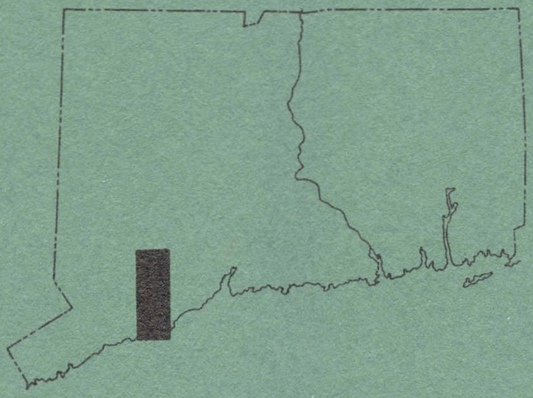
The Bedrock Geology of the Long Hill and Bridgeport Quadrangles

WITH MAPS

Plate 1 Plate 2 Plate 3 Plate 4 Plate 5

BY WILLIAM PATRICK CROWLEY



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

A DIVISION OF THE DEPARTMENT OF AGRICULTURE
AND NATURAL RESOURCES

1968

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BY WILLIAM PATRICK CROWLEY
Maryland Geological Survey

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CONTENTS

ILLUSTRATIONS

TABLES

The Bedrock Geology of the Long Hill and Bridgeport Quadrangles

by

William Patrick Crowley

ABSTRACT

In contrast to the largely metasedimentary rocks to the northwest, the Long Hill and Bridgeport quadrangles are underlain by intimately associated meta-igneous and metasedimentary rocks. Detailed mapping of these NE-striking rocks has established eight stratigraphic units that traverse the area and eight others of more limited extent. These sixteen units are assigned to nine formations that make up two groups, the basal group and the Hartland Group. Although there is neither fossil nor radiometric information on the ages of these rocks, long-range correlations suggest that the entire section is Middle to Late Ordovician. Chiefly because the metasedimentary and meta-igneous rocks are everywhere conformably interlayered on all scales, a volcanic origin is proposed for a large part of this section, which has been considered by others as plutonic.

The map pattern of the stratigraphic units defines a system composed of five major folds that appear to be the result of one major phase of deformation. In the northwestern part of the area these are recumbent isoclinal folds with few associated minor structures; in the southeastern part they are more upright and are characterized by abundant minor folds and strongly expressed mineral lineation. Older minor folds of uncertain origin, plunging down dip, are preserved in the eastern part of the Bridgeport quadrangle. Late northwest-trending folds are locally developed in the southwestern portion of the Long Hill quadrangle.

Staurolite and kyanite are present in aluminous rocks on both sides of the first sillimanite isograd, which strikes through the area approximately parallel to the regional trend of the stratigraphic units. The conditions of metamorphism beyond the first sillimanite isograd lie between 4 and 5 kilobars P_{total} and 500° to 580° C. In the extreme northwestern part of the Long Hill quadrangle the second sillimanite isograd was crossed where P_{H_2O} was locally reduced. Bodies of coarse-grained granodiorite in this same area may be the result of partial melting in response to the elevated P-T conditions.

Reaction zones between muscovite schist and interlayered amphibolite are 3 to 9 cm thick, consistent with the widely held assumption that the bulk composition

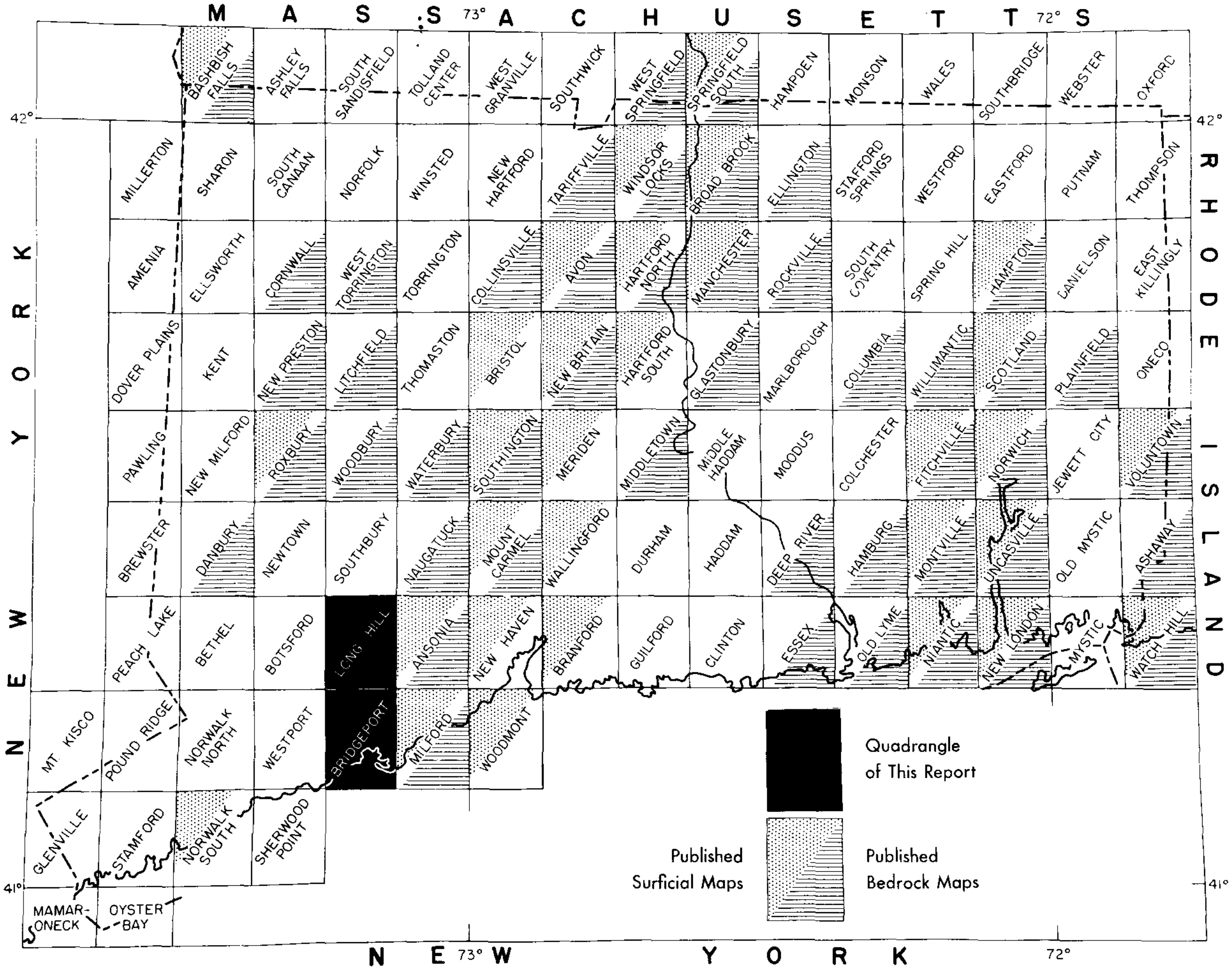

Fig. 1. Index map of Connecticut showing the location of the Long Hill and Bridgeport quadrangles and of other published quadrangles.

(exclusive of volatiles) of most igneous and sedimentary rocks suffers little change during metamorphism.

Sulfide and scheelite deposits, including the celebrated tungsten mine at Trumbull, occur in a thin zone of heterogeneous rocks at the top of the basal group over an area of at least 70 sq. mi. Booth's bismuth mine and Lane's mine are apparently localized zones of hydrothermal alteration and silicification, possibly related to late faulting.

INTRODUCTION

Location

The Bridgeport quadrangle frames the city of Bridgeport on Long Island Sound; the Long Hill quadrangle adjoins it on the north (fig. 1). Together they cover approximately 110 sq. mi. and are bounded by latitudes 41°07′30″ N and 41°22′30″ N and by longitudes 73°07′30″ W and 73°15′ W. The shoreline cities of Bridgeport and Stratford are important industrial and cultural centers. North of them are the actively growing suburban areas of Long Hill, Trumbull, Nichols, Huntington, and Monroe.

The quadrangles are readily accessible by such routes as Interstate 95, U.S. 1 and State Routes 8, 15, 25, 34, 58, 59, 108, 110, 111, 113 and 127. A network of minor paved and dirt roads provides convenient access to all parts of the quadrangles.

Topography and drainage

Both quadrangles lie within the crystalline uplands of western Connecticut. The range in altitude is from sea level to 650 ft; the highest elevation is on Barn Hill, a conspicuous drumlin in the northern part of the Long Hill quadrangle. Only locally, in areas of steep dips and/or poorly foliated to massive rock, has differential erosion shaped the topography significantly. Elsewhere, apparently because of pre-Cretaceous erosion to a surface of low relief (Flint, 1963) and the mantling glacial drift of variable thickness, the bedrock geology has little topographic expression.

Long Island Sound receives the area's entire drainage, in large part via the Housatonic River and its tributaries to a lesser extent by way of the Poquonock River. The Housatonic flows in a narrow channel for 2½ mi. across the northeastern corner of the Long Hill quadrangle. Farther south, in southern Stratford, it barely brushes the Bridgeport quadrangle. From southwest of Monroe, where it enters the Long Hill quadrangle, the Poquonock follows a rather direct course for 12 mi. to the Sound. Throughout most of this distance it flows at a small angle to the strike of the underlying bedrock.

Previous work

All the major stratigraphic units in the Long Hill and Bridgeport quadrangles were first recognized and described by James G. Percival. His map and report (1842) were frequently consulted during the present investigation. In the late 1800s and early 1900s William H. Hobbs mapped, for the U.S. Geological Survey, a large part of western Connecticut, including the area of this report. The several 30′ folios which were to incorporate this mapping never appeared; however, Hobbs' work was incorporated by Rice and Gregory (1906) and Gregory and Robinson (1907) into a text and map of the geology of Connecticut. Dale and Gregory (1911) and Dale (1923) described two granite-gneiss quarries in the Bridgeport quadrangle. Stewart (1935) revised and extended Hobbs' mapping in that quadrangle and described the Prospect porphyritic gneiss in more detail.

The literature on the several economic-mineral localities in the two quadrangles is covered in the section on economic geology.

Acknowledgments

The mapping for this report was done during the summers of 1963-1965 and in part of 1966 while the author was a graduate student at Yale University. Financial support was provided by a National Science Foundation fellowship and by the Connecticut Geological and Natural History Survey, whose director, Joe Webb Peoples, was a source of continual encouragement. The support of these two organizations is gratefully acknowledged.

From its beginning, John Rodgers has guided this study, instilling in me an enthusiasm for regional synthesis. Discussions and field conferences with Rolfe Stanley, Leo Hall, and James Dieterich, all currently mapping in western Connecticut, and correspondence with C. E. Fritts greatly clarified my concept of regional problems. I benefited from many stimulating discussions in metamorphic-petrology and structural-geology seminars at Yale University with Hannes Breuckner, James Dieterich, David Hewitt, Keith Howard, William Perry, Steven Schamel, Robert Scott, William Scott, John Suppe, and Rosemary Vidale. William Leopold and Earle Sullivan, both of Trumbull, Connecticut, contributed much helpful mineralogical information.

John Rodgers, Philip Orville, Richard Armstrong, and Neville Carter, all of Yale University, and Rolfe Stanley of the University of Vermont have critically read this report, contributing fresh ideas regarding both content and organization.

Rock thin sections were skillfully prepared by Malcolm McConnell of Yale University. Lin Min-hsiung provided professional assistance in drafting the illustrations.

The Remington Arms Company kindly granted access to their private park in Bridgeport so that the bedrock exposed there could be mapped. Donald Spalding of the Connecticut Highway Department aided in locating drill cores of drift-covered areas.

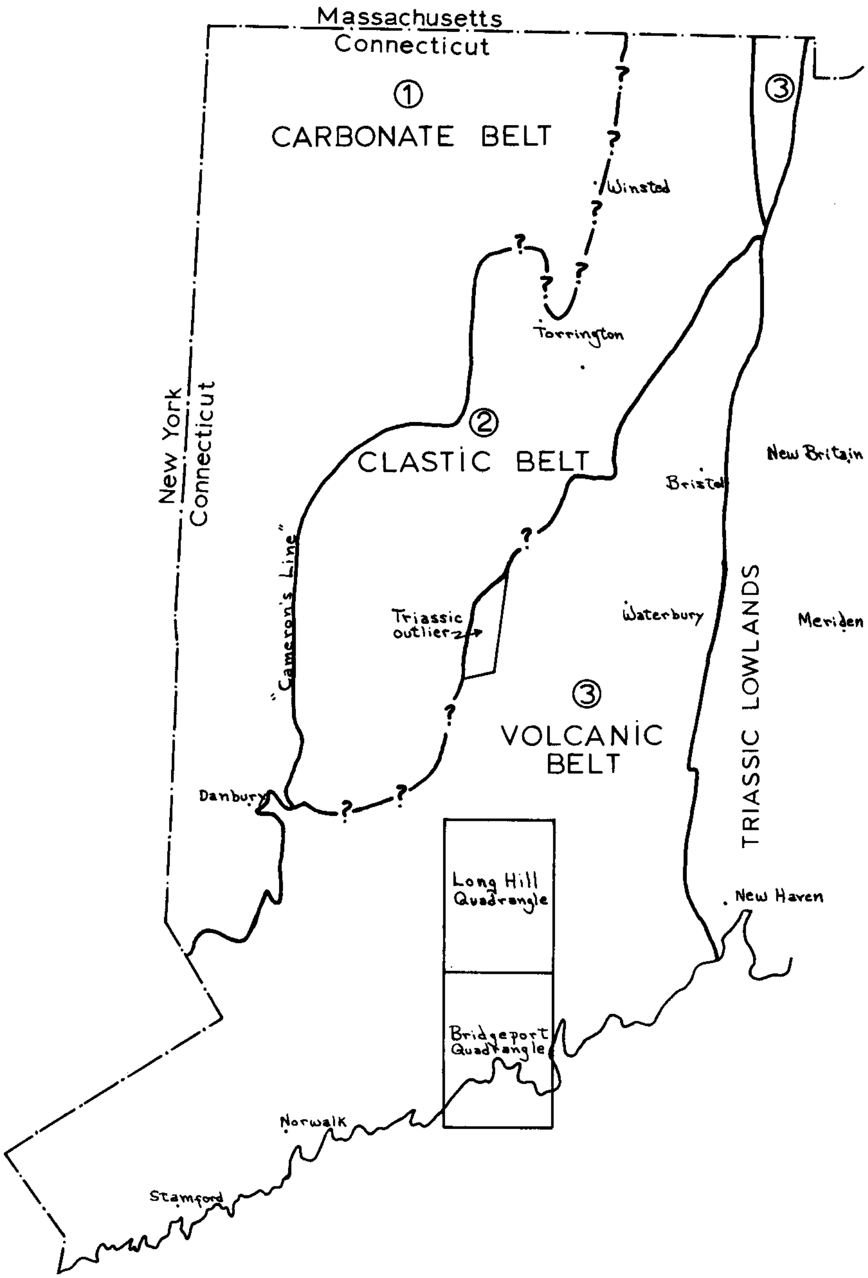

Fig. 2. Map of western Connecticut outlining the three lithologic belts of the Western Highlands. (1 in. = 8 mi.)

Regional Setting

The northern extension of the Atlantic Seaboard's Piedmont province lies in the part of the northern Appalachians east of the Precambrian Hudson Highlands and Green Mountains. In western Connecticut this province can be divided lithologically into three strike belts (fig. 2). The westernmost, here called the carbonate belt, is underlain by a typical miogeosynclinal assemblage—quartzite, carbonate, and schist—except where gneisses of the Precambrian massifs are exposed. To the east, separated from it by a sharp contact of uncertain tectonic significance ("Cameron's line"), is a broad clastic belt underlain chiefly by quartzose schist and gneiss and muscovite granite, together with some amphibolite. Between this belt and the Triassic rocks of the Central Lowland is an area underlain in large part by rocks of volcanic origin; it also includes rock similar to those of the central (clastic) belt. From Massachusetts south to at least the southern part of the Thomaston quadrangle the boundary between the clastic and volcanic belts (fig. 2) corresponds approximately to the western contact of The Straits Schist. Farther south the position of this boundary is less certain; it probably swings westward, north of the area in the southwestern part of the state mapped as "Hartland Formation plus granite" and shown in red stipple on the 1956 Preliminary Geological Map of Connecticut (Rodgers and others, 1959).

The southern extension of the carbonate belt into Westchester County, New York, has been mapped in detail by Leo Hall (personal communication), who has marshalled impressive stratigraphic and structural evidence showing that the metasedimentary rocks are Cambro-Ordovician and overlie Precambrian rocks unconformably. The clastic belt is continuous with the relatively well dated section of eastern Vermont; in Massachusetts, however, insufficient work has been done to firmly establish the correlations. Current thought is that the clastics are largely Ordovician, although some geologists believe that Precambrian and Cambrian rocks are also present, and others that part of the section is Silurian. The volcanic belt is terminated on the northeast by Triassic overlap and normal faulting; its southwestern limit is unknown, as that region is mostly unmapped. Its age is uncertain but at least part of it is probably Ordovician.

The Long Hill and Bridgeport quadrangles cross the volcanic belt near its widest part and hence provide an opportunity to study the detailed structure and stratigraphy of most of the eruptive sequence, and to relate it to depositional and deformational events that occurred to the north and northwest.

Procedure in formation description

Mappability on the scale of 1:24,000 was the chief criterion in defining formations. Type or reference localities for each stratigraphic unit are designated on the geologic maps (pls. 1, 2). The formations are described in the order of decreasing age—from oldest to youngest. This is also their order of outcrop across the quadrangle from northwest to southeast. However, two stratigraphic units of uncertain relative age, the Cooks Pond Schist and the Orange Formation, are described last.

Rocks in which the content of micaceous minerals is 40 percent or greater are designated as schists whereas those in which these minerals make up 30 percent or less are called gneisses; rocks containing 30 to 40 percent mica are termed schistose gneiss. The terms amphibolite, quartzite, and marble are used according to the definitions of Turner and Verhoogen (1960). Mineral modifiers preceding rock names are in the order of increasing abundance. For example, garnet-biotite-quartz-feldspar gneiss is composed chiefly of feldspar, with quartz, biotite, and garnet present in successively lesser amounts.

Modal analyses were made by point-count tabulation of a thousand points per thin section. Abbreviations used in the modal analyses are given in table 1. Colors of minerals are described in accordance with the Rock Color Chart distributed by the Geological Society of America (Goddard and others, 1948). Plagioclase compositions were determined on cleavage fragments immersed in refractive-index oils, using the method of Tsuboi (1923).

Table 1.—Explanation of abbreviations used in tables

Mineral abbreviations

Ab = albite
Ac = actinolite
An = anorthite
Bio = biotite
Cc = calcite
Chl = chlorite
Clz = clinozoisite
Di = diopside
Ep = epidote
Fr = fluorite
G = graphite
Gt = garnet
Hb = hornblende
Hm = hematite
Ky = kyanite
Mi = microcline
Ms = muscovite
Mt = magnetite
Or = orthoclase
Phl = phlogopite
Pl = plagioclase
Pr = pyrite
Q = quartz
Sil = sillimanite
Sph = sphene
Stau = staurolite
Tm = tourmaline
Tr = tremolite

Other abbreviations

T = trace amount (less than 0.1 percent)
fg = fine grained (<1 mm); mg = medium grained (1 to 5 mm);
cg = coarse grained (5 mm to 3 cm); vcg = very coarse grained (>3 cm)
An (followed by a numeral = anorthite content of plagioclase in percent
X, Y, Z or E, O (with color after each letter) = color in plane-polarized light

A grid system (fig. 3) facilitates location of areas on the geologic quadrangle maps (pls. 1, 2). Each quadrangle is divided into ninths numbered from left to right, top to bottom, and each ninth is subdivided in the same way. The Bridgeport quadrangle is abbreviated as BP and the Long Hill quadrangle as LH. An outcrop in the northeastern corner of the north-central sector of the Long Hill quadrangle, for example, is located at LH-2-3.

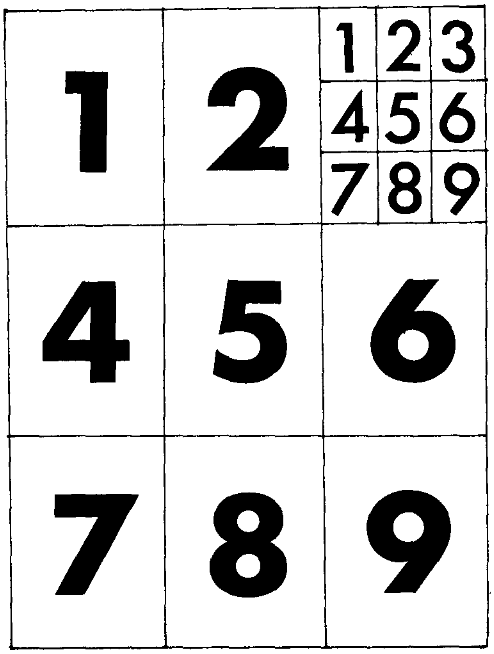

Fig. 3. Grid system used in this report.

Metamorphic rocks and their possible unmetamorphosed equivalents are best compared on the basis of chemical composition. Such comparisons are most clearly shown by normative composition plots (plate 3, in pocket) following Hopson (1964). Chemical analyses and CIPW norms were calculated from modes, using a Fortran-IV computer program, which also normalized the salic minerals to 100 percent. Mineral densities were taken from Winchell and Winchell (1956). Variable mafic phases were assigned compositions based on chemical analyses presented by Deer and others (1962) from areas metamorphosed under the influence of a geothermal gradient similar to that of western Connecticut. However, because FeO and MgO do not enter into the plotted normative minerals, it is not necessary to know their ratios; in addition, because mafic minerals do not commonly constitute more than 20 percent of the mode, the substitutions $Al_2O_3 \rightleftarrows SiO_2$ and $Fe_2O_3 \rightleftarrows Al_2O_3$ have no significant effect on the positions of plotted points. Retrograde minerals (chlorite after biotite and garnet, sericite after plagioclase and other aluminosilicate phases) in the modes were assigned the formulae of the minerals they replace.

The most critical assumption in this approach is that, on a small scale, the chemical composition of a rock, except for volatiles, has remained constant. Evidence discussed in the section on metamorphism suggests that movement of nonvolatile constituents has been limited to distances of 10 cm or less. If this is so, a homogeneous rock layer that is more than a few tens of centimeters thick has undergone essentially isochemical recrystallization, except for volatiles, during metamorphism.

METAMORPHIC STRATIGRAPHY

Recognition of mappable units in the Long Hill and Bridgeport quadrangles was greatly aided by the excellent maps of Fritts (1965a, 1965b) for the adjacent Ansonia and Milford quadrangles. The stratigraphic sequence proposed by Fritts has been modified, however, because a large volume of meta-igneous rocks (mapped by him as Ansonia and Prospect gneisses), which he designated as intrusive, is here considered as volcanic or as sediments of predominantly volcanic provenance.

Fossils are unknown in the crystalline rocks of western Connecticut, and nearly all radioactive age determinations have dated only the termination of metamorphic events. In western Connecticut no stratigraphic unit east of "Cameron's line" has been traced continuously through Massachusetts into the relatively well dated section of eastern Vermont. In the absence of other criteria, relative ages have been based on the sequence of units flanking the eastern side of the Waterbury dome, the southernmost of a line of domes extending from eastern Vermont, through western Massachusetts, and into Connecticut. Studies in eastern Vermont have shown that the oldest rocks are in the cores of such domes; this concept was applied by Fritts (1962a) to the Waterbury dome and by Stanley (1964) to the Bristol and Collinsville domes.

Mapping in the Long Hill and Bridgeport quadrangles has established eight continuous stratigraphic units and eight others of limited extent; these sixteen units have been assigned to nine formations. Eight of the formations correspond approximately to formations mapped by Fritts (1965a, 1965b)—the differences involve splitting of three of his formations and modification of others. The ninth formation is found only in the northwestern corner of the Long Hill quadrangle.

The Newtown Gneiss and the Collinsville Formation, which are feldspathic gneisses west of and interfolded with The Straits Schist, are classed together as the basal group. The Orange Formation, which occupies the southeastern corner of the Bridgeport quadrangle, has also been tentatively assigned to this group because stratigraphic-structural arguments suggest that it belongs low in the rock sequence. However, its age relationship to other formations in the basal group is uncertain.

Above the basal group is the Hartland Group, composed of six formations. At the base is The Straits Schist and its probable correlative, the Cooks Pond Schist. Above these are the Trap Falls Formation, the Southington Mountain Formation, the Prospect Formation, and the Ansonia Gneiss.

BASAL GROUP

Newtown Gneiss

GENERAL DISCUSSION

The name Newtown Gneiss is assigned to rocks that are well exposed in the hills north of Halfway River in Newtown (fig. 3, LH-1-2, 1-3) in the Long Hill quadrangle (pl. 1), hereby designated the type locality.

Exposures of the Newtown Formation are abundant throughout its areal extent in the Long Hill quadrangle, apparently because of the formation's nearly isotropic fabric, which makes it highly resistant to mechanical weathering. Because of this, the terrain that it underlies is rugged and only sparsely populated, resembling the wide belt underlain by the Pumpkin Ground Member of the Prospect Formation in northern Stratford.

LITHOLOGY

The Newtown Gneiss is composed chiefly of medium-grained, poorly foliated to massive biotite-quartz-feldspar gneiss (table 2) with a variable

Table 2.—Modal analyses (in volume percent) of the Newtown Gneiss[1]

sample[2]	Q[3]	Pl[4]	Mi[5]	Ms	Bio[6]	Hb[7]	Gt	Sph	Ky[8]	Sil[9]	Mt	Chl[10]	Ap	Py
LH-513a	29.8	30.8	21.4	5.6	11.6	—	—	—	—	—	0.4	—	0.4	—
LH-503	33.8	33.4	10.0	19.6	—	—	—	—	—	—	0.2	2.1	0.9	—
LH-520	16.2	41.5	3.2	—	15.5	21.1	—	1.6	—	—	—	—	0.8	0.1
LH-542	24.2	9.7	7.7	12.5	21.0	—	0.6	—	23.4	0.5	0.4	—	T	—

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

[2] LH-513a: prophyroblastic gneiss; mg-cg

LH-503: Bio-Ms granodiorite; cg-vcg

LH-520: Bio-Hb-Q-Pl gneiss; mg

LH-542: Ms-Bio-Ky-Q schist; fg-mg

Samples LH-511 and LH-519, not included in the table, are finely laminated gneiss (locally schist) with nonuniform alternation of simple mineral parageneses.

