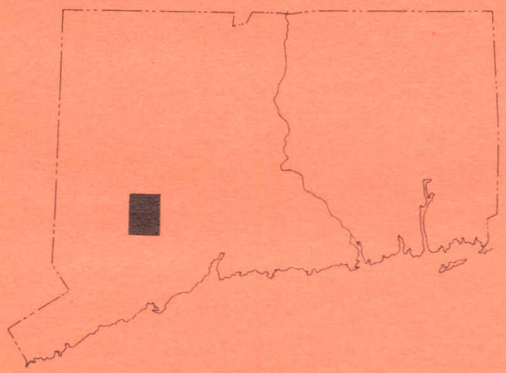
The Bedrock Geology of the Southbury Quadrangle

WITH MAP

Open Plate 1
Open Plate 1B
Open Plate 2

ROBERT B. SCOTT



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

DEPARTMENT OF ENVIRONMENTAL PROTECTION

1974

QUADRANGLE REPORT NO. 30

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ROBERT B. SCOTT
Texas A & M University

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Lectures, seminars, and discussions with John Rodgers and Richard Armstrong at Yale University first stimulated my interest in this part of the Appalachian fold belt. Numerous field trips led by researchers active in western Connecticut, including John Rodgers, James Dieterich, William Crowley, Philip Orville, Leo Hall, Rosemary Vidale, David Hewitt, Rolfe Stanley, Robert Gates and George Heyl, among others, were extremely beneficial. The field assistance of William Raymond during the summer of 1968 contributed significantly to the mapping project. Steven Schamel, Donald Bachinski, Norman Hatch, Rolfe Stanley, and Bruce O'Connor made valuable suggestions and observations during the mapping of the Southbury quadrangle.

Constructive criticism by John Rodgers of Yale University, Rolfe Stanley of the University of Vermont, and Norman Hatch of the U. S. Geological Survey added considerably to the clarity and substance of this report.

Robert B. Scott

College Station, Texas
October 10, 1973

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by

Robert B. Scott

ABSTRACT

In the Southbury quadrangle six major units of sedimentary and volcanic origin, of Cambro-Ordovician through Siluro-Devonian age, were metamorphosed to almandine-amphibolite grade and folded in at least four periods during the Acadian orogeny and then were cut by a major Triassic normal fault.

The three lower units are Cambro-Ordovician. The basal unit in the western part of the Southbury quadrangle is Hartland Unit II (Rowe Formation of western Massachusetts); its eastern facies equivalent is the Waterbury Formation. Hartland Unit II is characterized by abundant porphyroblasts of staurolite, garnet, and kyanite in muscovite-rich schists and schistose gneisses; the Waterbury Formation is a fine-grained schistose gneiss rich in kyanite and biotite. The overlying unit, Hartland Unit I (Taine Mountain Formation of northwestern Connecticut and Moretown Formation of western Massachusetts) has a distinctive lamination of biotite-rich folia separated by quartzofeldspathic lamellae. The next higher unit, the Collinsville Formation, is roughly equivalent to the Hawley Formation of western Massachusetts. The Collinsville Formation has a heterogeneous, metasedimentary, muscovite-rich western facies and a metavolcanic, feldspathic biotite-rich eastern facies.

Above a major unconformity, discontinuous lenses of quartzite, marble, calcsilicate and amphibolite of probable Silurian age are found (Russell Mountain Formation of southwestern Massachusetts). The highest Paleozoic strata are those of the Siluro-Devonian Straits Schist, a distinctive, homogeneous, coarse-grained, carbonaceous, quartz-muscovite-garnet-kyanite schist.

Four periods of Acadian folding are recognized: 1) early west-facing nappe formation, 2) large scale east-facing nappe formation, 3) high-angle axial-plane folds formed by compression of the nappes, and 4) folds formed by draping of units that mantle the Waterbury gneiss dome. Periods 1, 2, and 3 are nearly coaxial with N- to NE-trending axes. Period 4, however, is tangential to the Waterbury dome and has W- to NW-trending axes. Major granitic intrusion occurred after period-3 folding and before period-4 folding in the southwestern part of the quadrangle, somewhat before the mantled gneiss dome formed in the northeastern corner of the quadrangle. A post-deformation lamprophyric dike has a 344 m.y. K-Ar date, placing an upper limit on the age of Acadian deformation in the region. Almandine-amphibolite-grade metamorphism is characterized by coexisting

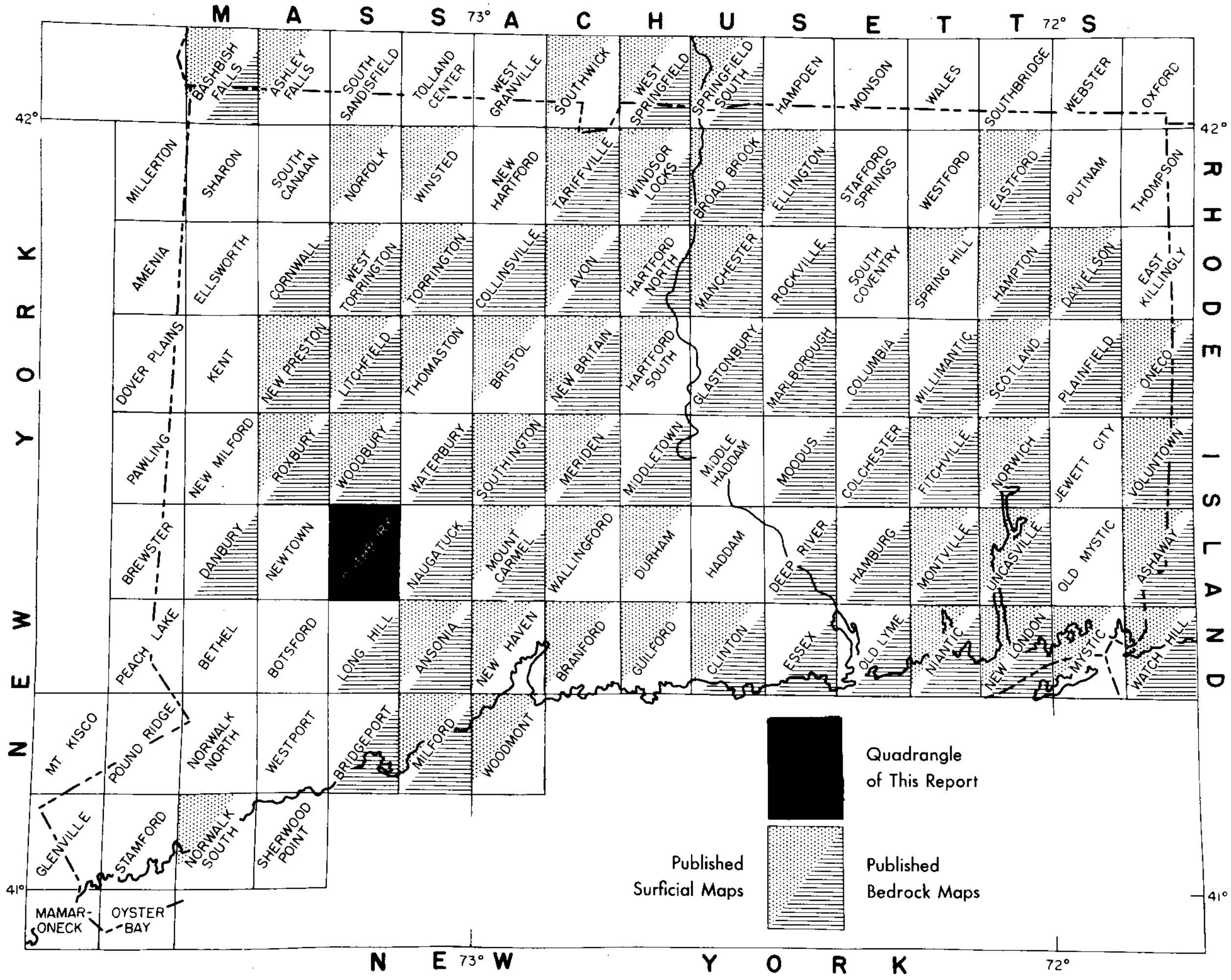


Fig. 1. Index map of Connecticut showing the location of the Southbury quadrangle and of other published quadrangle maps.

kyanite and sillimanite. This assemblage probably represents a disequilibrium assemblage between the first and second sillimanite isograds. Staurolite persists in the sillimanite-bearing rocks. West of the Pomeraug fault, on the downdropped side, sillimanite is absent and staurolite is more abundant than east of the fault. Slight chlorite retrogression of garnet and biotite is present locally.

Sets of post-metamorphic high-angle faults trend NW and may be related to Allegheny deformation; these faults have displacements too small to be mapped and only their attitudes are recorded. Other small-scale high-angle fault sets have NE trends parallel to the major Triassic Pomperaug fault. That fault probably formed after the Triassic arkoses and basalts were emplaced because basalts in the Talcott Formation have been tentatively correlated with those in the Pomeraug region.

Major economic resources are Pleistocene deposits of glacial sand and gravel; only a few pegmatites have been quarried and one copper-mineral sulfide deposit trenched.

INTRODUCTION

Location

The Southbury quadrangle, located in central-western Connecticut (fig. 1), is bounded by latitudes 41°22′30″N and 41°30′N and by longitudes 73°07′30″W and 73°15′W and covers an area of 140 sq km (54 sq mi). Widely spaced suburban homes, country estates, and small farms surround the small communities of Southbury, Stevenson, Riverside, Lakeside, and Southford; there are no industrial centers in the quadrangle. Kettletown State Park along Lake Zoar, a dammed portion of the Housatonic River, and Southford Falls State Park are major recreational areas. The quadrangle also encloses the Paugusett State Forest.

Interstate 84, U.S. 6 and 202, and State Routes 67, 34, and 188 provide major access to the region. Smaller paved and dirt roads give adequate access to the entire quadrangle, except Paugusett State Forest, where even foot paths are inadequate for easy access.

Topography and drainage

Topographic elevations in this portion of the crystalline highlands of western Connecticut range from 12 m above sea level at the Housatonic River to 278 m at the top of Woodruff Hill, along the border of the Southbury and Naugatuck quadrangles. The steep hillsides that enclose the incised Housatonic River channel are the most pronounced topographic features. More subdued topographic features elsewhere result from superposition of glacial carving and deposition on older landforms that reflect differential bedrock resistance to erosion and weathering. The long arcuate valley that trends northward from Stevenson Dam on Lake Zoar to Southford Falls and from there northwest toward Southbury parallels the Straits Schist and the Collinsville Formation (pl. 1A). Although the Straits Schist typically forms resistant ridges, it is unusually thin in this valley and does not form a positive topographic feature here. The Triassic arkose and basalt of the Pomeraug River valley in the northwestern corner of the quadrangle form small valleys underlain by sedimentary rocks and ridges underlain by basalts. Elongate rounded hills that trend slightly west of north appear to be drumlins. Although Walnut Hill and Preston Hill have no bedrock exposures and thus may be true drumlins, most of these hills have only thin partial veneers of glacial sediments that have been eroded along ridge crests, exposing bedrock. Bowers Hill is a good example of an incompletely veneered, glacially carved bedrock hill.

The entire Southbury quadrangle lies in the Housatonic River drainage basin. The 26-m Stevenson Dam across the Housatonic River creates Lake Zoar, which is restricted to the narrow incised river channel. Major tributaries to the Housatonic River are the south-flowing Pomperaug River, Kettletown Brook, and Eightmile Brook, and the north-flowing Halfway River and Boys Halfway River. Little River flows eastward into the Naugatuck quadrangle to the Naugatuck River, which in turn flows southward into the Housatonic River.

Previous work

The map and report of James G. Percival (1842) outlined the arkose and basalt units of the Pomperaug River valley but did little to differentiate among the metamorphic rocks of the Southbury quadrangle. The regional reports by Rice and Gregory (1906), Gregory and Robinson (1907), and Rodgers and others (1959) also did not add significantly to the recognition of the major metamorphic units of the quadrangle. However, several undergraduate students from Yale University made valuable contributions by mapping small areas in the southern and western portions of the quadrangle. Unpublished reports that were particularly helpful include those by Wheeler (1965), Scholle (1965), and Wightman (1965); these reports are available at the Department of Geology and Geophysics, Yale University. The reconnaissance map of the northern half of the quadrangle, made by DeWyk (1960) as part of his Masters thesis at the University of Massachusetts, outlined the trends of several major lithologic units for the first time in that area.

Several workers studied the Triassic Pomperaug River valley units: Benjamin Silliman first mentioned the Pomperaug rocks by reporting the presence of prehnite, stilbite, and agate in amygdules of these basalts (1818). Davis (1888) based much of his block-fault theory for the formation of the Connecticut valley structure on a study of the Pomperaug River valley. The log of a well that was drilled for oil in these arkosic sediments toward the end of the 19th century (Hovey, 1890) still provides some of the most valuable structural control for the basin. The first comprehensive report was made by Hobbs (1899). Longwell (1922) and Wheeler (1937) suggested that there is regional stratigraphic and structural continuity between the Connecticut Valley and the Hudson River Triassic rocks, including those of the Pomperaug area. This regional stratigraphic and structural framework has been emphasized in recent work by Krynine (1950) and Sanders (1960). Schutz (1956) made a detailed study of the Pomperaug Triassic rocks for a senior thesis at Yale University.

Regional setting

Two belts of gneiss domes parallel the Connecticut River and are mantled by eugeosynclinal deposits of the western Appalachian fold belt in New England (Rodgers and others, 1959; Thompson and others, 1968); the southern terminus of the western belt of domes lies in the Southbury quadrangle and is marked by the southern end of the Waterbury dome (fig. 2, pl. 2). Southwest of this area the abundance of syntectonic granitic intrusions increases significantly (George Heyl, personal communication, 1968). The units that mantle the gneiss dome include both metasedimentary and metavolcanic rocks; toward the west, the metavolcanic rocks diminish relative to the more micaceous and quartzose clastic-metasedimentary rocks. Still farther west, across the sharp tectonic line known as "Cameron's Line," is a miogeosynclinal belt of carbonate, quartzite, and schist. The best example of a feldspathic metavolcanic eastern facies that grades into a more heterogeneous micaceous and quartzose western facies is the Collinsville Formation. Crowley (1968) also recognized the distinction between eastern and western eugeosynclinal facies by the presence of abundant metavolcanic rocks in the eastern facies. This facies change is slightly different in Cambro-Ordovician units stratigraphically below the Collinsville Formation: a relatively aluminous and homogeneous eastern facies changes to an extremely heterogeneous quartz- and mica-rich western facies.

Lithostratigraphic correlations (Hatch and Stanley, 1970, and personal communications) with Massachusetts rock units indicate that the distinctive Straits Schist is correlative with the Siluro-Devonian Goshen Formation and thus is the youngest Southbury metamorphic unit. A discontinuous string of lenses of amphibolite, quartzite, marble, and calcsilicate below the base of the Straits Schist is considered by Hatch and Stanley to be equivalent to the Russell Mountain Formation of Massachusetts (Hatch and others, 1970). Beneath these two distinctive rock units is a heterogeneous suite of presumably Cambro-Ordovician units that include, in decreasing stratigraphic order, the Collinsville Formation, Hartland Unit I, and Hartland Unit II. These units appear to be the approximate southern representatives of the Hawley, Moretown, and Rowe formations of Massachusetts, respectively (Osberg and others, 1971).

The complex regional outcrop pattern of the Straits Schist (pl. 2) obviously reflects a complex multifolding history, similar to that proposed by Dieterich (1968a,b). Thompson and his co-workers (1968) also found alpine-type structures in western Massachusetts. In addition, the Southbury quadrangle covers the distinctive structural transition between the mantled Waterbury dome in its northeastern corner and the extensive intrusive terrane in its southwestern corner.

Petrographic methods

The mineralogical composition of samples of all the major rock types were measured by modal analysis of more than 250 thin sections; 250 points were counted per section. All sections were stained to distinguish among plagioclase, potassium feldspar, and quartz. The Turner twin-axis universal-stage method outlined by Slemmons (1962) was used to determine the anorthite content of plagioclases. Modal analyses often do not show chemical characteristics in a readily comparable form. Therefore, the mineralogical data were converted to critical chemical parameters that are indicative of distinctive sedimentary lithologies, in

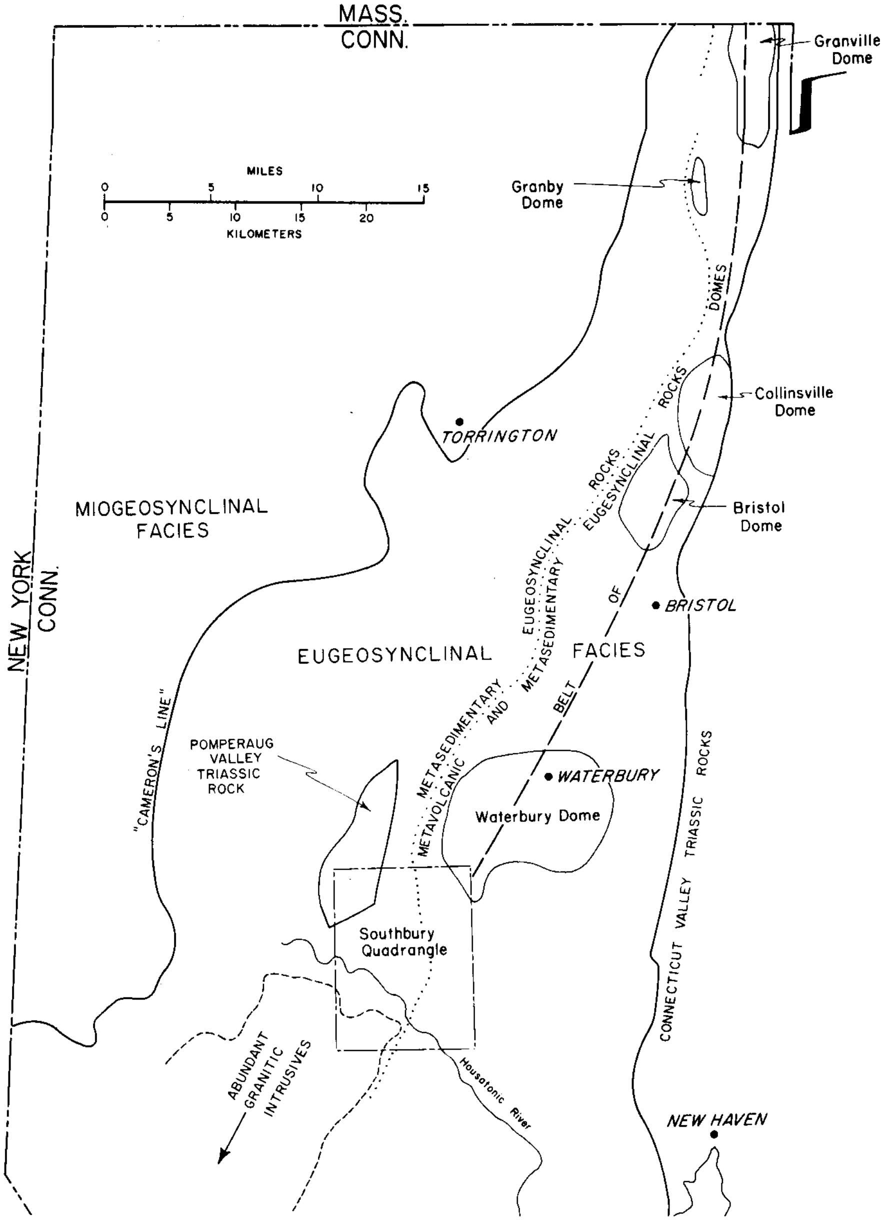


Fig. 2. Map delineating belts of major metamorphic rock types and distinctive structural trends. The Collinsville Formation best exhibits the metavolcanic character of the eastern facies and probably marks the site of an island arc active during that part of Cambro-Ordovician time. Hartland Unit I, Hartland Unit II, and the Waterbury Formation are more homogeneous and aluminous on the eastern side and more heterogeneous, micaceous, and quartz rich on the western side of the eugeosyncline. The southern end of the gneiss-dome belt and the northern end of massive granitic intrusive bodies occur within the Southbury quadrangle.

