The Bedrock Geology of the Waterbury Quadrangle

WITH MAP

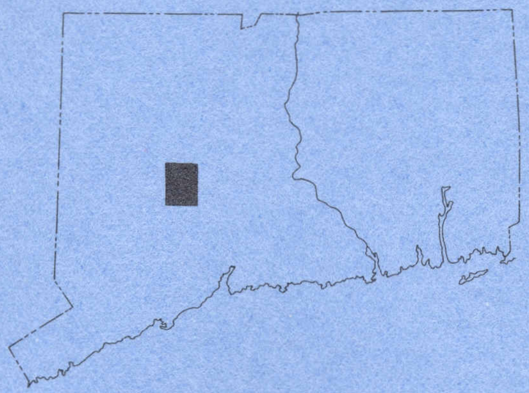
Open Map

Open Plate 2

BY ROBERT M. GATES

and

CHARLES W. MARTIN



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

A DIVISION OF THE DEPARTMENT OF AGRICULTURE
AND NATURAL RESOURCES

1967

QUADRANGLE REPORT No. 22

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by

Robert M. Gates and Charles W. Martin

ABSTRACT

The Waterbury gneiss dome is the southernmost of a series of gneiss domes extending from Chester, Vermont, to Waterbury along the eastern flank of the Green Mountain anticlinorium. Although not strictly a dome, since it is unroofed on its western side, it is mantled on the north, east, and south by a series of three conformable metasedimentary units traceable from the northern border of Connecticut almost to Long Island Sound. Igneous rocks ranging in composition from granitic to ultrabasic are erratically distributed throughout the quadrangle but do not constitute large plutons.

The Waterbury Formation is a metasedimentary gneiss complex forming the core of the dome. The complexly folded metasediments are intermixed in migmatitic fashion with granitic to trondhjemitic rocks. The structural style of the metasediments and of the migmatitic gneisses clearly separates the core gneiss from the mantling rocks.

Three distinctive lithologic units of the Hartland Formation mantle the core. The lowest, called Unit I (= part of the Waterbury gneiss of Fritts, 1963; = Taine Mountain Formation, Stanley, 1964), is predominantly a mica-plagioclase-quartz granulite and granulitic gneiss. The second unit, the Hitchcock Lake Member (= Collinsville Formation, Bristol Member of Stanley, 1964; = Reynolds Bridge Formation, Cassie, 1965), is a strikingly banded assemblage of quartzofeldspathic granulites and micaceous feldspar-quartz gneisses and schists. The third unit, The Straits Schist Member (= The Straits Schist Formation of Fritts, 1963; Stanley, 1964) is a lustrous medium- to coarse-grained muscovite-plagioclase-quartz schist containing porphyroblasts of garnet and kyanite. Of very limited extent in this quadrangle is the Southington Mountain Member, which overlies The Straits Schist Member. It differs from The Straits Schist in having thin layers of mica-poor plagioclase-quartz granulite. Associated with all members of the Hartland Formation are amphibolites which may be syntectonic intrusives, in part, and metavolcanics, in part. Discontinuous pods of amphibolitic rocks characterize the boundary between the Hitchcock Lake Member and The Straits Schist Member.

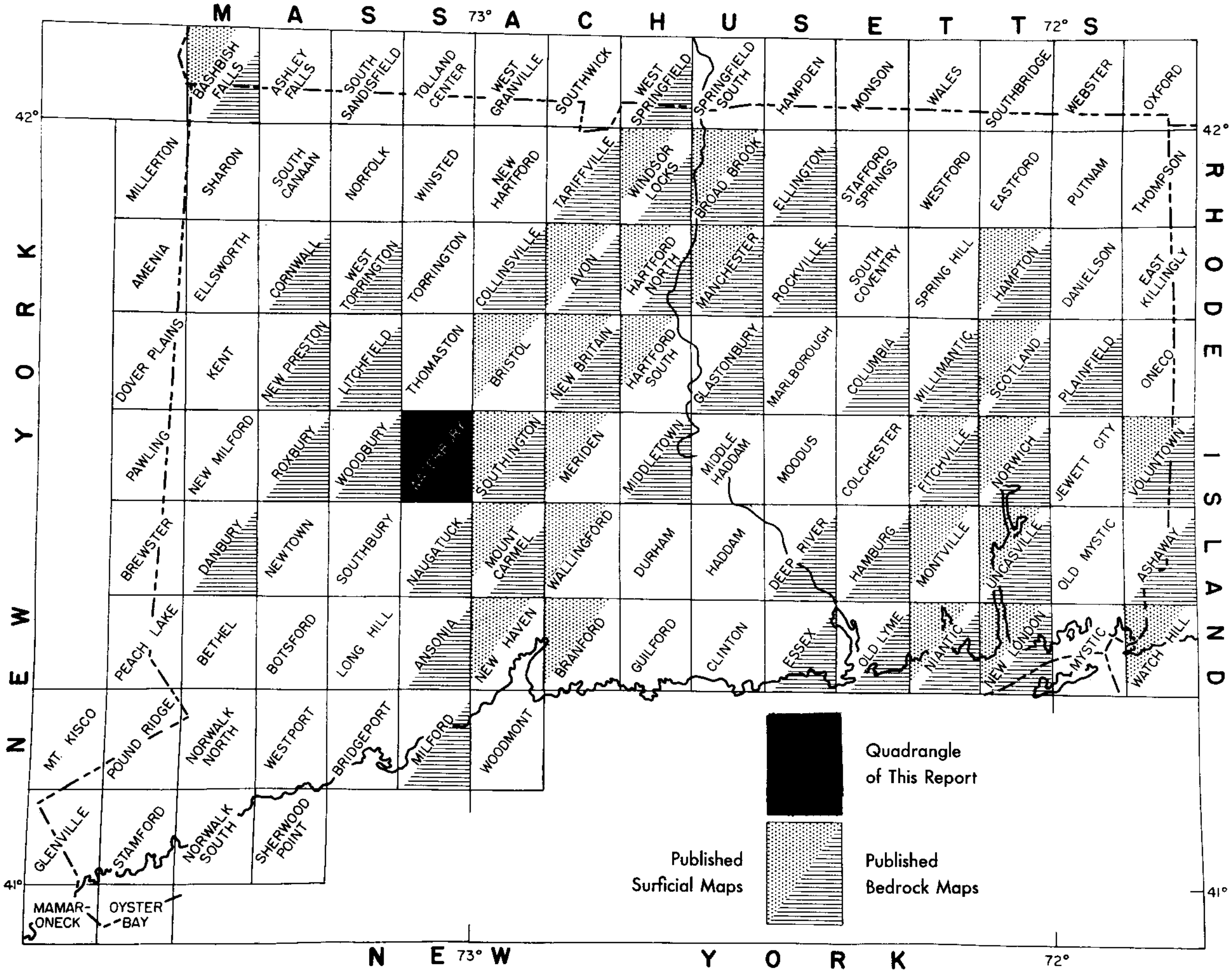

Fig. 1. Index map of Connecticut showing the location of the Waterbury quadrangle and of other published quadrangle maps.

Intrusive igneous (or igneous-appearing) rocks are ubiquitous. Granitic to granodioritic-gneiss sills are common in the Hartland Formation, particularly in Unit I and in the Hitchcock Lake Member. Post-tectonic Nonewaug-type granite and pegmatite are common, although rarely of mappable extent. Pegmatites are most common in The Straits Schist.

The Waterbury gneiss complex has numerous, small, anastomosing bodies of granodiorite-trondhjemite; some are mappable but most are intimately associated with the other rock types of the complex. These bodies are similar in composition to the biotite-quartz-plagioclase granulitic gneiss of the complex and may merely be recrystallized or mobilized parts of the metasedimentary pile. Small pink or white granitic-pegmatite stringers and patches are characteristic of the migmatitic parts of the complex, but are not abundant.

Structurally, the Hartland Formation is an isoclinally folded series of metasediments which have been refolded late in their tectonic and metamorphic history (probably in Acadian time). The late refolding was controlled or influenced by the resistant, buttressing pre-Hartland crystalline Waterbury Formation or by rising, partially melted "domes" in the formation.

INTRODUCTION

Location

The Waterbury quadrangle lies near the eastern edge of the Western Connecticut Highlands equidistant from Massachusetts and Long Island Sound (fig. 1). The City of Waterbury, which occupies the east-central part of the quadrangle, is accessible by major highways from all directions. Local roads make access to all parts of the quadrangle exceptionally easy.

Physical features

The topography is dominated by the Naugatuck River, which divides the quadrangle into approximately equal eastern and western halves. The center of the City of Waterbury is located near the topographic low point at the confluence of the Naugatuck River and its westward-flowing tributary, Mad River. Although the total relief is 800 ft, most hills range from 150 to 300 ft in height. The maximum elevation of 1,020 ft is in the northeastern corner and the lowest elevation is 200 ft, at the southern boundary where the Naugatuck River leaves the quadrangle. In large part, the topography reflects the lithology of the bedrock, although there are numerous rock-cored drumloidal hills. The Straits Schist is the most resistant formation and forms the most prominent ridges.

Acknowledgements

The quadrangle was mapped during the summers of 1962, 1963, and 1964 under the sponsorship of the Connecticut Geological and Natural History Survey. A special study of the gneiss dome was supported by

Grant No. 24344 of the National Science Foundation. The encouragement given over many years by Joe Webb Peoples, both as a Commissioner and as the Director of the Survey, is greatly appreciated.

Don Dewees and Dennis Howe, graduate students at University of Wisconsin, wrote Master's theses on special problems in the quadrangle. Dewees made a detailed structural analysis of the Sylvan Lake fold during the summer of 1965 and Howe made a petrographic study of the Hitchcock Lake Member during the 1965-1966 academic year. Their work was supported in part by grants from the Wisconsin Alumni Research Foundation. They have permitted us to use some of their results in this report and we gratefully acknowledge their contributions.

Joan Link Coles assisted materially during 1963-1964 in mineralogic and petrographic studies. Gail Habermann made many of the modal analyses. Their assistance is greatly appreciated.

Over the years, many hours of discussion with John Rodgers on the geology of Connecticut have been stimulating, informative, and necessary to the evolution of the present concepts of the geology of this area.

Previous work

The classical studies of James G. Percival laid the foundation for all subsequent work in the area. In a readily recognizable way he (1842, p. 65-66) described the major rock types. William N. Rice and H. E. Gregory (1906) included most of the rock types of the quadrangle in the "Waterbury gneiss" and "Thomaston granite," terms which are no longer applicable. The bordering quadrangles have been mapped recently by R. M. Gates (Litchfield, 1951; Woodbury, 1954), M. Carr (Naugatuck, 1960), C. E. Fritts (Mount Carmel, 1963a; Southington, 1963b), and R. M. Cassie (Thomaston, 1965).