Lengthwise along a standard 4½-cm thin section of LH-511 the following alternations are observed:

Thin lamina of densely packed Bio with some quite clean, round Gt and minor Q and Pl

Thin lamina of cg Q

Thick lamina of sericitized Pl with minor Q, Bio, and Gt

Discontinuous thin Q lamina succeeded by several Bio-Gt discontinuous laminae with some Q and Pl

A thin Q lamina

A remarkable Bio lamina with an abundance of small to large clean Gt which tend to be concentrated on either side of the lamina

Q lamina

Bio lamina

Q lamina

Q-Gt-Pl lamina

Thick Bio-Pl lamina with scattered Q and Gt

A bordering Gt concentration

Q matrix with Gt, Bio, Pl

LH-519 is similarly heterogeneous; Gt absent, Ms present; Ap as concentrates in discontinuous laminae

Texture of samples: granular in granodiorite; granular to weakly foliate in porphyry; foliate in gneiss and schist. Mi porphyroblasts commonly display domain structure, although large, optically continuous Carlsbad-twinned crystals are also common. Groundmass in immediate contact with both types tends to be fine grained.

[3] Undulatory extinction common

[4] Moderately to strongly sericitized. In LH-513a, An 19; in LH-503, An 15; in LH-520 and LH-542, An 35

[5] In granodiorite occurs both as individual grains and as fine-grained rims surrounding and penetrating cleavage plates of Ms and Bio. In prophyroblastic granulite it is notably full of inclusions, although there are large inclusion-free areas. The chief included minerals are Ms, Pl, and Q with only negligible Bio.

[6] X, pale to moderate greenish yellow; YZ, moderate brown to dark and dusky yellowish brown and red

[7] X, pale yellowish green; YZ, dark yellowish green

[8] Occurs both as long blades and as small equant grains

[9] Invariably euhedral in coarse prisms; commonly surrounded by Ky; appears locally to develop at the expense of Bio.

[10] Replaces Bio. X, pale yellowish green; YZ, dark yellowish green; optically negative; Berlin-blue interference color; probably penninite

content of euhedral, large, twinned microcline megacrysts. It is very similar to the porphyroblastic gneiss of the Prospect Formation's Pumpkin Ground Member except that the gneiss in the Newtown commonly grades into pinkish coarse-grained granodiorite and pegmatite. Minor amounts of metasediments are present. Most characteristic is a fine-grained, generally finely laminated garnet-biotite-plagioclase-quartz gneiss. Viewed normal to the foliation surface, this rock looks as though it had been sprinkled with salt and pepper. Individual laminae average about ⅓ cm in thickness. Fine-grained and medium-grained biotitic and binary (biotite and muscovite) schist and gneiss are locally present, in places carrying kyanite and/or sillimanite.

Through a decline in megacryst density and hence an improved definition of foliation, the Newtown Gneiss grades into feldspathic gneiss typical of the Collinsville Formation. The narrow belt of Collinsville that passes between the Newtown Gneiss and The Straits Schist toward the northern edge of the Long Hill quadrangle contains some feldspar megacrysts. Nevertheless, its rocks are, on the whole, more like the Collinsville gneiss and have been mapped as such (pl. 1).

ORIGIN

The relationship between the dominant porphyroblastic gneiss and the included schist is not entirely clear. In the hills north of the road that extends east from Great Ring Road (fig. 3, LH-1-3), the metasediments are a chaotic assemblage of large isolated blocks and smaller inclusions "floating" in a structureless porphyry. However, in the large outcrops east of Rowledge Pond (LH-1-1) thin tabular bodies of "salt-and-pepper" biotite gneiss in porphyroblastic gneiss all have the same orientation. The included rocks dip steeply at Rowledge Pond but have a very gentle inclination in the Great Ring Road exposures, suggesting that there the apparent chaos is at least partly due to the intersection of a gently dipping, probably broadly folded structure with an irregular topographic surface. Locally, as along the NYNH&H RR tracks west of Great Ring Road (LH-1-1), the porphyroblastic gneiss clearly cuts across the associated finer grained, foliated biotite gneiss.

The relationship of the Newtown Gneiss to the Collinsville Formation is not clear. The igneous composition and cross-cutting relations of the Newtown indicate an intrusive origin. However, the parallelism in the included metasediments of layering and schistosity with foliation (wherever apparent) in the porphyroblastic gneiss suggests metamorphism of interlayered acidic volcanics and detrital sediments. Cross-cutting relations and the local abundance of coarse-grained granodiorite might be attributed to mobilization of the igneous fraction accompanied by local partial melting. In this hypothesis, the Newtown Gneiss is a stratigraphic unit below the feldspathic biotite gneiss of the Collinsville Formation. An alternative hypothesis, adopted by Scholle (1965), who mapped part of the Southbury quadrangle, is that the Newtown Gneiss is an intrusive stock derived from greater depths. Clarification of the relationship of the Newtown to other map units over a broad area must await detailed mapping in the Botsford, Newtown, and Southbury quadrangles.

The norms of two of the minor rock types associated with the porphyroblastic gneiss are plotted on plate 3, triangle 2 (in pocket). The kyanite schist (sample LH-542) probably represents a highly aluminous shale. The biotite-hornblende gneiss (LH-520), typical of nonlaminated gneiss associated with the porphyroblastic gneiss, plots in the volcanic field; it lacks normative corundum and probably represents andesitic or quartz-poor dacitic flows or tuffs. Its occurrence in thin layers of very limited extent supports a pyroclastic origin.

Because of their heterogeneity, the laminated gneisses were not analyzed. It is unlikely that such compositional variations are wholly the result of metamorphic differentiation, yet it is difficult to imagine the nature of the unmetamorphosed parent. The overall composition of these rocks probably lies somewhere in the midst of the graywacke-arkose field; individual laminae are equivalent to graywacke or arkose and also to quartzite. These rocks may have had an origin similar to that postulated below for laminites in the Orange Formation—they may be turbidites derived, however, from less aluminous, much more ferruginous source rocks than those of the Orange. Their heterogeneity may be due in part to minor movement of material from one lamina to another during metamorphism.

Collinsville Formation

GENERAL DISCUSSION

The Collinsville Formation was named by Rice and Gregory (1906) and defined very precisely by Stanley (1964) for rocks cropping out in the village of Collinsville. A reference locality for the Collinsville Formation in the Long Hill quadrangle is the wooded terrain northeast of East Village (fig. 3, LH-2-3). A more convenient location for studying vertical and horizontal variations in the Collinsville Formation is the large, clean outcrop on the northern shore of the Housatonic River at the foot of Lake Zoar dam in the Southbury quadrangle; the section exposed there, however, shows a greater short-range vertical heterogeneity than is commonly observed in the Long Hill quadrangle. Although Stanley's twofold subdivision of the Collinsville was not recognized in the Long Hill quadrangle, the identity of stratigraphic position and the overall similarity in lithologic character of this unit in the Long Hill quadrangle to the type section at Collinsville supports the correlation of the two. The Collinsville Formation in the Long Hill quadrangle is remarkably similar to the gneiss exposed at Reynolds Bridge in the Thomaston quadrangle, described by Cassie (1965). Stanley (personal communication) considers the gneiss at Reynolds Bridge to be correlative with the type section Collinsville Formation, hence strengthening the correlation of the Collinsville Formation in the Long Hill quadrangle with that at Collinsville. In this report the very striking similarity with the gneiss at Reynolds Bridge is emphasized. In the adjacent Ansonia and Naugatuck quadrangles rocks physically continuous with the Collinsville in the Long Hill quadrangle have been assigned to the Prospect Gneiss. The stratigraphic arguments for separating the Collinsville from the Prospect are considered below in the discussion of the Prospect Formation.

The large area west of the westernmost belt of The Straits Schist is underlain by rocks similar in texture and mineralogy to the Collinsville Formation although nowhere in the Long Hill quadrangle is this western body known to connect with the eastern body. Correlation of the two is strengthened by the observation that at the contact of both with The Straits Schist is a zone of amphibolite commonly in association with coarsely crystalline calcite marble.

The eastern body of Collinsville is almost totally concealed on the south by the Barn Hill drumlin and adjacent broad-bottomed Means Brook valley. Elsewhere it is generally exposed on the flanks of strike ridges in the highlands and in the floors of valleys descending to the Housatonic River. The Housatonic cuts through the Collinsville Formation at almost a right angle to the trend of foliation; its tributaries, however, are well adjusted to bedrock structure. The western body is largely obscured by a widespread cover of glacial drift except in a small area north of Long Hill village centered about the old tungsten mine (LH-7-2).

Table 3.—Modal analyses (in volume percent) of the Collinsville Formation[1]

sample [2]	Q[3]	Pl[4]	Mi[5]	Ms[6]	Bio[7]	Hb[8]	Ep	Gt[9]	Mt	Chl[10]	Ap
LH-210	25.1	3.9	—	29.7	35.7	—	T	5.5	—	T	0.1
LH-257	26.1	50.9	8.1	1.3	13.5	—	—	0.1	—	—	T
LH-484	28.4	28.0	35.4	—	7.6	—	—	—	T	—	0.6
LH-487a	30.3	40.5	24.1	1.0	4.0	—	—	—	T	—	0.1
LH-487b	8.9	80.2	—	—	0.3	8.3	—	—	1.0	1.1	0.2
LH-488	41.2	35.4	10.6	—	12.7	—	—	—	T	—	T
LH-506	32.7	37.3	20.6	1.3	7.6	—	0.1	—	T	0.1	0.3

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

[2] *Description of samples*:

LH-210: Q-Ms-Bio schist; mg

LH-257: Bio-Q-Pl gneiss; fg-mg

LH-484: Pl-Q-Mi gneiss; mg-cg

LH-487a: Mi-Q-Pl gneiss; mg-cg

LH-487b: Pl gneiss; mg-cg

LH-488: Mi-Bio-Pl-Q gneiss; mg-cg

LH-506: Mi-Q-Pl gneiss; mg

Texture: Foliate. Grain contacts ungranulated and simple. Some tendency for arrangement of Mi into clusters but true prophyroblasts rare. Intergranular implication along boundaries of Mi grains uncommon.

[3] Undulatory extinction common

[4] Only very slightly sericitized except for sample LH-506, the only representative of the western body. An 26 in this sample; An 25 in LH-210, LH-257, LH-484; An 22 in LH-487a, LH-487b, LH-488.

[5] Shows well developed grid twinning

[6] In sample LH-487a occurs as fg aggregates at the junction of end-on cleavages in Bio with either Mi or Pl.

[7] In Hb-bearing rocks: X, colorless; YZ, light brown (5 YR 5/6); in other rocks: X, pale greenish yellow; YZ, very dusky red

[8] X, pale yellowish green; Y, dark yellowish green; Z, dark yellowish green

[9] Rounded and commonly poikiloblastic; inclusions chiefly of fine-grained Ms and somewhat coarser Bio.

[10] Replaces Bio and Hb. XY, moderately yellowish-green; Z, pale yellowish green

LITHOLOGY

Except for an interrupted contact zone with The Straits Schist (to be described below), the Collinsville Formation (table 3) is highly feldspathic, its feldspar/quartz ratio being seldom less than 2. Heterogeneity in these feldspathic rocks is due to variation in biotite content, yielding at one extreme coarse-grained, nearly structureless feldspathetic gneiss, generally in thin layers, and at the other, coarse-grained, non-rusty-weathering feldspathic biotite schist, invariably accompanied by garnet porphyroblasts up to 4 cm in diameter and by variable amounts of muscovite and kyanite. The bulk of the formation consists of medium- to coarse-grained feldspathic biotite gneiss intermediate between the two end members. There is a segregation of the mafic and felsic constituents in these intermediate rocks that produces quartzo-feldspathic bands about 1 cm thick, separated by thin biotite wisps, giving the rock a coarsely laminated aspect. Locally, the rock bears microcline augen and porphyroblasts that appear to be randomly distributed. Rarely the Collinsville is hornblendic; true amphibolite is common, however, only near the contact with The Straits Schist. Finer grained, less feldspathic, garnetiferous two-mica schist is locally important, as is calc-silicate gneiss. In a few outcrops this gneiss is associated with thin layers of calcite marble and highly graphitic coarse-grained feldspathic gneiss—for example, along the eastern side of the western branch of Webb Circle about ½ mi. northeast of its southern termination at East Village (fig. 3, LH-2-2). There the outcrop is intensely weathered to a dirty yellowish brown, indicating abundant disseminated sulfides.

At the upper contact of the Collinsville Formation is a discontinuous zone of very heterogeneous rock types (table 4), chiefly fine- to medium-grained, greenish-black amphibolite in layers up to 40 ft thick—a thickness greatly exceeded, however, at the old tungsten mine in Trumbull. Associated rocks include coarsely crystalline calcite marble, calc-silicate gneiss, clean quartzite, micaceous and graphitic quartzite, various schists (some identical to The Straits Schist), and feldspathic biotite gneiss. There is also in this zone a greater concentration of massive pegmatite, in thick stratiform bodies and cross-cutting dikes, than in any other part of the mapped area. The pegmatite tends to occur at the contacts of thick amphibolites.

Cassie (1965) has pointed out that the two finest exposures of gneiss of the Reynolds Bridge type in the Thomaston quadrangle are in immediate or close contact with The Straits Schist, and that the most obvious aspect of these exposures—the granite gneiss-amphibolite interlayering—is not typical of the Reynolds Bridge-type gneiss as a whole; large areas of the gneiss have little or no interlayered amphibolite. This is in complete agreement with the lithology of the Collinsville Formation in the Long Hill quadrangle; amphibolite is concentrated in a narrow zone at The Straits-Collinsville contact. Elsewhere the formation is chiefly coarse-grained feldspathic gneiss with little or no interlayered amphibo-

Table 4.—Modal analyses (in volume percent) of contact zone between the Collinsville Formation and The Straits Schist[1]

sample[2]	Q[3]	Pl[4]	Mi[5]	Ms	Bio[6]	Phl[7]	Hb[8]	Di	Cc[9]	Clz[10]	Gt[11]	Sph	Mt	Chl[12]	Ap	Py	Hm
LH-302[13]	—	41.0	—	—	3.9	—	48.6	—	0.6	—	—	1.3	0.4	0.1	0.1	—	—
S-477[13]	—	31.3	—	—	—	—	65.4	—	—	—	—	2.6	—	—	0.2	—	—
LH-464[14,15]	71.0	16.0	—	T	7.0	—	—	—	—	2.0	T	T	3.0	T	T	—	T
LH-304[15,16]	12.0	T	—	T	—	T	—	T	87.0	T	—	T	—	T	—	T	—
LH-465[15,16]	—	T	T	T	—	—	—	—	99.0	—	—	—	—	T	—	—	—

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

[2] *Description of samples*:
LH-302: Amphibolite; fg
S-477: Amphibolite; fg
LH-464: Pl quartzite; fg-mg
LH-304: Silicious marble; fg-mg
LH-465: Marble; mg-cg

[3] Uniform and undulatory extinction equally common in marble. In quartzite most grains show undulatory extinction; larger grains extinguish mosaically.

[4] In quartzite strongly sericitized and epidotized and full of rounded Q blebs. Moderately to strongly sericitized in amphibolite and marble. Twinning common except in quartzite. Zoning from sodic core to calcic rim common in amphibolite. In LH-302, An 56; in S-477, An 47; An undetermined in LH-464, LH-304, and LH-465.

[5] As tiny grid-twinned grains

[6] In amphibolite occurs as a primary phase in patches and lenses parallel to the foliation; X, colorless, YZ, light brown (5 YR 5/6). In quartzite X, colorless; YZ, moderate brown (5 YR 3/4).

[7] X, colorless; YZ, very light brown (5 YR 6/4).

[8] X, colorless to moderate yellow green; Y, moderate yellowish green to dusky yellow green; Z, pale green (5 G 7/2 to 10 G 6/2).

[9] In LH-304 feebly twinned; in LH-465 grains are notably large with extremely penetrative twinning, notable offsets, unrelieved strain and bending.

[10] In marble, zoned; in quartzite occurs both as a primary phase and replacing Pl.

[11] Commonly euhedral

[12] Replaces Bio in amphibolite and quartzite; XY, light green; Z, colorless. Apparently replaces Phl in marble and is colorless there

[13] Texture foliate with little compositional layering; C axes of amphibole not preferentially oriented; grain contacts mosaic.

[14] Grain contacts simple mosaic to implicate; Q-rich layers alternate with feldspathic layers; mica common to both. Foliation defined by micas and by a tendency for Q grains to be flattened in the same plane.

[15] Rough estimate based on 200 points

[16] Compositional layering defined by Q stringers in LH-304; Cc-grain contacts mosaic; mosaic to implicate in quartz layers

lite. The correlation is further strengthened by Cassie's observation that five of the seven marble outcrops in the Thomaston quadrangle are along the contact of The Straits Schist and Reynolds Bridge-type gneiss, and a sixth is areally well within the gneiss (although, as Cassie adds, it may be near the top of the gneiss, with The Straits Schist eroded away at this locality). With one exception, in the Long Hill quadrangle, every outcrop of marble with a thickness greater than a few inches occurs within the narrow contact zone between the Collinsville Formation and The Straits Schist. Cassie's descriptions of the granitic gneisses at Reynolds Bridge—predominance of biotite over muscovite, occurrence of biotite in thin folia, high feldspar/quartz ratio, widely varying microcline content, local occurrence of microcline porphyroblasts—apply equally well to the Collinsville Formation in the Long Hill quadrangle, leaving little doubt that these two isolated bodies of feldspathic gneiss are the same formation.

ORIGIN

The modal analyses in table 3 have been converted to CIPW norms and, together with data from Cassie (1965), are plotted on plate 3, triangle 3. Despite a widely varying plagioclase/microcline ratio, the Collinsville Formation and the Reynolds Bridge-type gneiss have in common (1) a low normative quartz content that places nearly all the samples either within or very close to the volcanic field and (2) little or no normative corundum (except for sample LH-210). Both these features support an igneous parentage. The layered nature of the feldspathic gneisses, with more and less micaceous layers alternating on a scale of several feet, is compatible with an origin as pyroclastics rather than as lava flows. Supporting evidence also lies in the overwhelming predominance over lava flows of tuff and other pyroclastics erupted in modern times from the rhyolitic and andesitic volcanos of the circum-Pacific belt and the Indonesian Island arcs (Rittman, 1962).

The lithology of the contact zone fits quite readily into a volcanic hypothesis. The well bedded amphibolites apparently mark a brief phase of basic volcanism; the associated marble and quartzite may represent limestone and chert precipitated either directly or biogenically, possibly as a result of the heightened activity of SiO_2 and CaO in response to the introduction of basic volcanics into sea water.

Cassie (1965) concluded that the association of marble with amphibolite indicated a sedimentary origin for the latter; hence he excluded a volcanic origin for at least some of the amphibolite. However, limestone interbedded with basic volcanics from unmetamorphosed eugeosynclinal sections has been described elsewhere (Bailey and others, 1964; Danner, 1965; Roberts, 1964, p. A15)—hence its presence is not inconsistent with a volcanic hypothesis. Stanley (1964, p. 95) suggested a volcanic origin for the Bristol Member of the Collinsville Formation.

The modal analyses of Collinsville gneisses in table 3 provide evidence that, given the mineralogical limits within which the formation varies, a significant proportion would plot close to the granite minimum. Thus it is likely that during the metamorphism of the Collinsville Formation, pockets of magma were locally generated and forced upward under the influence of gravity and tectonic stress. There were probably large differences in mechanical properties at the contacts of thick amphibolites with schists and gneisses that were undergoing deformation. Such differences might have caused localized areas of relatively low pressure into which magma could migrate, thus accounting for the large volume of pegmatite in the contact zone. In other words, this is a large-scale analog of pegmatite development at the margins of amphibolite boudins.

HARTLAND GROUP

The Straits Schist

GENERAL DISCUSSION

The Straits Schist was named by Rodgers (1959) who designated as type locality the narrow pass between Long Hill and Beacon Cap in northern Bethany. Rodgers assigned it member rank in the Hartland Formation; later detailed work by Fritts (1963a, 1963b) and by Stanley (1964) has led to its elevation to formation status in the Hartland Group.

In the Long Hill and Bridgeport quadrangles a twofold division of The Straits Schist is recognized. The type locality for the lower member is the prominent capping of the steep cliffs east of the Housatonic River along Route 34 (fig. 3, LH-3-6). On the gentler slopes immediately to the east are extensive ledges of the upper member.

Hills and valleys underlain by The Straits tend to be elongated along strike. In amphibolite belts, structural control of stream courses is particularly notable, as, for example, the streams outlining map-scale folds south of Waverly Road (LH-8-3). The prominent hills and rugged relief, so typical of The Straits topography in quadrangles to the north, are generally absent.

LOWER MEMBER

The lower member consists of uniform, medium- to coarse-grained, rusty-weathering garnet-plagioclase-biotite-muscovite-quartz schist, normally graphitic, and ordinarily bearing kyanite and/or sillimanite (table 5). Staurolite has been noted on both sides of the Housatonic River in the northeastern part of the Long Hill quadrangle and along the Poquonock River southeast of Long Hill village (fig. 3, LH-7-9). Black tourmaline is a common accessory mineral throughout the unit. Chloritization of biotite and garnet is a common feature; the significance of its distribution is unknown. The schist is characteristically so contorted that accurate determination of the attitude of foliation is difficult. On the whole, uniformity of rock type characterizes the lower member. However, more quartzo-feldspathic layers are associated with the schist along Hurd Street and Federal Road (LH-8-1), on the steep ridge flanking the western bank of Hurds Brook (LH-2-7), and locally along the Poquonock River east of Long Hill village (LH-7-5, 7-9).

A large body of poorly foliated, medium-grained biotite muscovite-quartz-plagioclase gneiss (table 5, samples LH-734, LH-743), exposed in the golf course just west of the intersection of Stroebel and Daniels

Table 5.—Modal analyses (in volume percent) of the lower member of The Straits Schist[1]

sample[2]	Q[3]	Pl[4]	Ms[5]	Bio[6]	Ep	Gt[7]	Ky[8]	Sil[9]	Stau[10]	Chl[11]	Ap	G+Mt[12]	Hm	Fr
LH-152	34.3	0.1	36.8	17.5	0.1	2.4	3.6	—	T	1.9	—	3.3	—	—
LH-155	59.1	0.4	15.0	12.0	T	11.2	0.9	0.1	0.2	—	T	1.1	—	—
LH-298	19.1	0.2	53.1	0.4	—	2.5	—	T	—	21.4	—	3.3	—	—
LH-299	48.4	4.3	34.0	T	—	1.4	—	—	—	10.6	—	1.3	—	—
LH-338	20.4	14.1	36.9	T	0.1	6.1	—	—	—	20.6	0.2	1.6	—	—
LH-385	35.1	2.6	37.8	1.3	—	3.9	T	T	—	18.3	—	1.0	T	—
LH-456	8.8	2.7	59.8	2.2	—	2.7	T	T	—	22.1	0.2	1.5	—	—
LH-462	35.3	5.2	35.1	21.9	T	1.6	—	—	—	—	T	0.9	T	—
LH-470	52.0	13.0	27.8	2.9	—	2.3	0.1	1.4	—	0.2	—	0.3	—	—
LH-475	48.4	—	25.7	15.9	0.2	1.5	—	4.4	—	1.9	T	2.0	T	—
LH-480	53.6	2.6	5.8	12.8	—	0.4	T	23.4	—	0.3	T	1.1	—	—
LH-734[13]	30.5	61.7	3.9	3.9	—	—	—	—	—	—	—	T	—	—
LH-743[13]	33.2	22.3	42.8	T	—	—	—	—	—	—	—	—	—	1.7

[1] For explanation of abbreviations used in this table and in the accompanying text, see table 1.

[2] *Description of samples*:

LH-352: Bio-Q-Ms schist; mg
LH-155: Gt-Bio-Ms-Q schist; mg-cg
LH-298: Q-Chl-Ms schist; mg-cg
LH-299: Chl-Ms-Q schist; mg
LH-338: Pl-Q-Chl-Ms schist; mg
LH 385: Chl-Q-Ms schist; mg
LH-456: Chl-Ms schist; mg
LH-462: Bio-Ms-Q schist; mg-cg
LH-470: Pl-Ms-Q schist; mg-cg
LH-475: Bio-Ms-Q schist; mg-cg
LH-480: Bio-Sil-Q schist; mg-cg
LH-734: Mica-Q-Pl gneiss; mg
LH-743: Pl-Q-Ms gneiss; mg

Texture: Foliate. Ky, Stau, and locally Gt tend to occur as porphyroblasts; the latter two are generally poikiloblastic. Sil occurs in fg swirling masses whose common alteration to sericite gives the rock a silky sheen.

[3] As large, strained grains, elongate in the foliation plane, and as clusters of smaller, generally unstrained, grains

[4] Generally well twinned, although some samples lack twinning. Some samples show alteration to an unidentified, opaque, yellowish brown substance; seriticization, however, is more common. An 13 in LH-338; An 15 in LH-743; An 16 in LH-155, LH-385, and LH-480; An 17 in LH-462, LH-734; An 20 in LH-299, An 25 in LH-298; An 32 in LH-470; An content undetermined in LH-352 and LH-456.

[5] As (1) large laths generally arranged with their greatest dimension in the plane of foliation. Includes primary Ms as well as Ms replacing Ky. (2) Streaks and pods of fg masses showing a random arrangement of individuals; includes Ms replacing Sil and Stau.

[6] X, colorless to light yellowish gray; YZ, moderate yellowish brown to moderate brown to dark reddish brown

[7] Rounded to elongate, with inclusions of Q, Pl, Ms, Bio, Sil, and opaques

[8] Exhibits a range in grain size; the larger grains contain abundant inclusions of Q and Bio. More or less altered to muscovite.

[9] Observed typically as swirling, fibrous masses blossoming from Bio flakes. In sample LH-475 the fibres in one clot in Bio are restricted to two orientations which intersect at nearly 60°, similar to an occurrence described by Chinner (1961). More or less altered to fg Ms.

[10] Pleochroic from yellowish gray to grayish yellow. More or less altered to fine-grained sericite. Abundant inclusions, chiefly Q. Euhedral Stau occurs near the wester bank of the Housatonic River close to the Southbury quadrangle (fig. 3, LH-3-1); this Stau exhibits a combination of prism {110}, side pinacoid {010}, bas {001}, and second-order prism {101}.

[11] XY, pale green to moderate greenish yellow; Z, colorless Replaces Bio and Gt.

[12] G and Mt are not easily differentiated in thin section.

[13] Gneiss from the golf course in LH-8-7 and LH-7-9 (fig 3); see accompanying text.

Farm Roads (LH-8-7, 7-9) is mapped separately on plate 1. Foliation in the gneiss parallels that in the schist and the contact between the two is a narrow zone of interlayering of the two rock types.

An isolated, small, poorly exposed knob of amphibolite crops out on Cross Hill Road (LH-4-6) more than 1½ mi. north northwest of the northernmost occurrence of the tungsten mine amphibolite. Apparently on the basis of this outcrop, Hobbs (1901, map facing p. 14), in reconnaissance work, mapped the intervening area as underlain by amphibolite. A careful search has found no evidence for any connection between the two, although it is possible, of course, that exposures known to Hobbs have since been covered. The lower member of The Straits Schist is exposed near Monroe School (LH-4-5), nearly 1 mi. west southwest of the Cross Hill Road amphibolite and ½ mi. south in a ravine north of the swamp at the southern termination of Elm Street (LH-4-6), making it more reasonable to consider this amphibolite a bed in the lower member of The Straits Schist.

