolite Facies	Quartz + plagioclase (oligoclase) + biotite ± muscovite
	Quartz + plagioclase (calcic oligoclase) + cummingtonite + hornblende
	Plagioclase (calcic oligoclase) + biotite + garnet + anthophyllite
	Quartz + plagioclase (calcic oligoclase) + biotite + hornblende + epidote (pistacite) ± garnet
	Quartz + plagioclase (calcic oligoclase-sodic andesine) + biotite + muscovite + garnet ± kyanite ± staurolite
	Quartz + plagioclase (sodic andesine) + biotite + muscovite ± garnet
	Quartz + plagioclase + biotite + epidote (pistacite)
	Quartz + plagioclase (andesine) + hornblende ± garnet ± epidote (pistacite)
	Quartz + plagioclase (calcic andesine) + diopside + hornblende + clinozoisite + microcline
	Quartz + plagioclase + calcite + biotite
	Quartz + plagioclase (bytownite-anorthite) + biotite + hornblende + garnet + clinozoisite

that some of the rocks are within the first sillimanite isograde that develops more fully to the north in the New Hartford and Southwick quadrangles. This facies assignment is based on mineral assemblages from a wide range of compositions, and on the anorthite content of plagioclase listed under the modal analyses for each stratigraphic unit.

The representative mineral assemblages found in the Collinsville quadrangle are listed in table 15. The task of selecting the subfacies that best fits the assemblages is not easy. According to Turner and Verhoogen (1960) the almandine-amphibolite facies is divided into four subfacies: the staurolite-almandine subfacies, the kyanite-almandine-muscovite subfacies, the sillimanite-almandine-muscovite subfacies, and the sillimanite-almandine-orthoclase subfacies. These are arranged in order of increasing grade and correspond to the staurolite, kyanite, first sillimanite, and second sillimanite isogrades. The two lower subfacies are identical except that staurolite is absent in the kyanite-almandine-muscovite subfacies. The sillimanite-almandine-muscovite subfacies differs from the next lower subfacies in that kyanite is replaced by sillimanite, plagioclase is slightly more calcic, and epidote is absent or sparse. The sillimanite-almandine-orthoclase subfacies differs from the lower subfacies in most compositional areas. Muscovite is absent, sillimanite and garnet are associated with orthoclase in the aluminous rocks, diopside rather than epidote is present in amphibolite, and grossularite and anorthite are present in the calcareous rocks. Clearly, the rocks in the Collinsville quadrangle are not in the sillimanite-almandine-orthoclase subfacies. It is unlikely that any of the assemblages are fully representative of the sillimanite-almandine-muscovite subfacies, because sillimanite, although found in some aluminous rocks, is only present in trace amounts and, therefore, can be disregarded if we only use the modally essential minerals. Furthermore, epidote is found in most beds of amphibolite as well as in felsic gneisses. According to Turner and Verhoogen (1960) the plagioclase should be oligoclase-andesine in pelitic rocks, andesine to labradorite in amphibolite, and anorthite in calcareous rocks. As listed in table 15 for each of the representative assemblages, the anorthite content is too sodic in most of the rock types from the Collinsville quadrangle. Commonly the plagioclase is oligoclase in the pelitic rocks, although sodic andesine is typical in the Sweetheart Mountain Member and the upper member of the Rattlesnake Hill Formation – both more calcic than the surrounding schists. In the amphibolite, andesine is typical – not labradorite. In the calcareous rocks, andesine to anorthite is typical – not just anorthite. The problem, therefore, is reduced to selecting one of the remaining two subfacies.

The staurolite-almandine subfacies and the kyanite-almandine-muscovite subfacies differ mainly in the aluminous assemblages. In the lower subfacies one finds kyanite-staurolite or garnet-staurolite coexisting in the same rock. According to Fyfe, Turner, and Verhoogen (1959), the plagioclase is oligoclase-andesine in the quartzo-feldspathic rocks, oligoclase-andesine in both the basic and calcareous rocks. In the higher subfacies one finds kyanite-garnet without staurolite. Presumably the plagioclase composition is intermediate between the staurolite-almandine and the sillimanite-almandine-muscovite subfacies, although that is not mentioned specifically by Turner and Verhoogen (1960). In the Collinsville quadrangle staurolite is found throughout the northeastward-trending folds, but is present in only two outcrops in the Bristol dome and is totally absent in the Collinsville dome. Commonly, staurolite is associated with garnet or with garnet and kyanite. The association of kyanite and staurolite without garnet was not found, but the assemblage kyanite-garnet is common. Typically, staurolite-garnet-kyanite schist, staurolite-garnet schist, and garnet-kyanite schist are interbedded in rocks of both the Satan's Kingdom and Slashers Ledges Formations. This certainly indicates a compositional control on these phase assemblages, in which Fe and Mg may be considered as separate components, assuming that these minerals represent equilibrium assemblages and thus obey the mineralogical phase rule. In the thin sections of rocks containing staurolite-garnet-kyanite no evidence was seen that any of the minerals grew at the expense of the others. The composition of the plagioclase in the different rock types is more calcic than those described for the staurolite-almandine subfacies, and thus falls between the lowest and the second highest subfacies. In overall aspect, the aluminous assemblages and the plagioclase compositions in the Collinsville quadrangle come closest to the kyanite-almandine-muscovite subfacies, although the fit is far from perfect.

If one considers separately the aluminous assemblages in each of the major structural units in the quadrangle, one finds a slightly higher grade in the domes compared to the northeastward-trending folds. The aluminous assemblages found in the major folds west of the domes are essentially those discussed in the previous pargraph. Staurolite is present in different proportions in all the aluminous schists. In the domes, however, staurolite was never found megascopically in rocks containing garnet and kyanite, and it appears in only two of the thin sections where it is modally less than 1 percent. This, of course, could be a result of poor sampling, but the common megascopic presence of staurolite in rocks of the major folds does suggest that the difference is real. The characteristic aluminous assemblage in the rocks of the domes is garnet-kyanite without staurolite. Therefore, neglecting the trace amounts of staurolite, the rocks in the domes fit nicely into the kyanite-almandine-muscovite subfacies. The composition of the plagioclase is the same in rocks of approximately similar bulk composition in both structural units, thus indicating that the aluminous assemblages were more sensitive to the subtle difference in grade than was the anorthite content of the plagioclase. The prominence of staurolite in the rocks west of the domes may be caused either by slightly lower conditions of metamorphism compared to that in the domes or by a slight difference in composition. Chemical analyses of selected aluminous rocks from these structural units could clarify this problem. In addition, a far more detailed study of the variation in plagioclase composition coupled with such ratios as the Fe-Fe+Mg relation in rocks of the same bulk composition might shed light on the more subtle differences within and between the subfacies in the quadrangle.

Origin of the granitic rocks

As is evident from their modal analyses and descriptions, the granitic rocks probably originated in slightly different ways and at different times during the metamorphic and structural evolution of the rocks now in the quadrangle. The foliated and deformed granitic rocks are presumably older than the unfoliated and undeformed ones, and those containing only quartz-plagioclase-muscovite may have suffered more recrystallization subsequent to their intrusion than the rocks with both plagioclase and microcline. Because only a limited study has been made of these rocks, no critically conceived hypothesis will be discussed; however, certain field observations do suggest a broad framework for their origin.

As shown on the geologic map (pl. 1), none of the granitic bodies is very large in extent, but many appear to be confined to particular stratigraphic units such as the Scranton Mountain Member of the Taine Mountain Formation, the Collinsville Formation, and the Ratlum Mountain Member of the Satan's Kingdom Formation. All these units are rich in muscovite, quartz, and plagioclase. In each of them, the granitic rocks are especially abundant in such selected structural positions as in the hinges of folds and perpendicular to linear structures. These field occurrences suggest that much of the "granitic" material was derived by partial melting of the selected metamorphic rocks during the peak of metamorphism in the amphibolite facies. Part of this material so derived in the Collinsville Formation may well have added mobility, particularly to the plagioclase gneiss, thus facilitating upward movement in the domes. It seems unlikely that much of the "granitic" material was derived exactly *in situ* because few, if any, of the bodies shown on the map are surrounded by obvious "basic" zones rich in such Fe-Mg minerals as biotite, which remained behind after the extraction of the felsic material. These zones, however, may not be a necessary consequence of partial melting *in situ.* No such zones surround the small isolated pods of granitic rock in many outcrops of schist where the most reasonable source for the pods seems to be the surrounding schist. Therefore, the source of the granitic material is debatable, although it is assumed that the material was derived by partial melting at a slightly higher metamorphic subfacies (perhaps the sillimanite-almandine-orthoclase subfacies) than represented by the rocks in the quadrangle.

Retrograde metamorphism

Two retrograde metamorphic events are recorded in the Collinsville quadrangle. The first is thought to have occurred during the waning stages of the main metamorphism in the almandine-amphibolite facies, whereas the second is only found along the Triassic border fault and, therefore, is no older than Late Triassic in age.

In almost every stratigraphic unit, trace amounts of chlorite are intimately associated with biotite, and sericite is very common in plagioclase and in some grains of kyanite. Uniform extinction in quartz is very common, yet many plagioclase grains display irregular extinction, particularly in the more mafic rocks. Although sericitization of plagioclase is typical in practically every thin section, the alteration of biotite and kyanite is far more spotty in any given thin section and is present in only about 30 percent of the samples. These features are best developed in rocks such as calc-silicate gneiss and plagioclase gneiss. The plagioclase gneiss of the Bristol Member of the Collinsville Formation contains noticeably more chlorite as an alteration of biotite than does any other stratigraphic unit in the quadrangle. As indicated under the description of that unit, part of the chlorite may be a result of the water given off by the formation of garnet from biotite. The rocks that underlie this member in the Bristol dome show no more — perhaps even less — alteration of biotite, plagioclase, and kyanite, than do the rocks of the Hartland Group which mantle the domes. The only relationship observed between structure and alteration was in the hinges of a few second-order folds on Ratlum Mountain. Of the many granitic bodies shown on the geologic map (pl. 1), only one, located just south of Route 4 on Bee Mountain, shows significant alteration in the adjacent country rock. The retrograde metamorphism, therefore, shows a much closer correlation to particular rock compositions than it does either to structure or to the bodies of granitic rock.

Such postcrystalline strain features as strong undulatory extinction and deformation lamellae in quartz, and kink-bands in mica, kyanite, and plagioclase are present only locally on Ratlum Mountain and Rattlesnake Hill. These microscopic structures may be related to the crenulate folds that deform mineral lineation and axial-surface foliation in the northeastward-trending folds. Admittedly, they could represent a much younger structural event, but because of their limited extent they are tentatively considered to be related to the crenulate folding which occurred during the closing phase of the main deformation in the quadrangle. It is very unlikely that they are related to faults of Triassic age because they are never found in any of the samples collected adjacent to either the Border Fault or the Cherry Brook fault. If this interpretation proves correct in the light of future study, then these strain features could be considered relics that escaped recrystallization during the waning stages of metamorphism. In most areas of the quadrangle, however, this late metamorphic activity not only altered some minerals but annealed such strain features as undulatory extinction in quartz and kink bands in micas, particularly those involved in the late crenulate folding.

The style of the retrogression found in the crystalline rocks adjacent to the Triassic Border Fault is very difficult from that described above. Whereas the earlier retrogression is limited in degree but present in many of the rocks throughout the quadrangle, the younger event is more intense but very limited in extent. Commonly the biotite and plagioclase are completely altered to chlorite and saussurite. Calcite normally forms 10 to 20 percent of each sample regardless of whether the unaltered rock was originally part of The Straits Schist or a plagioclase gneiss of the Bristol Member. Quartz always extinguishes uniformly, although some of the grain contacts are granulated. These features are thought to be a result of carbonate-bearing solutions that flowed along the border fault, retrograding and partially recrystallizing minerals in the adjacent crystalline rocks. Similar features are reported by Fritts (1963) in the Southington and Mount Carmel quadrangles to the south.

ROCKS OF TRIASSIC AGE

General discussion

Outcrops of sedimentary rocks are found only along the eastern border of the quadrangle and in a small patch in the Cherry Brook Valley just north of Sweeton Road. Although no fossils have been found in either areas the rocks presumably belong to the New Haven Arkose of the Newark Group and are considered Late Triassic in age (Rodgers and others, 1959). A large body of dolerite intrudes sedimentary rocks in the eastern area and forms the prominent ridges known as Onion Mountain and Pond Ledge Hill. Both the areas of sedimentary rock are in fault contact with the adjacent crystalline rocks for at least part of their areal extent. Although it is not exposed, the western contact of the Cherry Brook outlier is thought to rest unconformably upon the crystalline basement.

Sedimentary rocks

Sandstone, shale, and conglomerate – largely arkosic in composition – crop out in four localities within the eastern portion of the quadrangle and in one outcrop along Cherry Brook just north of Sweeton Road. The Cherry Brook locality was originally discovered by Platt (1957) who states that approximately 110 ft of section is exposed along this brook both in the Collinsville and New Hartford quadrangles. The reader is referred to this report for further information on the lithology and bedding attitudes observed in this locality. In the five localities on the eastern side of the quadrangle, the rocks are either sandstone or shale with little or no conglomerate. On the geologic map each locality is identified by the respective bedding attitude measured at that locality. At the locality shown on the southern side of Route 44 the rock was exposed in a trench in 1960 and is now covered.

Igneous rocks

Dolerite and basalt crop out in three areas in the eastern part of the quadrangle – Onion Mountain and the ridge that extends from it to the south, Pond Ledge Hill, and a small hill just north of Route 4 in Unionville. Complete exposures of the upper or the lower contacts have not been found in the Collinsville quadrangle, but the increase in grain size toward the center of each body, coupled with the lack of such typical lava-flow features as vesicles, breccias, and pillow structure, indicates a probable intrusive origin. In all three areas the contact has been estimated, and drawn (on pl. 1) along the change in slope. The dolerite and basalt is part of a large body that extends from Unionville northward to the Massachusetts border and is similar to the West Rock intrusive west of New Haven, Connecticut. Along much of its extent it forms an eastward-dipping sill, but in the Tariffville quadrangle it cuts rather sharply across the New Haven Arkose to a higher level. In the Collinsville quadrangle the dolerite appears as a sill except north of Lawton Road where the lower contact cuts down through the New Haven Arkose and touches The Straits Schist just east of Gracey Road.

In outcrop the rock ranges in grain size from fine near the outer border where it is termed a basalt to medium in the center where it is considered a dolerite. The colors are always dark, ranging from dark brown to black on the fresh surface to brown on the weathered surface. Joints are common in all outcrops, and in many places outline columns which generally dip steeply to the west and, therefore, indicate that the sill itself dips gently to the east. In thin section the texture in subophitic in both the basalt and the dolerite. Here subhedral laths of labradorite are randomly oriented with anhedral grains of clinopyroxene filling interstitial areas. Magnetite grains range from subhedral to skeletal and granules of iron ore are ubiquitous. Small areas of micropegmatites are found in medium-grained dolerite and consist of wormlike and chessboard intergrowths of quartz and potash feldspar. The texture in the basalt is much like that in the dolerite except that it is finer grained and does not contain micropegmatite. For further information on the intrusive rocks, the reader is referred to the report by Schnabel (1960) on the Avon quadrangle which is located just east of the Collinsville quadrangle.

STRUCTURAL GEOLOGY

Introduction

The twelve stratigraphic units in the Collinsville quadrangle outline a complex dominated by isoclinal folds and portions of two domes — throughout which are such minor structures as mineral lineation, boudinage, and folds of various styles. Superposed on this configuration are faults along Cherry Brook Valley and the eastern border of the quadrangle which are presumably no older than Late Triassic. The structural relation of the major isoclinal folds to the domes is particularly important and is based primarily on the interpretation that the formations in the major folds are younger than those in the domes. The geometry of these structures was analyzed by studying the spatial distribution, relative age, and style of minor structures observed in outcrop. Thus the data for the third hypothesis are not only the map units that connect separate outcrops but also the structural elements recorded in each outcrop.

Method of study

Many of the structural methods used in this study were introduced by W. Schmidt and Bruno Sander in the early part of this century. These techniques and others developed later in such places as Scotland and in the Alps have been recently described by Turner and Weiss (1963).

All structural elements such as foliation, lineation, and joints are recorded separately on a spherical projection and their preferred orientation and geometric relations to each other analyzed. An equal-area projection of the *lower* half of a sphere was used throughout this study, so that the density distribution of such selected elements as mineral lineation could be evaluated readily by contouring. In all of the diagrams (figs. 11 to 21) the plane of the equal-area projection is horizontal, with the north arrow at the top. In order to analyze more than twenty planar elements on a single diagram and still maintain clarity, the poles to planes were plotted instead of the planes themselves or their mutual intersections.