Petrographic methods

Modal analyses of all rocks were made using the point-count method of Chayes (1956) and counting 1,000 points per thin section. All thin sections were stained appropriately to aid in the recognition of quartz, plagioclase, and potash feldspar. Plagioclase compositions were determined in thin section on the five-axis Universal Stage by measuring the extinction angle $(010) \wedge X'$ in grains oriented normal to crystallographic a (Emmons, 1943, 1953).

GENERAL GEOLOGY

The Western Connecticut Highlands consist of three belts of metamorphic rocks bounded on the west by the sediments and low-rank metamorphic rocks of the Hudson River valley and on the east by the Triassic sediments of the Connecticut River valley. The oldest rocks are a disjointed belt of gneisses comprising, from north to south, the Berkshire Highlands, the Housatonic Highlands, and the Hudson Highlands. Presumably these are Precambrian—the southern extension of the core of the Green Mountain anticlinorium of Vermont. Between and east of the Highland gneisses is a belt of high-middle-rank gneisses which are included in the Waramaug Formation in the northern half of the Western Connecticut Highlands. East of the Waramaug Formation is an assemblage of middle-rank metasediments historically considered as the Hartland Formation but currently being subdivided into several units, members, and formations. The Hartland Formation, collectively, is separated from the western belts of rocks by a major tectonic line extending without apparent interruption from the Massachusetts border to the Hudson Highlands. The Waterbury quadrangle lies in this eastern rock belt.

The Waterbury dome is the southernmost of a series of gneiss domes extending from the Chester dome in Vermont along the eastern edge of this belt of metasediments. The core of the Waterbury dome, the Waterbury Formation, is composed of gneisses and migmatites whose structural style indicates at least one more deformation than do the rocks which mantle it. The mantling rocks are a conformable series of metasedimentary rocks, assigned here to the Hartland Formation, which are traceable in a reasonably satisfactory way from at least 10 mi. south of the Waterbury dome to the Massachusetts border.

The Waterbury Formation is an undifferentiated series of thinly to thickly interlayered rocks composed predominantly of quartz, plagioclase, and biotite in various proportions. Because the series typically is intricately folded, gross structural features are not readily seen. Migmatitic mixtures of these gneisses with granitic to trondhjemitic rocks[1] possessing structural features normally associated with plastic flow further complicate the structure. The dome is unroofed on its western side and the core rocks extend at least a short distance northward and southward around the two "horns" of the mantling rocks.

Three principal rock types in the mantling Hartland form rock units or members of the formation, although each unit shows the inevitable variations expected in such a metamorphic sequence. The lowest member, unit I, is a rather massive mica-plagioclase-quartz granulitic gneiss with subordinate kyanite-bearing layers and lenses. The second, the Hitchcock Lake Member, is a rock of striking appearance, banded and streaked with black, white, and gray and composed of thick to thin layers of plagioclase-quartz granulitic gneiss, quartz-plagioclase-biotite schist, and biotite-plagioclase-quartz gneiss. Both of these members contain many large and small bodies varying from granite to granodiorite gneiss and amphibolite. The third member, The Straits Schist, topographically the most prominent, is a coarse plagioclase-muscovite-quartz schist with porphyroblasts of garnet and kyanite.

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[1] Trondhjemite is essentially a variant of quartz diorite, containing abundant quartz (20 percent), with biotite as the major mafic mineral. The term "migmatite" is used here in the descriptive sense to include rocks which are heterogeneous and megascopically "mixed rocks" comprised of light-colored rocks of igneous appearance in a host of darker metasedimentary gneisses (Williams, Turner, and Gilbert, 1954, p. 110).

Metamorphically, the region in general, including the core of the dome, is in the kyanite subfacies of the amphibolite facies. Although there are several outcrops containing sillimanite, they are commonly related to nearby or contiguous pegmatites, and result from local rather than regional metamorphism.

THE WATERBURY FORMATION

General statement

The term "Waterbury Formation" (see Rodgers and others, 1959, for history of the name) as used in this report is restricted to the rock types which outcrop within 1½ mi. of the center of the City of Waterbury. Rocks typical of the formation (in this restricted sense) are found on Pine Hill in the center of the city. West of the city they crop out in the area bounded by Highway 63 on the west, Highway 73 on the east, Bunker Hill Road on the north, and Park Road on the south. These two areas can be considered as type areas. The formation is composed of a variety of metasedimentary gneisses and migmatites which occupy the southern 60 percent of the Waterbury quadrangle and extend westward into the Woodbury quadrangle, where they were mapped as Hartland Formation by Gates (1954), as far as the Pomperaug Valley fault. They extend southward into the Southbury quadrangle for an undetermined distance.

The paragneisses of the Waterbury Formation are a heterogeneous assemblage of thin to thick, interlayed biotite-streaked plagioclase-quartz granulitic gneisses, kyanite-bearing biotite-plagioclase-quartz gneisses and schists, and quartz-plagioclase granulites.[2] Commonly the paragneisses are in migmatitic mixtures with trondhjemitic to granitic material which provide the lighter colored portion (figs. 2, 3). The trondhjemitic-to-granitic outcrops are not commonly of mappable size; however, several areas where these rocks predominate are indicated on the map (pl. 1), as are two small ultrabasic bodies located by the symbol U.

The structural style of the Waterbury Formation tends to separate it from the mantling rocks. The foliation and layering are intricately contorted and rarely consistent over even a small outcrop. A lineation shown by the hinge line of minor folds, 6 in. to 2 ft in amplitude, is much more apparent in most outcrops. A statistical analysis of minor structural elements would be necessary to reveal any coherent pattern

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[2] The term "granulite" is used here for a rock of rather massive appearance, composed largely of granular minerals, chiefly quartz and feldspar, with subordinate amounts of micas or other platy minerals. The micas are both oriented and unoriented but do not constitute discrete folia or streaks. "Granulite" is used here as a textural term with no metamorphic-facies connotation.

Fig. 2. Waterbury Formation migmatites of thinly layered kyanite-biotite-oligoclase-quartz paragneiss and microcline-quartz-plagioclase material from Interstate Highway 84 near the Highway 63 interchange. Scale is given by 6-in. pencil.

in migmatite outcrops. The Waterbury Formation is not currently correlated with any other formation in Connecticut. In structural style it most nearly resembles the Waramaug Formation (Gates, 1961) but there are significant differences such as the presence of migmatites and trondhjemites.

Lithology

INTRODUCTION

The lithogic variations of the Waterbury Formation can be described best in terms of the individual layers in the gneisses, recognizing

Fig. 3. Waterbury Formation with migmatite with thick and thin biotitic gneiss and granulite layers containing trondhjemitic material from Interstate Highway 84 near the Highway 83 interchange. Scale is given by 10-in. hammer.

that the layers range from a fraction of an inch to several feet, are complexly folded, and do not constitute mappable units. Modal analyses are given for several of the rock types (tables 1, 2, 3), although the lack of textural homogeneity makes such analyses of questionable value in terms of the bulk mineralogy of the formation. They do, however, serve as a guide to the mineralogic variations from layer to layer and, in turn, to the possible parent materials.

The essential minerals are quartz, plagioclase, biotite, muscovite, and microcline. Microcline is generally restricted to the light-colored portion of the migmatites and to the trondhjemitic to granitic "intrusives"[3] and is not typical of the metasedimentary gneisses. Kyanite and garnet are present in amounts ranging from 1 to 10 percent. Accessory minerals are apatite, sphene, zircon, allanite, magnetite, chlorite, and hornblende.

All rocks of the Waterbury Formation are hard, tough, and coherent and tend to weather with a rough surface because of the alternation of felsic and biotitic layers. The biotite layers are commonly prickly to the touch because the kyanite crystals are resistant to weathering. The rocks break acrosss the layering as easily as along it. Most outcrops are irregularly rounded as a result of glacial abrasion.

GRANULITES AND GNEISSES

The granulites and the biotite-streaked and layered gneisses are essentially fine- to medium-grained plagioclase-quartz rocks with highly variable amounts of mica. The layered gneisses are composed of alternating quartzofeldspathic and biotite-quartz-plagioclase layers.

Micas are least abundant in the granulites, where they are more or less disseminated and unoriented, although even these rocks generally contain more than 10 percent. Mica content increases as streaks and thin layers become more abundant. Such rocks are referred to as biotite-streaked granulitic gneiss, since the muscovite is generally subordinate. Probably the most common type is one in which biotite streaks or layers are an integral part of any hand sample. These rock types may be considered a series and, indeed, all variations do exist. However, it is more accurate to consider them all as interlayered and intricately folded. A specific rock type forms a hand sample, but few form an outcrop (see fig. 4), and there is no apparent mappable pattern of the various rock types.

Table 1 shows the mineralogic composition of a granulite, a biotite-rich layer, and the average of fifty granulites and gneisses. No one sample has this average composition; a study of the range of compositions, which reflects the characteristic heterogeneity of the rocks, is more instructive.

Plagioclase is more abundant than quartz in nearly half the samples analyzed; this is not apparent from the averages. Biotite predominates over muscovite in 75 percent of the samples. In the most common type of gneiss the micaceous layers contain 30 to 60 percent of the micas and the bulk of the garnet and kyanite. In such layers kyanite ranges from 3 to 4 percent up to 20 percent. The composition of the plagioclase ranges from An 10-22 with no modal peak for over 300 determinations. Microcline is present in less than 20 percent of the samples and is usually associated with migmatitic material.

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[3] The term "intrusive" here includes those rocks which show no stratigraphic distribution or layering and which cut across the foliation and layering of the paragneiss.