Table 1. – Scheme for simplified conversion of mineralogical data to chemical parameters

Mineral	Weight percent allotted to each parameter Si	Al	K	Fe + Mg
Quartz	47	0	0	0
Plagioclase[1]	28	12	0	0
Potassium feldspar	30	10	14	0
Muscovite	23	22	11	0
Biotite	19	6	9	30
Garnet	17	11	0	34
Aluminosilicate	17	33	0	0
Staurolite	14	28	0	15
Chlorite	17	16	0	31
Hornblende	16	12	1	18
Magnetite	0	0	0	72

[1] Based on plagioclase composition of 20 percent anorthite.

order to facilitate relating metamorphic rocks to original sedimentary chemistry. Table 1 summarizes the simplified conversion scheme used.

After this conversion, density corrections were made. The probable compositions of minerals of variable composition was determined by selecting minerals from similar metamorphic rocks in the tables of Deer and his co-workers (1962).

Although this conversion can only approximate the chemical compositions of the rocks, it provides a useful relative means for a chemical comparison of metamorphic rocks with their possible sedimentary or igneous precursors.

Conventions and abbreviations

To avoid the ambiguities of such metamorphic terms as schist, gneiss, and granulite as defined in the *Glossary of Geology* (American Geological Institute, 1960) and in many textbooks, a set of rock-name definitions based on mineralogical composition rather than on subjective textural differences is used here:

Schist = a fine- to coarse-grained metamorphic rock with a distinct micaceous foliation and containing more than 40 volume percent of micaceous minerals.

Gneiss = a fine- to coarse-grained metamorphic rock with or without a well defined micaceous foliation but containing less than 20 volume percent of micaceous minerals.

Schistose gneiss = a metamorphic rock with a micaceous component of 20-40 percent, between that of schist and gneiss, as defined above.

Granulite is not used here as a term to describe the physical appearance of a rock; it is reserved as a metamorphic-facies name.

In this terminology, a banded rock is not restricted to a gneiss; and the term "banded gneiss" is not redundant. These terms are more directly related to mineralogy, and thus to the chemistry of the rock units, than are the classical definitions. Therefore, units identified by these terms during mapping are more likely to be representative of original sedimentary units. Crowley (1968, p. 7) used a similar set of definitions for the same reason.

The mineralogical composition of a rock is expressed by mineral modifiers preceding the rock term in *decreasing* order of abundance. Thus a rock consisting of 28 percent biotite, 42 percent quartz, 5 percent muscovite, 10 percent microcline, and 15 percent kyanite is described as a quartz-biotite-kyanite-microcline-muscovite schistose gneiss.

Table 2 lists the mineral abbreviations used in the tables of modal analyses in the rock descriptions which follow.

Table 2 – Abbreviations used in tables and text

Mineral names

A = anthophyllite
Ac = actinolite
Alm = almandine garnet
Ap = apatite
Arf = arfvedsonite
Au = augite
Bio = biotite
Cal = calcite
Chl = chlorite
Clz = clinozoisite
Di = diopside
Ep = epidote
G = graphite
Gr = grossularite
Gt = garnet
Hb = hornblende
Ky = kyanite
Mi = microcline
Ms = muscovite
Mt = magnetite
Or = orthoclase
Phl = phologopite
Pl = plagioclase
Pr = pyrite
Q = quartz
R = rutile
Sill = sillimanite
Sph = sphene
St = staurolite
Tm = tourmaline
Tr = tremolite
Z = zircon

Descriptive terms

T = trace (<1 percent)
medium grained = 1 to 5 mm
very coarse grained = >3 cm
fine grained = <1 mm
coarse grained = 5 mm to 3 cm
An$_{35}$ = plagioclase with an anorthite content of 35 percent by weight.

METAMORPHIC STRATIGRAPHY

Most of the mappable units in the Southbury quadrangle have been recognized in adjoining quadrangles. The Straits Schist, the Collinsville Formation, and the Newtown Gneiss extend from the Long Hill quadrangle northward into the Southbury quadrangle (Crowley, 1968). Carr (1960) mapped the Straits Schist to the eastern border of the Southbury quadrangle. Gates (1954) did not distinguish between Hartland lithologies in his earlier mapping in the Woodbury quadrangle. However, in the Roxbury quadrangle (Gates, 1959) and in the Waterbury quadrangle (Gates and Martin, 1967), he recognized several rock units that are found in the Southbury quadrangle, including the Straits Schist, the Hitchcock Lake Member, Hartland Unit I, and the Waterbury Formation within the Waterbury quadrangle and Hartland Unit I and Hartland Unit II within the Roxbury quadrangle. R.S. Stanley's (personal communication) mapping in the Newtown quadrangle correlated some of the Roxbury units with Southbury units. Figure 3 is a summary of proposed stratigraphic correlations of western Connecticut units; detailed support for conclusions expressed in that figure is set forth in the following discussions of metamorphic stratigraphy.

Because of the state of flux of stratigraphic terminology and correlation in western Connecticut, no formal stratigraphic names are introduced in this report, even though correlations with formalized units are suggested. Informal names, such as the laminated member of Hartland Unit I and the garnetiferous member of Hartland Unit II, are used.

The most distinctive lithologic break in the Southbury quadrangle and the adjacent Waterbury-Naugatuck-Long Hill quadrangle region is the boundary between the quartzo-feldspathic gneissic Collinsville Formation and the overlying muscovite-rich Straits Schist. Unnamed discontinuous lenses of quartzite, marble, calc-silicate, and amphibolite along this boundary (fig. 3) suggest that there is a major unconformity at this stratigraphic level.

Hatch and Stanley (1970, and personal communications) have made generalized correlations of western Connecticut formations with those of known age in western Massachusetts. Following their scheme, the Straits Schist is correlated with the Siluro-Devonian Goshen Formation; the unnamed lenses of quartzite, marble, calc-silicate, and amphibolite above the probable unconformity are considered to be the Silurian Russell Mountain Formation (Hatch and others, 1970); the Collinsville Formation is correlated with the uppermost Cambro-Ordovician unit, the Hawley Formation; Hartland Unit I is correlated with the Moretown Formation; and Hartland Unit II is the southern equivalent of the Cambro-Ordovician Rowe Formation (fig. 3). The basal units exposed in the Southbury quadrangle are the Waterbury Formation on the eastern side and Hartland Unit II on the western side of the quadrangle. No Precambrian rocks are recognized in the Southbury quadrangle or adjoining quadrangles. The metamorphic units will be discussed in order from oldest to youngest.

Waterbury Formation

GENERAL DISCUSSION

The Waterbury Formation crops out in the northeastern corner of the Southbury quadrangle, where it is continuous with rocks called the Waterbury Formation by Gates and Martin (1967) in the Waterbury quadrangle and with the lower part of a sequence of rocks that Carr (1960) termed the Waterbury Gneiss. Carr divided the Waterbury Gneiss into two phases in his text but mapped the Waterbury Gneiss as one unit; the Waterbury Phase seems to be roughly correlative with the Waterbury Formation and his Oxford Phase appears to contain both Hartland Unit I and Collinsville Formation as defined in this report. The migmatitic, granulitic, and trondhjemitic Waterbury Formation rocks described by Gates and Martin are not present in Southbury exposures; the rock in Southbury consists largely of that described by Gates and Martin as "thinly layered paragneisses." Gates (1954) made no distinction

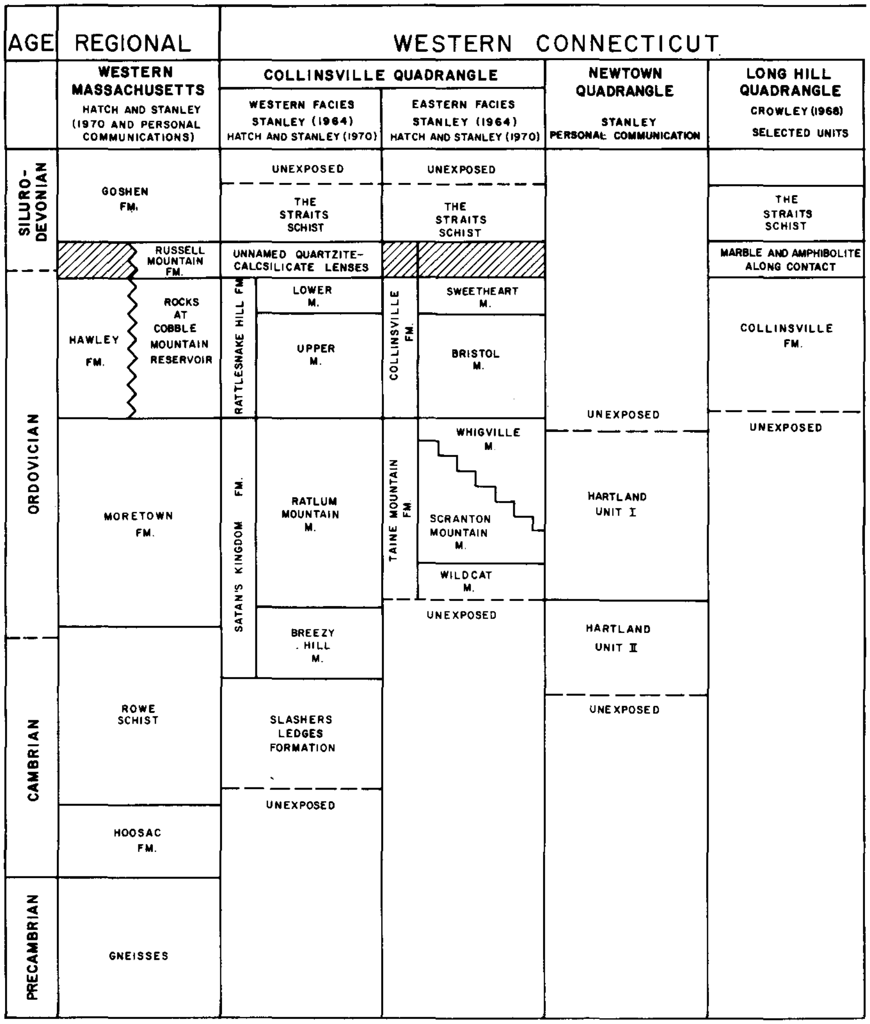
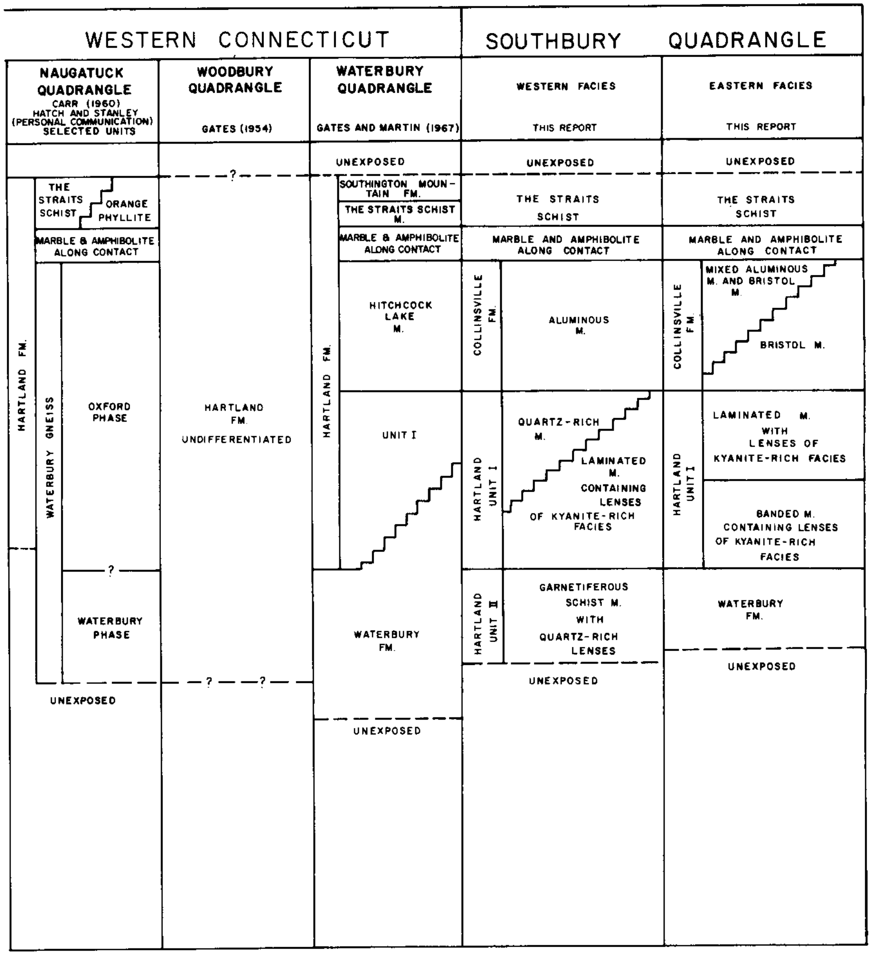


Fig. 3. Stratigraphic correlations of metamorphic rock units in the Southbury quadrangle with those of western Connecticut and western Massachusetts. Only selected units are shown for the Long Hill and Naugatuck quadrangles. Facies changes are indicated by the step pattern. The diagonally ruled regions indicate the absence of rocks at that stratigraphic interval. Approximate time intervals are shown on the left; dashed boundaries indicate uncertainty.

between the Waterbury Formation, Hartland Unit I, and the Collinsville Formation in the Woodbury quadrangle to the north.

The best exposures of the Waterbury Formation in the Southbury quadrangle are along the steep cliffs on the southwestern side of Woodruff



Hill and on the western side of Christian Road on the northern quadrangle boundary.

LITHOLOGY

The Waterbury Formation exposed in the Southbury quadrangle varies from fine-grained, thinly layered (0.5-2 mm) biotite-quartz-kyanite-plagioclase-muscovite-garnet or biotite-quartz-plagioclase-muscovite-garnet-microcline schist and schistose gneiss (with a contorted foliation parallel to the layering) to an extremely contorted, massive rock of the same mineralogical composition (table 3). The most distinctive characteristic of both these rocks is a fine-textured patchiness or feltlike appearance on fresh surfaces, particularly on sawed surfaces, due to the presence of

Table 3. — Average modal analyses of the Waterbury Formation

	Q	Pl[1]	Mi	Bio	Ms	Gt	Ky	Other[2]
Average of 7 samples	24.9	8.5	4.0	37.3	7.8	3.1	13.9	0.5
Range of values	12-53	1-22	0-18	20-52	0-15	1-10	3-24	0.1-2

[1] Plagioclase composition: average plagioclase of 6 measurements = An_{12}.

[2] Mt, Sill, Z, Ap, Sph

very fine-grained kyanite blades (<0.1 mm wide and <1 mm long). Along crumpled layers in some localities these kyanite crystals have grown in knots and patches to 1 mm in diameter. The rock is bluish white where kyanite is abundant. Fresh rock surfaces rich in biotite and kyanite vary between grayish blue and dusky blue. These characteristics led to the use of the field term "fuzzy purple." Characteristically the weathered surfaces are rusty. The lighter colored layers in the layered rocks are segregations of feldspar and quartz; the darker layers are predominantly biotite and kyanite.

ORIGIN AND AGE

These schists and schistose gneisses of the Waterbury Formation have lower Si/Al ratios and higher K + Fe + Mg values than do igneous rocks (table 4, fig. 4a). The extensive rusty weathering and the relatively aluminum-rich composition (10.5 percent Al or 19.8 percent Al_2O_3) of these metasediments indicate that, prior to metamorphism, they probably were uniform, sulfide-bearing, clay- and iron-rich shales with few quartz-rich sandy layers (fig. 4f).

The age of the Waterbury Formation is not readily determined either by stratigraphic correlation or by radiometric dating. Since the Waterbury Formation on the eastern, and the Hartland Unit II on the western, side of the quadrangle both appear to underlie Hartland Unit I, they may be facies equivalents. If so, the chemical and mineralogical changes are large because the more siliceous Hartland Unit II rocks overlap only slightly with the composition range of the Waterbury Formation (fig. 4a); the more heterogeneous clastic rocks found in Hartland Unit II are not found in the Waterbury Formation and the aluminum-rich Waterbury rocks are absent in Hartland Unit II. However, such a sequence of facies changes conforms with the framework of typical geosynclinal facies changes. The sequence of facies from west to east would be miogeosynclinal quartzite and carbonate west of Cameron's Line (fig. 2), a heterogeneous quartz- and mica-rich clastic transitional facies (Hartland Unit II) and a homogeneous sulfide-rich shale facies in the eugeosyncline proper (Waterbury Formation), far from coarse clastic sources. The contact between the Waterbury Formation and the overlying Hartland Unit I is probably not a major unconformity nor an abrupt change in sedimentary environment because lenses of a biotite-kyanite-rich member of Hartland Unit I (kyanite-rich member), mineralogically and chemically similar to the Waterbury Formation, are abundant in the eastern facies of the Hartland Unit I, even close to the Collinsville Formation contact.

A similar impasse is reached from radiometric dating. The 465 m.y.

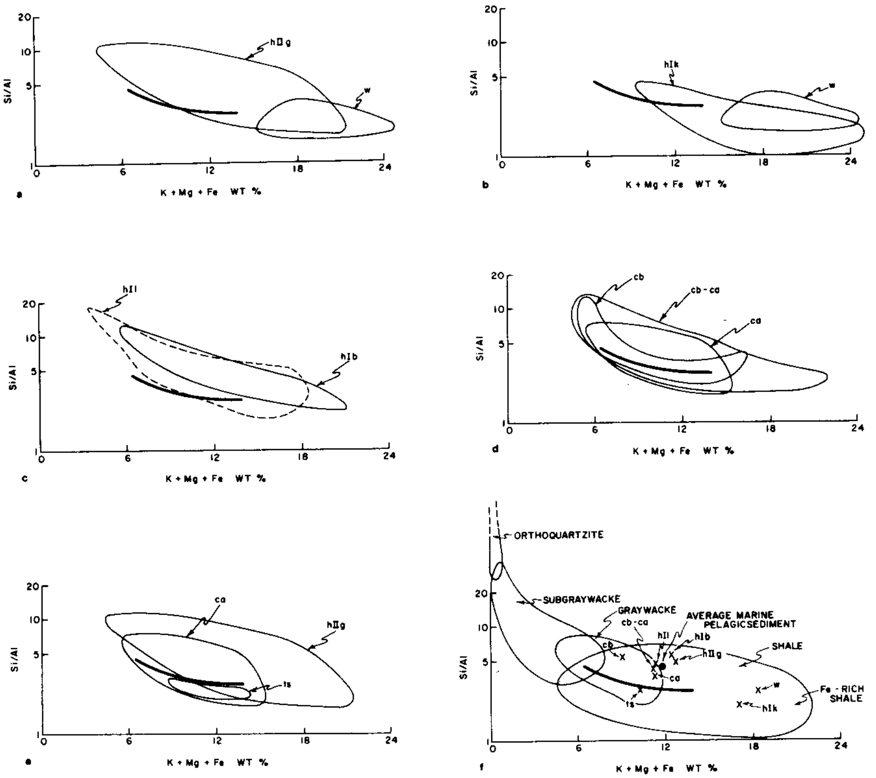


Fig. 4. Plots of Si/Al versus K + Mg + Fe weight percent for the major Southbury metamorphic rock units. The heavy lines shown on all diagrams represent the average igneous trend.

a) Comparison of the Waterbury Formation (w) with the garnetiferous member of Hartland Unit II (hIIg).

b) Comparison of the Waterbury Formation (w) with the kyanite-rich member of Hartland Unit I (hIk).

c) Comparison of the laminated member of Hartland Unit I (hII) with the banded member of Hartland Unit I (hIb).

d) Comparisons of the Bristol Member of the Collinsville Formation (cb) with the transitional member of the Collinsville Formation (cb-ca) and with the aluminous member of the Collinsville Formation (ca).

e) Comparison of the Straits Schist (ts) with the garnetiferous member of Hartland Unit II (hIIg) of the Collinsville Formation (ca).

f) Comparison of average compositions of all major units with the composition range of orthoquartzite, subgraywacke, graywacke, and shale; the average marine pelagic sediment also shown.

Data from Garrels and Mackenzie (1971), Pettijohn (1963), and Chester (1965).

