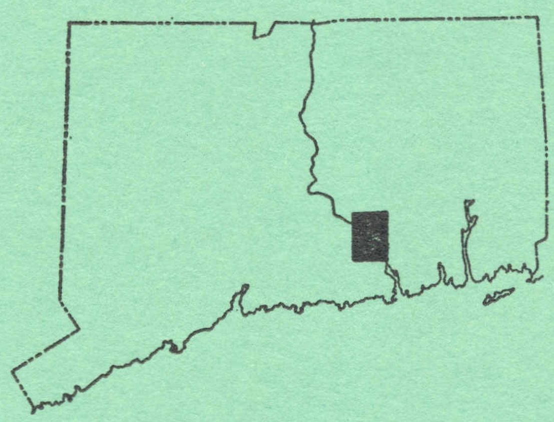
The Bedrock Geology of the Deep River Quadrangle

WITH MAP

Open Map

Open Figure 2

BY LAWRENCE LUNDGREN, JR.



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY OF CONNECTICUT

A DIVISION OF THE DEPARTMENT OF AGRICULTURE AND NATURAL RESOURCES

1963

QUADRANGLE REPORT NO. 13

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The Bedrock Geology of the Deep River Quadrangle

by

Lawrence Lundgren, Jr.

ABSTRACT

Bedrock in the Deep River quadrangle comprises the following units, from oldest to youngest: Plainfield formation (quartzite and schist); Sterling granite gneiss (pink, biotite granite gneiss of uncertain age); a sequence of banded granite gneisses tentatively correlated with the New London granite gneiss, and including an aegerine-augite granite gneiss member, here named the Joshua Rock member; Monson gneiss (quartz-plagioclase gneisses); Middletown formation (anthophyllitic gneisses and amphibolite); metamorphosed ultramafic rocks; Putnam gneiss and Brimfield formation (largely biotite-muscovite schists); Canterbury gneiss (quartzo-feldspathic augen gneiss); Hebron formation (calc-silicate gneiss and quartz-biotite schist). All of these rock units contain pegmatite. Two new chemical analyses of the metamorphosed ultramafic rocks and 85 modal analyses of the major rock units are presented. The age of these rocks ranges from Cambrian? or even Precambrian to Ordovician or possibly Silurian (Hebron formation).

Rocks below the base of the Putnam gneiss and the Brimfield formation are exposed in domes or anticlines; those above in complexly folded synclines, one of which appears to be a major recumbent fold (Chester syncline) overturned to the east. The rocks in this syncline are separated from the underlying Monson gneiss by a major low-angle fault, the Honey Hill fault, which is parallel to the stratigraphic contacts. The fault zone is marked by blastomylonitic gneisses. The assemblage biotite-muscovite-almandine-sillimanite is common in schists throughout the quadrangle; thus all the rocks are assigned to the sillimanite-almandine-muscovite subfacies of the almandine-amphibolite facies of metamorphism. Metamorphism and much of the accompanying structural development, including doming and recumbent folding, took place during the Middle or Late Paleozoic at some time prior to 265 million years B. P.

INTRODUCTION

The bedrock geology of the Deep River quadrangle (fig. 1) has never been mapped on a large scale before, but the broader outlines of the geology have been shown on small-scale geologic maps of Percival (1842), Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907), Foye (1949), and Rodgers and others (1956). The quadrangle is a small part of a terrain characterized by domes and anticlines of quartzo-feldspathic gneiss separated from one another by tight synclines containing intricately folded schists and calc-silicate gneisses. The relationships between geologic features displayed in the quadrangle and the major geologic features of eastern Connecticut have been described in a separate paper (Lundgren, 1962); figure 2 (in pocket) illustrates some of these larger scale features.

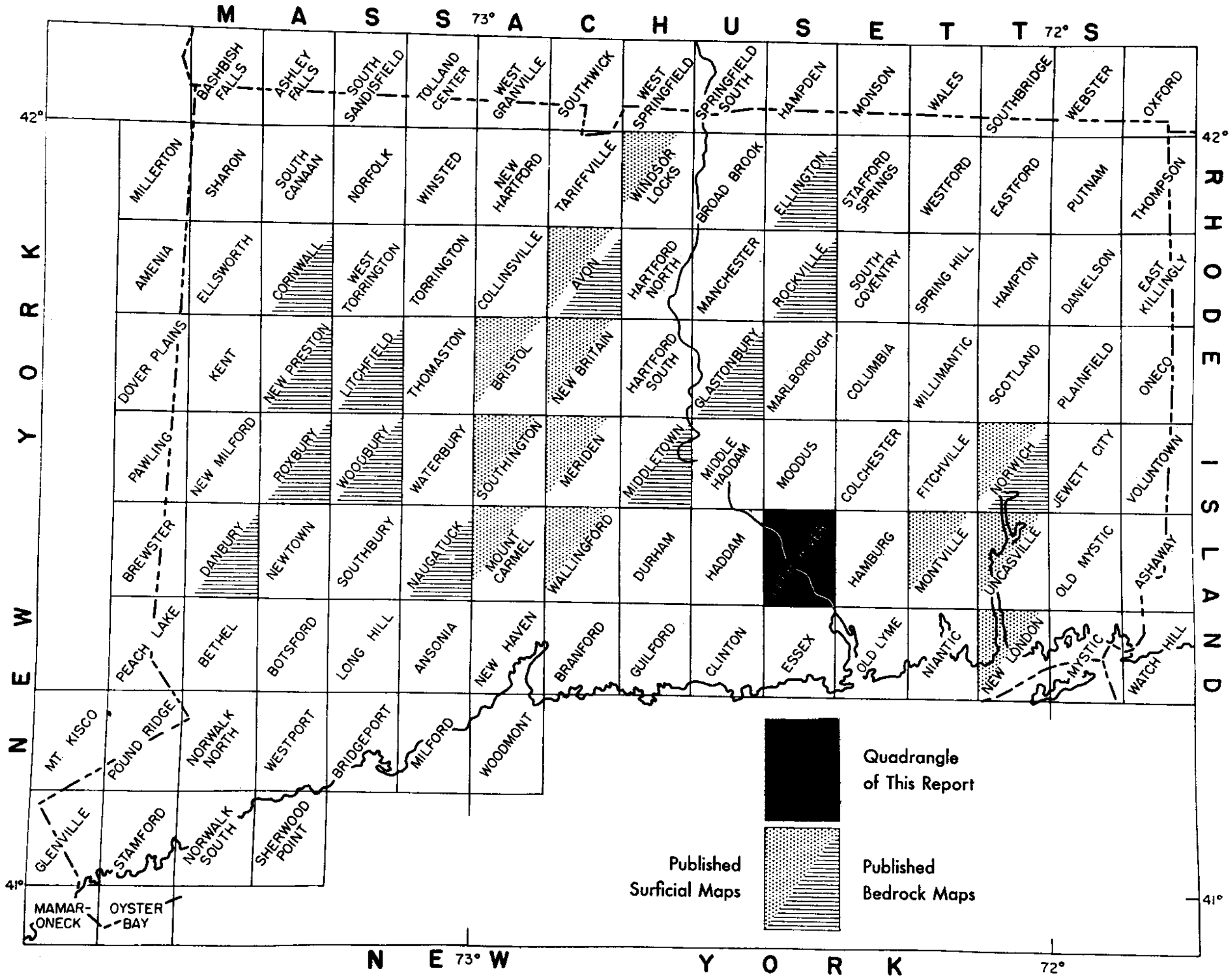

Fig. 1. Index map of Connecticut showing the location of the Deep River quadrangle, and of other published quadrangle maps. See Appendix for list of published maps.

The maps and text of this report are modified from an unpublished dissertation (Lundgren, 1957) in which the stratigraphic nomenclature differed substantially from that used here. I am grateful to Matt Walton and John Rodgers of Yale University for their comments on the dissertation, and to George Snyder, Richard Goldsmith, Lawrence Ashmead, Gordon Eaton, and John Rosenfeld for making available preliminary maps of surrounding quadrangles and for discussions of stratigraphic and structural problems in the region. The Connecticut Geological and Natural History Survey supported the field work, done in 1955 and 1958-1959, and, together with the Geological Society of America and the University of Rochester, paid for thin sections and chemical analyses.

