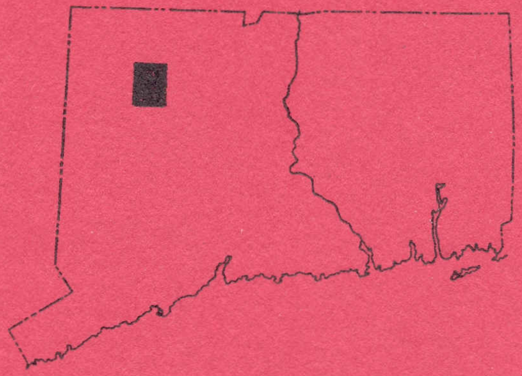
The Bedrock Geology of the West Torrington Quadrangle

WITH MAP

Open Map

BY ROBERT M. GATES
and
NIKOLAS I. CHRISTENSEN



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

A DIVISION OF THE DEPARTMENT OF AGRICULTURE
AND NATURAL RESOURCES

1965

QUADRANGLE REPORT NO. 17

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and
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University of Southern California

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A Division of the Department of Agriculture
and Natural Resources

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The Bedrock Geology of the West Torrington Quadrangle

by

Robert M. Gates and Nikolas I. Christensen

ABSTRACT

The five geologic units in the West Torrington quadrangle, listed in order of decreasing age, are 1) the Gneiss Complex of the Berkshire Highlands (Precambrian?), 2) the Waramaug Formation (Lower Paleozoic?), 3) the Hartland Formation (Lower Paleozoic), 4) the Hodges Mafic Complex (Middle Paleozoic), and 5) the Tyler Lake Granite (Middle Paleozoic). Of major geologic interest are 1) the fault between the Waramaug and Hartland Formations which separates rocks of sillimanite grade from ones of kyanite-staurolite grade, 2) the Hodges Mafic Complex with its genetically related amphibolite swarm in the Hartland Formation, and 3) the stratigraphy and structure of the Hartland Formation. The Gneiss Complex of the Berkshire Highlands is comparable to and probably connected with the Gneiss Complex of the Housatonic Highlands. The young Tyler Lake Granite is typical of the syn- to post-tectonic granites of northwestern Connecticut.

The Waramaug and Hartland Formations are juxtaposed as a result of a NW-SE compression which isoclinally folded the Hartland Formation against the competent and rising block of the Waramaug Formation. The fault is part of a major tectonic line between the Waramaug and Hartland Formations that extends from the southeastern side of the Berkshire Highlands southwestward at least to Danbury.

The Hodges Mafic Complex includes rocks ranging chemically from altered peridotites to diorites that vary in texture from massive to well foliated. The Waramaug-Hartland fault zone provided the major avenue for the intrusive magma. The development of a sharp flexure of the fault plane localized the basic magma and provided the feeder for an amphibolite swarm in the Hartland Formation. The development of the flexure culminated with the emplacement of a massive hornblende gabbro. It is significant that the amphibolites, typical of this metamorphic terrain, can here be traced directly into massive gabbro of unquestioned magmatic parentage.

Three stratigraphic units are recognized in the Hartland Formation here. They can be traced through the Litchfield and New Preston quadrangles to units I, II, and III of the Hartland Formation in the Roxbury quadrangle.

INTRODUCTION

Location

The West Torrington quadrangle is located in the Western Connecticut Highlands approximately 15 mi. south of Massachusetts and 15 mi. east of New York State (fig. 1). The Western Highlands, composed of igneous and metamorphic rocks (the latter of middle to high rank), are bounded

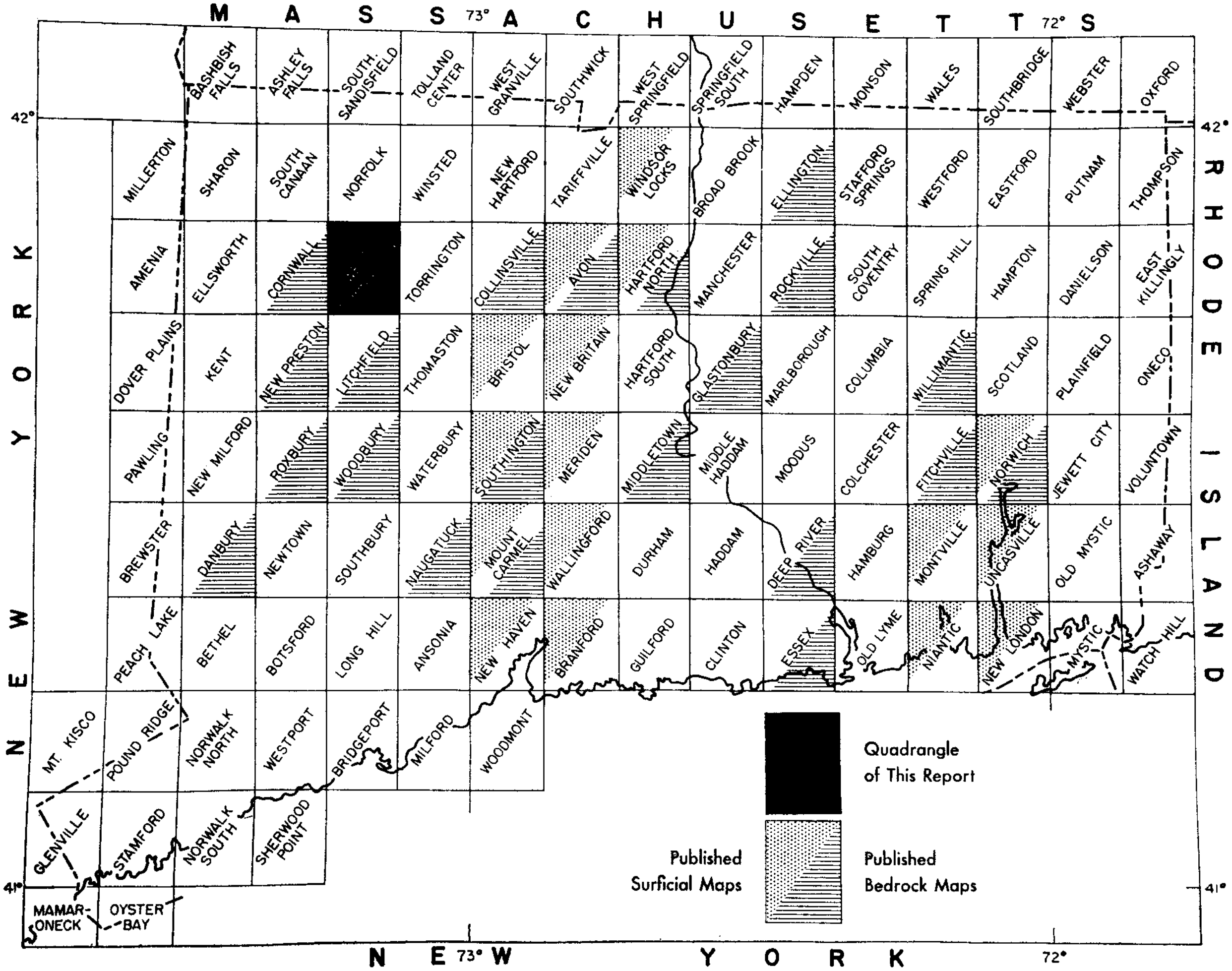

Fig. 1. Index map of Connecticut showing the location of the West Torrington quadrangle, and of other published quadrangle maps. See Appendix for list of published maps.

on the east by the Triassic rocks of the Connecticut River valley and on the west by the Lower Paleozoic rocks of the Hudson River valley. The quadrangle lies along the southern and western sides of the Berkshire Highlands and is only a few miles east of the Housatonic Highlands (Rodgers and others, 1956, 1959).

The quadrangle is dominated geologically by the nickel-bearing Hodges Mafic Complex with its related amphibolites. The Hodges Complex lies mainly between the Hartland and Waramaug Formations which underlie most of the quadrangle (pl. 1, in pocket).

Physical features

Drumloidal hills ranging in height from 50 to 250 ft characterize the terrain of the West Torrington quadrangle. Over two-thirds of the quadrangle is wooded; the remainder is cultivated or pasture land. The rocks are exposed typically in low-lying, pavement-type outcrops, apparently unrelated to the movement of Pleistocene ice. Elevations range from 1,658 ft at Ivy Mountain in the northwestern corner to around 600 ft along the eastern border south of Torrington. Only a few of the hills, such as Red Mountain, north of Torrington, have more than 300 ft of relief.

The drainage is controlled by the sluggish Bantam River and its tributary, Mountain Brook. This drainage system, running from the northern border of the quadrangle to Litchfield, trends S 15° E, almost paralleling the long axes of the drumlins. The West Branch of Naugatuck River provides the drainage for the northeastern quarter of the area, joining the main Naugatuck River about ½ mi. east of the quadrangle boundary.

Torrington is the only major city in the area and the greater part of it lies in the adjacent Torrington quadrangle.

Acknowledgments

The quadrangle was mapped by the senior author during the summers of 1949, 1960, 1961, and 1962 under the sponsorship of the Geological and Natural History Survey of Connecticut. The junior author collaborated in the mapping during the summers of 1960 to 1962, and was supported by a grant from the Wisconsin Alumni Research Foundation. John Thresher and Jeffrey Oster assisted during 1962 under a National Science Foundation Grant for Undergraduate Research participation. The writers gratefully acknowledge the continuing interest and support of the three organizations.

Previous work

The classic work of Percival (1842) and W. H. Hobbs (reported by Rice and Gregory, 1906, and by Gregory and Robinson, 1907) provides the framework for much of the geology of western Connecticut. In more recent years Agar (1929, 1930, 1932, 1934) has added substantially to our knowledge of the West Torrington quadrangle and the surrounding area. The senior author made a reconnaissance map (unpublished) of the southern half of the quadrangle in 1949 in conjunction with studies of the Hartland Formation in the Litchfield quadrangle. Judith Smith (1960) made a special study of the granite body west of Torrington. The discussion of the geology of the West Torrington quadrangle by Rodgers and Gates (Rodgers and others, 1959) was taken principally from Agar's publications, modified in part as a result of their own reconnaissance work.

Petrographic methods

The point-count method of Chayes (1956) was used in all mineralogic analyses. Thin sections were stained to show both plagioclase and potash feldspar. Plagioclase compositions were determined in thin section on the five-axis universal stage by measuring the extinction angles $(010)\wedge x'$ in grains oriented normal to crystallographic *a* (Emmons, 1943).

GENERAL GEOLOGY

The metasedimentary Waramaug and Hartland Formations provide the regional setting for the geology of the West Torrington quadrangle. The Gneiss Complex of the Berkshire Highlands is one of several Precambrian crystalline masses in western Connecticut (Rodgers and others, 1959). It underlies only the northeastern corner of this quadrangle. The Hodges Mafic Complex is a syntectonic to post-tectonic intrusive localized along a fault between the Hartland and Waramaug Formations. The young, late- to post-tectonic Tyler Lake Granite invades all the older rocks in the area.

The Gneiss Complexes of the Berkshire Highlands in the West Torrington quadrangle and of the Housatonic Highlands in the adjoining Cornwall quadrangle are probably related Precambrian rocks of the core of the Green Mountain anticlinorium. The Housatonic Highlands Complex is overlain in part by the Poughquag Quartzite, the Stockbridge Marble, and the Waramaug Formation (Gates, 1961). In Connecticut, the Berkshire Highlands Complex is overlain in part by the Waramaug Formation, the Canaan Mountain Schist, and, on the northeast, by rocks assigned in the past to the Hartland Formation (Rodgers and others, 1959).

The Waramaug Formation is a major metasedimentary unit extending from the West Torrington quadrangle southwestward to Danbury. It has commonly been correlated with the Berkshire Formation of western Massachusetts to the north (Rodgers and others, 1959) and with the Manhattan Formation near Danbury to the south (Clarke, 1958). A major fault separates the Waramaug Formation from the Hartland and Woodville units on the southeast. On the northwest the Waramaug Formation overlies the Gneiss Complex of the Housatonic Highlands (Gates, 1961) and probably the Berkshire Highlands Gneiss Complex also. The relations of the Gneiss Complexes and the Waramaug Formation to the Canaan Mountain Schist are currently under study.