Table 4. — Average chemical composition[1] of the Waterbury Formation in weight percent

Si	Al	Si/Al	K	Fe + Mg
27.1	10.5	2.7	4.9	12.3

[1] Note that these compositions are listed in elemental form rather than as oxides.

rubidium-strontium isochron determined by Clark and Kulp (1968) for the Waterbury Formation can be interpreted in several ways. If the date represents the time of deposition, the Waterbury Formation is an Ordovician metasedimentary unit that was subsequently metamorphosed by the Acadian orogeny between 382 m.y. (Besancon, 1970) and 413 m.y. (Armstrong and others, 1970). However, if the 465 m.y. isochron represents a complete or partial rehomogenization of the strontium isotopes during metamorphism, the Waterbury Formation may have been a Cambrian or Precambrian sediment or a Precambrian Grenville orogenic product.

The hypothesis favored in this report, that the Waterbury Formation is an eastern facies equivalent of Hartland Unit II, is based on their apparent equality of stratigraphic position, the logical sequence of lateral facies changes which fits a geosynclinal framework, a similar facies change between an eastern and western facies of the overlying Hartland Unit I, and the lack of radiometric evidence to the contrary.

Hartland Unit II

GENERAL DISCUSSION

In the Southbury quadrangle Hartland Unit II is found only west of the Pomperaug fault. The term Hartland Unit II was first introduced by Gates (1959) in the Roxbury quadrangle. R.S. Stanley (personal communication) has mapped this rock unit along the eastern border of the Newtown quadrangle. From regional correlations, Hatch and Stanley (1970, and personal communication) consider Hartland Unit II equivalent to the Rowe Formation of western Massachusetts and therefore place Hartland Unit II underneath Hartland Unit I (fig. 3). Because Hartland Unit II is absent east of the Pomperaug fault and other stratigraphic units are absent west of the fault, there is no evidence from the Southbury quadrangle to support or refute this contention.

Two members of Hartland Unit II are mapped in the Southbury quadrangle. By far the more abundant is an extremely heterogeneous suite of schist, schistose gneiss, and gneiss, containing amphibolite and calc-silicate layers. This unit is termed the garnetiferous member because of its prominent garnet porphyroblasts. It is very well exposed on Ichabut Hill and along Interstate 84 roadcuts north of Ichabut Hill and the parallel abandoned railroad. A lens of quartz-rich rock within Hartland Unit II occurs 800 m. southeast of the southernmost loop of the Pomperaug River; this distinctive rock is designated as the quartz-rich member of Hartland Unit II.

Garnetiferous member. This member of Hartland Unit II is extremely heterogeneous (table 5); the predominant rock is a well foliated, lustrous, quartz-biotite-plagioclase-muscovite-staurolite-garnet schist to schistose gneiss. Other rock types include common biotite-plagioclase-muscovite-quartz-garnet-kyanite schist, rare plagioclase-quartz-staurolite-biotite-muscovite-garnet gneiss, and rare biotite-plagioclase-quartz-garnet schist. Grain sizes vary from medium to coarse. Very coarse porphyroblasts of garnet, staurolite, kyanite, biotite, and magnetite are present in some localities. In no cases are garnet, kyanite, and staurolite found together; they coexist only as pairs. Chlorite, probably retrograde, is present in most of these rocks as rims around garnet porphyroblasts and between some biotite folia. Many porphyroblasts of garnet contain inclusion spirals in cores and have inclusion-free rims, indicating two stages of growth, synkinematic followed by static. The lack of parallelism between the foliation and the alignment of some biotite and staurolite porphyroblasts is suggestive of porphyroblastic growth after deformation had ceased at this locality. No sillimanite or microcline is present in these rocks. Although the lustrous concentration of muscovite on foliation surfaces is one of the most distinctive features of these rocks, the muscovite/biotite ratios are generally less than 1.

Table 5. — Average modal analyses of Hartland Unit 11 in volume percent

a) Garnetiferous member	Q	Pl[1]	Bio	Ms	Gt	St	Ky	Chl[2]	Mt	Other[3]
Average of 15 samples	35.8	22.2	22.5	11.9	1.6	3.4	T	1.7	1.4	0.4
Range of values	1-64	9-42	8-54	0-32	0-14	0-18	0-5	0-12	0-6	0-1
Specific examples[4] to demonstrate heterogeneity										
#1760	1.2	41.2	53.6	0	0.4	0	0	2.0	0	T
#1834	6.4	18.4	33.6	17.2	6.8	0	4.4	12.0	0.4	T
#3319	35.6	28.0	15.2	7.6	2.0	4.0	0	6.0	1.6	T
#3130	44.0	24.4	22.4	2.4	0	6.0	0.4	0	0.4	T
#3071b	29.6	42.0	11.2	2.4	13.6	3.6	0	0	1.6	T
b) Quartz-rich member										
#3135	68.0	17.6	8.0	4.0	0.8	0	0	0.4	0.8	T

[1] Plagioclase compositions:
Garnetiferous member: varies from An_{30} to An_{38} for 23 measurements.
Quartz-rich member: average of 2 measurements = An_{28}.

[2] Chlorite rims garnet porphyroblasts and is between biotite folia.

[3] Mostly Sph with minor Ap and Z.

[4] Exact location available from author.

The calc-silicate layers are symmetrically zoned assemblages that are the result of the reaction of calcareous sediments with adjacent pelitic sediments during metamorphism (Vidale, 1968). From the center of the calc-silicate layer to the edges of the reaction zone, the typical sequence of assemblages is:

1. Center: Q + Pl + Di + Sph ± Cal
2. Q + Pl + Clz + Gr + Tr + Sph
3. Q + Pl + Clz + Gr + Tr
4. Q + Clz + Mt ± sulfides
5. Q + Bio + Pl + sericite on Pl
6. Pelitic rock: Q +Pl + Bio + Ms

The entire sequence is present only in calcsilicate layers thicker than 15 cm; calcite remains only in layers thicker than 0.5 m. Relict calcite only 50 cm from unaffected pelitic metasediments is a measure of the limits of metasomatic diffusion under the metamorphic conditions.

Typical outcrops are medium-bedded schistose gneisses of alternating rock types; they have nonrusty-weathering surfaces with some rusty-weathering layers where calc-silicates or sulfides are locally abundant. The outcrop pattern is clearly outlined by the prominent exposures of continuous amphibolites (<30 m. thick) and continuous thin calc-silicates (<3 m. thick). The amphibolites make up less than 10 percent and the calc-silicates less than 1 percent of Hartland Unit II. Because of the variable resistance to weathering and erosion of these schists, gneisses, amphibolites, and calc-silicates, the hillsides underlain by Hartland Unit II are ledgy; the schists and calc-silicates weather more readily and therefore the abundance of exposures is biased toward amphibolites and gneisses.

Quartz-rich member. A lens of quartz-rich rock has been mapped northeast of Ichabod Hill and is called the quartz-rich member of Hartland Unit II. This lens is a quartz-plagioclase-biotite-muscovite gneiss for the most part. Table 5 lists the modal analysis of one sample.

ORIGIN

Most of the rocks in Hartland Unit II are obviously of sedimentary origin. The average composition is close to that of the average marine pelogic sediment (fig. 4f) but the range of composition extends from subgraywacke to iron-rich shales (figs. 4a, 4f, table 6). Originally the unit must have consisted of interbedded shale, quartz-rich silt and sand, subgraywacke, thin calcareous shale, and limestone. Basalt flows interrupt the sedimentary sequence at several levels. Such a diverse sedimentary sequence probably did not accumulate in a quiet sedimentary basin well removed from sediment sources; the presence of both volcanics and carbonates is suggestive of a transition between miogeosynclinal and eugeosynclinal deposits (Schwab, 1971).

The possibility that Hartland Unit II and the Waterbury Formation may represent facies equivalents is discussed in the preceding section.

Table 6. — Average chemical composition of the Garnetiferous member of Hartland Unit II in weight percent

Si	Al	Si/Al	K	Fe + Mg
30.8	7.8	4.9	3.3	9.3

Hartland Unit I

GENERAL DISCUSSION

Hartland Unit I forms a wide belt east of the central strip of the Straits Schist and is folded with the Collinsville Formation in a series of antiforms and synforms west of the Straits Schist to the Pomperaug fault. The best exposures of this quartzo-feldspathic schistose gneiss are along the northern bank of the Housatonic River, in roadside outcrops along Hogback Road and Governor Hill Road over Fivemile Hill, in power-line outcrops on either side of State Route 67, and in large exposures along Interstate 84.

Gates (1959) first defined Hartland Unit I in his Roxbury quadrangle report and later, with Martin, identified this unit in the Waterbury quadrangle (1967). Unit I is recognized as equivalent to the Taine Mountain Formation of the Collinsville quadrangle (Gates and Martin, 1967; R.S. Stanley, personal communication) and Hatch and Stanley (1970, and personal communications) consider it the southern extension of the Moretown Formation of Massachusetts. R.S. Stanley (personal communication) recognizes the Hartland Unit I in the Newtown quadrangle but it cannot be physically traced eastward into the Southbury quadrangle to the east.

LITHOLOGY

Eastern and western facies. These facies of Hartland Unit I are separated by the strip of Straits Schist and the complete transition is not exposed. On the eastern side, the rocks are divided into an upper laminated member, a lower banded member, and a kyanite-rich member that occurs as lenses within them. The banded member differs from the laminated member in bedding thickness; the mineralogical and chemical compositions of these two members are very similar (tables 7, 8, fig. 4c)

Table 7. — Average modal anaylses of Hartland Unit I in volume percent

	Q	Pl[1]	Mi	Bio	Ms	Gt	St	Ky	Sill	Mt	Other[2]
Laminated member											
Average of 40 samples	39.0	19.5	1.7	20.5	15.4	1.6	T	0.9	T	1.1	0.3
Range of values	16-80	3-37	0-20	3-41	0-46	0-7	0-0.4	0-10	0-2	0-12	0.2
Banded member											
Average of 9 samples	38.3	16.0	9.7	23.2	5.1	3.1	0	3.1	T	0.4	1.1
Range of values	13-74	2-46	0-18	9-39	0-13	0-10	0	0-12	0-1	0-1	0-2
Kyanite-rich member											
Average of 22 samples	19.2	6.6	4.7	31.3	16.5	3.6	–	14.9	2-5	1.5	
Range of values	0-42	0-22	0-18	14-47	2-40	0-14	–	0-34	0-16	0-7	

[1] **Plagioclase compositions:**
Laminated member: average of 23 meaasurements = An_{20}
Banded member: average of 5 measurements = An_{25}
Kyanite-rich member: average of 14 measurements = An_{21}

[2] **Laminated member: Sph, Chl, Hb, Tm, Pr, Z, Ap**
Banded member: Chl, Tm, Z, Ap
Kyanite-rich member: Sph, Chl, Pr, Z, Ap

Table 8. — Average chemical composition of Hartland Unit I members in weight percent

	Si	Al	Si/Al	K	Fe + Mg
Laminated member	31.9	7.9	4.7	3.8	7.4
Banded member	32.0	5.8	5.7	3.4	8.3
Kyanite-rich member	25.8	13.0	2.15	5.2	12.6

Gates and Martin (1967) and Gates and Christensen (1965) considered that rocks continuous with the banded member of this report are part of the Waterbury Formation. This conclusion is not supported by a comparison of the compositions of the Waterbury Formation and the banded member of Hartland Unit I (fig. 4, tables 6, 8). The abrupt termination of the uniform biotite- and kyanite-rich lithology of the Waterbury Formation in the northeastern corner of Southbury quadrangle has led to the restriction of that formation to this small portion of the quadrangle (pl. 1A). The kyanite-rich member of Hartland Unit I has a chemical composition, mineralogical composition, and physical appearance similar to those of the Waterbury Formation but occurs as isolated lenses in the banded and laminated members of Hartland Unit I on either side of the strip of Straits Schist. The Woodbury quadrangle, the northern part of the Naugatuck quadrangle, and other areas that surround the Waterbury dome will have to be remapped before this stratigraphic disagreement can be resolved.

The western facies of Hartland Unit I also includes the laminated member and lenses of the kyanite-rich member, along with a new member, the quartz-rich member. The western facies differs from the eastern in at least seven ways: 1) the banded rocks are absent, 2) a thick quartz-rich gneiss to quartzite is present, 3) the mica content of some beds in the laminated member is significantly higher, 4) the pin-stripe texture of the laminated member is less pronounced, 5) the kyanite-rich member is less abundant, 6) amphibolites are much more common, and 7) gondites (coticules) present in the eastern facies are absent in the western. The western facies is more clastic and heterogeneous, repeating the pattern of the proposed Hartland Unit II-Waterbury Formation facies change described above.

Laminated member. The most abundant rock in Hartland Unit I is a nonrusty-weathering quartz-biotite-plagioclase-muscovite schistose gneiss characterized by a fine-grained texture and millimeter-scale micaceous laminations separated by slightly thicker quartzose layers. Garnet, kyanite, and microcline are present in many samples but are generally rather minor constituents and microcline and kyanite do not coexist. Table 7 summarizes the mineralogical composition of this unit. With few exceptions, biotite is more abundant than muscovite. Most of the rocks have a "salt-and-pepper" speckled surface along the micaceous folia; this earned them the field name "laminated fine-grained speckled" unit. The eastern facies of this member has many thin gondites, which are distinctive layers of spessartitic garnet and quartz.

Banded member. Mineralogically, the banded member is essentially the same as the laminated member, with the exception that microcline is more abundant and muscovite less abundant. Also, garnet and kyanite are significantly more abundant in the banded rocks (table 7). The most common rock type is a nonrusty-weathering fine- to medium-grained quartz-biotite-plagioclase-muscovite-garnet-kyanite schistose gneiss that in most exposures has centimeter-thick bands of alternating quartzose and thinner micaceous layers and in fewer outcrops has millimeter-scale micaceous lamellae separated by slightly thicker quartzose layers. Another abundant schistose gneiss has a somewhat less aluminous assemblage of quartz, plagioclase, microcline, biotite, muscovite, and garnet.

Kyanite-rich member. Isolated lenses of biotite-kyanite-rich rocks are present at all stratigraphic levels in Hartland Unit I, in both laminated and banded members. This rock is a nonrusty- to rusty-weathering, fine-grained biotite-quartz-muscovite-kyanite schist to schistose gneiss that contains subordinate amounts of feldspars, garnet, and sillimanite. The fine kyanite blades have grown in irregular patches, 1-5 mm in diameter, giving the fresh surface a light-bluish spotted appearance and the weathered surface an irregular knobby texture. The massive structure and homogeneous mineralogical character give the rock a poorly defined foliation and bedding. Outcrops are rounded, without the ledgy character of more distinctly bedded units.

Quartz-rich member. In the western-central part of Southbury, a thick continuous band of quartz-rich gneiss and quartzite is interbedded with Hartland I rocks. The mineralogical composition of the quartz-rich band varies from that of the laminated member to almost pure quartzite. Thin calc-silicate bands occur in a few localities. Hillsides underlain by the quartzites have ledgy shoulders where the resistant quartzite crops out; bedding thickness varies from 10 cm to several meters. No relict sedimentary features were recognized. Most of the quartzites have yellowish-gray weathered surfaces and are nonrusty weathering. No modal analyses were determined for this quartz-rich member.

ORIGIN

Chemically, all the Hartland Unit I members can be categorized as metasediments (table 8, fig. 4c). The laminated member and the banded member are chemically similar and are within the composition range of shales and close to that of graywackes. Within the laminated member the average aluminum content increases from west to east, generally reflecting a more clay-rich eastern sedimentary facies and a more quartz-rich western facies. The manganese- and silicon-rich gondites of the eastern facies possibly represent manganiferous cherts thought to be indicative of regions far from sources of clastic continental debris.

The kyanite-rich member is extremely aluminous, with Si/Al ratios only slightly less than 2; probably this rock was a shale with a high clay-mineral content. The greater abundance of the aluminous rock in the eastern facies is thought to be a reflection of increasing distance from the source of clastic debris.

The quartz-rich member varies between a sedimentary quartzite and a subgraywacke.

Collinsville Formation

GENERAL DISCUSSION

The Collinsville gneiss was first named by Rice and Gregory (1906). After Stanley (1964) defined the Collinsville Formation in the Collinsville quadrangle report, Crowley (1968) extended the name southward to the Long Hill and Bridgeport quadrangles, where it is continuous with the same rock unit in the Southbury quadrangle. In this quadrangle it borders the strip of Straits Schist and is folded with Hartland Unit I on the western side of the quadrangle (pl. 1A). Several names have been used for units similar to the Collinsville Formation that wrapped around the Waterbury dome; Gates and Martin (1967) equated their Hitchcock Lake Formation with the Collinsville Formation (fig. 3) and Cassie (1965) used the name Reynolds Bridge Gneiss in the Thomaston quadrangle for part of this unit.

Three members of the Collinsville Formation are distinguished in the Southbury quadrangle. One is the Bristol Member, first defined by Stanley (1964); this is the quartzo-feldspathic gneiss and schistose gneiss that envelops Hartland Unit I around the Waterbury dome. A second member, consisting of rocks that are distinctly more aluminous, occurs west of the strip of Straits Schist and is separated laterally from the Bristol Member by a third member, a transitional one consisting of mixed rock types like those of the Bristol Member and the aluminous member. In the Collinsville quadrangle, Stanley (1964) also recognized an aluminous member that he called the Sweetheart Member. This member name is not used for the aluminous member in the Southbury quadrangle in this report because there is no definite correlation between the two; the Sweetheart Member occupies a stratigraphic position at the top of the Collinsville Formation in the Collinsville quadrangle but rocks with similar lithologies are not restricted to this stratigraphic position in the Southbury quadrangle. Also, aluminous rocks have not been recognized as a mappable unit within the Collinsville Formation in the region between the Southbury and Collinsville quadrangles.

Good exposures of the Bristol Member of the Collinsville Formation occur along the eastern side of Copper Mine Road just north of Stevenson Dam. Roadcuts and hillsides on either side of State Route 188, adjacent to Southford Falls State Park, are excellent examples of the transitional member, containing mixtures of rocks similar to those of both the Bristol and aluminous members. Large, readily accessible outcrops of the aluminous member are on the north side of the Housatonic River, particularly between Lakeside and Kettletown State Park.

LITHOLOGY

Bristol Member. The Bristol Member is distinctively uniform; most exposures are homogeneous, nonrusty-weathering, medium-grained quartz-plagioclase-biotite gneiss to schistose gneiss with a medium bedding caused by small changes in biotite content (table 9). Outcrops are rounded to slightly ledgy. Muscovite and garnet are minor constituents. Within 2 km of the Newtown Gneiss, Carlsbad-twinned microcline porphyroblasts are found; close to the intrusive body, these crystals

Table 9. – Average modal analyses of the members of the Collinsville Formation in volume percent

	Q	Pl[1]	M	Bio	Ms	Gt	St	Ky	Sill	Mt	Other[2]
Bristol member											
Average of 8 samples	41.7	34.6	0	19.3	2.7	0.4	0	0	0	1.2	0.1
Range of values	20-68	17-54	0	9-35	0-8	0-1	0	0	0	T-3	0-0.5
Aluminous member											
Average of 13 samples	35.0	16.5	1.3	17.9	25.7	1.7	T	0.2	0.8	0.7	0.2
Range of values	14-56	0-28	0-10	8-24	6-54	0-11	0-T	0-1	0-5	T-2	0-1
Transitional member (mixture of Bristol member and aluminous member rock types)											
Average of 19 samples	35.3	21.0	0	17.9	21.4	2.3	T	T	T	1.2	0.9
Range of values	18-68	1-54	0	5.2-41	0-50	0-10	0-6	0-T	0-2	T-3	0-3

[1] **Plagioclase composition:**
Bristol Member: average of 8 measurements = An_{24}
Aluminous member: average of 7 measurements = An_{31}
Transitional member: Chl, Tm, Hb, Sph, Ap, Z

[2] **Bristol member: Hb, Sph, Ap, Z**
Aluminous member: Sph, Chl, Tm, Ap, Z
Transitional member: Chl, Tm, Hb, Sph, Ap, Z

increase in size to 3 cm. In addition to the lenses of amphibolite, marble, and quartzite that are found close to the Straits Schist (to be discussed in the next section), the Bristol Member contains isolated pockets of calc-silicate rock with marble cores, lenses of amphibolite, and muscovite-garnet-rich regions very similar to the more extensive aluminous rocks of the transitional member and the aluminous member. The only abundant rock in the Bristol Member is a quartz-plagioclase-biotite gneiss to schistose gneiss.