For ease in locating geologic and geographic features, the quadrangle has been divided into ninths. General locations are indicated throughout this report by the particular ninth in which each is found, using the notation shown in figure 3.

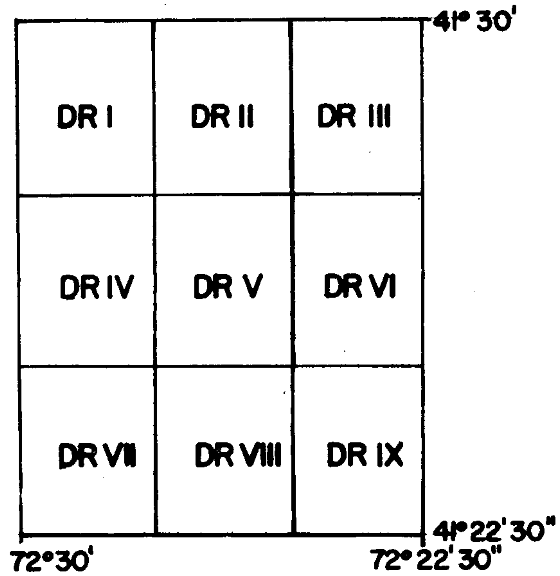

Fig. 3. Index map showing the division of the Deep River quadrangle into ninths.

ROCK UNITS

Bedrock exposures are unusually abundant except in the northeast ninth of the quadrangle (fig. 3, DR III). The mineral assemblages are typical of the sillimanite-almandine-muscovite subfacies of the almandine-amphibolite facies of metamorphism (Turner and Verhoogen, 1960, p. 548-549) except where obviously retrograde assemblages are present, notably along the Honey Hill fault.

The descriptions of the rock units are based on a study of approximately a hundred thin sections. Pleochroic colors of minerals as seen in these standard thin sections are described throughout the report by the most nearly similar color on the Rock Color Chart distributed by the Geological Society of America. Statements of the mineralogic constitution of the various rock units are based on modal analyses made for most of the thin sections. The modal analyses may be regarded as good samples of the hand specimens from which the sections were taken.

Where the mineralogy of a rock is indicated by a series of hyphenated mineral names (for instance, quartz-biotite-feldspar gneiss) the first mineral in the series is the most abundant of those listed. Rocks in which one or two accessory minerals are distinctive are described with the accessory mineral(s) before the hyphenated terms (for example, graphitic biotite-muscovite schist).

The rock units are described in order from youngest to oldest except for those rocks that are clearly intrusive. Rock units that lie along the Honey Hill fault display mylonitic or blastomylonitic facies; these facies are described in a separate section at the end of the descriptions of the rock units.

Hebron formation

The Hebron formation consists of interbedded quartz-biotite schist and calc-silicate gneiss. Gneiss in exposures near Moodus, at the north end of the quadrangle, is part of the type Hebron gneiss first described by Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907).

Typical outcrops, such as those on Route 149, north of East Haddam (fig. 3, DR I) and in Gillette Castle State Park (DR V), display interbedded brownish quartz-biotite schist, greenish-gray calc-silicate gneiss, and quartz-biotite schist containing one or more calc-silicate minerals. Layers of contrasting mineralogy are less than 1 in. thick in some outcrops; in others, layers of calc-silicate gneiss 2 or 3 ft thick are interbedded with thinner layers of quartz-biotite schist.

The quartz-biotite schist layers are fine-grained equigranular rocks. As table 1 shows, most samples contain 35 to 45 percent quartz, 25 to 35 percent biotite (Z = moderate reddish brown), and 25 to 35 percent plagioclase (oligoclase or andesine). Zircon and graphite are common accessory constituents; microcline is a less common accessory. Muscovite and garnet are not normally found in Hebron quartz-biotite schist.

Layers containing one or more calc-silicate minerals generally are resistant, dark-greenish-gray, medium-grained, equigranular rocks typically consisting of 60 to 70 percent quartz plus plagioclase (labradorite), and highly variable amounts of biotite (0 to 20 percent), diopside (0 to 10 percent), and a calcium-magnesium amphibole (1 to 20 percent), with accessory sphene, graphite, microcline, and rare calcite (table 1). Scapolite is a major constituent in some layers. The amphibole is a pale-green actinolite in some layers but a dark-green hornblende in others.

TABLE 1. — Modal analyses of the Hebron formation

	Quartz-biotite schists							Calc-silicate gneisses							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	13-6[1]	13-5	135-5	86-6	55-5	36-8	170-5	11a-6	11b-6	38-5	77-5	131-5	90-5	95-5	83-5
Q[2]	36.5	47.2	38.7	29.5	46.7	43.1	42.1	54.8	46.8	43.0	49.8	18.3	31.1	29.2	26.4
P	34.7	25.6	30.2	30.6	30.2	28.7	28.9	20.4	32.8	41.2[3]	25.7	49.3	38.1	21.2	30.2
K	—	—	—	—	0.1	2.2	0.3	0.6	—	—	—	1.0	—	12.7	14.3
B	28.0	26.8	31.0	38.5	22.8	24.3	26.2	17.8	—	—	0.1	—	14.2	8.9	4.4
D	—	—	—	—	—	—	—	4.1	13.5	15.2	—	21.6	—	5.1	—
A	—	—	—	—	—	—	—	0.6	5.0	0.2	21.8	6.9	14.5	20.0	23.5
N	0.4	0.2	0.1	1.4	0.2	1.7	0.8	0.9	1.7	0.4	2.8	2.1	1.6	2.8	1.1
O	0.4	—	—	0.1	—	—	0.4	0.6	0.2	—	—	—	0.6	—	0.1
XN[4]	15.1	6.1	8.1	21.6	16.1	1.9	13.8	14.2	14.2	42.4	36.8	24.4	21.9	16.8	19.7
XE[4]	7.1	13.6	8.3	30.1	4.1	17.0	14.8	7.7	7.7	1.8	1.7	3.9	38.7	19.3	28.7

[1]Specimen numbers.

[2]Abbreviations of mineral names are as follows: Q = quartz, P = plagioclase, K = potassium feldspar, B = biotite, D = diopside, A = amphibole (hornblende or actinolite), N = nonopaque accessory minerals, O = opaque accessory minerals (chiefly graphite).

[3]Scapolite is present in place of plagioclase in this specimen.

[4]XN and XE numbers are coordinates giving the location of each specimen. XN numbers are in thousands of ft north of the zero line at the southern edge of the quadrangle; XE numbers are in thousands of ft east of the zero line at the western edge of the quadrangle.

Canterbury gneiss

The rock mapped as Canterbury gneiss is a heterogeneous quartzo-feldspathic gneiss continuous with gneiss in the Fitchville quadrangle provisionally mapped as Canterbury gneiss (G. L. Snyder, personal communication, 1960; see also, Snyder, 1961) on the basis of probable continuity with the type Canterbury granite gneiss of Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907). It is well displayed on Story Hill (fig. 3, DR VIII) and other points between Chester and Honey Hill (DR VI) to the east.

The bulk of the rock shown as Canterbury gneiss is a medium-grained, inequigranular, medium-dark-gray augen gneiss consisting of quartz (30 to 35 percent), plagioclase (25 to 35 percent), microline (15 to 20 percent), and biotite (10 to 20 percent), with minor muscovite, garnet, allanite, epidote, hornblende, and magnetite-ilmenite (table 5, modal analyses 1 and 2). This augen-gneiss facies (Story Hill, DR VIII) typically displays large (2 to 3 cm long) augen of pink Carlsbad-twinned microcline and plagioclase, which stand out in sharp contrast against the dark-gray biotitic matrix. Pink pegmatitic and aplitic laminae are common; most are oriented parallel to the foliation, but some cut across it. The augen-gneiss facies grades into less biotitic and less well foliated pinkish granite gneiss (table 5, modal analysis 3) which is more muscovitic than the augen gneiss.