The Hartland Formation extends in a belt of varying width from the southwestern corner of Connecticut northeasterly up to Massachusetts. It is considered younger than the Waramaug (Gates, 1952) and is generally correlated with the Hoosac-Rowe-Savoy sequence along the east flank of the Green Mountains in Massachusetts (Gregory and Robinson, 1907). This correlation has not been traced successfully in outcrop and has several other complicating aspects. The stratigraphic succession in the Hartland Formation has not been definitely established, but the age increases from west to east (Rodgers and others, 1959; Gates, 1959). In Massachusetts the Hoosac-Rowe-Savoy sequence decreases in age from west to east. Furthermore, the regional foliation in the Massachusetts sequence dips eastward, whereas in Connecticut the prevailing dips are westward.

The Hodges Mafic Complex is structurally and mineralogically similar to the Mt. Prospect Complex (Cameron, 1951; Agar, 1930). Both are located along the fault separating the Waramaug and Hartland Formations, both contain nickel sulfides, and both have related amphibolites, hornblendites, and ultrabasic rocks.

Syntectonic to post-tectonic granites are ubiquitous in western Connecticut. Most have been classified collectively as the Thomaston Granite and Granite Gneiss (Rice and Gregory, 1906; Gregory and Robinson, 1907; Agar, 1934). Since 1950 discrete mappable granites of differing character have been given individual names, such as Nonewaug, Mine Hill, and Tyler Lake (Gates, 1954, 1959, 1961), in order to reduce confusion. The granite body near Torrington is included with the Tyler Lake Granite.

GNEISS COMPLEX OF THE BERKSHIRE HIGHLANDS

General statement

The Gneiss Complex of the Berkshire Highlands exposed in this quadrangle is similar in several respects to that of the Housatonic Highlands (Gates, 1961). It is bounded on the west by the Canaan Mountain Schist and by the Waramaug Formation on the south and east. The Preliminary Geologic Map of Connecticut (Rodgers and others, 1956) shows the Berkshire Highlands Complex flanked by the Hartland on the east, but detailed mapping in West Torrington quadrangle and reconnaissance mapping in the Torrington quadrangle shows that a belt of Waramaug separates the Berkshire Highlands Complex from the Hartland Formation in this area. Further exploratory mapping in the South Canaan and Norfolk quadrangles indicates that the bridge between the Housatonic and Berkshire Highlands Complexes shown on the 1906 map of Gregory and Robinson (1907) should be restored.

The Gneiss Complex underlies only a small part of the northeast corner of the quadrangle. The major outcrops are along the eastern border of of the quadrangle, in a narrow belt extending from Torrington to the northern edge of the map (pl. 1), where they are less abundant and occur as isolated patches.

The Gneiss Complex comprises several interlayered rock types which, in part, intergrade. The rock types are 1) a banded to massive granitic gneiss, 2) a rusty-weathering biotitic quartzofeldspathic gneiss, and 3) amphibolite and mafic gneiss. These correspond roughly to rock types 1, 2, and 3, respectively, of the Housatonic Complex of the Cornwall quadrangle. In the West Torrington quadrangle the Gneiss Complex is complicated by an intrusive granite and pegmatite which has made the tracing of the rock types difficult. A stratigraphic section was not established in this quadrangle, largely because of the limited extent of the complex here. However, three rock units were traced northward along the eastern border of the quadrangle from Red Mountain, north of Torrington, for 2½ mi. where they were lost under the drift. The parallelism of these units with the Waramaug-Gneiss Complex contact is considered significant.

A mappable tongue of granite and pegmatite separates the Gneiss Complex from the Waramaug Formation in the area north of Torrington, the only place where outcrops of the two formations are in close proximity. Elsewhere the inferred contact is covered by glacial drift. Speculation on the specific nature of the relationship of the Gneiss Complex to the Waramaug Formation should await further study in the contiguous quadrangles.

Lithology

The Gneiss Complex may be conveniently described in terms of the three rock types mentioned above, all of which are locally converted to migmatite by granite and pegmatite. The gray granitic gneiss predominates, and in it the mafic gneiss or amphibolite forms subordinate layers. The rusty-weathering, biotitic quartzofeldspathic gneiss generally is not interlayered with mafic gneiss. The granite and pegmatite that invade all these rocks are much coarser grained than the host rocks and tend to be more massive. A brief description of the three rock types follows.

GRAY, BANDED TO MASSIVE GRANITIC GNEISS (ROCK TYPE 1)

The best exposures of this granitic gneiss are found on the steep eastern slope of Red Mountain where it was once quarried. The interlayering of the light- to dark-gray granitic gneiss and the amphibolites can readily be studied here. The more massive granitic gneiss is similar to the light- to dark-gray, banded gneiss in all respects except for the lack of banding.

The gray, banded granitic gneiss extends in discontinuous outcrops from Red Mountain northward to Newfield in a belt approximately ¼ mi. wide. A small isolated outcrop of this same rock type, along with massive granite, is found 2,000 ft west of Whist Pond. Other excellent exposures are readily available in the roadcuts on Highway 72 southeast of Reuben Hart Reservoir where the New Hall Meadow dry dam is located.

The rock is a fine- to medium-grained, inequigranular rock composed principally of plagioclase, quartz, microcline, and biotite. Muscovite is usually present in subordinate amounts. Accessory minerals are garnet and magnetite, with trace amounts of sphene, epidote, and apatite. Plagioclase composition ranges from An 27 to An 29 and averages An 22, based on 30 determinations.

The average composition of the granitic gneisses as determined by point counting is given in table 1. Mineralogically and chemically these rocks lie between granite and granodiorite. They are considered to be acid metavolcanic rocks for the same reasons—although less compelling here—as were similar rocks in the Housatonic Highlands Gneiss Complex (Gates, 1961).

Table 1. — Modal analyses of the Gneiss Complex of the Berkshire Highlands[1]

	1	2	3	4
quartz	28	26	13	5–10
plagioclase	45	24	16	15–33
microcline	13	—	—	—
biotite	11	32	—	5–20
muscovite	2	9	—	—
hornblende	—	—	68	35–60
magnetite	T	1	2	T–3
kyanite	—	4	—	—
sillimanite	—	< 1	—	—
garnet	T	2	T	T
sphene	—	—	< 1	< 1
apatite	T	T	—	< 1
epidote	T	—	T	T–5

[1] The rock type in each column is as follows:

1. Banded to massive granitic gneiss; average of 15 samples, 1,000 points per section.
2. Biotitic quartzofeldspathic gneiss; average of 6 samples.
3. Amphibolite; average of 2 samples.
4. Mafic gneiss; range of 3 samples.

T = trace (less than 0.5 percent)

BIOTITIC, QUARTZOFELDSPATHIC GNEISS (ROCK TYPE 2)

The biotitic quartzofeldspathic gneiss occurs principally in two layers of undetermined thickness, trending almost N–S, and separated by banded granitic gneiss. One of the layers can be traced from Torrington to Newfield. Excellent exposures, somewhat complicated by granite and pegmatite, can be seen in the strings of low knobs 1 mi. south of Newfield. See plate 1 for location of the two layers, indicated by a special line (—— x ——).

This gneiss weathers to light, rusty brown; its surface is corrugated due to differential weathering of the quartz-feldspar streaks and the biotite folia (which typically contain kyanite and some sillimanite). The characteristically varying amounts of granite and pegmatite in the gneiss produce a migmatitic rock with mica in discontinuous streaks and wisps and quartz and plagioclase in irregular granulated lenses. The high biotite content makes this rock type easy to distinguish from the granitic gneiss (rock type 1) even where the pervasive granite and pegmatite are abundant. Except for their presence the biotitic quartzofeldspathic gneiss is lithologically similar to a gneiss, considered to be a part of the Waramaug Formation, which crops out on the western side of Red Mountain.

As its name implies, the biotitic quartzofeldspathic gneiss is composed of nearly equal parts of quartz, plagioclase (An 25–33), and biotite.

Muscovite is interleaved with the biotite and in shredded or fine-grained masses with kyanite or sillimanite, being generally about one-quarter as abundant as biotite. Kyanite is in small blades not readily seen in hand samples, and makes up from 2 to 10 percent of the rock. Sillimanite is invariably present with the kyanite, but only in trace amounts. Kyanite and sillimanite are in discrete grains with no indication of pseudomorphous replacement or other reactions. Small garnet crystals, 0.5 to 3 mm in diameter, are scattered throughout the gneiss. Magnetite is ubiquitous in trace amounts. Microcline is generally absent, even in close proximity to granite and pegmatite stringers.

The texture ranges from strongly gneissic and lepidoblastic to porphyroblastic and augenlike, where garnet, kyanite clusters, and blocky biotite knots are rolled between lenses and stringers of granular quartz and plagioclase. The biotite, much coarser grained than the muscovite, reveals the foliation.

A statistical study of six samples is of limited value in such a variable rock, but it does show clearly that the original rock has a K_2O:Na_2O ratio of about 2, and that it has excess alumina. A normal shale is a reasonable parent for such a gneiss. The modal analysis is given in table 1.

AMPHIBOLITE AND MAFIC GNEISS (ROCK TYPE 3)

Amphibolite and mafic gneiss are found throughout the Gneiss Complex as unmappable layers and lenses ranging in thickness from a few inches to 30 ft. Much more abundant in the gray, banded granitic gneiss than in the biotitic, quartzofeldspathic gneiss, they are generally dark and fine grained and can be distinguished readily from these gneisses. The mafic gneisses are between the amphibolites and the granitic gneiss in composition and consist of hornblende, biotite, plagioclase, and quartz.

Their mineralogy is relatively simple. The amphibolite consists primarily of hornblende and plagioclase (An 28 to An 37) with accessory amounts of quartz, magnetite, sphene, pistacite, clinozoisite, and apatite. The amphibolite grades into the mafic gneiss in a transition characterized by increase in biotite and plagioclase and an accompanying decrease in hornblende. The latter is irregularly prismatic and constitutes 60 percent of the pure amphibolites. It has the typical blue-green pleochroism of hornblende in amphibolites. Biotite, dark brown to pale yellow, is in large flakes with ragged terminations. The gneissosity is shown by simple segregation of the granular quartz and feldspar from the tabular or platy hornblende and biotite.

The mineralogy (table 1) and the simple layering of the amphibolites and mafic gneisses in a sequence of granitic gneiss suggests a volcanic ancestry for these rocks.

Summary

The limited extent of the Gneiss Complex of the Berkshire Highlands within the West Torrington quadrangle makes this summary parochial and not necessarily applicable to the Berkshire Highlands as a whole. The rock types are interlayered granitic, mafic, and biotitic gneisses and subordinate amphibolites. This assemblage is considered to be derived from the metamorphism of acid and basic volcanic rocks and ferruginous shale. The layered sequence was folded, metamorphosed, and intimately "intruded" by granite and pegmatite. It is equally possible that the granitic gneiss was partially mobilized to produce this migmatitic assemblage. In spite of deformation, metamorphism, and migmatization, a limited stratigraphic section is locally recognizable, its layers sensibly parallel to the Waramaug-Gneiss Complex contact.

Conclusions as to the relations of the Gneiss Complex of the Berkshire Highlands to the Waramaug Formation must be tentative. Along the eastern part of the contact, in the present quadrangle north of Torrington, the most significant observation is that in the Gneiss Complex there are five lithologic layers parallel both to the contact and to a uniform layer of the Waramaug Formation—thus a conformable contact is implied. As these lithologies are not of mappable extent where exposed in the West Torrington quadrangle and in the northern part are concealed, if present, under drift, further speculation must await field work in other areas.

THE WARAMAUG FORMATION

General statement

The Waramaug Formation is a metasedimentary biotite gneiss which extends in a belt approximately 6 mi. wide from Torrington to New Milford. According to Clarke (1958) the Manhattan Formation takes its place south of New Milford. In the latitude of the West Torrington quadrangle the Waramaug lies between the Gneiss Complex of the Housatonic Highlands to the west and the Hartland Formation to the east. Farther south the Waramaug Formation lies between the Stockbridge Marble and the Woodville Marble (Rodgers and others, 1959).

In this quadrangle the Waramaug Formation appears to divide as it flanks the Gneiss Complex of the Berkshire Highlands and wraps around their southward-projecting tip in a belt ½ to 1 mile wide. The narrow belt of the Waramaug Formation lying between the Berkshire Highlands and the Hartland Formation has been traced through the city of Torrington and eastward for about 3 mi., where mapping was discontinued. Earlier maps (Rodgers and others, 1956; Gregory and Robinson, 1907) show the Waramaug terminating just west of Torrington, with the Hartland Formation flanking the Gneiss Complex of the Berkshire Highlands from there northward to Massachusetts. But Percival (1842) indicates that the Waramaug (Percival's unit I) continues north to Massachusetts between the Hartland Formation (unit G) and the Gneiss Complex of the Berkshire Highlands (unit K).