To analyze the diverse orientation pattern of structural elements found throughout the quadrangle, the major structural areas were arbitrarily divided into subareas on the basis of the pattern made by poles to foliation in spherical projection. In approximately 80 percent of the subareas the poles to foliation are distributed in a girdle (some incomplete) that can be fitted approximately to a great circle either by inspection or by contouring. The pole of this great circle is the π-pole (β axis if computed from the intersection of foliations). Foliation measurements taken from around the hinges of minor folds seen in outcrop were excluded from these diagrams. This tends to eliminate the influence of minor folds on the diagrams and emphasizes the major folds shown on the geologic map (pl. 1). For most of the subareas, however, the axes of minor folds are approximately parallel with the π-poles.

In none of the subarea diagrams could the π-pole be located as a single point because the girdles are not distinct enough to define a unique great circle; the spread of poles from a single great circle being a function of the error of measurements and the fact that the folds are not truly cylindrical. The maximum amount of divergence permitted for any π-pole was 15 degrees. In order to account for this variation and any error in the measurements the π-pole is represented by a 1 percent circle instead of a single point. For the remaining 20 percent of the subareas the poles to foliation define patterns for which no π-pole can be located satisfactorily. Attempts to subdivide these subareas were unsuccessful. All other minor structures such as mineral lineation, boudin lines, and the axes of minor folds were plotted and analyzed for each subarea. At the end of each field day all structural information was recorded on equal-area diagrams so that the significance of a given orientation could be evaluated by the degree to which it was repeated from day to day.

Equal-area diagrams showing the orientation of different minor structures accompany the discussion of each major structural area such as the Collinsville dome. The π-poles for all of the subareas are not shown on these diagrams nor are the boundaries of the subareas shown on the geologic map. Diagrams for selected subareas, however, are presented for the major folds west of the domes. A brief statement on the orientation of the π-poles in each major structure is included in the discussion.

The geologic sections shown on plates 2 and 3 are partially constructed in the manner described by Wegmann (1929) and used by subsequent workers in such areas as Scotland and the Alps. Profile sections are drawn perpendicular to a fold axis and, consequently, give an undistorted view of the structure. Ideally, the construction is most valid in areas where the fold axes are straight and parallel from one fold to the next. In the Collinsville quadrangle it is impossible to define a unique cylindroidal axis for either the Collinsville or Bristol domes because their overall geometry is more conoidal than cylindroidal, although the poles to foliation readily define a π-pole in a few portions of the domes.

In the major folds west of the domes, the fold axes curve over a major culmination just south of the Farmington River. These folds, however, were easily subdivided into subareas, many of which contain girdles each with a well defined π-pole. The strike and plunge of these poles and the map pattern of the major folds were then used to construct the geologic sections. In the domes, however, the sections were not drawn perpendicular to the π-poles, but were drawn across the trend of the major structures wherever possible. The strike and plunge of π-poles in each subarea of the domes, however, did provide some control in projecting the map pattern to the surface of the geologic section. The orientation of the fold axes (π-poles) used to construct the geologic sections is shown above each section on plates 2 and 3.

Definition and description of structural elements

Many of the structural terms used in this report may have slightly different meanings for different geologists. As an aid to the reader, all structural elements in the report are defined and described as they appear in the Collinsville quadrangle.

FOLIATION

In the Collinsville quadrangle foliation is widely developed and is marked either by lithologic layering — here termed bedding foliation — or by parallel orientation of micaceous and granular minerals. Commonly the lithologic layering is accompanied by a parallel orientation of platy minerals, even in the hinges of major folds, where an axial-surface foliation (schistosity), outlined by micas oriented parallel to the axial surfaces of minor folds, cuts across the bedding foliation. Because the major folds are nearly isoclinal and much of the stratigraphic section is schist, only one foliation can be satisfactorily measured on the limbs of these folds. In outcrops of schist, the generalized term "foliation" is used because it it is impossible to distinguish bedding foliation from axial-surface foliation. As shown on the geologic map (pl. 1), most stratigraphic contacts parallel the generalized foliation symbol. If the outcrop consists of different rock types, a second foliation cutting the bedding foliation can generally be identified, but not satisfactorily separated on the map because the difference between the two foliations is less than the error of measurement (about ±5°). Both surfaces are represented on the map by the generalized foliation symbol except where the compositional difference is strong. There, as for example in the case of calc-silicate gneiss interleaved with schist, a bedding foliation symbol is used. In outcrops where bedding foliation can be separated from axial-surface foliation, as at the hinges of major folds, the two different symbols are shown on the map.

FOLDS

A fold is a curved surface that is generated from a plane. If the fold can be approximately produced by the translation of a single line of constant orientation — called the fold axis — then the fold is cylindroidal. In spherical projection the poles to the foliation of such a fold fall along a great circle with some spread across the great circle depending upon the amount of departure from a true cylinder and the size of the error in the measurements. The hinge is "the line on a single folded surface joining points of greatest curvature" (Turner and Weiss, 1963, p. 106). The axial surface connects hinge lines on successive folded surfaces. A noncylindroidal fold cannot be produced by the translation of a line of constant orientation. A hinge and an axial surface are present in most noncylindroidal folds. A fold with a curved axis lying in the axial surface is a type of noncylindroidal fold that commonly can be subdivided arbitrarily into cylindroidal segments. A conical fold is noncylindroidal and can be "generated by a straight line passing through a fixed point" (Turner and Weiss, 1963, p. 108). A conical fold does not have a unique hinge or a single axial surface. In spherical projection the poles to foliation of a conical fold form a small-circle girdle. A dome is a type of noncylindroidal fold in which the foliation near the borders dips outward from the center of the structure and the overall map pattern tends to be circular.

In the Collinsville quadrangle the fold structures are arbitrarily divided into folds and domes according to the length-width ratio of their map patterns. The length of a doubly plunging fold in map pattern can be measured along its trend from hinge to hinge of a given stratigraphic contact. The width of the fold is then measured across the trend of the fold at approximately half the length using either the same stratigraphic contact or the distance between the traces of adjacent axial surfaces – these measurements are sufficiently alike not to affect the final ratio significantly. In the Collinsville quadrangle the length-width ratio is greater than 5.0 for major folds and less than 5.0 for domes. Most of the structures in New England considered to be domes, as well as the classic gneiss domes in the Pitkäranta and Kuopio areas of Finland (Eskola, 1948) have length-width ratios less than 5.0.

The folds are further subdivided according to size into four orders. As shown on figure 8, high-order folds are located on the limbs of low-order folds. Although fourth-order folds are found on the limbs of third-order folds and so on, it is equally possible for high-order folds to jump to the next lower order fold – for example, third-order folds could be located on the limbs of first-order folds. As shown in figure 8, folds of the first two orders are mappable on the scale of 1:24,000 and correspond to major folds. Folds of orders three and four are not mappable on the scale of 1:24,000 and correspond to the minor folds observed in outcrop. The order classification can also be applied to domes. The Bristol dome is a first-order dome made up of a doubly plunging fold and a smaller second-order dome. Although higher orders of folds can generally be found on the limbs of fourth-order folds, most of the present study was confined to the orders shown in figure 8. The scheme as presented here is not intended to be rigorous; it is a convenient way to express the size of a fold within a given area of study – here a 7½-minute quadrangle.

The minor folds are further subdivided according to their style into crenulate and noncrenulate folds. The style of a fold can be defined as the general appearance of a fold viewed perpendicular to the fold axis and "can be described in terms of structural elements, such as the nature of the hinge, the presence of axial cleavage, and the relation to mineral grain lineation" (Hansen, in press). Crenulate folds in the Collinsville quadrangle form a distinct style group characterized by planar limbs, sharp to slightly rounded hinges, and the absence of any axial-surface foliation revealed by micas oriented parallel to the axial surfaces of these folds (fig. 9). However, their axial surfaces and, in some places, their attenuated limbs, do create a geometric surface that would form a foliation, according to Turner and Weiss (1963, p. 97, 125). The crenulate folds are small structures with amplitude and wavelengths commonly less than several inches and, with one exception, are found only in the mica schists, where these folds remain similar in profile along the trace of their axial surfaces.

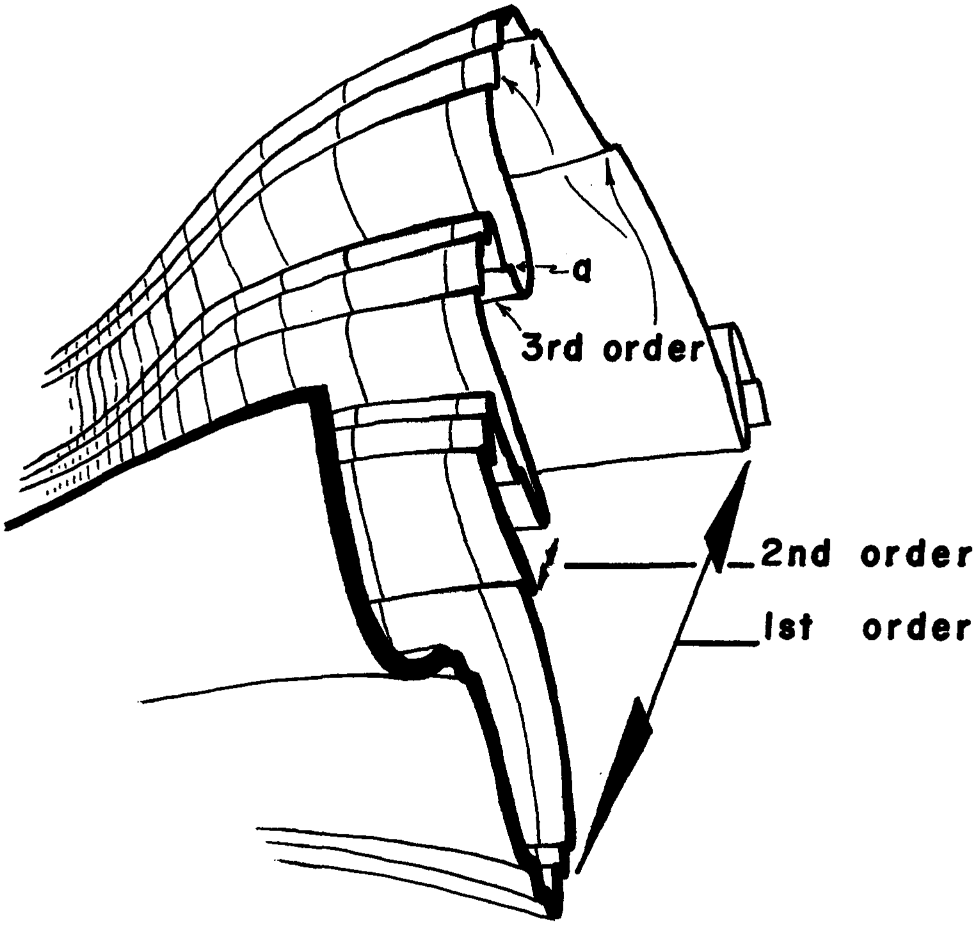


Fig. 8. Schematic diagram showing the orders of folds. The third-order fold at *a* shows counterclockwise rotation.

Order		*Size of map area that commonly includes fold*	
1	MAJOR	2 mi. by 1/2 mi.	Mappable (1:24,000)
2	FOLDS	600 ft by 300 ft	
3	MINOR	30 ft. square	Not mappable (1:24,000)
4	FOLDS	2 ft. square	

In outcrops with beds of gneiss these folds are restricted to the schist, and broad noncrenulate folds are found in the gneiss (fig. 9D). Although the fold axes and the axial surfaces in both of these folds are parallel, their style is quite different, indicating a different response by different rock types to what was presumably the same overall stress system. Although several orders of crenulate folds are found south of Taine Mountain, they commonly appear as single-order structures. Because none of

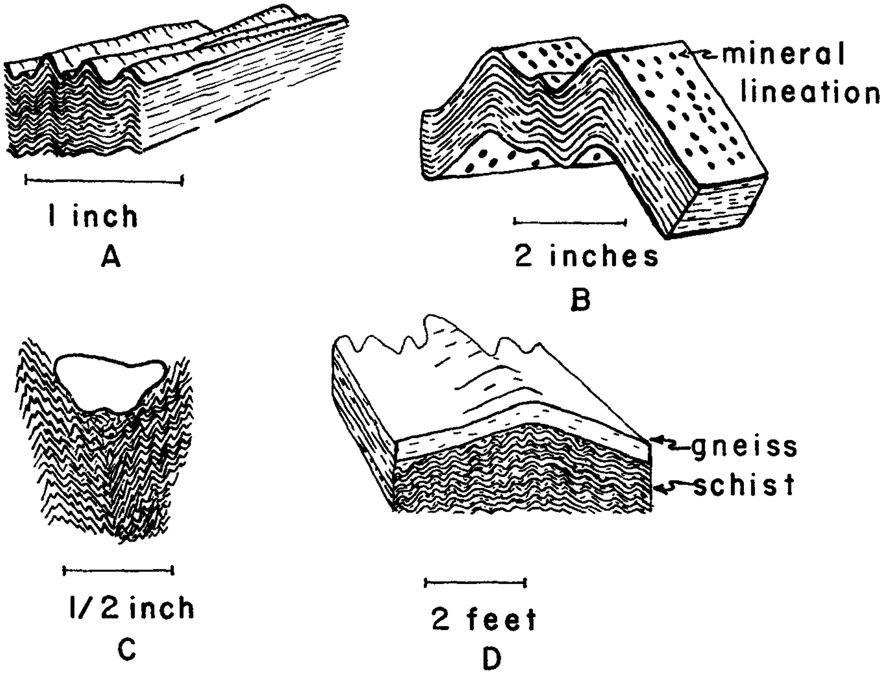


Fig. 9. Crenulate folds. *A* shows the character of the profile and the fold axis. Mineral lineation deformed by crenulate folds is shown in *B*. *C* shows the change in sense of rotation around a quartz porphyroblast. Contrasting fold styles in schist and gneiss are shown in *D*.

these folds is mappable on the scale of 1:24,000, their order must be greater than two, according to the scheme shown in figure 8. As shown in figure 9, the hinge ranges from rounded with a small radius of curvature to sharp and, thus, identical to chevron or kink folds (Turner and Weiss, 1963, p. 114). The term "crenulate" is preferred, however, because it seems to cover the overall properties of these folds better than the more restrictive term "chevron" which implies a sharp hinge similar to a military chevron. Approximately 150 crenulate folds were measured in the quadrangle.

The noncrenulate folds include a variety of styles such as disharmonic, isoclinal, fan, and step-folds. The styles of the noncrenulate folds are diagrammed and discussed under the description of each major structural unit. A little over 300 noncrenulate folds have been measured throughout the quadrangle. These folds are most abundant in the Bristol Member of the Collinsville Formation, in the Ratlum Mountain Member of the Satan's Kingdom Formation, and in the kyanite schist of the Slashers Ledges Formation.

MINERAL LINEATION

A total of 535 measurements was made of mineral grain lineation in all formations of the quadrangle except in The Straits Schist, where the micas are commonly equidimensional. Although hornblende and plagioclase-quartz streaks form the mineral lineation in many outcrops, elongate plates of muscovite and biotite oriented in the foliation are far more plentiful. These occur either as clusters or as separate grains. In areas where crenulate folds are moderately developed or where an axial-surface foliation cuts across bedding foliation, care was always taken not to record micas tilted at an angle to the dominant foliation but to measure only those micas elongate in the foliation. West of the domes most of the measurements were taken in schist on the limbs of the major structures.