Brimfield formation

The Brimfield formation is primarily a garnetiferous biotite-muscovite schist unit but it includes amphibolite, garnetiferous quartz-biotite schist, and quartzite interbedded with the schist. It occupies a shallow basin-like structure near Bashan Lake (fig. 3, DR III) and also occurs in a narrow belt that extends from Haddam Neck (DR I) south to the south edge of the quadrangle. As shown on figure 2, these separate belts of Brimfield join in the Moodus quadrangle (Foye, 1949; L. P. Ashmead, personal communication, 1959). The schist in the Haddam Neck belt can be traced north (see Rodgers and others, 1956), except for possible short breaks, to Brimfield, Massachusetts, the type locality of the Brimfield schist of Emerson (1898, 1917; see also Callaghan, 1931).

A separate belt of garnetiferous biotite-muscovite schist (bm_{PL}, pl. 1) is exposed along a topographic trough that extends from Cedar Lake (DR VII) southeast to Pine Ledge (DR VII) and Pratt Read Reservoir (DR VIII). This belt of schist was traced northward in reconnaissance (fig. 2) to meet a belt of schist mapped by Mikami and Digman (1957) as Bolton schist, and more recently by Eaton and Rosenfeld as Collins Hill formation (Rodgers and Rosenfeld, 1959). It is designated as Brimfield here, because it apparently is in the same stratigraphic position in relation to the Middletown formation and Monson gneiss as the main belt of Brimfield (see discussion in the section on stratigraphic sequence).

BIOTITE-MUSCOVITE SCHIST

The Brimfield formation in the belt around Bashan Lake consists largely of coarse-grained, dark-gray, and locally rust-stained, garnetiferous biotite-muscovite schist typically consisting of about 40 percent quartz, 50 percent micas (approximately equal amounts of muscovite and biotite, (Z = moderate light brown), 7 percent plagioclase (oligoclase), and 3 percent accessory minerals (table 2, modal analyses 1 to 4. (Common accessory minerals are garnet, graphite, zircon, and pyrite. Sillimanite is present locally. The schists are spotted with augen of plagioclase and muscovite set in a uniform matrix of quartz, plagioclase, biotite, and muscovite. Thin beds of dark-greenish-black calc-silicate gneiss (table 2, modal analysis 19) commonly are interleaved with the schist.

Biotite-muscovite schist also constitutes the bulk of the Brimfield in the belt extending from Haddam Neck south; it is much the same as the schist in the Bashan Lake belt. Here a typical specimen contains about 35 percent quartz, 45 percent micas (biotite generally more abundant than muscovite), 15 percent plagioclase (oligoclase), and 5 percent accessory minerals—garnet, graphite, pyrite, and zircon (table 2, modal analyses 5 to 10). Sillimanite is present in some layers, generally as a mat of needle-like crystals, but locally in large prismatic crystals as much as 5 cm long. Plagioclase commonly occurs as augen, and much of the schist might be described as schistose augen gneiss.

Although biotite-muscovite schist probably constitutes the bulk of the Pine Ledge belt of the Brimfield, exposures are few, and most of them are dip-slope outcrops lying on the Middletown formation. The exposed schists are rust-stained biotite-muscovite schists containing conspicuous graphite and garnet (table 2, modal analysis 11). The garnets commonly are clustered in small lens-shaped aggregates of nearly euhedral crystals.

QUARTZITE

Thin beds of quartzite (table 2, modal analyses 12 to 14) occur in a few places along the contact between the Middletown formation and the Haddam Neck and Pine Ledge belts of the Brimfield formation. The quartzite is interleaved with biotite-muscovite schist and, in most outcrops, is quite inconspicuous.

GARNETIFEROUS QUARTZ-BIOTITE SCHIST

Fine- to medium-grained, gray, garnetiferous quartz-biotite-plagioclase schist and gneiss, interleaved with biotite-muscovite schist and amphibolite, probably form a major part of the poorly exposed belt of Brimfield in the northeastern portion of the quadrangle. They are equigranular assemblages of quartz, oligoclase, and brown biotite; small subhedral garnets are a distinctive, although minor, constituent.

TABLE 2. — Modal analyses of the Brimfield formation

	Biotite-muscovite schist												Quartzite		Amphibolite				
	Bashan Lake belt				Haddam Neck belt						Pine Ledge belt		Haddam Neck belt						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18[3]	19[4]
	187-6[1]	91-5	111-5	105-5	1a-8	2a-8	2b-8	78-5	44-5	59-5	105-9	1-7	24-7	62-8	20a-9	20b-9	23-9	98-5	17-9
Q[2]	37.3	37.6	46.4	61.4	41.5	35.1	39.5	37.4	31.2	41.4	35.1	78.9	80.3	82.2	—	—	0.8	16.3	23.4
P	5.9	7.0	6.2	17.9	16.8	26.1	22.8	9.8	19.3	12.0	31.5	—	7.9	9.4	23.9	65.2	28.2	67.0	52.9
B	23.8	27.2	18.4	11.7	28.5	25.6	22.1	36.5	29.4	32.2	13.0	0.1	—	6.0	—	—	—	10.0	—
M	28.8	25.1	28.3	8.2	9.6	13.2	11.3	11.5	18.5	13.0	14.8	18.9	—	—	—	—	—	0.6	—
C	—	—	—	—	—	—	—	—	—	—	—	—	1.4	—	—	—	—	5.9	4.5
G	2.3	1.4	0.1	0.6	2.6	—	3.2	2.8	1.1	1.1	4.9	—	2.8	—	—	—	27.6	—	11.8
S	0.5	0.1	—	—	—	—	0.2	0.9	0.1	—	—	—	—	—	75.1	34.4	42.0	—	3.9
O	1.5	1.4	0.4	0.1	0.8	0.1	0.4	0.9	0.2	0.3	0.2	2.9	0.5	2.2	1.0	0.4	1.4	—	—
N	0.1	0.2	0.2	0.1	0.1	—	—	0.1	0.1	—	0.5	0.1	1.3	0.2	—	—	1.0	—	1.7
A	—	—	—	—	—	—	—	—	—	—	—	—	6.3	—	—	0.1	—	—	1.7
XN[5]	33.8	29.0	29.1	38.8	40.5	33.2	33.2	39.9	29.2	8.8	10.7	4.0	17.8	9.1	40.5	40.5	36.7	35.0	45.0
XE[5]	33.4	33.8	30.3	22.4	1.0	2.0	2.0	1.0	3.3	7.9	0.9	10.7	2.4	7.2	26.3	26.3	28.7	30.4	22.8

[1]Specimen number.

[2]Abbreviations of mineral names are as follows: Q = quartz, P = plagioclase, B = biotite, M = muscovite, C = chlorite, G = garnet, S = sillimanite, O = opaque accessory minerals (pyrite and graphite), N = nonopaque accessory minerals, A = amphibole (actinolite).

[3]Quartz-feldspar gneiss layer in amphibolite.

[4]Calc-silicate bed in biotite-muscovite schist.

[5]XN and XE numbers are coordinates giving the location of each specimen. XN numbers are in thousands of ft north of the zero line at the southern edge of the quadrangle; XE numbers are in thousands of ft east of the zero line at the western edge of the quadrangle.

AMPHIBOLITE

Amphibolite is well displayed in the Bashan Lake belt of the Brimfield formation, but it is only a minor part of the Brimfield in the Haddam Neck belt[1]. Outcrops just east of Bashan Lake illustrate the varied character of these amphibolites; they are well bedded to massive, coarse-grained, dark-greenish-black, hornblende-plagioclase rocks with variable amounts of diopside and sphene (table 2, modal analyses 15 to 17). Where diopside is present, a well developed laminar structure is generally evident; light-colored laminae rich in diopside and plagioclase alternate with dark-colored laminae rich in hornblende. Diopsidic layers and nodules of diopside-plagioclase aggregate stand out in relief against the more easily weathered hornblende-plagioclase layers. These laminar diopsidic amphibolites grade laterally into sharply banded amphibolites in which black layers of hornblende-plagioclase rock alternate with light-colored layers consisting of quartz, plagioclase, biotite, garnet, and minor hornblende (table 2, modal analysis 18).