The Waramaug Formation (unit G) is principally a metasedimentary quartz-oligoclase biotite gneiss with varying amounts of garnet, staurolite, and sillimanite. In the West Torrington quadrangle kyanite is present locally along with sillimanite in the vicinity of Red Mountain. Amphibolite layers, considered here to be metamorphosed basic intrusives, are present in minor amounts. There are several amphibolites in the Waramaug in the vicinity of the Hodges Mafic Complex. The Tyler Lake

Granite intrudes the Waramaug Formation but has had very little effect on it. Except for some variants poor in biotite but rich in quartz and plagioclase, the Waramaug Formation seems to have been very refractory to alteration (or granitization) by the granite. Even where granite penetration is intimate, the screens of Waramaug retain their normal mineralogy and texture. Two predominant rock types can be considered end members of a series: 1) quartz-plagioclase-biotite gneiss and 2) sillimanite-garnet-quartz-plagioclase-biotite gneiss. The amphibolite in the Waramaug Formation is typical of that of the Hodges Mafic Complex and is described in a later section.

Lithology

QUARTZ-PLAGIOCLASE-BIOTITE GNEISS

This gneiss is light brown and smooth weathering, with a well foliated, uniform appearance. Muscovite, not very apparent in the field, makes up about one-third of the total mica. There are only the usual accessories, garnet, magnetite, tourmaline, and zircon. Although the rock varies considerably in amount of essential constituents, the average values given for its lithology in the Cornwall quadrangle (Gates, 1961, p. 22–23) are valid for the West Torrington quadrangle (see table 2).

Table 2. — Modal analyses of the Waramaug Formation[1]

	1	2	3	4
quartz	45	37	50	33
plagioclase	24	19	18	18
biotite	26	25	18	23
muscovite	2	10	11	16
garnet	1	5	2	3
magnetite	2	1	<1	2
sillimanite	—	2	—	1
staurolite	—	<1	T	1
apatite	—	1	T	—
kyanite	—	—	—	1
tourmaline	—	T	—	T
microcline	T	—	—	T

[1] The rock type in each column is as follows:

1. Quartz-plagioclase-biotite gneiss; average of 28 samples from the Cornwall quadrangle.
2. Sillimanite-garnet-quartz-plagioclase-biotite gneiss; average of 34 samples from the Cornwall quadrangle.
3. Quartz-plagioclase-biotite gneiss; average of 7 samples from the West Torrington quadrangle.
4. Sillimanite-garnet-quartz-plagioclase-biotite gneiss; average of 20 samples from the West Torrington quadrangle.

T = trace (less than 0.5 percent)

By an increase in the amounts of mica and alumino-silicates, the quartz-plagioclase-biotite gneiss grades into the sillimanite-garnet-staurolite-bearing gneiss described in the following section. The quartz-plagioclase-biotite gneiss should not be considered a distinctive mappable lithology, but rather one which is interlayered and intergradational with the sillimanite-garnet-quartz-plagioclase-biotite gneiss.

The texture is simple lepidoblastic without marked segregation of the micas or of quartz and plagioclase. The micas may be interleaved, disseminated, or in thin streaks; they are typically oriented. Grain size is variable, but generally fine to medium. The quartz generally shows sharp extinction; only rarely does it show strain. The plagioclase tends to be somewhat elongate parallel to foliation and somewhat poikilitic, with inclusions of micas and stringers of magnetite. The composition of the plagioclase ranges from An 22 to An 37, with an average of An 34. The biotite shows strong pale-yellow to reddish-brown or very dark-brown pleochroism.

SILLIMANITE-GARNET-QUARTZ-PLAGIOCLASE-BIOTITE GNEISS

This gneiss is recognized in the field by its ribbed, corrugated, or roughly weathered surface in contrast to the more simple gneiss described above. The mica-rich folia contain sillimanite, garnet, and staurolite and tend to weather positively as compared to the quartz-plagioclase streaks, producing a characteristic surface. Mineralogically the quartz-plagioclase-biotite gneiss (described in the preceding section) grades into this sillimanitic gneiss with increasing mica content and with the development of streaks and knots of sillimanite, garnet, and staurolite. Kyanite is not typical in the Waramaug Formation in this area, but is found persistently in a narrow belt along the contact with the granite and pegmatite that mark the border of the Gneiss Complex of the Berkshire Highlands. Kyanite was found in two other places in the Waramaug, in septa between tongues of the Tyler Lake Granite north of Goshen. Wherever kyanite was found, sillimanite was also present.

Except for the scarcity of kyanite, the mineralogic composition (table 2) of the sillimanitic gneiss in the West Torrington quadrangle is similar to that in the Cornwall quadrangle (Gates, 1961, p. 22–23).

Where an augen or porphyroblastic texture has developed around garnet crystals and sillimanite knots the foliation of the sillimanitic gneiss is less well defined. This gneiss is characteristically coarser grained than the mineralogically simpler quartz-plagioclase-biotite gneiss. Both textural and mineralogical interest centers on the sillimanite and staurolite. Although the sillimanite is in fibrous and prismatic needles in quartz, its most distinctive association is with biotite. The sillimanite-bearing biotite is typically "bleached" and is only slightly pleochroic whereas the normal biotite is strongly so. The staurolite is in small polygonal grains along with the fibrolitic sillimanite. Some of the sillimanite-bearing biotite is in thin folia, but is more commonly in knots or augen along with garnet.

Kyanite is found in the sillmanitic gneiss as small, stubby grains, along with sillimanite and staurolite. There is no indication of reaction between any of these minerals even though they are commonly in contact.

Plagioclase occurs as small, discrete, untwinned grains (in much the same manner as quartz) and as large, irregularly shaped porphyroblasts which contain inclusions of biotite, magnetite, and quartz. This included material is commonly oriented parallel to the foliation. In some sections the helicitic structure indicates a rotation of about 90°. The large plagioclase porphyroblasts commonly have reverse zoning. As in the simpler biotite gneiss, the plagioclase composition varies widely, ranging from An 23 to An 41. Although the average value is An 33, there appear to be two modes, at An 27 and at An 39.

The garnets range in shape from euhedral to anhedral, the larger porphyroblasts tending to be more euhedral. Elongate garnet stringers parallel to the foliation are common. Many garnet crystals show a zoning of inclusion-free and inclusion-rich layers, but there is no general rule regarding the position of the inclusion-free zone.

Summary

The quartz-plagioclase-biotite gneiss, with and without minor amounts of garnet, staurolite, sillimanite, and kyanite, is considered to derive from a series of interlayered and intergradational argillaceous sandstones and silicous shales now metamorphosed to the high amphibolite facies. The chemical composition of the Waramaug Formation was discussed in an earlier publication (Gates, 1961); that of this series is similar to the composition normally accepted for mixtures of sandstones and shales.

THE HARTLAND FORMATION[1]

General statement

This formation is a complex assemblage of metasedimentary rocks cut by syn- to post-tectonic intrusives ranging from peridotite to granite. It forms a belt of varying width, roughly parallel to the belt of Waramaug Formation, and extending from Massachusetts to Long Island Sound. It is generally agreed (Rodgers and others, 1956, 1959) that these two formations are separated by a tectonic line of considerable importance.

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[1] The Hartland Formation in this report includes the rock units considered to belong to that formation in the Litchfield, Woodbury, New Preston, and Roxbury quadrangles (Gates, 1951, 1954, 1952, 1959) except that the rocks in the southeastern part of the Woodbury quadrangle (Gates, 1954), east of the Pomperaug fault and south of the Nonewaug (Woodbury) Granite, have now been removed from the Hartland Formation and included with the Waterbury Gneiss.

In the report on the Collinsville quadrangle (Stanley, 1964) the Hartland Formation has been raised to group status and all rocks below The Straits Schist have been excluded from it. Stanley's Hartland Group includes 1) The Straits Schist, 2) the Rattlesnake Hill Formation, 3) the Satan's Kingdom Formation, and 4) the Slashers Ledges Formation.

As a guide to readers of these reports, the present writers suggest the following tentative correlations. Unit I of the Hartland Formation in the West Torrington quadrangle is equivalent to the Taine Mountain Formation in the Collinsville quadrangle. The Collinsville Formation, which lies below The Straits Schist and above the Taine Mountain Formation, is apparently absent in the West Torrington quadrangle. Unit II of the Hartland Formation (West Torrington quadrangle) is considered equivalent to the upper member of the Satan's Kingdom Formation (the Breezy Hill Member) and the Slashers Ledges Formation. Unit III of the Hartland Forma-

Although the Hartland Formation is generally considered to be the correlative of the Hoosac-Rowe-Savoy Series, which flanks the Precambrian of the Green Mountains in Massachusetts, the correlation has never been firmly established because a Triassic fault cuts off most of the Hartland Formation at the state line. In any event, a Lower Paleozoic age is indicated for the Hartland because it has been intruded by pegmatites determined to be about 360 million years old (Rodgers, 1952; Wasserburg, Hayden, and Jensen, 1956).

In the Roxbury quadrangle (Gates, 1959) the Hartland Formation is divided into four mappable units. Three of these (I, II, and III) are found in the West Torrington quadrangle and have been traced (Martin, 1962) through the Litchfield and New Preston quadrangles to Roxbury.

Unit I is predominantly mica-plagioclase-quartz granulite. In the southeastern corner of the quadrangle it forms the core of what appears to be part of a dome but is actually the nose of an isoclinal anticline with axial plane striking NE and dipping steeply northward. This unit is correlated with similar rocks in the eastern part of the Litchfield quadrangle and in the northwestern part of the Thomaston quadrangle.

Unit II is a coarse, garnet-staurolite-muscovite-plagioclase-quartz schist which overlies unit I and occupies the south-central part of the quadrangle. It extends eastward to northeastward into the Torrington quadrangle in a narrow belt less than 1 mi. wide, separating unit I from rocks to the south with which unit I is correlated, and also extends in a narrowing wedge southward into the Litchfield quadrangle.

Unit III, a thinly interlayered mica-plagioclase-quartz granulite and schist, occupies a narrow belt along the western side of the Hartland Formation, lying within the fault zone separating that formation from the Waramaug.

Terminology

During the past half century the Hartland Formation has been referred to as a mica quartzite, a feldspathic mica quartzite, a mica-quartz schist,

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tion is tentatively correlated with the lower member of the Satan's Kingdom Formation, the Ratlum Mountain Member. The writers realize that this correlation reverses the sequence proposed by Stanley. However, the reverse sequence is more consistent with the less complicated structure of the Hartland Formation in the belt from the West Torrington to the Roxbury quadrangle.

The correlation of unit I of the Hartland Formation with the Taine Mountain Formation is based on unpublished maps of the Thomaston and Waterbury quadrangles. In these quadrangles the Collinsville Formation or its equivalent underlies The Straits Schist and overlies unit I of the Hartland Formation. In this suggested scheme The Straits Schist and the Rattlesnake Hill Formations together become a correlative, or a facies, of unit II, as do the Satan's Kingdom Formation (Breezy Hill Member) and the Slashers Ledges Formation.

The definitive correlation of the formations in the West Torrington quadrangle with those in the Collinsville quadrangle must await the completion of the Torrington and Thomaston quadrangles. All correlations suggested here must be considered tentative, because several attractive alternatives might readily be proposed.

a feldspathic mica-quartz schist, and simply as quartzite and schist. Geologists working in New England have pointed out at recent field conferences that these terms are misleading and confusing to those unfamiliar with traditional usage. With our present metamorphic-rock terminology no simple rock name can be adequately definitive. Nor is there substantial agreement on the method of naming these rocks. Therefore, the terms used in this report must be explained; they are not intended to establish new definitions, and they are based on mineral content and texture, without genetic significance. These terms are:

1. A *granulite* is composed largely of equigranular minerals with less than 20 percent platy minerals. The latter are in large part disseminated but may or may not be oriented. Minor thin mica folia are permissible.

2. A *gneiss* normally contains 15 to 30 percent platy minerals which are at least roughly oriented. They may be in continuous or discontinuous folia. Granular and platy minerals are visibly segregated.

3. A *schist* normally contains more than 30 percent platy minerals, largely in parallel orientation. The folia may be wavy, crenulated, or planar. Segregation of platy and granular minerals is not obvious or uniform. Irregularly distributed quartz pods and lenses are permitted.

4. An *amphibolite* is composed principally of hornblende and plagioclase. Typically a large part of the hornblende is oriented.