Aluminous member. Several distinct rock types comprise the aluminous member. The most abundant is a medium-grained nonrusty-weathering quartz-muscovite-biotite-plagioclase schist to schistose gneiss that commonly contains minor garnet and a trace of staurolite, kyanite, and/or sillimanite (table 9). A medium- to coarse-grained quartz-plagioclase-biotite-garnet-kyanite-muscovite gneiss to schistose gneiss resembles the Sweetheart Member of the Collinsville Formation (Stanley, 1964); the greatest concentration of this rock is in a series of exposures from the Housatonic River west of Good Hill northward to Thorson Road. Rare muscovite-quartz-biotite-plagioclase schists are interbedded with other rocks.

Although muscovite-rich rocks are the most prevalent type found in the aluminous member, a significant part of this member consists of schistose gneisses less rich in muscovite and of gneisses very similar to those of the Bristol Member. Note (table 9) that muscovite/biotite ratios for the aluminous rocks are greater than 1; the Straits Schist is the only other unit for which this is true. Because these interbedded rocks differ in resistance to erosion, hillsides have ledges of angular, well bedded outcrops. Scattered lenses of amphibolite are present, both within the aluminous member and along its border with Hartland Unit I. These amphibolites vary in thickness from 0.5 m to at least 100 m. Unfortunately, they cannot be traced far enough to define stratigraphic levels within the unit.

Transitional member. The rock types described above for the Bristol Member and the aluminous member are present in the mixed or transitional facies. Boundaries between facies are indistinct but are defined on the basis of the relative abundances of rock types: where the abundance of aluminous rock types is roughly equal to that of Bristol rock types, the transitional member classification is used; where the Bristol or the aluminous rock types distinctly predominate throughout a wide region, the appropriate member name is used. Recognition of a member from observation of one outcrop is impossible because of the great heterogeneity of the rocks, which also makes mapping difficult.

An average mineral content for the transitional member is given in table 9.

ORIGIN

Except for a few quartz-rich and a few shale-rich examples, most of the compositions of Bristol Member rocks are close to those of igneous rocks (table 10, fig. 4d). The homogeneity and obviously stratified origin of the Bristol Member and the presences of interbedded amphibolites and a few layers of andesitic composition is suggestive of a volcanic origin. A tuffaceous origin similar to that suggested by Crowley (1968) is probable. The more quartz-rich layers probably represent concentration of quartz by weathering and sedimentary reworking of tuffs. Most probably, the amphibolites represent small, local basalt flows. Such a concentration of silicic, andesitic, and basaltic volcanic products within a eugeosynclinal suite of rocks is likely to have been the product of island-arc volcanism.

Table 10. — Average chemical composition of members of the Collinsville Formation in weight percent

	Si	Al	Si/Al	K	Fe + Mg
Bristol member	33.5	6.3	6.2	2.0	6.9
Aluminous member	31.3	9.6	3.6	4.6	6.6
Transitional member	31.7	9.1	4.2	4.2	6.8

The aluminous member appears to have resulted from the metamorphism of an intercalation of tuffaceous units similar to those which made up the Bristol Member, with clay-rich sediments deposited between the volcanic source and the carbonate miogeosyncline. The heterogeneity of the aluminous member is thus in part the result of the intertonguing of material from two distinct sediment sources.

Unnamed amphibolites, quartzites, and marbles

A remarkably distinctive suite of rocks occurs along the boundary between the Straits Schist and the Collinsville Formation; it includes amphibolite, quartzite, and marble in discontinuous lenses. Associated with these rocks is a string of metalliferous sulfide deposits. At most localities these rocks are less than a few tens of meters thick or entirely absent but, regionally, the consistency with which the discontinuous lenses are found is impressive. Within Connecticut they are found in the Collinsville (Stanley, 1964), Thomaston (Cassie, 1965), Waterbury (Gates and Martin, 1967), Naugatuck (Carr, 1960), Long Hill and Bridgeport (Crowley, 1968), and Westport (Dieterich, 1968a) quadrangles as well as in the Southbury quadrangle. Hatch and his associates (1970) defined similar rocks at the same stratigraphic position in western Massachusetts as the Russell Mountain Formation and assigned them a Middle Silurian age, based on their correlation of this unit with the Shaw Mountain Formation of Vermont. Lithologic similiarities suggest that the Russell Mountain Formation extends through western Connecticut.

Most of the quartzite layers are slightly calcareous and have light-gray to slightly rusty weathering surfaces. One of the thickest quartzites (about 3m) is well exposed on a hillside a few tens of meters west of Boys Halfway River along the southern boundary of the Southbury quadrangle. The quartzite contains medium-grained crystals of 70 percent quartz, 15 percent plagioclase (An_{92}), 6 percent biotite, 3 percent opaques, 4.5 percent clinozoisite, and about 1 percent sphene. The amphibolite lenses consist largely of hornblende, plagioclase (An_{34-43}) and quartz but locally biotite, anthopyllite, garnet, or pyroxenes are abundant. The marbles have reaction zones on their boundaries similar to those described by Vidale (1968) and in the discussion of Hartland Unit II above. An easily accessible marble reaction zone is found at the abandoned exploratory pit of the Stevenson mine, 1.5 km north of Stevenson Dam on the eastern side of Copper Mine Road. The sequence from normal Collinsville schistose gneiss to the pure marble consists of remarkably simple assemblages; in fact some layers are essentially monomineralic:

(1) Marble core, almost pure calcite
(2) Calcite + pyrite + chalcopyrite + magnetite + malachite + azurite + sphene
(3) Epidote + actinolite
(4) Almost pure actinolite
(5) Almost pure phlogopite
(6) Diopside + actinolite + grossularite
(7) Rusty-weathering quartz layer
(8) Essentially unaffected Collinsville schistose gneiss.

Although no relic pebbles were observed in the quartzite, conglomerates have been reported by Hatch and his associates (1970) in western Massachusetts. This indicates a probable major unconformity between the Ordovician Collinsville Formation and these Middle Silurian rocks.

Straits Schist

GENERAL DISCUSSION

Since Rodgers and his co-workers (1959) originally named the Straits Schist and gave it member rank in the Hartland Formation, this distinctive muscovite-rich schist has been mapped along tectonic strike from the

Collinsville quadrangle (Stanley, 1964) to the Bridgeport quadrangle (Crowley, 1968). Recent workers have elevated the schist from a member to formation status. Hatch and Stanley (1970) consider the Straits Schist to be the southern equivalent of the Goshen Formation of western Massachusetts, which overlies the Russell Mountain and the Hawley formations. Because the Straits Schist and the Goshen Formation are believed to be separated from underlying rocks by a major unconformity, they should not be included in the same group with formations beneath the unconformity. Thus, if the term "Hartland Group" is to be preserved, it should be restricted to those units stratigraphically below the unconformity.

Outcrops of the Straits Schist in the adjoining Long Hill (Crowley, 1968) and Naugatuck (Carr, 1960) quadrangles are continuous with exposures in the Southbury quadrangle. The Straits Schist is bounded on both sides by discontinuous pods of the unnamed amphibolite, quartzite, and marble and the Collinsville Formation. Obviously from this relationship, the Straits occupies the core of a synclinal structure everywhere in the Southbury quadrangle. The most accessible outcrops of the Straits Schists are in roadcuts along State Route 34 along the Housatonic River at the southern boundary of the quadrangle and on the steep hillside west of Boys Halfway River. The narrow N- and NW-trending belt that bisects the map (pl. 1A) is exposed only in the small isolated outcrops indicated on the map.

LITHOLOGY

The lustrous, silver-gray foliation surfaces separated by pod-shaped quartz segregations, the yellowish to rusty-weathered surface, the homogeneous mineralogical and textural character, and the massive, rounded outcrops make the Straits Schist the most distinctive unit in the Southbury quadrangle and in western Connecticut. The average Straits Schist is a medium- to coarse-grained quartz-muscovite-biotite-plagioclase-garnet-graphite-sillimanite-kyanite schist (table 11); garnets and biotite have been partially retrograded to chlorite in some localities. The graphite is concentrated between muscovite folia. Garnets are abundant enough to give the surfaces a slightly knotted or knobby appearance. Sillimanite and kyanite coexist in all samples studied; the sillimanite grew in knots, 1 cm in diameter, and on biotite folia; only in a few cases does sillimanite appear to have replaced kyanite. Ilmenite, rather than magnetite, is present.

Table 11. — Average modal analyses of the Straits Schist in volume percent

	Q	Pl[1]	Ms	Bio	Gt	Ky	Sill	Chi	G	Il[2]	Other[3]
Average of 12 samples	33.5	10.1	32.4	10.2	2.9	0.5	2.0	3.1	3.3	1.1	0.9
Range of values	17-46	3-32	14-51	2-21	1-7	T-3	T-6	0-11	0-5	1-2	0.2-2

[1] Plagioclase composition: average of 14 measurements = An_{17}

[2] Probably ilmenite rather than magnetite.

[3] Tm, Ep, Ap

Chemically, the Straits Schist resembles a clay-rich shale (table 12, fig. 4e), with a low quartz content. The chemical parameters used in figure 4 show the composition of the Straits Schist to be close to that of igneous rocks but the low sodium and calcium content of the Straits Schist exclude the possibility of an igneous origin for the schist. The presence of graphite in the unit, the high aluminum content, and the homogeneous composition suggest a deep, quiet deposition of clays in an oxygen-poor environment that allowed the preservation of organic carbon.

Table 12. – Average chemical composition of the Straits Schist in weight percent

Si	Al	Si/Al	K	Fe + Mg
29.3	10.6	2.7	4.9	5.2

Alternative stratigraphic scheme

There is considerable similarity in the chemical and mineralogical composition of Hartland Unit II, the aluminous member of the Collinsville Formation and the Straits Schist (fig. 4c, tables 6, 9, 11). All three are muscovite rich and contain aluminous phases such as garnet, kyanite, and staurolite and their ranges of chemical composition have considerable overlap. Gates and Christensen (1965) and Gates and Martin (1967) suggested that the Straits Schist may be an eastern facies of Hartland II and that the Bristol member of the Collinsville Formation is not present in the western facies. In a regional map that includes the Thomaston quadrangle, Martin (1971) shows a Hartland II connection with the Straits Schist. Proof or disproof of this hypotheis is not found in the Southbury quadrangle and, therefore, using local relationships only, the stratigraphic scheme shown in figure 5 can be considered as an alternative to the one adopted in this report.

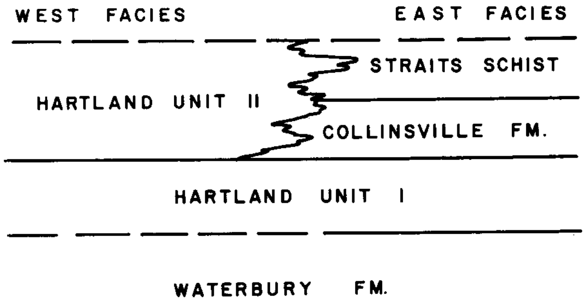


Fig. 5. Alternative stratigraphic scheme requiring Hartland Unit II to be the western facies equivalent of the Straits Schist and the Collinsville Formation.

Difficulties in using this scheme are encountered in regional correlation of western Connecticut units with those in western Massachusetts (fig. 3). Obviously the alternative scheme for Southbury does not match the regional trend and therefore is rejected on that basis.

PRE-TRIASSIC IGNEOUS ROCKS

Newtown Gneiss

GENERAL DISCUSSION

The southwestern corner of the Southbury quadrangle is underlain by a weakly foliated and bedded granitic to granodioritic gneiss characterized by large euhedral to subhedral microcline porphyroblasts. In the Long Hill quadrangle, Crowley (1968) called this unit the Newtown Gneiss; this terminology is extended to the Southbury quadrangle. R.S. Stanley (personal communication) also found this rock in the adjacent Newtown quadrangle. The northern extent of this body is shown on plates 1A and 2. The cross-cutting relationships seen on these maps indicate an igneous plutonic origin, rather than the metasedimentary one suggested by Crowley (1968). On a local outcrop scale cross-cutting features at the margins of the body of gneiss and xenoliths of country rock within the gneiss (both Hartland Unit I and Collinsville Formation) clearly require an intrusive origin for the Newtown Gneiss. A weak but penetrative deformation has created a pervasive, indistinct foliation of the feldspar porphyroblasts. The attitude of this indistinct foliation is essentially parallel to the NW strike of more distinct foliation in the country rock, indicating that intrusion was followed by a later phase of deformation related to the doming (period-4 folding). The microcline porphyroblasts in the Newtown Gneiss also occur in adjacent country rocks, both Hartland Unit I and the Collinsville Formation, but not in the Straits Schist. In fact, the absence of intrusive cross-cutting relationships with the Straits Schist can be considered as negative evidence of a pre-Silurian age of the Newtown Gneiss. The abundance and size of the porphyroblasts in the country rock decrease with increasing distance from the Newtown Gneiss border. Collinsville and Hartland Unit I rocks do not abruptly terminate against the Newtown Gneiss in most regions; there is a gradational boundary, with the abundance of country-rock xenoliths decreasing inward. The lithologic character of these xenoliths is preserved well enough to extend the original outcrop pattern of the country rocks into the intrusive body. Such relationships can best be explained by a combination of intrusion and widespread potassium metasomation, resulting in growth of porphyroblasts during a period of deformation and recrystallization.

GRANITIC BODY

The largest area of the Newtown Gneiss is underlain by medium- to coarse-grained quartz-plagioclase-microcline-biotite-muscovite gneiss of granitic composition that contains microcline porphyroblasts 1-5 cm long (table 13). The gneiss has a nearly isotropic fabric, with only a weak alignment of porphyroblasts. Weathered outcrops are rounded and massive. The biotite folia are contorted about the porphyroblasts to such

Table 13. – Average modal analyses of the Newtown Gneiss in volume percent

	Q	Pl[1]	Mi	Bio	Ms	Hb	Sph	Other[2]
Granitic body								
Average of 3 samples	33.6	28.3	25.8	8.1	3.9	0	T	0.7
Granodioritic body, (1 sample)	13.2	36.0	10.0	12.0	0	25.6	2.0	0.2

[1] Plagioclase composition: Granitic Body: Average of 3 measurements = An_{18}
Granodioritic Body: 1 measurement = An_{33}

[2] Ap, Z, Mt, Gt

an extent that only slight micaceous foliation has been produced.

GRANODIORITIC BODY

A part of the Newtown Gneiss, considerably more mafic than the granitic body, is found on either side of the Pomperaug fault along the western quadrangle boundary. The one sample studied in thin section is a hornblende-rich granodiorite (table 13); other areas in the granodiorite body appear to have less microcline than the hornblende-rich granodiorite and to more nearly approach the composition of quartz diorite. As in the granitic part of the Newtown Gneiss, the small micaceous content and the abundant porphyroblasts of the more mafic phase produce an indistinct fabric—outcrops are massive and rounded. Microcline porphyroblasts are less abundant than in the granitic part of the gneiss and smaller (0.25-2 cm in length).

An isolated outcrop of rock lithologically similar to the Newtown Gneiss was found on the eastern cliffs of Horse Hill along the western border of Southbury quadrangle. The western extent of this small outcrop is unknown but is of interest because it lies about 2 km outside the perimeter of intermixed Newtown Gneiss and country rocks.

The Newtown Gneiss intrudes the Collinsville Formation and Hartland Unit I east of the Pomperaug fault, and on the western side of the fault, the gneiss intrudes Hartland Unit II. Pegmatites and nonporphyritic medium-grained granitic rocks intrude the Newtown Gneiss.

Nonporphyritic granites and granodiorites

Cross-cutting features record several periods of granitic intrusion in the Southbury region. Relatively large bodies are indicated on plate 1A; they are not exclusively igneous rock; abundant country-rock xenoliths are included. With the exception of numerous pegmatites, relatively few granitic rocks intrude the Straits Schist; most granites are restricted to lower stratigraphic units. This restriction may indicate that most granites predate the Straits Schist, or it may indicate a relative stratigraphic level to which granitic rock intruded, or it may indicate a physical behavior of the Straits Schist that was not conducive to granitic intrusion. At this stage of study it is not clear which explanation is correct.

Although there is considerable spread in the mineralogical and chemical composition of these granitic rocks (table 14), no change in composition

Table 14. — Modal analyses of granitic rocks in volume percent

Sample #[1]	Q	Pl[2]	Mi	Bio	Ms	Gt	Other[3]
1083	34.2	15.4	22.8	2.4	24.8	0	0.8
2423	34.8	16.0	29.6	5.6	14.0	0	T
1883	27.2	19.6	44.8	8.4	0	0	T
2322	30.4	23.6	36.8	4.0	5.2	0	T
1254	40.0	28.4	27.6	3.2	0.8	0	T
1264	32.4	30.8	24.8	8.0	2.4	0	1.6
2151	44.4	33.2	0	2.0	20.2	0	0.2
2511	29.2	54.0	0	16.0	0	0	0.8
2663	19.6	55.2	0	24.0	0.4	0.4	0.4
2629	16.4	42.4	6.0	33.6	0	0.8	0.8
2612	22.0	49.5	T	26.5	0	0.5	1.5
2734K	26.0	43.6	4.0	23.6	0.8	1.6	0.4
2734T	12.4	50.8	0	32.8	0	1.2	2.8
2688	36.4	21.2	0	20.0	16.4	4.0	2.0

[1] The first six samples listed are granitic; the remainder are granodioritic to dioritic in composition.

[2] Plagioclase composition: Average of 13 measurements = An_{22}
Range: Granitic = An_{12} (sample #1083) to dioritic = An_{31} (sample #2734T)

[3] 1083, Sph, Mt, Ap, Z; 2423, Sph, Mt, Ap, Z; 1883, Mt, Ap, Z; 2322, Mt, Ap, Z; 1254, Mt, Ap, Z; 1264, Mt, Ap, Z; 1251, Mt, Ap, Z; 2511, Mt, Sph, Ap, Z; 2663, Mt, Sph, Ap, Z; 2629, Mt, Sph, Ap, Z; 2612, Mt, Sph, Ap, Z, Chl; 2734, T, Mt, Ap, Z, Sph = 2.0; 2688, Mt, Ap, Z.

Table 15. — Average modal analyses of amphibolites in volume percent

	Q	Pl[1]	Bio	Hb[2]	Gt	Mt	Sph	Other[3]
Metabasalt[4]	4.9	37.1	11.8	37.8	0.5	1.1	3.4	3.4
Metaandesite[5]	20.9	44.2	0.8	31.3	0	T	1.0	1.8

[1] Plagioclase composition: Average of 6 measurements = An_{38}

[2] One of the metabasalt samples contains anthophyllite and one of the metaandesite samples has coexisting anthophyllite and hornblende.

[3] Metabasalt, Mt, Chl, Cal, Ms, Ap, Z; metaandesite, Z, Ap, Mt

[4] Average of 5 samples.

[5] Average of 2 samples.

with apparent time of intrusion is obvious. Muscovite-rich granites are in a minority; most contain more biotite than muscovite. Only a few rocks lack potassium feldspar and these have high contents of muscovite or biotite that may reflect metamorphic replacement of potassium feldspar by hydrous potassic phases.

The last six analyses listed in table 15 are from lenslike bodies of uniform granodioritic to dioritic rocks within the laminated and banded member of Hartland Unit I; they are either metavolcanic lenses or sill-like metaintrusive bodies.

Amphibolites

Numerous amphibolites are present in Hartland Unit II, the western facies of Hartland Unit I, the Collinsville Formation, and the unnamed rocks along the Straits-Collinsville contact. Table 15 lists the average modal analyses for basaltic and andesitic amphibolities in these units. No distinctive differences in mineralogical character were noted between amphibolites in different units.

Pegmatites

Pegmatites intrude all the metamorphic rock units of the Southbury quadrangle. A few of them show evidence of having been folded and a few have a superimposed schistosity but most are undeformed, suggesting that, although some pegmatites intruded relatively early in the series of deformation events, most followed the major phases of deformation. These bodies are chiefly sill-like; others cross cut the foliation. Mineralogically these pegmatites are simple, consisting of quartz, microcline or orthoclase, albite, and muscovite. Those in an area north of Mount Pisgah contain abnormal amounts of tourmaline, garnet, beryl, apatite, and columbite. In the country rocks adjacent to these pegmatites are local concentrations of tourmaline.