Putnam gneiss

The Putnam gneiss (upper part) consists of biotite-muscovite schist and subordinate calc-silicate gneiss, garnetiferous quartz-biotite schist, amphibolite, and quartzite. The Putnam forms a narrow rim around the northern and western sides of the Selden Neck dome. The rocks which form this rim can be traced northeast, except for short gaps in outcrop, to the Fitchville quadrangle, where they merge (G. L. Snyder, personal communication, 1959; see also Snyder, 1961) with rocks known to be continuous with the type Putnam gneiss of Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907).

BIOTITE-MUSCOVITE SCHIST

The predominant rocks in the Putnam are well foliated, medium-grained, dark-gray, quartz-biotite-plagioclase (oligoclase)-muscovite rocks, characteristically spotted with augen of plagioclase. Good exposures may be seen along the road immediately southeast of Hearse Hill Cemetery and along most of the other small roads east and southeast of the town of Chester (fig. 3, DR VIII); they may also be seen in the belt of Putnam north of Roaring Brook, east of Route 82 (DR VI).

Quartz and oligoclase together constitute 65 to 70 percent, and the micas 25 to 30 percent in the modes of most specimens of these schists (table 3, modal analyses 1 to 3). Biotite (Z = olive gray) is more abundant than muscovite; muscovite commonly is only a minor constituent. Garnet is an erratically distributed accessory mineral, which is abundant locally; magnetite is a conspicuous and rather uniformly distributed accessory.

[1]Amphibolite included as part of the Brimfield formation by Lundgren (1962) is here included in the Middletown formation.

Rusty-weathering graphitic biotite-muscovite schist is interleaved with and grades into the gray schists, generally appearing along topographic grooves in these gray schists. Exposures may be seen along the east side of Straits Road south of Chester, on the east side of Route 9 near the southern edge of the quadrangle, and in many other roadcuts in the vicinity of Chester. These schists generally are lustrous gray although deeply rust-stained rocks in which quartz and plagioclase constitute 35 to 65 percent and micas 35 to 65 percent in the modes (table 3, modal analyses 4 to 7). Biotite (Z = dusky red) and muscovite are equally abundant in most specimens; muscovite is the more abundant mica in others.

TABLE 3. — Modal analyses of the Putnam gneiss

	Biotite-muscovite schists							Calc-silicate gneiss		Garnetiferous quartz-biotite schist
	1	2	3	4	5	6	7	8	9	10
	82-5[1]	63-5	30-5	11b-9	15-9	38a-9	23-8	7-9	21-8	25a-8
Q[2]	42.9	47.7	34.2	55.0	24.4	43.5	40.7	38.9	27.6	62.9
P	27.7	16.1	36.4	10.2	12.1	19.8	12.7	44.2	37.8	18.4
B	22.4	21.2	24.5	17.6	36.9	13.2	4.2	11.3	30.3	16.7
M	6.1	14.3	—	16.4	25.0	19.7	19.8	—	—	—
C	—	—	1.1	—	—	—	6.5	—	—	—
G	—	0.1	3.0	—	0.5	—	3.0	—	—	1.0
S	—	—	—	—	—	—	0.2	—	—	—
K	—	—	—	—	—	—	0.8	1.5	—	—
D	—	—	—	—	—	—	—	3.6	—	—
A	4.5	—	—	—	—	—	—	4.5	3.1	—
Se	—	—	—	—	—	—	10.3	—	—	—
Sp	—	—	—	—	—	—	—	1.1	0.8	—
O	0.6	0.1	0.5	0.3	1.1	1.9	1.7	—	—	—
N	0.7	—	0.3	—	—	—	0.1	0.3	0.4	0.3
XN[3]	18.0	12.4	10.3	18.2	18.3	0.8	7.3	6.2	7.6	
XE[3]	26.7	14.9	16.3	27.7	27.8	18.3	13.7	14.3	12.9	

[1]Sample numbers.

[2]Mineral abbreviations: Q = quartz, P = plagioclase, B = biotite, M = muscovite, C = chlorite, G = garnet, S = sillimanite, K = microcline, D = diopside, A = amphibole (hornblende, actinolite), Se = sericite (fine-grained white mica restricted to plagioclase grains), Sp = sphene, O = opaque accessory minerals, chiefely magnetite, N = nonopaque accessory minerals.

[3]XN and XE numbers are coordinates giving the location of each specimen. XN numbers are in thousands of ft north of the zero line at the southern edge of the quadrangle; XE numbers are in thousands of ft east of the zero line at the western edge of the quadrangle.

Sillimanite, pyrite, garnet, and tourmaline are common accessory constituents.

CALC-SILICATE GNEISS

Diopsidic and hornblendic calc-silicate gneisses form an important part of the Putnam gneiss from Chester south; thin layers of calc-silicate gneiss also occur within Putnam schists east of the Connecticut River. The calc-silicate gneisses generally are interbedded with gray quartz-biotite-plagioclase gneiss and, less commonly, with biotite-muscovite schist. They are similar to the calc-silicate gneiss in the Hebron formation and are most common where the Putnam gneiss is adjacent to the Hebron. All of the calc-silicate gneiss interbedded with muscovitic schist has been included in the Putnam rather than in the Hebron formation.

Exposures of calc-silicate gneiss may be seen in the steep-sided knobs east of Straits Road south of Chester, or near the top of the 230-foot unnamed hill north of Jennings Pond (fig. 3, DR VIII). The gneisses are well bedded and moderately well foliated, equigranular, medium-grained, dark greenish-gray rocks typically consisting of 30 to 40 percent quartz, 35 to 45 percent plagioclase, 10 to 15 percent biotite (Z = moderate reddish brown), and 0 to 10 percent diopside and hornblende (Z = light olive brown), with minor sphene, microcline, pyrite, graphite, and garnet (table 3, modal analyses 8 and 9). Diopsidic layers grade across the bedding into hornblendic layers; diopsidic and hornblendic layers grade into quartz-biotite-plagioclase layers containing neither hornblende nor diopside.

Middletown formation

The Middletown formation comprises garnetiferous and anthophyllitic quartz-plagioclase gneisses interbedded with amphibolite, biotite schist, and a variety of biotitic quartz-feldspar gneisses. Two belts of rock are shown as Middletown formation. One, the Cedar Lake belt, extends from the east side of Cedar Lake (fig. 3, DR VII) southeast; the other, the Ruth Hill belt, extends south from the Connecticut River (DR I) and is well displayed in the vicinity of Ruth Hill (DR IV). These belts do not meet within the Deep River or adjacent quadrangles (fig. 2).

The Cedar Lake belt is continuous with the Middletown gneiss of Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907) as shown by the mapping of Mikami and Digman (1957) and my own mapping in the Haddam quadrangle. The original Middletown gneiss apparently corresponded with the aptly named Anthophyllitic formation of J. G. Percival (1842, p. 199-201). The Middletown, as mapped in the Deep River quadrangle, is essentially a formation distinguished by the intimate association of anthophyllitic gneisses and amphibolites. Because of the difficulty of separating the Middletown formation from the adjacent Monson gneiss, the Middletown had previously been grouped with the Monson, and considered an anthophyllitic facies of that gneiss (Lundgren, 1962). It is also difficult to separate the Middletown from the lower part of the Brimfield formation, and, in the discussion noted above (Lundgren, 1962) much of the Ruth Hill belt of the Middletown was considered as the lower half of the Brimfield formation. The relationship between the Middletown and contiguous units is discussed further in the descriptions of stratigraphic sections of the Brimfield formation.

ANTHOPHYLLITIC GNEISSES

The gneisses that distinguish the Middletown formation from the adjacent Monson gneiss are coarse-grained quartz-plagioclase gneisses containing abundant dark-brown prismatic anthophyllite (table 4, modal analyses, 1 to 4), or, less commonly, light-brown cummingtonite. These gneisses are characteristically rust stained, in contrast to the gray surface of outcrops of Monson quartz-plagioclase gneiss. The anthophyllitic rocks are generally spotted with large garnets and irregularly distributed lens-like masses of garnet, and they commonly contain masses of intergrown quartz and prismatic black tourmaline as well.