Lithology

GENERAL STATEMENT

The Hartland Formation in the West Torrington quadrangle can be classified as granulite, granulitic gneiss, and schist (as defined in the preceding section) with the inevitable intermediate or gradational types. In all of these the essential minerals are quartz, plagioclase, muscovite, and biotite. Garnet, staurolite, and kyanite are characteristic porphyroblasts in the schist of unit II but are subordinate in the granulite and granulitic gneiss. In summary, unit I is predominately a mica-plagioclase-quartz granulite with subordinate layers of two-mica-quartz schist. Unit II is typically a coarsely porphyroblastic garnet-staurolite-mica-quartz schist. Unit III is mainly interlayered granulite and schist.

UNIT I

General statement. This unit of the Hartland Formation is characteristically a quartz-plagioclase granulite containing 5 to 20 percent well oriented micas. Heterogeneity is introduced by thin mica folia, quartz seams, and thin to thick layers of mica-plagioclase-quartz schist. The schistose layers, ranging from sheets of pencil-line thinness to beds 1 to 3 ft thick, are everywhere subordinate to the granulite in total thickness. Further heterogeneity is introduced by isoclinal folding of the beds within the unit, with amplitudes ranging from less than 1 ft to at least 50 ft. In outcrop the rocks appear slabby, spindled, or ropy, depending on the orientation of the section in which they are viewed. Rock types typical of unit I can be seen readily in the knobs immediately north and south of new Highway 116, east of the power line and 3¼ mi. east of Litchfield center.

Petrography. The essential minerals of the granulite of unit I are quartz, oligoclase, biotite, and muscovite; the accessories are chlorite, staurolite, garnet, magnetite, and apatite. The grains of the essential minerals range in size from 0.1 mm to 0.5 mm. They are anhedral and equidimensional to slightly elongate parallel to foliation. The micas may be either discrete and disseminated throughout the rock or segregated in thin, continuous folia. They are typically well oriented. The plagioclase ranges from An 11 to An 37, with a mode of An 15. The average composition of the 31 samples analyzed is given in table 3 (col. 1).

Table 3. — Modal analyses of the Hartland Formation[1]

	1	2	3
quartz	51	31	33
plagioclase	30	7	14
biotite	12	8	5
muscovite	5	30	30
garnet	< 1	0–15	0–5
staurolite	< 1	1–40	0–25
kyanite	—	trace	1–9
magnetite	< 1	1	2–6
chlorite	< 1	1	1–8

[1] The rock type in each column is as follows:

1. Mica-plagioclase-quartz granulite, unit I; average of 31 samples, 1,000 points per sample. All samples stained to show untwinned plagioclase.
2. Muscovite-quartz schist with porphyroblasts of garnet, straurolite, plagioclase, and biotite, unit II; average of 12 samples.
3. Muscovite-quartz schist with porphyroblasts of kyanite, staurolite, garnet, plagioclase, and biotite, unit II.

Origin. Although a full discussion of the origin of the mica-oligoclase-quartz granulite of unit I will be presented in a later publication dealing with the Hartland Formation in the Western Highlands, it is worthwhile to point out here one of the significant features. If the modal analysis (table 3) is converted to its chemical constituents, it most nearly approaches the composition of a siltstone or a subgreywacke. The most significant difference is in soda content — nearly double that of the average siltstone (Clarke, 1924) and reflected in the high plagioclase content. Two possible explanations for the large amount of soda are currently being studied: 1) The soda is derived from unweathered, fine-grained volcanic detritus mixed with silt grains composed of quartz and clay minerals. 2) A reaction between connate water and the clay minerals during an early stage of metamorphism may be the cause.

UNIT II

General statement. The major rock type of unit II is a lustrous muscovite schist with porphryoblasts of garnet, staurolite, plagioclase, and biotite.

The most obvious variable is the amount and size of the porphyroblasts. In some places, such as the knob in the extreme southeastern corner of the quadrangle, subhedral to anhedral garnet and staurolite crystals attain a length of 3 to 4 in. and plagioclase porphyroblasts reach ¼ to ¾ in. In a railroad cut in the Torrington quadrangle, 3,000 ft east of this knob, the plagioclase crystals are two to three times this size. Kyanite porphyroblasts are relatively rare in unit II. However, they are very prominent locally, accompanied by lesser amounts of garnet and staurolite.

Because it crops out in such a wide belt, an attempt was made to subdivide unit II. The effort was fruitless because of lack of recognizably distinctive horizons and the scarcity of outcrops. The most distinctive lithology is a very coarse garnet-staurolite-muscovite-plagioclase-quartz schist, indicated on plate 1 by the symbol *X*. This rock type can be traced satisfactorily in a narrow belt following the trend of the unit I-unit II contact from the southeastern corner of the quadrangle up into the amphibolite swarm of the Hodges Mafic Complex. Outcrops farther west may be repeats of the same belt.

A distinctive kyanite-bearing rock within unit II was traced in nearly continuous outcrop for 1½ mi., from an outcrop on Spruce Brook, 1,500 ft south of East Litchfield Road to the waterfalls on Picket Brook (in the Torrington quadrangle), 1,000 ft east of Highway 8. Two additional outcrops of the kyanite-bearing rock indicate that this belt, only 50 to 200 ft wide, may extend northward for another mile parallel to the unit I-unit II contact.

In the narrow belt of unit I in the southeastern corner of the West Torrington quadrangle and in the contiguous southwestern corner of the Torrington quadrangle, there are several outcrops of a graphitic schist. This schist could not be traced for more than ½ mi. in any direction and is not present in the main outcrop area of unit II. Its outcrops appear to be unrelated, discontinuous pods within the normal schist.

Excellent exposures of the very coarse garnet-staurolite-muscovite-quartz schist are readily accessible 1) on Town Farm Road north of Highway 25, 2) on Highway 63, ½ mi. north of Litchfield center, and 3) in the bed of the tributary of Bantam River east of Forman School (pl. 1).

Petrography. Unit II is a fine- to medium-grained muscovite-quartz schist with porphyroblasts of garnet, staurolite, oligoclase, biotite, and locally, kyanite. The porphyroblasts range from microscopic to 3 to 4 in. long; they are generally prominent and readily seen in the field. The mica folia are predominantly muscovite with subordinate biotite and a trace of chlorite. The quartz occurs as an integral part of the schist as well as in coarse-grained pods 2 to 6 in. long and ½ to 2 in. across. Accessory minerals are chlorite, magnetite, zircon, tourmaline, graphite, apatite, and epidote. The average mineralogical compositions of the schists of unit II are given in table 3 (cols. 2 and 3).

Plagioclase occurs as small, anhedral, untwinned grains with quartz and as twinned, inclusion-loaded porphyroblasts. Its composition ranges from An 15 to An 54, but most of it is calcic oligoclase. The more calcic plagioclase was found in the schist near the amphibolite bodies. Two plagioclase compositions in the schist adjacent to amphibolites have been noted in several localities (Gates, 1959).

Garnet is in euhedral to subhedral equidimensional crystals with abundant inclusions of magnetite and quartz. Some crystals are vaguely zoned in terms of abundance of inclusions with an intermediate zone relatively free of inclusions. Trains of inclusions are gently curved in some grains, indicating rotation during formation.

Staurolite ranges in size and shape from small, euhedral or subhedral crystals to larger, anhedral grains. Many of the large porphyroblasts show evidence of inheriting the texture of the micas, and retain the quartz as inclusions. The foliated structure can commonly be traced through the staurolite crystals. Locally, staurolite has been altered to muscovite along its edges.

Kyanite is abundant only locally, but it is spectacular in these occurrences. Typically it is in small, bladed aggregates in random to radial arrangements. Locally the kyanite blades are 3 to 5 in. long. The porphyroblasts of kyanite are similar to those of staurolite except that the kyanite does not reflect its antecedents. There is nothing to indicate the mineralogical reactions that produced the kyanite. The staurolite seems clearly to have developed at the expense of biotite and muscovite and appears to coexist in harmony with the kyanite.

Origin. From the average composition of the schist of unit II (table 3) it is fairly clear that the original sedimentary rock was a ferruginous, high-alumina shale or clay, low in soda and lime, perhaps a graphitic or pyritic black shale — the sedimentary type expected to result from rather mature chemical weathering. It seems unlikely that the parent rocks of unit II weathered to this composition *in situ* above unit I (although there is a narrow transition zone between them); it is thought rather, that the original sediments of unit II were transported from an area of mature weathering.

UNIT III

The rock types of this unit are the most variable and the least distinctive, partly because of its limited exposure and partly because of its proximity to the faults between the Hartland and Waramaug Formations. The unit is composed of a thinly interlayered assemblage of mica-quartz schist and mica-plagioclase-quartz granulite or gneiss. Garnet, staurolite, and kyanite are present locally in small grains in the micaceous layers and are not readily seen in the field.

The essential minerals are quartz, oligoclase, muscovite, and biotite. Their variability from sample to sample makes a modal analysis of the limited exposures somewhat meaningless. The mica content ranges from 2 to 50 percent of any single sample, with quartz and plagioclase making up the remainder. The micas are well oriented; they are present as disseminatons in mica-poor rocks and as thin folia in mica-rich rocks. In general, muscovite predominates over biotite.

The plagioclase is in small (0.01 to 1.0 mm), clear, untwinned, equidimensional grains forming an interlocking mosaic with quartz; some is in larger, twinned, anhedral grains.

Accessory minerals are magnetite, chlorite, zircon, apatite, sphene, and tourmaline.

Summary

In this quadrangle the Hartland Formation consists of three readily mappable units. The lowest (unit I) is a rather fine-grained, gray, quartz-plagioclase granulite with subordinate oriented mica and thin schistose layers. The middle unit (unit II) is a coarse porphyroblastic garnet-staurolite-muscovite-quartz schist characterized by garnet-staurolite crystals. The transition from unit I to unit II is rather abrupt, although it is gradational over about 200 ft. Unit III grades abruptly out of unit II as the garnet and staurolite diminish in size and abundance and as the quartz-plagioclase layers increase. Features requiring explanation in terms of parent sediments are the rather high soda content of unit I and the high iron and alumina content of unit II.

THE HODGES MAFIC COMPLEX

General statement

The Hodges Mafic Complex is an octopus-shaped mass, approximately 1¼ mi. wide and 4½ mi. long, with the "head" occupying the crest of a fold and the "tentacles" extending into the Hartland Formation. The complex consists of hornblende gabbro, hornblendite, and amphibolite. Textures are hypidomorphic-granular in the northern portion of the complex, becoming schistose to the south.

The complex is named for the Hodges nickel prospect, a nickel-sulfide deposit in the hornblende gabbro (Agar, 1930). The complex includes 1) a hornblende gabbro that has been considered part of the Brookfield Diorite Gneiss (Rice and Gregory, 1906; Rodgers and others, 1959), 2) an amphibolite designated on previous maps (Rice and Gregory, 1906) merely as amphibolite (their no. 38), and 3) rocks intermediate between gabbro and amphibolite. Altered ultrabasic rocks, designated by a separate symbol on plate 1, are probably related genetically to the Hodges Mafic Complex.

The Hodges Mafic Complex is similar and probably related to the Younger Mafic Intrusives in the Mt. Prospect Complex (Cameron, 1951), nickel-bearing gabbroic rocks intrusive into a series of dioritic gneisses of the Brookfield type. These dioritic gneisses are found in the West Torrington quadrangle only in five isolated outcrops northwest of Litchfield near the Waramaug-Hartland fault (see circles on pl. 1). The type Brookfield and that of the Mt. Prospect area are quite different lithologically from the Hodges Mafic Complex (Agar, 1927, p. 28-31; Cameron, 1951, p. 13-24; Clarke, 1958, p. 31-38; Rodgers and others, 1959, p. 28). The latter is probably related to the Brookfield Diorite in much the same way as the Younger Mafic Intrusives of Mt. Prospect are related to the Brookfield Diorite Gneiss.

Lithology

GENERAL STATEMENT

The Hodges Mafic Complex consists primarily of hornblende gabbro, a transition gabbro-amphibolite rock, and amphibolite with subordinate hornblendite and altered ultrabasic rock. With the exception of the ultrabasic rock there are no sharp breaks between the various rock types; they form a complete series from massive hornblende gabbro at one extreme to well foliated amphibolite at the other. Separation in the field is made primarily on the basis of the grain size and the fabric, hornblende gabbro grading into amphibolite principally by a decrease in grain size and an increase in parallel fabric.

HORNBLENDE GABBRO

This is a dark, massive, medium-grained rock composed essentially of tabular to subrounded crystals of hornblende and plagioclase, together with interstitial quartz and flakes of biotite. It is designated as hornblende gabbro rather than diorite because 1) the chemical composition is equivalent to gabbro, due to the high percentage of hornblende, 2) some hornblende has formed from pre-existing pyroxene, and 3) corroded remnant laths of labradorite are locally abundant.