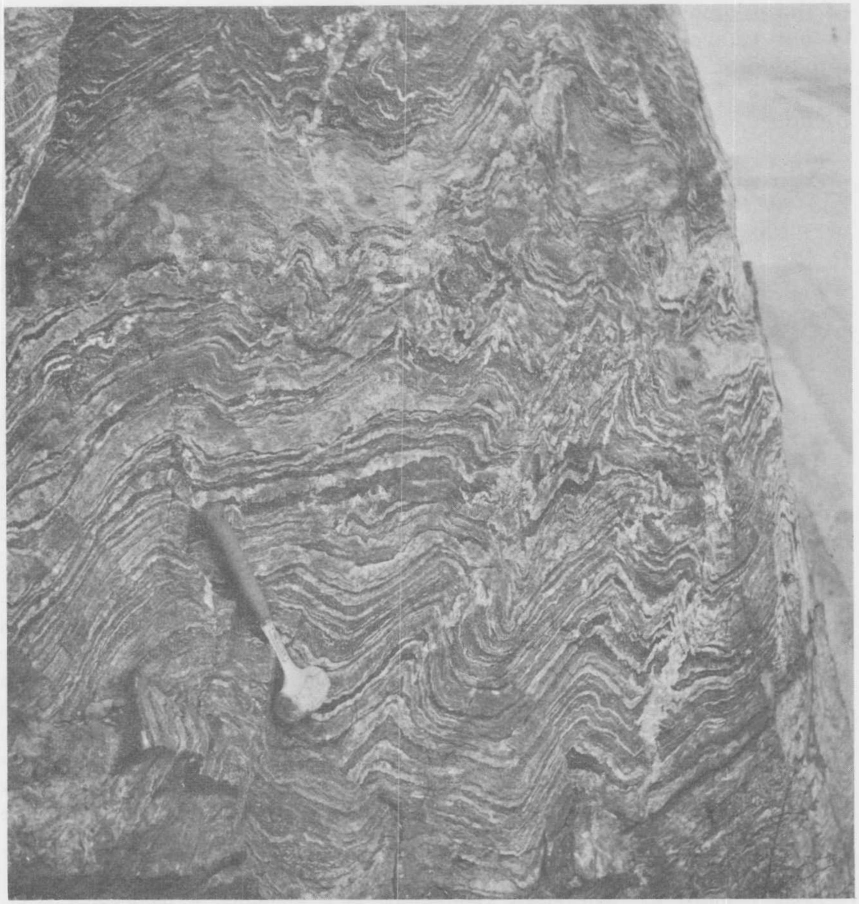

Fig. 4. Thinly layered Waterbury Formation paragneiss from Highway 63, ¼ mi. north of Interstate Highway 84. Scale is given by 10-in. hammer.

In texture, the granulite and gneiss are as variable as in composition. They are very fine grained to medium grained, equigranular to inequigranular, and crudely gneissic. The quartz and plagioclase are anhedral, in a granular mosaic, in the granulitic layers and form interspersed grains or stringers in the micaceous layers. It is not uncommon to find elongate, coarse quartz grains or streaked aggregates enclosing areas of the granular mosaic of quartz and plagioclase. The micas range from well oriented to unoriented. The crude foliation of the rocks is revealed by the layering as much as by the parallelism of the micas. In the micaceous layers the mica folia are highly contorted but still reveal a trend. Abundant, irregular, ragged biotite flakes are transverse to the layering and foliation. The micas are typically irregular in shape with ragged terminations. Kyanite is present

Table 1.—Petrographic data[1], granulites and gneisses of the Waterbury Formation

	Plagioclase[2]	Quartz	Microcline	Biotite	Muscovite	Garnet	Kyanite	Other[3]
1[4]	58	32	—	7	2	0.6	0.2	0.2
2[5]	9	22	—	51	6	2.0	10.0	—
3[6]	35	25	3	18	11	1.0	3.0	4.0

[1] Modal analyses in volume percent.

[2] Plagioclase data: Average composition of 28 samples = An 14.6 (308 determinations). Average An range per sample = 4 percent An (11 determinations per sample). Range of Composition between samples = An 10-22.

[3] Magnetite, chlorite, sphene, apatite, and zircon.

[4] Sample WT-121, granulite layer, from Overlook in City of Waterbury.

[5] Sample WT-131, micaceous layer, 2,000 ft SW of Bunker Hill School.

[6] Average composition of 50 samples of granulites and gneisses from the Waterbury quadrangle.

as fine-grained, granular crystals in streaks, irregular grains, or convoluted clusters in the biotitic layers. Garnet is present in small rounded to angular grains intimately associated with the kyanite. Calc-silicate pods, 1 in. to 6 in. thick, are sparsely scattered throughout the paragneisses.

TRONDHJEMITIC ROCKS

The trondhjemitic rocks are very fine- to medium-grained granulitic rocks of varied and ill-defined geologic distribution. In this area they have a relatively uniform composition and generally massive appearance. They are smooth weathering, light to dark gray, with biotite abundantly disseminated throughout. Trondhjemitic granulites are present, apparently interlayered with the granulites and gneisses described in the previous section. They also contain thin streaks of kyanite-bearing biotite, making them very similar in appearance to the quartz-plagioclase granulites. They are present also as disjointed slabs (boudinage?) and as rounded or irregularly shaped inclusions in slightly coarser grained and more massive rocks of intrusive appearance, with the same trondhjemitic composition. As shown in plate 1, there are several areas in which the massive to gneissic, fine- to medium-grained trondhjemite predominates, both as layers in the paragneisses and in an irregular, anastomosing pattern in the paragneisses. The massive trondhjemite, intrusive in appearance, forms a migmatitic mixture with the paragneisses. Typical relationships of the trondhjemite to the paragneisses are well exposed in the hills east and west of Jones Farm Road southwest of Highways 188 and 63.

The trondhjemitic rocks are clearly set apart from the quartz-oligoclase granulites of the paragneisses by their petrography. Unfortunately, however, the critical features are not obvious in the field. Strong reverse zoning of the andesine, with rims usually 5 percent more anorthitic than the core, is a common feature in all thin sections. The texture is xenomorphic granular with the biotite distributed throughout in small, nearly equant flakes. Most of the trondhjemites are equigranular. In thin section, the inequigranular trondhjemites have inclusion-like fine-grained areas in a medium-grained host much as, on an outcrop scale, the fine-grained trondhjemitic rocks are inclusions in a

Table 2.—Petrographic data[1], trondhjemitic rocks of the Waterbury Formation

	Quartz	Plagioclase	Biotite	Muscovite	Microcline	Garnet	Hbl.	Sphene	Other[2]
Average[3]	26.1	44.5[4]	24.3	1.3	0.4	0.7	1.0	0.3	1.4
Range[3]	(14-40)	(30-52)	(10-39)	(0-10)	(0-7)	(0-2.8)	(0-7)	(0-2.2)	
Average[5]	27.6	41.7[6]	29.0	—	—	0.4	–	0.6	0.7
Range[5]	(21-35)	(33-50)	(25-37)						

[1] Modal analyses in volume percent.

[2] Chlorite, apatite, zircon, allanite, epidote, and magnetite.

[3] Twenty-one trondhjemites.

[4] Plagioclase data: Average composition of 21 samples = An 33.8 (72 determinations). Range of composition between samples = An 26-40. Reverse zoning characteristic.

[5] Five modal analyses of trondhjemitic rocks which are layers in the paragneisses or inclusions in other trondhjemites.

[6] Average composition of plagioclase in 5 samples = An 33.3; reverse zoning characteristic.

medium-grained host. Table 2 gives the average composition of the trondhjemites as well as their plagioclase compositions. Quartz, plagioclase, and biotite in various proportions compose over 95 percent of the rock. It is clear that there is no significant difference between the "intrusive" trondhjemites and those which are layers in the paragneiss or inclusions in the "intrusive" trondhjemites. Sphene is a characteristic mineral in the trondhjemites, but is absent in the paragneisses. The plagioclase of the trondhjemites is sodic andesine and that of the paragneisses is sodic oligoclase.

MIGMATITES

In many outcrops of the Waterbury Formation the layered granulites and gneisses (paragneisses), although intricately folded, are not complicated by migmatitic material. However, in most large outcrops migmatites are a part of the gneiss complex. Figures 2 and 3 show types of migmatites which differ partly because of the type and thickness of the layers of the host paragneiss. In figure 2 the light-colored felsic component is present as irregular, amoeboid patches where the dark layers have been crumpled and broken. If the felsic material is white, plagioclase usually predominates over microcline; if it is red, microcline predominates. The grain size of the felsic areas ranges from very fine grained to coarse grained. In figure 3 the thicker granulitic layers appear to have lost their competency, recrystallized, and flowed into structurally favorable sites, leaving isolated wisps of the kyanitic biotite-rich layers. These felsic areas are commonly trondhjemitic in composition but are coarser in grain size and lack the reverse zoning of the more massive trondhjemites. Microcline is present in subordinate amounts.

The mineralogic composition of the light-colored portion of the migmatite varies from trondhjemitic to granitic and, of course, includes mixtures of these and the partly dispersed or disaggregated host rock.

Table 3.—Petrographic data[1], granitic rocks of the Waterbury Formation

Sample	Quartz	Microcline	Plagioclase	Muscovite	Biotite	Kyanite	Garnet	Other[2]
WT-184[3]	36	45	9	6	3	—	0.3	0.7
WT-217[3]	42	18	11	9	17	2	0.3	0.7
WT-219[3]	37	48	—	2	10	3	—	—
granite gneiss[4]	34	27	21	4	13	—	—	1.0

[1] Modal analyses in volume percent.

[2] Chlorite, magnetite, apatite, zircon, and rutile.

[3] Light-colored, red portion of migmatites. Plagioclase = An 26 (2 determinations). Location, Westview Heights.

[4] Average of 6 samples. Plagioclase = An 27.5 (12 determinations).

Table 3 gives the modal composition of three samples of the granitic migmatite. Sample Wt-219, a pink granitic amoeboid area in the migmatite, is representative of manv thin felsic stringers in the migmatites. Of particular interest is the abundance of microcline, essentially to the exclusion of plagioclase, and the presence of kyanite in an apparently stable relationship. In all the light-colored part of the migmatite, only microcline is foreign to the Waterbury paragneisses and would have had to be introduced or formed by reaction or partial melting.

GRANITE GNEISS

The granite gneiss in the Waterbury Formation is in discrete tabular bodies generally 10 to 30 ft in width and of unknown length. Only two such bodies have been found to be mappable units. Their modal composition is given in table 3 and should be compared with the mappable granite gneiss in the Hartland Formation.

Summary

The Waterbury Formation is considered to be an assemblage of metasedimentary and metavolcanic rocks representing sedimentary mixtures of quartz and plagioclase sands, clay minerals, volcanic ash, coarser clastics, and possibly flows. No volcanic flows were recognized but they may be represented by the layered trondhjemitic rocks. In that case, the interlayering of these trondhjemitic rocks with the kyanite-biotite schists, which presumably were originally clays, would imply a sedimentary reworking of volcanic material.

The intimate folding and refolding of the layered assemblage, accompanied by a rising metamorphic grade, apparently brought the metavolcanics to a rheologic state so that they behaved as a viscous liquid. The larger trondhjemite bodies may be simple, classic intrusives or accumulations of the mobilized metavolcanics. The granitic parts of the migmatites, with an adundance of microcline, must represent material introduced into the paragneiss from an external source or generated locally by partial melting. It is hoped that further petrologic studies, now in progress, will resolve the manner of origin of these migmatites.