Massive, cross-cutting, muscovite-bearing pegmatite, locally accompanied by quartz pods, is common in both the lower and upper members and the larger bodies of it have been mapped.

The upper contact of the lower member is placed where layered rocks, typical of the upper member, succeed largely uniform schist characteristic of the lower. Throughout most of the area this contact is marked by amphibolite.

UPPER MEMBER

In the reference area (fig. 3, LH-3-6) the upper member consists chiefly of medium- to coarse-grained kyanite-bearing garnet-biotite-plagioclase-muscovite-quartz schist, identical with the dominant rock type in the lower member but also includes abundant interlayered biotitic schist and feldspathic schist and gneiss. Amphibolite is absent here, its place taken by thinly interbedded, fine-grained biotitic quartzite and medium-grained biotitic and binary schist exposed in sections up to 50 ft thick exposed only in stream valleys and not traceable along strike. SW of the Housatonic River a discontinuous amphibolite marks the lower contact; the higher rocks are, however, almost totally concealed by glacial drift. Farther SW the amphibolite also disappears and the scarcity of outcrops makes separation of upper- and lower-member rocks difficult. In the southern part of the Long Hill quadrangle (fig. 3, LH-8-3, LH-8-6), amphibolite, accompanied locally by calc-silicate gneiss and quartzite (commonly sulfidic), reappears and can be traced through the Bridgeport and into the Westport quadrangle. Here the upper member is interlayered medium- to coarse-grained garnet-biotite-muscovite-quartz schist and fine- to medium-grained quartzose and feldspathic garnet-biotite gneiss (table 6). In places the gneiss is missing and the coarse-grained schist is interlayered with a more feldspathic variety, much as it is in the reference area in the northeastern part of the Long Hill quadrangle.

A layer of marble 15 ft thick can be traced discontinuously for ¼ mi. in the reference area (LH-3-6). It is composed almost entirely of medium-

Table 6.—Modal analyses (in volume percent) of the upper member of The Straits Schist[1]

sample[2]	Q[3]	Pl[4]	Ms	Bio[5]	Phl[6]	Ac-Tr[7]	Hb[8]	Ep	Cc[9]	Clz	Gt[10]	Sph	Mt	Chl[11]	Ap	Py	Hm	Tm[12]
LH-352	0.4	2.1	0.6	—	T	10.3	—	T	86.0	—	—	0.1	—	0.3	0.1	0.1	—	—
LH-375	77.2	10.6	0.5	2.9	—	—	—	0.1	—	3.3	T	0.7	2.5	1.7	0.1	—	0.3	0.1
LH-401a	31.2	57.1	1.8	5.2	—	—	—	—	—	—	1.2	—	0.8	1.8	0.9	—	—	—
LH-401b	23.2	17.9	34.0	15.0	—	—	—	—	—	—	2.6	—	2.0	4.7	0.2	—	0.4	—
LH-431	0.5	38.8	—	T	—	—	57.7	—	—	—	—	2.5	—	0.2	—	—	0.3	—

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

[2] *Description of samples*:

LH-352: Tremolite marble; mg

LH-375: Feldspathic quartzite; fg-mg

LH-401a: Mica-Q-Pl gneiss; mg

LH-401b: Bio-Pl-Q-Ms schist; mg

LH-431: Amphibolite; fg-mg

Texture: Foliation expressed by micaceous minerals and Sph in marble, by Hb in amphibolite, and principally by mica in other rock types. Small-scale alternation of Pl and Hb layers forms lamination in amphibolite. Lamination in quartzite caused by alternation of layers of nearly pure Q with finer grained layers of Q and all other phases. Sparsely distributed, larger Hb grains give some amphibolites a "porphyritic" appearance.

[3] Undulatory extinction common in schist and gneiss, less common in quartzite, and absent in amphibolite and marble.

[4] In quartzite, moderately to strongly sericitized, with notable development of hematite along grain boundaries and cracks. Only slightly sericitized in other rock types. In amphibolite, zoned from sodic core to calcic edge. An 18 in LH-401a, LH-401b; An 44 in LH-431; An undetermined in LH-352, LH-375.

[5] In amphibolite, X, colorless; YZ, light yellowish brown. In quartzite, X, moderate greenish yellow; YZ, light brown (5 YR 5/6); in schist and gneiss, X, yellowish gray to very light brown; YZ, moderate reddish brown. In gneiss has distinctive pleochroic halos about what appears to be epidote (allanite?) and zircon.

[6] X, colorless; YZ, very light brown

[7] Colorless, non-pleochroic; presumably highly magnesian

[8] X, very pale yellowish green; Y, light dusky yellow green; Z, pale green

[9] Gentle flexing of twin lamellae observed locally

[10] Tends to be somewhat skeletal in gneiss and schist

[11] Colorless in marble, presumably retrogressive, although it occurs in patches not associated with other minerals. In other rocks, XY, colorless to pale greenish yellow; Z, pale green to moderate greenish yellow; replaces Bio and Gt

[12] E, colorless; O, light olive brown and light blue

grained calcite and at one time was actively quarried. Although a few marble fragments were observed in the float on the hills on the west side of the Housatonic River at about the same stratigraphic horizon, their bedrock source was not discovered.

The upper contact of the upper member is placed below the first occurrence of the distinctive feldspathic gneisses of the Trap Falls Formation.

ORIGIN

Norms of The Straits Schist are plotted in plate 3, triangle 4. The relatively high normative corundum of the typical coarse-grained muscovitic schist, coupled with its large normative orthoclase/plagioclase ratio, indicate a shale parentage. However, there is a broad spread in normative quartz/orthoclase ratios, with a visually estimated mean value significantly lower than the average shale value. Apparently The Straits represents a rather clay-rich shale, the anomalously low silica content indicating a reduced silt contribution and hence deposition in either a restricted basin or on the sea floor far enough from land to favor a high clay/silt ratio. In view of the overall eugeosynclinal nature of the rocks flanking the line of domes in western Connecticut and their wide areal extent, the latter origin is more likely. Graphite in The Straits is probably derived from the remains of pelagic organisms incorporated in the shale.

The feldspathic gneisses associated with both the lower and upper members probably represent dacitic tuffs indicating that the volcanic activity of Collinsville time had not completely subsided. In fact, the amphibolite and associated quartzite (basic tuff and chert) suggest a renewal of volcanism that began as the upper part of The Straits Schist, with its greater amount of feldspathic gneiss, was laid down.

Trap Falls Formation

GENERAL DISCUSSION

The name Trap Falls is proposed for the leucocratic feldspathic gneiss and interlayered schist that are well exposed along the east and west shores of Trap Falls Reservoir (fig. 3, LH-9-5, 9-6, 9-7, 9-8, 9-9), here designated the type locality. In the Ansonia quadrangle Fritts mapped the feldspathic gneiss as Ansonia Gneiss and the interlayered schist as Southington Mountain Schist. In the Long Hill and Bridgeport quadrangles, schist (and other metasediments) and gneiss are interlayered on all scales, and to facilitate mapping, the entire complex was considered a single map unit, the Trap Falls Formation. The unit is not physically continuous with the type Ansonia Gneiss, and there are sufficient textural and lithologic differences between the two to warrant the use of separate names.

In the Long Hill quadrangle the Trap Falls Formation crops out in two belts, the chief one being the Shelton anticline. Thus it is referred to as the Shelton facies in the following discussion. Northwest of it the Trap Falls is exposed in a small anticline and in the White Hills recumbent syncline where it is referred to as the northwestern facies. The Shelton facies is the continuation of a large body of gneiss mapped in the adjacent Ansonia quadrangle by Fritts (1965a) as Ansonia Gneiss with inclusions of Southington Mountain Schist. The northwestern facies is the continuation of Fritts' Southington Mountain Schist with included layers of Ansonia Gneiss. On lithologic grounds alone, differences between the Shelton and the northwestern facies warrant treating them as separate units. Nevertheless, although separate in the Ansonia quadrangle, the two are joined in the hinge area of the Trap Falls syncline (LH-9-4) and both are sandwiched between The Straits Schist and the Southington Mountain Formation. Thus there is justification for considering them equivalent facies of a single stratigraphic unit, the Trap Falls Formation.

The northwestern facies, largely composed of schist, crops out poorly, except where the ratio of schist to gneiss is low, as in the rugged area south and west of Walnut Tree Hill (LH-5-6).

Northeast of Trap Falls Reservoir (LH-9-5) the more gneissic Shelton facies underlies extensive strike ridges separated by long, narrow stretches of swamp. This is unquestionably the finest illustration of structural control of topographic form in the entire area. In places these ridges are flanked by precipitous cliffs, and the area as a whole is virtually uninhabited. Southwest of Trap Falls Reservoir the relief is less spectacular; however, the same pattern of elongate hills and swampland persists and is equally uninviting to suburban settlement. Traced into the Bridgeport quadrangle, topographic expression of the Trap Falls Formation is little changed except that erosion along cross joints has subdued the dominant linear element so that the drainage here is oriented principally across strike.

SHELTON FACIES

The long eastern strip of Trap Falls Formation corresponds to the "Granitic range of Huntington" of Percival (1842) who drew contacts in the northern part that do not differ from those shown on modern maps, although he did not recognize the westward trend north of Bridgeport.

Approximately 80 percent of the exposed Shelton facies consists of medium-grained, generally poorly foliated garnet-muscovite-microcline-quartz-plagioclase gneiss (henceforth called garnet-muscovite gneiss) that weathers very light tan. Tiny spheroidal garnets less than 1 mm in diameter, standing out like bird shot on weathered surfaces, are a distinctive feature of the rock. Biotite is locally an important constituent but rarely exceeds muscovite in abundance. In five outcrops the rock contains Carlsbad-twinned porphyroblasts of microcline, stubby and poorly formed in contrast to the euhedral porphyroblasts of the northwestern facies and in rocks of the Prospect Formation. Stubby, jet-black tourmaline crystals are seen here and there. Both concordant and discordant lenses of vein quartz are locally abundant and commonly associated with a streaky variety of the garnet-muscovite gneiss that weathers chalky white. An abandoned quarry in the largest quartz vein is shown on the geological map of the Long Hill quadrangle (pl. 1) near the northern limit of the Shelton facies (fig. 3, LH-6-9).

Layering is parallel to foliation and is defined by variations in grain size and in mica content. The latter also influences the quality of foliation: gneiss low in mica is massive; foliation is more clearly defined as mica content increases. With increase of grain size the rock grades directly into structureless, nonconformable pegmatite, although not all pegmatite is this closely related to the host rock. Few outcrops show a recognizable mineral lineation.

There is a wide variety of metasediments in the Shelton facies. In the Long Hill quadrangle these are conformable layers of medium- to coarse-grained biotitic and muscovitic schist (generally with garnet) and finer grained biotite-plagioclase-quartz gneiss. Tough, fine-grained garnet-plagioclase-actinolite-quartz gneiss and other calc-silicate rock, rarely containing calcite, are also quite common. South southeast, 0.3 mi. from the concave NW bend in Shelton Avenue (LH-6-9), in an outcrop of typical garnet-muscovite gneiss, is a thin septum of tourmaline-phlogopite schist bearing scattered small grains of vesuvianite—the only occurrence of that mineral observed in the Long Hill and Bridgeport quadrangles. Fritts (1965a), however, reports vesuvianite from impure marbles associated with the northward continuation of the Shelton facies (called by him Ansonia Gneiss) in the Ansonia quadrangle. Less common than calc-silicate rock is fine-grained, finely laminated garnet-biotite-muscovite schist interlayered in places with thinly laminated quartzite. Two occurrences of gondite (garnet-quartz rock) were noted, one in woods 1,400 ft east northeast of the termination of the unnamed light-duty road leading E out of Huntington (LH-9-3), the other 1,600 ft west southwest of the intersection of Isinglass and Waverly roads (LH-9-1). This rock type was not seen in any other stratigraphic unit in either quadrangle.

In the Bridgeport quadrangle metasediments are much more abundant in the Shelton facies but tend to occur in distinct bodies that can be separately mapped; three large patches and two smaller ones are shown on the geologic map (pl. 2). The largest mass, north of Lake Forest (BP-2-4), is composed in large part of coarse-grained, rusty-weathering tourmaline-biotite-quartz-plagioclase-garnet-muscovite schist bearing round anhedral garnet porphyroblasts 2 to 3 cm in diameter. This schist is interlayered most commonly with thin layers of finer grained biotite-plagioclase-quartz gneiss. However, fine- to medium-grained biotite and muscovite schist and mica-quartz-feldspar gneiss are also common. Most distinctive, although quantitatively insignificant, are amphibolite and hornblende-garnet-plagioclase quartzite. Half of the occurrences of amphibolite are fine-grained, well foliated, black plagioclase-hornblende gneiss; the others comprise two varieties of amphibolite seldom seen outside this Lake Forest body. One is glomeroblastic amphibolite containing elongate clusters averaging 5 mm in diameter, composed of a core of fine-grained plagioclase, clinozoisite, and unidentified semi-opaque brownish material surrounded by larger plagioclase grains; the other is amphibolite containing a considerable amount of biotite. The Lake Forest metasediments are similar in most respects to the upper member of The Straits Schist and to the banded-schist member of the Southington Mountain Formation, described below.

The elongate strip of metasediment hugging the southern contact of the Shelton facies for a long distance in the northern part of the Bridgeport quadrangle is lithologically very similar to the Lake Forest body but lacks amphibolite. The metasedimentary mass centered near Ninety Acres Park (BP-1-8) is composed of thin-bedded, medium-grained biotitic schist and thinly laminated, fine-grained, blue-gray sillimanitic schist, which weathers rusty red.

NORTHWESTERN FACIES

Because of the many textural and mineralogic variations in the schistose and gneissic rocks of the northwestern facies (table 7) a concise description of its lithology is impossible. This facies is largely schistose, much of it nongraphitic, medium- to coarse-grained garnet-biotite-muscovite-quartz schist like that of The Straits Schist's upper member, which underlies it. Finer grained biotitic and muscovitic schists, quite commonly feldspathic, are also bundant. Both biotitic and muscovitic gneisses occur, varying from fine- to coarse-grained, from poorly to well foliated, and from thinly layered to massive. Porphyroblastic biotite-quartz-feldspar gneiss identical with the major rock type in the Pumpkin Ground Member of the Prospect Formation is particularly well developed in the northernmost and southernmost outcrops of this facies. Most muscovite gneiss in the northwestern facies differs both texturally and mineralogically from that characteristic of the Shelton facies: it contains more biotite, which tends to form clusters of large flakes that give the rock a blotchy aspect. Muscovite is commonly very fine-grained but uniformly disseminated; garnet is much less common. Nevertheless, beds of typical Shelton-facies garnet-muscovite gneiss locally form thin layers in schist outcrops. Muscovite gneiss as thin dikes sharing the country-rock foliation occurs locally. Most distinctive and rather widely developed is a fine-grained, finely laminated biotite-muscovite-quartz schist locally containing garnet and sillimanite; this rock weathers to a deep rusty red and is interlayered with medium- to coarse-grained weakly foliated quartz-feldspar gneiss bearing sparse, fine-grained biotite and/or muscovite and containing isolated streaks of the laminated schist. The laminated schist is very similar to schists in the Ninety Acres patch of metasediments in the Shelton facies; it can also be matched in outcrops along the northern side of Buddington Road northeast of Trap Falls Reservoir (LH-9-3). There are good exposures at the southern end of Walnut Tree Hill and between Walnut Tree Hill Brook and Bohem Brook (LH-5-8, LH-5-9). Quartzite and calc-silicate rock are minor in amount except in a small zone east and southeast of the intersection of Sawmill and Birdseye roads (LH-6-5), where fine-grained, impure marble also crops out.

The upper contact of the Trap Falls Formation is placed below the first occurrence of the ribbon-banded metasediments and the coarse-grained, uniform muscovitic schist (or of their facies equivalent, feldspathic biotite gneiss) that together constitute the Southington Mountain Formation.

ORIGIN

The two most significant features of the Trap Falls Formation are: (1) Except for two or three outcrops containing thin dikes of the characteristic muscovite gneiss, metasediments and muscovite gneiss are conformably interlayered, everywhere and on all scales. (2) The physical continuity of the northwestern and the Shelton facies shows that, even though they are separate in the Ansonia quadrangle, they can be considered as the same unit.

The igneous parentage of the feldspathic muscovite gneiss is not disputed (see plate 3, triangle 5); these rocks either constitute a sill of great areal extent, in which metasedimentary xenoliths are invariably oriented parallel to the sill walls, or they represent a pile of interbedded volcanics and sediments. Although large basic sills are common in many parts of the world, acidic ones are quite rare, presumably because of the relatively high viscosity of silicic magmas. Nonetheless, Ruppel (1963) found that, throughout much of the Basin quadrangle, Montana, the upper surface of the Boulder batholith is in contact with volcanic rocks of a single stratigraphic unit and that many varieties of the batholithic rocks crop out in arcuate bands that are roughly parallel to stratigraphic units in the older, folded rocks. On the other hand, he points out that other studies indicate that the main mass of the Boulder batholith is generally discordant. Moreover, inclusions in the batholith are everywhere sparsely present, range from several centimeters to many feet in diameter, and have gradational contacts with the enclosing rocks. In contrast, feldspathic gneiss in the Trap Falls Formation is, with few exceptions, in conformable layers, the formation as a whole is largely conformable, "inclusions" are everywhere abundant, they range in greatest dimension from centimeters to more than a mile, and they have sharp contacts with the enclosing meta-igneous gneisses. Probably most difficult to reconcile with an intrusive origin are the numerous outcrops of muscovite gneiss that display thin metasedimentary layers, only a few centimeters thick, traceable for many feet and showing no signs of disruption.

These very features, however, point to their origin as interbedded volcanics and sediments. The small-scale interlayering of schist and feldspathic gneiss is most consistent with a pyroclastic origin for the gneiss with composition close to average dellenite (pl. 3, triangle 5). As is also true for the Collinsville Formation, this origin is consistent with the eugeosynclinal setting of these rocks and with the predominantly explosive activity of present-day andesite-line volcanoes in the western Pacific and the Indonesian island arcs.

Normative corundum in the metavolcanics is high as compared to typical acid volcanics and is expressed mineralogically by the high muscovite content. Notably these gneisses cluster toward the quartz-plagioclase side of the composition triangle and approach the composition of zeolitized and albitized volcanic epiclastic and pyroclastic rocks. If this is the correct explanation of the alumina enrichment, it might indicate an originally high proportion of glassy material in the volcanics, favoring post-depositional alteration.

The medium-grained garnetiferous schist and two of the three fine-grained laminated schists plotted on plate 3 (triangle 5) have an alumina content typical of shale but are extremely depleted in normative quartz. The third plots close to the average shale.

Table 7.—Modal analyses (in volume percent) of the Trap Falls Formation[1]

sample[2]	Q[3]	Pl[4]	Mi[5]	Ms[6]	Bio[7]	Di[8]	Hb[9]	Ep	Cc[10]	Clz	Gt[11]	Sil[12]	Sph	Mt	Chl[13]	Ap	Hm	Tm[14]	Fr[15]
LH-22a	33.6	9.5	0.1	—	—	9.9	—	—	38.7	7.7	—	—	0.5	—	—	T	—	—	—
LH-22d	31.1	27.2	32.8	5.8	2.1	—	—	—	—	—	0.4	—	—	—	0.6	T	—	—	—
LH-689	49.8	5.7	—	26.0	13.9	—	—	—	—	—	0.5	—	—	1.3	2.7	0.1	T	—	—
LH-393	37.2	32.5	—	29.3	—	—	—	—	—	—	—	—	0.1	0.6	—	0.4	—	—	—
LH-569	31.0	42.6	22.8	0.6	2.3	—	—	—	—	—	—	—	—	0.1	0.5	0.1	—	—	—
LH-870	18.4	10.2	—	45.3	24.1	—	—	—	—	—	0.8	—	—	1.2	T	—	T	—	—
BP-106a	30.0	43.9	10.2	15.3	—	—	—	—	—	—	—	—	—	—	—	0.1	—	—	0.5
BP-106b	31.9	39.1	15.5	12.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.7
BP-429	33.5	38.1	23.9	3.5	0.2	—	—	—	—	—	0.6	—	—	—	—	0.4	—	—	—
BP-138	—	38.3	—	—	0.7	—	56.9	—	—	—	—	—	3.1	0.1	—	0.3	0.6	—	—
BP-144	22.1	0.9	—	21.1	35.5	—	—	—	—	0.4	8.9	3.4	—	0.9	—	—	—	6.8	—
BP-389	45.3	34.5	—	—	—	—	5.9	—	—	5.6	6.4	—	2.2	—	—	0.1	—	—	—
BP-392	—	34.2	—	—	4.5	—	56.7	1.7	0.3	—	—	—	2.6	—	—	—	—	—	—
BP-417	7.6	8.5	—	59.7	1.3	—	—	—	—	—	11.8	—	—	1.0	8.5	0.1	1.1	0.4	—

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

[2] *Description of samples*:

Northwestern facies:
- LH-22a: Siliceous marble; fg
- LH-22d: Pl-Q-Mi gneiss; fg-mg
- LH-689: Laminated Bio-Ms-Q schist fg

Shelton facies:
- LH-393: Ms-Pl-Q gneiss; mg
- LH-569: Mi-Q-Pl gneiss; fg-mg
- LH-870: Laminated Pl-Q-Bio-Ms schist; fg
- BP-106a: Mi-Ms-Q-Pl gneiss; mg
- BP-106b: Ms-Mi-Q-Pl gneiss; mg
- BP-429: Mi-Q-Pl gneiss; mg
- BP-138: Porphybroblastic amphibolite; fg
- BP-144: Laminated Ms-Q-Bio schist; fg
- BP-389: Feldspathic quartzite; fg-mg
- BP-392: Bio amphibolite; fg-mg
- BP-417: Gt-Ms schist; mg

Texture: Schist, gneiss, marble, and quartzite: foliate in micaceous rocks, more granular in mica-poor rocks; grain contacts mostly mosaic with intergranular implication at some Mi-Ms contacts; Gt and Pl commonly porphyroblastic in nonlaminated schist; lamination in schist due to alternation of quartzose and micaceous laminae. Amphibolite: foliate to nematoblastic, rarely laminated; amphibole axes commonly preferentially oriented; amphibole grains generally subhedral and inclusion free; Pl glomeroblasts with epidotized and kaolinized (?) cores in some specimens; Bio commonly in clots as a primary phase, not replacing Hb.

[3] Mosaic and undulatory extinction about equally as common as uniform extinction in some gneisses; uniform extinction rare in all other rocks.

[4] Polysynthetic twinning generally well developed. Continuous zoned extinction common in amphibolite. Degree of sericitization highly variable. Inclusions of Q common where intimately associated with Mi. Porphyroblasts in schists contain numerous Ms inclusions. An 7, LH-22d; An 8, LH-393, An 11, LH-569, BP-106a, BP-106b; An 12, BP-529; An 18, BP-417; An 42, BP-138; An 44, BP-392; An 94, BP-389; An undertermined, LH-22a, LH-689, LH-870, BP-144.

[5] Unaltered; mosaic to amoeboid grain boundaries; grid twinning well developed.

[6] Large, fg swirls in sample BP-417 suggest complete alteration of either Stau or Sil.

[7] In gneiss and schist: X, pale yellowish brown to light brown; YZ, moderate yellowish or reddish brown to dark reddish brown. Pleochroic halos about tiny zircons (?) in gneiss. In amphibolite: X, colorless; YZ, light brown; in some specimens tends to be associated with Ep and Cal.

[8] As equant grains and subhedral laths lying within the foliation plane.

[9] X, very pale green; Y, moderate yellowish green; Z, light green.

[10] Minor bending of planar features in some grains.

[11] In gneiss and laminated schist occurs as tiny rounded grains singly and in clusters or as elongated blebs. Large porphyroblasts in nonlaminated schist contain numerous tiny inclusions of Q and lesser amounts of Pl and both micas. In quartzite occurs as solid to poikiloblastic rounded masses in contact with and containing all other mineral phases. High grossularite content in latter rock suggested by association with Clz, Sph, and anorthite.

[12] Forms at the expense of Bio and occurs in bundles of relatively coarse prisms.

[13] Forms chiefly at the expense of Bio but also rims Gt in some rocks. XY, pale yellowish green; Z, pale green.

[14] As tiny subhedral to euhedral grains. E, colorless; O, light olive brown.

[15] In amounts less than a few tenths of a percent. Fr-bearing rocks, however, are characterized by distinctive red and green hues.

The few observed dikes of muscovite gneiss are thin offshoots of larger conformable layers and probably represent a eutectic liquid phase formed during metamorphism. This hypothesis is strengthened by the observation that muscovite gneiss of the Shelton facies locally grades directly into structureless pegmatite.

Southington Mountain Formation

GENERAL DISCUSSION

The name Southington Mountain Schist was proposed by Fritts (1962a) for the ribbon-banded schist that underlies Southington Mountain in the Southington quadrangle. All schist lying between The Straits Schist and the Orange Formation was included by Fritts in the Southington Mountain Schist. In the present investigation, however, the upper member of The Straits Schist, the Cooks Pond Schist, and schists belonging to the Trap Falls and Prospect formations have not been considered as part of the Southington Mountain Schist. In addition, that Schist is herein renamed the Southington Mountain *Formation,* inasmuch as in the Long Hill quadrangle the schist is succeeded along strike by facies-equivalent feldspathic biotite gneiss.

Three members of the formation are informally recognized: the staurolite-schist member, the banded-schist member, and the biotite-gneiss member.

The Southington Mountain Formation has almost no topographic expression in the Trap Falls syncline (pl. 1) but underlies strike ridges on both limbs of the Bridgeport syncline. The broad wedge of banded-schist and staurolite-schist members that opens to the west in the Bridgeport quadrangle underlies irregularly scalloped hills. These are elongated approximately N-S, apparently a result of the nearly 90° divergence between regional strike and the movement direction of Pleistocene ice sheets.

STAUROLITE-SCHIST MEMBER

The staurolite-schist member is best displayed in a roadcut along White Plains Road, 0.9 mi. S of the Merritt Parkway (fig. 3, BP-2-6), here designated its reference locality. It is composed chiefly of uniform, rusty-weathering, medium- to coarse-grained, graphitic garnet-plagioclase-biotite-muscovite-quartz schist (table 8) identical to the principal rock type of the lower member of The Straits Schist. Staurolite, and to a lesser extent, kyanite, although not modally abundant, are readily observed at most outcrops as large sericitized porphyroblasts; staurolite is more prominent in this member than in any other unit in the area. Accompanying the uniform schist are minor amounts of fine-grained, biotitic to pure quartzite and thinly laminated to thinly bedded amphibolite. The amphibolite generally occurs close to the upper contact of the unit and at the type locality is underlain directly by several inches of calcite marble and calc-silicate rock. The quartzite beds are of variable thickness and are interbedded with the uniform schist and quartzose biotitic gneiss. Like the amphibolite, the quartzite lies near the top of the unit. Banded rocks, characteristic of the overlying banded-schist member, are rarely observed.