Ultramafic body

At the roadcut on the western side of the Interstate 84 overpass adjacent to Horse Hill is a lens of contorted phlogopite, chlorite, serpentine, and talc, 1 m long. This magnesium-rich assemblage probably was an olivine-rich ultramafic rock that was subsequently hydrated during regional metamorphism. Regional maps (for example, Rodgers, 1970, pl. I) and discussions of northern Appalachian ultramafic rocks (Chidester, 1968) suggest that this small altered ultramafic pod might be a southern representative of a string of ultramafic bodies in Vermont and western Massachusetts. Such strings of ultramafic bodies become critical in plate-tectonic reconstructions, such as those by Dewey and Bird (1970) and Bird and Dewey (1970) and perhaps mark the suture or junction of major plate boundaries or, at least, deep structures during orogenesis. In this case, however, this small pod does not seem to be associated with any major fault system and plate-tectonic inferences seem unjustified.

Post-orogenic Paleozoic igneous rocks

A small undeformed mesocratic syenite stock and a biotite lamprophyre dike cut the metamorphosed units of the Southbury quadrangle. The stock is about 150 x 70 m and is located about 300 m west of the dam at Southford Falls State Park. A biotite lamprophyre (minette), 1 m in width, is exposed along Interstate 84 roadcuts on the western side of the junction with State Route 188. The modal analyses of these rocks are listed in table 16. There is a detailed description of them in an earlier report (R.B. Scott, R.L. Armstrong, and J.R. Hartung, unpub. ms.). The lamprophyre dike (biotite K-Ar date of 334 m.y.) has an age that is comparable with K-Ar dates related to regional metamorphism; although the undeformed dike postdates Acadian metamorphism, it cooled to argon-retention temperatures at the same time as the surrounding metamorphic rocks (Clark and Kulp, 1968; Zartman and others, 1965). The stock

Table 16. — Modal analyses of post-orogenic alkalic rocks in volume percent

Minette dike						
Bio	Au	Or	Ap	Sph	Cal	
31.8	25.0	20.4	14.6	2.8	5.4	
Mesocratic amphibole syenite						
Bio	Arf	Mi	Ap	Ru/Sph[1]	Cal	Mt
5.2	39.2	45.8	8.0	1.4	1.4	T

[1] Rutile is present along boundaries with xenoliths, and sphene is the titanium phase farther from xenoliths and country rock.

intruded at a distinctly later period (whole rock K-Ar date of 263 m.y. and biotite K-Ar date of 277 m.y.), after the country rock had cooled to argon-retention temperatures.

Sequence of Paleozoic igneous events

Amphibolites and other metavolcanic rocks within the metamorphosed strata of the Southbury quadrangle are undoubtedly the oldest igneous rocks of the region. It is more difficult to determine the relative ages of granitic plutons that intruded the orogenic belt during phases of deformation. Obviously, the porphyroblastic Newtown Gneiss is older than pegmatites and nonporphyroblastic granites that intrude it; in turn, the Newtown Gneiss cuts period-3 lineations and folds (see discussion under *Sequence of fold events)* but period-4 schistosities penetrate the gneiss. Relative ages of the smaller nonporphyroblastic granitic bodies are more difficult to ascertain because the large scale of the structures, the limited outcrops, and the indistinct foliations of many granite bodies introduce ambiguous evidence or give none. Some highly deformed, well foliated, and folded granitic bodies appear to have been deformed during folding-periods 2, 3, and 4. Other plutons seem to have been only slightly affected by deformation and their only foliations are close to boundaries; these may have been intruded after period-3 folding and before that of period 4. Although some pegmatites have been deformed, the vast majority show no evidence of deformation and clearly cut across the latest fabrics and thus are probably the youngest igneous event directly related to metamorphism and orogenesis. The 344-m.y. lamprophyre dike intruded the belt after the last deformation but before the argon-retention temperature was reached in the cooling metamorphic country rock; thus the dike has a K-Ar date compatible with the K-Ar dates of the country rock. A still later alkalic event was marked by the intrusion of mesocratic, alkali-amphibole syenites (263-277 m.y. K-Ar dates). Only one body was mapped (pl. 1A) but erratics of this distinctive lithology were found northwest of the known body; glaciers that moved southeastward undoubtedly carried the erratics from one or more identical plutons.

TRIASSIC ROCKS

Although detailed discussion of the Triassic rocks of the Pomperaug Valley is beyond the scope of this report, a short summary of previous studies of these rocks and observations made during mapping for this report are included.

Percival's (1842) mapping first outlined the regions underlain by basalt and arkose in the Pomperaug Valley. The block-fault theory of Davis (1888) was based largely on his observations in this region. Shortly thereafter, Hovey (1890) reported on the rocks encountered in a dry hole drilled for oil and later (1899) Hobbs made the first comprehensive report of the Pomperaug Triassic region. Davis and Hobbs established the stratigraphic sequence at the base of the Triassic, where outcrops are adequate on the hills and slopes north and east of South Britain.

The sequence consists of covered arkosic sediments (?) west of South Britain, overlain sequentially by shale, arkosic conglomerate, and sandstone, a distinctive amygdaloidal basalt, a thin shale, more conglomerate, a thick columnar-jointed basalt, reddish and greenish shale, a pillow basalt, and more arkosic sediments (fig. 6) found north and east of South Britain. The thickness of the covered arkosic sediments below the base of the amygdaloidal basalt can be estimated from the width of the Pomperaug River valley west of South Britain and from the drilling record from the dry well 0.5 km. west of Middleground Cemetery; Hovey (1890) noted that two trap sheets were encountered in arkosic sediments before the crystalline basement was encountered at 1,235 ft (380 m) and Hobbs (1899) reported that the two traps were found near the top of the dry hole. Even the thickness of well exposed beds is difficult

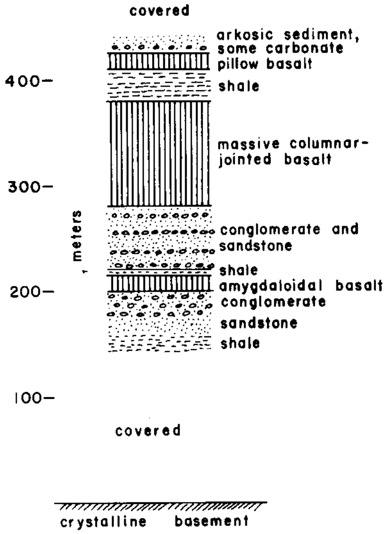


Fig. 6. Generalized stratigraphic section of the lower portion of Triassic rocks in the Pomperaug Valley north and east of South Britain.

to measure because of variations in bed attitude; an average dip of 40° was estimated for the section drawn in figure 5. Although the sketch map (fig. 97, p. 470) and cross section (fig. 98, p. 472) drawn by Davis (1888) are too generalized to express all the structural details indicated by the outcrop control on pl. 1A, this report conforms with the fundamental structural block-fault cross section of Davis (pl. 1A, fig. 7). However, the extreme detail shown by Hobbs (1899) does not seem to be justified by the outcrop control, particularly in areas of very limited outcrop, where the rare exposures are all basalt. For example, in the area north and south of Durkee Hill, no arkose is exposed in the narrow valleys which lie between narrow basalt ridges. The drilling record of the dry hole drilled for oil about 0.5 km west of Middleground Cemetery provides structural and stratigraphic control that requires a major normal fault west of the well (pl. 1A); this fault repeats the lower stratigraphic section in the Triassic, as shown in figure 7.

Longwell (1922), Wheeler (1937), Krynine (1950), and Sanders (1960) have built a regional stratigraphic scheme that correlates the sediments and flows of the Pomperaug area to those of the Connecticut Valley. Sanders interpreted the Pomperaug as a down-dropped central portion of the Danbury anticline that stretched from the E-dipping Connecticut Triassic rocks to the W-dipping New York and New Jersey rocks. Several stratigraphic features strengthen such a correlation, at least in the lower part of the sequence shown in figure 6. Table 17 compares the units defined by Sanders (1970) north of New Haven with those described by Davis, Hobbs, and this report.

The similarities of three basalts are striking, even though the thicknesses are not the same and the intervening sedimentary rocks do not correlate well. Based on table 17, it is concluded that the section of rocks exposed on Rattlesnake Hill north of South Britain in the Southbury quadrangle is the Talcott Formation of the Connecticut Valley. Probably the poorly exposed sediments below the amygdaloidal basalt west of Rattlesnake Hill are equivalent to the New Haven Arkose. Note that in the Pomperaug area the sedimentary units are both thinner and generally finer grained than in the Connecticut Valley.

Problems are encountered in attempting to correlate rocks higher in the Connecticut Valley section with rocks in the Southbury quadrangle; the Shuttle Meadow Formation (arkosic sediments), Holyoke Formation (basalts), East Berlin Formation (arkosic sediments), and Hampden Formation (basalts) may be present but evidence to support definite correlation is absent. The exposures north of Rattlesnake Hill and north and east of the well exposed hills north of Flood Bridge Road are limited to basalts (pl. 1A). Attitudes of strata at these inadequately exposed outcrops can only be estimated at best, and the basalts lack distinguishing features. Three interpretations are thus possible (fig. 7):

1) Only five N-S normal faults are present, one west of Rattlesnake Hill repeating the New Haven Arkose, the second east of Rattlesnake Hill repeating the Talcott Formation, a third close to Cass Road also repeating the Talcott Formation, a fourth a small distance (<0.5 km) west of a dry well drilled for oil, and a fifth along the crystalline boundary east of Southbury. In this construction, the area between the third and fourth normal faults is underlain by a sequence of alternating ridges of

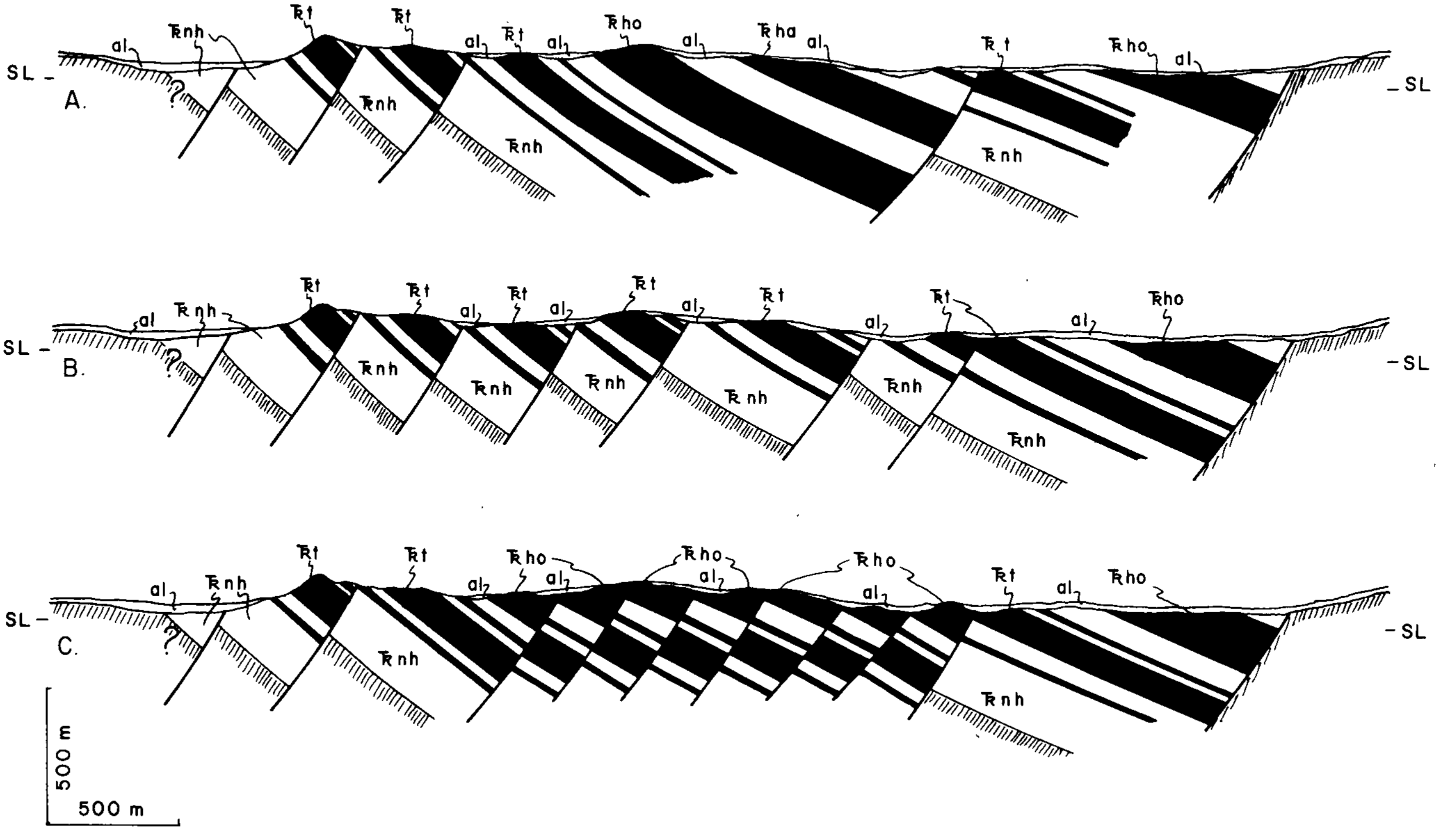


Fig. 7. Three possible interpretations of the structural and stratigraphic section through the Pomperaug region from the Pomperaug River valley west of Rattlesnake Hill (Conn. coordinates 461,350 ft E-W and 233,700 ft N-S) to the 149-m hill east of Southbury (Conn. coordinates 475,500 ft E-W and 239,450 ft N-S). TRnh = New Haven Arkose, TRt = Talcott Formation, TRho = Holyoke Formation, and TRha = Hampden Formation (after the Connecticut Valley stratigraphic section by Sanders, 1970). The symbol al = all types of covering alluvium, including glacial debris. Dark strata are basalt; light strata are arkosic sediment; lined areas are crystalline basement. The question mark at the western boundary of Triassic rock indicates the exact nature of this boundary is unknown; the boundary could also be an E-dipping normal fault forming a graben similar to the Gaillard graben system of the Connecticut Valley (Sanders, 1970).

Table 17. – Comparison of Connecticut Valley and Pomperaug Valley Triassic rocks

Name	Sanders (1970) Connecticut Valley	Thickness (m)	This report Pomperaug Valley	Thickness (m)
TALCOTT FORMATION				
Upper breccia member	basalt breccia	60	covered	?
Upper sedimentary member	siltstone and carbonate pebble arkose	75	arkosic conglomerates, sandstones, and siltstones; some carbonates (?)	20+
Pillowed and brecciated member	brecciated top pillow basalt	60	pillow basalt	15
Middle sedimentary member	coarse pebble arkose	20	shale	30
Lower massive member	massive columnar basalt	30	massive columnar basalt	100
Lower sedimentary member	coarse pebble arkose	12	conglomerate and sandstone shale	65
Basal member	brecciated and amygdaloidal basalt	45	amygdaloidal basalt	15
NEW HAVEN ARKOSE	coarse and fine arkose; base not exposed	1,500+	arkosic conglomerate, sandstone, and shale; base not exposed	20+

basalt and valleys of unexposed arkosic sediments. These rock units may (or may not) correspond to the upper Connecticut Valley formations (fig. 7A).

2) A second cross section can be drawn that differs from the first only east of the third normal fault; instead of a continuous sequence of alternating basalts and sediments, this could be a highly faulted area, with the Talcott Formation repeated several times. In this case, the valleys represent either unexposed arkoses or fault zones. Three additional normal faults would be necessary (fig. 7B) for this construction.

3) The third cross section that can be drawn differs from the first only east of the second normal fault. On the basis of negative outcrop evidence it can be postulated that only basalt underlies the region east to the normal fault required by evidence of the dry hole drilled for oil. The small valleys would then represent more easily eroded fault zones. Unless an abnormally thick basalt layer is present here, a minimum of six additional normal faults would then be required (fig. 7C); such a construction is considered highly unlikely. The structure represented by figures 7A or 7B or by a combination of the two is considered more likely.

Paleomagnetic evidence collected by J. de Boer and L. Pond (personal communication) suggests the possibility that the Pomperaug basalts do not correspond to all three Connecticut Valley events; the basalts that underlie Rattlesnake Hill and those that underlie the western flank of East Hill have thermal-remnant magnetism with low inclinations, similar to those of the Talcott event. No inclinations correspond to those of the Holyoke event. High inclinations similar to those in the Hampden event were found in the Pomperaug basalts by de Boer and Pond but not in the Southbury quadrangle; they found such inclinations to be restricted to the Orenaug Hills in the Woodbury quadrangle to the north. Before a stratigraphic interpretation based on paleomagnetic evidence can be used in the Southbury quadrangle, further sampling of higher basaltic units must be done and the depositional attitudes of basalt layers carefully checked to remove rotation correctly. In any case, to show that basalts in Pomperaug Valley were emplaced at the same period of the magnetic time scale does not indicate that they were necessarily part of the same extrusive unit. If the Talcott basalt correlations from the Southbury quadrangle to the Connecticut Valley are correct, this requires that no large obstructions for flood basalts lay between the Triassic Border fault east of New Haven and the Pomperaug area. Therefore the sediment source for the Pomperaug area must have been east of the Triassic Border fault east of New Haven and the Pomperaug area. Therefore, the sediment source for the Pomperaug area must have been east of the Triassic Border fault, a distance of 35-40 km. This conclusion requires a mechanism that was capable of transporting subangular to very angular cobbles, 20 cm in length, over 35 km. These cobbles are found in the arkosic conglomerates below the amygdaloidal basalt of the Talcott Formation near South Britain.

STRUCTURAL GEOLOGY

General discussion

A complex Paleozoic fold history is required for the outcrop pattern of

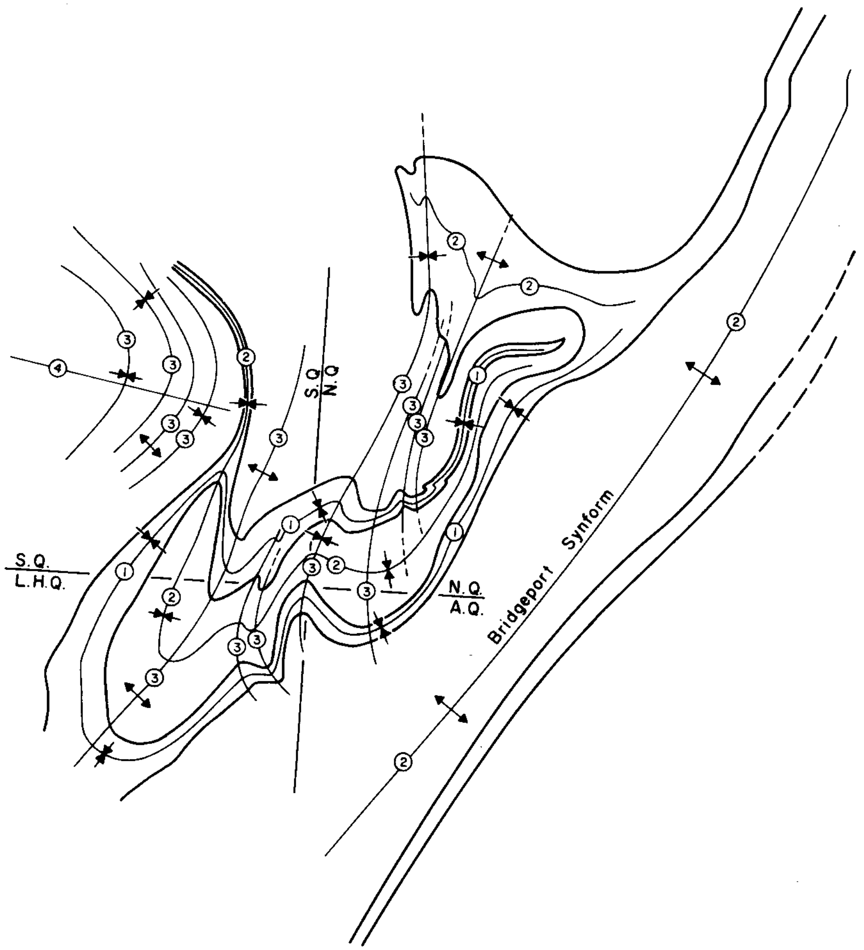


Fig. 8. Generalized outcrop pattern of the Straits Schist in parts of the Southbury (S.Q.), Naugatuck (N.Q.), Long Hill (L.H.Q.), and Ansonia (A.Q.) quadrangles. The fold symbols refer to stratigraphic anticlines and synclines without regard to later rotation of beds into recumbent or overturned positions. Three axial-plane traces are numbered from the oldest fold generation to the youngest. The fourth-generation axial plane trace is shown only west of the Straits Schist in the Southbury quadrangle because east of this region this period of deformation produced only kink bands and fracture cleavage. Data from Crowley (1968), Fritts (1965a), Carr (1960), Dieterich (1968a,b) and this report.

the Straits Schist in southwestern Connecticut (figs. 8, 9, 10, pls. 1A, B, 2). Stanley (1964, 1968) proposed that the complex fold history in northwestern Connecticut in the Collinsville quadrangle consisted of nappe formation followed by doming. Dieterich (1968a, b) also recognized this requirement on a regional scale in southwestern Connecticut and developed a series of folding events that are compatible with the local and regional stratigraphic

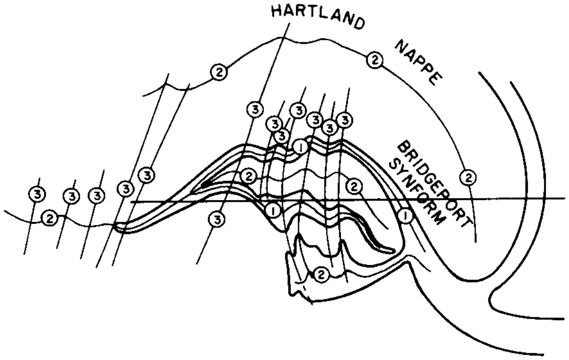


Fig. 9. Generalized west-east structure section drawn facing north from the outcrop pattern of figure 8. The heavy horizontal line represents a hypothetical ground level. Data from same sources as figure 8. Axial-plane traces of fold generations are numbered from the oldest to the youngest. Generation 4 is not shown because it is essentially parallel to the plane of the section. The uppermost generation-2 axial-plane trace plunges below the hypothetical ground level, forming a large synformal fold nose that represents the Bridgeport synform.

and structural schemes. Crowley (1968) also constructed a complex sequence of nappe formation to explain structural relations in the Long Hill and Bridgeport quadrangles. This report uses the Dieterich scheme with minor changes and additions to fit local problems.