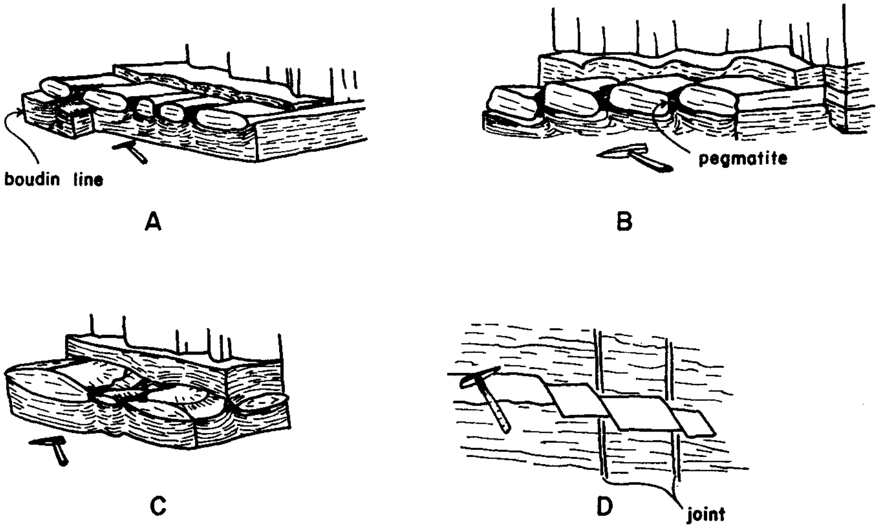


Fig. 10. Boudinage. *A,* sausage-shaped boudins; *B,* offset boudins; *C,* pillow-shaped boudins; *D,* lozenge-shaped boudins. Scale shown by geologic hammer. Closely spaced lines represent schist. Beds of gneiss are shown by blanks with or without widely spaced lines.

BOUDINAGE

As originally defined by Lohest (1909), boudinage is a structure that resembles linked sausages in profile view. It is commonly found in an outcrop composed of rocks of quite different composition. In the Collinsville quadrangle approximately 120 of these structures were found in amphibolite, calc-silicate gneiss, and quartzite, and are represented on the geologic map (pl. 1) and on the equal-area diagrams by the strike and plunge of the boudin line. Many of these lines are marked by elongate bodies of pegmatite. Four types of boudinage are found in the quadrangle and are sketched in figure 10. The sausage-shaped boudinage is the most common and is characterized by boudin lines of approximately parallel orientation. The pillow-shaped boudinage is found primarily near the margin of the Collinsville dome and the northern part of the Bristol dome. Typically, each boudin is surrounded by two or more boudin lines. Similar structures are described by Wegmann (1932) and were experimentally formed by Ramberg (1955). The offset boudinage is found mostly in the major folds west of the domes. In this type each boudin is tilted in a direction that bears a consistent relation to nearby noncrenulate folds, showing a clear sense of rotation (fig. 11). On the geologic map and equal-area diagrams this is the only group identified by a slight modification of the boudin-line symbol. Lozenge-shaped boudinage similar to that described by Rast (1956) is found in only a few places.

OTHER LINEAR STRUCTURES

Mullions, rods, and axes of rotated porphyroblasts compose the remaining linear structures recorded in the quadrangle. Following the definitions of Wilson (1953), the term "mullion" refers to columnar bodies with variable profiles. They are composed of local country rock and are commonly exposed through differential weathering. Rods are polycrystalline masses of varying size elongate in one prominent direction. In the Collinsville quadrangle all of the mullions are parallel to fold axes and, in many outcrops, are formed from the hinges of folds whose limbs were detached during deformation. Mullions are found normally in quartz-rich gneiss and schist of the Taine Mountain Formation, in the Bristol Member, and in the Ratlum Mountain Member. Locally, they are developed in The Straits Schist, particularly south of Taine Mountain between the Collinsville and Bristol domes. The rods are composed either of quartz or quartz and plagioclase and are found throughout the quadrangle. Quartz-plagioclase rods capped with garnet are especially abundant in the amphibolite of the Bristol Member exposed along the Farmington River in the Collinsville dome.

In the schist of the Ratlum Mountain Member, many of the larger porphyroblasts of plagioclase contain discontinuous trails of mica that form "S" or "Z" patterns, as viewed in sections cut perpendicular to the axis of rotation. Where possible the strike and plunge of the rotation axis was measured. In none of the porphyroblasts did the rotation exceed 180° nor did the rotation direction reverse as in the garnet porphyroblasts described by Rosenfeld (1960) in southeastern Vermont. Excellent samples of these structures are found along Farmington River near Satan's Kingdom.

Sense of rotation

Minor structures such as offset boudinage, rotated porphyroblasts, and asymetric folds display a relative sense of movement, when viewed in profile, here termed the sense of rotation. This sense is determined by looking down the plunge of the respective axes of rotation. In offset boudinage the axis of rotation is the boudin line. As shown in figure 11, the sense of rotation is either clockwise or counterclockwise depending on the relative movement suggested to an observer by the asymmetry of the structure. The conventions of Hansen (Hansen and others, 1961) for describing the sense of rotation about a fold axis is used in this report and is extended here to rotated porphyroblasts and offset boudinage.

Minor folds with one limb shorter than the other are commonly used in the field to determine the location of antiformal and synformal hinges of lower order folds. Such asymmetric folds are generally thought to be

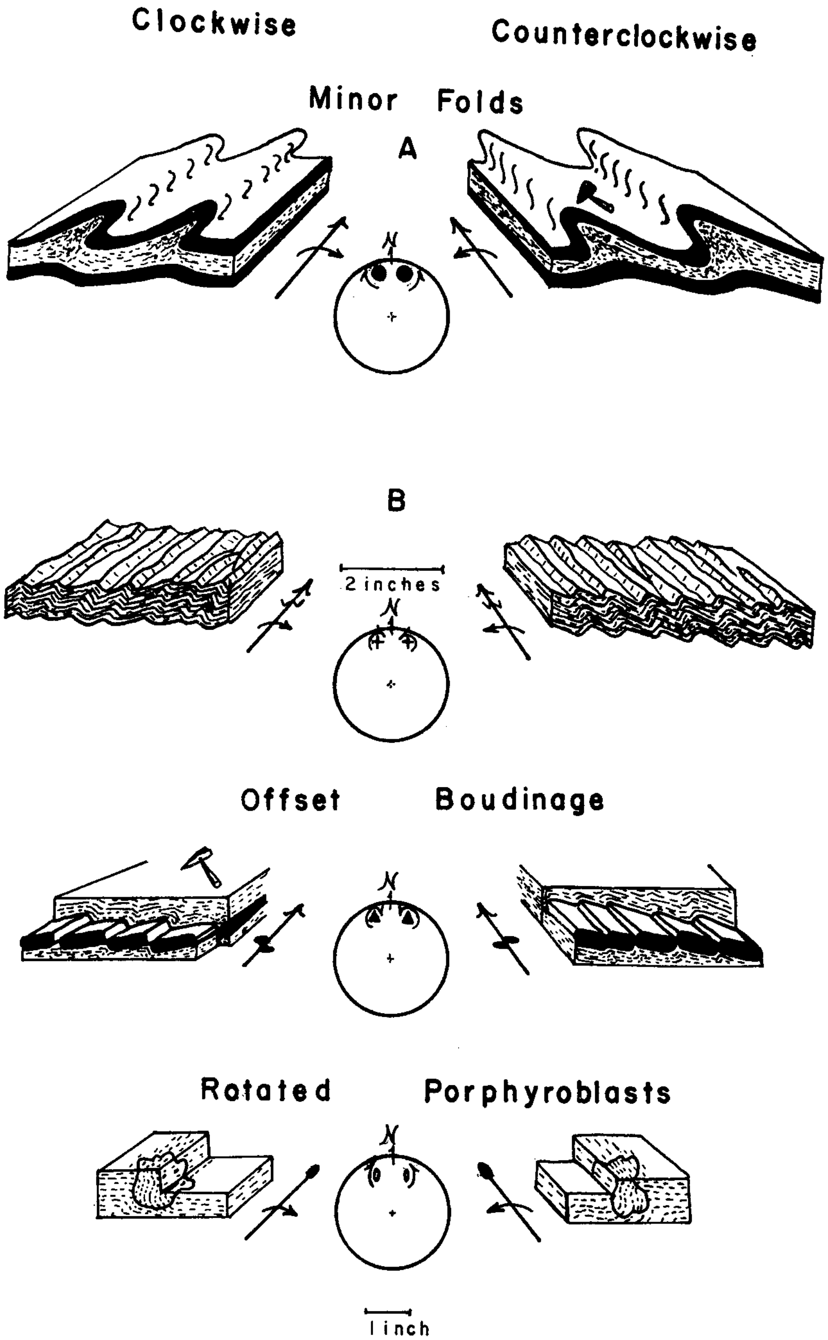


Fig. 11. Sense of rotation as shown by minor folds, offset boudinage, and rotated porphyroblasts. *A*, noncrenulate folds; *B*, crenulate folds. Map symbols shown beside each diagram. Small equal-area projections contain the symbols for each structure.

the result of the translation of one bed over another, and are called drag folds. "The acute angles between the axial planes of the drag folds and the main bedding planes point in the direction of differential movement" (Billings, 1954, p. 78). Using this rule, then, drag folds can either indicate movement of an upper bed toward the hinge of an antiform (normal drag folds) or they can indicate movement of an upper bed away from the hinge of an antiform. In this last situation the drag folds describe a "spruce-tree" pattern about the antiform or dome as viewed in profile section (Skehan, 1961, p. 105). Spruce-tree folds are reported by Thompson and Rosenfeld (1951) and Skehan (1961) around such structures as the Chester, Lake Raponda, and Sadawga Pond domes, whereas normal drag folds are found on the limbs of many of the major folds on either side of the domes.

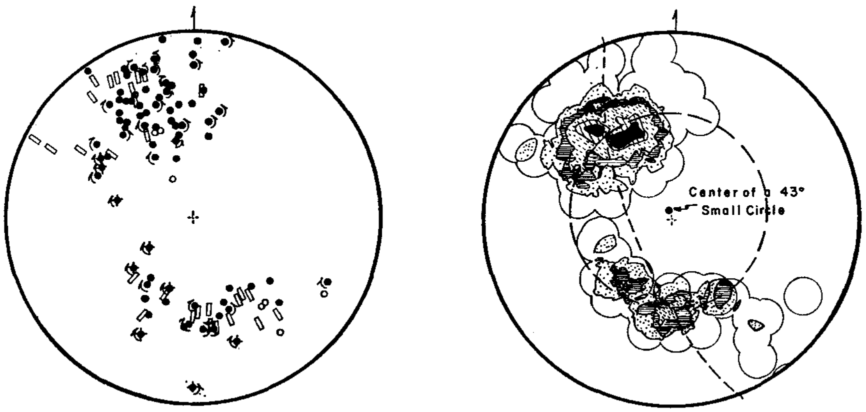
In the Collinsville quadrangle the second-order folds show a normal relationship to the first-order folds. On the limbs of mappable second-order folds, the third-order folds are also in normal relationship; this also applies to higher order folds in the same area. The same is true for many minor folds in the domes. Schematically, the normal relationship is shown on figure 8. Noncrenulate folds showing a sense of rotation are found in many isolated outcrops in the northeastward-trending folds, but whether or not they have a normal or spruce-tree relationship to lower order folds is not known, although it is thought to be normal. The danger of trying to relate these folds to first-order structures is shown at fold *a* in figure 8. If one related the counterclockwise sense shown by *a* to the first-order structure without realizing that it was actually located on the short limb of a second-order fold, then one would conclude that the noncrenulate fold was a "spruce-tree" fold. Such situations, however, do not negate the use of minor folds as aids to locating lower order folds; they only emphasize the need for caution when relating minor folds to first-order structures. In this study an attempt was always made to use folds of the same order when interpreting their relationship either to each other or to folds of the next lower order. For example, second-order folds were used to locate the hinges of first-order folds. Furthermore, when interpreting the relationship between the domes and the northeastward-trending folds, only first-order structures were used. In all situations these determinations were used in conjunction with stratigraphic mapping and spherical projections of the structural elements for the particular area under study.

As shown in figure 11, crenulate folds also show a sense of rotation that is determined by the angle made by their axial surfaces with the deformed foliation. Commonly this sense may change in a given outcrop or around a large pod (fig. 9C). As will be pointed out in the next section, most of the crenulate folds deform the axial-surface foliation of the major folds west of the domes and, therefore, are younger. Consequently, these superposed structures are not reliable guides in locating lower order folds of the earlier generation.

Major structures

GENERAL REMARKS

The major structures in the quadrangle include not only domes and major folds, but also three faults of which two are presumably no older than Late Triassic. The oldest fault is located in the northwestern part of the quadrangle and is thought to have formed with the major folds. Minor structures and joints found in the domes and northeastward-trending folds are shown in equal-area projections of the lower hemisphere. The style of some of the noncrenulate folds is sketched in figures 14 and 21. Geologic sections on plates 2 and 3 portray the major features in the third dimension.

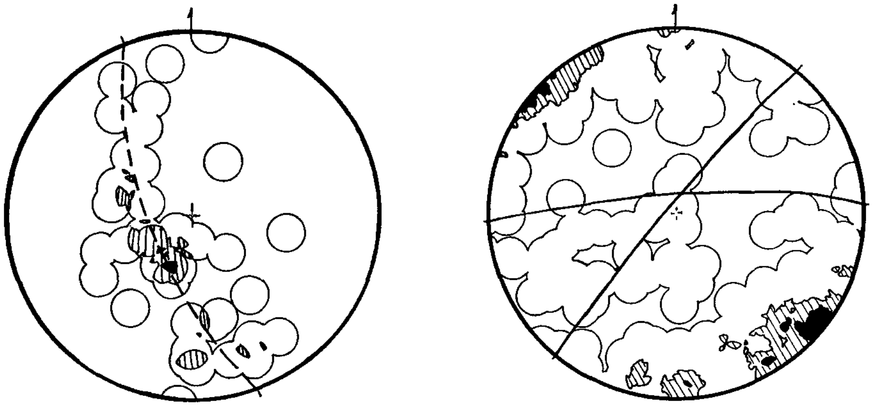


78 Fold Axes, 28 Mullions, 8 Rods

A

118 Mineral Lineations

B



40 Boudin Lines

C

Poles to 156 Joints

D

Fig. 12. Equal-area projections showing the orientation of minor structures in the Collinsville dome. In *B* the contours are 0.9, 2.6, 4.3, 6.0, 7.7, 9.4 percent, respectively, per 1 percent area. In *C* the contours are 2.5, 7.5, 12.5 percent, respectively, per 1 percent area. In *D* the contours are 0.6, 3.2, 5.8 percent, respectively, per 1 percent area. Some of the symbols in *A* are given in figure 11. Additional symbols are: open rectangles = mullions, open circles = rods, and the ten black circles with barbs = noncrenulate fold axes orientated at an angle to mineral lineation.

The equal-area diagrams of poles to joints are not truly representative of all the orientations in the domes and major folds because the steeply dipping joints are more easily recognized than the gently dipping joints which are often obscured by erosion processes. Therefore, there is a strong sampling bias in all the joint data, and any conclusions based on their relation to other structures must be tempered by this consideration.

DOMES

Collinsville dome. The Collinsville dome, located east of the Farmington River, is a hemi-elliptical structure, bounded on the west by a syncline separating the Collinsville dome from the Bristol dome and cut off on the east by a normal fault of Late Triassic age. Foliation and lineation in the unfaulted border of the dome dip and plunge outward at moderate to steep angles from the dome center where foliation commonly strikes north and dips steeply to the west or east. The poorly defined axial surface of the dome strikes northward and dips westward at moderate to steep angles. Large folds such as those shown by the amphibolite north of Canton are present in the Collinsville dome, but cannot be mapped accurately because of insufficient outcrop. Section *A-A‴* (pl. 2) shows the generalized morphology of such folds as determined from available data.

The orientation of minor linear structures and joints is shown in equal-area projections in figure 12. Because the distribution of outcrop is not uniform, the full portrayal of the geometry is not complete. I believe, however, that the geometry of the margin of the dome is fairly represented because most of the outcrops with minor structures are located on the borders and northern part of the dome.

Rods, mullions, and axes of noncrenulate folds are shown in figure 12A. The arrow near each fold symbol shows the sense of rotation determined in the field. Figure 12B represents 118 measurements of mineral lineation. Except for ten fold axes shown by a special symbol in *A*, the mineral lineation measured at a given spot in an outcrop was observed to be parallel (±10°) to either a fold axis, mullion, or rod present in the same spot. This relationship is reflected in the similar patterns of *A* and *B* where practically all of the linear structures in *A* fall within the lowest contour in *B*. Included in *B*, of course, are measurements of mineral lineation from localities devoid of other linear structures. The converse is true for *A*. Furthermore, in any given subarea diagram (none shown), the π-pole to the foliation girdle falls within the area occupied by mineral lineation, fold axes, mullions, and rods.

Figure 12C shows the orientation of 40 boudin lines. Because most of these were collected from outcrops along the Farmington River south of the Collins Company dam, their spatial distribution certainly is not representative of the whole dome, although their pillow-shaped style is thought to be typical. Poles to 156 measurements of joint surfaces found in all the outcrop areas of the dome are shown in *D*. The pole maximum corresponds to a nearly vertical joint set striking approximately N 45° E or about 20° from the trend (N 65° E) of the granitic bodies on Huckelberry Hill and Mount Horr. A submaximum in the southern part of the diagram corresponds to a less prominent set striking east-west and dipping steeply to the north.