Table 8.—Modal analyses (in volume percent) of the Southington Mountain Formation[1]

sample[2]	Q[3]	Pl[4]	Mi[5]	Ms[6]	Bio[7]	Hp[8]	Ep	Clz	Gt[9]	Ky[10]	Stau[11]	Sph[12]	Mt	Chl[13]	Ap	Hm	Tm[14]
BP-474	39.6	6.1	—	34.9	5.2	—	T	—	1.5	0.4	0.2	0.2	2.2[15]	9.0	0.7	—	T
BP-484	45.2	6.1	—	36.7	4.3	—	—	—	T	—	—	0.3	0.9[15]	6.5	T	—	—
BP-348a	39.9	26.5	—	14.2	16.7	—	0.2	T	0.3	—	—	—	1.0	0.8	0.1	0.1	0.2
BP-348b	21.2	16.3	—	32.8	23.1	—	—	—	2.5	—	—	—	0.7	2.6	0.7	0.1	T
LH-570	31.8	8.3	—	24.8	16.9	—	T	—	7.7	—	—	—	1.4	8.6	0.1	0.4	—
LH-9	23.3	41.8	5.0	—	17.1	9.6	0.3	—	0.5	—	—	1.7	T	T	0.6	0.1	—
LH-136	28.8	39.7	4.9	—	20.6	2.7	0.2	—	1.2	—	—	1.1	—	0.1	0.6	0.1	—

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

[2] *Description of samples*:

Staurolite-schist member:
  BP-474: Ms-Q schist; mg
  BP-484: Ms-Q schist; mg
Banded-schist member:
  BP-348a: Ms-Bio-Pl-Q gneiss; fg
  BP-348b: Pl-Q-Bio-Ms schist; fg
  LH-570: Bio-Ms-Q schist; mg
Biotite-gneiss member:
  LH-9: Bio-Q-Pl augen gneiss; mg
  LH-136: Bio-Q-Pl augen gneiss; mg

Texture: Foliate; grain contacts ungranulated and generally mosaic; crinkling widespread in schist.

[3] Undulatory extinction common in all specimens

[4] Slightly to moderately sericitized. Twinning much more common in biotite gneiss member than in metasedimentary units. Occurs commonly as augen in biotite-gneiss member. An 16, BP-484; An 18, BP-474, BP-348a; An 32, LH-9; An 35, LH-136; An undetermined, BP-348b, LH-570

[5] Chiefly as grains similar in size to other phases and as optically continuous patches in Pl.

[6] In sample BP-484, 18 percent of the Ms is in augen-shaped patches of sericite which probably represent the complete alteration of Stau and Ky.

[7] In schist and quartzose gneiss: X, colorless; YZ, dark reddish brown. In biotite-gneiss member: X, grayish yellow; YZ, moderate brown.

[8] X, grayish yellow green; Y, grayish olive green; Z, dusky yellowish green.

[9] In feldspathic gneiss occurs as small rounded grains; in schistose rocks as large poikiloblastic grains commonly sheathed in chlorite and sericite. Divergence of lines of inclusions from plane of foliation indicates passive rotation of some grains subsequent to recrystallization.

[10] Elongate blades sheathed in sericite.

[11] Augenlike elongate grains sheathed in sericite bearing tiny flakes of Mag. Pleochroic from colorless to grayish orange.

[12] Tends to be associated principally with mafic minerals in some feldspathic gneiss.

[13] A retrogressive phase replacing Bio and Gt.

[14] E, colorless; O, moderate olive brown to olive gray. Commonly zoned; the inner core exhibits either a darker olive brown or a grayish blue green.

[15] Includes graphite.

The upper contact of the staurolite-schist member is placed where uniform schist and associated quartzite and amphibolite are succeeded by ribbon-banded schist and paragneiss typical of the banded-schist member. The staurolite-schist member pinches out northward between the Trap Falls Formation and the banded-schist member. The northernmost exposure is along the low ridge flanking the east shore of Frog Pond (BP-3-1).

BANDED-SCHIST MEMBER

The first outcrop along White Plains Road south of the reference locality for the staurolite-schist member is here designated the reference locality for the banded-schist member.

Two belts of this member were mapped; no systematic differences between them were detected. The northernmost and principal belt is the southern continuation of a strip mapped as Southington Mountain Schist by Fritts (1965a) who traced it around the hinge of the NE-plunging Shelton anticline. The schist on the western limb of the anticline interfingers with the biotite-gneiss member at the etxreme eastern edge of the Long Hill quadrangle (fig. 3, LH-6-6) and is totally replaced by it farther to the southwest along strike. The schist on the eastern limb can be traced continuously through the Long Hill and Bridgeport quadrangles and into the Westport quadrangle. The southeastern and narrower belt is also continuous with a unit mapped by Fritts (1965a, 1965b) as Southington Mountain Schist, although a strip of this belt is here considered a separate formation, the Cooks Pond Schist.

The banded-schist member in both belts is typically a thinly layered unit composed of alternating layers of medium- to coarse-grained garnet-plagioclase-biotite-muscovite-quartz schist and finer grained quartzose and feldspathic biotite gneiss (see table 8), very much like the upper member of The Straits Schist. In many places the alternation is between schists that differ in muscovite/biotite ratio and in the abundance of garnet—but whatever the lithology, it is the thin layering, ranging generally from a few inches to 2 ft, that is characteristic; only rarely is uniform schist encountered. Such thinly layered schist has been described as "ribbon-banded" by Fritts (1962a).

The upper contact of the banded-schist member is drawn below the first occurrence of porphyroblastic biotite-microcline-quartz-plagioclase gneiss typical of the overlying Pumpkin Ground Member of the Prospect Formation, although the two are interlayered over a vertical distance of about 40 ft. This interlayered zone is well exposed at the northern end of Beardsley Park (BP-2-6) and also behind the Nathan Hale School (BP-4-6).

BIOTITE-GNEISS MEMBER

A reference locality for the biotite-gneiss member is the triangular intersection of Willoughby Road and Shelton Avenue near the eastern edge of the Long Hill quadrangle (fig. 3, LH-6-6).

In the Long Hill quadrangle the biotite-gneiss member is restricted to the Trap Falls syncline. On the eastern limb of the syncline it is interlayered with the banded-schist member over a strike distance of about 1,500 ft at the eastern edge of the quadrangle. Farther north, in the Ansonia quadrangle, it is completely replaced by the banded-schist in what is here interpreted as a facies relationship between the two members. On the western limb of the syncline the biotite-gneiss member can be traced northward into the Ansonia quadrangle where it was mapped as Prospect Gneiss by Fritts (1965a).

The biotite-gneiss member is composed largely of medium- to coarse-grained feldspathic biotite gneiss typically containing a small amount of garnet and hornblende and characterized by plagioclase augen (see table 8). The content of mafic minerals is variable and defines a layering in which mafic-poor and mafic-rich layers alternate. Muscovite is locally conspicuous in nonhornblendic, mafic-poor layers.

The upper contact of the biotite-gneiss member is drawn below the first occurrence of porphyroblastic biotite-microcline-quartz-plagioclase gneiss of the overlying Pumpkin Ground Member of the Prospect Formation.

ORIGIN

CIPW norms of the Southington Mountain Formation are plotted in plate 3, triangle 6. The biotite-gneiss member represents normal rhyodacite. Facies-equivalent metasediments represent shale (staurolite-schist member) and shale and graywacke (banded-schist member), including minor chert and basic tuff (quartzite and amphibolite).

Prospect Formation

GENERAL DISCUSSION

The name Prospect Porphyritic Gneiss was first used by Rice and Gregory (1906) for the "light gray porphyritic gneiss which occupies a triangular area in the towns of Prospect, Cheshire and Southington, limited eastward by the Triassic strata, and extends south as a belt of varying width through Derby, Huntington (Shelton) and Stratford." They recognized that the gneiss is not everywhere porphyritic and that the formation includes narrow bands of mica schist. The Prospect, as so defined, is shown as formation 9 on the 1907 preliminary geological map of Connecticut (Gregory and Robinson), although it is more accurately delineated on Percival's map (1842).

Stewart (1935) changed the southern end of the eastern boundary and extended the Prospect to include a body of gneiss cropping out in Fairfield and Westport that had been shown as Danbury Granodiorite Gneiss on the 1907 state map. He noted that the western contact was only approximate because of interlayering of the porphyritic gneiss with other rock types.

In the Naugatuck quadrangle Carr (1960) mapped two separate bodies of Prospect Gneiss. Both can be traced directly into the Long Hill quadrangle where they are considered to be separate formations. The northwestern body, the Collinsville Formation, is demonstrably equivalent to

Table 9.—Modal analyses (in volume percent) of the Prospect Formation[1]

sample[2]	Q[3]	Pl[4]	Mi[5]	Ms	Phl[6]	Bio[7]	Di[8]	Hb[9]	Ac-Tr[10]	Ep[11]	Cc[12]	Clz	Gar[13]	Sph[14]	Mt	Chl[15]	Ap[16]	Hm	Tm[17]	Py
BP-71	34.2	37.4	17.4	2.6	—	5.9	—	—	—	—	0.1	—	—	T	—	2.0	0.4	—	—	—
BP-194	27.4	38.8	10.7	2.8	—	18.9	—	—	—	0.5	—	—	—	0.7	0.1	—	0.1	T	—	—
BP-267	26.0	46.9	4.3	0.5	—	20.8	—	—	—	—	—	—	—	0.2	—	T	0.7	0.6	—	—
BP-343	31.5	32.5	21.0	1.8	—	12.9	—	—	—	—	—	—	—	—	—	0.4	0.2	—	—	—
LH-627a	36.7	41.7	2.2	1.6	—	16.9	—	—	—	—	—	—	—	—	0.6	—	0.3	—	—	—
BP-196	16.2	34.3	20.2	—	—	8.9	—	14.3	—	5.8	—	—	—	0.5	—	—	—	—	—	0.2
BP-211	13.3	36.2	21.7	—	—	8.8	—	11.2	—	7.5	—	—	—	0.4	—	—	0.6	—	—	0.3
BP-274	15.4	37.7	18.8	—	—	12.4	—	11.3	—	3.3	—	—	—	0.7	—	—	0.3	—	—	0.1
BP-276	38.3	6.5	—	35.9	—	13.7	—	—	—	—	—	—	2.4	—	1.3	1.0	—	—	0.9	—
BP-305	—	—	6.1	—	—	—	90.6	—	—	—	0.5	0.8	—	0.8	—	—	—	—	—	1.2
BP-320	42.5	14.5	—	—	11.9	—	—	—	3.2	—	23.5	0.7	—	0.3	—	—	0.2	—	—	3.2

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

[2] *Description of samples*:

Pumpkin Ground Member
- BP-71, porphyroblastic Mi-Q-Pl gneiss, fg
- BP-194, porphyroblastic Mi-Bio-Q-Pl gneiss, mg
- BP-267, porphyroblastic Bio-Q-Pl gneiss, mg
- BP-343, porphyroblastic Bio-Mi-Q-Pl gneiss, mg
- LH-267a, porphyroblastic Bio-Q-Pl gneiss, mg

Beardsley Gneiss Member
- BP-196, porphyroblastic Hb-Q-Mi-Pl gneiss, mg
- BP-211, porphyroblastic Hb-Q-Mi-Pl gneiss, mg
- BP-274, Hb-Bio-Q-Mi-Pl gneiss, mg

Golden Hill Schist Member
- BP-276, Bio-Q-Ms schist, fg-mg

Calcareous member
- BP-305, Calc-silicate rock, fg
- BP-320, Calcareous phlogopitic quartzite, fg-mg

Texture: Granular in calc-silicate rock, foliate in schist, foliate to granular in gneiss (although tending toward nematoblastic in some horblendic gneiss). Grain contacts ungranulated and generally mosaic except for complex implicate relationships among Q, Pl, and Mi grains surrounding Mi megacrysts in porphyroblastic rocks. Strong lineation in hornblendic rocks expressed by all major minerals except large Mi megacrysts and Ep. Lineation in Pumpkin Ground Member expressed by groundmass Q and feldspar rodding and Bio streaming. Porphyroblasts are both large Carlsbad-twinned Mi crystals and clusters of smaller optically unrelated grains. Crinkling is widespread in schist.

[3] Undulatory extinction common in all specimens

[4] Slightly to moderately sericitized. Twinning much more common in feldspathic gneiss than in metasediments. As inclusions within Mi of the Beardsley Gneiss Member, commonly occurring as highly altered poikiloblastic grains with thin unaltered overgrowths. An 23, BP-196, BP-211; An 27, BP-343; An 30, BP-71, BP-194; An 33, BP-274; An 34, BP-267; An 35, LH-627a; An undetermined, BP-320.

[5] In porphyroblastic rocks all megacrysts as well as some smaller grains have myrmekite rims which appear as whitish borders in hand specimen. Megacrysts bear inclusions of all other minerals. In calc-silicate rocks as small grid-twinned grains disseminated ubiquitously throughout the rock.

[6] X, colorless; YZ, light brown

[7] In schist and nonhornblendic gneiss: X, colorless to yellowish gray; YZ, dark reddish brown. In Beardsley Gneiss Member: X, light yellow; YZ, dark olive green; commonly associated with Hb and Ep but appears to be a primary phase in this member.

[8] As subhedral laths and rounded grains

[9] Contains inclusions of Bio, Ep, Gt, Sph, Ap, and Q. X, light brownish yellow; Y, dark yellow green; Z, deep blue green. Commonly twinned on $\{100\}$.

[10] In sample BP-320 as ragged laths bearing inclusions of all other phases.

[11] Important mineral in the Beardsley Gneiss Member, where it occurs as a fg, anhedral to subhedral primary phase, in a few cases twinned on $\{100\}$.

[12] As unstrained grains showing little twinning

[13] As large poikiloblastic grains; inclusions are chiefly Q

[14] Commonly in clusters with Ap and associated with Bio in Pumpkin Ground Member.

[15] As a retrogressive phase replacing Bio

[16] Commonly in clusters with Sph and associated with Bio in Pumpkin Ground Member.

[17] E, colorless; O, moderate olive brown, commonly zoned, with inner core exhibiting a grayish blue green

the uppermost Waterbury Gneiss described by Carr. The body to the southeast is physically continuous with rocks in the Long Hill and Bridgeport quadrangles that are herein assigned to the Prospect Formation. It can be distinguished from the Collinsville Formation on the following grounds: 1) It is nowhere in contact with The Straits Schist except locally in the Naugatuck quadrangle, where normal faulting has dropped it against older rocks. 2) Its most distinctive rock type is biotite-quartz-feldspar gneiss bearing numerous, large well twinned microcline megacrysts, in contrast to the chief rock type of the Collinsville Formation that rarely includes microcline megacrysts but has segregation banding in which quartzo-feldspathic and biotitic layers alternate.

Fritts (1963a, 1963b, 1965a) also mapped the northwestern belt as Prospect Gneiss. However, unlike Carr, he considered the interlayered schist and other metasediments as Southington Mountain Schist. The present investigation has shown that, as in the Trap Falls Formation, these schists are intimately associated with the feldspathic gneisses and are more reasonably mapped with them as a single formation.

Three formal members and one informal member are recognized. Because there is no small area where they are all well exposed, reference localities are given for each member rather than for the formation as a whole.

Topographic expression of the Prospect Formation is most marked close to the axial trace of the Bridgeport syncline where ridges and hills are elongated parallel to the regional strike.

PUMPKIN GROUND MEMBER

The Pumpkin Ground Member is named for outcrops northeast of Pumpkin Ground Brook in northern Stratford (fig. 3, BP-3-3), here designated the type locality.

Typically this member underlies bold strike ridges broken by cross joints into lines of steep-sided hills, forming a rugged topography that is relatively sparsely settled even within the city limits of Bridgeport.

The most common rock type in this member is medium-grained, moderately well foliated, medium-gray biotite-quartz-microcline-plagioclase gneiss (see table 9) bearing numerous, large, euhedral megacrysts of Carlsbad-twinned microcline averaging 3 cm by 1½ cm. Many variations occur, however. Locally, the rock is massive with no apparent foliation. The megacrysts vary from light to medium gray and from much less than 3 by 1½ cm to more than twice this average size; some outcrops seem stuffed with them—in others they are completely absent. They vary from euhedral crystals to round augen to stretched augen that locally merge into thin feldspathic laminae parallel to the foliation in layers that have been extremely thinned. In places the rock carries muscovite and, very rarely, garnet; an increase in muscovite seems to be correlated with a decrease in microcline.

Generally there is a strong mineral lineation expressed by elongation of groundmass quartz, feldspar, and biotite. Most of the microcline megacrysts have their twin planes parallel to foliation but are otherwise nonoriented except where they are in the form of augen.

About 10 percent of the exposed Pumpkin Ground Member is composed of muscovitic and biotitic schist, feldspathic and quartzose biotite gneiss, garnet-muscovite-quartz-feldspar gneiss and minor micaceous quartzite. Between Willoughby Road and the eastern boundary of the Long Hill quadrangle (LH-6-6) the micaceous quartzite is associated with fine-grained, tough, muscovitic and biotitic schists weathering deep rusty red; pods of fine-grained kyanite stand out in bold relief on weathered surfaces. On strike to the northeast in the Ansonia quadrangle Fritts (1965a) has separately mapped these various rock types as inclusions of Southington Mountain Schist and intrusions of Ansonia Gneiss. However, in the present report they are all mapped as Pumpkin Ground Member for reasons discussed in the preceding section.

Locally, in the Trap Falls syncline, the biotite-gneiss member of the Southington Mountain Formation pinches out and the Pumpkin Ground Member rests directly on the Trap Falls Formation.

The upper contact of the Pumpkin Ground Member is drawn where light biotitic gneiss is succeeded by dark hornblendic gneiss typical of the overlying Beardsley Gneiss. Locally the contact is a zone of interlayering; there the boundary is arbitrarily drawn so that from 75 to 100 percent of the interlayered zone is assigned to the Pumpkin Ground Member.

BEARDSLEY GNEISS MEMBER

The Beardsley Gneiss Member is well exposed in the hills of Beardsley Park east of Bunnells Pond (fig. 3, BP-2-9); this area is hereby designated the type locality.

The Beardsley Gneiss is a very homogeneous member (see table 9), composed almost exclusively of epidote-biotite-hornblende-quartz-microcline-plagioclase gneiss (referred to hereafter as biotite-hornblende gneiss). Very minor amounts of biotite-quartz feldspar gneiss are found in proximity to and generally on strike with the Ansonia Gneiss. The predominant biotite-hornblende gneiss is texturally similar to the underlying porphyroblastic gneiss of the Pumpkin Ground Member. Both commonly contain microcline megacrysts or augen varying widely in size and abundance—their average size is less in this member and they are commonly pink. Elongation of hornblende and biotite is nearly universal and gives the rock a lineation locally so intense as to obscure the foliation. The biotite-hornblende gneiss is accompanied throughout by pods and lenses much richer in hornblende and hence much darker than the host rock. These vary in longest dimension from 2-3 in. to a little over 1 ft and are everywhere elongate parallel to the pervasive mineral lineation. The distribution of these "mafic streaks" precludes their formation by the pulling apart of a pre-existing continuous layer. Whatever their origin, it is clear that they were present as numerous, discrete, mafic bodies in the unmetamorphosed parent rock. Locally, where very rich in hornblende, they are rimmed by a thin biotitic zone. Unique also to this

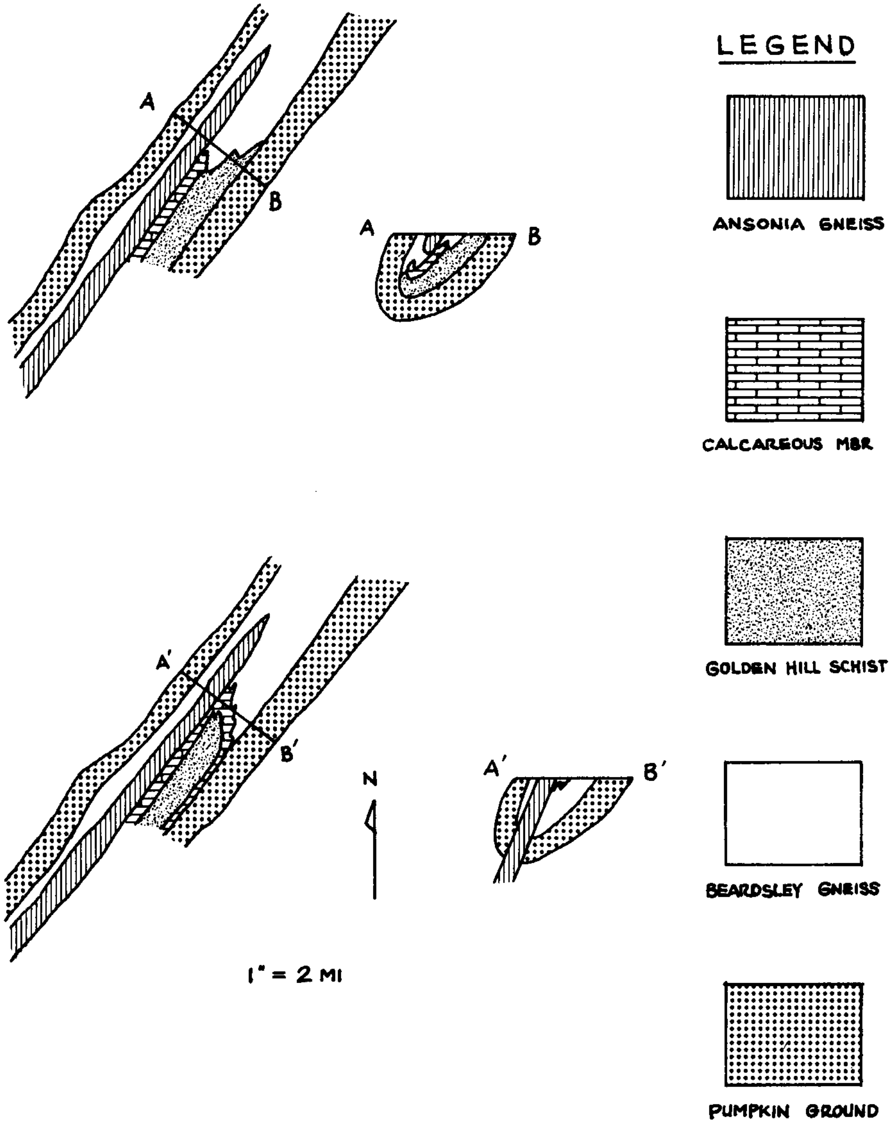

Fig. 4. Alternate interpretations of the rocks in the southern end of the Bridgeport syncline.

member is pink pegmatite in clots and veins, both conformable and cross cutting. Less common, but distinctive, are epidote-rich veins and pods.

Along strike to the south, the Beardsley Gneiss Member is replaced by the Golden Hill Schist and calcareous members of the Prospect Formation on the southeastern limb of the Bridgeport syncline (pl. 2); the transition zone, however, is covered. Information from closely spaced drill holes (in a line extending from Seeleys Pond, BP-5-1, south to the intersection of Main Street and Washington Avenue) indicates that the Ansonia Gneiss is succeeded on the southeast by rocks of the Golden Hill Schist Member, with a single occurrence of Beardsley Gneiss about half way between Read and Columbus schools. This occurrence and an outcrop just northeast of the County Jail (BP-5-4) are the only evidence for interfingering of the Golden Hill Schist Member (and, presumably, the calcareous member as well) with the Beardsley Gneiss. This interfingering suggests a facies relationship between the Golden Hill and the Beardsley—a suggestion weakened, however, by the lack of evidence for a similar transition on the northwestern limb of the Bridgeport syncline. An alternate hypothesis is illustrated in figure 4, which interprets the Golden Hill Schist as a higher stratigraphic unit, occupying the keel of the syncline, and the Ansonia Gneiss as a synkinematic intrusive granite. The absence of Beardsley Gneiss in the southeastern limb could be explained by either stratigraphic or tectonic pinchout. However, three additional observations support the facies concept: 1) The contact between the Pumpkin Ground Member and the Golden Hill Schist Member, exposed on the eastern flank of Golden Hill[1] (BP-5-7), is exactly on strike with the contact between the Pumpkin Ground and the Beardsley Gneiss to the northeast, south of Success Lake (BP-5-3). 2) There is no evidence of repetition of the calcareous member in a fold. 3) As the Bridgeport syncline is traced northeastward, only Pumpkin Ground Member is present as far north as the Housatonic River in the Ansonia quadrangle (see pl. 4). North of the Housatonic the reappearance of Beardsley Gneiss in a N-plunging syncline succeeded northward by Ansonia Gneiss, is a duplication of the Bridgeport-syncline stratigraphy. It suggests that the Ansonia Gneiss is a stratigraphic unit or that it is a sill, rather than a cross-cutting granite.

The upper contact of the Beardsley Gneiss Member is drawn at the first appearance of muscovite gneiss typical of the overlying Ansonia Gneiss.

GOLDEN HILL SCHIST MEMBER

The type locality for the Golden Hill Schist Member is 300 ft east of the northern termination of Harral Avenue in the Golden Hill section of Bridgeport (fig. 3, BP-5-4).

This member is composed chiefly of medium- to coarse-grained garnet-plagioclase-biotite-muscovite-quartz schist (table 9). Finer grained

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[1] During trenching operations connected with construction work, the Golden Hill Schist Member was exposed in a cut 15 ft long just 20 ft north of an outcrop of Pumpkin Ground Member northeast of the landmark building (BP-5-5) designated Central High School (now City Hall).

garnet-muscovite-biotite-plagioclase-quartz gneiss and quartzite are interlayered with the schist on a scale ranging from 2-3 in. to 2 ft; these rock types, however, are everywhere subordinate in amount. The quartzite, which is generally garnetiferous and/or micaceous, is more prominent to the south. Except for its interlayered quartzite this member resembles the banded-schist member of the Southington Mountain Formation.

The Golden Hill Schist Member is overlain on the northwest by the limy metasediments of the calcareous member; the contact is nowhere exposed.

CALCAREOUS MEMBER

The informal calcareous member is best exposed in a field on the west side of Fairfield Avenue just south of the Ash Creek Bridge (fig. 3, BP-7-4); this is designated the type locality.

Underlying a narrow strip between the Golden Hill Schist Member and the Ansonia Gneiss, the calcareous member is composed of thin to thick beds of rusty-weathering, punky biotite schist, coarse-grained, graphitic biotite-muscovite-quartz schist, medium-grained felsic biotite gneiss, pyritiferous calc-silicate quartz rock, and thin bands of impure calcite marble (see table 9).

The upper contact of the calcareous member is drawn at the first appearance of homogeneous muscovite gneiss typical of the overlying Ansonia Gneiss.