The age of the Waterbury Formation is not known, although it is certainly older than the mantling Hartland Formation which is generally considered older than 360 m.y. (Rogers and others, 1956). Stanley (1964, pp. 43-51) proposed several possible correlations of The Straits Schist with the better dated rocks in Vermont and Massachusetts. In all of these proposed correlations The Straits Schist is considered Cambrian. Thus, if the Hartland unit I member and Hitchcock Lake Member conformably underlie The Straits Schist they, too, can be considered Cambrian or older. On this basis the Waterbury Formation is most probably Precambrian. The only significant conclusion drawn from this study is that the Waterbury Formation is older than the Hartland. Absolute age must be determined by correlations elsewhere.

HARTLAND FORMATION

The history and use of the term, Hartland Formation, is given by Rodgers and others (1959). In this report the formation will be described in terms of its four members, Unit I, Hitchcock Lake, The Straits Schist, and Southington Mountain Members.

Unit I member

GENERAL STATEMENT

The term, Hartland Unit I, is used in this report for the lowest unit mantling the core of the Waterbury dome. It is restricted to the northern half of the quadrangle where it forms a belt that dips northward off the core rocks of the dome, wraps around the hinge of a large fold, and trends northeastward out of the quadrangle. Rocks which form the continuation of Unit I on the eastern and northern sides of the dome have been called Waterbury gneiss by Fritts (1963a, b). Lithologically similar rocks in the same stratigraphic position in the Collinsville quadrangle to the northeast have been called the Taine Mountain Formation (Stanley, 1964). Similar rocks in the Roxbury, New Preston, Litchfield, and West Torrington quadrangles have been called Unit I of the Hartland Formation (Gates, 1959; Gates and Christensen, 1965; Martin, 1962), and this designation is used in this report. Excellent exposures of Unit I are easily accessible on the steep slope east of Frost Bridge in the northern part of the quadrangle, on the small knob immediately southeast of Fort Hill Park in Waterville, and on the hills west, north, and east of Lakewood Pond.

The rocks of Unit I are typically fine-grained, light-gray, muscovite-biotite-plagioclase-quartz granulite or granulitic gneiss. They are designated as gneiss where they contain discontinuous streaks and lenses of quartz-plagioclase and mica, and as granulite where the minerals are more uniformly distributed. It is not uncommon, however, to find subordinate thin layers of mica-plagioclase-quartz schist in the granulite. Overall, Unit I is a quartz-feldspathic rock. With the exception of a few kyanite-bearing varieties, its rocks are sandy and friable. Weathered outcrops range from rounded and massive to slabby, depending upon the total content and degree of layering of the mica.

Table 4.—Petrographic data[1], Hartland Formation, Unit I member

	Quartz	Plagioclase[2]	Biotite	Muscovite	Garnet	Kyanite	Chlorite	Other[3]
Average[4]	46.8	34.6	9.8	5.5	1.0	1.1	1.1	1.2
Range[4]	22-67	6-58	3-16	0-31	0-3.6	0-7	0-16	

[1] Modal analyses in volume percent.

[2] Plagioclase data: Average composition of 13 samples = An 22.1 (125 determinations); range of composition between samples = An 13-29; average An range per sample = 6 percent An (9 determinations per sample); reverse zoning present.

[3] Microcline, zircon, apatite, tourmaline, sphene, magnetite, rutile, and monazite.

[4] Average and range of 21 modal analyses of rocks from 16 samples of Hartland Unit I.

Amphibolite bodies of various sizes are abundant in Unit I east of the Naugatuck River; granitic gneiss and Nonewaug granite and pegmatite are present in it in the Oakville-Watertown area.

PETROGRAPHY

Mineralogically, the rocks of Unit I are simple, consisting essentially of quartz, plagioclase, biotite, and muscovite. Garnet, chlorite, and opaques are nearly everywhere present in minor amounts, and in a few localities kyanite is found. Small amounts of microcline are present in a few samples and apparently represent additions from adjacent granite. Common accessory minerals present in trace amounts include apatite, zircon, monazite, sphene, tourmaline, and rutile. One specimen contains a small amount of fibrolitic sillimanite. Table 4 gives the modal analyses and plagioclase composition of the Unit I rocks.

Texturally, the rocks of Unit I typically are fine grained and granular and show pronounced parallel orientation of the mica flakes. In many samples the micas are concentrated in thin folia or streaks about $\frac{1}{16}$ to $\frac{1}{4}$ in. thick, from a fraction of an inch to several inches in length, and, in all cases studied, parallel to the mica foliation. These streaks are interpreted as relict beds. There are all textural gradations between granulitic gneiss with nearly perfect segregation of mica and quartz-plagioclase to homogeneous granulite with mica flakes evenly scattered through the rock. In some areas, coarser and thicker micaceous layers, best described as quartz-plagioclase-muscovite-biotite schist, are interlayered with the granulite. Although these schist layers may be several inches thick, their total thickness is generally less than that of the granulite.

Quartz and plagioclase are the main minerals in the granulite. They are usually fine grained; in some quartz-plagioclase lenses they are slightly coarser. The grains are either equidimensional or slightly elongated parallel to the foliation. Weak strain shadows are common in quartz.

The plagioclase is typically untwinned although in some thin sections albite twinning is abundant. Zoning can be found in most thin sections and in some it is reverse. Antiperthite was noted in four thin sections as small patches of microcline in coarse, poikilitic plagioclase grains. The plagioclase composition determinations made on 125 grains in 13 thin sections of Unit I rocks are summarized in table 4. The average of 125 determinations is An 22.1. However, in each thin section studied there is a range of plagioclase compositions, the greatest being 8 percent An. A frequency diagram of An content of the 125 grains reveals two distinct peaks, one about An 15, the other about An 27. The significance of this pattern is not known; there is no apparent correlation with geographic location or with geologic occurrence. Sericitization of plagioclase is common around grain borders and along cleavages.

In most of the granulites, biotite is the predominant mica, although it seldom constitutes more than 20 percent of the rock. In some places both it and muscovite are evenly distributed throughout the rock, and in other places one or both are concentrated into streaks or layers. Biotite generally is fine grained with the muscovite somewhat coarser. In a few samples muscovite is blocky and poikilitic. Rarely are the two micas interleaved. In nearly all thin sections examined at least a few biotite flakes are partly altered to chlorite.

Garnet is present as small subhedral or anhedral grains, most of them poikilitic. Quartz, plagioclase, biotite, muscovite, zircon, tourmaline, and opaques have been observed as inclusions. In a few garnets the inclusions are concentrated in the core with the rim zone nearly free of them. In one thin section, strings of inclusions suggest rotation of some garnet, whereas other garnet in the same section appears to have been crushed and granulated.

Kyanite is present in a few Unit I granulites as stringers of small grains associated with micaceous layers. These granulites are tough and coherent rather than friable.

Fibrolitic sillimanite is present in one sample of Unit I (from the knobs east of Brookside Road) as small, rather widely spaced bundles or wispy streaks associated with biotite. It should be noted that, in the same thin section, kyanite in small grains is associated with blocky muscovite.

Hitchcock Lake Member

GENERAL STATEMENT

The name "Hitchcock Lake Member" was given by Fritts (1963b) to rocks which lay beneath The Straits Schist and above a paragneiss. He assigned both of these units below The Straits Schist to the Waterbury gneiss, with the type locality at Hitchcock Lake in the Southington quadrangle. The present writers designate the Hitchcock Lake a member of the Hartland Formation, overlying Unit I and underlying The Straits Schist Member. It is equivalent to the Bristol Member of the Collinsville Formation (Stanley, 1964). A unit of variable thickness, probably not exceeding 2,000 ft, it nevertheless crops out extensively in the northern third of the quadrangle because of the convoluted folding of the Hartland Formation. Although not mapped by Carr (1960), it is traceable along the western side of The Straits Schist in the western part of the Naugatuck quadrangle from near the northern border southward for about 4 mi. Similarly, in the Thomaston quadrangle it is found on the western side of the western ridge of The Straits Schist, between that member and Hartland Unit I. It can be traced from near the southern border of that quadrangle, where the Nonewaug Granite separates it from the Waterbury quadrangle, northward to a point at least ½ mi. north of Highway 109.

The upper and lower boundaries of the Hitchcock Lake Member are gradational and somewhat arbitrarily defined. The lower contact with Hartland Unit I is drawn above the first thick mica-quartz-plagioclase granulite or granulitic gneiss, the upper contact beneath the coarse muscovitic, kyanite-bearing schist. This upper contact is commonly marked by discontinuous lenses of amphibolitic rocks, by thin marbles (particularly in the Thomaston quadrangle, Cassie, 1965), and by crumbly, rusty-weathering schists and carbonate rocks. This transition zone is probably equivalent to the Sweetheart Mountain Member of the Collinsville Formation (Stanley, 1964).

The Hitchcock Lake Member is a strikingly interlayered assemblage of 1) finely streaked, plagioclase-quartz granulites, 2) mica-streaked plagioclase-quartz gneiss, and 3) massive, gray friable mica-plagioclase-quartz granulites. In addition, there are subordinate calc-silicate rocks, amphibolites, hornblendic gneisses, and garnetiferous gneisses and schists. Also, as in the other members, there are discrete sill-like bodies of granite gneiss.

Excellent outcrops and roadcut exposures of the Hitchcock Lake Member are readily available along Highway 8 (old and new) from the Chase Brass plant near Sylvan Lake northward to the quadrangle boundary. Other good exposures are on old Highway 8 north of Waterbury Road and on new Highway 8 north of Frost Bridge Road underpass. Contacts between the Hitchcock Lake Member and The Straits Schist are exposed in the cliffs immediately east of the Chase Brass plant (north of Waterville) and in the new Highway 8 roadcut immediately north of the quadrangle boundary.

LITHOLOGY

General statement. The Hitchcock Lake Member is a banded and streaked rock lying between the relatively massive gray granulite of Hartland Unit I and The Straits Schist, a micaceous rock. The bands are alternating thick and thin layers of a hard, fine-grained plagioclase-quartz granulite and a coarsely streaked, biotitic plagioclase-quartz gneiss. Both types of layers are streaked or gneissic—the granulite because of its quartz-plagioclase and the gneiss, more obviously, because of biotite. The characteristic gray granulite of Unit I is also interlayered with these in subordinate amounts. Individual layers range from less than an inch to as much as 20 ft, although most of them are in the lower half of this range. The layers are isoclinally and convolutely folded, making it difficult to work out the stratigraphic succession. Calc-silicates, garnetiferous gneisses and schists, hornblendic rocks, and limestones are minor in this quadrangle and do not mark definite stratigraphic horizons. However, in the Thomaston quadrangle limestones and amphibolites are abundant and stratigraphcally significant (Cassie, 1965).