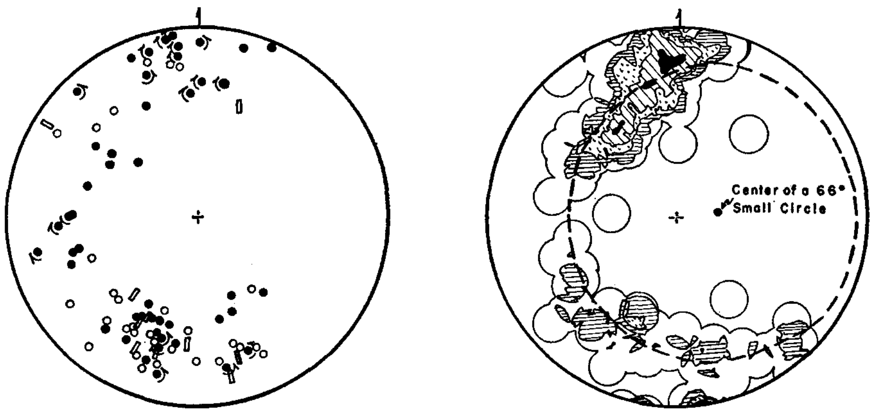
The pattern of mineral lineation in *B* is compared to the great circle and the small circle that appear to fit the data best. The great circle is one that passes through the center of points outlined by the 6.0 percent contour. The best small circle is a 43° circle with an axis that is nearly coincident with the center of the diagram. Of these two the mineral lineation falls closest to a small circle distribution, although the fit is certainly not perfect or complete. The same observation applies to the distribution of linear elements in *A*, even though a great circle and a small circle are not drawn. The boudin lines in *C* fall along a great circle which is identical to the one used in *B*. No overall importance can be attached to the distribution in *C*, however, because most of the measurements come from outcrops along Farmington River and therefore are not as representative of the whole dome as is the mineral lineation.

Bristol dome. The Bristol dome, which is approximately twice as large as the Collinsville dome in total area, underlies the southern one-third of the Collinsville quadrangle, the western two-thirds of the Bristol quadrangle and the eastern one-fourth of the Thomaston quadrangle. The deepest structural level and oldest formation of the Bristol dome crops out in the Collinsville quadrangle where gneiss and schist of the Taine Mountain Formation outline a tear-shaped complex composed of an eastern anticline that trends northwestward and a western hemi-circular dome. Axial surfaces of these structures strike northwestward and dip westward at moderate to steep angles. The eastern limb of the Bristol dome is overturned in the Collinsville quadrangle and conforms to the shape of the southern portion of the Collinsville dome. These relationships are shown in sections B-B‴ (pl. 2), and sections C-C′, D-D″, and D-E (pl. 3).

Two small antiforms and synforms that plunge southwestward are mapped on the eastern side of Wildcat Mountain and are shown on profile section *D-D′-E* on plate 3. In these folds the Scranton Mountain Member of the Taine Mountain Formation forms cores of antiforms whereas biotite-plagioclase-quartz gneiss, which lies stratigraphically below the Scranton Mountain Member, forms troughs of synforms. If these folds are interpreted as drag folds to the structural center of the Bristol dome, then they are of spruce-tree type and indicate relative upward movement of the core rocks.

The orientation of minor linear structures and joints is shown in the three equal-area diagrams of figure 13. Although outcrop is scanty in the center of the dome, it is far more abundant along the border than in the case of the Collinsville dome. Linear structures were sampled in all of outcrops around the tear-shaped complex and therefore should be representative of the geometry of the dome's surface at the level of present-day erosion.

The orientation of rods, mullions, and noncrenulate fold axes with the respective rotation sense are shown in figure 13A. Measurements of 116 mineral lineations are contoured in *B*. Both diagrams display the same pattern as those from the Collinsville dome, with most of the points in *A* falling within the first contour interval in *B*. Furthermore, the areas of high density in *A* correspond fairly closely with those in *B*. At any given part of an outcrop the mineral lineation was observed to be parallel

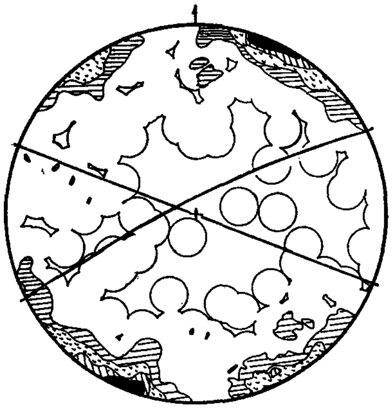


47 Fold Axes, 30 Rods, 10 Mullions

A

116 Mineral Lineations

B



Poles to 266 Joints

C

Fig. 13. Equal-area projections showing the orientation of minor structures in the Bristol dome. In *B* the contours are 0.9, 2.6, 4.3, 6.0, 7.7 percent, respectively, per 1 percent area. In *C* the contours are 0.4, 1.9, 3.4, 4.9, 6.4 percent, respectively, per 1 percent area. For symbols in *A* see figure 12.

(±10°) to fold axes, mullions, or rods in the same spot. The girdle in *B* approximates more closely a 66° small circle than any possible great circle. It is important to point out, however, that this fit is not perfect and, therefore, the girdle cannot be called a small circle in the strict meaning of the term. The π-poles to foliation are oriented approximately parallel to the linear structures in each subarea and collectively display the same overall pattern as *A* and *B*. Thus the linear structures (except boudin lines) of the Collinsville and Bristol domes fit neither great circles nor small circles, although the girdles they describe can be approximated by small circles far better than by great circles.

Poles to 266 joint surfaces are contoured in *C*. The pole maximum corresponds to a statistical joint set striking N 70° W and the submaximum corresponds to another set striking N 62° E.

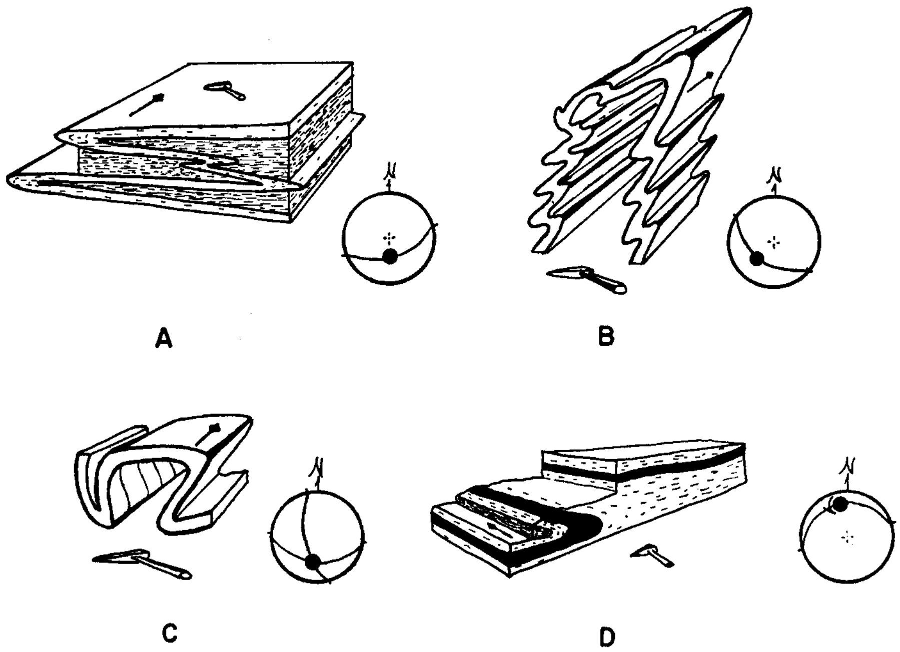
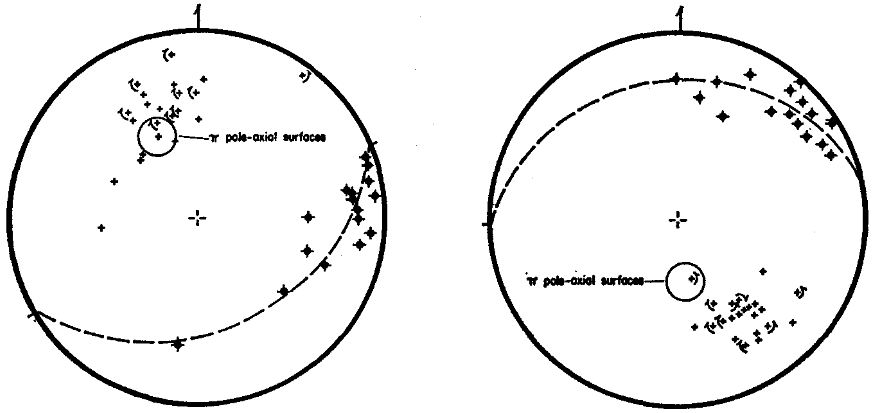


Fig. 14. Fold styles in the domes. Small equal-area projection next to each diagram shows the orientation of the fold axis and of the axial surface. Scale is given by the geologic hammer. Closely spaced lines represent schist. Beds of gneiss are shown by blanks with or without widely spaced lines. Amphibolite is shown in black. Arrow on each fold indicates the orientation of mineral lineation. *A*, isoclinal fold with well developed axial-surface foliation, *B*, refolded fold; note that the sense of rotation is the same on both limbs. *C*, fan fold. *D*, isoclinal fold. The amphibolite is presumably a single bed.

Fold styles. Figure 14 shows the styles of the noncrenulate folds in the Collinsville and Bristol domes. In general, these folds display a greater variety in form and appearance than do the noncrenulate folds in the northeastward-trending folds. Isoclinal folds (*A* and *D*) with well developed axial-surface foliation are common. Fan folds (*C*) without axial-surface foliation are less so. In one outcrop a refolded fold (*B*) was found with the sense of rotation the same on both limbs. The axial surfaces of the isoclinal folds in any one outcrop are more or less parallel to the contacts of stratigraphic units shown on plate 1. In other styles the axial surfaces show considerable variation in attitude about the fold axes and are commonly oriented at an angle to the map contacts. The primary style feature of all these folds is the parallelism of their axes to mineral lineation on their limbs and hinges. This feature was found in about 85 percent of the noncrenulate folds in the domes, but was common to only about 5 percent of these folds in the northeastward-trending folds. The style features shown in figure 14 are best seen in two outcrops: one along Farmington River just east of Route 4 a mile northwest of the center of Unionville (in the Collinsville dome) and the other along the Nepaug Reservoir in the type locality of the Collinsville Formation.

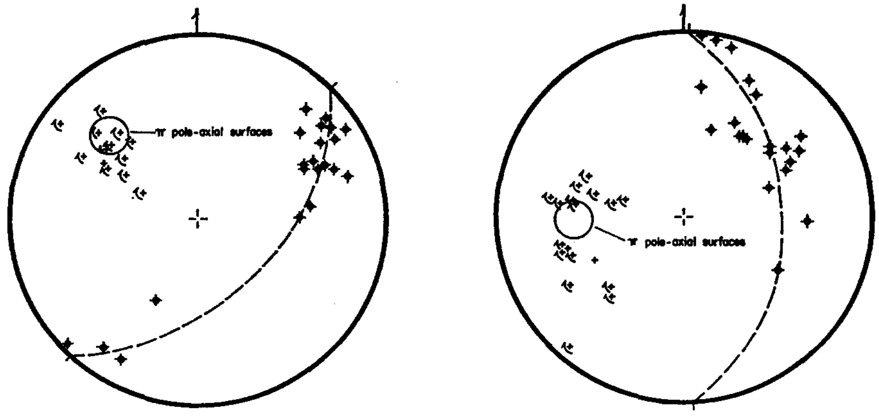


22 Fold Axes, Poles to 16 Axial Surfaces

A

22 Fold Axes, Poles to 17 Axial Surfaces

B



13 Fold Axes, Poles to 21 Axial Surfaces

C

18 Fold Axes, Poles to 21 Axial Surfaces

D

Fig. 15. Crenulate folds from Rattlesnake Hill, *A*, south to Taine Mountain, *B*, Barnes Hill, *C*, and Johnnycake Mountain northeastward to Burlington. Great circles that approximate the distribution of poles (dots with barbs) to axial surfaces are dashed. Symbol for fold axes is shown in figure 11.

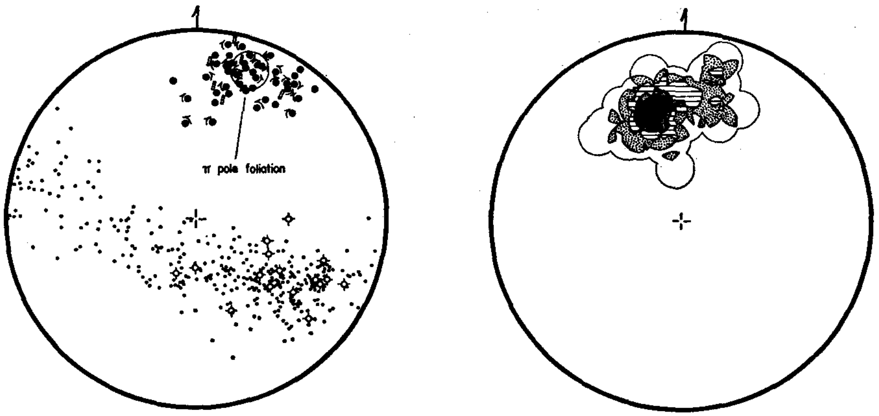
Crenulate folds were found only in mica schist in and around the domes except for one outcrop of amphibolite in the southwestern part of the Collinsville dome. Everywhere the crenulate folds deform the foliation, but never develop their own axial-surface foliation. A total of 75 fold axes and axial surfaces were measured on Rattlesnake Hill, Barnes Hill, from Johnnycake Mountain northeastward to Burlington, and south of Taine Mountain between the Collinsville and Bristol domes, all of which are underlain by The Straits Schist. The crenulate folds are developed best south of Taine Mountain and are moderately or weakly developed in the other areas. In all of the diagrams on figure 15 the poles to the axial surfaces form incomplete girdles that can be approximated by great circles; the poorest fit is in diagram *D*. The π-poles to these girdles plunge westward or northwestward except in *B* (south of Taine Mountain) where it plunges southward. In the localities on the western side of the domes (*A, C,* and *D,* fig. 15) the axial surfaces are oriented at moderate to high angles to the axial surface of the domes, whereas south of Taine Mountain they are approximately parallel to the trace of the synform between the domes and the major structures directly west in the Bristol dome. In all the diagrams the fold axes tend to cluster near the respective π-poles, although most of the axes are not parallel to the π-poles. The sense of rotation was determined in the field for approximately 60 percent of the folds. With the exception of one fold (*A*) all of the 37 folds in *A, C,* and *D* show a clockwise sense of rotation. These folds are all from localities on the western side of the domes where the foliation strikes northeastward. In *B* the sense of rotation is about evenly divided.

NORTHEASTWARD-TRENDING FOLDS

The folds northwest of the Collinsville and Bristol domes are divided into two parts – the Ratlum Mountain-Garrett Mountain fold system and the Slashers Ledges-Nepaug fold system. A line trending northeastward along the eastern limits of the rusty schist of the Slashers Ledges Formation forms a convenient boundary between these two systems. Profile sections *A-A‴* and *B-B‴* (pl. 2) show that the axial surfaces of the Ratlum Mountain-Garrett Mountain fold system conform to the western limb of the Bristol and Collinsville domes and therefore dip westward, whereas the axial surfaces of the Slashers Ledges-Nepaug fold system dip steeply eastward. Both fold systems culminate south of the Farmington River over a cross axis that plunges southeastward.

Ratlum Mountain-Garrett Mountain fold system. Two northeastward-trending antiforms and synforms and three southwestward-plunging antiforms and synforms compose the Ratlum Mountain-Garrett Mountain fold system. The folds are based upon the map pattern of stratigraphic units, the geometry of structural elements, and the sense of rotation of second-order folds which were useful in locating the hinges of first-order folds. For example, the repetition of map units in belts of approximately parallel foliation as encountered in a traverse from Cherry Brook to Breezy Hill might not at first be recognized as a product of folding. Detailed mapping of all of Ratlum Mountain, however, has shown that the belts of similar rock actually connect around the hinges of three first-order folds. Furthermore, the subarea diagram (*A*, fig. 16) shows that the foliation is not parallel for the whole mountain, but forms a complete girdle about a π-pole plunging northeastward. The cluster of noncrenulate fold axes and mullions around the π-pole indicates that the axes of the major and minor folds are approximately parallel. Their axial surfaces dip at a moderate angle to the northwest. Second-order folds in all well exposed localities on the limbs of first-order folds are normal and resemble those in figure 8. Thus, there can be little doubt that folds repeat the map units on Ratlum Mountain. Similar evidence is found in other parts of the quadrangle where map units are repeated across the strike.