The most conspicuous structural feature of the metamorphosed units in the quadrangle is the long strip of the Straits Schist that extends from the southern border northward to Southford Falls and then northwestward to the Triassic Pomperaug fault (pl. 1A). The Straits Schist is interpreted to occupy a synclinal position because it is enveloped by the older Collinsville Formation. This fold is a northward continuation of Crowley's (1968) Monroe nappe. Another related structure is the zig-zag of the Straits Schist in the southeastern corner of Southbury quadrangle that forms the northern extension of the White Hills recumbent syncline mapped by Crowley. The southwestern corner of the Waterbury dome dominates the structure in the northeastern part of the quadrangle. West of the strip of the Straits Schist, a series of folds in Hartland Unit I and the Collinsville Formation has been bent into an arc parallel to the arched strip of Straits.

Sequence of fold events

On plate 2 is a regional map of the major metamorphic units of western Connecticut and figure 8 is a summary of the outcrop pattern of the Straits Schist in the Southbury-Naugatuck-Long Hill-Ansonia region. Notice that the Straits Schist is enclosed in older units everywhere along the western belt of the schist from the Long Hill quadrangle northward to the Torrington quadrangle. This requires that the Straits Schist form the core of early-formed synclines everywhere north and west of the Bridgeport synform (pl. 2). The eastern belt of Straits shown on plate 2 and figure 8 lies to the south and east of the Bridgeport synform and is in contact with the younger Wepawaug Formation.

Closer inspection of the pattern of the Straits Schist on the northern and southern sides of the Waterbury dome on plate 2 shows a distinct symmetry of tongues of Straits that are folded back on themselves with clockwise rotation to the south and counterclockwise rotation to the north of the dome. Geometrically, these tongues require an early

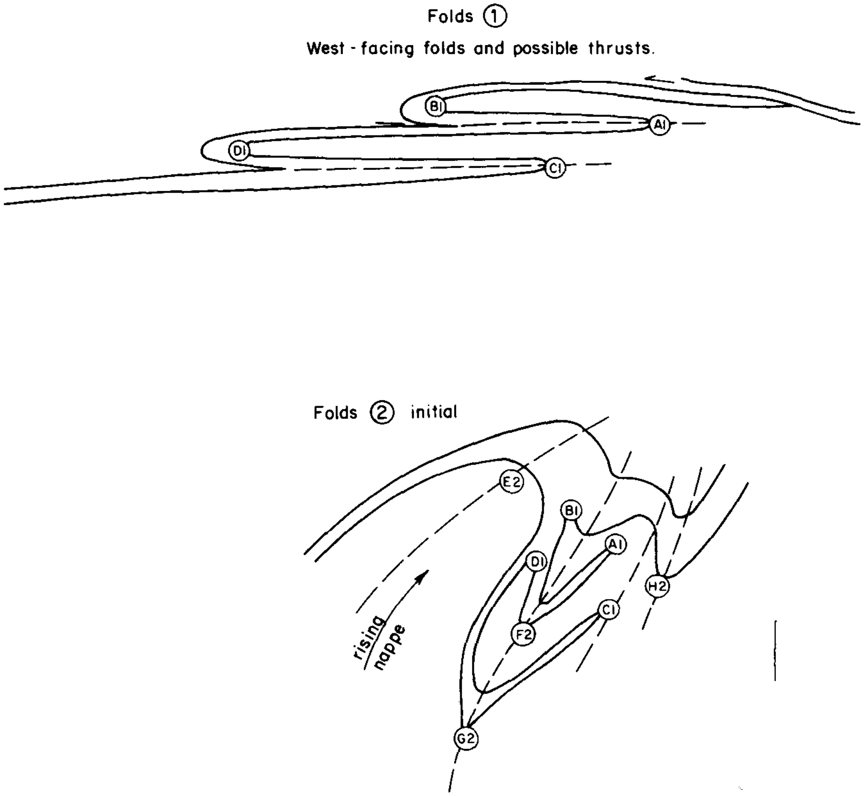
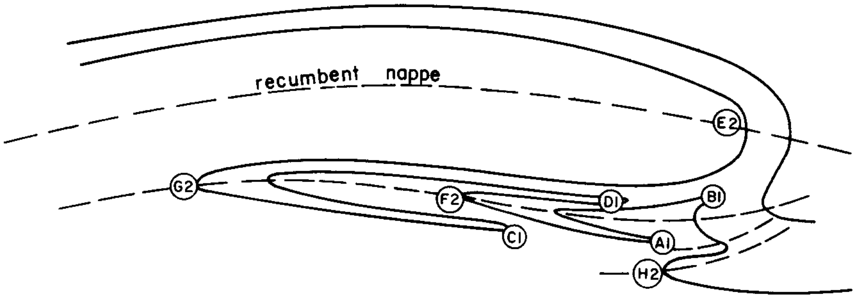


Fig. 10. Hypothetical sequence of fold events for the Southbury-Long Hill-Ansonia-Naugatuck quadrangle region; these are west-east sections facing north. This hypothesis is essentially the same as that proposed by Dieterich (1968a,b) and is supported by field relationships in the Southbury quadrangle. The numbers refer to the same sequence of events as in figures 8 and 9. The letters identify the particular fold nose both in cross section and in map view (pl. 2).

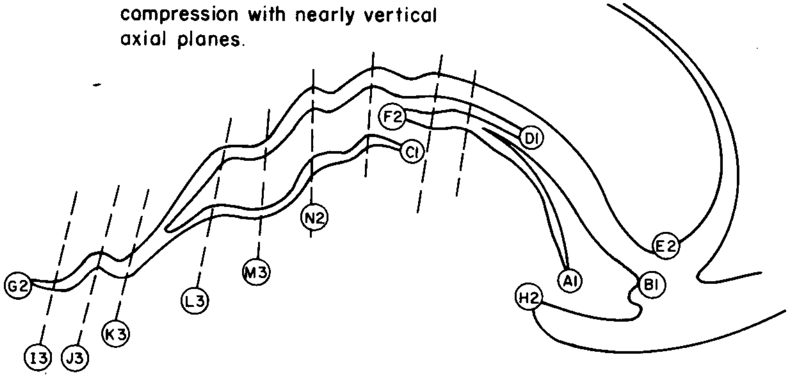
Folds ② mature

East-facing nappe and tightly folded syncline on lower limb.



Folds ③

Folding related to NW-SE compression with nearly vertical axial planes.



Folds ④

Kink bands and fracture cleavage to east. Open folds in transition. WNW-trending lineations and axial-plane schistosity on western side of the quadrangle may be related to doming.

period of folding; this is the earliest period recognized in the region (Dieterich, 1968a, b) and is labeled period 1 in this report. The ends of tongues have been labeled by circled A1 and C1 on plate 2 and figure 10. Because the tongues of Straits form the cores of synclines and because the syncline hinges are east facing, these early nappes probably were west facing and rooted to the east of the present outcrop of Straits (pl. 2, figs. 9, 10).

No field evidence of period-1 folds was observed in the Southbury quadrangle; only the evidence of the regional outcrop pattern described above supports this conclusion. No recognizable schistosity is related to period-1 folding.

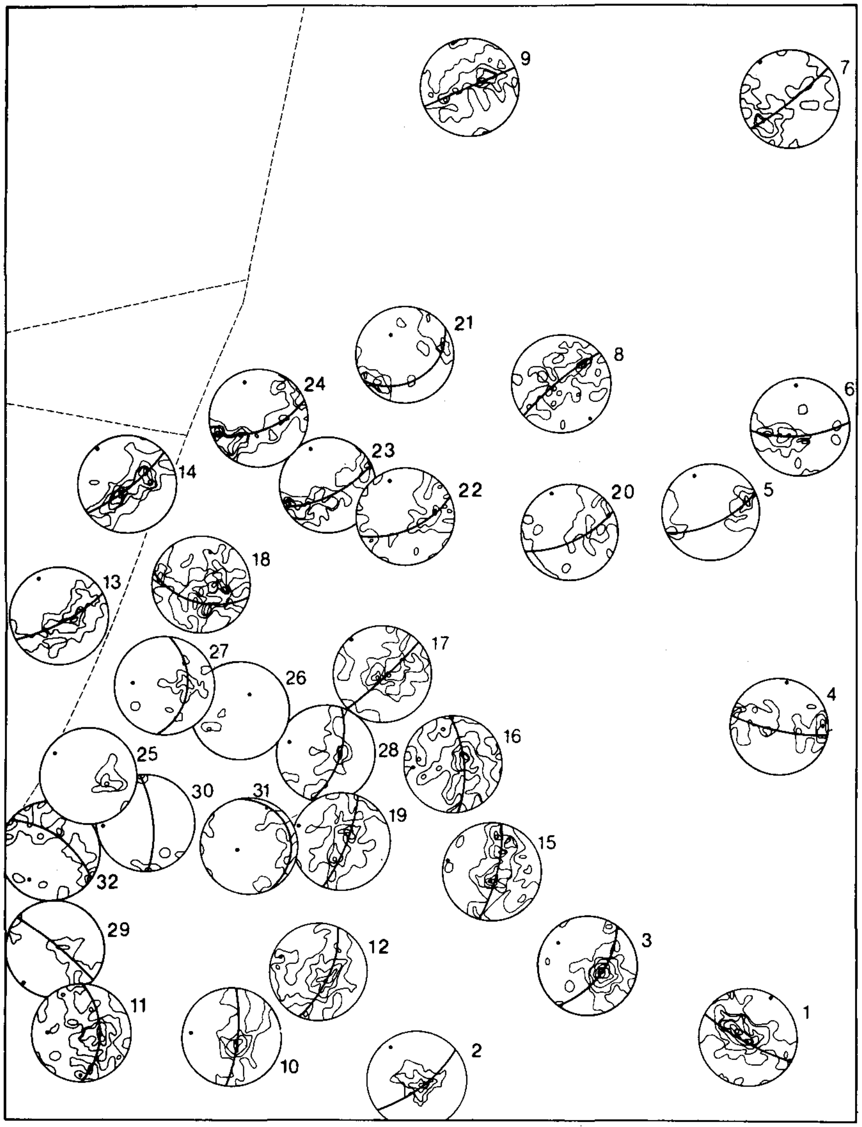
The Bridgeport synform, the widespread presence of Straits Schist in a synclinal-core structural position, and the synclinal-fold hinges labeled G2, H2, and F2 (pl. 2, fig. 10) require a major recumbent syncline with its nose lying to the west. To produce this recumbent syncline, a major, nappelike, east-facing fold must be rooted somewhere in the older Hartland units between the western boundary of the Southbury quadrangle and the tectonic line (Cameron's Line) between the miogeosynclinal and eugeosynclinal facies; the nose of this nappe forms the Bridgeport synform. Informally, this nappe will be called the Hartland nappe in this report and the related syncline of the Straits Schist (called the Monroe nappe by Crowley, 1968) will be called the Monroe recumbent syncline. Stanley (1969) also postulates east-facing nappes in the Collinsville quadrangle of northwestern Connecticut, and Dieterich (1968a, b) first proposed such a regional structure in southwestern Connecticut. In this report and in Dieterich's work these structures are considered to be second-period folds. The axial traces of period-2 folds are drawn on figures 8 and 9 and the fold hinges are indicated by circled labels E2, F2, G2, and H2 on figure 10 and plate 2. A penetrative schistosity can be identified with period-2 folding; domains 1, 4, 5, and 6 (figs. 11, 12) have remnants of period-2 schistosities and lineations. Domain 1 has the least affected period-2 fabric, with an average schistosity that is nearly horizontal; domains 4, 5, and 6 have been refolded by period-3 folding. Domains 2 and 3 also show a period-2 schistosity pattern that is characterized by low-angle schistosity with nearly isoclinally folded strata; in these two domains, period-4 deformation has produced a weak, NW trend to axes of open folds and mineral-train lineations superimposed on isoclinal folding. The G2-fold noses found both north and south of the Waterbury dome suggest a NNE axial trend to period-2 folding (pl. 2). The exterior G2 fold nose is nowhere exposed in the Southbury quadrangle but the enclosure of the Bristol Member of the Collinsville Formation north of Stevenson (pl. 1) is the interior G2 fold nose. Period-3 folding is essentially coaxial with period-2 folding; the fundamental difference between the two fold generations is that the original attitude of period-2 axial planes and schistosities was subhorizontal whereas the axial planes and axial-plane schistosities of period-3 folding are more nearly vertical. Several major structures are related to period-3 folding; the zig-zag pattern of the axial trace of the Monroe recumbent syncline in the southeastern corner of the Southbury quadrangle must have been caused by a superposed NE-trending fold system, period 3. The fabric patterns reflect this superposition of period-3 schistosity on period-2 schistosity in two ways: 1) measured poles to axial planes of folded schistosities in domains 4, 5, and 6 form great circles parallel to the schistosity great circles; that is, preexisting axial planes, presumably period-2 structures, have been rotated about axes essentially parallel to preexisting axes. 2) The domain-4 lineation pattern shows a weak small circle of lineations that trend NE; such a pattern is again suggestive of the rotation of preexisting (period-2) lineations about subparallel young fold axes. West of the Straits Schist belt, a series of major-fold axes follow the outcrop pattern of Hartland Unit I and the Collinsville Formation; probably these are period-3 folds but a superimposed period-4 schistosity related to small-scale folding has obscured the original period-3 attitudes of foliations in this area. Thus, the folds outlined by the outcrop pattern of Hartland Unit I and the Collinsville Formation west of the Straits belt could be period 2. Period 3 is chosen as a preferable interpretation because in those domains that appear to have the least period-4 deformation (domains 20, 21, and 22), the schistosity and axial planes are nearly vertical, typical of period-3 attitudes.

On a regional scale, period-3 deformation probably is related to NW-SE compression perpendicular to the axial traces. This deformation must have preceded the formation of the Waterbury Gneiss dome because the trends of the axial traces of period-3 deformation appear to have been rotated counterclockwise on the southwestern flank of the dome and clockwise on the southeastern flank by the doming.

Whereas periods 1, 2, and 3 are nearly coaxial, period 4 crosses these earlier fabrics at a high angle. On the eastern side of the Southbury quadrangle several gentle warps with E-W axes and gentle W plunges are indicated on plate 1A by the slash across the axis symbol. Also, some gneisses have a fracture cleavage cutting period-3 schistosity. This late fracture cleavage is essentially vertical and generally has an E-W trend. Locally, biotite has recrystallized within these new cleavage planes, creating a late schistosity superposed over the early. The result is a checkerboard pattern of schistosites, the earlier schistosity being obviously offset by the later fracture cleavage. Both the gentle warps and the fracture cleavage are related to period-4 folds.

From the eastern to western side of the Collinsville Formation of the Monroe recumbent syncline north of Stevenson Dam, a distinct mineral lineation in gneisses and amphibolites and a minor-fold-axis lineation is imposed on the major period-2 structure; these lineations have a NW trend and plunge, even though the major period-2 fold has a NE-trending axis and probably a SW plunge. Obviously, these superposed NW lineations are not related to the Monroe recumbent syncline. West of the Straits Schist belt, the attitudes of schistosities seem random and without order (pl. 1A), particularly in the vicinity of the Newtown Gneiss pluton. However, stereographic projections of the poles of foliations (fig. 11) define distinct great circles that geometrically, clearly require gently NW-plunging β axes (for example, domains 15, 16, 17, 19, 11, 12); the fold lineations and other lineations of figure 12 confirm this fold-axis orientation with B maxima. These fold axes, rotated foliations, axial-plane schistosities, and axial planes are obviously superposed on the NE-trending outcrop pattern in the vicinity of Jackson Cove and Kettletown State Park. This superposed NW-trending foliation is period-4 folding and is essentially parallel to the axes of gentle open warps and fracture cleavages east of the belt of the Straits Schist.

On quadrangle scale, all the units have been arched with orientations tangential to the Waterbury dome. Since period-4 axes are nearly tangential to the Waterbury dome, they probably were formed by a pinching of rocks along the flanks or a draping of the rocks off the dome during doming.



The reason that period-4 lineations, rotations of foliations, and axial-plane schistosity are well formed in the central to southwestern part of the Southbury quadrangle and not elsewhere probably is related to remnant thermal effects of the Newtown plutonic body that intruded the region between period-3 and period-4 folding. Clear outcrop-scale "refolded-refolded folds" recording three periods of deformation are common along the northern bank of the Housatonic River between Good Hill and Riverside. The north-central part of the Southbury quadrangle between the Straits belt and the Pomperaug fault has been rotated enough by initial doming after period-3 folding and before period-4 folding so that period-3 and period-4 folds are essentially coaxial and indistinguishable.

Because the styles of folding characteristic of periods 2, 3, and 4 are so similar that it has been impossible to distinguish between fold generations by style, the foliations of all three periods were lumped into figure 11. Also, the attitudes of different types of lineations (fold axes, crinkles, mineral lineations, mineral streaks, and boudins) form indistinguishable B maxima; thus, all lineations were plotted on figure 12. The nearly coaxial nature of periods 1, 2, and 3 certainly is not conducive to the association of one group of lineations with a particular period of folding.