The hornblende gabbro underlies an area in the central portion of the quadrangle immediately south of Nickel Mine Brook and extends southward for approximately 7/10 mi. to the transition gabbro-amphibolite rock (see below) from which it is readily distinguished by its greater homogeneity, green-black color, even grain, and total lack of structure.

Although characteristically homogeneous, the hornblende gabbro locally contains inclusions of the older Waramaug. Mainly confined to areas near the Waramaug contact, these can readily be seen along Nickel Mine Brook.

The hornblende gabbro is composed of hornblende, plagioclase, and biotite, with accessory quartz, magnetite, ilmenite, sphene, and apatite. The proportions of these minerals are shown in table 4.

Table 4. — Modal analyses of the Hodges Mafic Complex

	Hornblende gabbro[1]		Amphibolite[2]	
	Range	Mean	Range	Mean
hornblende	48.2–60.6	54.7	47.6–70.2	59.5
plagioclase	21.2–34.6	26.5	19.8–29.0	26.3
biotite	9.8–20.2	13.5	0.0–1.3	0.4
opaques	0.6–6.2	2.7	0.1–2.4	1.3[3]
quartz	0.0–3.4	1.7	0.6–11.6	3.8
sphene	0.2–1.8	0.9	0.0–2.0	0.4
epidote	—	—	0.0–21.2	7.3
accessories	—	—	0.0–5.8	1.0[4]

[1] Based on modal analyses of 9 samples, 1,000 points each

[2] Based on modal analyses of 14 samples, 2,000 points each

[3] Ilmenite

[4] Chlorite and pyrite

Hornblende, the most abundant mineral, occurs as large anhedral to subhedral grains and as smaller euhedral crystals. The larger crystals are commonly riddled with small inclusions of magnetite and ilmenite which either form rounded zones in the central portions of the grains (fig. 2) or outline former crystal boundaries suggestive of pyroxene.

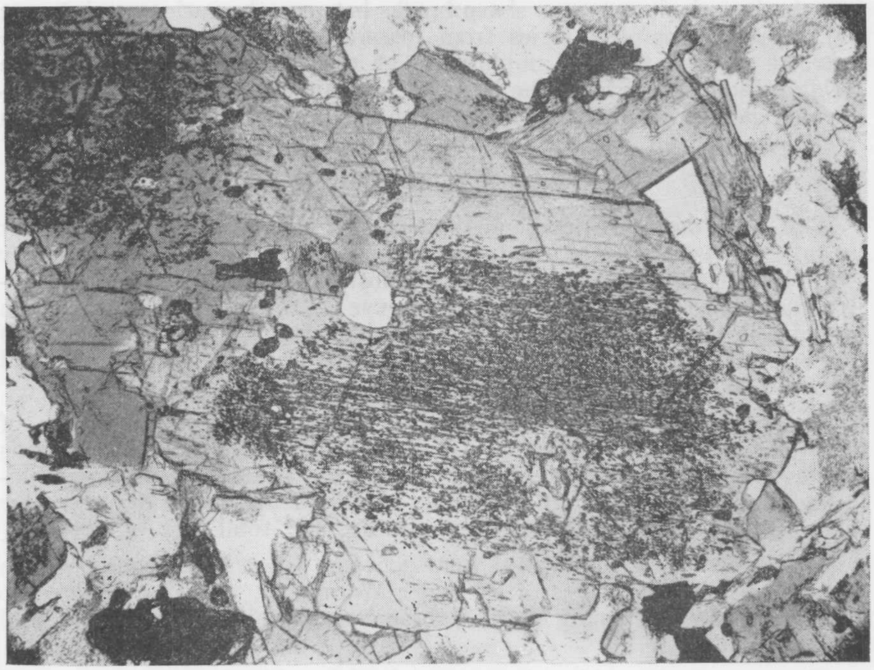

Fig. 2. Large hornblende crystal (in hornblende gabbro) containing inclusions of magnetite and ilmenite; uncrossed nicols; 63X.

Two generations of plagioclase are found in some outcrops. The first generation, represented by the more calcic cores of large crystals, has an average composition of An 54. These crystals are usually anhedral due to resorption. The more abundant second-generation plagioclase consists of smaller granular to lath-shaped crystals ranging in composition from An 28 to An 43.

Resorption of the first-generation plagioclase (fig. 3) indicates an increase in water pressure during crystallization and, therefore, a lowering of the temperature of crystallization. Theoretically, in a closed system this would produce an increase in anorthite content of the second-generation plagioclase being precipitated. However, during the build-up of water pressure which caused the resorption, continuing crystallization of hornblende, during a hiatus in the precipitation of plagioclase, presumably extracted calcium from the magma. Thus when crystallization of the second generation of plagioclase began, andesine was precipitated. The texture substantiates this order of crystallization: the first-generation plagioclase crystallized early, whereas the interstitial character of

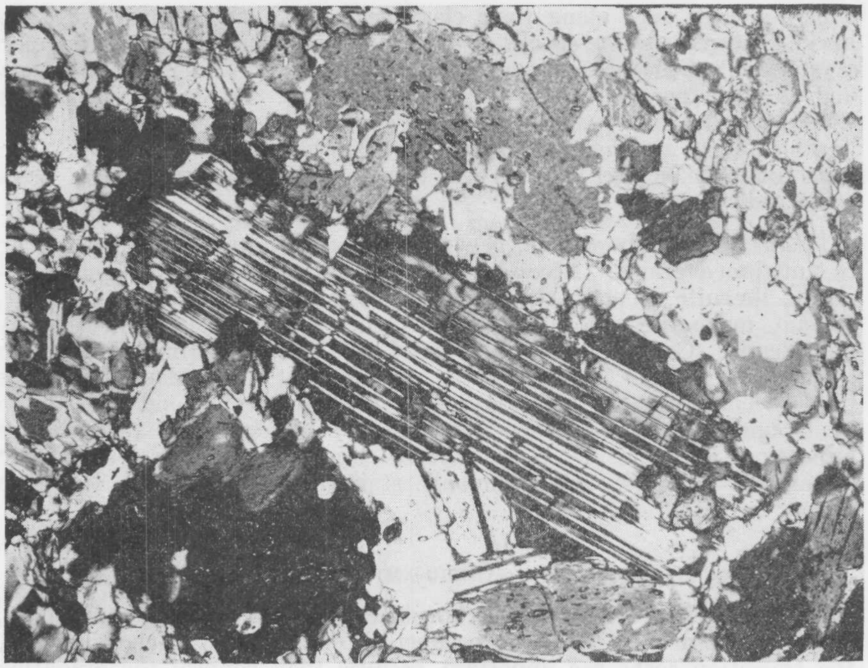

Fig. 3. Corroded lath of labradorite in hornblende gabbro. Light-gray grains are hornblende; white areas are andesine; crossed nicols; 63X.

the second generation of plagioclase indicates its development after the hornblende.

Biotite, independent flakes with ragged to sharp edges of finer grained, irregular, discontinuous edges on amphibole, is commonly golden brown to reddish brown and sometimes altered to pale-green chlorite. Quartz is usually subordinate, unstrained, and interstitial.

Accessory minerals are sphene, magnetite, ilmenite, pyrrhotite, pentlandite, pyrite, hematite, and chalcopyrite. Sphene occurs as large wedge-shaped crystals and as small granular patches. Magnetite is present both as a primary mineral and as fine dust released by the alteration of the mafic minerals. Together with ilmenite it is commonly included in biotite and hornblende grains.

HORNBLENDITE

Hornblendite, a rock consisting chiefly of hornblende, occurs in small pods, enclosed by and subordinate to the hornblende gabbro. In outcrop it is massive and uniformly dull green to black. Unlike the hornblende gabbro it does not contain recognizable plagioclase and biotite in hand specimen.

The hornblende in this rock is commonly a lighter green than the amphiboles of the hornblende gabbro. The amphibole crystals are commonly spongy and, along their cleavages and in the central portions, heavily laden with fine specks of magnetite and ilmenite. Small angular crystals of sphene are commonly enclosed as randomly oriented grains and as trains parallel to the amphibole cleavage. Small laths of biotite with a parallel orientation are seen in many thin sections traversing the hornblende at an angle of about 45°. Uralite is also common. The form and schiller structure of the original pyroxene is in many cases preserved.

Plagioclase is subordinate, generally in pods containing a fine mosaic of untwinned grains. Accessory minerals include biotite, sphene, magnetite, ilmenite, quartz, chlorite, apatite, and various sulfides. Biotite, sphene, magnetite, and ilmenite are generally completely enclosed by hornblende. Quartz is invariably interstitial. In some instances, as in the Hodges nickel prospect, the amount of disseminated sulfides may be considerable. Chalcopyrite, pyrite, pyrrhotite, and pentlandite are abundant and everywhere interstitial, commonly with relationships indicating replacement of the silicate minerals. Where sulfides are abundant, the rocks are commonly stained deep yellow to brownish yellow.

TRANSITION GABBRO-AMPHIBOLITE ROCK

Occupying a zone between the hornblende gabbro and the amphibolite, and with textures intermediate between those of these two end members, the transition rocks are important because they confirm the gradation from the hornblende gabbro to the amphibolite.

In the gabbro-amphibolite rocks the individual minerals are generally medium in size and possess a crude subparallel orientation. Some specimens are slightly gneissic due to the segregation of hornblende, plagioclase, and biotite into bands, streaks, and augen. Many of the transition rocks may truly be referred to as "mixed rocks." In the field they have a patchy or uneven appearance with much variation from place to place in proportions of constituent minerals, color, and grain size. In general, the coarse-grained types appear to belong to the hornblende-gabbro suite, while the finer grained, more schistose varieties cannot be distinguished in hand specimen from the biotite amphibolites. A streaked or banded relation between the types is common, and in places pods of the coarser grained varieties are found in the finer amphibolite. Although both hornblende gabbro and amphibolite are distinguishable in the streaks, sharp contacts between the types are absent and the transition from one to the other is gradual.

The common constituents of the transition rocks are hornblende, plagioclase, and biotite. Quartz is present in minor amounts. Sphene, epidote, pyrite, pentlandite, pyrrhotite, apatite, ilmenite, magnetite, and zircon are common accessories.

The size of the hornblende crystals varies considerably within any single thin section. Coarse, anhedral to subhedral equant grains are commonly intermixed with medium- to fine-grained, euhedral prismatic ones. The larger crystals, like much of the hornblende in the hornblende gabbro, commonly contain dusty cores of fine magnetite and ilmenite.

The smaller crystals are similar in size to the hornblende in the amphibolite. Segregation and orientation of the hornblende crystals contribute prominently to the streaked nature of the transition rocks.

Plagioclase, ranging in composition between An 26 and An 40, is present as a fine, granular mosaic of crystals in light-colored bands, streaks, and augen, and as small grains interstitial to the hornblende in the darker bands. Quartz, usually in small amounts within the plagioclase segregations, is fine- to medium-grained and generally shows no optical strain. Biotite is present as streaks of interwoven reddish-brown flakes and as dispersed tabular flakes with a subparallel orientation.

The sphene is in irregular aggregates of small grains and also forms individual, small, wedge-shaped crystals. Magnetite and ilmenite are common as small grains and fine specks within hornblende. Fairly large euhedral crystals of apatite are present. Small amounts of pyrite, pentlandite, and pyrrhotite are interstitial to the silicates.

AMPHIBOLITE

Amphibolite of the Hodges Mafic Complex lies within the Hartland Formation as a series of sill-like bodies which strike approximately N-S. They pinch out to the south and grade into the transition rocks to the north. The amphibolite is best exposed for about 1 mi. along Soapstone Hill Road and for 1½ mi. along Weed Road. Other excellent outcrops are found along stream beds east of Town Farm Road and in the general area of Soapstone Hill Road.

Foliation of the amphibolite is generally parallel to the Hartland-amphibolite contacts. Furthermore, most of the amphibolite bodies are concordant with the foliation of the schist which encloses them. Local discordant relationships exist where small appendages of the larger amphibolite sills cut across the foliation of the enclosing schist.

Hornblende, plagioclase, and epidote are the major mineral constituents (table 4). In some thin sections biotite, quartz, or chlorite may be major minerals, but in general they are relatively minor in abundance. Accessory minerals include clinozoisite, sphene, ilmenite, magnetite, hematite, pyrite, apatite, and zircon.

Hornblende is the dominant constituent, composing 50 to 70 percent of the rock. It is deeply pleochroic and generally in well developed prisms. Individual crystals lie with their long dimensions in the plane of schistosity and many show a microscopic lineation in the foliation plane.