The map pattern of the upper member of the Rattlesnake Hill Formation shows several interesting features that are a function of the

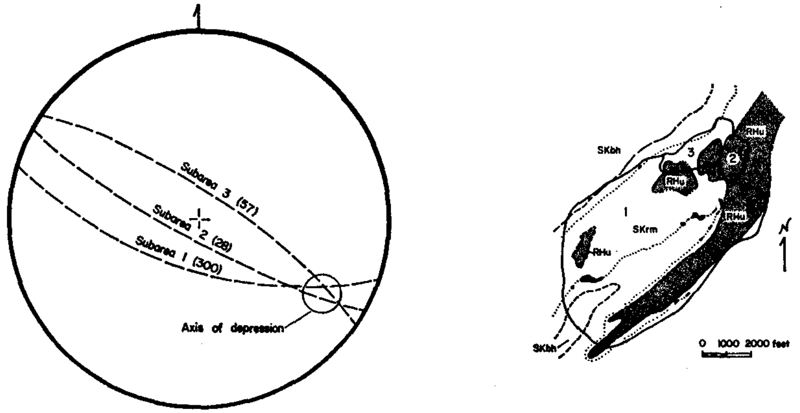


300 Poles to Foliation, 43 Fold Axes
16 Poles to Axial Surfaces, 6 Mullions

A

40 Mineral Lineations

B



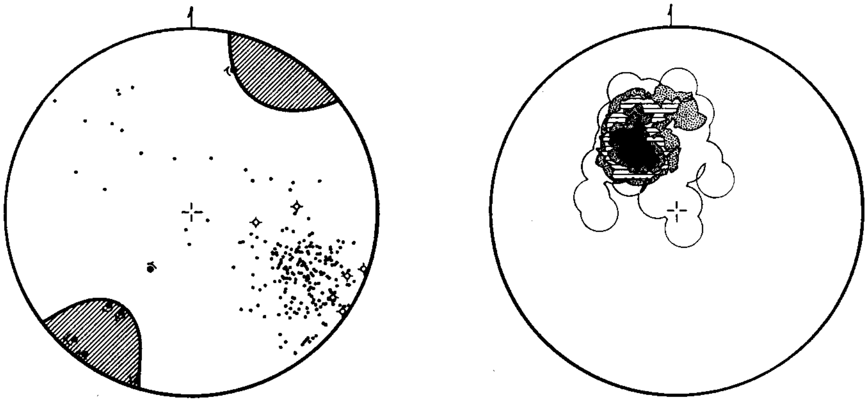
C

D

Fig. 16. Equal-area projections showing the geometry on Ratlum Mountain. *A* and *B* present the geometry of subarea *1* of *D*. Contours in *B* are 2.5, 7.5, 12.5, 17.5, 22.5 percent, respectively, per 1 percent area. *C* contains the great circles that approximate the girdles of poles to foliation in subareas *1, 2,* and *3* in *D*. Number of foliation measurements in each subarea is shown on the respective great circle. *D* shows three subareas on Ratlum Mountain. Symbols for the map units are explained on plate 1. Additional symbols not used in figures 11 or 12: dots = poles to foliation; open circles with barbs = poles to axial surfaces of noncrenulate folds.

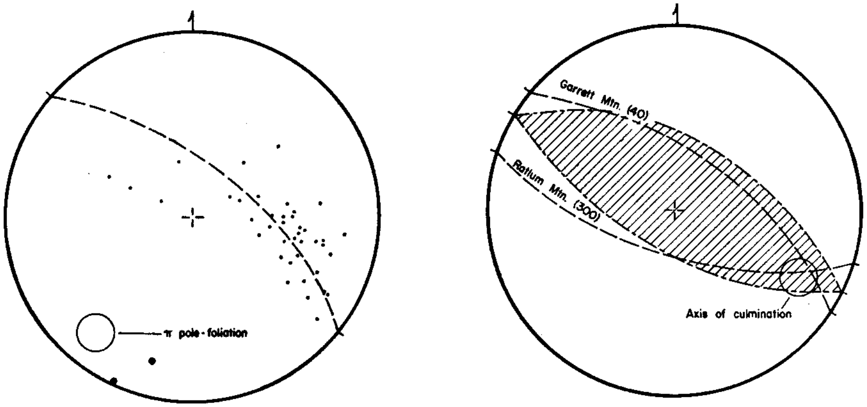
geometry of the fold system. South of Barbour Brook on Ratlum Mountain the contact between the Rattlesnake Hill Formation and the Satan's Kingdom Formation outlines an irregular pattern that is explained by a small depression in the axes of the major folds, and by gentle folding of their axial surfaces as shown in section *A-A‴* (pl. 2). The area under discussion is shown in figure 16D. Figure 16C shows the great circles that approximate the complete girdles of poles to foliation in the three subareas outlined in *D*. From subarea 1 northeastward to subarea 3 the axes of the major folds (π-poles to the great circles in *C*) form a depression; the intersection of these great circles defines the axis of this depression, which plunges southeastward at about 30°. Thus the geometry of the major folds is consistent with the map pattern in this area.

In Nepaug State Forest south of Farmington River isolated patches of the upper member of the Rattlesnake Hill Formation are interpreted



207 Poles to Foliation, 7 Fold Axes
6 Poles to Axial Surfaces
A

64 Mineral Lineations
B



40 Poles to Foliation
2 Fold Axes
C

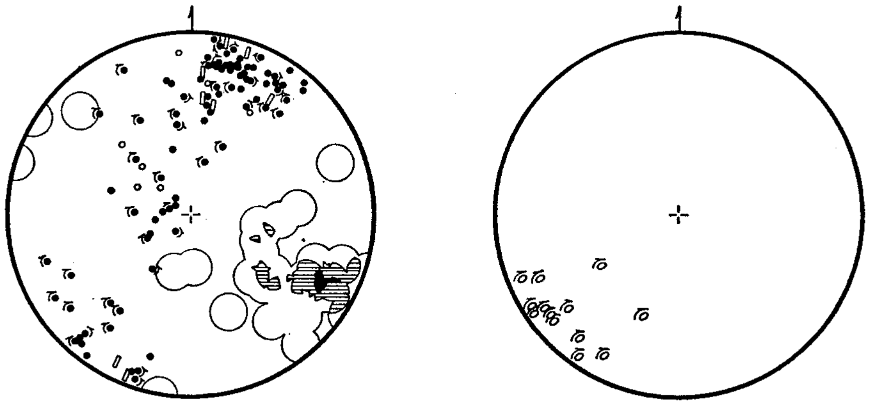
D

Fig. 17. Equal-area projections showing the subarea geometry of Nepaug State Forest, *A* and *B*, and Garrett Mountain, *C*. *D* contains the great circles (dashed) that approximate the girdles of poles to foliation on Ratlum Mountain (subarea *1* of *D*, fig. 16) and Garrett Mountain. The ruled portion of *D* represents the diffuse girdle of poles to foliation from Nepaug State Forest (*A*). Number of foliation measurements for each subarea is shown on the respective great circle. Contours in *B* are 1.6, 4.8, 8.0, 11.2, 14.4 percent, respectively, per 1 percent area. For explanation of symbols see figures 11, 12, and 16.

as remnants preserved in small doubly plunging synforms on the crest of a major culmination. Unlike those in the Barbour Brook area, the outcrop here is not complete enough to enable any of these synforms to be closed with any degree of certainty. Poles to 207 foliation measurements in this subarea form a diffuse girdle in figure 17A with a strong maximum which corresponds to the predominately northwestward-dipping foliation shown on the geologic map (pl. 1). This girdle can be described by a π-pole which would fall within the ruled part of figure 17A, indicating that the axes of the major folds are essentially horizontal, with small inclinations to the northeast and southwest. Therefore, the geometry is consistent with the synformal interpretation of the Rattlesnake Hill Formation in Nepaug State Forest. To the south on Garrett Mountain the map units outline a series of plunging folds. As shown in figure 17C the poles to 40 foliations form an incomplete great-circle girdle about a π-pole plunging to the southwest. Thus, from Ratlum Mountain (subarea 1, fig. 16D) southwestward to Garrett Mountain the axes of the major folds pass over a major culmination. The great circles that approximate the foliation girdles for the three subareas are shown in figure 17D; the diffuse girdle for Nepaug State Forest is ruled. The axis of the culmination plunges southeastward at about 30° and is parallel to the depression axis south of Barbour Brook. Therefore, the geometry of the major folds as shown by the foliation girdles is consistent with the map pattern of the upper member of the Rattlesnake Hill Formation. In arriving at this pattern both stratigraphy and geometry were used.

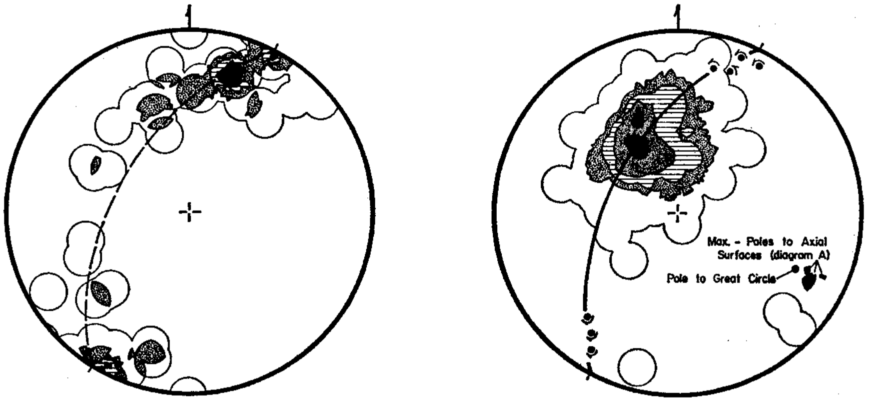
The geometry typical of many of the subareas in this fold system is illustrated by figure 16A, B, and figure 17A, B, C. In each of these subareas the axes of noncrenulate folds, mullions, and boudin lines (not shown) cluster around the π-pole defined by the poles to foliation. A total of 40 mineral lineations from Ratlum Mountain (fig. 16B), and a total of 64 from Nepaug State Forest (fig. 17B) form point maxima whose center plunges northwestward at an angle to the π-poles in both subareas; the angle is about 35° for the Ratlum Mountain subarea and 75° for the Nepaug State Forest subarea. The center of the two maxima differ by only 20°. On Garrett Mountain only two mineral lineations were found; these also plunge northwestward at about 70° to the π-pole. As illustrated in figure 18D, the mineral lineation maintains a fairly constant northwestern orientation throughout the fold system, in contrast to the variable orientation of π-poles and axes of noncrenulate folds (see fig. 18A). The center of the maximum of 238 mineral lineations corresponds to a statistical lineation striking N 30° W and plunging at about 55°. The lack of parallelism between mineral lineation and the axes of major and noncrenulate folds is a unique feature of the northeastward-trending folds and contrasts sharply with the domes, where mineral lineation and the axes of noncrenulate folds are parallel.

A synopsis of the geometry of the fold system is shown in figure 18. *A* represents all the axes of noncrenulate folds, mullions, and rods measured in all of the 15 subareas. The poles to the axial surfaces of 29 noncrenulate folds are contoured; the maximum corresponds to a statistical surface striking N 28° E and dipping 68° to the northwest. Rotated porphyroblasts were found only in Satan's Kingdom, located on the western limb of the westernmost synform in the fold system. As shown in



87 Fold Axes, 29 Poles to Axial Surfaces
8 Mullions, 7 Rods
A

13 Rotated Porphyroblasts
B



55 Boudin Lines
C

238 Mineral Lineations
7 Axes of Major Folds
D

Fig. 18. Equal-area projections showing the synoptic geometry of the **Ratlum Mountain-Garrett Mountain** fold system. In *A* the contours for 29 poles to axial surfaces of minor folds are 3.5, 10.4, 17.3 percent, respectively, per 1 percent area. *B* contains 13 rotated porphyroblasts from the western limb of the western synform of the fold system. In *C* the contours are 1.8, 5.5, 9.1, 12.7 percent, respectively, per 1 percent area. In *D* the contours of mineral lineation are 0.4, 2.9, 5.5, 9.2, 13.0 percent, respectively, per 1 percent area. For explanation of symbols see figures 11, 12, and 16.

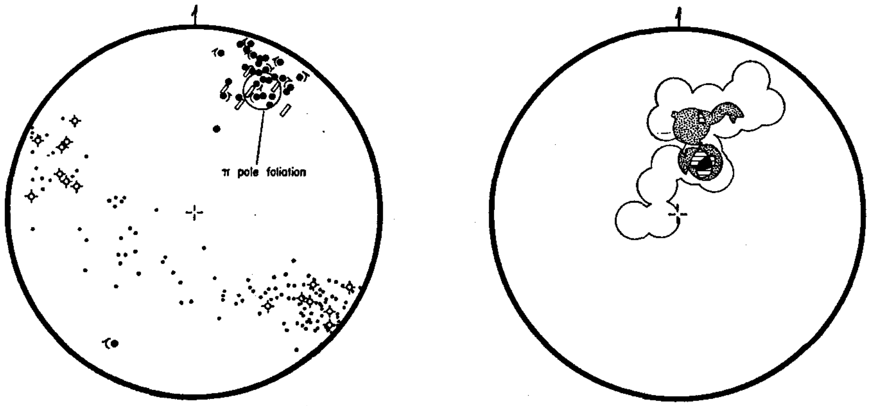
figure 18B, their axes plunge southwestward, and the sense of rotation is consistently clockwise. The linear structures in *A* mostly plunge, at gentle angles, either northeastward or southwestward, with a spread of the data between these two positions in a diffuse girdle which can be approximated by a great circle. The spread of data in *A* is about equal to that in figures 12A and 13A except that in the domes the distribution of similar data tends to approach a small circle. The sense of rotation varies throughout most of figure 18A because the noncrenulate folds were collected from both limbs of all the major folds and, therefore, show a rotation sense that depends on location and order. A total of 55 boudin lines are contoured in figure 18C and contain maxima in the same general positions as those in *A*, although the tendency for the data to spread along the great circle is greater in *A* than in *C*. A total of seven axes of major folds that correspond to the π-poles in seven subareas in the fold system are shown in *D*; five of the seven come from north of Farmington River. The sense of rotation for each axis is based on the geologic sections that show counterclockwise rotation for northeastward-plunging folds and clockwise rotation for southwestward-plunging folds – both of the first order. If the hypothesis on which the geologic sections are based is not accepted, then the only feature that changes in *D* is the rotation sense and not the orientation or density distribution of any of the structural elements. As shown in *D*, the great circle defined by the seven axes passes through the maximum for the mineral lineation. The pole to this great circle corresponds to the axis of the depression and the culmination shown in figures 16C and 17D. The maxima defined by the poles to the axial surfaces of noncrenulate folds (fig. 18A) fall very close to this pole (fig. 18D). Furthermore, the linear structures of *A* and *C* (fig. 18) tend to form girdles that can be approximated by the great circle of *D*. Hence *D* provides a satisfying summary of the geometry of the Ratlum Mountain-Garrett Mountain fold system.

Slashers Ledges-Nepaug fold system. This fold system is similar geometrically to the fold system to the east and consists of a northeastward-plunging antiform and synform that culminate north of the Nepaug River and plunge to the southwest in the vicinity of Nepaug. As interpreted in the geologic sections, these folds are practically a mirror image of the Ratlum Mountain-Garrett Mountain fold system and only differ in the attitude of their respective axial surfaces. Again the oldest stratigraphic unit in the area appears in the trough of the synform and the youngest stratigraphic unit – the rusty schist member of the Slashers Ledges Formation – forms the core of the antiform. The thin septum of rusty schist that separates the two major fold systems presumably marks the axial trace of the Connecticut Valley synclinorium which can be traced south from Quebec through Vermont to northern Massachusetts (Cady, 1960).