Plagioclase-quartz granulite. This is the most distinctive rock in the texturally varied Hitchcock Lake Member (see fig. 5). It is a light-gray rock with fine white streaks. Very compact and hard, it is even

Fig. 5. Finely streaked, mica-oligoclase-quartz granulite of the Hitchcock Lake Member (Hartland Formation) from new Highway 8 south of the Frost Bridge Road underpass. Scale is given by 10-in. hammer.

brittle in some samples and, in strong contrast to the coarser grained, micaceous plagioclase-quartz gneisses with which it is interlayered, breaks across the plane of streaking and mica orientation. The micas are fine grained and disseminated and do not form discrete folia. Excellent outcrops can be seen in the cliff east of Carter Road in the south-central part of the Thomaston quadrangle as well as in the roadcuts on new and old Highway 8. Typically, the layers are a few inches to about 4 ft thick although some range up to 20 ft.

The texture and mineralogy of the granulite is simple and uniform; there is only a slight range in composition and grain size. Quartz and oligoclase compose nearly 90 percent of the rock in all cases (see table 5, no. 1). The texture is

Table 5.—Petrographic data[1], Hitchock Lake Member rock types

		Quartz	Plagioclase[2]	Biotite	Muscovite	Garnet	Other[3]
1.[4]	Average	57.2	31.8	6.5	4.1	0.5	0.4
	Range	36–72	15–53	0–12	0–9	0–3	—
2.[4]	Average	47.1	30.0	11.1	11.3	1.7	0.8
	Range	30–58	13–58	5–34	1–29	0–18	—
3.[4]	Average	51.7	30.7	10.7	6.1	0.5	—
	Range	39–56	26–35	6–14	0–19	0–1	—
4.[4]	Average	44.3	52.9	0.9	1.3	—	0.6
	Range	41–51	47–60	0–2.5	0–5.2	—	—
5.[4]	Average	66.6	2.7	14.7	14.1	0.6	1.3
	Range	58–78	1.6–4	6–23	0–22	0–2.6	—

[1] Modal analyses in volume percent. Part of the data for this table was obtained from Howe (1966).

[2] Plagioclase data:

	Average composition	Number of determinations	Range
1.	An 21.1	156	10–33
2.	An 22.9	213	10–34
3.	An 21.0	60	–

[3] Sphene, magnetite, chlorite, zircon, and epidote.

[4] Composition and number of samples:

1. Finely streaked plagioclase-quartz granulites (12 samples)
2. Micaceous plagioclase-quartz gneisses (16 samples)
3. Friable, gray, mica-quartz-plagioclase granulites (5 samples)
4. Felsic layers in the micaceous quartz-plagioclase gneisses of group 2 (4 samples from 4 layers)
5. Micaceous layers contiguous to the felsic layers of group 4 (4 samples from 4 layers)

fine- to medium-grained xenomorphic granular, with a tendency toward elongation of the quartz in the plane of the layering. The two micas, always subordinate, are finer grained than the quartz and plagioclase. The granulite is streaked by fine felsic seams, generally less than 1 cm. thick, of slightly coarser grained quartz or quartz-oligoclase. The fine felsic seams carry a higher proportion of plagioclase than does the finer grained granulite. The plagioclase in the seams is commonly reverse zoned and in poikiloblastic crystals containing rounded quartz grains. The grain size of the quartz and plagioclase in the mica-bearing granulite (exclusive of the streaks) averages less than 1 mm; in the felsic streaks it ranges from 1 to 5 mm.

Although the finely streaked granulite is distinctive and may enable a stratigraphic sequence to be established in the Hitchcock Lake Member, there are gradations between it and the coarser micaceous plagioclase-quartz gneiss described next.

Mica-plagioclase-quartz-gneiss. The lithology of this gneiss differs from that of the plagioclase-quartz granulite mainly in being more micaceous, coarser grained, and having a much more heterogeneous mica distribution. In the field it is striking in appearance—a white rock with black streaks (see fig. 6). The streaking is due to alternating layers of felsic and micaceous composition of variable thickness, measured normally

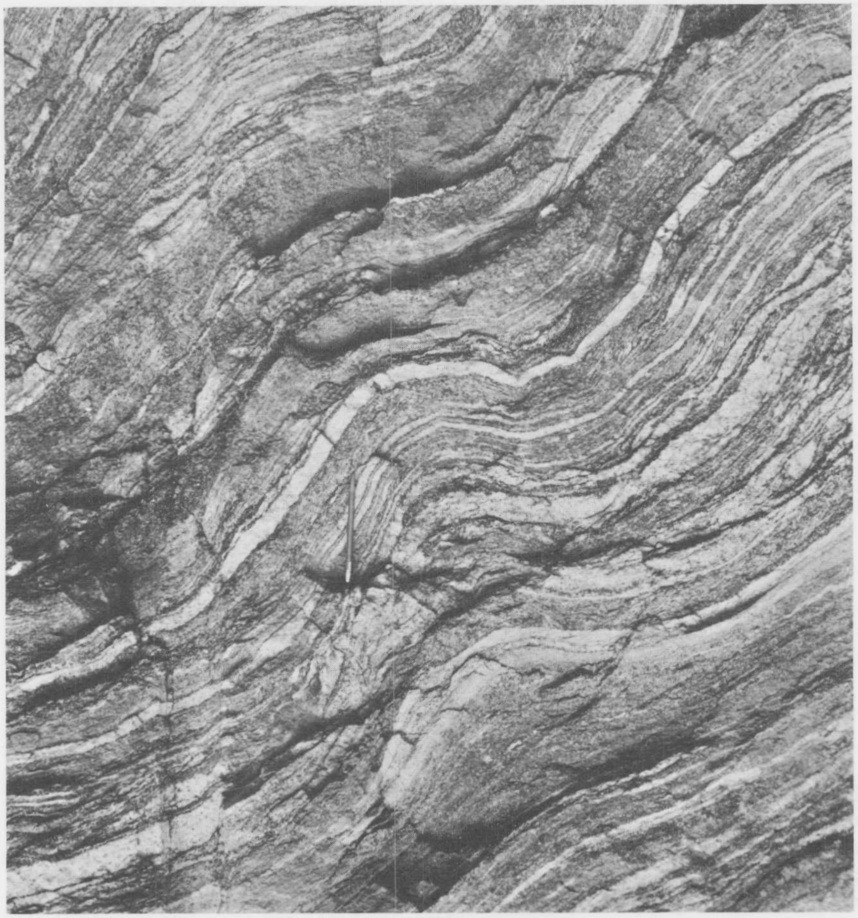

Fig. 6. Coarsely streaked mica-oligoclase-quartz gneiss of the Hitchcock Lake Member (Hartland Formation) from new Highway 8 south of the Frost Bridge Road underpass. Scale is given by 6-in. pencil.

in inches rather than feet. As a whole, the gneiss is interlayered with finely streaked granulite on a scale of inches to feet. Except for a few layers carrying an abundance of garnet crystals, the micaceous gneiss is heterogeneous and has no distinctive lithology which can be represented by a hand sample.

Muscovite is as abundant as biotite but is interleaved with the biotite and hence is not so noticeable. In contrast to the granulite, these micas are coarser grained than the quartz and plagioclase and constitute marked folia.

The average modal composition of the mica-plagioclase-quartz gneiss differs little from that of the plagioclase-quartz granulite (see table 5, no. 2). The major mineralogic difference is that the amount of each mica is more than double that in the granulite. The amount and composition of the plagioclase (An 22.9) is almost identical to that of the finely streaked plagioclase-quartz granulite. With coarser felsic and micaceous streaks or layers it was possible to obtain modal analyses of contiguous layers, as given in table 5 (no. 4 and no. 5), which show that there is a marked contrast between the plagioclase content of these types of layers.

The texture of the gneiss is strongly lepidoblastic in the micaceous layers and xenomorphic inequigranular in the felsic layers. All textural variations from the micaceous gneiss to the plagioclase-quartz granulite are easily found and a rigid distinction between the two cannot be made in the thin layers.

Mica-plagioclase-quartz granulite. This type of granulite is very subordinate in the Hitchcock Lake Member and is distinguished from the finely streaked plagioclase-quartz granulite by its friable texture and lack of streaking. It has a massive aspect in the field and tends to crumble under the hammer. As the common rock type in the underlying Hartland Unit I, it is described in more detail above. Table 5 (no. 3) shows that the major mineralogic difference is the substitution of micas for quartz. The plagioclase is An 21 and thus is slightly more sodic than that in the streaked granulites and micaceous gneisses.

This massive, friable granulite is fine grained, xenomorphic granular with oriented but disseminated micas. The plagioclase is somewhat finer grained that the quartz and is interstitial to it. Twinning is not common. The biotite is pleochroic, pale yellow to reddish or gray brown.

Amphibolitic rocks. The amphibolitic rocks in the Hitchock Lake Member should not be considered as a separate unit but as part of an interlayered assemblage of granulites, gneisses, and amphibolitic rocks. Amphibolites are present in very subordinate amounts throughout the member; there are two areas where they predominate. One of these is an isolated lens on the northern side of The Straits Schist Member northeast of Sylvan Lake along Frost Bridge Road. The other is a narrow belt less than 800 ft wide along the same boundary between The Straits Schist and the Hitchcock Lake Member, extending from the northern border of the quadrangle west of Greystones Road southward for 1½ mi. In these lenslike areas abundant amphibolitic rocks are interlayered with the other rock types of the Hitchcock Lake Member described above. Northeast of Sylvan Lake the amphibolitic layers are several feet in thickness, but west of Greystones Road they are thinly interlayered with the other granulites and gneisses. This interlayering, on a scale of inches, is well exposed below the falls where Greystones Road crosses Hancock Brook. The Greystones Road belt extends northward into the Thomaston quadrangle where it is considered part of the Reynolds Bridge gneiss (Cassie, 1965). This assemblage of plagioclase-quartz granulites, micaceous gneisses, amphibolites, and amphibolitic rocks becomes very prominent immediately beneath The Straits Schist in the Reynolds Bridge area of the Thomaston quadrangle, where granitic gneisses further complicate the melange (Cassie, 1965).

The amphibolitic rocks range in composition from simple black hornblende-plagioclase amphibolites to dark-gray rocks carrying considerable biotite and quartz. Abundant wedge-shaped crystals of sphene are a characteristic and obvious accessory. The hornblende is in prisms or anhedral crystals, pale green and weakly pleochroic in thin section. The biotite is interleaved with the hornblende and is pleochroic—pale yellow to dark brown. The plagioclase is in anhedral, equant grains with a mottled extinction pattern and is commonly twinned. Layers of these rocks contiguous to the amphibolitic layers contain minor amounts of hornblende and sphene in addition to their normal mineralogy.