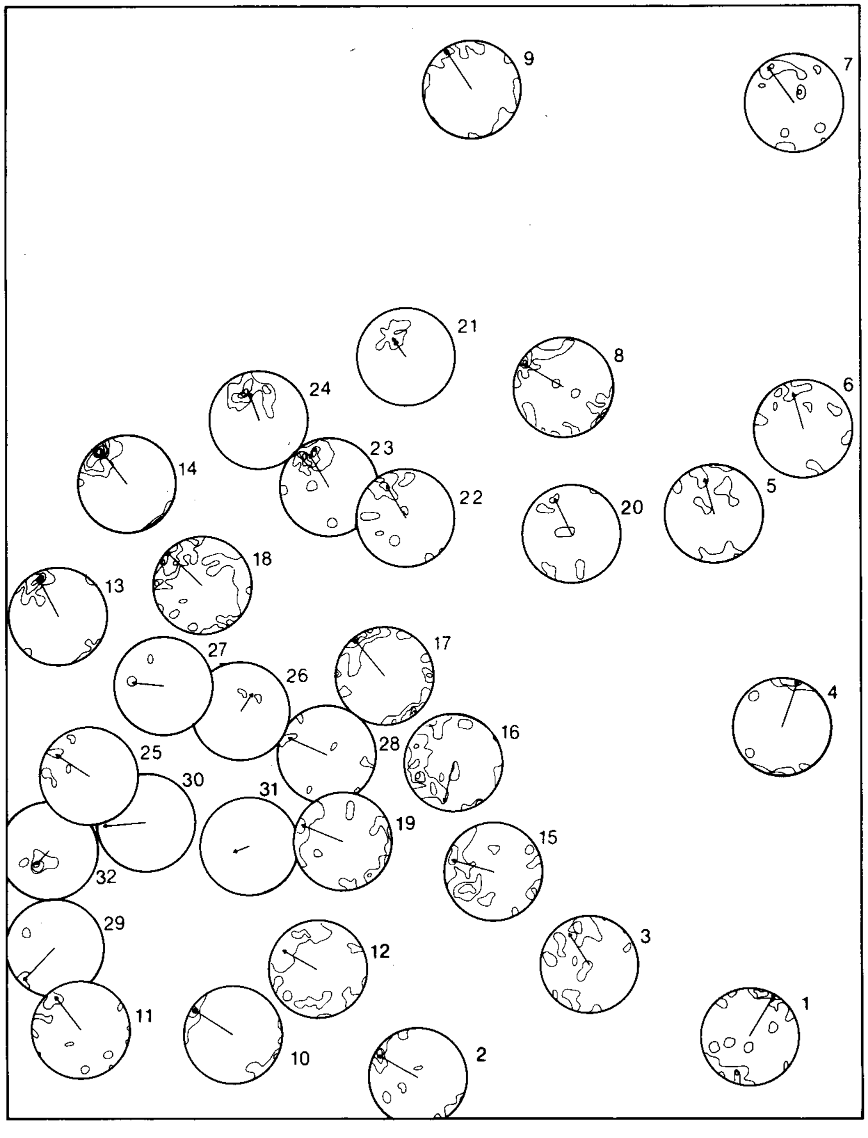
Fig. 11. Stereographic projections of the poles to foliations, including schistosity and axial planes. The β axes indicated by the solid circles are the poles to the surfaces defined by the average great circle of poles to foliations. The contours for the plots of the barious domains enclose areas of at least the following poles per unit area:

Domain	Poles per unit area	Domain	Poles per unit area
1	1, 3, 7, 10, 13, 16, 18, 20	17	1, 3, 6, 8
2	1, 3, 5, 8	18	1, 3, 5, 7, 9, 10
3	1, 3, 7, 14, 20, 30, 40	19	1, 3, 5, 7
4	1, 3, 5, 7	20	1, 3
5	1, 3, 4	21	1, 3, 6
6	1, 3, 6	22	1, 3, 5
7	1, 3, 6, 9	23	1, 3, 5, 7, 10
8	1, 3, 7, 9	24	1, 3, 5, 7, 9
9	1, 3, 6, 8, 10	25	1, 3, 5
10	1, 3, 6, 9, 12	26	1, 3
11	1, 3, 6, 9, 13	27	1, 2
12	1, 3, 6, 9, 11	28	1, 3, 4, 6
13	1, 3, 6, 8, 11	29	1, 2
14	1, 3, 6, 9, 13	30	1-2
15	1, 3, 5, 7, 9, 13	31	1-2
16	1, 3, 6, 9, 12	32	1, 3, 5

The regions covered by each domain are indicated in figure 13.

Styles of folds

Fold-periods 2, 3, and 4 have a similar range of fold geometries and styles of deformation; distinction between them is essentially impossible on a basis of style alone. Several styles of folds are exhibited by all three periods of deformation: (1) Open gentle folds that do not show any axial-



plane schistosity; the schistosity of a previous period of crystallization is folded about the latest fold axis. Some of these folds have a faint fracture cleavage. (2) Tight to isoclinal folds are abundant; axial-plane schistosity is most prevalent in rocks with the highest mica content. Either the micas are more easily recrystallized in the new stress environment or they are more readily rotated parallel to the axial plane. Feldspathic and quartzose rocks that contain only a few micas rarely show any change of mica orientation beyond that directly related to fold rotation. In a few cases fracture cleavages formed with newly grown biotite flakes parallel to the cleavages. Thus, the degree of formation of axial-plane schistosity is a function of mineralogy, rather than of the style of folding of a particular period of folding. (3) Crenulation folding or crinkling is common in all three periods of folding in mica-rich rocks and is rare in mica-poor rocks. The crude generalizations can be made that simple isoclinal folds with nearly horizontal limbs commonly are period-2 folds, that high-angle axial plane folds with consistent axial-plane attitudes over small regions are period-3 folds, and that folds of relatively diverse axial plane attitudes over small regions are period-4 folds. Variations in the style of folding are common in single outcrops of inhomogeneous units, characteristically Hartland Unit II, Hartland Unit I, and the Collinsville Formation.

Fig. 12. Stereographic projections of lineations, including fold axes, crinkles, mineral lineations, mineral streaks, and boudins. Maxima define the B axes. Arrows are drawn from the center of each projection to the strongest B maximum, indicating the plunge and direction of fold axes. The contours for the plots of the various domains enclose areas of at least the following lineations per unit area:

Domain	Lineations
1	1, 3, 4
2	1, 3, 4
3	1, 3
4	1. 3. 5
5	1, 3
6	1, 3, 6
7	1, 3
8	1, 3, 5, 6
9	1, 3
10	1, 3, 5
11	1, 3

Domain	Lineations
12	1, 3, 5
13	1, 3, 5, 7
14	1, 3, 6, 9, 12, 17
15	1, 3
16	1, 3, 5
17	1, 3, 6, 10
18	1, 3, 5, 7
19	1, 3
20	1-2
21	1, 3
22	1, 3

Domain	Lineations
23	1, 3, 5, 6
24	1, 3, 5, 6
25	1-2
26	1
27	1
28	1-2
29	1
30	1-2
31	1
32	1, 2. 3

The regions covered by each domain are indicated on the map in figure 13. No distinct differences in the B maxima were found between plots of the different types of lineations: also, the styles of folding of the four superposed periods of folding completely overlapped, making distinction by style impossible. Therefore, all lineations are plotted together by necessity not by choice.

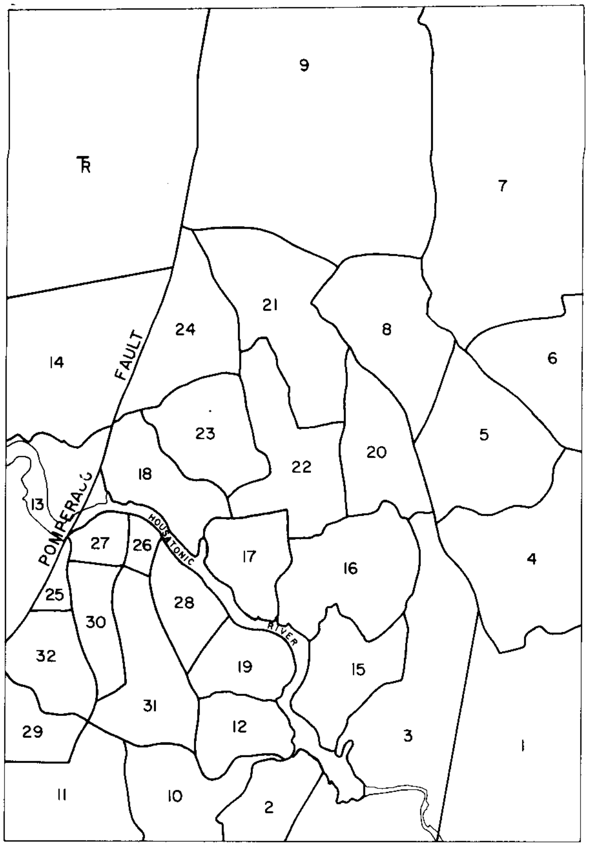


Fig. 13. Map of domains of the Southbury quadrangle used in figures 11 and 12. Domain numbers refer to the numbers of the stereographic projections in those figures. The domains were outlined on a basis of locally consistent mesoscopic fabric symmetry.

In addition to a mineralogical control of the behavior of a rock in a stress field, a second significant control of fold style in the Southbury quadrangle seems to be the proximity of the Newtown Gneiss pluton. Presumably the pluton was still hot or semifluid at the time of period-4 deformation. The aureole of potassium feldspar porphyroblasts in the country rock around the pluton requires the introduction of deuteric fluids into surrounding rocks. Both these factors would increase the rate of crystallization near the pluton, which should increase the rate of strain in response to a uniform regional stress. Certainly the generation of a fold cannot be recognized by the style of folding in a region of such variable lithology and thermal and chemical histories.

If the style of folding in a region is one of widely spaced major folds with subsidiary satellite drag folds, the regional pattern of the sense of rotation of these smaller structures should be very useful in predicting the position of major antiformal and synformal axes. Where fold axes are not widely spaced, however, as in the case of the Southbury quadrangle, opposite rotation directions appear to be intermingled in a confusing pattern, without consistent rotation patterns.

High-angle faults

The Pomperaug fault is both the best exposed normal fault and the major post-Paleozoic structure in the Southbury quadrangle. The fault can be traced readily, by the juxtaposition of Triassic basalts and pre-Triassic metamorphic rocks, northward into the Woodbury quadrangle. The presence of metamorphic rocks in drill-hole cuttings at new homesites on the western side of Dublin Road on the hill northeast of Southbury restrict the fault to the Pomperaug River valley. South of the southernmost exposures of Triassic rocks, the fault is exposed in two stream beds where the fault plane dips at 75° and 53° NW. Also, the mineralogic and lithologic differences between Hartland Unit II on the west and Hartland Unit I and the Collinsville Formation are so distinct that the fault boundary can be mapped on the basis of these differences. In particular, the presence of common sillimanite but rare staurolite on the upthrown eastern side of the fault and the contrasting absence of sillimanite and abundance of staurolite on the downthrown side were used; kyanite is common on both sides of the fault. Along the western border of the Southbury quadrangle, the Pomperaug fault cuts the Newtown Gneiss with an apparent right-lateral offset.

The fractured and partially mylonitized rocks along the Pomperaug fault zone have anastomosing fractures coated with potassium clays in a matrix of fine-grained mylonite, clays, and small angular fragments of quartz. Most larger fragments consist of quartz with abundant deformation lamellae and microfractures. The only recognizable retrograde minerals found along the fault zone are clay-alteration products.

The other normal faults associated with the Pomperaug Triassic rocks are not exposed; the presence of faults with a NE trend is indicated by aligned offsets of basalt ridges. A N-trending set of faults is required by the repetition of the stratigraphic sequence of basalts and arkosic rocks and by the shallow depth at which metamorphic rocks were encountered in the dry well drilled for oil (fig. 6, pl. 1A).

Figure 14 shows the location and attitude of a number of high-angle faults of unknown offset in the Southbury quadrangle. One fault with chlorite in fracture zones, suggestive of retrograde metamorphism, is identified by the letter "R." Another set of faults has pyrite and pyrrhotite veinlets along the associated fractures; these faults are indicated by the letter "M." Apart from the attitudes shown by the Pomperaug fault, there are two major fault trends. The most prevalent has a NW strike and dips steeply SW in most localities. This fault trend seems unrelated to major Triassic ones and may be related to high-angle faults in eastern Connecticut with similar attitudes; Dixon and Lundgren (1968) consider that much of this deformation occurred after the peak of metamorphism in eastern Connecticut and suggest that it may be as recent as Permian. Some of these NW-trending, high-angle faults are terminated by the Lake Chargoggagoggmanchaugagoggchaubunagungamaugg fault (commonly called Lake Char fault) and *vice versa* (Dixon

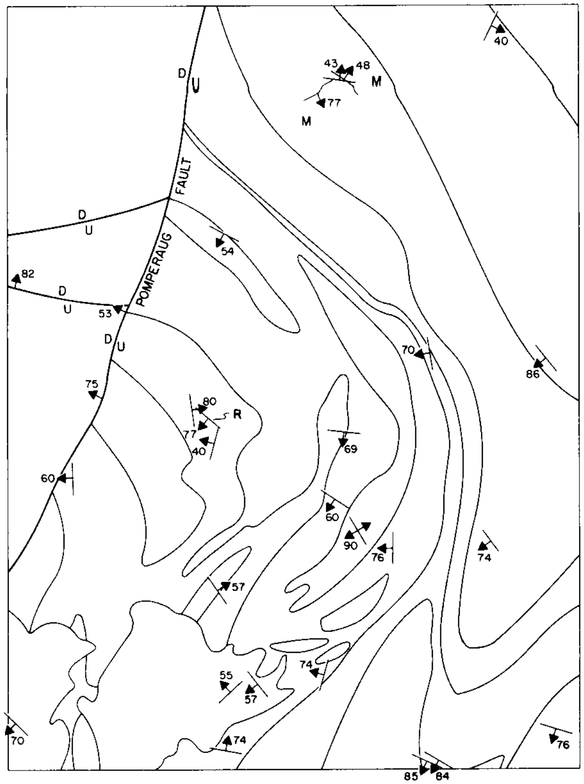


Fig. 14. Map showing high-angle faults of unknown offsets in the Southbury quadrangle. "R" refers to a fault with chlorite retrogression and "M" indicates faults with pyrite and pyrrhotite veinlets in associated fractures. Mapped faults are shown by heavy lines, contacts by lighter lines. Upthrown and downthrown sides of faults are shown by "U" and "D," respectively. The strike and dip symbols with arrowheads on dips indicate the direction of strike and dip; the amount of dip is numerically indicated.

and Lundgren, 1968, fig. 2). Age relationships are unclear but the presence of 250 m.y. mineral-strontium isochrons (Zartman and others, 1965) and the Permian deformation of the adjacent Narragansett Basin do lend credence to the possibility that Allegheny orogenic events affected eastern Connecticut and possibly slightly affected western Connecticut.

A second set of high-angle faults trends NNE, parallel to the majority of the Triassic faults.

Joints

Four sets of joints are found in the Southbury quadrangle; these are, in order of abundance, a N 75° E set, a N 60° W set, a N 20° E set, and a weakly developed N 30° W set (fig. 15). The joint spacing seems to be related roughly to the mica content of the rocks. Those with abundant muscovite and biotite have more widely spaced joints (1-3 m apart) than do less micaceous gneisses, quartzites, and amphibolites (1 m apart), where the rock schistosity is nearly perpendicular to the joints. Most of these joints dip 60° to 90°. No attempt is made to explain the origin of these joints; in such a structurally complex region, the interpretation of joints is ambiguous.

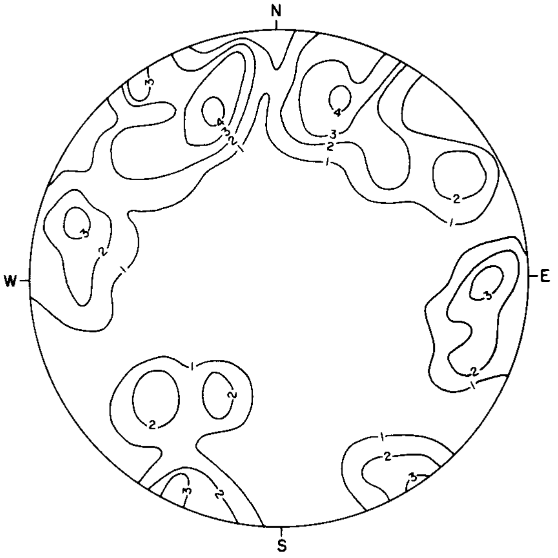


Fig. 15. Stereographic projection of poles to joints in the Southbury quadrangle. Four major sets are recognized, a N 75° E, a N 60° W, a N 20° E, and a N 30° W set. The contours refer to the number of poles to joints per unit area.

Correlation between aeromagnetic map and structural patterns

The most prominent structures in the Southbury quadrangle are the arc of the Straits Schist syncline that can be followed from the southeastern part of the quadrangle to the Pomperaug fault and the Triassic Pomperaug fault; the aeromagnetic map that covers the Southbury quadrangle (U.S. Geological Survey, 1973) distinctly shows large magnetic anomalies associated with both structures.

The Straits Schist syncline forms a 200^+ gamma negative magnetic trough. This trough is well displayed at the Southford Falls State Park and nearly coincides with a 5425-gamma low and is bounded by a 5660-gamma high to the southwest at Mount Pisgah and a 5900-gamma high 1 km east of Southford. One km east of the junction of U.S. Interstate 84 and State 67 highways, this negative trough abruptly turns northward, suggesting that the outcrop pattern of the Straits Schist may not be terminated at the Pomperaug fault but may follow this magnetic trend northward into the Woodbury quadrangle. Glacial cover is too continuous in this area to test this hypothesis by outcrop pattern within the Southbury quadrangle. However, reinvestigation of the Woodbury quadrangle may reveal that the Straits Schist syncline does wrap farther around the western side of the Waterbury dome. The magnetic lows associated with the Straits Schist are probably a reflection of the lower iron content and the presence of ilmenite and graphite rather than magnetite in that unit.

Along the Pomperaug fault is a discontinuous series of 150 to 250 gamma positive magnetic anomalies. It is difficult to definitely attribute these highs to any specific phenomenon without subsurface knowledge.

As expected, thick basalts in the Triassic sequence have 100-gamma highs associated with them.

METAMORPHISM

General discussion

The metamorphic units of the Southbury quadrangle belong to the almandine-amphibolite facies of Barrovian type metamorphism. Pelitic rocks contain sillimanite, kyanite, garnet, or staurolite; basic rocks contain plagioclase and hornblende; calc-silicate rocks contain diopside—all of these minerals are stable in the almandine-amphibolite facies of metamorphism. Sillimanite coexists with kyanite in all the rocks east of the Pomperaug fault. West of the fault, sillimanite is absent and kyanite-almandine, kyanite-staurolite, or almandine-staurolite assemblages are present. The western side of the Pomperaug fault has been downthrown; thus the assemblage on the western side was formed at a lower pressure and temperature than that on the eastern, upthrown side. Therefore, the dT/dP gradient in the rocks must have been greater than the dT/dP slope of the kyanite-sillimanite boundary or greater than about 14°C/km in customary geothermal gradient units. Barrovian type metamorphism requires geothermal gradients in excess of 14°C/km (Turner, 1968).

Coexistence of sillimanite and kyanite

Sillimanite occurs as very small patches and as bundles of needles coexisting with well formed, large kyanite blades in western Connecticut rocks above the first sillimanite isograd (Crowley, 1968; Gates, 1961; Gates and Christensen, 1965). In many localities in the Southbury quadrangle and elsewhere, sillimanite growth seems to have been initiated on and at the expense of biotite (Crowley, 1968; Gates, 1961; Gates and Christensen, 1965). More rarely, sillimanite replaces kyanite. Three possible interpretations of this coexistence are possible: 1) The assemblage may represent divarient equilibrium with variable compositions of kyanite and sillimanite (for instance, Fe^{+3} and boron substitution for aluminum (Deer and others, 1962; Robinson, 1963). 2) The assemblage may represent a univarient equilibrium. 3) The assemblage may reflect the sluggish behavior of aluminosilicate reactions and thus be a disequilibrium assemblage. The second possibility is logically rejected because of the widespread coexistence of the two phases. The first possibility is also rejected because it is doubtful that limited Fe^{+3} or boron substitution in sillimanite would broaden the univarient reaction into a sizeable divarient field that would incorporate the wide range of temperature and pressure expected throughout the large region where kyanite and sillimanite coexist. A disequilibrium assemblage is therefore considered more likely, particularly in high-grade assemblages where abundant catalytic fluids would not be expected. Staurolite is found only in very minor abundance above the first sillimanite isograd. Although most of the staurolite appears from textural evidence to be chemically stable, some staurolite-bearing rocks have fibrous sheaths of sillimanite growing at the expense of staurolite.

The relative modal abundances of kyanite and sillimanite have been drawn as contours of kyanite abundance divided by the kyanite + sillimanite abundance (Ky/Ky + Sill, fig. 16). On the background of small- to trace-amounts of sillimanite present in many kyanite-bearing rocks, there are two sillimanite highs that appear as kyanite lows in figure 16. One encircles the Newtown Gneiss and therefore is considered to be related to the thermal event created by injection of that body between period-3 and period-4 folding. The other hot spot, with abundant sillimanite, is in the north-central region and, although not spatially related to any exposed large intrusive body, it can be considered indirect evidence of another intrusive body below the surface.