East of Farmington River near New Hartford the upper member of the Rattlesnake Hill Formation is exposed just west of Ratlum Brook. Approximately 500 ft to the northeast in the New Hartford quadrangle, staurolite schist of the Breezy Hill Member of the Satan's Kingdom Formation crops out with a thinly laminated amphibolite similar to that found in the Slashers Ledges Formation. Consequently, the Ratlum Mountain Member, which normally crops out between the Rattlesnake Hill Formation and the staurolite schist of the Breezy Hill Member, is missing along Ratlum Brook, although it is found just to the west on the hill between the eastern and western branches of Farmington River. A likely solution to this problem is a westward-dipping reverse fault located along Ratlum Brook. This interpretation is shown on the geologic map (pl. 1) and in the geologic section *A-A‴* (pl. 2). The hinge of the antiform located just south of Pine Grove Cemetery, and discussed in the section on the stratigraphy of the Rattlesnake Hill Formation would then be on the upper block. The Ratlum Brook fault may possibly extend south and separate the Ratlum Mountain Member from the rocks on Jones and Yellow Mountains, where the structural elements lack the strong preferred orientation so typical of the structures in the Slashers Ledges-Nepaug fold system. If the fault does exist there the displacement is thought to be a fraction of the 1,000 ft of section missing along Ratlum Brook, because the rocks on Jones and Yellow Mountains are considered to be facies equivalents of the upper member of the Rattlesnake Hill Formation. The quartz-plagioclase gneiss, calc-silicate gneiss, and amphibolite typical of the lower part of the Ratlum Mountain Member in the type locality is missing from the belt of schist belonging to this member just east of Jones and Yellow Mountains. This, of course, could also be interpreted as a slight change in facies, but at least the evidence found there is compatible with a southern extension of the Ratlum Brook fault.

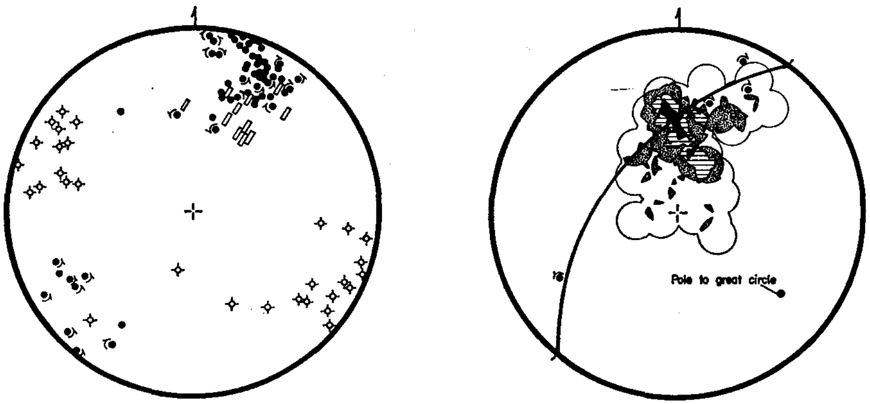
In none of the rocks presumably bordering the fault were any signs detected of unusual granulation or blastomylonitic textures. Instead all grains are well recrystallized and devoid of any such postcrystalline strain features as undulose extinction in quartz or kink-banding in micas. Thus the faulting is thought to have taken place during folding while the rocks were still undergoing distortion and metamorphism. Because the sense of movement on the fault is the same as the sense of rotation of the folds as seen in the geologic sections, they are considered a product of the same overall stress system.

The geometry of the fold system is shown in figure 19. Diagrams *A* and *B* are typical of the geometry in any of the four subareas of the fold system. In each subarea the poles to foliation form complete girdles that are easily approximated by great circles. Characteristically, the axes of minor folds, mullions, and boudin lines (none shown) cluster around the individual π-poles. The mineral lineation commonly plunges to the north at an angle to the respective π-poles; the center of the maximum in *B* is about 40° from the π-pole shown in *A*. The π-poles for the four subareas are represented by the four axes of major folds in *D*. The sense of rotation about these axes is based on the map pattern and is opposite to that in the Ratlum Mountain-Garrett Mountain fold system (compare figs. 18D and 19D). As in the fold system to the east, the axes of major folds and the center of mineral lineation are approximately oriented on a great circle whose pole corresponds to the axis of the culmination, located north of the Nepaug River. The pole of this great circle differs by only 6° from the pole to the great circle in figure 18D. The orientation of mullions, axes of noncrenulate folds, and poles to their axial surfaces from all four subareas is shown in figure 19C. The sense of rotation of noncrenulate folds varies for the northeastward-plunging folds because they were collected from both limbs of the major folds. Seven of the eight folds which plunge southwestward show a counterclockwise sense of rotation. As shown in *A* and *C*, the axial surfaces of the noncrenulate folds dip steeply either to the northwest or southeast and tend to spread along the girdle defined by poles to foliation. Unlike the fold system to the east, the pole to the great circle defined by axes of first-order folds and the maximum of mineral lineation does not coincide with the densest concentration of poles to axial surfaces (compare *C* with *D*).



127 Poles to Foliation, 30 Fold Axes
15 Poles to Axial Surfaces, 6 Mullions
A

22 Mineral Lineations
B



61 Fold Axes
30 Poles to Axial Surfaces, 11 Mullions
C

43 Mineral Lineations
4 Axes of Major Folds
D

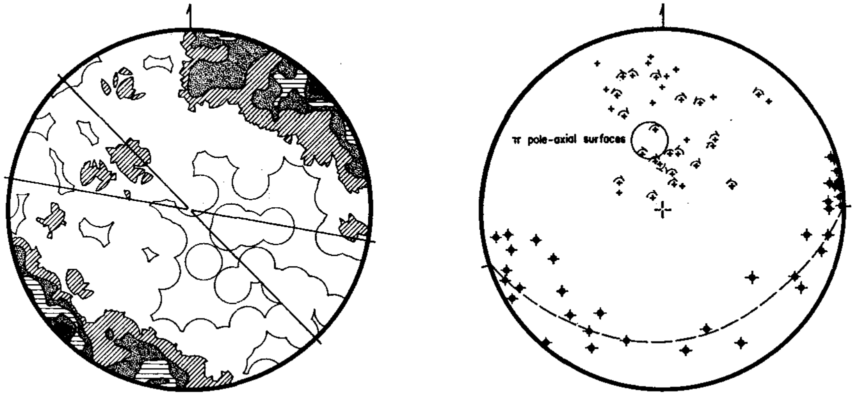
Fig. 19. Equal-area projections *A* and *B* show the geometry of the subarea near Slashers Ledges. Contours in *B* are 4.5, 13.5, 22.5, 31.5 percent, respectively, per 1 percent area. Equal-area projections *C* and *D* show the synoptic geometry of the Slashers Ledges-Nepaug fold system. Contours in *D* are 2.3, 6.9, 11.5, 16.1 percent, respectively, per 1 percent area. For explanation of symbols see figures 11, 12, and 16.

Major fold geometry compared to dome geometry. The overall geometry of the Slashers Ledges-Nepaug fold system and that of the Ratlum Mountain-Garrett Mountain fold system is very similar. The mineral lineations in each system form a distinct maximum that corresponds to a statistical lineation plunging northwestward in the eastern fold system and northward in the western fold system. The axes of the major folds plunge northeastward and southwestward *at an angle* to mineral lineation: the angle between the center of the maximum and the axes of major folds ranges from 45° to 90° in the eastern fold system and from 20° to 90°

in the western fold system. Together the mineral lineation maxima and the axes of the major folds define great circles whose poles correspond to the axes of two culminations and a depression; the cross axes are essentially parallel in both fold systems. Furthermore, the axes of noncrenulate folds, mullions, and boudin lines fall along the same great circles; the spread along the great circle, however, is greater in the eastern fold system than in the western.

The geometry of the domes is very different from that of the major folds. In both domes the distribution of mineral lineation, axes of noncrenulate folds, mullions, and rods is better approximated by a small circle than by a great circle, although the small-circle fit is far from perfect. At any one locality in the domes, mineral lineation was found to *parallel* the axes of noncrenulate folds; a relationship rarely found in the northeastward-trending folds. Thus, based on geometry, the major structures in the quadrangle fall into two distinct groups — the domes and the major folds west of the domes.

Joints and fold styles. Poles to 357 joint surfaces from both fold systems are contoured in figure 20A. The 4.8 percent maxima correspond to two sets of vertical joints that strike N 45° W and N 80° W. Approximately 75 percent of the noncrenulate fold axes, mullions, rods, and rotated porphyroblasts fall within the largest area outlined by the second contour interval (1.4 percent) in the northeastern and southwestern part of the diagram. Furthermore, 10 of the 11 axes of major folds shown in figures 18D and 19D fall in this same area. This shows a strong tendency for steep joints to be oriented at high angles (70° to 90°) to the axes of folds



Poles to 357 Joints

A

36 Fold Axes
36 Poles to Axial Surfaces

B

Fig. 20. Equal-area projection *A* shows the poles to joints for both fold systems. Great cirles corresponding to the two maxima are shown by solid lines. Contours are 0.3, 1.4, 2.5, 3.6, 4.8, 5.9 percent, respectively, per 1 percent area. Equal-area projection *B* shows the crenulate folds on Breezy Hill. Great circle that approximates the distribution of poles (dots with barbs) to axial surfaces is dashed. Symbol for fold axes is shown in figure 11.

of all orders. Note that the poles to a large percentage of the foliation measurements taken throughout the northeastward-trending folds would fall in the gap in the southeastern part of figure 20A. The relation between joints and the axes of folds, therefore, is more readily apparent in the major folds than in the domes.

The style of the noncrenulate folds in the northeastward-trending folds is far less varied than that in the domes. As shown in figure 21 the most common form is asymmetric with one limb shorter than the other. Some of these are clearly disharmonic (fig. 21B, D), whereas others are not, at least within the confines of a given outcrop. Although these folds are commonly referred to as "drag folds," other nongenetic terms, such as "step folds" (Whitten, 1959) or "parasitic folds" (Turner and Weiss, 1963, p. 121), are preferred here. Axial-surface foliation is developed in most of the noncrenulate folds, although it appears to be better developed in the Ratlum Mountain-Garrett Mountain fold system than in the other system. In all these folds the mineral lineation is at an angle to the fold axis. Much of the mineral lineation is found in the axial-surface foliation and is the same age as the fold, but in some areas, as on Ratlum Mountain, the mineral lineation is also found on the bedding foliation and is possibly older than the fold. Deformed mineral lineation wrapping around

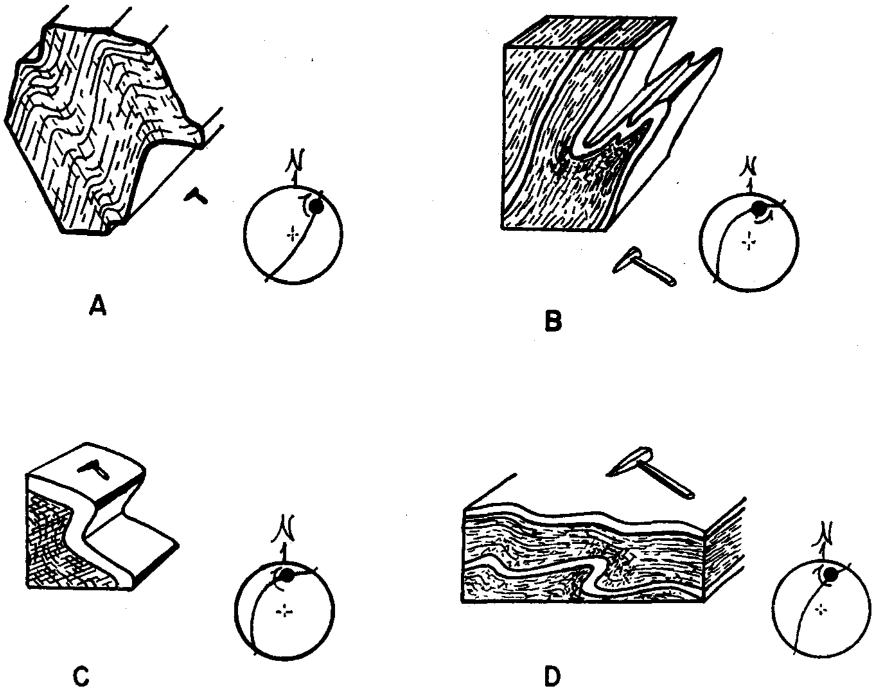


Fig. 21. Fold styles in the northeastward-trending folds. Small equal-area projection next to each diagram shows the orientation of the fold axis and the axial surface. Scale is given by the geologic hammer. Closely spaced lines represent schist. Beds of gneiss are shown as blanks. All folds are asymmetrical with an axial-surface foliation best developed in *C*. *A* is a similar fold; *B* and *D* are disharmonic folds.

the hinges of noncrenulate folds was not recognized in either of the fold systems, although more careful study might reveal it.

A total of 75 crenulate folds was measured in schist throughout the northeastward-trending folds, although they are more abundant and better developed in the Ratlum Mountain-Garrett Mountain fold system. Crenulate folds are considered to be slightly younger than the other structural elements related to the major folds because they deform both the axial-surface foliation and the mineral lineation. Their abundance and the degree to which their profiles are closed varies with rock type and location. The folds are better developed in the mica schist than in the quartz schist and the porphyroblastic schist of both the Satan's Kingdom and Slashers Ledges Formations. In the mica schist of the Ratlum Mountain-Garrett Mountain fold system the crenulate folds are best developed on Breezy Hill and are identical in style to those found south of Taine Mountain between the Collinsville and Bristol domes. In both places the individual folds are normally closed (tight) and in places possess sharp hinges which form a strong lineation on foliation surfaces.

As shown on the geologic map (pl. 1) and on figure 20B, the axial surfaces of the crenulate folds are commonly oriented at a high angle to the foliation in a single outcrop and to the axial surfaces of the major folds. Furthermore, they commonly vary in orientation in a single subarea, but when plotted in spherical projection their poles form incomplete girdles that can be approximated by a great circle; the π-poles plunge northwestward. For example, in figure 20B, the fold axes and poles to axial surfaces of 36 crenulate folds are plotted for Breezy Hill, where these folds best developed. Unlike other subareas in the major folds or the domes where the crenulate folds are not generally as well developed, these poles to the axial surfaces describe a complete girdle. The axes of the folds are scattered around the π-pole; the densest concentration, however, does not coincide with the 1 percent circle representing the π-pole. The sense of rotation is shown for 22 folds; 13 are clockwise and 9 are counterclockwise. This lack of consistency in rotation sense is also characteristic of the folds south of Taine Mountain (fig. 15B) where these structures are as well developed as on Breezy Hill. In contrast, the rotation sense is predominantly clockwise in all the subareas throughout the quadrangle where the crenulate folds are only weakly or moderately developed, such as those shown by figure 15A, C, D.

The areas where crenulate folds are well developed and the areas where they are absent both have a direct relation to the major structures in the quadrangle. The crenulate folds are best developed in depressions in the major fold structures: the locality where well developed crenulate folds occur south of Taine Mountain is just south of the culmination in the synform between the Collinsville and Bristol domes; Breezy Hill is north of the major culmination in the northeastward-trending fold. Just to the north of Breezy Hill in the New Hartford quadrangle, the crenulate folds are also well developed but apparently they die out toward the South Granby dome. As shown in figure 2 and on the Geological Map of Connecticut (Rodgers and others, 1956), this area forms a major structural depression in the center of a triangle formed by the Collinsville dome, the South Granby dome, and the Berkshire Highlands. In contrast, crenulate folds are commonly absent or only poorly developed in mica schist in the Collinsville and Bristol domes. On Rattlesnake Hill, Barnes Hill, and Johnnycake Mountain, the crenulate folds are commonly open and only moderately developed. Consequently, the intensity of these minor structures appears to increase *away* from the domes toward the structural depressions.

TRIASSIC STRUCTURES

Normal faults. In the northeastern part of the quadrangle two northward-trending normal faults bring sedimentary rocks of Late Triassic age in fault contact with pre-Triassic metamorphic rocks. As shown on profile section *A-A'''* (pl. 2), these faults are presumed to dip away from each other, forming a horst that includes the Collinsville and Bristol domes. The dips of the fault surfaces, which cannot be measured directly, are inferred from the dips of nearby foliation on the assumption that these structures are normal faults, a common interpretation for faults cutting Triassic rocks in Connecticut.

The Cherry Brook fault, located on the eastern side of Cherry Brook Valley, is based on stratigraphic and topographic evidence.

1) Shale, sandstone, and conglomerate discovered by Platt (1957) crop out only along the western branch of Cherry Brook about 400 ft north of the twin bridges on Sweeton Road and dip gently southeastward. The questionable extent of the rocks is inferred from the low topography between Barbourtown Road and Route 179 and from abundant float on the small hill south of the corner of Sweeton and Barbourtown Roads. Because the sedimentary rocks north of Sweeton Road dip southeastward into metamorphic rocks near Route 179, a fault is assumed to form the eastern contact of this area. Platt (1957) tentatively concluded that the western contact is an unconformity because no evidence of faulting was found in outcrops of conglomerate and schist located in the bed of Cherry Brook in the New Hartford quadrangle, and this interpretation seems correct.