SUMMARY

It is beyond the scope of this report to determine the type of sedimentary rocks that gave rise to the Hitchcock Lake rock types. Nevertheless, it is worthwhile to point out some features that must be explained if the geologic history is to be reconstructed correctly. First, in spite of the seemingly great textural diversity, the mineralogy of the rock types is surprisingly similar and simple. Assuming that prograde regional metamorphism tends to increase the grain size of the parent material as recrystallization proceeds, the parent material must have been no larger than fine sand, since most minerals in all the lithologies are now fine grained. Only in the layers of the micaceous gneiss, which are rich in quartz-plagioclase, is the grain size equal to coarse sand or granules. (There is nothing to suggest mylonitization of a rock somewhat like a greywacke prior to metamorphism.) It appears that the original sedimentary material, of fine sand size or smaller, had a composition such as to give, in the kyanite subfacies of metamorphism, a quartz-rich rock with Na_2O:K_2O ratio of 1 to 1.8. Assuming further that a substantial part of the parent material was clay size, the soda-to-potash ratio would require clay minerals other than those produced by normal weathering processes.

The writers tentatively favor acid to intermediate volcanic ash as the source of at least part of the clay-size sedimentary debris. The local concentrations of amphibolitic material interlayered with the felsic granulites and gneisses near the contact with The Straits Schist also are most readily explained by the introduction of basic volcanic ash. The compact, coherent, finely streaked plagioclase-quartz granulite is strongly suggestive of recrystallized volcanic material.

The diversity of textures in the rock types making up the Hitchcock Lake Member are considered to be directly related to the primary sedimentary features and parent materials. However, it seems most likely that some, if not many, of the existing textures formed when metamorphic processes, recrystallization, and possibly partial melting accentuated the primary sedimentary features.

The Straits Schist Member

GENERAL STATEMENT

The Straits Schist is a lustrous medium- to coarse-grained plagioclase-biotite-muscovite-quartz schist with porphyroblastic garnet and kyanite. It occupies a wedge-shaped area in the northeastern portion of the Waterbury quadrangle; the best exposures are found on the high ridges between Sylvan Lake and Hancock Brook, ½ to 1 mi. north of Waterville.

On a large scale, The Straits Schist is a uniform and homogeneous rock; on a small scale textural and compositional variation results in interlayering of thin, discontinuous mica-plagioclase-quartz granulite with the more abundant coarse mica schist. None of these thin layers can be traced more than a few feet.

White quartz and quartz-feldspar pods are a distinctive feature of The Straits Schist. These are commonly lens-shaped along the foliation and range from a few inches to several feet in length. Patches and stringers of pegmatite are abundant, and at least some of them crosscut the foliation. At one locality a crosscutting pegmatite appears to be responsible for the development in the schist of exceptionally coarse garnets up to 1 in. in diameter. At a few widely scattered localities in The Straits Schist there are pods of sillimanite from a few inches to 2 or 3 ft in length.

On fresh surfaces, The Straits Schist is silver gray and appears spangled because of the slightly differing orientations of adjacent coarse muscovite flakes. Graphite is common as smears of fine flakes along some foliation surfaces and imparts a darker gray color to them. Weathering produces rounded, rusty-colored surfaces made prickly by the edges of projecting coarse muscovite flakes and kyanite blades. Because of the high quartz, muscovite, and kyanite content, The Straits Schist is a very resistant unit and underlies the highest parts of the quadrangle.

PETROGRAPHY

The Straits Schist is a medium- to coarse-grained plagioclase-biotite-muscovite-quartz schist containing porphyroblasts of garnet and kyanite and, in some places, staurolite. Chlorite, graphite, and magnetite are present in nearly all samples, always in minor amounts. Other accessory minerals found in some samples include tourmaline. zircon, apatite, rutile. sphene, and sericite. Table 6 shows the average modal analysis and relevant plagioclase data of 13 samples of The Straits Schist from the Waterbury quadrangle.

The texture of The Straits Schist is lepidoblastic. Although there is considerable variation in the mica-flake orientation in some samples, there is a distinct preferred orientation in all thin sections studied. Commonly the mica, especially

Table 6.—Petrographic data, The Straits Schist

	Quartz	Plagioclase[1]	Biotite	Muscovite	Garnet	Kyanite	Graphite	Other[2]
Average[3]	41.9	10.1	15.0	23.7	3.3	3.1	0.9	2.0
Range[3]	29–60	1–19	3–25	16–42	T[4]–8	T[4]–11	0–3.5	—

[1] Average composition of plagioclase = An 24.1 (21 determinations); range of composition between samples = An 21-30.

[2] Magnetite, chlorite, staurolite, rutile, sphene, tourmaline, zircon, and apatite.

[3] Of 13 modal analyses of The Straits Schist.

[4] T = trace amount (less than 0.05 percent).

biotite, is concentrated in streaks about ⅛ in. thick, separated by quartz-plagioclase-rich streaks of about the same thickness. Lenses consisting entirely of coarse quartz and plagioclase are nearly everywhere present. Albite twinning is common and many grains show zoning, which in five samples is of the reverse type. Minor alteration of plagioclase around grain boundaries, along cleavages, or along selective twin lamellae is present in every sample studied. In several thin sections, inclusions of quartz, magnetite, and graphite are present in the plagioclase; in two of these, trails of fine graphite flakes pass uninterruptedly through plagioclase grains and continue into mica layers on either side of them.

Micas are present as poorly to well foliated flakes concentrated in distinct layers or streaks. Muscovite is usually coarse; however, in several sections two distinct grain sizes are present, the finer muscovite (possibly paragonitic) containing clouds of fine graphite grains. Biotite is strongly pleochroic from pale brown or pale yellow to dark brown. Minor alteration of biotite to penninite and other chlorites is invariably present.

Garnet is present as poikilitic anhedral to subhedral grains. Commonly the inclusions of quartz, feldspar, mica, and opaques are concentrated in the core of a garnet crystal, leaving the rim nearly inclusion free. Rim-zone inclusions found in some garnet crystals are much coarser and less abundant than those in the core. Some garnet contains strings of inclusions parallel to the surrounding foliation, and others contain strings aligned at an angle to the foliation, indicating rotation of the garnet. Both relationships can be found within a single thin section. Minor border alteration of garnet to chlorite is common.

Kyanite is present in nearly all thin sections studied, and ranges from small blades to very coarse ones, most of them irregularly shaped. Most of the kyanite lies within the plane of foliation and is generally free of inclusions. In several thin sections kyanite is partly altered to sericite and, in one instance, only small isolated remnants of kyanite remain, surrounded by pseudomorphic sericite.

Staurolite is present in many samples of The Straits Schist in minor amounts as euhedral porphyroblasts that show a considerable size range. It generally is found in mica-rich layers, and in some crystals strings of graphite pass from the mica through the staurolite without disruption.

Graphite is present in small amounts in most thin sections, as small grains restricted to mica layers. It is most abundant in masses of fine-grained muscovite (possibly paragonitic), and is present sparingly in coarse muscovite and biotite, where the graphite grains typically are strung out along the mica cleavage.

REGIONAL SUMMARY

On a regional scale, The Straits Schist is one of the few readily recognizable units in the Western Highlands. From its type locality in the narrow gorge just east of Straitsville, 2½ mi. south of the southeastern corner of the Waterbury quadrangle, it can be traced northward nearly to the Massachusetts State Line as an irregular, sinuous, but well defined belt. Mapping in the Waterbury quadrangle and unpublished work in the Thomaston quadrangle to the north lead the writers to suggest that its correlative or facies equivalent is present to the north and west of the generally accepted belt of The Straits Schist.

In the Roxbury, New Preston, Litchfield, and West Torrington quadrangles, all of which are west or northwest of The Straits Schist belt in the Waterbury quadrangle, the Hartland Formation has been subdivided into four units (Gates, 1959; Gates and Christensen, 1965; Martin, 1962). The lowermost of these, Unit I, is predominantly mica-plagioclase-quartz granulite, lithologically identical to Unit I of the Waterbury quadrangle. In these western quadrangles Unit I is overlain by the lustrous garnet-staurolite-muscovite-plagioclase-quartz schist of Unit II. If Unit I of the Hartland belt to the west is the same as Unit I of the Waterbury quadrangle, then Unit II and The Straits Schist occupy similar stratigraphic positions above it and can reasonably be assumed to be equivalents.

Correlation of The Straits Schist and Unit II then depends in part on correlation of Unit I in the Waterbury quadrangle with rocks previously designated Unit I in the Roxbury, New Preston, Litchfield, and West Torrington quadrangles. Two lines of evidence suggest this correlation of the two granulitic units: 1) They are lithologically nearly identical. 2) The granulite of Unit I in the Waterbury quadrangle is separated from Unit I of the western belt in the Litchfield quadrangle only by a later intrusive, the Nonewaug granite. North of the Nonewaug granite, along the western edge of the Thomaston quadrangle, Unit I of the western belt is succeeded eastward by gneisses of the Hitchcock Lake Member which, in turn, are succeeded by The Straits Schist. This stratigraphic sequence is identical to that in the Waterbury quadrangle and further substantiates the correlation of Unit I in the western belt with Unit I of the Waterbury quadrangle.

Two major arguments can be presented against the correlation of Unit II of the western belt and The Straits Schist, even though both occupy similar stratigraphic positions relative to what is apparently the same unit (Unit I): 1) The two schists show lithologic differences. 2) There are no rocks which at all resemble the Hitchcock Lake Member between Unit I and Unit II in the west. The writers suggest that the variation in the two lithologies may well represent a facies relationship. Both The Straits Schist and Unit II were originally aluminous shale, and it is reasonable to suppose that there may have been some lateral variation in the original sediments. The absence of the Hitchcock Lake Member between Units I and II becomes somewhat less serious when it is recalled that in the Waterbury quadrangle this unit is highly variable in thickness. Perhaps it was never deposited in the western belt. Clearly there are alternative interpretations for the relationship of The Straits Schist and Hartland Unit II. The writers tentatively favor correlating them as facies equivalents.

Southington Mountain Member

The name Southington Mountain schist was applied by Fritts (1963b) to rocks previously included in the upper part of The Straits Schist. The type area is near the New Britain Reservoir, about 3¼ mi. east of the northeastern edge of the Waterbury quadrangle. In the Waterbury quadrangle, the Southington Mountain schist is found only in a small area in the northeast corner.

The Southington Mountain schist is a medium-grained biotite-muscovite-plagioclase-quartz schist, locally containing kyanite, staurolite, and graphite. Penninite, apparently replacing biotite, is present in one thin section. Minerals present in accessory amounts include tourmaline, zircon, apatite, sphene, and opaques. In most exposures the schist is clearly interlayered with fine-grained biotite-muscovite-plagioclase granulite, which distinguishes it from The Straits Schist which underlies it. There are other differences between the two schist units: 1) The schist layers of the Southington Mountain are generally finer grained than those of The Straits Schist and contain fine, powdery muscovite rather than the coarse, spangled variety. 2) Kyanite and garnet are sparser and smaller than in The Straits Schist and, in some areas of the Southington Mountain Member, kyanite is absent.