Generally the anthophyllitic gneisses are interleaved with numerous amphibolite layers, some of them containing cummingtonite intergrown with hornblende. Locally, the gneisses contain pods or lenses of coarse-grained, massive, garnet-anthophyllite rock consisting largely of anthophyllite prisms, dodecahedral garnets, and biotite, with minor amounts of magnetite, quartz, and plagioclase. These lenses are no more than five feet long in the outcrops examined, and they appear to grade into the anthophyllitic gneisses.

GARNETIFEROUS QUARTZ-BIOTITE-FELDSPAR GNEISSES

Several varieties of garnetiferous quartz-biotite feldspar gneisses are interbedded with the amphibolite and the anthophyllitic gneiss. Two major types may be distinguished, although they cannot be separately mapped. One consists of well bedded quartz-plagioclase-biotite-(muscovite) gneisses spotted with small garnets (table 4, modal analyses 5 to 7); the other consists of rather massive and weakly foliated quartz-plagioclase-microcline-biotite-muscovite gneisses, which also are spotted with small garnets (table 4, modal analyses 9 and 10).

NODULAR GNEISS

A distinctive quartz-plagioclase-biotite-muscovite gneiss (table 4, modal analysis 5) is found in the Cedar Lake belt of the Middletown formation, generally in contact with anthophyllitic gneiss. It is designated as nodular gneiss, as it contains resistant nodular and sheet-like masses of quartz intergrown with sillimanite and muscovite. Excellent outcrops are displayed along the 300-ft contour immediately east of the hairpin turn in the unpaved road through Cockaponset State Forest west of Pine Ledge (fig. 3, DR VII).

TABLE 4. — Modal analyses of Middletown formation and Monson gneiss

	Middletown formation[1]											Monson gneiss[2]							
	Anthophyllitic gneisses				Quartz-feldspar gneisses						Amphibolite								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	169-6[3]	6-7	102-0	38-6	23-5	34-5	186-6	1-0	67-8	37-8	54-5	106-5	52-5	108a-5	108b-5	9-5	17-5	20-5	4-5
Q[4]	46.2	8.2	12.3	30.8	48.6	42.1	56.7	55.9	41.1	39.4	—	38.6	30.8	21.0	44.4	25.6	25.0	41.7	43.7
P	47.9	55 8	60.0	56.0	42.1	44.8	34.7	20.3	45.7	41.1	29.1[5]	47.5	52.4	42.6	51.2	48.6	47.5	45.4	48.2
K	—	—	—	—	1.3	—	—	—	4.8	9.3	—	8.2	3.9	—	—	—	2.2	0.6	—
B	0.1	—	—	4.4	3.9	13.1	6.0	23.1	6.8	8.8	—	5.2	11.2	—	0.4	16.0	10.0	11.7	3.8
M	—	—	—	—	4.3	—	1.7	—	1.5	—	—	0.5	0.9	—	—	—	—	—	—
G	1.9	—	—	—	—	—	0.2	0.5	0.5	1.4	—	—	—	—	—	—	—	—	2.6
An	3.1	34.6	26.1	7.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
H	—	—	—	—	—	—	—	—	—	—	52.1	—	—	36.0	3.5	8.7	12.7	—	—
D	—	—	—	—	—	—	—	—	—	—	17.8	—	—	—	—	—	—	—	—
O	0.1	1.1	1.2	1.0	—	0.4	0.4	—	—	0.1	0.1	—	—	—	—	0.2	—	—	1.5
N	0.1	0.2	0.4	—	0.1	—	0.3	0.1	0.1	0.1	0.7	0.1	0.6	0.4	0.5	0.9	1.3	0.4	—
XN[6]	2.6	4.7	9.6	25.5	3.8	10.4	10.1	30.2	25.0	0.5	17.4	42.4	17.4	6.5	6.5	6.0	0.6	2.1	2.0
XE[6]	10.7	8.8	1.4	2.1	9.9	0.8	1.2	1.5	6.0	17.0	2.1	0.4	0.2	9.3	9.3	9.0	20.3	10.2	2.0

[1]Modal analyses 1 to 3 and 5 to 7 are of rocks from the Cedar Lake belt. Modal analyses 4 and 8 to 11 are of rocks from the Ruth Hill belt.

[2]Modal analyses 12 to 16 are from the Turkey Hill belt; 17 is from the Hadlyme belt, and 18 and 19 are from the Cedar Lake belt.

[3]Specimen numbers.

[4]Mineral abbreviations: Q = quartz, P = plagioclase, K = potassium feldspar, B = biotite, M = muscovite, G = garnet, An = anthophyllite, H = hornblende, D =diopside, O = opaque accessory minerals, chiefly magnetite, N = non-opaque accessory minerals.

[5]Scapolite is present in place of plagioclase.

[6]XN and XE numbers are coordinates giving the location of each specimen. XN numbers are in thousands of ft north of the zero line at the southern edge of the quadrangle; XE numbers are in thousands of ft east of the zero line at the western edge of the quadrangle.

AMPHIBOLITE

Amphibolites of various types are abundant in the Middletown formation and are particularly well displayed in the Ruth Hill belt. All are dark-greenish-black hornblende-plagioclase rocks (table 4, modal analysis 11), interbedded with all of the various types of quartz-feldspar gneisses. They vary from massive, nearly structureless rocks to extraordinarily well layered gneisses consisting of alternating thin layers of black amphibolite and light-gray quartz-feldspar gneiss. As the massive amphibolites grade into the layered ones, the two types cannot be distinguished on the map.

The massive type is well displayed on the east slope of hill 581 (fig. 3, DR IV) near the west edge of the quadrangle; this rather massive amphibolite can be traced southward into strikingly laminar diopsidic amphibolite in which thin laminae of hornblende-plagioclase or hornblende-scapolite rock alternate with thin laminae of diopside-plagioclase rock. Numerous outcrops of this type are displayed in the amphibolite belt immediately south of Ruth Hill (DR IV).

Monson gneiss

The Monson gneiss comprises medium-grained, light to dark gray, biotitic and hornblendic quartz-plagioclase gneisses, amphibolite, and subordinate pink granitic gneiss. The biotitic gneisses generally are well foliated; the hornblendic gneisses are more nearly massive. Subtle mineralogic layering, commonly accentuated by thin, dark-gray amphibolite beds, is evident in most outcrops. These beds are parallel to the foliation and to one another; they commonly display well developed boudinage.

Modal analyses (table 4) demonstrate that the Monson gneiss is largely a one-feldspar (plagioclase) gneiss in which microcline is a minor constituent or is absent. Much of the Monson might be classed as a IP granite in Chayes' (1957) classification of granites, but, as it is neither massive nor weakly foliated for the most part, it is best described simply as plagioclase or quartz-plagioclase gneiss. Quartz (25 to 40 percent) and oligoclase or andesine (40 to 55 percent) are the major minerals. Biotite ($Z =$ olive gray to brownish black) is present in all specimens; hornblende ($Z =$ dusky green to grayish olive green) is common. Magnetite-ilmenite is a common accessory; garnet is present locally, as is anthophyllite.

The Monson occupies several more or less distinct belts; the rocks in each are described separately, and the modal analyses are grouped accordingly. Published maps (Percival, 1842; Collins, 1954; Herz, 1955; Emerson, 1917; Rodgers and others, 1956) and reconnaissance for this report demonstrate that the gneiss in what is here described as the Turkey Hill belt can be traced north almost without interruption to the type locality at Monson, Massachusetts (Emerson, 1917). Modal analyses of the type Monson gneiss demonstrate that it is similar to the Monson gneiss in the Deep River quadrangle. The only possible gaps between the Deep River quadrangle and Monson, Massachusetts are in the Marlborough quadrangle and possibly in the Rockville quadrangle (Aitken, 1955). The reasons for describing the gneiss in the other belts as Monson equivalents have been presented elsewhere (Lundgren, 1962) and are summarized below.