2) Farther south along Cherry Brook Valley, the outcrops, although sparse, are sufficient to show that the Rattlesnake Hill Formation is thinned or cut out by a fault. Thus at locality X (see geologic map, pl. 1) along Cherry Brook, thinly bedded quartzite and garnet-quartz granulite of the upper member are found in fault contact with The Straits Schist.

3) In Cherry Brook Valley, the quartz-rich rocks of the Ratlum Mountain Member of the Satan's Kingdom Formation underlie a topographic low, although they normally form topographic highs such as Ratlum Mountain, Garrett Mountain, and an unnamed mountain north of Nepaug Reservoir. Therefore, these resistant rocks may have been dropped down or shattered by the fault.

The western margin of the main Triassic area in Connecticut was discussed comprehensively by Wheeler (1937) who showed the contact as an unconformity in some places and as a fault in others. His interpretation is essentially that shown on the Preliminary Geologic Map of Connecticut (Rodgers and others, 1956). Recent work by Fritts (1963) in south-central Connecticut has shown that even more of the western margin is a fault contact than was previously thought. Many of the faults can be traced into the metamorphic rocks, where they generally parallel the foliation. In the Collinsville quadrangle, Wheeler (1937) shows the contact between the sedimentary and metamorphic rocks as an unconformity. In the light of the following evidence, however, a fault seems more likely. Direct evidence for this fault was found in a temporary trench along U.S. Route 44 where the New Haven Arkose dips into and is in contact with the Bristol Member of the Collinsville Formation. Moreover, the metamorphic rocks are severely retrograded and contain abundant calcite which may have come from solutions migrating along the fault. To the north retrograded schist is exposed just south of Woodchuck Road near Onion Mountain. Near this locality and just north of the junction of Bahre Corner, Lawton, and Gracey Roads arkose near the eastern border of the quadrangle either strikes or dips toward the schist. Thus north of U.S. Route 44 it is likely that the New Haven Arkose has been faulted against the metamorphic rocks.

To the south the evidence is more equivocal. On a hill east of Roaring Brook and a mile south of Secret Lake several outcrops of flat-lying arkose were found just east of plagioclase gneiss in which the foliation dips steeply to the southeast. In the gneiss nearest the arkose (about 20 ft separate the two) the upper part is stained red by hematite and is cut by flat-lying joints that Wheeler (1937, p. 28, 29) considered products of pre-Triassic weathering. Because this weathered surface appears to project eastward under the arkose, Wheeler considered the contact an unconformity, although the actual contact is concealed. Data supplied by Randall (written communications, 1962) from water wells just to the north and to the south on Country Club Road, however, suggest a fault. These records, unfortunately, are of questionable value because much of the glacial material in this area is stained red and can be confused with the red sandstone of the New Haven Arkose. Although the contact south of U. S. Route 44 is shown as a fault on the map, an unconformity cannot be ruled out. If Wheeler is correct, then the fault north of Route 44 could be located east of the fault contact shown on the map, and eventually connect near Unionville with the fault exposed at the Bristol Copper Mine. In this interpretation, the horizontal arkose on the hill east of Roaring Brook would be a remnant of the New Haven Arkose resting unconformably on bevelled gneiss as in the Roaring Brook locality in the Southington quadrangle (Fritts, 1963a).

Several northwestward-trending faults offset dolerite bodies along the border of the Collinsville and Avon quadrangles (Schnabel, 1961). Although these faults parallel the strike of the foliation on the northwestern side of the Collinsville dome, no direct evidence of faulting was found in the area. Accordingly these faults are terminated against the northeastward-trending fault.

The faults along the westward margin of the main Triassic area are younger than at least part of the New Haven Arkose, because the lower part of that formation is cut by faults in such places as the Roaring Brook locality in the Southington quadrangle (Fritts, 1963).

Tilting. Central, and presumably western, Connecticut was tilted eastward 15° to 30° during or at the end of the Triassic period; the Triassic strata, composed mostly of material brought from the east (Krynine, 1950), now dip in that direction. Thus, the structural elements of western Connecticut were presumably rotated 15° to 20°, the average dip of the sub-Triassic surface exposed west of West Rock near New Haven. Although primary evidence of tilting was not found in the Collinsville quadrangle, the limbs of the Bristol dome and the axial surfaces of the northeastward-trending folds become symmetrical relative to sea level if 17° of eastward tilt is subtracted from profile sections. The axial surfaces of the major folds west of the domes would dip approximately 52° toward each other, a likely relation if they had both slid off rising masses of light rock.

Tectonic synthesis

To set the stage for a synthesis of the structures in the Collinsville quadrangle one may turn to eastern Vermont where detailed work during the last twenty years has resulted in the coherent geologic framework presented in the recent Geologic Map of Vermont (Doll and others, 1961). The work of White and Jahns (1950), Thompson and Rosenfeld (1951) and Skehan (1961) forms the basis of many of the cross sections in the southern part of eastern Vermont where the structures are similar to those of the Collinsville quadrangle (see sections *C-C′* through *F-F′*, Geologic Map of Vermont, Doll and others, 1961). The overall tectonic history in eastern Vermont appears to involve an early generation of east-facing nappes followed by a later generation of gneiss domes that deformed the older structures. How much time separated these events is not known, but it is probable that they represent phases of the continuous deformation process known as the Acadian Orogeny. The effects of doming on the older nappes ranges from gentle arching north of the Chester dome (fig. 2, and sections *A-A′* to *C-C′*, Geologic Map of Vermont) to a more intense stage where the vertical movement of the domal rocks has produced new major folds of "spruce-tree" type on the flanks of the domes (see section *E-E′*, Geologic Map of Vermont). Going from west to east across the Chester dome, for instance, the sense of rotation changes from counterclockwise to clockwise; the change takes place at the crest of the dome.

The upward movement of the gneiss domes is attributed to the difference in density between the rocks in the domes and those mantling the domes. Recent gravity studies in Vermont and New Hampshire (Bean, 1953) have shown that the domes are areas of negative gravity anomalies and that the densities of the domal rocks average 2.68, whereas those of the mantle rocks range from 2.79 to 2.85. Thus, in eastern Vermont and western New Hampshire it appears that the domes have moved upward under a gravitational potential generated by a density difference between the domal rocks and the mantling rocks—analogous to the intrusion of salt domes. Such a mechanism for doming has been suggested by Thompson and Rosenfeld (1951), Rosenfeld and Eaton (1956), and Skehan (1961). Because some of the domal rocks are rich in feldspar and quartz and thus approach the low melting composition in the granite system, partial melting during metamorphism may have added energy to the existing gravitational potential as well as increasing mobility.

This general hypothesis of doming can be extended to include the domes of western Connecticut because they are all on the same trend as those in Vermont (fig. 2) and consist of approximately the same rock types. Although recent gravity work has been done in western Connecticut by the U.S. Geological Survey, the results have yet to be published. Longwell (1943) published maps showing free-air, Bouguer, and isostatic anomalies based on work of the U.S. Coast and Geodetic Survey in which a regional gravity high was found between the Berkshire Highlands and the domes in the Bristol, Collinsville, and New Hartford quadrangles. Eaton and Rosenfeld (1961) tentatively connect this gravity high with the gravity high over the Green Mountains (Bean, 1953). According to the measurements given by Longwell, the gneiss of the Waterbury dome and the plagioclase gneiss of the Collinsville and Bristol domes have densities of 2.68 to 2.70 whereas the rocks near Satan's Kingdom have densities of 2.78. To the degree that the density of crystalline rocks controls the location of the gravity anomalies shown by Longwell (1943), the location of the gravity high in Connecticut indicates that the density is highest in the rocks forming the complex synform between the Berkshire Highlands and the domes, a situation that is consistent with the hypothesis of doming. In both the Collinsville and Bristol domes the plagioclase gneiss of the Bristol Member of the Collinsville Formation is considered the buoyant element in the doming process, primarily because it is similar to the low density rocks in the domes of northern Massachusetts, eastern Vermont, western New Hampshire, and eastern Connecticut. Furthermore, the numerous bodies and pods of granitic material associated with the plagioclase gneiss suggest that it may have been partially melted during doming and metamorphism in the middle part of the almandine-amphibolite facies.

Although the hypothesis of doming is similar in many respects to the model described by Eskola (1948), it differs by requiring neither two periods of deformation marked by a profound unconformity between domal and mantle rocks, nor remobilization of a pre-unconformity granite. No evidence of an unconformity was found between the lower group and the Hartland Group in the Collinsville quadrangle, although Fritts (1962) believes one exists around the Waterbury dome. The plagioclase gneiss of the Bristol Member, which is considered the buoyant element in this doming, is not a discordant intrusive because it is conformably sandwiched between the Sweetheart Mountain Member and the Taine Mountain Formation. Moreover, the Bristol Member is a heterogeneous rock unit of which the plagioclase gneiss is just one type, although the most abundant one. Even though no conclusive evidence can be presented here, the Bristol Member is considered to have been originally a sequence of acid and basic volcanics (plagioclase gneiss and amphibolite) mixed with varying amounts of impure sandstone and shales (mica-quartz gneiss and schist).

The tectonic relationship of the northeastward-trending folds to the domes is a problem because of the limited area of this study. Possible solutions to this problem, however, are based on the assumption that the third hypothesis discussed in the section entitled "Basis for Rock Stratigraphic Sequence" is correct—namely, that the sequence of map units in the major folds west of the domes is upside down. This interpretation, along with the geometry and the map pattern, forms the real basis of the geologic sections (pls. 2, 3). The portion of the sections where the configuration is controlled by structural data is shown by a solid line; the speculative portions are shown by a dashed line. The counterclockwise sense of rotation shown in sections *A-A‴* and *B-B‴* for the Ratlum Mountain-Garrett Mountain fold system is based on the third hypothesis, whereas the clockwise sense of rotation for the Slashers Ledges-Nepaug fold system is based on the map pattern. As shown on plate 2, the sense of rotation of the major folds changes across the axial surface of the complex syncline between the domes and the Berkshire Highlands.

Using the solid-lined portions of the geologic sections and the senses of rotation of the major folds, two hypotheses which describe the tectonic relationship of the major folds to the domes seem possible. In the first hypothesis the major folds are a direct consequence of the upward movement of the dome and thus are of spruce-tree type. In the second hypothesis the major folds are considered a part of an older nappe that was subsequently deformed by the domes. Both hypotheses assume that the domes have behaved tectonically like salt domes; they differ, however, in the intensity ascribed to the doming process. The first hypothesis is based on the assumption that the complex syncline between the domes and the Berkshire Highlands resembles the inverted mushroom shown in sections *A-A‴* and *B-B‴* (pl. 2). In this interpretation the map units in the eastern fold system form a syncline at depth and reappear in the western fold system. It is unlikely that major folds in this interpretation represent part of an older nappe because they change their sense of rotation across the axial surface of the complex syncline. Alternatively, the eastern fold system could be part of an older nappe if the western fold system formed during doming. In such a sequence, one would expect the older fold system to be deformed in some fashion by the younger fold system. This alternative suggestion seems unlikely because the geometry of both fold systems is so similar. Consequently, in the first hypothesis the major folds are thought to result from the upward movement of the domes and the Berkshire Highlands. This hypothesis, however, does not rule out an older generation of nappes as described in eastern Vermont. It is quite likely that the major folds in the Collinsville quadrangle could have developed from a limb of an older nappe. The kinematic sequence envisaged for the major structures in the quadrangle is diagrammatically sketched under *1* of figure 22. Here the rock units are considered part of an earlier nappe structure. Unlike the large east-facing nappe in eastern Vermont north of the Chester dome, the hypothetical nappes in figure 22 are all overturned to the west. There is certainly no evidence in western Connecticut for this choice, much less the very existence of the nappes themselves. In northern Massachusetts, however, the map pattern of Hoosac Mountain has been interpreted recently as a nappe overturned to the west (Christensen, 1963). In hypothesis *1* the direction of overturn makes no difference to the final configuration, but in hypothesis *2* (fig. 22) the nappe must be overturned to the west in order to conform to the stratigraphic sequence proposed for the quadrangle and be consistent with the rotation sense implied by the major folds. In sketch *B* under *1* the major folds are shown developing from the lower limb of a nappe; the folds are actually produced by the upward movement of the domes and Berkshire Highlands. Such a hypothesis explains all the major structures in the quadrangle by a single phase of deformation in which the vertical movement of the domes and Berkshire Highlands has caused

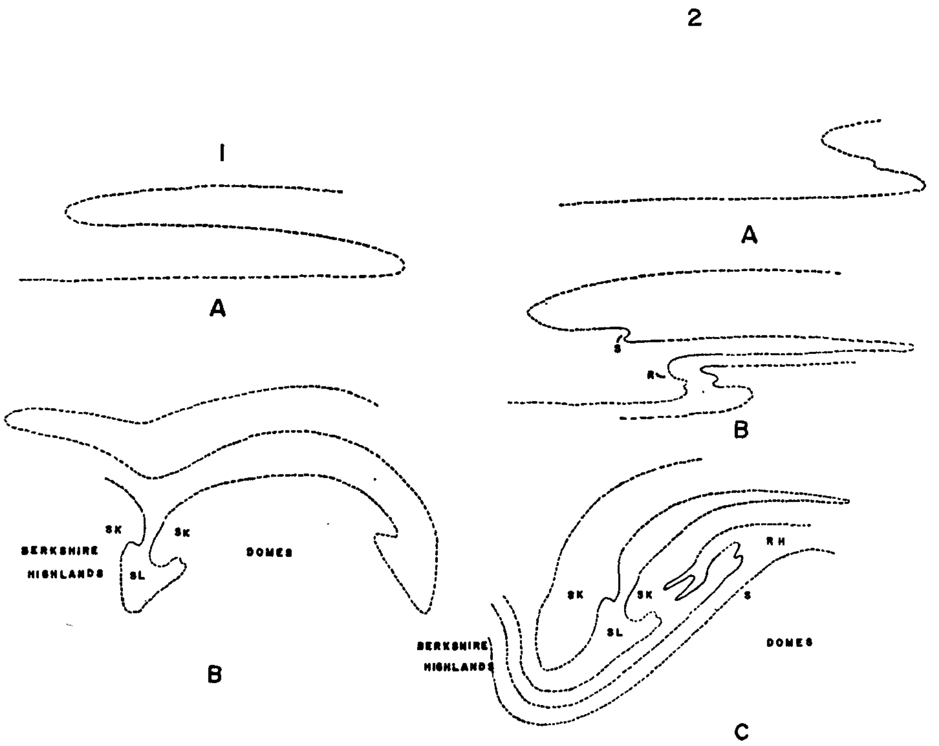


Fig. 22. Diagrammatic sketches illustrating two hypotheses on the origin of the northeastward-trending folds. *R* represents the Ratlum Mountain-Garrett Mountain fold system. *S* represents the Slashers Ledges-Nepaug fold system. Symbols for formations are shown on plate 1. Sketches oriented parallel to *A-A'''* of plate 2.

the overlying mantle to slide downward into the intervening area producing folds that locally overturn the stratigraphic sequence.