Staurolite stability

West of the Pomperaug fault, the abundance of staurolite is much greater than on the eastern side (fig. 17), even though the rock compositions overlap considerably (fig. 4). Because of this overlap in the composition of rocks with and without staurolite, the presence and absence of staurolite is attributed to other variables, particularly pressure and oxygen fugacity. Ganguly (1968) has shown that at 10 kilobars the stability field of staurolite is extremely limited and probably pinches out at higher pressure. Such may be the case for the Waterbury dome and vicinity (Bruce O'Connor, personal communication).

Aluminous assemblages

The coexisting phases in pelitic rocks can be shown conveniently in Thompson projections (Thompson, 1957). Figure 18 represents the assemblages for the major muscovite-bearing rocks in the Southbury quadrangle. The mineral compositions are not known and only hypothetical composition fields are indicated.

The greatest difference between the AFM diagrams in figure 18 is the presence or absence of staurolite. Only in Hartland Unit II is staurolite

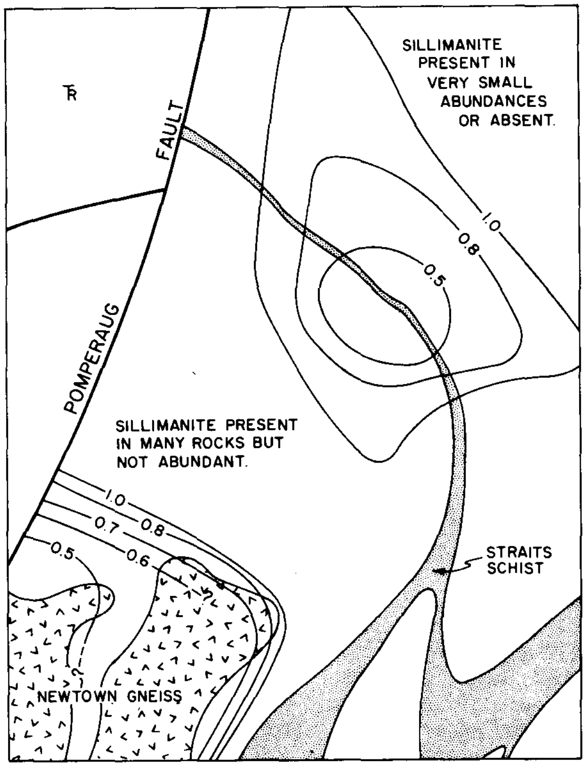


Fig. 16. Map showing the relative abundances of sillimanite and kyanite expressed as the ratio of kyanite to kyanite plus sillimanite (Ky/Ky + Sill) in the Southbury quadrangle. Only kyanite is present west of the Pomperaug fault. In the region between the 1.0 contours, at least a trace of sillimanite is present in some of the more aluminous rocks.

definitely stable throughout the rocks; in Hartland Unit I and the Collinsville Formation, staurolite is rarely present and possibly is only locally stable. In the Straits Schist and the Waterbury Formation staurolite is totally absent, even though the composition is appropriate for its presence.

The Waterbury Formation and the kyanite member of Hartland Unit I have extremely simple assemblages consisting of Ky ± Sill + K-feld + Q + Pl + Gt + Bio or Ky ± Sill + Q + Pl + Gt + Bio (fig. 18a).

The heterogeneous rock compositions of Hartland Unit II are well expressed in figure 18b, which shows three 6-phase and three 5-phase equilibrium assemblages. The extremely F- and A-rich but M-poor compositional requirements for coexisting St-Alm-Ky, rather than other variables of the system, possibly excludes that assemblage.

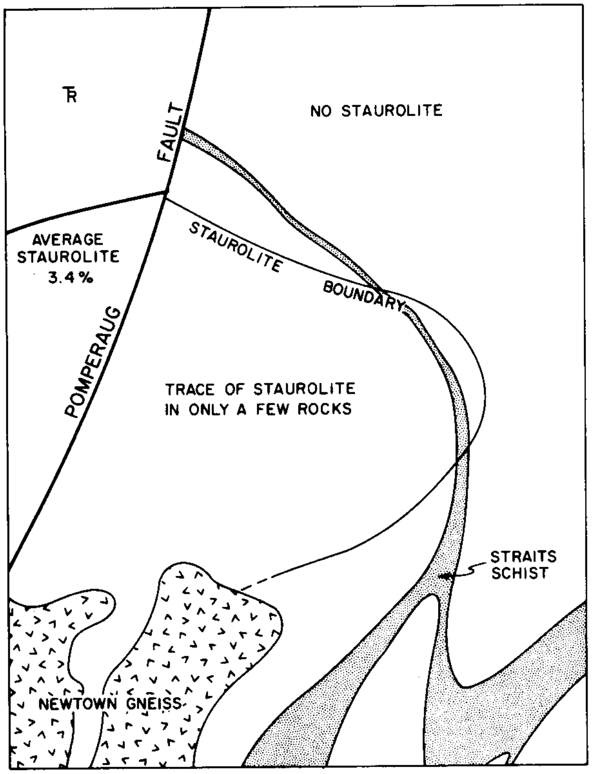


Fig. 17. Map of the Southbury quadrangle showing the boundary of the area within which staurolite has been recognized. This line probably represents a limitation of stability or isograd rather than a boundary of rock compositions capable of producing staurolite.

Hartland Unit I (fig. 18c) is compositionally restricted to assemblages that are more F- and A-rich, with three 6-phase, four 5-phase and one 4-phase equilibrium assemblages. The presence of sillimanite with kyanite is considered to be evidence of disequilibrium, principally an incomplete first-sillimanite-isograd reaction.

The aluminous member and the transitional member of the Collinsville Formation are very heterogeneous and include three 6-phase, two 5-phase, and one 4-phase equilibrium assemblages; however, most examples of the Bristol Member do not contain muscovite and therefore its assemblage cannot be plotted on the muscovite projection on Thompson's (1957) AFM diagram (fig. 18d).

The restricted chemical composition of the Straits Schist is reflected in the small number of assemblages; only the Ky- or Sill-Alm-Bio 6-phase, Alm-Bio 5-phase, and Bio 4-phase assemblages occur (fig. 17e). The 6-phase assemblage is the most common. No staurolite was observed in

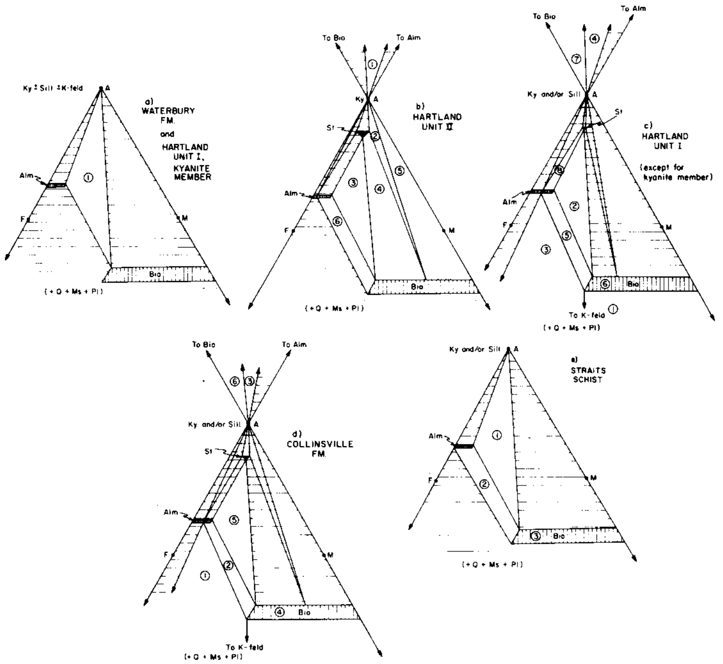


Fig. 18. Mineralogy of pelitic assemblages shown on Thompson (1957) muscovite projections on the AFM diagram. Horizontal lines indicate the absence of representative assemblages. The areas of mineral solid solution, indicated by vertical lines, are hypothetical. All numbered areas contain muscovite, quartz, and plagioclase in addition to those phases indicated by the areas on the diagram. a) 1 = Alm + Bio + Ky ± K-feld; b) 1 = Bio + Alm + Ky, 2 = ky + St + Bio, 3 = St + Alm + Bio, 4 = St + Bio, 5 = Ky + Bio, 6 = Alm + Bio; c) 1 = Bio + K-feld, 2 = St + Alm + Bio, 3 = Alm + Bio + K-feld, 4 = Ky ± Sill + Bio + Alm, 5 = Alm + Bio, 6 = Bio, 7 = Bio + Ky ± Sill; d) 1 = Alm + Bio + K-feld, 2 = Alm + Bio 3, = Ky ± Sill + Bio + Alm, 4 = Bio, 5 = St + Alm + Bio, 6 = Bio + Ky ± Sill; e) 1 = Ky ± Sill + Alm + Bio, 2 = Alm + Bio, 3 = Bio.

the Straits, where the staurolite boundary overlaps the belt of Straits in the east-central part of the quadrangle (fig. 17). No staurolite was found in the one thin section studied from this part of the Straits. Possibly small staurolites were unnoticed in field observations of the schist from that region; there is no obvious explanation for the apparent absence of staurolite in that region.

Metasomatism

Evidence of two styles and degrees of metasomatism are exhibited in the Southbury quadrangle; one has occurred where calcareous sediments reacted with pelitic sediments during dehydration and decarbonation. The diffusion of potassium, calcium, and CO_2 in both directions away from the original sedimentary calcareous band produced sequences of banded mineralogical assemblages of calcium-bearing phases symmetrically arranged on either side of the original calcareous band, as described previously (under the heading *Hartland Unit I* and by Vidale (1968). These banded assemblages show that metasomatism occurred on a small scale (a few meters) locally within Hartland Unit I, Hartland Unit II, the Collinsville Formation, and the Straits Schist.

A case can be made for large-scale potassium diffusion from the Newtown Gneiss pluton into the surrounding country rocks. The aureole of potassium-feldspar porphyroblasts extends as far as 2 km from the pluton contact and the abundance and size of porphyroblasts increase toward the contact. However, data to distinguish between possible potassium diffusion from the pluton into the country rock and possible local diffusion of potassium from the country rock to potassium-feldspar nucleation sites are not available. The few modal analyses of the Newtown Gneiss, porphyroblastic country rock, and nonporphyroblastic country rock do not allow discrimination between these two possibilities; perhaps a portable gamma-ray-spectrometry survey designed to integrate the potassium content of the wide range of compositions in the gneisses and schists of the country rock could provide an answer. In any case, the presence of the pluton triggered the growth of these potassium feldspar porphyroblasts, perhaps thermally or catalytically, by aqueous fluids. It is of interest to note, however, that those sillimanite-rich rocks in the east-central part of the quadrangle (fig. 16) that are not associated with any exposed large pluton lack these porphyroblasts.

Summary of metamorphism

With the exception of the western downdropped block of the Pomperaug fault, all the metamorphic units in the Southbury quadrangle are above the first sillimanite isograd, requiring a geothermal gradient in excess of 14°C/km, in keeping with the almandine-amphibolite grade of metamorphism. In no place was evidence seen for the breakdown of muscovite in the second-sillimanite-isograd reaction ($Ms + Q = K\text{-feld} + Sill + H_2O$). The pressure-temperature boundaries of metamorphism of sillimanite- and staurolite-bearing rocks can be estimated at 5.5 to 10 kilobars and 625 to 700°C, based on aluminosilicate- and staurolite-stability relations (Richardson, and others, 1968; Ganguly, 1968; Turner, 1968). Fairly widespread partial replacement of biotite and garnet with chlorite, and partial sericitization of plagioclase and staurolite represent limited retrograde metamorphism. The ultramafic assemblage of phlogopite, talc, and serpentine in the ultramafic body in Hartland Unit II is either a retrograded assemblage or the body must have been emplaced after the height of thermal metamorphism. The former interpretation seems unlikely because surrounding rocks have only partial chlorite replacement of garnet and biotite; if the latter case is accepted, this requires a rather large-scale tectonic event, capable of emplacing ultramafic rocks of probable mantle origin. There is no structural evidence for such an event after the peak of metamorphism. A probable explanation is that ultramafic assemblages are more readily retrograded than are almandine-amphibolite-grade assemblages of pelitic schists.

The kyanite-sillimanite reaction was probably incomplete throughout the quadrangle, producing the widespread disequilibrium, two-aluminosilicate assemblages. Close to the Newtown intrusive gneiss the reaction is somewhat closer to completion (fig. 16) and the abundant sillimanite in the central portion of the quadrangle possibly indicates the presence of another intrusive body at shallow depths.

ECONOMIC GEOLOGY

No deposits in the metamorphic or igneous rocks of the Southbury quadrangle are of economic significance for present commercial markets. However, numerous mines, pits, and diggings testify to past attempts at commercial production. In particular, the unnamed units between the Straits Schist and the Collinsville Formation contain local concentrations of sulfides. The best exposed example is the abandoned Stevenson Mine, 100 m east of Copper Mine Road, where the contact between marble and pelitic schistose gneiss contains pyrite, chalcopyrite, malachite, and azurite. Shepard (1837), Percival (1842), and Schairer (1931) listed arsenopyrite, pyrite, and copper minerals from this locality. Where exposed, the zone of mineralization is only a few centimeters thick and only a few pockets of sulfides, 1-5 mm long, are present. In the Bridgeport and Long Hill quadrangles, Crowley (1968) described a string of sulfide deposits at this stratigraphic level that include tungsten, bismuth, copper, and nickel minerals; he attributed the origin of these sulfide deposits to H_2S generated by the action of anerobic bacteria on organic debris and the extraction of metal ions from the volcanic Collinsville Formation. He suggested that only the scheelite from tungsten deposits in the Long Hill quadrangle is of igneous origin; the remainder of the minerals were the result of metasomatism in sulfide-rich sediments along the calcareous-pelitic-sediment reaction zone at the almandine-amphibolite grade of metamorphism. I concur with Crowley's conclusions.

Only one of the numerous pegmatites, consisting of quartz, albite, potassium-feldspar, noncommercial-grade muscovite, and small amounts of tourmaline, apatite, and garnet, is of commercial interest. It is found in the Hulls Hill pegmatite quarry, located on the eastern side of Hulls Hill Road about 1 km south of its intersection with Jeremy Swamp Road. This body (150 x 70 m) has been intermittently quarried from 1906 to the present, first for quartz and feldspar and recently for rose quartz, large beryl crystals, and small amounts of columbite. This body is described in greater detail by DeWyk (1960) and Cameron (1954).

Minor attempts to quarry muscovite left two holes, 15 x 15 m, in pegmatites on the eastern side of Jeremy Swamp Road, approximately 600 m from its intersection with State Route 67. Another small pegmatite that was mined for quartz is on the western side of Peter Road, about 600 m from its intersection with North Georges Hill Road; a pit 15 x 25 m remains.

Fresh roadcuts along Interstate 84 on the western side of Bucks Hill expose abundant 1- to 2-cm veinlets of pyrite and pyrrhotite, forming a belt of sulfide-rich exposures of the Hartland Unit I metasediments (pl. 1A). The veinlets parallel the schistosity. It is not clear whether the sulfide-rich region is elongated parallel to the highway or is too intensely weathered in adjacent exposures to be recognized. Joint surfaces in the area just west of the Interstate 84-State Route 188 junction have coatings of stilbite and heulandite close to the minette dike discussed earlier.

Hovey (1890) mentioned the presence of gold and silver in the metamorphic rocks drilled during oil exploration in the Pomperaug Valley: "At 1,250 feet free-milling gold and silver-bearing rock was struck, which assayed at $10 worth of gold and $3 worth of silver to the ton, and the rock for ten feet above and twenty feet below this depth shows this amount or more of silver."

Several gravel and sand pits have recently been exploited in the quadrangle. The largest is on the northern side of the Housatonic River just below Stevenson Dam. Another is 200 m south of the eastern junction of Community House Road and State Route 67 where a 15-m hill has been entirely excavated since 1953. Another extensive deposit of gravel and sand underlies Bullet Hill, which appears to be an erosional remnant of glacial deposits.

A trap-rock quarry in the Triassic basalts is a few meters west of the junction of State Route 172 and U.S. 202 and 6.

GEOLOGIC HISTORY

The oldest rocks in the Southbury quadrangle are Cambro-Ordovician eugeosynclinal metasediments; the original sedimentary-rock pattern consisted of an eastern facies of aluminous pyritiferous shale (Waterbury Formation) and a more heterogeneous western facies of interbedded shale, quartz-rich siltstone and sandstone, subgraywacke, and thin calcareous shale and limestone (Hartland Unit II). The western facies may represent continental-slope or continental-rise sedimentary rocks that are transitional between the eastern eugeosynclinal facies and the western miogeosynclinal shelf facies. These basal rocks may lie on Precambrian crust, as indicated by the isotopic ages of many gneiss domes in New England but there is no evidence that the rocks in the gneiss-dome belt west of the Connecticut Triassic Valley are Precambrian. Then, in Cambro-Ordovician time, interbedded aluminous shale, shale, and subgraywacke (Hartland Unit I) were deposited on the oldest units. In the east the sedimentary rocks were more highly aluminous than those to the west and were most prevalent, whereas in the west quartz-rich sedimentary rocks were more commonly interbedded with shales and graywackes. The sedimentary pattern is similar to that of the basal units. A distinctly different sedimentary pattern was established in the uppermost Cambro-Ordovician rocks: in the west, aluminous shales were intercalated with subordinate tuff (Aluminous member of the Collinsville Formation) but in the east, abundant basaltic, andesitic, and rhyolitic rocks had few interbeds of shale, sandstone, and thin limestone (Bristol Member of the Collinsville Formation). The eastern facies may represent island-arc deposits. A major unconformity was developed above this stratigraphic level. No evidence of Taconic deformation was recognized in the Southbury quadrangle.

Discontinuous lenses of quartz sandstone, limestone, and calcareous shale, together with basalt flows of probable Silurian age were deposited on the unconformity (southern equivalents of the Russell Mountain Formation of Massachusetts). Above these heterogeneous rocks a homogeneous, organic black shale of Siluro-Devonian age was deposited (the Straits Schist); this unit is the youngest Paleozoic rock exposed in the Southbury quadrangle.

The 334-m.y. K-Ar date of an undeformed lamprophyre dike restricts the metamorphism and complex deformation of the region to the Acadian orogeny. The sequence of deformation consists of an initial western thrusting and/or folding of moderate-scale nappes, followed by a major east-facing nappe that was subsequently domed by rising gneiss bodies. Four periods of Acadian folding can be recognized. The first deformation, the west-facing nappes, produced fold noses that can be seen on regional maps (pl. 2) but no schistosity or lineations related to this deformation were seen. The second period of folding produced the major E-facing nappe, low-angle isoclinal folds, and a strong schistosity. The third period of folding produced folds nearly coaxial with those of period 2 but period-3 folds are not as highly isoclinal and have more nearly vertical axial planes and a less pronounced schistosity. Period-3 folding possibly was formed during an E-W compression of the E-facing nappes. All three fold periods have NS to NE-SW trends. The fourth period of folding has a W to NW axial trace that is approximately tangential to the Waterbury Gneiss dome; therefore it is postulated that this last period of deformation was caused by draping of folds off the sides of the rising dome. The axial-plane schistosity of period-4 folding is well developed only locally.

The large granitic body (Newtown Gneiss) intruded metasedimentary units in the southwestern part of the Southbury quadrangle prior to period-4 folding and was subsequently deformed by that folding, producing a weak foliation. Smaller granitic bodies predate the Newtown pluton but are difficult to place exactly in a time sequence. Abundant late-stage pegmatites cut all periods of deformation.

Snowball structures in garnets with post-rotational overgrowths, large unoriented poikiloblasts of staurolites, unoriented porphyroblasts of biotite and kyanite, and unoriented sillimanite fibers suggest that the highest temperature period of metamorphism to the almandine-amphibolite facies occurred after the last period of deformation.

NW-trending high-angle faults may be related to the Allegheny orogeny, in which metamorphism and plutonism affected eastern Connecticut and southern Rhode Island.

A prolonged period of erosion exposed kyanite-staurolite-bearing metamorphic rocks in the Southbury region prior to deposition of Triassic arkoses and basalts. Then Triassic faulting downdropped the arkosic sediments and basalt flows in fault basins (arkoses and basalts) of the Pomperaug valley. Erosion followed this deformation.

The topography was smoothed by the scraping of topographic highs by Pleistocene glaciers and the filling of lows with glacial debris. Renewed stream erosion has only partially modified the glacial landscape.

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