ORIGIN

Whether the "Prospect Gneiss" occupies a consistent stratigraphic position is disputed. Carr (1960) noted its restriction to the belt of what he called "undifferentiated Hartland"; Fritts (1962a) mapped the Prospect as stocklike bodies, including in it rocks that are considered in this report to belong to the Collinsville Formation, the biotite-gneiss member of the Southington Mountain Formation, and the feldspathic gneisses of the Prospect Formation (Pumpkin Ground and Beardsley Gneiss members). Because all of these units maintain constant stratigraphic positions the discussion of the origin of the Trap Falls Formation is applicable to that of the Prospect Formation; this includes the observation that there are very thin conformable metasedimentary layers traceable for many feet, with no sign of disruption, through feldspathic gneiss.

In addition to his argument based on the shape and distribution of the gneiss bodies, Fritts (1962b) supported, with several interesting petrologic observations, the idea of an intrusive origin for the Prospect Gneiss. He argues that vesuvianite and wollastonite in calc-silicate rocks near the contact of the Prospect Gneiss with the Southington Mountain Schist can be interpreted as contact-metamorphic minerals. On his map of the Southington quadrangle are five such calc-silicate bodies, all within an area of 0.3 sq. mi. It is generally true that the principal mode of occurrence of vesuvianite and wollastonite is in calcareous rocks of contact-metamorphic aureoles. Nevertheless, Deer and others (1962) report vesuvianite also in regionally metamorphosed limestones and conclude that it appears to be stable over a wide metamorphic-temperature range (see also Chatterjee, 1962). Misch (1964), moreover, has described the widespread development of wollastonite from the amphibolite facies of Barrovian metamorphism in Nanga Parbat in the northern Himalayas, and Harker (1932, p. 254) cites wollastonite associated with grossularite and vesuvianite in the Loch Tay Limestone within the garnet zone of regional metamorphism in the Scottish Highlands.

Fritts also cites the following evidence of an earlier contact metamorphism "(1) graphite, which is fine-grained and abundant in Southington Mountain Schist away from Prospect Gneiss, is coarser and less abundant in the schist near the gneiss and (2) moscovite and garnet in the schist near the gneiss are coarser than in the schist in the type area," although he qualifies these statements with the observation that "in most places evidence of early metamorphism is obscured by superimposed progressive regional metamorphism." In view of this qualification there is no way of determining how common and hence how significant these phenomena are. Observations in the Long Hill and Bridgeport quadrangles indicate that the grain size of certain minerals is stratigraphically controlled, bearing no relation to proximity of the meta-igneous rocks under discussion.

CIPW norms of the Prospect Formation are plotted in plate 3, triangle 7. The Beardsley Gneiss plots as quartz-deficient dellenite. Facies-equivalent metasediments represent shale with minor graywacke and chert (Golden Hill Schist Member) and limy sediments (calcareous member). Feldspathic gneisses of the Pumpkin Ground Member plot as a scatter about dellenite, and as they are intimately interlayered with metasediments representing shales and graywackes, probably are the result of eruptive volcanic activity for the reasons given in the discussion of the Collinsville and Trap Falls formations. Interbedded metasediments are rare in the Beardsley Gneiss Member, and hence it could be argued that it consists largely of flows; however, the widespread occurrence of "mafic streaks" with their resemblance to volcanic bombs lend support to the theory of a pyroclastic origin.

Ansonia Gneiss

GENERAL DISCUSSION

Beginning a short distance northwest of Bunnells Pond (fig. 3, BP-2-9), a belt of Ansonia Gneiss occupies the keel of the SW-plunging Bridgeport syncline. This gneiss belt corresponds to "D3" of Percival (1842) and was shown as Thomaston Granite-gneiss on the 1907 state map (Gregory and Robinson). A smaller mass crops out farther northeast along strike, and the intervening ground is underlain by numerous pods of gneiss resembling the Ansonia, too small to show on the geologic map (pl. 2). Correlation of this belt with the Ansonia Gneiss of Fritts (1962a) is based on its stratigraphic equivalence to the type Ansonia in the northern part of the Ansonia quadrangle as well as on its lithologic resemblance to the granitic gneiss exposed there. The quarry just east of the intersection of

East Main Street and Broadbridge Road in Bridgeport (BP-2-9) is designated a reference locality.

The Ansonia Gneiss lies entirely within the city limits of Bridgeport and has very little topographic expression. Its upper contact is not exposed in either the Long Hill or Bridgeport quadrangle.

LITHOLOGY

The Ansonia Gneiss is composed entirely of homogeneous, very well foliated, fine- to medium-grained, tan-weathering biotite-muscovite-microcline-quartz-plagioclase gneiss, locally lacking muscovite and rarely bearing garnet (see table 10). Fresh surfaces are light bluish gray. Biotite flakes are characteristically much smaller than muscovite flakes. The rock is strongly lineated due to elongation of mica flakes. Its homogeneity and pleasing appearance make it an excellent dimension stone. Dale and Gregory (1911) and Dale (1923) have described the detailed structure and petrology of two formerly active quarries in the Ansonia.

Table 10.—Modal analyses (in volume percent) of the Ansonia Gneiss[1]

sample[2]	Q[3]	Pl[4]	Mi[5]	Ms	Bio[6]	Ep	Gt[7]	Sph	Mt	Chl[8]	Ap	Hm
BP-200	25.4	36.0	26.3	4.8	2.6	1.7	—	0.1	0.6	2.3	0.2	—
BP-286	26.6	38.9	25.9	4.4	2.7	—	T	—	0.2	1.2	0.1	—
BP-314	31.1	29.6	27.8	6.8	3.7	—	—	—	—	0.1	0.1	0.8
BP-335	30.7	32.1	25.3	8.6	3.0	T	0.2	—	—	—	0.1	—

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

[2] *Description of samples:*

BP-200: Q-Mi-Pl gneiss; mg
BP-286: Mi-Q-Pl gneiss; mg
BP-314: Mi-Pl-Q gneiss; mg
BP-335: Mi-Q-Pl gneiss; mg

Texture: Foliate; grain contacts mostly mosaic. Mi composites and Q elongated in foliation. Myrmekite rims around Mi very rare; complex implicate contacts in Mi-Pl-Q clusters somewhat commoner.

[3] Mosaic and undulatory extinction about equally as common as uniform extinction.

[4] Polysynthetic twinning variably developed. Inclusion of Q common where intimately associated with Mi. An 13, BP-314; An 16, BP-200, BP-286; An 20, BP-335.

[5] Unaltered; mosaic to amoeboid grain boundaries; grid twinning well developed.

[6] X, pale yellowish brown to light brown; YZ, yellowish brown to dusky yellow to dark reddish brown to olive gray.

[7] As tiny rounded grains.

[8] Forms at the expense of Bio. XY, pale yellowish green; Z, pale green.

ORIGIN

CIPW norms of the Ansonia Gneiss are plotted in plate 3, triangle 8; they range from rhyolite to dellenite. A volcanic origin is consistent with the stratigraphic character of the Ansonia but does not fully account for its relative chemical homogeneity and the absence of layering. Very fine-grained tephra settling out from the atmosphere could have produced such a rock. However, this would have been such a slow process that one would expect to find contemporaneous clastic sedimentation, of which there is no trace. Alternatively, the Ansonia could be a synorogenic adamellite sill.

STRATIGRAPHIC UNITS OF UNCERTAIN RELATIVE AGE

Cooks Pond Schist

GENERAL DISCUSSION

The name Cooks Pond Schist is assigned to rocks cropping out immediately west and south of Cooks Pond (fig. 3, BP-3-3) in northern Stratford, here designated the type locality. In the adjacent Milford quadrangle and in the southern half of the Ansonia quadrangle Fritts (1965a, 1965b) did not recognize the Cooks Pond as a separate formation; in the northern part of the Ansonia quadrangle, however, he mapped it as Southington Mountain Schist.

Ridges and valleys are elongated along the strike of the schist north of Cooks Pond; to the south, however, bedrock does not control the topography.

LITHOLOGY

The Cooks Pond Schist is a uniform, fine-grained, rusty-weathering biotite-muscovite-quartz schist (table 11) with a distinctive sheen due to abundant fine-grained graphite interleaved with mica. Its western contact is placed at the first outcrop of interbedded nongraphitic schist and paragneiss characteristic of the banded-schist member of the Southington Mountain Formation. Its eastern contact is described below under the Orange Formation.

ORIGIN

The CIPW norm of the one analysis made of the Cooks Pond Schist is plotted in plate 3, triangle 9. Its shale parentage is clearly shown but, like much of the schist in the Long Hill and Bridgeport quadrangles, its quartz content is anomalously low.

Orange Formation

GENERAL DISCUSSION

The name Orange Phyllite was originally proposed by Rice and Gregory (1906, p. 101) for the belt of rock between the Prospect Porphyritic Gneiss and the Milford Chlorite Schist (Prospect Formation and Milford Formation of this report). Fritts (1962a) presented evidence of an important unconformity within the Orange that separates Siluro-Devonian rocks from underlying Cambro-Ordovician rocks, and on this basis urged abandonment of the name Orange Phyllite. He assigned the name Wepawaug Schist to that part of the Orange above the unconformity and split the remainder into Southington Mountain Schist and Derby Hill Schist (including the Oronoque Member and an unnamed

Table 11.—Modal analyses (in volume percent) of the Orange Formation and the Cooks Pond Schist[1]

sample[2]	Q[3]	Pl[4]	Mi[5]	Ms	Bio[6]	Hb[7]	Ep	Gt	Stau[8]	Mt[9]	Chl[10]	Ap	Tm[11]
BP-157	36.4	29.1	0.6	17.4	11.9	—	—	—	—	0.3	4.0	0.3	—
BP-163	12.6	13.1	4.7	48.1	1.7	—	0.1	T	3.0	2.1	14.4	0.2	—
BP-167	19.8	14.8	—	—	0.1	52.9	0.1	—	—	10.7	0.7	0.9	—
BP-171	29.5	60.6	—	7.1	2.7	—	—	—	—	—	—	0.1	—
BP-89	43.9	1.1	—	29.9	11.7	—	—	2.2	0.1	2.5[12]	8.2	T	0.4

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

[2] *Description of samples*:

Orange Formation

BP-157: Gneissic "pinstripe"; fg

BP-163: Schistose "pinstripe"; fg-mg

BP-167: Mt-Q amphibolite; mg

BP-171: Bio-Ms-Q-Pl augen gneiss; matrix fg

Cooks Pond Schist

BP-89: Bio-Ms-Q schist; fg-mg

Texture: Foliate in all rock types. Segregation of minerals into quartzo-feldspathic and micaceous laminae in "pinstripe." Porphyroblastic Q and Pl in augen gneiss. Chief minerals uniformly distributed in other rock types. Hb poikiloblastic and is preferentially oriented in some outcrops. Grain contacts mosaic and ungranulated; however, simple implicate pattern occurs in Q-cluster megacrysts in augen gneiss.

[3] Uniform to slightly undulatory extinction in amphibolite; undulatory in "pinstripe" and augen gneiss. Q megacrysts in augen gneiss strongly marked by numerous tiny bubble inclusions arranged in parallel planes.

[4] In amphibolite generally untwinned but extinguishes zonally; untwinned and moderately sericitized in other rocks. Matrix Pl anhedral and untwinned in augen gneiss; Pl megacrysts well twinned with bent lamellae and mosaic extinction in some, but inclusion free. An 10 to An 15, BP-157, BP-163; An 18 in augen of BP-171; An 35 in BP-167; An undetermined in matrix of BP-171 and in BP-89.

[5] As elongate augen completely rimmed by Bio or by Chl retrogressive after Bio. Some grains show grid twinning; all extinguish patchily or sweepingly.

[6] In "pinstripe": X, grayish yellow; YZ, grayish olive. In augen gneiss and Cooks Pond Schist: X, colorless, YZ, moderate brown (5 YR 3/4). In amphibolite: X, moderate greenish yellow; YZ, grayish olive green.

[7] Contains numerous tiny inclusions of Q and Mt. X, yellowish gray; Y, dark yellowish green; Z, grayish yellow.

[8] Partially altered to fg sericite. XY, pale greenish yellow; Z, grayish yellow.

[9] In amphibolite as elongate tiny blades and subhedral large-size crystals.

[10] Appears to be a primary phase in amphibolite; XY, pale greenish yellow; Z, pale yellowish green—clinochlore (?). Retrogressive after Bio and Gt in other rocks; XY, moderate greenish yellow; Z, moderate yellowish green.

[11] E, colorless; O, moderate olive brown.

[12] Includes graphite

member). The presence of the unconformity is denied in this report and the Oronoque Member of the Derby Hill Schist is considered to be a facies equivalent of the Wepawaug Schist. Hence it is proposed here to retain the name Orange to include the Derby Hill Schist, Wepawaug Schist, and the body of amphibolite west of the staurolite isograd in the Milford quadrangle, as described by Fritts (1962a). The inclusion of the amphibolite requires changing the name of the unit from Orange Phyllite to Orange Formation. I suggest that the name Derby Hill be restricted to the unnamed member of the Derby Hill Schist of Fritts' report—the schist that, in fact, underlies the type locality at Derby Hill in the Ansonia quadrangle. The Orange Formation would then include four members: Derby Hill Member, Oronoque Member, Wepawaug Member, and amphibolite member. According to Fritts (1965b) the contact of his unnamed member (Derby Hill Member of this report) with the Oronoque Member follows the western bank of the Housatonic River through most of the Milford quadrangle, entering the Bridgeport quadrangle near Frash Pond (fig. 3, BP-6-9). It is clear from the geological maps of Bridgeport and Milford quadrangles that this is a projection of the contact along strike into an area where no bedrock is exposed. For reasons discussed below this contact is revised in the present report to enter the Bridgeport quadrangle at Long Brook Park (BP-6-3).

The Oronoque Member is well exposed in a string of discontinuous outcrops along Honeyspot Road south of its intersection with the Connecticut Turnpike (BP-6-8); this is designated a reference locality. A reference locality for the Derby Hill Member is the outcrop where the Merritt Parkway is crossed by the contact of Orange Formation and Cooks Pond Schist (BP-3-3).

The Oronoque Member crops out in a belt of low strike ridges and knobs flanking both sides of the Connecticut Turnpike along its NE-SW stretch in Stratford. Elsewhere only isolated small outcrops of Orange Formation poke through the blanket of glacial drift.

DERBY HILL MEMBER

The Derby Hill Member consists of thin-bedded, fine- to medium-grained muscovite schist and gneiss with interlayered medium- to coarse-grained garnet-biotite-chlorite-plagioclase-quartz-muscovite schist (see table 11). In the former there is a tendency for mineral segregation into alternating micaceous laminae and mica-poor quartzo-feldspathic laminae. This development, however, is uneven; the rock varies from a nearly homogeneous gneiss, through one with short micaceous wisps, to a true laminite characterized by nearly paper-thin micaceous laminae of great extent, a rock long called "pinstripe" by New England geologists. No systematic distribution of these variants was observed at any scale, nor any consistent pattern in sharp versus gradational contacts among the various rock types.

Garnet and staurolite, although common to the coarse-grained pelitic schist, are uncommon constituents of the finer grained "pinstripe," and kyanite is rarely observed in any of the rock types. The presence of potassium feldspar in these rocks, although modally sparse, is unique, in view of their high alumina content and the absence of K-spar in rocks of similar composition elsewhere in the Bridgeport and Long Hill quadrangles.

In the northern part of the area, along Cutspring Road (fig. 3, BP-3-6), the "pinstripe" is mostly nonmuscovitic and the weathered outcrops have a greenish cast. The northernmost outcrop on Cutspring Road has a few thin layers of chlorite-hornblende gneiss.

The contact of the Derby Hill Member with the Cooks Pond Schist is placed where laminated rocks of the former are succeeded by uniform graphitic schist of the latter. The contact is gradational but restricted to a zone about 15 ft wide, which is exposed along the northern side of the Merritt Parkway just west of the quadrangle boundary (BP-3-3).

ORONOQUE MEMBER

About 95 percent of the Oronoque Member consists of rocks that fit the description of the Derby Hill Member, except that garnet (mostly somewhat chloritized) is slightly more common in the Oronoque (table 11) and concordant pods of vein quartz are locally abundant. The remaining 5 percent of the Oronoque is chiefly green-weathering, dark-greenish-black, fine- to medium-grained, magnetite-rich, quartzose amphibolite, uniformly distributed in discontinuous layers less than 2 ft thick. Also distinctive are two occurrences of "pinstripe" gneiss interlayered with thin quartzite beds, one outcrop of crumbly, white muscovite-quartz-feldspar gneiss, and two of very fine-grained quartzo-feldspathic gneiss bearing small augen (1-5 mm) of plagioclase and quartz. This last rock type is somewhat similar to, and on strike with, the belt of Woodbridge Granite in the Ansonia and Mount Carmel quadrangles, although it lacks microcline and is nearly 7 mi. southwest of the southernmost outcrop of Woodbridge mapped by Fritts (1965a).

Fritts (1965a, 1965b) emphasized that the Oronoque Member is distinguished by a greater abundance of quartz-rich paragneiss, whereas the subdivisions of this report are based on the presence or absence of amphibolite, the contact between the members being drawn west of the westernmost occurrence of amphibolite. It is possible, of course, that in this report the Derby Hill Member has been subdivided, and that the Oronoque Member, as defined by Fritts, does not crop out in the Bridgeport quadrangle. Although there appears to be no significant difference in the amount of quartz-rich paragneiss in the two Orange units in the Bridgeport quadrangle there is, nevertheless, evidence for correlating them with the subdivisions made by Fritts. The geologic maps of the Ansonia and Milford quadrangles (Fritts, 1965a, 1965b) show that, with two exceptions, amphibolite in the Derby Hill Schist of Fritts is restricted to the Oronoque Member. Moreover, the two exceptions are within 300 ft of the Oronoque-Derby Hill contact as shown by Fritts. Thus, on the regional map (pl. 4, in pocket), this contact has been modified; it parallels the contacts between other units on the southeastern limb of the Bridgeport syncline.

CIPW norms for all rocks in table 11, except the amphibolite, are plotted on plate 3, triangle 9. Although the coarse-grained garnetiferous schist was not sampled, its mineralogy suggests a typical pelite. Samples BP-157 and BP-163 are extremes in "pinstripe" chemistry; it is probable that all the fine-grained laminated rocks would plot in a narrow band connecting these two points. This range falls almost entirely within the field of volcanic rocks; however, the high alumina content of the "pinstripe" rules out a volcanic origin. Altered volcanic material is also an unlikely parent—the result of such alteration is usually an enrichment of Na_2O, CaO, and SiO_2 at the expense of K_2O (Hopson, 1964, p. 35). No such exchange is evident. The most reasonable interpretation is that these rocks represent a gradation from slightly potassic graywacke to decidedly potassic, quartz-poor shale.

The primary structures characteristic of graywacke-turbidite sequences are absent in the Orange Formation, except for a few equivocal occurrences of graded bedding. However, Lombard (1963) has described similar unmetamorphosed sections of thin, well bedded flysch (from the European Alps) that consist of interbedded shales and thinly laminated sandstones and lack typical turbidite structures and textures.

The Oronoque Member amphibolites, which are of limited thickness and extent, probably represent tuffaceous strata. The augen gneiss probably represents pyroclastic debris of dacitic composition, perhaps somewhat altered after deposition and prior to metamorphism. The augen may represent relict crystals in an otherwise fine-grained or vitric tuff.

Serpentinite in southern Stratford

In the Dana Collection at Yale University is a specimen of serpentinite collected in Stratford. Professor Dana wrote in a notebook accompanying the collection, only that the specimen had been collected at Oldfield Rock. The serpentinite is massive, green to gray, and composed largely of dark-yellowish-green antigorite. Accessory magnetite is present, as well as minor carbonate.

Oldfield (fig. 3, BP-6-9, BP-9-3), a name no longer in use, is an elongated strip of land trending E-W, north of Lordship, and includes the site of the Lycoming Division of AVCO, as well as Frash Pond and a part of the Bridgeport Municipal Airport. It was reserved by the early colonists for cattle grazing.

No bedrock is now exposed in the area, nor do older topographic maps indicate any sort of prominence, as one might expect from the name Oldfield Rock. That such an outcrop did exist at one time, however, is verified by the description given by Percival (1842) who states, "A ledge of Serpentine, with small points of Limestone, similar to that accompanying this Chloritic formation, occurs on the West bank of the Housatonic below Stratford Landing . . ." Although the precise location of Stratford Landing is uncertain, it probably was but a short distance north of the mouth of the Housatonic and, in view of Dana's reference to Oldfield, must have been located somewhere between the Marine Basin (Milford quadrangle) and the north end of the AVCO property. A careful search of this area, as well as a check with AVCO officials regarding engineering records kept during construction of the present building, was fruitless; the exact location of the sepentinite is still a mystery. Nonetheless, the references to it by both Percival and Dana indicate that the belt of limestone-serpentinite outcrops mapped by Fritts (1965b) in the northeastern part of the Milford quadrangle continues into Stratford, a conclusion reached long ago by Percival, who added that the Stratford outcrop is displaced relatively northward.

CORRELATION OF THE METAMORPHIC ROCKS

The eastern body of Collinsville Formation in the Long Hill quadrangle can be traced continuously into the Naugatuck quadrangle. There Carr (1960), who called it Prospect Gneiss, considered it interfolded with, and in stratigraphic contact against, The Straits Schist. Field checking in early 1966 showed that Carr's westernmost belt of The Straits is not everywhere continuous—in an area of abundant outcrops one can walk directly from Waterbury Gneiss to Collinsville Formation without crossing The Straits Schist. The consequent interpretation that Collinsville Formation is correlative with the highest rocks in the Waterbury dome is further strengthened by the fact that, for a considerable distance along strike in the Naugatuck quadrangle, the Waterbury Gneiss immediately west of The Straits Schist is quite similar to the Collinsville. Analogy with the observation that the rocks in other New England gneiss domes decrease in age outward suggest that the sequence, basal group to The Straits Schist, is a succession from older to younger rocks and is succeeded on the southeast by even younger rocks, provided that there are no repetitions. In this manner, the stratigraphic section can be built up through the Trap Falls, Southington Mountain, and Prospect formations to the Ansonia Gneiss. Beyond the Ansonia and down-section across the eastern limb of the Bridgeport syncline, the sequence is Prospect, Southington Mountain, Cooks Pond, and Orange. Except for the absence of kyanite, the Cooks Pond Schist is identical, mineralogically and in its uniformity, to both the staurolite-schist member of the Southington Mountain Formation and to the lower member of The Straits Schist. Because, like The Straits Schist, the Cooks Pond Schist is continuous (except locally in the southern part of the Ansonia quadrangle), in contrast to the limited extent of the staurolite-schist member, the correlation of the Cooks Pond Schist with the lower member of The Straits Schist is proposed here. Moreover, stratigraphic arguments advanced below indicate that the Orange Formation belongs in the basal group. Hence correlation of the Cooks Pond Schist with The Straits is stratigraphically consistent. This correlation requires that the upper member of The Straits Schist, the Trap Falls Formation, and the staurolite-schist member of the Southington Mountain Formation pinch out under the Bridgeport syncline.

A regional map (pl. 4, in pocket), based on the present work, as well as that of Fritts (1963a, 1963b, 1965a, 1965b), Carr (1960), Cassie (1965), Burger (1967), and Gates and Martin (1967), has been constructed as a basis for discussion of correlation and regional relationships. On this map contacts are drawn, and formation names assigned, according to concepts that developed during the present investigation. (References to plate 4 are accompanied by a letter-number combination in parentheses to facilitate rapid location. The letters refer to the quadrangle and are identified in the "Index to 7½′ Quadrangles" on plate 4. The numbers refer to the particular ninth of a given quadrangle, as illustrated in figure 3.)

Although more micaceous than typical Collinsville Formation, Fritts' (1963b) Hitchcock Lake Member of the Waterbury Gneiss in the Southington quadrangle (ST-5) resembles this unit in all other respects: coarse grain size, relatively high feldspar/quartz ratio, and the local occurrence of very large garnets. The very distinctive contact zone of the Collinsville with The Straits Schist is apparently absent, although amphibolites and minor calc-silicate rock do occur throughout The Straits. The contact zone is locally present in adjacent Waterbury quadrangle (Gates and Martin, 1967).

A twofold division of The Straits Schist is recognizable near the western boundary of the Ansonia quadrangle but only the lower member is present as the rocks are followed into the Naugatuck quadrangle. The overlying Trap Falls Formation similarly narrows and disappears, seeming to confirm the southward extension of a normal fault (Triassic?) mapped by Carr (1960), which dropped the Southington Mountain and Prospect formations against the lower member of The Straits.

Fritts (1963a) mapped both Southington Mountain Schist and Ansonia Gneiss between The Straits Schist and the Prospect Gneiss in the northwestern corner of the Mount Carmel quadrangle; it is likely that the two units can be carried westward to the fault in the Naugatuck quadrangle (NT-6) although the few outcrops in this zone expose only schist. However, I consider this belt of Ansonia to be Trap Falls Formation and interpret the Southington Mountain Schist here as the upper member of The Straits, which has been shown to be continuous with the narrow belt of schist that runs between the lower member of The Straits Schist and the elongate body of Fritts' type-section Prospect Gneiss (in this report, the biotite-gneiss member of the Southington Mountain Formation) in the Mount Carmel and Southington quadrangles. Because the Trap Falls Formation is absent in the Southington quadrangle, the upper member of The Straits Schist cannot be separated, on the basis of map study alone, from redefined Southington Mountain Formation. It is of interest, however, that from Hitchcock Lake (ST-5, ST-6) northward, The Straits Schist, as defined by Fritts, includes considerable amphibolite and thinly banded paragneiss suggesting that there The Straits includes both members.

The northwesternmost belt of Southington Mountain Schist in the Ansonia quadrangle contains scattered bodies of Ansonia Gneiss (as defined by Fritts), whereas on either side of this belt this distinctive muscovite-quartz-feldspar gneiss is either lacking or present to a very minor degree. Thus, I interpret this belt as a continuation of the Trap Falls Formation, as defined in the present study. As pointed out above, it is apparently faulted out in the southern part of the Naugatuck quadrangle; presumably it reappears and joins the large body of Ansonia Gneiss mapped by Fritts at the western edge of the Mount Carmel quadrangle. From there it extends northeastward along the western limb of the Bethany synclinorium. This is the northern limit of Trap Falls volcanism; no outcrops of the gneiss were mapped in the Southington quadrangle nor does the formation occur on the western limb of the Prospect syncline.