The Southington Mountain schist forms massive, rounded outcrops. It commonly contains quartz and quartz-plagioclase pods and pegmatite. Scattered exposures of this unit are found on the small knobs south of the unnamed pond on the northern edge of the quadrangle, ¼ mi. east of the Litchfield-New Haven County Line.

GRANITE AND GRANITE GNEISS

General statement

Granite, pegmatite, and granite gneiss are present throughout all formations in the quadrangle and are particularly abundant in the Hartland Unit I and in the Hitchcock Lake Member. The granitic rocks of the Waterbury Formation migmatites are treated separately in the section on that formation. Typically, the pegmatites and granites are present as small dikes, sills, and irregularly shaped cross-cutting bodies too small to map separately. The few which are mappable are shown on plate 1. The cross-cutting granites and pegmatites are unquestionably late intrusives, probably related to the Nonewaug granite (Gates, 1954; Gates and Scheerer, 1963).

Several sill-like granite-gneiss bodies are of considerable size and less certain origin since they are conformable with the contiguous rocks and appear locally to grade into them. However, careful sampling of several contacts showed no appreciable effect of the granite gneiss on the contiguous metasediments; mineralogic gradations are lacking. Sparse microcline is found in the metasediments for only a few inches from the contact. The writers consider the granite gneiss to be syntectonic, harmonious intrusives and the precursor of the granite and pegmatite. The petrologic characteristics are given below for comparison with other granites and granite gneisses of western Connecticut. They are very similar (see table 7) to the Nonewaug granite, the Mine Hill granite gneiss (Gates, 1959) and the Tyler Lake granite (Gates, 1961; Gates and Christensen, 1965). Excellent exposures of the granite gneiss are easily accessible south of The Straits Schist ridge east of the Chase Brass plant on old Highway 8 and in the cliff under the power line west of new Highway 8 at the Frost Bridge Road underpass.

Table 7.—Petrographic data[1], granite and granite gneiss in the Hartland Formation

	Quartz	Plagioclase	Microcline	Biotite	Muscovite	Other[2]
1. Average[3]	28.9	35.9[4]	21.8	8.8	2.9	1.7
Range[3]	22–33	27–45	11–33	T[5]–22	T[5]–9	—
2. Average[3]	33.3	41.5	52.2	—	—	—
3. Average[3]	31.0	38.0	22.0	1.0	8.0	—
4. Average[3]	32.0	40.0	18.0	2.0	8.0	—
5. Average[3]	36.0	24.0	29.0	7.0	4.0	—

[1] Modal analyses in volume percent.

[2] Garnet, magnetite, sphene, apatite, allanite, tourmaline, zircon, and chlorite.

[3] Rock types and number of specimens:

1. Granite and granite gneiss in the Waterbury quadrangle (14 samples).
2. Recalculation of 1, granite and granite gneiss, to quartz + plagioclase + microcline = 100.
3. Nonewaug granite (10 samples).
4. Mine Hill granite (5 samples).
5. Tyler Lake granite (22 samples).

[4] Average plagioclase content of the 14 samples (of rock type 1) = An 22.9 (160 determinations); range = An 14-30; maximum range in percent of An per sample = 10; average range in percent of An per sample = 5.

[5] T = trace amount (less than 0.05 percent)

Petrology

The massive granites in the Waterbury quadrangle form rather small bodies that cross cut and intimately intrude the metasediments without significant contact effects. The granite gneisses differ from the massive granites mainly in being concordant, sill-like bodies, the orientation of micas giving the gneissic texture. Most of the granitic rocks are white to gray, fine to medium grained, and homogeneous in their field aspect. The granite gneiss is rather uniformly streaked with the biotite folia and is characterized by pronounced biotite "selvages" along the coarser grained quartz and feldspar layers. The granite gneisses typically are fine to medium-grained hypidiomorphic-granular intergrowths of oligoclase, microcline, and quartz with subordinate micas. All minerals show the same range in grain size; in any one sample they can be of different sizes. Generally, the feldspars are coarser than the quartz and the plagioclase coarser than the microcline.

The plagioclase is rather uniform in composition in any one sample but, from sample to sample, ranges from sodic to calcic oligoclase (see table 7). The granite gneisses seem to fall into two groups: one with plagioclase An 15-21 and the other with An 24-30. Oligoclase is present in anhedral to euhedral grains with commonly sutured, interfingering contacts with quartz, microcline, and other plagioclases. Twinning is common, but ranges from sharp, clear twins to those with ill-defined, hazy composition planes.

Microcline is always subordinate to plagioclase and varies inversely with the amount of that mineral. As expected, microcline is most abundant in rocks with a more sodic oligoclase. It is in clear, well twinned, anhedral grains that range from very fine to coarse, although most of them are about 1 mm in diameter. Typically the microcline is nonperthitic.

Antiperthitic intergrowths of plagioclase and microcline are present in the majority of the granite gneisses. In one type of antiperthite the microcline is in stringers in plagioclase, much like the plagioclase in microcline perthite. In most antiperthite, however, the microcline is in small, irregular rectangles or polygons clustered in various parts of the plagioclase. The proportions of plagioclase to microcline in the antiperthite are extremely variable. Commonly, the microcline polygons are arrayed along plagioclase twin lamellae. The amount of plagioclase antiperthite appears to be inversely related to microcline content and directly related to An content of the plagioclase, that is, the plagioclase-rich granite gneisses have a more calcic plagioclase and have more antiperthite. All the granite gneisses with antiperthite have discrete grains of nonperthitic microcline and plagioclase.

Muscovite and biotite are interleaved and highly variable in their ratios. They are in discrete folia as well as disseminated and unoriented throughout the granite gneiss. Both are in raggedly terminated flakes from 0.5 to 2 mm long, with biotite typically coarser than muscovite. As expected in rocks of magmatic parentage, muscovite increases with microcline and biotite with more calcic plagioclase.

The accessory minerals, apatite, zircon, allanite, sphene, and magnetite, tend to be in the biotite or in biotite folia, but they are also present throughout the granite gneiss. Allanite is commonly present as large, euhedral brown, greenish, and bright-yellow crystals that are zoned and altered; small granular aggregates are also common.

METAMORPHISM

General statement

All the rocks of the Waterbury quadrangle are in the metamorphic almandine-amphibolite facies of Turner and Verhoogen (1960); no major isograds can be drawn. Each formation contains basic and pelitic rocks which are sensitive to their metamorphic environment and thus should reflect slight changes in it. The principal modal mineral assemblages indicate that the area should be assigned to the kyanite-almandine-muscovite subfacies, although local mineral assemblages carry sillimanite. Chlorite is a very minor but ubiquitous mineral in all rock types, and is considered to represent retrograde metamorphism. However, much of the chlorite is in discrete radiating sheaves not clearly related to any pre-existing minerals. Chloritic alteration of biotite and garnet is observed and is clearly retrograde. Sericitic alteration of plagioclase and staurolite is present in very minor amounts and only locally. Two small, isolated bodies of serpentinized ultrabasic rock with remnant olivine and pyroxene are assigned to the greenschist facies. These bodies are not of mappable size; however, they are identified on plate 1 by the symbol U. Textures indicate that the metamorphic peak followed the final deformation—even the bent and crumpled micas have recrystallized and are relatively strain free. Porphyroblastic crystals of garnet, plagioclase, and micas show neither strain nor rotation.

The Waterbury Formation

The kyanite-bearing and the hornblende-rich rocks give the critical mineral assemblages needed to establish the metamorphic facies of the Waterbury Formation. Throughout it, both in the interlayered paragneisses and in the trondhjemitic and granitic migmatites, is the persistent assemblage *quartz-oligoclase-muscovite-biotite-garnet-kyanite.* Much less common are the amphibolites with the assemblage *hornblende-andesine-epidote-garnet-quartz.* Both assemblages are assignable to the kyanite-almandine-muscovite subfacies. However, the hornblendic assemblage can also occur in the lower grade staurolite subfacies.

Anomalous mineral assemblages are found in the migmatites, where it is not uncommon to have quartz-microcline stringers contiguous with kyanite-biotite-oligoclase-quartz folia. The microcline and kyanite crystals commonly are within 0.1 to 0.3 mm of each other. In the granitic portions of the migmatites, such as samples WT-217 and 219 (table 3), kyanite and microcline crystals are in contact, the former present as irregular and discontinuous streaks in a fine-grained mosaic of clear, well twinned microcline. The mineral assemblage is *quartz-oligoclase-microcline-muscovite-biotite-garnet-kyanite.* A comprehensive analysis of this assemblage, as well as of the migmatites themselves, is beyond the scope of this report, requiring more detailed mineralogic and chemical analyses.

The Hartland Formation

HARTLAND UNIT I MEMBER

Within the Hartland Unit I member are pelitic horizons in which the mineral assemblage is identical to that in the kyanitic paragneisses in the Waterbury Formation: *quartz-oligoclase-muscovite-biotite-garnet-kyanite.* Also within this member are amphibolites with the mineral assemblage *hornblende-andesine-garnet-quartz.* Based on these two assemblages, the metamorphic subfacies is the same as that of the Waterbury Formation.

Fibrolitic sillimanite in biotite is present in *quartz-oligoclase-muscovite-biotite-garnet* schist, in an area where there are a large number of small bodies of young granites and pegmatites. Presumably the sillimanite is related to the pegmatites, as it is local.

HITCHCOCK LAKE MEMBER

The common mineral assemblage in the Hitchcock Lake Member is *quartz-oligoclase-muscovite-biotite-garnet.* The presence of oligoclase requires assignment of these rocks to the almandine-amphibolite facies. Lack of other diagnostic minerals makes further refinement difficult.

THE STRAITS SCHIST MEMBER

Except locally, The Straits Schists mineral assemblage is *quartz-kyanite-oligoclase-muscovite-biotite-almandine.* This assemblage clearly establishes the kyanite-almandine-muscovite subfacies. Here, too, there are scattered, local, sillimanite-bearing rocks clearly related to pegmatites. In the vicinity of Sylvan Lake, in pegmatites and in the schist along their borders, are several exposures of sillimanite in fibrous bundles up to 6 in. long.

SUMMARY

The metamorphic grade in the Waterbury quadrangle is clearly established as the kyanite-almandine-muscovite subfacies of the almandine-facies as defined by Turner and Verhoogen (1960). The presence of sillimanite is explained by the slightly higher temperatures produced by the nearby pegmatites.