TURKEY HILL BELT

The Turkey Hill belt of Monson borders the west margin of the quadrangle from Haddam Neck (fig. 3, DR I) south to Turkey Hill (DR IV), extending southeast from there to Pratt Read Reservoir. Both hornblendic and biotitic gneisses are well represented (table 4, modes 12 to 15); typically they are interleaved with thin amphibolite and diopsidic amphibolite beds. There are anthophyllitic and cummingtonitic gneisses in the belt, but it is not clear that they are layers within the Monson. They may represent downfolds of Middletown gneiss, an interpretation suggested by the presence of small-scale isoclinal folds. A band of biotitic and garnetiferous quartz-plagioclase gneiss (pl. 1, *mhg*) along the west side of the Turkey Hill belt is shown separately on the quadrangle map (pl. 1), as it is more heterogeneous than the bulk of the rock mapped as Monson. It is similar to some of the Middletown formation except that anthophyllitic rocks are not evident.

CEDAR LAKE BELT

The triangular area of plagioclase gneiss that occupies the southwestern corner of the quadrangle (pl. 1) is indicated as the Cedar Lake belt of Monson gneiss. It is separated from the Turkey Hill belt by the Middletown and Brimfield formations. The bulk of the gneiss in this belt is quartz-plagioclase-biotite gneiss (table 4, modal analyses 18 and 19); amphibolite layers are numerous, and anthophyllitic layers are fairly common. All these rocks were grouped together as an amphibolitic and anthophyllitic facies of the plagioclase gneiss sequence in the summary paper (Lundgren, 1962); previously they were mapped as Haddam gneiss (Mikami and Digman, 1957). The structural relationships between this belt and the adjoining belt of Monson gneiss are not clearly understood, but it seems that these rocks represent the upper part of the Monson gneiss.

HADLYME BELT

The Hadlyme belt of Monson gneiss rims the Selden Neck dome. Roadcuts on Mitchell Hill Road, north of Sleu Road (fig. 3, DR IX), made in the summer of 1961, illustrate the most common type of rock in this belt, a quartz-plagioclase-biotite-hornblende gneiss (table 4, mode 17) identical with much of the gneiss in the Turkey Hill belt. Amphibolite is common near the contact with the Putnam formation, but neither anthophyllitic nor cummingtonitic gneisses have yet been recognized. The Hadlyme belt is separated from the Turkey Hill belt by the narrow septum of Brimfield and Hebron formations and Putnam gneiss, but the rocks in the two belts are regarded as equivalent because of their physical similarity and because they both are overlain by Brimfield and Putnam schist units also believed to be equivalent (Lundgren, 1962).

New London (?) granite gneiss

In the Selden Neck dome, the Plainfield formation (quartzite and schist) is separated from the Monson gneiss (quartz-plagioclase gneiss) by a sequence of granitic gneisses. The bulk of this sequence consists of medium-grained, gray or pink, magnetite-bearing gneiss, interleaved with numerous thin layers of black amphibolite and pink alaskite, parallel to each other, except where the whole sequence is tightly folded. However, it also includes a layer of distinctive aegerine-augite granite gneiss. This layer is here named the Joshua Rock gneiss, as it is exposed in a quarry at Joshua Rock (fig. 3, DR IX; Dale and Gregory, 1911, p. 99). It is regarded as a member of the sequence.

In the Deep River quadrangle a typical section of these rocks may be seen on both sides of River Road (DR IX), just northwest of Sleu Road and southeast of Observatory Hill (pl. 1, hill 273). The entire sequence is particularly well exposed in the town of Hamburg, just beyond the boundary of the Deep River quadrangle, immediately east of DR IX. An excellent section may be seen along a north-south line extending from Candlewood Ledges (SW ninth of the Hamburg quadrangle) south to Hamburg Cove. In this section the lower contact of the sequence is marked by highly garnetiferous and sillimanitic schists of the Plainfield formation; the upper contact by gray plagioclase-quartz-biotite-hornblende gneisses of the Monson gneiss. This section will be described in detail in a forthcoming report on the Hamburg quadrangle.

These rocks are almost certainly equivalent to rocks that Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907) called the New London granite gneiss and that Rodgers (Rodgers and others, 1956, 1959) included in the Stonington gneiss. They have been traced east into the Uncasville and New London quadrangles where Goldsmith (1961, p. 55) has also mapped aegerine-augite granitic gneiss within a sequence of granodioritic gneisses. Although Dale and Gregory (1911, p. 106-107) described these rocks as Mamacoke gneiss bordering New London granite gneiss, it appears from Goldsmith's map that they are continuous with the type New London.

The magnetite-bearing granitic gneisses typically have modal compositions within the following limits: quartz (30 to 40 percent), feldspar (55 to 65 percent) with plagioclase generally more than twice as abundant as microcline, biotite (1 to 5 percent), conspicuous magnetitite-ilmenite (1 to 2 percent), and accessory dark-green hornblende, garnet, zircon, sphene, and apatite. As the modes (table 5, modes 12 to 15) indicate, these gneisses are modally similar to the biotitic and hornblendic granite gneisses in the core of the Selden Neck dome. However, they are typically finer grained, have less biotite, and are texturally more uniform within any single

TABLE 5. – Modal analyses of the granitic rocks

	Canterbury gneiss			Sterling granite gneiss					New London (?) granite gneiss							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	133-5[1]	63-8	88-6	150-6	67-5	200-6	18-5	37-9	42-5	76-5	88-5	19-5	85-5	43a-9	116a-5	41-5
Q[2]	32.6	33.0	34.1	42.3	23.8	22.2	38.7	33.3	39.5	40.2	37.7	39.4	29.2	33.8	32.8	32.4
P	27.7	33.4	27.6	26.9	33.8	43.4	16.9	35.3	23.3	19.3	22.5	55.0	47.5	36.0	49.4	24.7
K	19.1	21.6	25.1	26.9	37.0	26.4	42.5	36.5	35.3	39.2	38.1	2.9	18.7	25.7	13.3	34.0
Bi	19.1	12.0	5.0	3.9	3.0	7.6	1.8	—	—	—	—	2.8	4.0	2.5	0.9	—
H	—	—	—	—	2.0	—	0.1	3.6	—	—	—	—	—	0.4	—	—
Ae	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.3
M	1.5	—	6.9	—	—	—	—	—	—	—	—	—	—	—	0.9	—
O	—	—	—	0.1	0.4	0.1	—	1.1	0.7	0.9	1.0	—	0.8	1.1	2.1	2.1
N	—	—	1.3	—	—	0.2	—	0.2	1.0	0.3	0.4	0.1	0.2	0.5	0.6	0.3
XN[3]	6.5	11.9	18.1	1.0	5.4	4.1	4.1	6.5	1.5	10.0	9.7	1.1	8.2	2.4	11.7	2.3
XE[6]	14.6	13.2	26.5	27.8	7.9	25.4	22.7	31.6	33.7	26.1	22.1	25.0	22.7	25.2	32.0	33.3

[1]Specimen numbers.

[2]Abbreviations of mineral names are as follows: Q = quartz, P = plagioclase, K = potassium feldspar (microcline), Bi = biotite, H = hornblende, Ae = aegerine augite, M = muscovite, O = opaque minerals, chiefly magnetite-ilmenite, N = non-opaque accessory minerals.

[3]XN and XE numbers are coordinates giving the location of each specimen. XN numbers are in thousands of ft north of the zero line at the southern edge of the quadrangle; XE numbers are in thousands of ft east of the zero line at the western edge of the quadrangle.

layer than the biotitic granite gneisses. In addition, outcrops commonly show striking banding resulting from the parallel orientation of the amphibolite and alaskite layers noted above.

The alaskitic layers are homogeneous pink gneisses (table 5, modes 9 to 11) consisting of quartz (38 to 40 percent), microcline (35 to 39 percent), plagioclase (20 to 24 percent), and accessory magnetite-ilmenite (1 percent), zircon, apatite, sphene, monazite, and xenotime. They are pink, equigranular rocks in which the only structure is the parallel orientation of laminar aggregates of flat quartz grains and magnetite grains. They are relatively finer grained and more uniform than alaskitic granites associated with biotitic granite gneiss in the core of the Selden Neck dome.