Lithologically, the biotite-gneiss member of the Southington Mountain Formation resembles feldspathic gneisses of the Prospect, and was mapped as that formation in the Ansonia quadrangle by Fritts (1965a). Stratigraphically, however, it appears to be a member of the largely sedimentary Southington Mountain Formation and a harbinger of Prospect volcanism. In the northwestern part of the Ansonia quadrangle, Fritts mapped this belt of rock (as Dpg) around a narrow hinge of Pumpkin Ground (Dpp) into the broad synclinal mass of Beardsley Gneiss (Dpg) that occupies most of the Bethany synclinorium in the Naugatuck quadrangle. Field reconnaissance has shown that, according to the criteria used in the present report for recognizing units in the Southington Mountain and Prospect formations, the Pumpkin Ground can be followed northward along the western limb of the Bethany synclinorium well into the Naugatuck quadrangle, where it gradually pinches out stratigraphically (NT-8), bringing the higher Beardsley Gneiss into contact with the lower biotite gneiss. From there the latter member can be mapped northeastward into the Mount Carmel quadrangle, where it changes facies to banded-schist (MC-4) and wraps around the S-plunging hinge of the Bethany synclinorium.

Except for the biotite-gneiss member of the Southington Mountain Formation, the Prospect grandodiorite gneiss, mapped by Fritts (Dpg or DOpg) in the Bethany synclinorium, corresponds to the Beardsley Gneiss Member of the Prospect (as defined in the present study). And, except for the thin tongue of Pumpkin Ground on the western limb of that synclinorium, so do the rocks that Carr (1960) called Undifferentiated Hartland Formation.

Regional stratigraphic relations suggest that, where the synclinorium plunges northward, the Ansonia Gneiss should reappear—as indeed it does in the northern part of the Ansonia quadrangle (AN-2), where the formation was first described. Northeastward along strike in the Naugatuck quadrangle Carr mapped small bodies of Ansonia along or near a contact that probably closely approximates the axial trace of the synclinorium. In the Mount Carmel quadrangle muscovite gneiss is present in every unit younger than The Straits Schist; hence it ceases to be a useful stratigraphic marker.

At least part of the sequence outlined above, and shown in figure 5, can be recognized in the Prospect syncline, a tight N-plunging fold that succeeds the Bethany synclinorium en echelon to the north. An elongate body of Southington Mountain Formation, largely biotite-gneiss member but grading northward into banded-schist member, is succeeded on the

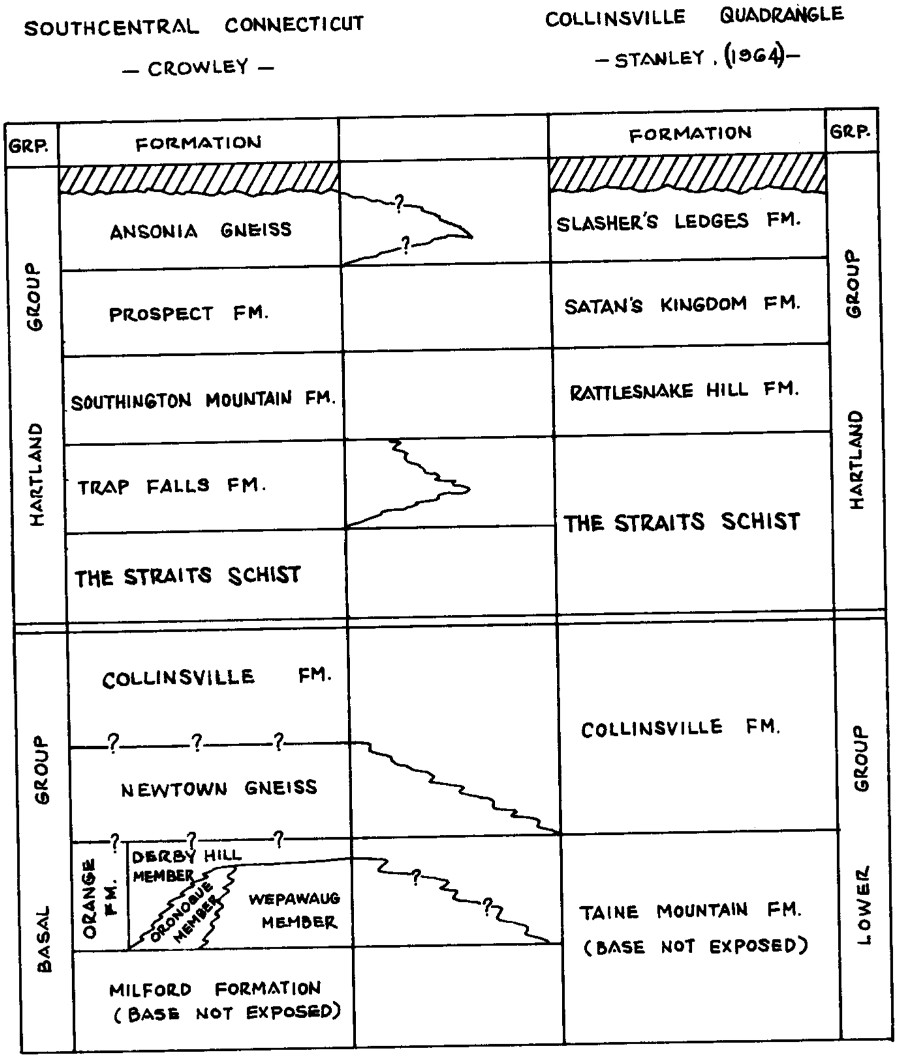


Fig. 5. Correlation of the stratigraphic section in the Collinsville quadrangle with that in south-central Connecticut.

north by a boot-shaped mass of the Pumpkin Ground Member of the Prospect Formation. Still farther north are rocks that were divided into two units by Fritts (1963b) who mapped both as Southington Mountain Schist. These do not correspond to any of the higher units of the Bridgeport syncline or the Bethany synclinorium; however, the presence in the upper one of gneiss bodies mapped by Fritts as *DOpg* suggests that they may represent a predominantly metasedimentary facies of the

Beardsley Gneiss—that is, the Golden Hill Schist. This view was adopted in constructing the regional map (pl. 4), where the two units are designated "younger schists."

The Bethany synclinorium and the Bridgeport syncline are succeeded eastward, according to Fritts (1965a, 1965b) by a synclinal axis in the Wepawaug Schist. Neither he nor the present writer mapped an anticline between the two synclines; thus a reinterpretation of the data is required. Correlation of the section in the Long Hill and Bridgeport quadrangles with that proposed in the Collinsville quadrangle by Stanley (1964)—shown in figure 5—confirms the relative-age interpretations of the present report and makes it unlikely that the Long Hill-Bridgeport section is upside down, although it should be added that more recent mapping by Stanley (personal communication) in Massachusetts has led him to consider alternative stratigraphic-structural interpretations. Stratigraphic relations in the Ansonia and Milford quadrangles suggested to Fritts that the Wepawaug Schist unconformably overlies the rocks with which it is in contact. The symmetrical arrangement, shown by Fritts, of the pre-Wepawaug rocks folded in the Wepawaug syncline is possible if the older rocks below the unconformity are anticlinal although this requires a reversal in the age sequence of the older rocks. It seems unlikely, however, that stratigraphic contacts on both sides of the unconformity could be so closely parallel in such a compound structure.

A possible alternative is that the Wepawaug Schist is part of a homoclinal sequence that becomes progressively older, from Prospect Formation on the northwest to Milford Formation on the southeast. Contrary to Fritts' (1962a) opinion, it seems to the present writer that it cannot be conclusively demonstrated that amphibolite west of the staurolite isograd in the Milford quadrangle is physically continuous with the Maltby Lakes Volcanics. Resolution of this problem depends on whether a disputed outcrop across from the Kay Avenue School in southern Devon (MF-4) should be assigned to the Wepawaug or Oronoque member of the Orange Formation—two units that are difficult to differentiate in this area. Although Fritts supports a Derby Hill age, John Rodgers (personal communication) and John Sanders (personal communication) as well as the present writer consider it Wepawaug; Rodgers suggests a southerly extension of the Mixville fault to explain the presence of this thin sliver of Wepawaug. Thus it cannot be shown unequivocally that the eastern and western limbs of the Wepawaug syncline are connected around a plunging hinge, nor has it yet been demonstrated that the detailed stratigraphy described by Holdaway (1958) and Burger (1967) in rocks southeast of the Wepawaug can be matched in rocks south and west of the Wepawaug. The hypothesis of a homoclinal sequence necessitates a facies relationship between the Wepawaug and Oronoque members of the Orange Formation, the facies transition being marked by a large increase in the concentration of amphibolite (Oa of pl. 4) associated with the Oronoque. Possible additional support of a facies change comes from the proposed correlation of the dike phase of the Woodbridge Granite (Dwp of Fritts, 1965a) with two outcrops of fine-grained augen gneiss in the Oronoque within the Bridgeport quadrangle. Although the medium-grained Woodbridge described by Fritts (Dw, 1965a) may be intrusive granite, the dike phase that he describes, particularly that in low-grade areas, closely resembles acidic tuff.

Figure 5, the suggested correlation of Stanley's (1964) section with that of south-central Connecticut, was constructed on the basis of two field trips to the Long Hill and Bridgeport quadrangles with Rolfe Stanley and field trips with others to the Collinsville quadrangle. In this correlation The Straits plays a key role—it is the only unit that can be traced continuously between the two areas. Stanley (personal communication) agrees that the Collinsville in both areas is correlative. Correlation of the Orange Formation with the Taine Mountain Formation is based on the opinion of Gonthier (1964) that the Savoy Formation flanking the eastern side of the Berkshire Highlands resembles the Taine Mountain Formation of Stanley's (1964) report. The judgment of several Vermont geologists that the Oronoque Member of the Orange Formation at its type locality is equivalent to the Savoy (= Moretown Formation in Vermont) implies in turn that the Orange is correlative with the Taine Mountain.

Trap Falls gneisses can be traced northward only as far as the northern part of the Mount Carmel quadrangle; however, the associated schists probably continue northward as part of the Southington Mountain Schist described by Fritts. Stanley (1964) thought that the Rattlesnake Hill Formation in the Collinsville quadrangle resembled the Southington Mountain Formation. As this correlation was presumably based on a study of the more restricted section at Southington Mountain, it has been retained in figure 5. The Golden Hill Schist Member of the Prospect Formation is considered by Stanley (personal communication) to correspond to his Satan's Kingdom Formation.

The suggested correlation of the Orange with the Taine Mountain indicates a pre-Collinsville age for the Orange, placing it low in the basal group. This can be explained only if—by virtue of their largely volcanic composition—the Newtown Gneiss, the Collinsville Formation, and the Trap Falls Formation pinch out under the Bridgeport syncline and are absent on its eastern limb.

A Moretown age (Middle Ordovician) for the Orange Formation suggests correlation of the Collinsville Formation and The Straits Schist with the Ammonoosuc Volcanics and Partridge Formation, respectively, of the New Hampshire and eastern Connecticut section, thus making that part of the western Connecticut section younger than previously thought (Fritts, 1962a). In this scheme the Milford Formation is equivalent to rocks older than Moretown; units above The Straits probably represent Ordovician rocks removed elsewhere by erosion prior to deposition of the Siluro-Devonian section.

IGNEOUS ROCKS

Pinewood Adamellite

Straddling the boundary of the Long Hill and Bridgeport quadrangles is an elliptical pluton of adamellite, which, viewed from the south or west, forms a conspicuous topographic dome. Almost the entire mass is included within Beach Memorial Park. Flanking part of its eastern contact is Pinewood Lake from which the name Pinewood Adamellite is taken and here formally proposed.

Medium-grained adamellite, weathering to a very light gray, predominates (table 12). The albite/microcline ratio varies from 2.0 to 0.6.

Table 12.—Modal analyses (in volume percent) of the Pinewood Adamellite[1]

sample[2]	Q[3]	Pl[4]	Mi[5]	Ms[6]	Ep	Mt	Ap	Fr[7]
1	30.7	41.0	19.6	8.7	—	—	—	—
2	33.8	25.1	23.9	16.8	—	—	—	0.4
3	20.6	19.2	33.5	26.2	T	T	0.1	0.4

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

[2] *Description of samples*:

1: Ms adamellite; fg-mg

2: Ms adamellite; mg

3: Ms adamellite; mg

Texture: Granitic. Complex implicate contacts of Mi with Pl are common.

[3] Shows undulatory extinction.

[4] Most grains are polysynthetically twinned. Locally includes numerous optically oriented, long, thin books of Ms. An 7 in all samples.

[5] Grid twinning well developed.

[6] As tiny books disseminated throughout the rock.

[7] As very tiny grains ubiquitously disseminated in the rock.

Muscovite invariably occurs as tiny books disseminated throughout the rock, and ranges modally from 9 to 26 percent. Fluorite is an important accessory mineral and is followed in abundance by apatite, epidote, and magnetite. The southern part of the pluton is characterized by numerous irregular pods and streaks of pegmatite that weather out as whitish knobs. Elsewhere, uniform, medium-grained muscovite adamellite predominates. Veins of clear quartz, commonly with muscovite selvages, are seen here and there. Layering such as that noted by Gates (1954) in the Nonewaug Granite is rarely observed; the chief structures are two sets of nearly vertical joints, which strike about N-S and E-W, respectively.

It is interesting to note that a natural gamma-radioactivity high of 1,300 counts per second (Popenoe, 1966) is centered over the Pinewood Adamellite. This is the highest natural gamma radioactivity in western Connecticut and would seem to relate the Pinewood to similar highly radioactive granitic rocks in eastern Connecticut, although mineralogically it is more like the muscovite granites of the western half of the state. The radioactivity is probably due to a uranium-bearing phase (apatite?), an inference supported by the well known association of fluorite with uranium minerals (see Park and MacDiarmid, 1964).

Contacts with The Straits Schist are nowhere exposed; however, bedding and foliation in the schist near the pluton appear to parallel its outline. The age of the Pinewood is unknown but it may be Permian (see "The Fluorite Zone" below).

Rhyolite porphyry

About 300 ft SW of Merritt Parkway Interchange 52 (fig. 3, BP-3-4), nestled in a S-plunging hinge of Beardsley Gneiss, a small stock of rhyolite prophyry is exposed as an ellipse approximately 30 x 60 ft. It is a massive porphyry consisting of phenocrysts of (in order of increasing abundance) anhedral dusky-red biotite, anhedral quartz, euhedral plagioclase (An 23), and subhedral microcline (commonly displaying grid twinning) set in an extremely fine-grained groundmass that includes muscovite, a small amount of biotite, and accessory fluorite. The groundmass is composed mainly, however, of low-birefringence material that appears to be chiefly quartz and untwinned K-spar. The phenocrysts, which comprise one third of the volume of the rock, average 2 to 3 mm in diameter, although some feldspars are 1 cm in longest dimension.

Although numerous outcrops of the country rock occur in the vicinity of the stock, the contact between the two is nowhere exposed. Rare inclusions, ranging in size from 2 to 10 cm, have sharp contacts with the enclosing porphyry; they are composed of biotite schist and feldspathic gneiss and include one piece of quartzite. They are probably derived from the Pumpkin Ground Member of the Prospect Formation, which is estimated to lie not more than 250 ft below the surface.

The texture of the porphyry leaves no doubt that its emplacement postdates the mid-Paleozoic metamorphism of the country rock. The occurrence of microcline is, however, anomalous and may indicate later reheating or emplacement at a sufficient depth to recrystallize orthoclase. Determination by Clark (1966) of the Rb/Sr ratio from a microcline phenocryst gives an age of 250 million years B.P., suggesting contemporaneity with the Permian plutonic episode of southernmost New England.

Dacite porphyry

A dacite porphyry, texturally similar to the rhyolite porphyry discussed above, is poorly exposed in a steep embankment along the western side of Connecticut Route 25, just north of Long Hill village (fig. 3, LH-7-2). At the southern end of the outcrop the rock occurs as a cross-cutting dike 10 ft wide that becomes a sill of the same width and can be traced for about 60 ft northward along the outcrop before it dies out. It is composed of phenocrysts of quartz and plagioclase (An 37) set in an extremely fine-grained groundmass of quartz, feldspar (plagioclase?), and muscovite. Its age is unknown but it may be Permian (see following section).

The fluorite zone

The only macroscopic occurrence of fluorite in the area of this report is in cross-cutting veins restricted to the small area of Tungsten Mine Park (fig. 3, LH-7-2). All other occurrences of fluorite were discovered in examining rock thin sections. All the fluorite localities are plotted on plate 4; they lie in a fairly narrow zone that strikes about N 40° W for a distance of 6 mi. It is probably no coincidence that within this same zone lie all known post-metamorphic igneous bodies except the Mesozoic Buttress Diabase, suggesting a single Permian episode of igneous activity and fluorine metasomatism.

Buttress Diabase

Orange-weathering, fine- to medium-grained, dark-gray diabase crops out as isolated knobs and linear dikes that together form one long, discontinuous dike striking N 30° E through the Bridgeport and Long Hill quadrangles. The diabase is composed chiefly of plagioclase (An 64) and clinopyroxene in an intergranular relationship. Both augite and pigeonite are present; their relative abundance could not be determined. Accessory magnetite and a small amount of green biotite replacing clinopyroxene complete the diabase mineralogy. Although the dike is on strike with the westernmost of two diabase dikes mapped by Fritts (1965a) in the Ansonia quadrangle, it lacks the grayish-green phenocrysts of calcic bytownite that, according to him, distinguish these dikes, which he called Buttress Diabase, from older West Rock Diabase of the nearby New Haven and Mount Carmel quadrangles. Where contacts with the country rock are exposed, as in the abandoned quarry just south of the Merritt Parkway (fig. 3, BP-2-5), the dike is vertical or nearly so. Cooling-joints, most clearly displayed just east of Johnson School in Bridgeport (BP-2-7), also indicate near verticality. The dike's width varies from a few feet to over 200 ft; it is accompanied locally by thin offshoots.

The margins of the dike exhibit a fine-grained chilled zone, characterized in thin section by a trachytic texture. Visible contact effects extend only a few inches into the country rock, although thin sections of specimens taken from a foot or so away show marked alteration of both microcline and plagioclase. Minor carbonate is also present in the contact zone.

Despite the absence of bytownite phenocrysts, there is no reason to doubt the essential continuity of the dike with the Buttress Diabase mapped by Fritts (1965a) in the Ansonia quadrangle. Fritts (1962b) reviewed the stratigraphic evidence bearing on the age of the Buttress Diabase and concluded that it is Triassic or younger. De Boer (1967), on the basis of paleomagnetic evidence, has recently suggested a Jurassic age for the Mesozoic dike swarms of the Appalachians.

STRUCTURAL GEOLOGY

General statement

The map pattern formed by stratigraphic units in the Long Hill and Bridgeport quadrangles defines five major folds, named from northwest to southeast the Monroe nappe, the White Hills recumbent syncline, the Trap Falls syncline, the Shelton anticline, and the Bridgeport syncline. With the exception of a terminal northwestern bend in the Monroe nappe, all strike NE and are apparently the result of one major phase of deformation, here denoted F_D.

On the basis of fold orientation, the map area can be divided into two domains, a southeastern one of generally upright, isoclinal folds and strongly expressed lineations, and a northwestern one of recumbent isoclinal folds and few lineations. Common to both domains is a penetrative mineral foliation, which parallels compositional layering. In the following discussion this foliation will be referred to as S_1. Locally a penetrative axial-plane foliation is the dominant structure in the rock; it is denoted S_2.

Southeastern domain

BRIDGEPORT SYNCLINE

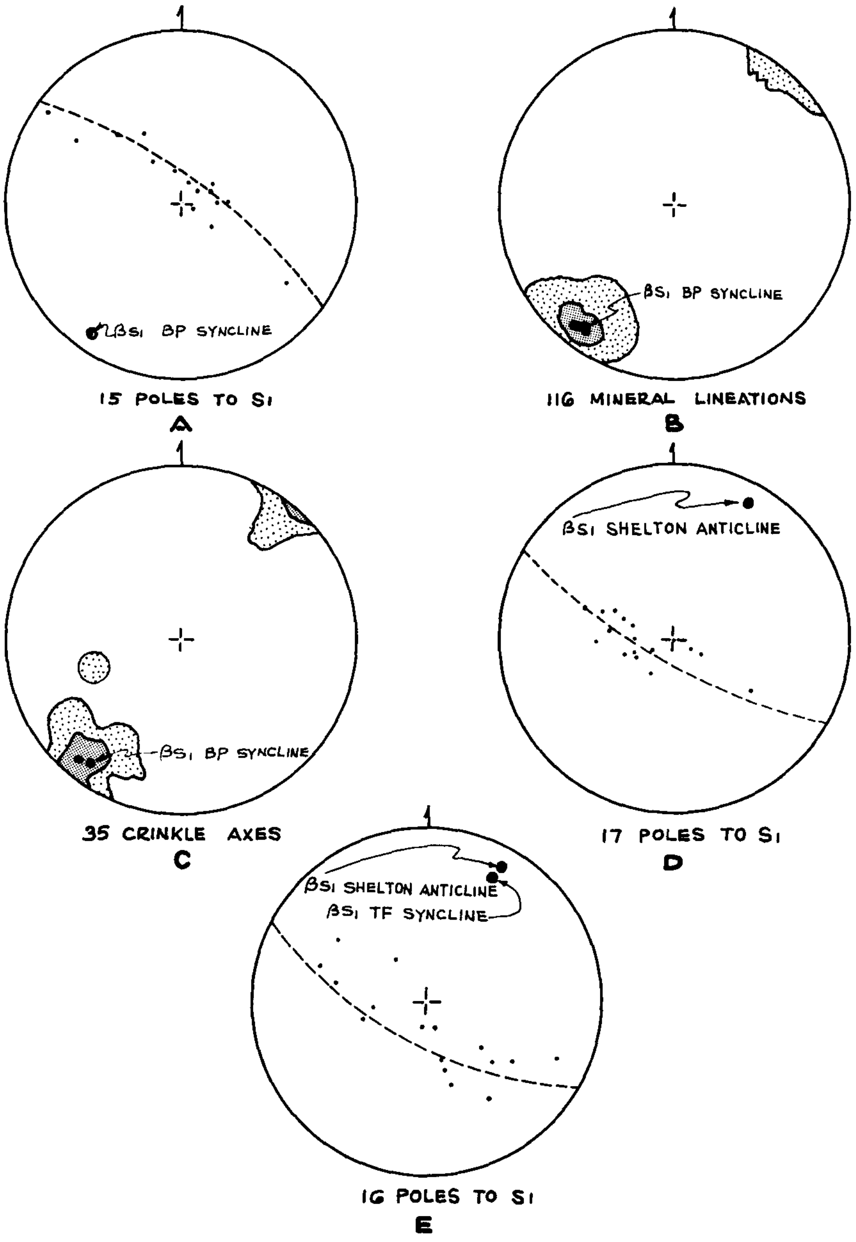
The doubly-plunging Bridgeport syncline can be traced for almost 15 mi. along a nearly straight course, which is well delineated by the map pattern of the Beardsley Gneiss and Pumpkin Ground members of the Prospect Formation. The structural and stratigraphic evidence for this fold complement each other almost perfectly. There are four structural features that define it: 1) attitude of S_1, 2) orientation of mineral lineation, 3) orientation of minor folds in S_1, and 4) orientation of crinkle folds in S_1.

In the nearly isoclinal Bridgeport syncline, S_1 generally dips quite steeply. However, in the vicinity of the S-plunging hinge of Beardsley Gneiss (fig. 3, BP-3-1), it wraps around the structure in perfect parallelism with the stratigraphic contact, flattening to a minimum dip of 11° at the hinge. Poles to these foliations are plotted in figure 6A, where they define a great circle; the β-axis plunges S 35° W at 14°.

Farther south along the axial trace of the Bridgeport syncline is a hinge in Ansonia Gneiss. Foliation within the Ansonia is strictly parallel to the axial plane and nowhere wraps around, apparently representing a local development of S_2 that has totally obliterated S_1. Supporting this view is an isolated sliver of Ansonia nearly ½ mi. north along strike from the main belt. If this were a bed of muscovite gneiss in the Beardsley it should be traceable along the limbs of the syncline; its restriction to the axial region of the fold, up-plunge from a unit of identical lithology and with smaller bodies in its wake, suggests that it is a boudin produced by stretching of the Ansonia to the point of complete separation.

The hinge in the Ansonia Gneiss also corresponds approximately to the transition of the Bridgeport syncline from an upright to an overturned structure; to the north and deeper in the structure both limbs dip inward; to the south and higher in the structure both dip northwest.

Penetrative mineral lineation is a distinctive feature of the Bridgeport syncline, particularly in the Beardsley Gneiss, where hornblende alignment is so intense that commonly it is the only structure observed. Rodding of quartz and feldspar and mica streaming define a mineral lineation in the Ansonia Gneiss and in the Pumpkin Ground Member of the Prospect Formation. In figure 6B are plotted 116 mineral lineations from the entire strike length of the Bridgeport syncline in the Bridgeport quadrangle. Superposition of the β_{S_1} -axis from figure 6A on this plot shows the parallelism of mineral lineation with the axis of the syncline.



15 POLES TO S₁
A

116 MINERAL LINEATIONS
B

35 CRINKLE AXES
C

17 POLES TO S₁
D

16 POLES TO S₁
E

Fig. 6. Equal-area projections defining the major axis of folding in the southeastern domain. *A* is from the fold hinge of Beardsley Gneiss (fig. 3, BP-3-1, BP-3-3). *B* and *C* represent the entire strike length of the Bridgeport syncline (contours, 50, 25, and 0.9 percent per 1-percent area in *B;* 34, 14, and 3 percent per 1-percent area in *C.*) *D* is from the Shelton anticline near Shelton in the Ansonia quadrangle. *E* is from the Trap Falls syncline at Trap Falls Reservoir (LH-9-1, LH-9-2, LH-9-4, LH-9-5).

As the syncline is traced northward into the Ansonia quadrangle, mineral lineation plunges less and less steeply S, flattens out, and finally plunges N into the Bethany synclinorium. Syncline stratigraphy depicts an identical variation in axial plunge, at least in the western of the two lesser synclines into which the structure degenerates to the north.

Minor folds that belong to F_D are almost entirely absent from the eastern limb of the Bridgeport syncline. Folds on the western limb are developed almost exclusively in the staurolite-schist and banded-schist members of the Southington Mountain Formation. Metasediments in the Pumpkin Ground show folds in only a few places; the Ansonia Gneiss and the Beardsley Gneiss are totally devoid of them. There is no element of style that these folds possess in common. Their orientation generally parallels that of the syncline, as can be seen from plates 1 and 2. Their axes are similar in trend and in plunge to the associated mineral lineation, and their axial planes share the attitude of the major structure. The folds are asymmetric and, with respect to the synclinal axis, almost all show the correct sense of rotation for flexural-slip folding. All these features are well illustrated in the two successive outcrops along White Plains Road that expose the type staurolite-schist member and the reference banded-schist member of the Southington Mountain Formation, and also in outcrops nearly continuous with these in the very northern corner of Beardsley Park. Nearly 20 distinct minor folds can be seen in this short strip, all similarly oriented and all showing the same sense of asymmetry. Although one cannot demonstrate a reversal in rotation sense across the syncline, the close parallelism between the axes of these folds and associated mineral lineation strongly suggests that the folds belong to F_D.