Although all the rocks of the quadrangle are properly assigned to the kyanite subfacies and, according to Winkler (1965), partial melting and regional migmatization is likely to have taken place, only the Waterbury Formation has appreciable migmatite content. Most of the paragneisses have compositions capable of yielding an anatectic granite melt (tables 1, 2, 4, 5, 6); yet the migmatites of the Waterbury Formation are trondhjemitic (quartz-andesine-biotite) and granitic (quartz-microcline-plagioclase). The coarser felsic layers and streaks of the micaceous gneisses of the Hitchcock Lake Member are much more plagioclase rich than their "host" rock, and can reasonably be considered to be partly anatectic in origin. Yet here the streaks are of quartz and oligoclase rather than granitic. The metamorphic conditions producing the intimate migmatites in the Waterbury Formation must have been different from those in the Hartland Formation, even though the mineral assemblages indicate the same metamorphic facies. The tough, coherent aspect of the Waterbury Formation rocks compared to the generally softer, "sandy" or cleavable gneissic aspect of the Hartland rocks is further testimony to different conditions.

STRUCTURE

General statement

The structure of the southern half of the Waterbury quadrangle is dominated by the dome core and the Waterbury Formation, that of the northern half by a mantling series of refolded folds in the Hartland Formation. The core of the dome is a structural unit, distinctly different in its style of folding from the Hartland Formation. The relationship of the Waterbury Formation, in the restricted sense used in this report, to the Hartland Formation is not clear. Fritts (1963a, 1963b) indicates a fault along the eastern side of the dome in the Southington and Mount Carmel quadrangles. On the northeastern side of the dome, Fritts (1962) did not distinguish between the Waterbury Formation (as used here) and the Hartland Unit I but believed that the major break, an unconformity, was between The Straits Schist and the Hitchcock Lake Member. Carr (1960) also included the Hitchcock Lake Member and Hartland Unit I with the Waterbury gneiss, but did distinguish between a Waterbury and an Oxford phase.

The Waterbury Formation is not restricted to the core of the dome; it swings around the two west-facing horns of the Hartland Formation in the Waterbury and Naugatuck quadrangles and trends northward and southward beyond them. The northward extension is cut off abruptly by the Nonewaug Granite. The extent of the southward extension in the Naugatuck and Southbury quadrangles is not known.

In the Waterbury quadrangle the contact between the Waterbury and Hartland Formations is neither well exposed nor informative. Generally, there is a marked break in the topography reflecting the different character of the rocks and the break is accompanied by heavy glacial drift. This is particularly true along the contact east of Naugatuck River. In the hills northwest of the confluence of Naugatuck River and Steel Brook, the rocks near the contact are not typical of either formation. The distinction between them is based in large part on the presence of trondhjemitic rocks, characteristic of the Waterbury Formation and not known in the Hartland. The paragneisses are not unequivocally assigned to either formation. Textural features shown in thin sections also were used to aid in delineating this contact. The narrow belt of the Hitchcock Lake Member along the northern contact requires a fault between the two formations. However, this fault would not be required if the rocks interpreted as the Hitchcock Lake Member were a stratigraphic repetition below Unit I.

The Waterbury Formation

The Waterbury Formation is a layered paragneiss assemblage characterized by convolute folding and by migmatites of paragneisses and trondhjemite to granite. In the migmatites the paragneiss layers are commonly disjointed, attenuated or ill-defined wisps in the felsic migmatitic material. Locally, where layering is more regular, the paragneiss appears as boudins in the trondhjemite. In this preliminary study, only the layering of the paragneisses and the hinge lines of the convolute folds were measured. In many areas the paragneisses are so intricately folded that a layering trend could not be determined and only a lineation of the fold axes was obtained. Similarly, there are outcrops, particularly of the migmatites, where the attitudes of the fold axes are so varied that a trend for the outcrop as a whole cannot be determined. Such areas are indicated by a special symbol on plate 1. Doubtless, a detailed structural analysis would reveal some systematic deformational sequence in these highly contorted rocks.

The foliation symbols (pl. 1) show the average attitude of the compositional layering and also the orientations of the micas. Mica orientation in the kyanite-bearing micaceous layers is not obvious in outcrop, but thin sections generally show it to be at least crudely parallel to the compositional layering.

The hinge lines were measured on folds ranging from about 6 in. to 4 ft in amplitude, generally with a high ratio of amplitude to wavelength. Usually five to ten fold axes were measured for each outcrop. Where fold axes are highly divergent, no trend is given.

In a general way, the fold axes trend southeast-northwest and range from nearly horizontal at the western margin of the quadrangle to moderately steep toward the eastern margin. The fold axes appear to have little relationship to the contact with the Hartland Formation. In the Woodbury quadrangle to the west the fold axes turn more northwesterly and plunge in that direction, although the plunge angle is quite variable. The variability in plunge of the fold axes and the relatively constant trend indicate cross folding.

The Hartland Formation

The Hartland Formation in this quadrangle is characterized by isoclinal folds with long planar limbs and rather sharp hinge areas. In most outcrops only the limbs are exposed and the hinge areas are seldom seen. Although the lithologies of the various members of the Hartland Formation have responded differently to deformation, a feature common to all is the compositional layering. The micas are typically well oriented and parallel to the compositional layering, except in the hinge areas where they tend to be parallel to the axial plane of the early isoclinal folding. In The Straits Schist the compositional layering takes the form of quartz-plagioclase segregations in a micaceous host or of garnet or kyanite-rich surfaces. The compositional layering and the mica orientation are represented on plate 1 by a foliation symbol.

Linear directions were measured on the small-scale crenulations of the micaceous layers, which represent the fold axes of a deformation following the isoclinal folding. Generally, the mica crenulations are more common in The Straits Schist, but they are found also in the micaceous folia in the Hitchcock Lake and Hartland Unit I Members.

Dewees (1966), as a result of a detailed study of 2 sq mi. in the vicinity of Sylvan Lake, concluded that there are three types of folding which are sequential and synchronous. Metamorphic intensity was greatest during the first folding but remained great enough to remove the strain from micas subsequently deformed. The first folding is isoclinal, as shown by the compositional layering and development of the strong foliation of micas parallel to the layering. The mica crenulations represent a subsequent folding of the early foliation surfaces. These folds are characterized by amplitude-to-wavelength ratios of 0.2 or more. The third episode of folding was a gentle warping of the initial isoclinal axial surfaces. Locally, the axial surfaces of the mica crenulations can be observed. Dewees (1966) found that the second and third folding episodes have nearly parallel fold axes and suggests that they are closely related in time. The mica crenulations are readily seen anywhere in The Straits Schist. The late folding, with a very small amplitude-to-wavelength ratio, is well shown in the new Highway 8 roadcuts south of the Frost Bridge Road underpass.

For convenience, the major fold in the Hartland Formation in this quadrangle is called the Sylvan Lake fold. As interpreted by the present writers, it is a refolded fold of the isoclinally folded Hartland Formation whose axial surface trends roughly east-west and dips moderately northward. Dewees (1966) has shown, from an analysis of the compositional layering and the mica foliation (parallel to the layering) that the fold axis plunges N 50° W at 40° at the western end of the fold and 50° N in the vicinity of the Chase Brass plant. A synclinal axis trending east-west in the southern limb of The Straits Schist has a sharp hinge in the region of Sylvan Lake and then trends northeastward up to the northeastern corner of the quadrangle. The trace of this synclinal axis outlines the antiform which dominates the structure. A less well defined anticlinal axis in the center of the belt of Hartland Unit I parallels the synclinal axis in The Straits Schist. These two axial lines extend northward into the Thomaston quadrangle (Cassie, 1965) where they make a complicated bifurcating counterclockwise spiral. The southern extension of the synclinal axes are seen in the three narrow belts of The Straits Schist in the northwestern corner of the quadrangle. The broad belt of the Hitchcock Lake Member results from low dips and open folding, as seen on new Highway 8 south of the Frost Bridge Road underpass (see cross section A-B-C, pl. 2).

The possibility that the duplication of the stratigraphic units reflects recumbent nappes has been considered seriously. In that interpretation the three narrow belts of The Straits Schist northwest of the Sylvan Lake fold would be antiformal crests projecting through the overlying Hitchcock Lake Member. From purely geometric considerations, nappe structure is a reasonable interpretation for this local area, but from a regional viewpoint the writers believe that it introduces more problems than it solves.

Summary

The crucial question, still unresolved, is the role of the core of the "dome" (the Waterbury Formation) in producing the structures of the mantling rocks. Many of the structures associated with domes in Connecticut (Stanley, 1964), Vermont (Thompson and Rosenfeld, 1951; Rosenfeld and Eaton, 1956) and New Hampshire (Skehan, 1961) have been attributed to a light core moving upward because of a gravity difference between the core and the mantling rocks. On the basis of present mineralogy and lithology, there is little reason to assign a lower density to the rocks of the Waterbury Formation than to those of the overlying Hartland Formation. Any density difference would almost certainly have to be attributed to the degree of partial melting at the time when the structure developed.

The indications in the adjoining quadrangles to the west, south, and southwest are that the Waterbury Formation is an extensive (probably Precambrian) unit basal to the Hartland Formation. The structures of the Hartland Formation around this "dome" do not appear to differ significantly from those found where there is no dome. It is reasonable to consider the Waterbury Formation merely as an irregular, resistant basement surface which, in part at least, controlled the folding and refolding of the Hartland Formation. The structures in this quadrangle can be explained by either an upward-moving or a resistant basement block which provided the control for the location of the major deformation. Further studies, now in progress, are directed toward answering these questions.

BEDROCK CONTROL OF TOPOGRAPHY

The topography of the Waterbury quadrangle has been controlled only in part by the bedrock. The Naugatuck River cuts directly across the stratigraphic units throughout the northern half of the quadrangle and was apparently superposed on it. North-south trending joints may have influenced its course somewhat. The Straits Schist is the most resistant rock in the quadrangle and produces essentially all of the major cliffs. It also underlies the greatest elevations in the area. The foliation, layering, and jointing in The Straits Schist and Hitchcock Lake Members are reflected in the topography: the cliff faces follow joints across the layering and the gentle north slopes parallel the dip of the layering.

The Waterbury Formation also reflects the topography to a limited degree. It is a massive, coherent rock which yields to glacial abrasion by scouring rather than plucking. Smoothly glaciated surfaces are common in the Waterbury Formation as are rock-cored drumloidal hills. Joints in the Waterbury Formation are not well defined and produce an irregular, blocky surface where there has been blasting for road construction. Road construction in the Hartland Formation is considerably easier due to the pronounced gneissosity, schistosity, and layering. Controlled blasting yields rather planar surfaces on road cuts.

More details relating to breaking characteristics are found in the sections on the various rock units.

ECONOMIC GEOLOGY

The only bedrock units that have been used commercially are the granitic gneisses and the trondhjemitic to granitic intrusives. Locally, they were used for foundation stone at least a quarter of a century ago. Although there are abundant kyanite-bearing schists, it is unlikely that the kyanite will ever be of economic importance. No other minerals of economic value are known to occur in abundance in the quadrangle.

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