Plagioclase forms a mosaic of crystals in thin parallel streaks or is evenly dispersed. Relatively abundant, it generally makes up 20 to 40 percent of the rock. Studies of 13 samples using a combination of the Rittman zone method and the five-axis method (Emmons, 1943) yielded compositions ranging from An 24 to An 40.

Epidote is generally present as small, evenly disseminated grains. Although optical variations were noted, the average birefringence is 0.035, indicative of pistacite (Winchell and Winchell, 1951, p. 449).

Randomly distributed throughout the southern portion of the Hodges Mafic Complex are patches of amphibolite containing augen and bands of epidote. Here the large epidote grains commonly contain dusty portions filled with magnetite.

Although commonly present, biotite generally comprises less than 1 percent of the rock, occurring with hornblende as large, blocky flakes with random distribution and subparallel orientation. Chlorite, when present, is either in radiating flakes or large blocky ones which have formed from hornblende, or as small greenish flakes on the tips of biotite. Chlorite is more abundant near the contacts of the amphibolite bodies and the enclosing Hartland Schist than in the main mass of the amphibolite.

Quartz is found as small grains interstitial to the hornblende and plagioclase. Cubes of pyrite from 1 to 8 mm in width are commonly present. Ilmenite, with subordinate hematite and magnetite, is generally interstitial to the silicates. Sphene is in irregular aggregates of small grains and in individual, small, wedge-shaped crystals.

ULTRABASIC INTRUSIVES

In the West Torrington quadrangle and the western half of the Torrington quadrangle at least seven separate bodies of ultrabasic rocks are present, all more or less altered to talc and tremolite (see pl. 1). North of Soapstone Hill Road a tabular body about 250 ft long and 50 ft wide, elongated parallel to the foliation of the enclosing Hartland schist, has been quarried for soapstone.

All of the ultrabasic bodies discovered are within ¾ mi. of the Hartland-Waramaug contact, three of them located directly at the contact, indicating that the magma was channeled along the Hartland-Waramaug fault. The alteration shown by these intrusives suggests that they were emplaced early in the orogenic cycle and were partners with the metasediments in metamorphism. Lithology appears to have had no control over the position of the ultrabasics; they are enclosed by Hartland quartz-mica schist, staurolite-quartz-mica schist, granulite, and by Waramaug mica-poor feldspar-quartz gneiss.

Texture and mineralogy vary greatly within an individual body, although talc and tremolite are invariably present. Portions of the bodies with abundant talc and tremolite either have a fine-grained sugary texture or are composed of larger radiating crystals of tremolite in a fine meshwork of small flakes of talc. Crystals of actinolite and green to brown hornblende are also present locally. Magnetite may be either in small octahedra or in fine dustlike particles. Shreds of chlorite are also common. Less than 1 percent carbonate was observed in thin sections from two of the bodies.

Less altered portions of these two bodies are similar to peridotite in mineral composition and texture. Small irregular patches, less than 1 in. in diameter, containing olivine, enstatite, and serpentine, are commonly enclosed by a lighter talc-tremolite matrix. Enstatite is present as large blocky crystals with irregular grain boundaries, commonly surrounded by fine flakes of talc. Some serpentine encircles small rounded grains of olivine in a meshlike arrangement (fig.4). Light-green amphibole is also generally present.

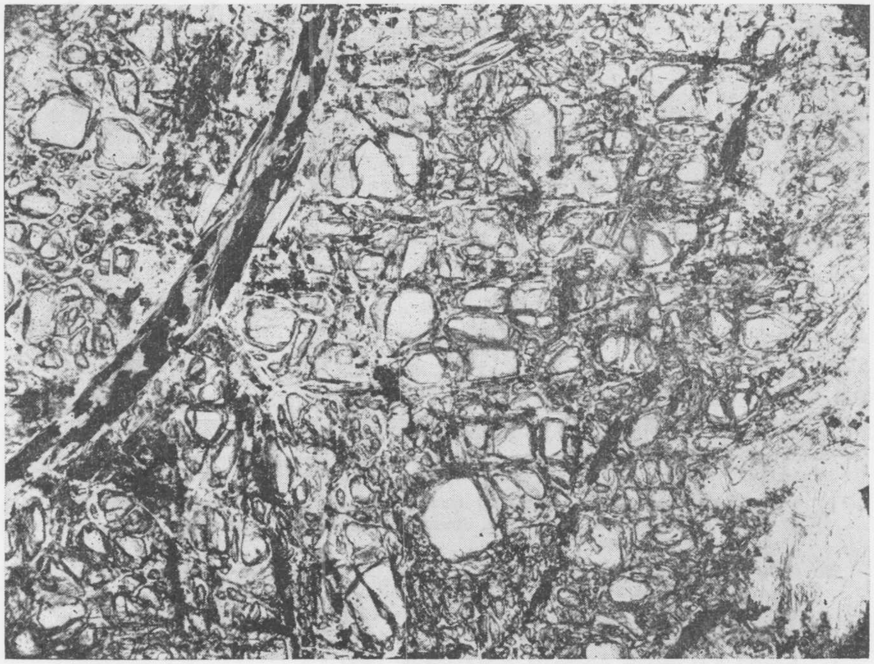

Fig. 4. Partially altered ultrabasic. White, rounded olivine is in a matrix of serpentine with subordinate tremolite, actinolite, and talc; uncrossed nicols; 63X.

Origin

The amphibolite, transition rock, and hornblende gabbro are textural — and, to a lesser extent, mineralogical — variations of a basaltic magma which crystallized under high water pressure. All three rock types were emplaced as a single but continuing injection during a period of structural activity, and the differences between them are consequences of the different environments under which they crystallized. The environments, in turn, were controlled by the structural position of each rock type.

Calculated chemical compositions of the hornblende gabbro and of the amphibolite are given in table 5. Modal-volume mineral percentages were obtained and converted into mineral-weight percentages. These, in turn, were converted to oxide-weight percentages. The chemical compositions of plagioclase and epidote were obtained from optical data. An average composition of hornblende (table 5, col. E), obtained by averaging 26 analyses of hornblende from amphibolite and metagabbro, was used to obtain the calculated chemical compositions. It was found that the hornblende of amphibolite is not extremely variable in chemical composition, nor is the composition sensitive to wide variations in temperature and pressure, a conclusion substantiated by Engel and Engel (1962, p. 1511).

Table 5. — Chemical composition[1] of Hodges hornblende gabbro (A), amphibolite (B), an average hornblende (E), and related rocks (C, D)[2]

	A	B	C	D	E
SiO_2	45.4	46.1	50.61	48.15	42.7
TiO_2	2.9	2.4	1.91	2.64	1.8
Al_2O_3	15.2	15.5	13.58	18.02	12.3
Fe_2O_3	3.5	3.4	3.19	2.52	3.8
FeO	9.9	9.6	9.92	9.50	13.6
MnO	0.1	0.1	0.16	0.12	0.2
MgO	8.9	7.5	5.46	5.25	9.9
CaO	8.8	10.7	9.45	10.17	11.5
Na_2O	2.6	2.7	2.60	3.46	1.4
K_2O	1.6	0.7	0.72	0.14	1.1
H_2O	1.1	1.3	2.13	0.22	1.6
P_2O_5			0.39	0.05	trace
	100.0	100.0	100.12	100.24	100.0

[1] In weight per cent

[2] A. Hodges hornblende gabbro calculated from: hornblende, 54.7; plagioclase (An 34), 26.5; biotite, 13.5; quartz, 1.7; sphene, 0.9; ilmenite, 1.7; magnetite, 1.0. Biotite composition from Wahlstrom (1955, p. 88).

B. Hodges amphibolite calculated from: hornblende, 59.5; plagioclase (An 30), 26.3; biotite, 0.4; ilmenite, 1.3; quartz, 3.8; sphene, 0.4; epidote, 7.3; chlorite, 0.9. Biotite composition taken from Wahlstrom (1955, p. 88). Epidote composition = $Ca_2 (Al_{2.25}Fe_{.75}) (OH)Si_3O_{12}$; chlorite composition = $Mg_5 (AlSi_3O_{10}) (OH)_8$.

C. Average of 11 tholeitic basalts (H. S. Washington, 1922)

D. Gabbro (Wagner and Deer, 1939)

E. Average hornblende composition from 26 analyses

The Hodges amphibolite and hornblende gabbro are similar in chemical compositions to basaltic magma. The similarity in their mineral compositions (table 4), coupled with their transitional nature, suggest strongly that there are no significant differences in their bulk chemistry, and table 5 shows that their calculated chemical compositions are much alike. Both rock types contain practically identical proportions of SiO_2, Al_2O_3, FeO, Fe_2O_3, and Na_2O, and the differences in the relative percentages of MgO, CaO, and K_2O are small. The x-ray spectrochemical data of table 6 show that the amount of iron in the various rock types of the complex is remarkably consistent, as was indicated by the calculations.

Structural and petrographic features of the hornblende gabbro indicate that it was emplaced as basaltic liquid into the crest of a flexure after the peak of deformation. Along Nickel Mine Brook the rock locally contains inclusions of the Waramaug Formation. Oscillatorily zoned plagioclase and reaction pairs also indicate that the hornblende gabbro was truly magmatic. Its massive character indicates that it has not been involved in the general deformation of the area as were the sediments. In direct contrast, the amphibolite of the complex is foliated; the foliation is parallel to that of the enclosing Hartland Formation, suggesting that the two foliations were formed contemporaneously. Field observations and petrographic study of the textures of the rocks within the Hodges Mafic Complex indicate that the hornblende gabbro and the amphibolite are completely transitional into one another (fig. 5).

Table 6. — X-ray spectrochemical counting rates of $FeK\beta$ for rocks of the Hodges Mafic Complex

Specimen no.	Rock type	Counting rate (counts/sec)
N-47	hornblende gabbro	5050.7 ± 9.4
N-50		5022.9 ± 9.4
N-120		4915.0 ± 9.2
N-46	transition rocks	4782.5 ± 9.0
N-53		4989.6 ± 9.3
N-24	amphibolite	4935.3 ± 9.3
N-41		4915.0 ± 9.2
N-54		5163.2 ± 9.6
N-62		4958.2 ± 9.3
N-22	epidote amphibolite	4747.1 ± 8.9

These facts present a paradox: Two chemically similar rock types, surrounded by metasedimentary formations of the amphibolite facies, grade into one another. One has been deformed along with the enclosing sedimentary rocks; the other has not.

The paradox disappears if the intrusion of the complex is considered to postdate the regional metamorphism. This hypothesis requires the direct precipitation of the amphibolite from a melt of basaltic composition — a possibility which recent laboratory investigations by Yoder and Tilley (1962) substantiate. They conclude (p. 465) that a diabase or gabbro is indicative of a parent basaltic magma which was either initially dry or lost its water before crystallization, because otherwise the rock type resulting would be hornblendite or amphibolite.

The complex is considered to have crystallized at a depth sufficient to maintain water at elevated pressures during the crystallization of the magma. Contact metamorphic effects on the contiguous Hartland schist indicate that it, too, was at reasonably high temperatures and probably aided the retention of water in the magma by acting as a seal. The coarse texture of the amphibolite in the vicinity of the schist contacts substantiates this hypothesis. Hornblende crystals over 1 in. long are not uncommon near exposed contacts. Furthermore, plagioclase within the Hartland Formation adjacent to the amphibolites possesses a faint surface alteration of fine mica and contains up to 5 percent more anorthite than does typical Hartland schist. Also, the biotite of the Hartland Formation is commonly altered to chlorite in contact areas. All observed contact effects indicate that the emplaced magma was rich in water and that water was concentrated at the contacts because of the impermeable nature of the Hartland schist.