The Joshua Rock member is a medium-gray, weakly foliated gneiss consisting of quartz, a coarse microperthite of nearly pure albite and microcline, dark-green aegerine-augite, magnetite-ilmenite rimmed with sphene, and accessory zircon commonly conspicuous as clusters of tiny euhedral crystals (table 5, modal analysis 16). Deep red hematite spots on outcrop surfaces are characteristic of the aegerine-augite granite, but not restricted to it. These spots generally help to distinguish aegerine-augite granite from adjacent hornblende-bearing alaskite, but in places the two types of rocks are difficult to distinguish in hand specimen.

At Joshua Rock the aegerine-augite gneiss is structurally underlain by alaskitic gneisses and amphibolite, which apparently interfinger with the Joshua Rock member here and along strike to the east. The contact with the structurally overlying rocks is not exposed here, but exposures to the east make it clear that the gneiss is in contact with non-resistant garnetiferous and sillimanitic schist (Plainfield formation).

Plainfield formation

Rocks mapped as Plainfield formation are exposed only in isolated outcrops in contact with the granite gneisses of the Selden Neck dome. These rocks are described provisionally as Plainfield, because they can be traced east to meet a quartzite unit in the Montville quadrangle (Richard Goldsmith, personal communication, 1959) that apparently is continuous with the type Plainfield quartz schist of Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907). Although a new formation name may prove to be desirable for the rocks mapped here as Plainfield, the unit is not well enough exposed in the Deep River quadrangle to justify assigning a new name.

The belt designated by letter symbol *p* (pl. 1) is a belt in which outcrops are virtually non-existent but which most probably is underlain by interbedded sillimanitic schist, coarse-grained epidotic calc-silicate gneiss and marble, and quartzite, all of which are displayed on strike to the east in the Hamburg quadrangle. The narrow belts shown as *pq* are those in which well bedded medium-gray biotitic quartzite (quartz 80 to 90 percent) is well exposed.

The quartzite generally is interbedded with amphibolite, biotitic quartz-feldspar gneiss, and sillimantic biotite schist.

Sterling granite gneiss

Biotitic and hornblendic granite gneisses[2] and associated alaskitic gneiss in the core of the Selden Neck dome are collectively considered to be part of the Sterling granite gneiss. They were mapped as Sterling orthogneiss by Foye (1949), because they are similar to pink granite gneisses first mapped as Sterling granite gneiss by Loughlin (1910, 1912). Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907) first published the name Sterling, taking it from unpublished work by Loughlin. The Sterling granite gneiss typically is in the cores of domes and anticlines, and, as the name is used here, it includes all the pink granite gneisses interleaved with the Plainfield formation. These granite gneisses are well displayed in old quarries on Selden Neck (Dale and Gregory, 1911, p. 99-100) and also in small quarries in the hills east of Selden Neck, immediately north of Brockway Landing (fig. 3, DR IX). A roadcut made in Mitchell Hill Road at the south end of Mitchell Hill (DR IX) in the summer of 1961 provides an excellent display of rather typical biotite-granite gneiss.

The biotitic and hornblendic granite gneisses in the core of the dome are pink, rather heterogeneous, medium-grained rocks consisting of quartz (20 to 40 percent), plagioclase (15 to 45 percent), microcline (27 to 43 percent), and biotite (2 to 8 percent), accompanied by hornblende (0 to 5 percent) and accessory zircon, sphene, allanite, and apatite (table 5, modes 4 to 8). The biotite is typically very dark ($Z =$ brownish black), as is the associated hornblende ($Z =$ dark brownish black or green).

Most of the granite gneiss is well foliated as a result of the parallel orientation of biotite flakes, flattened quartz grains, and augen of microcline. An augen fabric is common, particularly in the highly biotitic phases of the gneiss, which locally grade into layers of hornblende-biotite-plagioclase-quartz gneiss with scattered augen of microcline.

Ultramafic rocks

Small masses of massive dark-green rock consisting largely of an amphibole with the optical properties of actinolite are shown on plate 1 as ultramafic rocks. The two chemical analyses given in table 6 demonstrate that the term ultramafic is reasonably appropriate, even though the rocks have been metamorphosed. The modal analyses (table 7) illustrate that amphibole is the most abundant mineral, generally accompanied by one or more of the following minerals: hypersthene, olivine, magnetite-ilmenite, green spinel, plagioclase, and chlorite.

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[2]These rocks are described as granite gneisses, because all the modal analyses fall within the composition field for granite outlined by Chayes (1957). They are largely type-II* granites in his classification.

TABLE 6. — Chemical analyses of ultramafic rocks[1]

Chemical analyses[2]		
	DR-22-7[3]	DR-29a-9
SiO_2	44.08	46.84
TiO_2	0.49	0.36
Al_2O_3	14.12	9.77
Fe_2O_3	3.48	3.02
FeO	7.43	7.18
MnO	0.17	0.22
MgO	19.62	17.38
CaO	9.93	10.58
Na_2O	0.58	1.16
K_2O	0.25	0.86
P_2O_5	0.09	0.10
H_2O+	0.25	2.28
H_2O-	0.03	0.00
CO_2	0.00	0.00
Total	100.52	99.75

[1]H. B. Wiik, analyst.
[2]In percents by weight.
[3]Specimen numbers.

TABLE 7. — Modal analyses of ultramafic rocks

	1	2	3	4
	22-7[1]	45-5	148-5	29a-9
Actinolite	46.9	86.8	93.9	82.1
Hypersthene	41.6	—	0.3	—
Plagioclase	—	5.8	—	2.7
Sericite	—	1.4	—	—
Biotite	—	—	1.9	6.6
Talc	—	5.8	—	—
Serpentine	—	—	1.8	—
Spinel	11.0	—	—	—
Opaque	0.4	0.1	1.9	—
Chlorite	—	—	—	8.6
XN[2]	19.5	22.3	10.3	10.3
XE[2]	2.1	1.8	16.4	16.4

[1]Sample numbers.
[2]XN and XE numbers are coordinates giving the location of each specimen. XN numbers are in thousands of ft north of the zero line at the southern edge of the quadrangle; XE numbers are in thousands of ft east of the zero line at the western edge of the quadrangle.

The largest mass of ultramafic rock is a few hundred feet long; the smallest is less than 20 feet long. All of the ultramafic rock masses occur at or not far below the base of the Putnam gneiss or Brimfield formation, generally in contact with amphibolite. They are most numerous and best displayed in the segment of the Middletown formation lying between Deep Hollow Reservoir and Roaring Brook (fig. 3, DR IV). Six separate masses have been mapped in this belt. Each is readily recognizable in the field, because it forms a rounded knob conspicuously in contrast to the outcrop of the adjacent banded gneisses and amphibolites. Large hypersthene grains stand out in relief on outcrop surfaces of some of these masses, making them even more distinctive.

The only other ultramafic rock in the quadrangle is a small, poorly exposed mass first described by Foye (1949, p. 50) as the Chester hornblendite. This lies along the Honey Hill fault at the contact between Putnam schists and calc-silicate gneiss and underlying Monson hornblendic gneiss (see table 6 for location).

Pegmatite

Pegmatite occurs in abundance in all the rock units but is most conspicuous and probably most abundant in the Hebron, Putnam, and Brimfield formations. The largest masses of pegmatite, which are as much as 1000 ft long, are truly pegmatitic, centimeter-to decimeter-grained rocks[3]. These large masses form resistant knobs and thus are well exposed. The smallest masses are small laminae of pegmatitic material interleaved with schist. Many of the smaller masses are millimeter grained and could be described as granite. However, they commonly grade into, or are closely associated with, larger masses of coarser grained pegmatite. All the pegmatites shown on plate 1 are more or less concordant masses that tend to be elongated parallel with the strike of the enclosing rocks. Many may actually consist of several smaller masses separated by septa of schist.

All the pegmatites are granites; they consist of perthitic microcline, sodic plagioclase, quartz, and minor biotite or muscovite. The accessory minerals in any one pegmatite commonly are the same as those in the surrounding rocks. For this reason it is convenient to describe the pegmatites separately, according to the rock units in which they are found. The descriptions are brief; they are presented to call attention to some of the more obvious differences among the pegmatites in the quadrangle.