A fourth structural feature associated with the Bridgeport syncline is crinkling or crenulation in S_1. Strictly speaking, these are folds of very small amplitude, but they are designated by a special symbol on plates 1 and 2 because, unlike larger folds, they rarely show a clearly defined axial plane. In general, crinkles are much more common than minor folds, particularly on the eastern limb of the syncline where folds are very rarely observed. A plot of 35 crinkles from the syncline is shown in figure 6C. Comparison with figures 6A and 6B demonstrates the essential identity in orientation of all these minor structures.

SHELTON ANTICLINE

Complementing the Bridgeport syncline on the northwest is the Shelton anticline, best defined in the Ansonia quadrangle (see fig. 6D) where it is outlined by successive N-plunging hinges of Trap Falls Formation (Ansonia Gneiss of Fritts, 1965a), Southington Mountain Formation, and Pumpkin Ground Member of the Prospect Formation (Dpp of Fritts, 1965a). In the Long Hill quadrangle it can be traced southward along strike for about 4 mi. before it dies out. The Shelton anticline has the same types of related minor structures as the Bridgeport syncline, and here, too, they agree in orientation with the major structure. Apparently because of the relatively massive character of the Trap Falls Formation, they are not widely developed—there are too few to be plotted separately. Plate 1 does show, however, that they all relate to the major structure.

TRAP FALLS SYNCLINE

In the northwestern part of the Trap Falls Reservoir, S_1 wraps around a N-plunging syncline defined by hinges of Trap Falls, Southington Mountain, and Prospect formations. In order to demonstrate the coaxiality of this fold with the Shelton anticline, a plot of poles to S_1 from the hinges exposed at Trap Falls Reservoir is compared in figure 6E with a plot of poles to S_1 taken from the N-plunging hinge of Trap Falls Formation in the Shelton anticline (fig. 6D). Minor folds and mineral lineations are not widely developed in the Trap Falls syncline. The scarcity of minor folds is probably due to the somewhat massive nature of the gneissic rocks folded in the syncline. The general absence of mineral lineation reflects the transition from the intensely lineated Bridgeport syncline on the southeast to the poorly lineated White Hills recumbent syncline on the northwest.

West of Trap Falls Reservoir and north of the Pinewood Adamellite is a group of smaller map-scale folds, most clearly defined by the layer of amphibolite separating the lower and upper members of The Straits Schist. From south to north these folds are progressively more overturned to the southeast, marking the transition from the southeastern domain to the northwestern domain.

Northwestern domain

WHITE HILLS RECUMBENT SYNCLINE

In the broad belt of Trap Falls Formation west of the Trap Falls syncline, S_1 dips mostly W toward older rocks. Hence this belt is considered to be part of a W-closing overturned syncline. Variation in both direction and amount of dip of S_1 in this belt suggests a group of smaller scale folds like those north of the Pinewood pluton, but the absence of guide horizons and the generalized nature of the contact with The Straits Schist make confirmation of this interpretation impossible. In the cross sections (pl. 5, in pocket), therefore, the structure is shown as a simple recumbent syncline. The trace of the axial plane continues SW into the broad terrain underlain by gently NW-dipping The Straits Schist. In this southern region there is no repetition of strata between the axial traces of the White Hills recumbent syncline and the Bridgeport syncline but there are systematic variations in the dip of S_1 that indicate broad flexures in the axial surface of the White Hills recumbent syncline (see pl. 5, section A-A′). Complementary evidence for progressive rotation of S_1 through the vertical is missing. It is therefore postulated that S_1 has been locally transposed in the hinge of the syncline, where foliation and layering are an expression of S_2.

MONROE NAPPE

Hugging the southern lobe of the Waterbury dome is a long, narrow belt of Collinsville Formation that can be followed south as far as the Long Hill quadrangle. Two lines of reasoning support a synformal interpretation of this belt: 1) The attitude of foliation and the plunge of linear features at the northern end of the belt in the Naugatuck quadrangle

(Carr, 1960) defines a synform, a structure also suggested by the meagre data at the southern end in the Southbury quadrangle (Scholle, 1965). 2) The association of broad domal uplifts and tight sinuous synforms is typical of mantled-gneiss-dome regions—the interpretation of this belt as a tight antiform wrapping around a dome is structurally anomalous.

The consequent interpretation of this belt as a synformal anticline suggests its origin as a fold shed from the rising Waterbury dome, thus relating it to what may be a similar flop-over of Reynolds Bridge Gneiss off the northern flank of the dome in the Thomaston quadrangle (Cassie, 1965) as well as to known major folds flanking the Collinsville dome (Stanley, 1964, and personal communication).

Minor structures predating F_D

S_1

Parallel to compositional layering is a pervasive mineral foliation, generally referred to as bedding foliation by New England geologists. It predates F_D as is best demonstrated in the S-plunging hinge of Beardsley Gneiss in the Bridgeport syncline, as well as in numerous outcrop-scale folds related to F_D. It does not parallel the axial surface of any observed fold system and is perhaps the result of mimetic recrystallization.

DOWN-DIP FOLDS

In the town of Stratford, east of the Prospect Formation in the Bridgeport quadrangle, minor structures belonging to F_D can be identified on the basis of their subhorizontal orientation. These are folds of S_1, with associated crinkling in schist, in two outcrops of the Derby Hill Member of the Orange Formation. Elsewhere crinkles alone define F_D in this area but, in contrast to their parallelism with the major structure in the axial region of the Bridgeport syncline, here they plunge N almost as commonly as they do S. Although gentle plunges are the rule, steeper ones are locally developed. There are, in fact, exposures in the reference area of the Oronoque Member of the Orange Formation where vertical beds display crinkles that rise and fall erratically along strike. This absence of systematic variation in plunge of crinkles, coupled with the nearly total absence of gently plunging folds, is interpreted as a dying-out of F_D east of the Bridgeport syncline. Support of this interpretation lies in the stratigraphic evidence for the absence of any major structure in this area.

In this same region an earlier deformation is well documented by abundant, down-dip-plunging, asymmetric folds. Apart from an exposure of steeply plunging crinkles of uncertain age in the Cooks Pond Schist, this deformation can be observed in two outcrops of the Derby Hill Member of the Orange Formation and in about one third of the outcrops of the Oronoque Member. This deformation is defined by folds in S_1 that almost invariably plunge down dip and hence are all very steep in the Stratford area. The folds are particularly well expressed in the Oronoque where the striking contrast in color and resistance to erosion between amphibolite and schist causes the folds to stand out in conspicuously bold relief. Parallel to these folds is a strong hornblende lineation in fold hinges of amphibolites; elsewhere mineral lineation is weak or absent. Moreover, with the possible exception of the crinkle exposure in the Cooks Pond Schist mentioned above, no crinkling is associated with this fold system.

The folds vary in amplitude from 1 in. to more than 1 ft. Where the rocks are thin bedded, hinges are sharp and axial plane schistosity well developed; hinges in thick amphibolites are round and S_2 schistosity is only weakly developed in adjacent micaceous rocks. Every fold observed in the Oronoque Member displays a dextral sense of asymmetry. Both dextral and sinistral folds were observed in the Derby Hill Member.

As this fold system does not deform rocks west of the easternmost extent of the Prospect Formation, its age relative to F_D is uncertain. However, because the axes plunge down dip, and because the dip varies from place to place (presumably in response to F_D), these folds are probably also deformed by F_D and hence predate it. If they do relate to a major structure, its details must be worked out in quadrangles to the east, where this fold system is more widely developed.

DOWN-DIP LINEATION

All mineral lineations observed in the eastern body of Collinsville Formation, except two, plunge down dip and normal to the axial trace of the Monroe nappe. This down-dip lineation is defined in every case by biotite streaming; in some outcrops an associated rodding of quartz and feldspar is also noticeable, and in one exposure coarse blades of kyanite are lined up parallel to this lineation. As the lineation is almost everywhere perpendicular to the axial trace of the nappe it may be a streaming that parallels the movement direction of the nappe in much the same fashion as slickensides record the relative movement along fault surfaces. If so, it does not predate F_D. A possible alternative is to correlate this streaming with down-dip folds observed in the Derby Hill Schist (see preceding section). In the absence of any evidence for down-dip minor structures in rocks above the basal group, this is consistent with the hypothesis of an unconformity at the base of The Straits Schist, a view suggested by Rodgers and others (1959) and advanced by Fritts (1962a) but denied by Stanley (1964) and also unsupported by the present mapping. This hypothesis also requires that the development of bedding-plane foliation in basal group rocks predate its development in Hartland Group rocks.

Structures postdating F_D

In contrast to the coaxial warping of the White Hills recumbent syncline is the cross folding defined by map pattern and structural details in the vicinity of the old tungsten mine at Long Hill (fig. 3, LH-7-2, LH-7-3). Hobbs (1901) first recognized the broad synformal flexure in the interlayered amphibolite and marble near the mine workings, but his projection of contacts to the north led him to infer incorrectly that the structure closes to the north to form an elongate basin trending N to NE. Present mapping defines a broad NW-plunging synform and a complementary tight antiform. The superposition of NW-trending folds onto the NE-striking principal fold system indicates that the tungsten-mine folds postdate F_D. South of the tungsten mine, formational contacts in every unit as far southeast as the Southington Mountain Formation show a swing in strike from approximately N 30° E to nearly E-W. The location of the tungsten-mine folds, near the hinge of this bend and in the contact zone between two major units of contrasting lithology, is perhaps a localized manifestation of the strain resulting from the bending stress.

Alternate stratigraphic-structural model

An alternate, internally consistent, model of the map area can be constructed by accepting certain correlations, which were, in effect, assumed by Fritts (1965a). The Shelton facies of the Trap Falls Formation was mapped as Ansonia Gneiss by Fritts, and it has been shown in this report that the northwestern facies is physically continuous with the Shelton. This suggests that the Ansonia can be correlated with the Trap Falls. The biotite-gneiss member of the Southington Mountain Formation (as defined in this report) was mapped by Fritts as continuous with what is here considered a higher stratigraphic unit, the Beardsley Gneiss Member of the Prospect Formation. Correlation of these two formations requires that the termination of the Pumpkin Ground Member on both limbs of the Bethany synclinorium in the Naugatuck and Mount Carmel quadrangles be interpreted as fold hinges. This leads directly to correlation of the entire Southington Mountain Formation with the Beardsley Gneiss by means of the facies change demonstrated at the east-central edge of the Long Hill quadrangle, and, in this model, repeated near the northern termination of the Pumpkin Ground in the Mount Carmel quadrangle. The facies relationship between the Beardsley Gneiss and Golden Hill Schist could be similarly interpreted, implying a Southington Mountain age for the Golden Hill.

The revised stratigraphic section now reads from oldest to youngest: Basal Group, The Straits Schist, Trap Falls Formation (= Ansonia Gneiss), Southington Mountain Formation (= Beardsley Gneiss and Golden Hill Schist), Pumpkin Ground. This column, unchanged below the Trap Falls Formation, preserves the Monroe nappe, the White Hills recumbent syncline, and the Trap Falls syncline. However, the Shelton and Bridgeport structures must be interpreted as later upright folds that deform earlier recumbent folds, namely the White Hills recumbent syncline (which in this model would share the same axial surface as the Trap Falls syncline) and the Monroe nappe. The pinch-outs, here interpreted as fold hinges, of the Pumpkin Ground on the two limbs of the N-plunging Bethany "synformorium" require that the axes of the early structures cross the axes of the later structures, although there is no fabric evidence in these rocks supporting a noncoaxial double deformation. Acceptance of this hypothesis, therefore, requires a pre-metamorphic age for the formation of the White Hills recumbent syncline and the Monroe nappe, perhaps due to gravity gliding off a rising sea floor when the rocks were in a semi-consolidated state.

METAMORPHISM

General statement

The common occurrence of kyanite, staurolite, and sillimanite in pelitic rocks and of diopside in calcareous rocks, together with widespread hornblende-plagioclase amphibolite in the Long Hill and Bridgeport quadrangles indicate that the rocks there belong to the almandine-amphibolite facies. Northwest of nonsillimanitic rocks, and separable from them by a sillimanite isograd, are aluminous rocks containing sillimanite, confirming the progressive westward increase in metamorphic grade shown by Fritts (1962a). There are, however, problems related to this sillimanite isograd; they are discussed below.

Chloritization of biotite and garnet, as well as sericitization of feldspar and other aluminous phases is widespread and penetrative, especially in rocks with a high concentration of hydrous phases.

Sillimanite isograd and related problems

The increase in metamorphic grade northwest from New Haven was demonstrated by Fritts (1962a), who mapped the Barrovian isograds, biotite, garnet, staurolite, and kyanite, in the Ansonia and Milford quadrangles. The widespread occurrence of sillimanite in the Long Hill quadrangle indicates a further increase in metamorphic grade in this direction. Sillimanite occurs in very fine-grained, felted masses in most rocks in the map area; it cannot be identified with certainty in hand specimens. Consequently, the sillimanite isograd is drawn almost entirely on the basis of thin sections and is not as precisely located as the lower isograds to the east. Kyanite and staurolite persist on the high-grade side of the sillimanite isograd—this has also been noted by other geologists working in Connecticut (Gates, 1961, 1965; James Dieterich, Rolfe Stanley, and Gordon Eaton, personal communications) and in Massachusetts (Robinson, 1963). In many rocks, sillimanite appears to form at the expense of biotite; this was also noted by Gates (1961, 1965).

If kyanite and sillimanite are chemically identical, their stable coexistence requires univariant equilibrium, a condition unlikely to be maintained throughout a large volume of rock. Neither the assumption of chemical identity nor of stable coexistence of the two polymorphs is necessarily correct, however. Chemical analyses cited by Deer and others (1962) show that sillimanite may accept between 1 and 2 percent Fe^{3+} in place of aluminum. Pearson and Shaw (1960) concluded that the small enrichment of boron, beryllium, and barium that they found in sillimanite, as compared to kyanite, was not likely to cause a significant broadening of the kyanite-sillimanite univariant. However, Robinson (1963) noted that in the Orange, Massachusetts, area, tourmaline is less common in the sillimanite zone than it is in the kyanite zone. He suggested as an explanation that kyanite in the sillimanite zone was enriched in boron—that it is chemically distinct from sillimanite. The complete substitution of boron for octahedrally coordinated aluminum in the feldspar known as reedmergnerite (Milton and Eugster, 1959) raises the possibility that similar extensive substitution in kyanite is also possible. There is no correlation in the Long Hill and Bridgeport quadrangles, however, between the occurrence of tourmaline and the grade of metamorphism. Hence Robinson's explanation probably does not apply here. In fact, the greatest concentration of tourmaline observed (table 7, sample BP-144) is from a rock carrying sillimanite.

Reactions in the dry alumino-silicate system are known to be extremely sluggish. Clark (1961), for example, was able to reverse the kyanite-sillimanite equilibrium only above 1,300° C. Bell (1963) reversed the reaction at much lower temperatures only in the presence of large shearing stresses. The sluggishness of the inversion probably explains the metastable co-existence of the two minerals in the Long Hill and Bridgeport quadrangles.

Weill (1963) and Newton (1966a, 1966b) showed that the presence of a fluid phase accelerates reaction rates, even in the sluggish alumino-silicate system, permitting reversals to take place within days under temperatures and pressures that are geologically reasonable. It is very unlikely, however, that an appreciable fluid phase existed under sillimanite-zone conditions. Any connate water would have been used in the production of hydrous minerals—if some remained, it would have been driven out of the system. Also, except for the very local decomposition of biotite and muscovite discussed below, no fluid was available from the breakdown of other hydrous phases.

In the classic Scottish Highlands area studied by Barrow (1893), staurolite does not appear beyond the kyanite isograd. This has been interpreted as the result of the reaction: 3 staurolite + 2 quartz → 5 kyanite + 1 almandine + 3 H_2O. This restriction of staurolite to the zone between the staurolite and kyanite isograds has been noted by other petrologists (Turner and Verhoogen, 1960; Winkler, 1965) and also by Miyashiro (1961), who included it in the definition of his kyanite-sillimanite type of regional metamorphism. The reason for the association of staurolite with kyanite and even with sillimanite in the Long Hill and Bridgeport quadrangles is not known, although at least two explanations can be suggested. In view of the structural similarity of staurolite and kyanite, staurolite might be similarly nonreactive and coexist metastably with kyanite. However, this is an unsatisfactory solution because evidence from the Scottish Highlands suggests that there staurolite has reacted and does not persist metastably. Alternatively, the physical conditions of metamorphism in western Connecticut may have differed from those in Scotland, making the stability field of staurolite different in the two areas. There is no positive evidence supporting this hypothesis but, in view of the widespread staurolite in the higher grade rocks of western Connecticut, it is reasonable to assume that the compositional field of chloritoid is represented at lower grades; its absence from western Connecticut, in contrast to its presence in the Scottish rocks, suggests somewhat lower pressure in western Connecticut.

The intimate association of biotite and sillimanite has been reported not only from western Connecticut but also from Glen Cova in the Scottish Highlands (Chinner, 1961). There, biotite was a nucleating agent, according to Chinner; the trigonally arranged oxygen octahedra and tetrahedra in the alternate mica layers acted as nuclei for the growth of the octahedral Al-O and the tetrahedral (Al, Si)-O chains that constitute the sillimanite structure. It is assumed that aluminum and silicon for sillimanite were mainly derived from the solution of unstable kyanite and that biotite played no direct part in the reaction. The orientation of sillimanite parallel to the pressure-figure directions in mica (also noted by the present writer), and the structural similarities between these two phases support Chinner's suggestion. However, his argument that the sillimanite is not derived from the breakdown of biotite runs counter to the evidence in thin sections from the Long Hill and Bridgeport quadrangles: the decoloration of biotite and the marked association of magnetite granules with sillimanite clusters. It has been widely observed that biotite is a stable phase in rocks where muscovite is unstable; nevertheless, the broad limits of solid solution in biotite leave open the possibility that certain compositions may have a more restricted field of stability. A highly aluminous biotite such as eastonite or siderophyllite might fractionally break down to sillimanite and a more stable biotite plus other products. No experimental data exist on alumina-rich biotites and there is, therefore, no supporting evidence for this hypothesis.

The assemblage, muscovite + quartz + alumino-silicate + microcline occurs locally in metasediments associated with the Newtown Gneiss (see table 2, sample LH-542). In thin section the four minerals are closely associated and appear to be in mutual equilibrium. If P_{H_2O} were equal to P_{total} then the four solid phases plus H_2O vapor represent a univariant assemblage in the four-component system: K_2O-Al_2O_3-SiO_2-H_2O. If P_{H_2O} varied independently of P_{total}, then the four solid phases represent a divariant assemblage. Variability in P_{H_2O} might be suspected in these rocks because nearly anhydrous porphyroblastic gneiss is interlayered with relatively hydrous metasediments. Some schist contains muscovite and quartz without K-spar and alumino-silicate, suggesting that in these cases P_{H_2O} was maintained at a sufficiently high level to inhibit muscovite decomposition. Apparently the conditions of temperature and rock pressure approached the second sillimanite isograd at the peak of metamorphism; this boundary was crossed where P_{H_2O} was locally reduced. The restriction to the northwestern corner of the Long Hill quadrangle of the assemblage, muscovite + quartz + alumino-silicate + microcline is consistent with the increasing metamorphic gradient in this direction, lending support to the hypothesis that the numerous bodies of coarse-grained granodiorite in this area resulted from partial melting of the porphyroblastic gneiss.

Magnitude of indirect componental movements

GENERAL DISCUSSION

As pointed out in the introduction, the discussion of the origin of the various rock types is based on the assumption that, during metamorphism, there has been constant chemistry on a small scale. Evidence supporting this assumption is presented in the following paragraphs.

A maximum transport distance of chemical components ("indirect componental movements," Sander, 1930) is defined by the distance separating incompatible phases in a rock—if communication between incompatible phases had been possible, a reaction to form a stable assemblage would have occurred. Thus the proof of small-scale constant chemistry lies in demonstrating the close proximity of incompatible phases. Although any incompatible mineral pair might be used in this study, to be useful the minerals must be common in medium-grade, regionally metamorphosed eugeosynclinal rocks, and they must be sufficiently coarse grained and distinctive to be easily identified in the field. In the Long Hill and Bridgeport quadrangles the mineral pair, hornblende + high-aluminum silicate, meets these requirements.

AMPHIBOLITE-MUSCOVITE SCHIST CONTACTS

Hornblende does not occur with kyanite, sillimanite, staurolite, or muscovite in the area studied and no example of a presumed equilibrium assemblage of this type has been described elsewhere. Tilley (1937) has described kyanite amphibolites from the Scottish Highlands, but these are all retrograded eclogites and probably do not represent equilibrium assemblages. The system SiO_2-Al_2O_3-(Fe,Mg)O-CaO-K_2O-H_2O includes all relevant phases and tie-lines, and these can be plotted in the tetra-

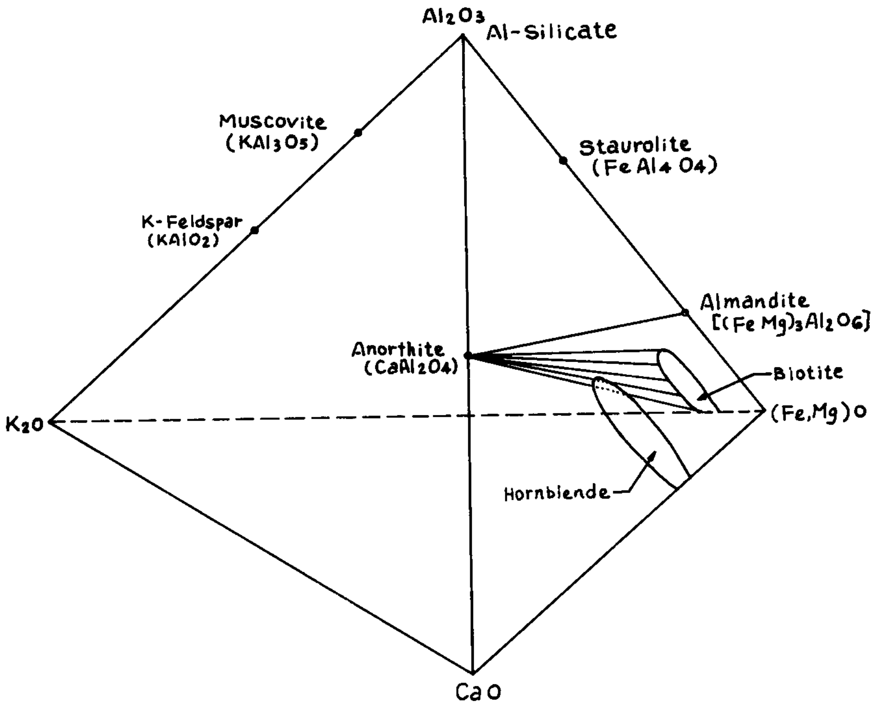


Fig. 7. The system SiO_2-Al_2O_3-(Fe, Mg)O-CaO-K_2O-H_2O, showing stable mineral pairs (connecting tie-lines) that rule out the assemblage, Hb + Al-silicate (or muscovite or staurolite).

hedron K_2O-Al_2O_3-CaO-$(Fe,Mg)O$ (fig. 7) assuming that SiO_2 is present as a phase (quartz) and that Na_2O occurs only in feldspar. The pairs plagioclase + biotite and plagioclase + almandine are both very common in the Long Hill and Bridgeport quadrangles. The tie-lines that define these pairs rule out the coexistence of hornblende with muscovite, staurolite, or any of the Al_2SiO_5 polymorphs. A possible equation representing the hornblende-muscovite reaction might be as follows: $3\ Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2 + 5\ KAl_3Si_3O_{10}(OH)_2 + Al_2SiO_5 = 5\ K(Fe,Mg)_3AlSi_3O_{10}(OH)_2 + 6CaAl_2Si_2O_8 + 13\ SiO_2 + 3\ H_2O$. Kyanite may be considered a reacting phase in this equation or, alternately, the reaction may be written with the excess alumina distributed in the other phases.

The mineralogy of pegmatites adjacent to amphibolites in the Long Hill and Bridgeport quadrangles provides an interesting illustration of this reaction. Pegmatites are common in all stratigraphic units of the two quadrangles but their mineralogy is virtually invariant—quartz, feldspar, muscovite, and, locally, tourmaline. Where pegmatite is in contact with amphibolite, however, biotite is the only mica present. Such contacts are common in the heterogeneous zone separating the Collinsville Formation and The Straits Schist, readily observable in the vicinity of the old Trumbull tungsten mine (fig. 3, LH-7-2).

If this incompatibility is real, what happened where a layer having one member of an unstable pair is in contact with a layer containing the other? In the area mapped, kyanite and staurolite are not sufficiently abundant in any rock to facilitate study of this problem, and sillimanite is almost everywhere so fine grained that it is usually overlooked. Fortunately, however, interlayered amphibolites are common in muscovite schist; many of these schist-amphibolite contacts were examined closely.

Conditions are most favorable for this study in the Oronoque Member of the Orange Formation, where numerous thin amphibolites occur throughout muscovitic schists and gneisses. Moreover, the bedding is everywhere nearly vertical, and all exposures are clean and easily accessible. The least distance separating muscovite and hornblende at these contacts is 3 cm. Without exception, the contact is a reaction zone characterized chiefly by a high concentration of biotite and secondarily of feldspar. In places this zone is a homogeneous layer of feldspathic biotite schist; elsewhere amphibolite is enclosed by a layer of biotite schist succeeded by feldspathic biotite gneiss and, finally, by muscovite-bearing rock.

Interlayered amphibolite and muscovite schist are also characteristic of the Forest Lake body of metasediment in the Trap Falls Formation but, because dips are low, contacts are rare. Nonetheless, a roadcut on the Merritt Parkway 2,000 ft west of the overpass over Reservoir Avenue (BP-2-4) exposes several amphibolites interlayered with muscovite schist. Each schist-amphibolite contact is marked by a zone 3 to 6 cm thick, consisting of decomposed biotite mud. Between this mud zone and the muscovite schist is a thinner layer of feldspathic biotite gneiss; the succession of zones here is similar to that observed in the Oronoque. The thickness of the reaction zone is nowhere greater than 9 cm and generally less than this.

A third zone where schist-amphibolite contacts are common is the heterogeneous zone separating the Collinsville Formation and The Straits Schist. In the Long Hill quadrangle, contacts in this zone are commonly cut out by intrusive pegmatite or covered by till. An excellent exposure flanks Route 8 east of the Naugatuck River in the Naugatuck quadrangle; there the contact of The Straits Schist with underlying amphibolite can be traced for several tens of feet. As at the other contacts studied in detail, amphibolite is rimmed by biotite schist, which in turn is rimmed by feldspathic biotite gneiss followed by muscovite schist. The contact reaction zone here is approximately 4 cm in greatest thickness.

These observations suggest that indirect componental movements during metamorphism have varied from 3 to 9 cm. The evidence is not conclusive but is consistent with the common assumption that the bulk composition of most metamorphic rocks is not very different from that of igneous and sedimentary parent rocks.