The position of the Hodges Mafic Complex is controlled by a flexure of the Hartland-Waramaug fault. The flexure closes to the north, plunges

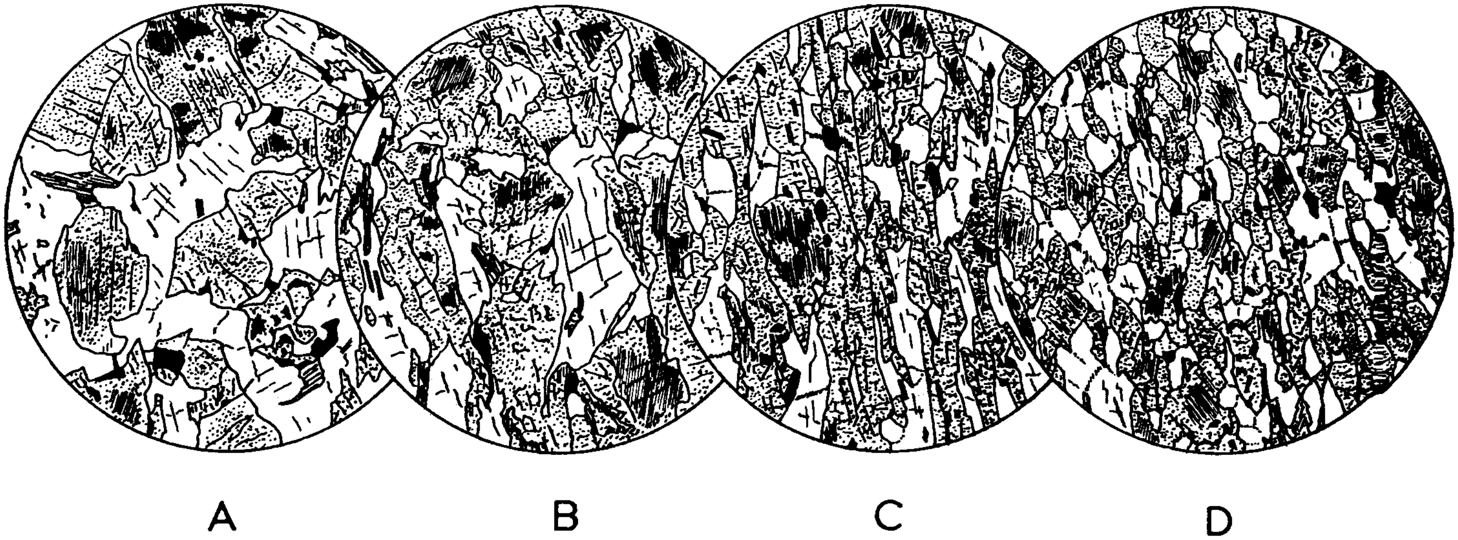

Fig. 5. Tracings of photographs illustrating the textural transition of hornblende gabbro to amphibolite. *A* is a typical hornblende gabbro, *D* is amphibolite, *B* and *C* illustrate transitional textures. Stippled minerals are hornblende; white areas are plagioclase with minor quartz; uncrossed nicols; 39X.

almost vertically, and both limbs conform to the W-dipping regional foliation. The hornblende gabbro occupies the crest of the flexure and the amphibolite is located within the limbs.

Cameron (1951) noted that the Mt. Prospect Complex also lies within a flexure of the regional foliation. Two plutons of Brookfield rocks in the Danbury quadrangle also coincide with flexures (Clarke, 1958). Both authors suggest that dilatation resulting from the development of the flexure may have produced channels for the invading magma. Clarke (1958, p. 36) also considers the possibility that the "Brookfield rocks acted as competent masses in later deformation, and they became cores around which the surrounding rocks were flexed." The latter process does not appear to have played a significant part in the history of the Hodges Mafic Complex: 1) There is no evidence of marginal deformation of the complex as there should be if the complex were responsible for the fold. 2) The complex has a delicate branching pattern, not a blocky one, indicating that the position and form of the Hodges Mafic Complex were controlled by previous structure and by the structural changes that took place during intrusion. Amphibolites, intrusive in origin and related to structural activity, have been noted in this same unit of the Hartland Formation from the West Torrington quadrangle to Roxbury (Gates, 1951, 1952; Martin, 1962). Gates (1959) related the texture of the amphibolitic rocks to the time of emplacement.

Structural openings, produced by the Hartland-Waramaug fault and its flexuring, controlled the emplacement of the basaltic magma. Folding of the Hartland Formation against the competent Waramaug Formation, coupled with flexuring of the fault, produced structural openings between the weak Hartland folia, allowing the basaltic magma to penetrate that formation. Within the crest of the flexure the basaltic magma crystallized under hydrostatic pressure to produce hornblende gabbro with a typical igneous texture. The amphibolite in the vicinity of the fault plane and within the appendages along the limbs of the flexure is also of magmatic parentage, but it crystallized under differential stress and produced well foliated amphibolites.

Summary

The most abundant rock types of the Hodges Mafic Complex, amphibolite and hornblende gabbro, are chemically equivalent to basalt. The greatest differences between the rock types of the complex are textural ones. The amphibolite is a well foliated, fine-grained rock, whereas the hornblende gabbro is a coarse-grained, massive rock. The hornblende gabbro and amphibolite texturally grade into one another in the north-central portion of the complex.

Structural activity along the Hartland-Waramaug fault enabled it to act as a channel for the invading magma. Small bodies of ultrabasics were emplaced syntectonically along the fault. At a somewhat later time, folding of the fault and continued movement along it opened the Hartland folia and produced an area of dilatation which localized basaltic magma. Like the early ultrabasics, the invading magma was channeled from below along the Hartland-Waramaug fault.

The variations in texture of the rocks within the Hodges Mafic Complex are the result of the different deformational environments which existed during the crystallization of the basaltic magma. At localities of maximum shear amphibolite was produced, whereas at other localities minimum shearing stress allowed the magma to crystallize as a massive hornblende gabbro. The formation of amphibole rather than pyroxene was a result of the retention of sufficient water at the time of crystallization.

THE TYLER LAKE GRANITE

This is a young syn- to post-tectonic granite once included in the Thomaston Granite and Granite Gneiss of Agar (Agar, 1934).

On the western side of the West Torrington quadrangle, the Tyler Lake Granite is fine- to medium-grained, white, and rather massive or structureless — a large amoeboid mass with anastomosing, poorly defined dikes near the borders. The bulk of this mass of Tyler Lake Granite is in the Cornwall quadrangle; its petrography is discussed in some detail in the report on that quadrangle. Therefore it is sufficient here to state that its texture is cataclastic and to give its mineral composition in table 7.

Table 7. — Modal composition of the Tyler Lake Granite

	Tyler Lake area[1]	Torrington area[2]
quartz	35	37
plagioclase	25[3]	23
microcline	32	27
muscovite	4	10
biotite	4	3

[1] Based on 10 samples, 1,000 points per sample
[2] Based on 12 samples, 15,000 total points
[3] An 10 to An 20

Another mass of the Tyler Lake Granite is in the southeastern corner of the West Torrington quadrangle (in the general vicinity of Torrington). Its major outcrops are in unit I of the Hartland Formation near the crest of an anticlinal fold — there is very little granite in unit II. The east-facing 200-ft cliff west of Iffland Pond (readily accessible from new Highway 116 between Litchfield and East Litchfield) is the largest single outcrop area. The other major outcrop area is a tongue of granite and pegmatite on Red Mountain (northwest of Torrington) that separates the Waramaug Formation from the Gneiss Complex of the Berkshire Highlands. The isolated outcrops due west of Torrington (pl. 1) are old quarries.

These granite bodies near Torrington are discordant in large part, but do have numerous sills in the Hartland Formation near the main mass. For instance, in the hill immediately west of Haas Road is a series of granite and pegmatite sills 5 to 15 ft thick in the Hartland mica-quartz-plagioclase granulite. The granite seems to have had almost no effect on the Hartland metasediments, even though inclusions of these rocks are found within the granite. Samples of the Hartland Formation in direct contact with the granite do not contain microline or more plagioclase than do Hartland rocks elsewhere.

This granite near Torrington is somewhat different than the amoeboid mass in the western part of the quadrangle, around Tyler Lake. It is a white to pink, medium-grained to pegmatitic, massive to gneissic rock, composed principally of quartz, microline, plagioclase, and muscovite, with accessories of garnet, magnetite, chlorite, apatite, tourmaline, and zircon. The modal composition is given in table 7.

The texture of the main body (in unit I of the Hartland Formation) is typically gneissic due to oriented micas and to lensoid grains or grain aggregates of pink and white feldspar. Isolated bodies are massive, medium-grained, or, as in the tongue on Red Mountain, mixed, patchy granite and pegmatite. Microline occurs interstitially in small grains, and as large anhedral grains poikilitically including quartz and plagioclase. The latter ranges from An 12 to An 15 in most of the rocks, but it is common to find a clear sodic rim at the interface with microline. The plagioclase may be untwinned or have a few twin lamellae, and these may be bent, curved, or broken. The larger grains commonly show wavy extinction or a cataclastic texture. The micas are in fine to coarse flakes, well oriented in most samples.

The granite body near Torrington, with its associated pegmatitic parts and its related dikes and sills, is shown by field and petrographic evidence to be a syn- to post-tectonic intrusive, much like the mass around Tyler Lake. It differs from the latter mainly in being more sill-like, more commonly gneissic, more micaceous, and not as cataclastic.

STRUCTURE

General statement

The structure of the West Torrington quadrangle is dominated by the fault between the Waramaug and Hartland Formations. Large and small intrusives, ranging in composition from ultrabasic to granitic, lie along this fault. Due to the lack of recognizable stratigraphic units, the structural history of the Waramaug is not readily determined. It was apparently a crystalline gneiss prior to the faulting. The stratigraphy of the Hartland Formation reveals an anticlinal nose plunging gently westward. The granite and amphibolite intrusives in the lowest unit of the Hartland make this structure resemble such "domal" structures of western Connecticut as the one in Roxbury (Gates, 1959). At least two sets of folds, related closely in time, are recognized in the Hartland Formation.

Hartland-Waramaug fault

The contact between the Hartland and Waramaug Formations has been recognized as a major tectonic line throughout its extent for many years (Rodgers and others, 1959). There are several lines of evidence from the West Torrington quadrangle to support this view.

1. A series of small to large intrusives extend from the Mt. Prospect Complex in the Litchfield quadrangle (Gates, 1951) to the Tyler Lake Granite near Torrington. These intrusive rocks range from ultrabasic to granitic in composition and from schistose to massive in texture. The ultrabasic rocks, now tremolite-talc bodies, were emplaced along the fault in its early tectonic stage; the Tyler Lake Granite and the Hodges Mafic Complex were emplaced in the final stages when the NE-trending fault plane was locally flexed into a tight fold. Only in the area between Highway 63 and Beach Street, 1½ mi. northwest of Litchfield, are the Hartland and Waramaug Formations seen in contact, and even here a series of five diorite[2] outcrops line up essentially along the contact. Elsewhere the contact is not exposed or is masked by intrusives.

2. The stratigraphic units of the Hartland Formation (units I, II, III) are truncated successively by the fault zone from east to west. Farther southwest, in the New Preston quadrangle, unit IV of the Hartland Formation lies against the fault.

3. The foliations of the Hartland and Waramaug Formations are essentially parallel along the fault in the southwestern part of the quadrangle, but not elsewhere. In general the foliation of the Hartland Formation becomes 20° to 40° steeper near the fault. The foliation of the Waramaug Formation is variable in strike and dip except along the fault zone. The conclusion is that the foliations of the two formations were brought into near conformity either by the faulting or by related pre-fault structural events.

The Hartland foliation and bedding in the central part of the quadrangle are nearly at right angles to the sharp fold in the fault plane.

4. In the adjoining Torrington quadrangle, along the power line just east of Breezy Hill Road, the Waramaug Formation immediately north of the outcrops of the Hartland Formation is brecciated and has a cataclastic texture.

The area located about 1½ mi. northwest of Litchfield is an excellent place to study the rocks immediately along the fault. Unit III of the Hartland Formation is here contiguous to the Waramaug, and is similar in mineralogy to the non-sillimanitic phases of the latter formation, making it necessary to set up petrographic criteria (table 8) based on typical occurence in order to distinguish the two formations.

Because of the mineralogic similarities of the two formations, no attempt was made to separate them on the basis of mineral content. Nevertheless,

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[2] The diorite outcrops indicated by the small circles on the map (pl. 1) cannot properly be assigned to any of the major rock units in the quadrangle. They are massive to gneissic, fine- to medium-grained gray rocks composed primarily of oligoclase-andesine, biotite, and hornblende together with subordinate quartz, sphene, apatite, epidote, and magnetite. The plagioclase is conspicuously zoned, highly twinned, euhedral to anhedral, and granulated on the edges. The biotite and hornblende are typically anhedral to ragged. The texture is semi-cataclastic.

Lithologically, this rock is similar to the diorite gneiss of the Mt. Prospect Complex (Cameron, 1951) which is included with the Brookfield Diorite Gneiss (Rodgers and others, 1959).

it may be noted that, in general, muscovite is the predominant mica in the Hartland Formation while biotite is the major mica in the Waramaug. Also, even in the fault zone, kyanite proved to be typical of the Hartland Formation and sillimanite of the Waramaug.