It is possible to modify the speculative parts of sections *A-A'''* and *B-B'''* slightly and produce a configuration that suggests that the major folds are a part of an older generation of nappes overturned to the west. This configuration is shown in *2C* of figure 22. Note that this second hypothesis incorporates the same basic data as the other hypothesis, but it differs in that the map units of the Ratlum Mountain-Garrett Mountain fold system continue at depth under the Slashers Ledges-Nepaug fold system and reappear farther west in the Berkshire Highlands. The Slashers Ledges-Nepaug fold system is here considered a second-order fold on a nappe that is now nested in the syncline between the domes and a portion of the Berkshire Highlands to the west. Furthermore, this hypothesis requires that the eastern part of the Berkshire Highlands shown on figure 2 be part of the nappe configuration of the mantle and not part of the Precambrian(?) basement which would then be farther west. Recent work just to the west in the Torrington quadrangle (Gonthier, 1963, personal communication) has shown that much of the eastern part of the quadrangle is underlain by the Waramaug Formation, and, therefore, is not part of the Berkshire Highlands as shown on the Preliminary Geologic

Map of Connecticut (1956). The tectonic history that could possibly result in the major structures in the Collinsville quadrangle is presented diagrammatically in sketches *A* to *C* under *2* of figure 22. The early phase of deformation involves the formation of a nappe by the horizontal flow of material of which a component is shown in the east-west sketches. Sometime during the growth of the nappe smaller second-order folds were formed at *R* and *S*; these later became the major folds of the Collinsville quadrangle. At a somewhat later time in the orogeny the light rocks at depth moved upward forming the domes and the Berkshire Highlands, thus deforming the older nappe. The result is the configuration shown in *C* under *2*. Which of these two hypotheses in figure 22 is more likely is not known. Both hypotheses are consistent with the tectonic style of eastern Vermont where nappes and folds of spruce-tree type are found. Perhaps one point against the first hypothesis (*1* in fig. 22) is that few of the folds on the east side of the Green Mountains bear the same relationship to the Green Mountains as do the folds of the Slashers Ledges-Nepaug fold system to the Berkshire Highlands. The folds on the east side of the Green Mountains are commonly overturned to the west and, therefore, indicate movement of the upper part of the stratigraphic section toward the crest of the Green Mountain Anticlinorium. Perhaps the higher metamorphic grade in Connecticut has permitted the eastern part of the Berkshire Highlands to behave in a more mobile fashion than the Green Mountains. On the other hand, the second hypothesis (*2* in fig. 22) requires that much of the eastern portion of the Berkshire Highlands in Connecticut be part of the nappe configuration of the mantle. There is no evidence for this at present, although Gonthier's work just to the west in the Torrington quadrangle is compatible with this requirement. Of the two hypotheses I prefer the first, at present, because it is far less speculative. Future mapping in the surrounding areas should clarify which of these hypotheses is more likely.

In both of these hypotheses the domes and the northeastward-trending folds are considered to represent two distinct tectonic environments; the upward flow of rock material, analogous to the flow of salt in a salt dome, dominates the domes, whereas horizontal or sliding movement, analogous to the translation of one bed over another, characterizes the northeastward-trending folds. In the first hypothesis the major folds are formed by the sliding of heavier material off the sides of the rising domes and the Berkshire Highlands. In the second hypothesis the rock material has flowed horzontally; the cause is unknown. The difference in the geometry and the styles of the minor structures between the domes and the northeastward-trending folds is considered a consequence of these respective environments. In the domes the axes of noncrenulate folds, mullions, and rods are parallel to mineral lineation in any given locality, but for the domes as a whole they tend to form a small-circle girdle if viewed in spherical projection. In the northeastward-trending folds, however, the mullions and the axes of major and noncrenulate folds are oriented at an angle to mineral lineation which plunges rather constantly to the northwest. Together these structures approximate a great circle in spherical projection. The direction of movement in the major folds is thought to be represented by the mineral lineation, particularly the elongate micas that are found in the foliation in schist, which would include at least 70 percent of the mineral lineations. Evidence for this hypothesis is shown best in the Nepaug State Forest where the center of mineral lineation on diagram *B* (fig. 17) is oriented 80° to 90° to the axes of noncrenulate folds (diagram *A*, fig. 17) and rotated porphyroblasts (diagram *B*, fig. 18). For both the fold systems, however, the angle between the major fold axes and the centers of mineral lineation maxima on *D* of figures 18 and 19 range from 20° to 90°; an even greater range is shown by the axes of noncrenulate folds (compare diagrams *A* and *D*, fig. 18). If the mineral lineation represents the direction of movement, the axes of the folds are oriented at all angles to this direction. A similar relationship has recently been described and analyzed by Hansen (1962, and Memoir in press) who shows that disharmonic folds can form at any angle to the direction of movement. In the domes the direction of movement is thought to be represented also by mineral lineation primarily because it is consistent with the upward movement postulated for the domes. If true, then the axes of noncrenulate folds have formed parallel to the direction of movement and therefore bear the same relationship to the gneiss domes as do the steeply plunging folds in salt domes.

Most of the crenulate folds throughout the quadrangle are younger than the major structures. This relationship is best seen west of the domes where the crenulate folds deform both the axial-surface foliation and mineral lineation of the northeastward-trending folds. With the exception of the south end of the synform between the domes, the axial surfaces of the crenulate folds are oriented at an angle to the axial surfaces of the domes and thus are considered younger. Because the intensity of the crenulate-fold development appears to be related to major structural depressions between such positive areas as the domes and the Berkshire Highlands, it is likely that the crenulate-fold event is related to a late stage in the doming process. South of Taine Mountain in the synform between the domes the crenulate folds probably formed during an earlier stage and may well have continued to the end of the domal phase of deformation. This hypothesis is compatible with either hypothesis on the tectonic relationship of the northeastward-trending folds to the domes.

A second major deformation recognized in the Collinsville quadrangle is represented by the high-angle faults along Cherry Brook and near the eastern border of the quadrangle. These structures are presumed to be no older than Late Triassic. During the deformation the rocks of western Connecticut were tilted gently to the east.

Age of deformation and metamorphism

Except for the normal faulting and tilting of Triassic age, the major deformation and prograde metamorphism recorded in the Collinsville quadrangle presumably occurred during the Acadian Orogeny of Middle to Late Devonian age. Even though the Hartland Group is tentatively correlated with rocks of either Cambrian or Cambrian and Ordovician age in southeastern Vermont, rocks of Silurian and Devonian age in eastern Vermont, western Massachusetts, and south-central Connecticut, were also deformed when the domes west of the Connecticut River rose to their present relative positions. Because the style of deformation and the location of domes in western Connecticut is apparently similar to that of eastern Vermont, it is reasonable to conclude that deformation in the Collinsville quadrangle and possibly that in much of western Connecticut occurred during the Acadian Orogeny. This conclusion implies that if the rocks of the quadrangle were also deformed during the earlier Taconic Orogency of Late Ordovician age (or even in an earlier deformation), then Taconic structures were either destroyed during the more intense Acadian Orogeny, or have not been recognized. Evidence for a Taconic Orogeny is found near the Hudson River, where rocks of Middle Silurian age overlie unconformably rocks of Middle Ordovician age. In western New Hampshire rocks of Lower or Middle Silurian age overlie presumed Ordovician rocks which are intruded by the Highlandcroft Magma Series. Presumably, the Taconic Orogeny affected the rocks in western Connecticut.

Radioactive dates have been determined in several places in western Connecticut and eastern New York. Much of this information was recently published by Long and Kulp (1962) who show that the apparent ages based on K/Ar and/or Rb/Sr analyses from micas range from about 870 m.y. near Bear Mountain, New York, to 280±11 m.y. in a gneiss of the Berkshire Highlands near Burrville, Connecticut (Torrington quadrangle). In the Collinsville quadrangle muscovite from a schist of the Ratlum Mountain Member cropping out on Route 4 just north of the Nepaug River was analyzed by R. A. Armstrong of Yale University. The K/Ar value gave an age of approximately 280±30 m.y. Farther south in western Connecticut, Long (1962) reports older K/Ar ages that range from 365 m.y. at Branchville to 325±13 m.y. at Minortown. Both these samples are from granitic rocks that are in part discordant to the surrounding metamorphic rocks and, therefore, younger. Because the major deformation and metamorphism in western Connecticut is presumably Acadian, which is considered to be associated with events in the range 400-350 m.y. (Faul and others, 1963), the 280 m.y. figure in the Collinsville quadrangle and in the nearby Berkshire Highlands must indicate a late recrystallization after the major metamorphism. This is certainly consistent with evidence of late-stage recrystallization found in thin section in the quadrangle.

GEOLOGIC HISTORY

Although the age of the metamorphic rocks in the Collinsville quadrangle is not known, tentative correlation with the rocks of southeastern Vermont suggests that the lower group was deposited during the Precambrian, and the Hartland Group was deposited during the Cambrian and Ordovician periods. Black silty shale, sandy shale, impure sandstone, and some impure carbonate rocks were presumably the chief sedimentary rocks that are represented now by the metamorphic rocks in the quadrangle. At several times during sedimentation volcanic rocks were apparently deposited and are thought to be represented by the plagioclase gneiss and amphibolite of the Bristol Member and by many layers of amphibolite in the higher stratigraphic units. Detailed stratigraphic mapping indicates a facies change in the Taine Mountain Formation and a possible east-west facies change in the upper member of the Rattlesnake Hill Formation. Although the lower group is considered Precambrian in age, no unconformity was recognized in the whole section.

The metamorphic rocks of the quadrangle record only one major deformation which presumably occurred during the Acadian Orogeny (Middle and Late Devonian) and was part of the regional deformation and metamorphism that produced the major folds and the gneiss domes of western Connecticut, western Massachusetts, and eastern Vermont. In the Collinsville quadrangle this deformation may have occurred in two phases; an earlier phase of recumbent folding followed by a later phase of doming. The major folds west of the domes may be either part of the early nappe configuration or directly related to the upward movement of the domes and the Berkshire Highlands. During the waning stages of doming most of the crenulate folds were formed and are developed best in structural depressions. Throughout this time metamorphism produced mineral assemblages of the almandine-amphibolite facies. No evidence of older deformations and metamorphisms of possible Precambrian or early Paleozoic age was recognized in the quadrangle.

From the end of the Acadian Orogeny until the Triassic Period, the rocks over those presently exposed in the quadrangle were eroded. Renewed deformation during the Late Triassic resulted in deposition of sedimentary rocks over central and presumably western Connecticut. These areas were then tilted eastward and broken by normal faults, two of which are found in the eastern part of the Collinsville quadrangle.

Between the end of this deformation and the Pleistocene, the sedimentary rocks of Triassic age were eroded from western Connecticut, except in the Pomperaug and Cherry Brook Valleys. During the Pleistocene the area was covered by ice, and till was deposited over much of it. Stratified glacial material, formed during the retreat of the ice sheet, was deposited chiefly in the valleys and basins of the quadrangle.

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APPENDIX

A complete list of the publications of the State Geological and Natural History Survey of Connecticut is available from its Distribution and Exchange Agent, State Librarian, State Library, Hartford, Connecticut.

Quadrangle Report Series

The quadrangle reports listed below will be sent postpaid at $1.00 each, the quadrangle map alone for 25¢ postpaid. Residents of Connecticut shall add 3½ percent sales tax. Payment must accompany order. Make checks or money orders payable to Connecticut State Library. Quadrangle reports, and all other publications of the State Geological and Natural History Survey of Connecticut, are available without charge to public officials, exchange libraries, scientists, and teachers, who indicate, under their official letterhead, that these publications are required in their professional work. Established book dealers shall receive a 20 percent discount.

Orders should be sent to the Survey's Distribution and Exchange Agent, State Librarian, State Library, Hartford, Connecticut.

1. The Bedrock Geology of the Litchfield Quadrangle, by Robert M. Gates, Ph.D.; 13 p., with quadrangle map in color (Misc. Ser. 3), 1951.
2. The Geology of the New Preston Quadrangle: Part I. The Bedrock Geology, by Robert M. Gates, Ph.D.; Part II. The Glacial Geology, by William C. Bradley; 46 p., 14 pls., with charts and quadrangle map in color (Misc. Ser 5), 1952
3. The Bedrock Geology of the Woodbury Quadrangle, by Robert M. Gates, Ph.D.; 32 p., 8 pls., 1 fig., with quadrangle map in color, 1954.
4. The Bedrock Geology of the Ellington Quadrangle, by Glendon E. Collins; 44 p., 1 fig., with quadrangle map in color, 1954.
5. The Bedrock Geology of the Glastonbury Quadrangle, by Norman, Herz, Ph.D.; 22 p., 2 pls., 1 fig., with quadrangle map in color, 1955.
6. The Bedrock Geology of the Rockville Quadrangle, by Janet M. Aitken, Ph.D.; 55 p., 20 pls., 1 fig., with quadrangle map in color, 1955.
7. The Bedrock Geology of the Danbury Quadrangle, by James W. Clark, Ph.D.; 47 p., with quadrangle map in color, 1958.
8. The Bedrock Geology of the Middletown Quadrangle, by Elroy P. Lehmann, Ph.D.; 40 p., 7 figs., with quadrangle map in color, 1959.
9. The Bedrock Geology of the Naugatuck Quadrangle, by Michael H. Carr; 25 p., 5 figs., with quadrangle map in color, 1960.
10. The Surficial Geology of the Wallingford Quadrangle, by Stephen C. Porter; 42 p., 18 figs., with quadrangle map in color, 1960.
11. The Bedrock Geology of the Cornwall Quadrangle, by Robert M. Gates, Ph.D.; 35 p., 5 figs., with quadrangle map in color, 1961.
12. The Surficial Geology of the Mount Carmel Quadrangle, by Richard F. Flint, Ph.D.; 25 p., 3 figs., with quadrangle map in color, 1962.
13. The Bedrock Geology of the Deep River Quadrangle, by Lawrence Lundgren, Jr., Ph.D.; 40 p., 6 figs., with quadrangle map in color, 1963.
14. The Surficial Geology of the Branford Quadrangle, by Richard F. Flint, Ph.D.; 45 p., 4 pls., 7 figs., with quadrangle map in color, 1964.
15. The Bedrock Geology of the Essex Quadrangle, by Lawrence Lundgren, Jr., Ph.D.; 44 p., 9 figs., with quadrangle map in color, 1964.
16. The Bedrock Geology of the Collinsville Quadrangle, by Rolfe S. Stanley, Ph.D.; 99 p., 2 pls., 22 figs., with quadrangle map in color, 1964.

Quadrangle Maps of Cooperative Program with U. S. Geological Survey

These maps are published by the U. S. Geological Survey. The Connecticut State Library carries a stock for sale; the Geologic Quadrangle Maps are $1.00 each, the Miscellaneous Geological Investigations Maps are 50¢ each, both postpaid. Payment must accompany order. Make checks or money orders payable to Connecticut State Library. Connecticut residents must add 3½ percent sales tax. No free copies can be distributed.

QUADRANGLE GEOLOGIC MAPS

Geologic Quadrangle No. 119. Surficial Geology of the New Britain Quadrangle, by Howard E. Simpson, 1959.

Geologic Quadrangle No. 121. Bedrock Geology of the Roxbury Quadrangle, by Robert M. Gates, 1959.

Geologic Quadrangle No. 134. Bedrock Geology of the Avon Quadrangle, by Robert Schnabel, 1960.

Geologic Quadrangle No. 137. Surficial Geology of the Windsor Locks Quadrangle, by Roger Colton, 1960.

Geologic Quadrangle No. 138. Surficial Geology of the Uncasville Quadrangle, by Richard Goldsmith, 1960.

Geologic Quadrangle No. 144. Bedrock Geology of the Norwich Quadrangle, by George Snyder, 1961.

Geologic Quadrangle No. 145. Surficial Geology of the Bristol Quadrangle, by Howard E. Simpson, 1961.

Geologic Quadrangle No. 146. Surficial Geology of the Southington Quadrangle, by Albert La Sala, 1961.

Geologic Quadrangle No. 147. Surficial Geology of the Avon Quadrangle, by Robert W. Schnabel, 1962.

Geologic Quadrangle No. 148. Surficial Geology of the Montville Quadrangle, by Richard Goldsmith, 1962.

Geologic Quadrangle No. 150. Surficial Geology of the Meriden Quadrangle, by Penelope M. Hanshaw, 1962.

Geologic Quadrangle No. 165. Surficial Geology of the Norwich Quadrangle, by Penelope M. Hanshaw and George L. Snyder, 1962.

Geologic Quadrangle No. 176. Surficial Geology of the New London Quadrangle, by Richard Goldsmith, 1962.

Geologic Quadrangle No. 199. Bedrock Geology of the Mount Carmel Quadrangle, by Crawford E. Fritts, 1963.

Geologic Quadrangle No. 200. Bedrock Geology of the Southington Quadrangle, by Crawford E. Fritts, 1963.

Geologic Quadrangle No. 223. Geology of the Hartford North Quadrangle, by Robert V. Cushman, 1963.

Geologic Quadrangle No. 329. Surficial Geology of the Niantic Quadrangle, Connecticut, by Richard Goldsmith. In press.

MISCELLANEOUS GEOLOGICAL INVESTIGATIONS

Miscellaneous Geological Investigations Map I-401. Contour Map of the Bedrock Surface of the Broad Brook Quadrangle, by R. V. Cushman and R. B. Colton, 1963.

Miscellaneous Geological Investigations Map I-402. Contour Map of the Manchester Quadrangle, by Roger B. Colton and Robert V. Cushman, 1963.

BULLETINS

Bulletin 1161 I. Petrochemistry and Bedrock Geology of the Fitchville Quadrangle, Connecticut, by G. Snyder. In press.