If a rock layer with a thickness of several tens of centimeters presents uniform mineralogic composition across this entire thickness, it seems reasonable to conclude that metamorphism has been isochemical with respect to nonvolatile constituents, and an analysis of a small sample centrally located within the layer should be a reasonable representation of the chemistry of the rock prior to metamorphism. The contact between layers that contain mutually incompatible phases is a region of steep gradients in chemical potentials during metamorphism. A zone of intermediate chemistry should develop there whose thickness is a function both of the chemical potential gradients and reaction kinetics.

Not all the modal analyses recorded in this report were taken from rock layers showing uniform mineralogical composition across layering for at least 10 cm on either side of the sampled zone. However, virtually all those whose norms were computed and plotted do satisfy at least this criterion, and in most cases come from considerably thicker layers of uniform mineralogy.

Physical conditions of metamorphism

A starting point in most discussions of the conditions under which a volume of rock was metamorphosed is the location of the triple point in the Al_2SiO_5 system. This has been subject to wide fluctuations depending on how the determination was made. However, the work of Newton (1966a, 1966b), who used hydrothermal methods, is probably the most reliable determination of the precise pressure and temperature of the invariant point (fig. 8).

Based on the many reactions investigated in his laboratory as well as on the work of others, Winkler (1965) states, "the succession of subfacies or zones in a metamorphic terrain can be attributed unequivocally to a rise of temperature towards the source of the thermal energy, while the pressures operating at the then deep-seated niveau of metamorphism . . . could not have been appreciably different in the different subfacies . . ." This has been the conclusion of other workers as well (see Clark and others, 1957). In the absence of andalusite in western Connecticut, this

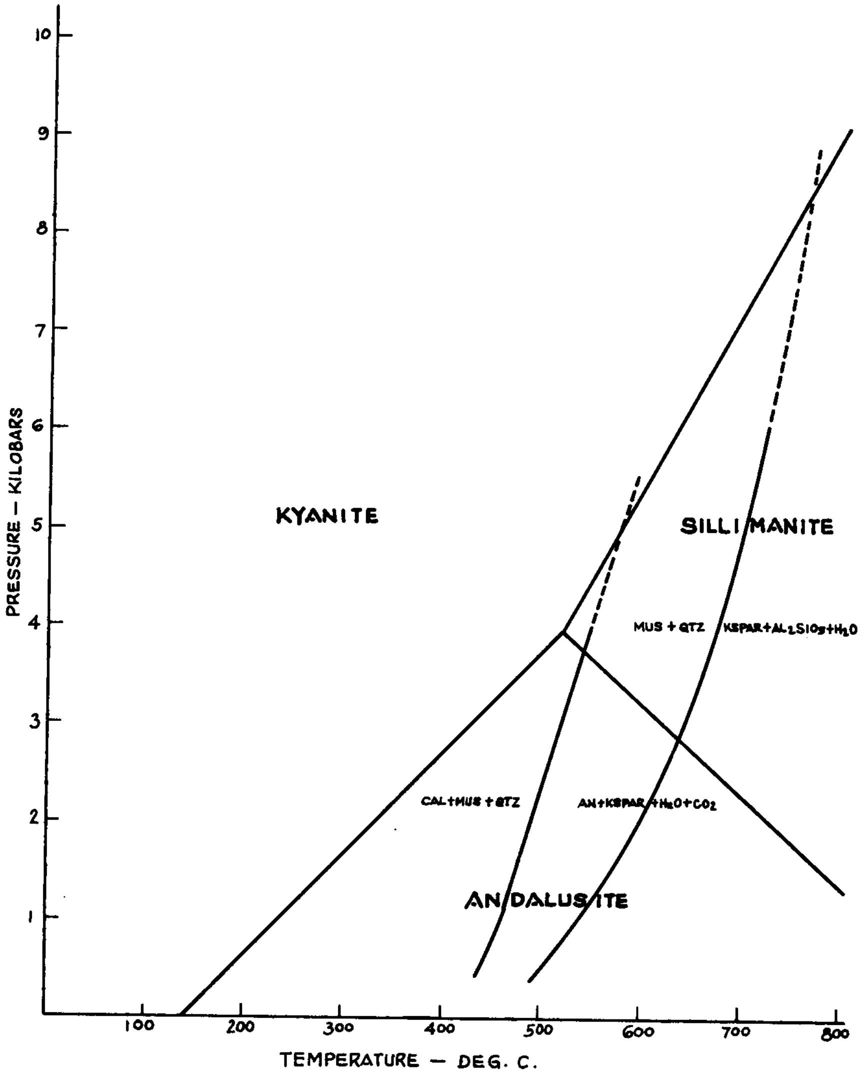


Fig. 8. Al_2SiO_5 phase diagram of Newton (1966b) with superimposed devolatilization curves. Muscovite + quartz reaction from Evans (1965) ($P_{H_2O} = P_{total}$). Calcite + muscovite reaction from data of Hewitt (Hewitt and Orville, 1966) ($P_{fluid} = P_{total}$; $P_{fluid} = \rho H_2O + \rho CO_2$, $\rho H_2O = \rho CO_2$.

requires a minimum pressure of 4 kb and a temperature of at least 500° C for those parts of the Long Hill and Bridgeport quadrangles that are underlain by sillimanite-bearing rocks.

There are no experimental data on relevant solid$\rightleftarrows$solid reactions that can be used to set an upper limit on pressure and temperature, but at least two reactions involving volatiles have been investigated.

Evans' (1965) muscovite + quartz stability curve (fig. 8) sets a temperature maximum of about 750° C, provided that $p_{H_2O} = P_{total}$. If $p_{H_2O} < P_{total}$ the reaction goes at an even lower temperature and hence 750° C is an absolute maximum. A pressure maximum is fixed by the intersection of the muscovite stability curve with the kyanite-sillimanite univariant, but this requires a long extrapolation of the former curve, and in any case would probably give a value of around 8½ kb, which is so high as to be almost meaningless.

Much tighter limits on conditions of metamorphism are set by the reaction: calcite + muscovite + 2 quartz $\rightleftarrows$ anorthite + K-spar + H_2O + CO_2, a reaction that has been investigated by Hewitt (Hewitt and Orville, 1966). Figure 8 shows his curve for the conditions:

$$P_{fluid} = P_{total}, P_{fluid} = p_{CO_2} + p_{H_2O}, \text{ and } p_{CO_2} = p_{H_2O},$$

under which the P-T curve defines an absolute maximum temperature for any given pressure, regardless of the composition of the fluid phase.

Sample LH-352 (table 6) is a calcite marble containing accessory quartz and muscovite but lacking K-spar. Although both quartz and muscovite touch calcite, they are themselves nowhere in direct contact; 2 mm is the least distance between them. Muscovite and quartz are separated by less than ¼ mm in marble (table 4, sample LH-304) at the Trumbull tungsten mine. This probably represents an equilibrium assemblage and, as it occurs beyond the first sillimanite isograd, sets temperature- pressure maxima of 580° C and 5 kb, respectively. Unfortunately, corroboratory field evidence for the stability of this assemblage is lacking. Despite the occurrence of calcite marble in schist units, the marble is everywhere in immediate association with nonmuscovitic, commonly sulfidic, calc-silicate rock, and separated from muscovite schist by at least several feet. The only exception—from the kyanite zone, however—occurs at the type locality of the staurolite-schist member of the Southington Mountain Formation (fig. 3, BP-2-6), where calcite-bearing calc-silicate gneiss is separated from muscovite schist by 2 cm of biotitic quartzite with neither plagioclase nor K-spar in evidence.

Marble from the top of the Collinsville Formation in the northwestern part of the Long Hill quadrangle (table 4, sample LH-465) contains microcline, muscovite, and plagioclase, but no quartz. All phases touch calcite, but muscovite and microcline are separated from each other by a minimum distance of 2 mm. Microcline occurs chiefly in intimate association with plagioclase. This assemblage is interpreted as a natural occurrence of Hewitt's reaction, arrested before completion by the total consumption of quartz. The location of this marble, well northwest of the first sillimanite isograd, indicates that the grade of metamorphism continues to rise in this direction, a conclusion also hinted at by the higher anorthite content of plagioclase from amphibolite in the northwestern part of the area, and confirmed by the local decomposition of muscovite in this area.

It is evident that the westward increase in grade of metamorphism demonstrated by Fritts (1962a) continues across the Long Hill and Bridgeport quadrangles. Maximum physical conditions of metamorphism just beyond the first sillimanite isograd are bracketed between 4 and 5 kb and 500 to 580° C. Locally, in the northwestern corner of the Long Hill quadrangle, metamorphism breached the second sillimanite isograd where P_{H_2O} was locally reduced.

ECONOMIC GEOLOGY

Introduction

The discovery of metallic-mineral deposits in western Connecticut dates to the time of the earliest colonists; mining was an important industry until the westward expansion of the middle 19th century. The only metals produced in western Connecticut today are calcium and magnesium from the carbonate rocks of the westernmost part of the state; all the old mines have been abandoned.

Three old mines are located in the Long Hill quadrangle—the celebrated tungsten mine in Trumbull and, in Monroe, Booth's bismuth mine and Lane's mine. The geology and mineralogy of these mines have been described by earlier workers; the present report attempts to relate these occurrences to the regional geology of western Connecticut in the hope of shedding additional light on the origin of these deposits.

Trumbull tungsten mine

The Trumbull tungsten mine is located just north of Long Hill village (fig. 3, LH-7-2). Accounts of its history are given by Harte (1944) and by Sullivan and others (1966). Operations were on a small scale until 1897, when the mine was taken over by The American Tungsten Mining and Milling Company, which erected an extensive plant and set up heavy machinery. Changes in ownership and various difficulties culminated in a disastrous fire in 1916; after that no major efforts were made to mine the ore. Representatives of various companies who have visited the mine from time to time have generally considered the property to show little promise as an important source of tungsten. It is now a town park and recreation area.

Descriptions of the mine have been given by Gurlt (1893), Hobbs (1901), Shannon (1921), and in a recent publication by Sullivan and others (1966); its mineralogy has been studied by Shannon (1920) and Schairer (1931).

The first geological map of the mine site was prepared by Hobbs (1901). He made a detailed study of an area of 500 x 300 sq. yards in the immediate vicinity of the mining operations, and then, on the basis of a brief reconnaissance, projected the mapped contacts into an area of about 6 sq. mi. His large-scale detailed map of the mine workings is much more accurate than his small-scale projected map. The only other map of the mine was made by Fisher (1942). His regional map is more detailed than Hobbs' but, particularly north of the mine, the contacts he drew are incompatible with the structure as described in the present report. Only in the vicinity of the mine workings and on the western slope of the hill immediately east of them does his map correctly portray the geology.

The present concept of the local structure has been discussed in the section above entitled "Structures postdating F_D." The rocks belong to the upper limb of the White Hills recumbent syncline—hence the terms "lower" and "upper" (with respect to the rock layers) is in the structural sense; stratigraphically the rocks are upside down.

The mining property is confined to the contact zone separating the Collinsville Formation and The Straits Schist. Hobbs, and apparently Fisher as well, considered that (apart from one thin bed of marble at the southern end of the mining property) all marble outcrops belong to a single thick bed separating the amphibolite into a lower and upper division. The mapping for this report confirms the presence of a major bed of marble; there are, however, several marble outcrops that overlie or underlie this major bed and are separated from it by amphibolite.

The marble-amphibolite contacts (commonly characterized by a skarnlike zone of lime-bearing silicates) are parallel to layering within the marble and also to the contacts of other minor rock types. Thin, conformable amphibolite layers are locally observed in marble. Hobbs noted the remarkable conformity of marble and amphibolite but concluded, on the basis of what he considered to be igneous textures in amphibolite thin sections, that the amphibolite is a metamorphosed intrusive dioritic magma. The local development of the skarnlike zone separating amphibolite from marble he attributed to reaction between the limestone and this magma, a theory made more attractive by the localized development of scheelite in this same zone. The conformable relationship between amphibolite and marble on all scales raises a serious objection to Hobbs' proposed origin of the amphibolite, particularly in view of the wide areal extent of the thin Collinsville-The Straits Schist contact zone.

Hess (1917) was the first to suggest a volcanic origin for the amphibolite. Hobbs' contact evidence for an intrusive origin was negated by Shannon (1920), who remarked on the absence of contact metamorphism traceable to visible igneous masses and added that the metamorphic minerals of the limestone are "characteristic minerals of regionally metamorphosed limestones throughout the Taconic region rather than minerals of true contact origin."

The large concentration of non-exotic pegmatite in this zone has been noted. Visible contact effects with the country rock are limited to a fine-grained chilled margin less than 1 in. thick. No chemical or mineralogical changes have been noted in adjacent rocks elsewhere in the Collinsville-The Straits Schist contact zone; the theory of Schairer (1931), supported by Kerr (1946), attributing "contact metamorphism" and ore deposition in the tungsten-mine area to the intrusion of these pegmatites is rather questionable.

The author's ideas on the origin of the tungsten deposit are discussed below under the heading "Basal-group ore zone."

Booth's bismuth mine

Booth's bismuth mine, located near the intersection of Barn Hill Road and State Route 110 (fig. 3, LH-2-8), is named from the occurrence there of small masses of native bismuth. However, bismuth is far less abundant than the several sulfide species present (pyrrhotite, chalcopyrite, pyrite, sphalerite, and arsenopyrite), the most common of which is pyrrhotite. Schairer (1931) gives a brief description of the mineralogy of the mine but little is known of its history. It clearly has been inactive for many years.

The mine is in a ledge of massive quartz throughout which are disseminated the small masses of bismuth and larger veins and pockets of sulfides. Nowhere is any contact with the surrounding gneisses of the Collinsville Formation exposed but there are a few lenses of schist in the massive quartz.

About ½ mi. north northwest of the mine is a trench dug into another massive ledge of quartz, exposing large pockets of platy pyrrhotite. Here the quartz is broken by gently W-dipping planar surfaces that parallel layering in nearby outcrops of gneiss. Also parallel to these surfaces and embedded in the massive quartz are a few thin lenses of punky, very rusty-weathering quartz-mica schist.

These two outcrops are apparently part of a zone of silicification where the pre-existing bedrock has been totally replaced by quartz, leaving only a suggestion of layering plus a few less altered lenses of the original rock.

A very different outcrop, 1,400 ft southeast of the bismuth mine exposes fine-grained schist and intrusive pegmatite. This very vuggy outcrop is weathered to a peculiar blue gray. A thin section from it reveals that 1) quartz is totally absent, 2) there are two size fractions of muscovite, tending to be in mutually exclusive layers with bent muscovite blades common in both, 3) plagioclase grains show bending and offsetting of twin lamellae, and 4) carbonate occurs as untwinned grains in pockets, usually associated with plagioclase.

The location of the vuggy schist and massive quartz outcrops along a nearly straight line that strikes about N 20° W (see pl. 1) suggests that this is a narrow zone of hydrothermal alteration, perhaps associated with faulting. The country rock is too poorly exposed in this area to afford any stratigraphic or structural evidence for faulting, but it is interesting to note that the strike of this zone is the same as that reported by Rodgers and others (1959) for the faults that deform the Pomperaug Valley outlier of Triassic rocks in Woodbury and Southbury, 11 mi. north. Silicification is common along many Triassic faults and other late faults of unknown age in New England, although sulfide mineralization is seldom as striking in these other areas as it is along Booth's zone, and native bismuth has never been reported from the late faults.

Lane's mine

Lane's mine is located a little over 1 mi. due west of Monroe village (fig. 3, LH-4-2). It is mentioned by Percival (1842), several times by Shepard (1837) and Schairer (1931), and is described in a brief paragraph by Hobbs (1901, ftn. p. 13).

The mine consists of several pits and trenches sunk into massive quartz, which bears pockets and veins of sulfides. The mineralogy is, in most respects, similar to that of Booth's bismuth mine, including the reported occurrence of native bismuth (Schairer, 1931) and the wide distribution of pyrrhotite. The mine is in the western body of Collinsville Formation not far from the western contact of the westernmost belt of The Straits Schist. However, there are no outcrops of the country rock in the immediate vicinity of the mine, nor were any lenses of schist or gneiss observed in the massive quartz. Hobbs (1901) described the quartz body as having a northerly trend, although this was not obvious in the present investigation. There appears to be a nearly horizontal layering in the quartz. As the country rock in this area has gentle dips, this may indicate silicification of pre-existing rock, indicating that Lane's mine is probably part of a zone of hydrothermal alteration related to late faulting, as has been suggested for Booth's bismuth mine.

Other mines and quarries

PEGMATITE QUARRY

About ½ mi. north of East Village and 800 ft east northeast of the hairpin bend in Boys Halfway River is an old quarry in an extremely coarse-grained pegmatite, which locally exhibits a graphic-granite texture (fig. 3, LH-2-2). Schairer (1931) describes it as "a small feldspar quarry where rose quartz, muscovite, biotite, garnet, columbite and feldspar are abundant." This may be the location described by Shepard (1837, p. 137): "A coarse grained granite in the northwestern part of Monroe, has afforded the most interesting variety of well crystallized and handsomely colored beryl . . ."

GRANITE GNEISS

Granite gneiss for dimension stone was formerly quarried out of the Ansonia Gneiss at four localities. Two of these are in the small, isolated body that crops out near the intersection of Broadbridge and White Plains roads (fig. 3, BP-2-9), a third is at the site of the County Jail (BP-5-4), and the fourth (which may be Burr's Quarry described by Percival, 1842, p. 30) is on the eastern bank of Rooster River in Mount Grove Cemetery (BP-4-8). There is an old quarry in a ledge of rather uniform garnet-muscovite-quartz-feldspar gneiss of the Trap Falls Formation, 1,000 ft southwest of the southern end of Trap Falls Reservoir (LH-9-7).

QUARTZ

There is an old quarry in a quartz body 1,100 ft southeast of the intersection of Shelton Avenue and Willoughby Road (fig. 3, LH-6-9). Quartz for paper filler was formerly quarried from a cross-cutting vein known as the Champion lode, at the old Trumbull tungsten mine.

DIABASE

There is an abandoned quarry in a diabase dike just south of the Merritt Parkway a little west of Interchange 50 (fig. 3, BP-2-5). A large volume of "trap rock" was removed, and a pond now covers the floor of the northern half of the quarry. The very large exposure makes this quarry an ideal location for studying the detailed geometry of the dike and its contact effects on the country rock.

MARBLE

Marble, presumably for use as agricultural lime, has been quarried from two localities along the contact zone separating the Collinsville Formation and The Straits Schist. One is at the old tungsten mine and the other at an exposure along Boys Halfway River (fig. 3, LH-2-2). Marble was also quarried from the marble layer in the upper member of The Straits Schist in the hills east of the Housatonic River (LH-3-6).

Basal-group ore zone

INDIVIDUAL DEPOSITS

The Trumbull tungsten mine is restricted to the contact zone separating the Collinsville and The Straits Schist formations. There is a remarkable concentration of ore deposits in south-central Connecticut along this relatively thin zone over an area of at least 70 sq. mi. They are numbered 1 to 6 on the regional map, plate 4. These deposits are briefly described below. Only those in the Long Hill quadrangle were visited in the course of the present investigation.

(1) Pine Bridge. Carr (1960) noted that pyrite and chalcopyrite are disseminated throughout the Collinsville Formation (which he called Prospect Gneiss) just north of Swamp Brook and west of Pine Bridge and that they were reputed to have been prospected for copper during the Civil War. This is clearly the area meant by Percival (1842) who states, "Traces of copper are observed in a bed of hornblende . . . West of the Naugatuck at Pines Bridge (Oxford)."

(2) Nickel Mine Brook. Schairer (1931) states that arsenic and nickel ore was mined on a small scale at the mouth of Nickel Mine Brook, and that arsenopyrite can still be found there.

(3) Stevenson mine. Schairer (1931) noted the occurrence of copper minerals at the Stevenson mine at Bowers Hill in Oxford, and this is presumably the locality referred to by Shepard (1837) who mentions arsenopyrite and by Percival (1842) who noted a bed of pyrite there.

(4) Trumbull tungsten mine. Although the tungsten mine is best known for its scheelite, which occurs chiefly as crystalline masses in epidote-quartz rock at the lower contact of the major marble bed, sulfides are also important. Those found include marcasite, pyrite, chalcopyrite, sphalerite, galena, and pyrrhotite. The tungsten mine is also the site of

the major fluorite deposit of Connecticut. Fluorite occurs with topaz, quartz, margarite, and margarodite in cross-cutting veins that apparently postdate the metamorphism.

(5) Booth's bismuth mine and (6) Lane's mine. These two mines are not located precisely in the contact zone but occur quite close to it.

Other occurrences. Carr (1960) noted pyrite and chalcopyrite in the Collinsville Formation (which he called Prospect Gneiss) in a roadcut along State Route 8, west of Rock Rimmon. His geologic map indicates that this occurrence is within 600 ft of The Straits Schist-Collinsville contact.

The pegmatite quarry described above is in Collinsville Formation less than 700 ft from amphibolite of the contact zone.

The evidence for stratigraphic control of ore deposits in the Long Hill, Southbury, and Naugatuck quadrangles suggests that other ore deposits may be present farther north in the Southington, Waterbury, and Thomaston quadrangles where the contact zone between the Collinsville Formation and The Straits Schist can also be locally recognized, and perhaps also in the Bristol, Collinsville, and Tariffville quadrangles. None has been reported, however, with the exception of a small columbite deposit in The Straits Schist near Reynolds Bridge in the Thomaston quadrangle discovered by Charles R. Warren (personal communication) of the U.S. Geological Survey. An abandoned mine is shown at the base of The Straits Schist on the geologic map of Collinsville (Stanley, 1964), and is reputed to be an old silver prospect according to local residents (Stanley, personal communication) but there is no known published description of it.

ORIGIN

Although the Collinsville Formation has been considered by some geologists as a metamorphosed igneous intrusive, arguments have been presented above in favor of a volcanic origin. A similar origin for the amphibolites of the contact zone is even more compelling. This leaves no intrusive source for the ore minerals.

Notably, in the few places outside the ore zone where carbonate occurs (in the calcareous member of the Prospect Formation), it is invariably associated with abundant, fine-grained sulfide (probably largely pyrite) disseminated throughout the interlayered, commonly quite graphitic schists and gneisses. The association of graphitic rocks with sulfides suggests the common situation whereby metallic ions in sea water are precipitated by H_2S generated from the action of anerobic bacteria on organic debris. The simultaneous deposition of limestone could also be due to decay processes such as the production of ammonia either by decomposition of nitrogenous materials or by the life processes of certain bacteria. The metallic ions may ultimately have been derived from the same source as the Collinsville volcanics. Syngenetic origins have been proposed for numerous sulfide deposits (see Amstutz, 1964) but scheelite is generally considered a product of either contact metamorphism or hydrothermal deposition related to igneous intrusion. Although sulfides are present throughout the ore zone, scheelite is known only from the one Long Hill locality, which is precisely where the ore zone is intersected by the fluorite zone. Possibly, therefore, the scheelite was deposited much later than the sulfides, by the reaction of fluorine- and tungsten-bearing hydrothermal fluids with the marble of the ore zone.

The basal-group ore zone is part of a stratigraphic sequence that is remarkably similar to the sequence of rocks in the Pitkäranta mining area on the northern shore of Ladozhskoye Ozero (Lake Ladoga) in southwestern Karelskaya, A.S.S.R., studied by Trüstedt (1907; see also Eskola, 1948). There an extensive terrain of mica schist is broken by gneiss-cored domes. Separating the banded granitic gneiss of the domes from the mantling schist is a zone varying from 500 to 1,000 ft thick, composed chiefly of amphibolite but also including marble, calc-silicate rock or skarn, stratiform and cross-cutting pegmatite, and minor quartzite. Associated with the marble and calc-silicate rock are numerous deposits of chalcopyrite, sphalerite, galena, cassiterite, and magnetite. One is tempted to ascribe to the ore deposits of this region an origin similar to that postulated for those of the basal-group ore zone; Trüstedt, however, thought the ores were derived from a rapakivi granite mass, which cuts sharply across the dome complex.

Hydrothermal replacement along post-metamorphic faults has been argued above as the origin of Lane's mine and Booth's mine, and the location of these mines close to the basal-group ore zone may be purely fortuitous. However, if these zones of alteration continue downward for considerable distances, as they probably do if related to faulting, then they must intersect the ore zone at depth. Sulfides in the ore zone may then have been mobilized by ascending hot fluids during faulting and deposited with silica in structurally higher rocks.

Whether or not there is any significance to the occurrence of columbite and beryl near the ore zone is unknown.

GEOLOGIC HISTORY

The metasediments and metavolcanics of the Long Hill and Bridgeport quadrangles were probably deposited on oceanic crust in a continually subsiding eugeosyncline that was located along the eastern margin of North America. Although rocks of possible Cambrian age may be exposed in the core of the Waterbury dome just north of the map area, the section in the Long Hill and Bridgeport quadrangles is confined to rocks of probable Ordovician age. On the east these begin with flysch deposits (Derby Hill and Oronoque members of the Orange Formation), which are replaced by black shale (Wepawaug Member) to the north, and include a discontinuous acidic tuff zone (Woodbridge Gneiss Member). To the west these are succeeded chiefly by acidic pyroclastics (Newtown Gneiss and Collinsville Formation), interrupted toward the top by basaltic tuffs and minor limestone. Foul bottom conditions caused the local deposition of sulfides (basal-group ore zone). Black shale (The Straits Schist) was then deposited over the entire area, followed on the west by acidic pyroclastics (Trap Falls Formation), interbedded with and overlain by shale and graywacke (Southington Mountain Formation), although to the east only shale and graywacke were deposited. Volcanism was then renewed with the deposition of basic and normal dellenitic tuffs and facies-equivalent shales (Prospect Formation), followed by more aluminous rhyolitic to dellenitic tuffs (Ansonia Gneiss). Erosion has destroyed the record of subsequent deposition, which probably extended through the Silurian into the Devonian.

Intense deformation and metamorphism reconstituted and uplifted the rocks in Middle to Late Devonian time, driving out the seas and initiating a long period of subaerial erosion. The deformation formed more or less upright folds in the lower grade kyanite-zone rocks of the southeastern part of the map area; to the northwest, and in the sillimanite zone, recumbent folds were shed off the southern lobe of the rising Waterbury dome.

The Allegheny orogeny, which metamorphosed and plutonized the southern coastal region of Rhode Island and eastern Connecticut, produced granitic intrusions and fluorine metasomatism along a narrow NW-striking zone in the northern part of the Bridgeport and the southeastern part of the Long Hill quadrangles. Tungsten mineralization at Long Hill may also belong to this period.

Local faulting in the northern part of the Long Hill quadrangle, accompanied by silicification and deposition of sulfides and native bismuth, is of probable Triassic age. Diabase was intruded in a long, discontinuous, NE-striking dike, probably in the Jurassic.

The gentle seaward slope of the map area records a prolonged period of pre-Cretaceous erosion, Cretaceous deposition, and post-Cretaceous stripping.

Late in geologic time Pleistocene glacier ice scraped the thin mantle of regolith from the bedrock and deposited a variable thickness of till and stratified drift; the resulting landscape has persisted to the present with little change.

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