Table 8. — Petrographic comparison of the Hartland and Waramaug Formations in the southwestern portion of the West Torrington quadrangle

Hartland Formation	Waramaug Formation
Kyanite present	Sillimanite present
No cataclasis	Cataclasis common
Long, slender micas	Large, blocky, ragged micas
Rounded, unzoned garnet	Zoned or stretched garnet
Elongated magnetite interwoven with muscovite	Dispersed, rounded magnetite
Plagioclase generally untwinned	Some plagioclase with simple twinning
Small percentage of chlorite	No chlorite

Of more significance are the textural differences both of the micas and of the granular minerals. In the Hartland Formation the micas tend to be well oriented flakes whereas in the Waramaug they are blocky, ragged, and unoriented. In the Waramaug the garnet crystals are elongated and zoned, and granulated quartz and plagioclase make the texture somewhat cataclastic. In the Hartland the garnet tends to be rounded, and quartz and plagioclase show no cataclasis.

Structure of the Hartland Formation

The three stratigraphic units of the Hartland Formation form an isoclinal anticline plunging gently westward. Unit I, which forms the core of the anticline, becomes the core of a N-dipping isoclinal fold in the Torrington quadrangle as the S-dipping limb steepens and overturns farther east. Unit II extends southward in a narrowing belt into the Litchfield quadrangle, and eastward in a narrow synclinal keel between the outcrops of unit I south of Torrington and the area of similar lithology (here interpreted as unit I) in the eastern part of the Litchfield quadrangle and in the northwestern part of the Thomaston quadrangle.

The major structural elements in the Hartland Formation are foliation surfaces and two sets of lineations. Compositional layering is apparent in all units and probably represents original sedimentary bedding. Although such primary sedimentary structures as graded bedding and crossbedding are possibly preserved, lack of substantial agreement among workers in the area on the recognition of such relict structures makes their use questionable. The foliation is sensibly parallel to bedding (or compositional layering) except on the crests of isoclinal folds within the units, where it is parallel to the axial plane. The primary lineation is represented by small crenulations of the foliation planes, crenulations which are parallel to the axial line of the isoclinal folding. This lineation generally plunges 10° to 40° W. The later or second lineation (double-shafted arrows on the map, pl. 1) plunges 40° to 80° SW. This lineation is not so readily measured because it is a crenulation of an already isoclinally folded and crenulated surface. The second lineation is rather local, being most strongly developed in the southeastern corner of the quadrangle.

Except for the local anticlinal structure in the southeastern corner of the quadrangle, unit I is an isoclinally folded group of metasediments which extends eastward with a persistent NW dip. Unit II, although dipping W or steeply S in the West Torrington quadrangle, passes through a vertical attitude and, farther to the east, dips NW.

The complications in stratigraphy and structure near the juncture of the West Torrington, Torrington, Litchfield, and Thomaston quadrangles have not been fully resolved. At present, however, it appears that unit II is a synclinal structure striking slightly N of E with unit I north and south of it. The secondary lineation is apparently local and probably related to the same forces or movement which produced the sharp fold in the fault plane between the Hartland and Waramaug Formations. It also seems reasonable that this same movement disjointed unit I in the West Torrington quadrangle from its proposed correlative in the Litchfield and Thomaston quadrangles south of unit II.

METAMORPHISM

General statement

The West Torrington quadrangle can be divided into two metamorphic zones, the fault between the Waramaug and Hartland Formations separating a sillimanite zone to the north and west from a kyanite zone to the south. Metamorphism appears to have been synchronous with deformation and to have had its thermal peak following the last significant movement. Except locally, as mentioned below, the intrusive rocks have not had a noticeable effect on their enclosing metasediments. The Waramaug and the Gneiss Complex of the Berkshire Highlands are thought to have undergone more than one period of deformation, but in terms of mineral assemblages there is only questionable evidence of polymetamorphism.

Waramaug Formation

This formation consists of sandy to shaly sediments which, where the composition of the original sediment was appropriate, are now biotite-quartz-feldspar gneisses containing garnet, staurolite, and sillimanite. Magnetite and tourmaline are common accessories. Chlorite and microcline are rarely present. Kyanite is notably absent except in a narrow strip of Waramaug north of West Torrington, adjacent to the granite tongue lying between that formation and the Gneiss Complex.

The coexistence of sillimanite and staurolite has recently been a concern of several petrologists (Chinner, 1960, 1961; Green, 1963). In the Waramaug the sillimanite (fibrolite) occurs with biotite that is bleached or weakly pleochroic in contrast to nonsillimanitic biotite in the same thin section. The sillimanite also forms clusters of needlelike crystals enclosed by quartz and aggregates at the boundaries of quartz, plagioclase, and garnet. Small euhedral grains of staurolite are commonly present with sillimanite in the biotite or lie adjacent to the sillimanitic biotite. The conclusion that the sillimanite grew at the expense of biotite seems inescapable. There is no petrographic evidence of any pre-existing kyanite that may have been resorbed to produce the sillimanite, as Chinner (1961) suggests, nor are there any indications of retrograde metamorphism. Although the staurolite may be a remnant of an earlier metamorphism, its close association with sillimanite and bleached biotite is considered significant. There is no definitive explanation for this assemblage but the association is too common a one to require special or unique conditions of metamorphism.

A second example of an "unstable" or "excess phase" assemblage is the coexistence of kyanite and sillimanite (fibrolite) in biotite-garnet-plagioclase-quartz gneiss in the Waramaug Formation and in the Gneiss Complex of the Berkshire Highlands. This assemblage is restricted to the area on both sides of the contact north of Torrington. The two minerals are together in a felted mass in quartz and feldspar. There is no petrographic evidence of corrosion, pseudomorphism, alteration, of reactions of any kind; the minerals appear perfectly in harmony. These are the only pelitic rocks in the Gneiss Complex: the remainder of the rocks are granitic, felsic, or mafic gneisses. The proximity of granite along the contact here may have a bearing, as yet unexplained, on this assemblage.

Hartland Formation

High-alumina parent rocks here have produced a muscovite-quartz schist with porphyroblastic development of garnet, staurolite, kyanite, biotite, oligoclase, and chlorite. Magnetite and tourmaline are common accessory minerals. Biotite is in foliation planes and also as porphyroblasts; its cleavage is transverse to the foliation. The metamorphism and deformation were apparently in large part synchronous, with the thermal peak and the retrograde effects following the major movement. Garnet crystals show spiral or curved inclusion trains indicating movement during growth. Staurolite crystallized in part at the expense of pre-existing micas, inheriting in surprising detail the textural features of the mica, and poikilitically including the minerals normally interstitial to the micas. In two samples some of the staurolite was altered peripherally to fine muscovite or sericite.

Kyanite generally is subordinate to staurolite, and nowhere does it occur without staurolite. The presence of kyanite is considered dependent on the original composition of the sediment rather than on metamorphic reactions involving other minerals.

Chlorite, chiefly in porphyroblastic radiating clusters, is ubiquitous. Biotite may be altered to chlorite; in only a few samples was there alteration of garnet to chlorite. The chlorite is considered to be a retrograde product.

The presence of chlorite throughout the Hartland Formation and its virtual absence in the Waramaug Formation may well be related to the water content of the rocks prior to the last metamorphism. As the Waramaug is considered to have been crystalline prior to the last metamorphism it may have been relatively dry. The Hartland, on the other hand, probably had more pore water during metamorphism and the persistence of this water into the retrograde stage could account for the chlorite.

ECONOMIC GEOLOGY

Although bedrock from the West Torrington quadrangle has been used in the past for building stone and other commercial purposes, there are no active quarries now.

There are two abandoned quarries in the Tyler Lake Granite northwest of Torrington and one in the Gneiss Complex of the Berkshire Highlands on the western slope of Red Mountain. Several unsuccessful attempts to develop quarries in the gray, banded to massive granite gneiss on Red Mountain were made many years ago.

An abandoned soapstone quarry, about 250 ft long and between 50 and 100 ft wide, is located approximately ½ mi. north of Soapstone Hill Road. The rock here, now completely quarried out, was an altered ultrabasic in a kyanite-bearing schist of the Hartland Formation (unit II).

Located in the hornblende gabbro west of Nickel Mine Brook is the Hodges nickel prospect (Agar, 1930), now a water-filled pit surrounded by dump piles of sulfide-bearing gabbro. In recent years nickel-mining companies have made a magnetic survey of the area and have done some test drilling in the gabbro, apparently with discouraging results, for there has been no further activity.

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APPENDIX

A complete list of the publications of the State Geological and Natural History Survey of Connecticut is available from its Distribution and Exchange Agent, State Librarian, State Library, Hartford, Connecticut, 06115.

Quadrangle Report Series

The quadrangle reports listed below will be sent postpaid at $1.00 each, the quadrangle map alone for 25 cents postpaid. Residents of Connecticut shall add 3½ percent sales tax. Payment must accompany order. Make checks or money orders payable to Connecticut State Library. Quadrangle reports, and all other publications of the State Geological and Natural History Survey of Connecticut, are available wthout charge to public officials, exchange libraries, scientists, and teachers, who indicate, under their official letterhead, that these publications are required in their professional work. Established book dealers shall receive a 20 percent discount.

Orders should be sent to the Survey's Distribution and Exchange Agent, State Librarian, State Library, Hartford, Connecticut, 06115.

1. The Bedrock Geology of the Litchfield Quadrangle, by Robert M. Gates; 13 p., with quadrangle map in color (Misc. Ser. 3), 1951.
2. The Geology of the New Preston Quadrangle: Part I. The Bedrock Geology, by Robert M. Gates; Part II. The Glacial Geology, by William C. Bradley; 46 p., 14 pls., with charts and quadrangle map in color (Misc. Ser. 5), 1952.
3. The Bedrock Geology of the Woodbury Quadrangle, by Robert M. Gates; 32 p., 8 pls., 1 fig., with quadrangle map in color, 1954.
4. The Bedrock Geology of the Ellington Quadrangle, by Glendon E. Collins; 44 p., 1 fig., with quadrangle map in color, 1954.
5. The Bedrock Geology of the Glastonbury Quadrangle, by Norman Herz; 22 p., 2 pls., 1 fig., with quadrangle map in color, 1955.
6. The Bedrock Geology of the Rockville Quadrangle, by Janet M. Aitken; 55 p., 20 pls., 1 fig., with quadrangle map in color, 1955.
7. The Bedrock Geology of the Danbury Quadrangle, by James W. Clarke; 47 p., with quadrangle map in color, 1958.
8. The Bedrock Geology of the Middletown Quadrangle, by Elroy P. Lehmann; 40 p., 7 figs., with quadrangle map in color, 1959.
9. The Bedrock Geology of the Naugatuck Quadrangle, by Michael H. Carr; 25 p., 5 figs., with quadrangle map in color, 1960.
10. The Surficial Geology of the Wallingford Quadrangle, by Stephen C. Porter; 42 p., 18 figs., with quadrangle map in color, 1960.
11. The Bedrock Geology of the Cornwall Quadrangle, by Robert M. Gates; 35 p., 5 figs., with quadrangle map in color, 1961.
12. The Surficial Geology of the Mount Carmel Quadrangle, by Richard F. Flint; 25 p., 3 figs., with quadrangle map in color, 1962.
13. The Bedrock Geology of the Deep River Quadrangle, by Lawrence Lundgren, Jr.; 40 p., 6 figs., with quadrangle map in color, 1963.
14. The Surficial Geology of the Branford Quadrangle, by Richard F. Flint; 45 p., 4 pls., 7 figs., with quadrangle map in color, 1964.
15. The Bedrock Geology of the Essex Quadrangle, by Lawrence Lundgren, Jr.; 44 p., 9 figs., with quadrangle map in color, 1964.
16. The Bedrock Geology of the Collinsville Quadrangle, by Rolfe S. Stanley; 99 p., 2 pls., 22 figs., with quadrangle map in color, 1964.
17. The Bedrock Geology of the West Torrington Quadrangle, by Robert M. Gates and Nikolas I. Christensen; 38 p., 5 figs., with quadrangle map in color, 1965.
18. The Surficial Geology of the New Haven and Woodmont Quadrangles, by Richard F. Flint; 42 p., 7 figs., with quadrangle map in color.

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

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

QUADRANGLE GEOLOGIC MAPS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Geologic Quadrangle No. 329. Surficial Geology of the Niantic Quadrangle, by Richard Goldsmith, 1964.

Geologic Quadrangle No. 335. Bedrock Geology of the Willimantic Quadrangle, by George L. Snyder, 1964.

MISCELLANEOUS GEOLOGICAL INVESTIGATIONS

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

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

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Bulletin 1161-I. Petrochemistry and Bedrock Geology of the Fitchville Quadrangle, by George L. Snyder, 1964, $1.00.