PEGMATITE IN THE HEBRON FORMATION

Pegmatites in the Hebron formation typically are white or light-gray millimeter- to decimeter-grained rocks containing reddish-

[3]Grain size of pegmatites is designated as follows: If no grains are more than 3 mm in diameter the rock is described as millimeter grained. If no grains are more than 3.2 cm in diameter the rock is described as centimeter grained. If grains more than 3.2 cm in diameter are present, then the rock is described as decimeter grained.

brown biotite, tourmaline, and garnet as accessory minerals. Muscovite is not common. Pegmatite is most abundant along the axis of the Chester syncline where the Hebron formation is tightly folded. Here, the larger, coarser grained masses appear as elongate, probably cigar-shaped bodies aligned more or less parallel to the major fold axes. Much of the centimeter-grained pegmatite is in conformable lenses and layers, and many of the layers show well developed pinch-and-swell structure or rather striking boudinage.

Prospect pits were opened in one of the larger pegmatites after field work was completed. This pegmatite is almost 1800 ft long and at least 200 ft wide; it forms the crest of a ridge on the east side of Mt. Tom (fig. 3, DR I, 6,500 ft east, 2,000 ft south). Bedding in Hebron calc-silicate gneiss is nearly horizontal on the east side of the pegmatite but dips steeply on the west side. The prospect pits expose centimeter- to decimeter-grained white pegmatite with abundant white perthitic microcline, quartz, plagioclase, minor muscovite, and variable but small amounts of tourmaline, beryl, and garnet. Tourmaline is abundant near the contacts, in small prisms lying parallel to the contact surface and in larger, tapered prisims (6 to 8 in. long) oriented perpendicular to the contact. Beryl, in crystals with diameters up to 4 in. and as long as 6 in., is common, although it is unevenly distributed.

PEGMATITE IN THE BRIMFIELD FORMATION AND PUTNAM GNEISS

Pegmatite is abundant in the biotite-muscovite schists of the Brimfield formation and fairly abundant in the schists of the Putnam gneiss, occurring as large, partly discordant masses, and smaller, more or less conformable layers and lenses. The largest pegmatites lie along the contact between muscovitic schist and the amphibolite of the Bashan Lake belt of the Brimfield.

All pegmatite in biotite-muscovite schist is centimeter- to decimeter-grained, white, quartz-microcline-oligoclase pegmatite with accessory muscovite, tourmaline, garnet, and biotite. Muscovite is abundant, more so than in any of the other pegmatites, and biotite-muscovite schist could be mapped rather successfully by mapping the muscovitic pegmatites, because muscovite is rare in pegmatite in the adjacent Hebron, Middletown, and Monson gneisses. Pegmatites in the biotite-muscovite schists of the Putnam gneiss are smaller than those in the Brimfield, and almost all are more or less sheared, as they lie within the Honey Hill fault zone.

PEGMATITE IN THE MONSON GNEISS AND MIDDLETOWN FORMATION

Pegmatites in the quartz-plagioclase gneisses of the Monson gneiss and Middletown formation display a variety of structural relationships but little obvious mineralogic variation. White pegmatites generally appear to be granites in which plagioclase is the more abundant feldspar; the accessory minerals in these pegmatites are commonly the same as those of the adjacent gneiss. For example, cummingtonite-bearing pegmatite occurs in cummingtonitic gneiss; epidote-bearing pegmatite in epidote-bearing gneiss, and hornblende-bearing pegmatite in hornblendic gneiss. Pink pegmatites, which are more common, are more likely to be discordant; many of them are remarkably rich in pink microcline. Their accessory mineralogy is simple: biotite and chunks of magnetite are common; muscovite, tourmaline, and garnet are less common.

Mylonitic and blastomylonitic gneisses

Along the Honey Hill fault the Putnam and Canterbury gneisses and the Hebron formation, and, to a lesser extent, the Monson gneiss are mylonitic and blastomylonitic schists and gneisses showing textures characteristic of crushed but partially recrystallized rocks. These rocks typically are darker, better layered, and more closely jointed than adjacent layers of normal rock, and slickensided foliation surfaces are fairly common in them. Similar rocks occur in the Putnam gneiss in quadrangles to the east (Snyder, 1961). Detailed descriptions of such rocks have been presented by Sclar (1958); excellent photographs in Sclar's report illustrate features similar to those described below.

Any outcrop of Putnam schists between Honey Hill and Chester displays layers of blastomylonitic schist characterized by large augen of plagioclase and muscovite set in an unusually fine-grained matrix of quartz, feldspar, and mica. Plagioclase augen are sharply twinned, and twin lamellae are bent and offset. Many augen consist of aggregates of small grains of plagioclase and quartz. Muscovite augen are bent or twisted flakes with tapered ends. Biotite commonly forms a network of small flakes (0.05 mm) much smaller than the usual biotite flakes in these schists (1 to 2 mm). Chlorite interleaved with biotite represents an alteration product of biotite. Chlorite also occurs in veinlets along cracks in fractured garnets. Sillimanite is rare but where present it appears to be fresh. The contrast between the mineralogy of fresh, uncrushed rock and that of thoroughly crushed and recrystallized rocks is evident from a comparison (table 3) of modal analyses of DR-15-9 (fresh) with DR-30-5 and DR-23-8 (crushed).

Within a few hundred feet of the fault the Monson gneiss shows at least traces of the effects of faulting that are much better shown in the overlying Putnam. Layers and dikelets of aphanitic, dusky, yellow-green mylonite are irregularly distributed through the plagioclase-quartz-biotite-hornblende gneisses. These mylonite layers consist of angular fragments of quartz and plagioclase and more irregular fragments of hornblende set in a fine-grained matrix of quartz, potassium feldspar, epidote, sphene, and chlorite. Much of the epidote, chlorite, and potassium feldspar apparently formed during or after the period in which the mylonite was formed.

All specimens of Canterbury gneiss show some evidence of crushing, ordinarily in the form of laminae of extremely fine-grained quartz, plagioclase, and biotite. These laminae generally curve around the large, Carlsbad-twinned augen of plagioclase and microcline, which apparently represent porphyroclasts.

The quartz-biotite schists and calc-silicate gneisses of the Hebron formation within the fault zone commonly show a strongly developed lamination parallel to bedding. This lamination is developed where fine-grained layers of crushed rock alternate with coarser grained, uncrushed layers. Quartz-biotite schists typically have a well developed mortar structure; smooth-surfaced porphyroclasts of plagioclase having an elliptical cross section are set in an abnormally fine-grained matrix of biotite and quartz. The calc-silicate gneisses typically display well oriented actinolite prisms set in a finer matrix of quartz, plagioclase, and biotite. These prisms are folded and broken along small shears. Plagioclase is sharply twinned and twin lamellae are bent and offset. Laminae and veinlets of chlorite and strained and sutured quartz are common.

STRUCTURAL GEOLOGY

The large-scale structural framework that seems to provide the most satisfactory basis for discussion of structures within the quadrangle is one dominated by domes and anticlines of quartzo-feldspathic gneiss (fig. 2), separated from one another by asymmetric, overturned or recumbent isoclinal synclines in which the schists and calc-silicate gneisses are found. This general picture of the structural framework has been advocated by most geologists who have worked within the area of figure 2 (Mikami and Digman, 1957; Rodgers and others, 1959, fig. 2 and p. 19-21; Lundgren, 1962).

Structural relationships of the quartzo-feldspathic gneisses

The quartzo-feldspathic gneisses (Middletown formation, Monson gneiss, New London (?) granite gneiss, and Sterling granite gneiss) are exposed in structural highs that border the quadrangle on the south and west. These structural highs, which are described below, are the Selden Neck dome in the southeast corner, the Killingworth dome in the southwest corner, and the Monson anticline along the western margin.

SELDEN NECK DOME

The mass of Sterling granite gneiss cut by the Connecticut River forms the core of the Selden Neck dome, an elongate and internally complicated dome, probably a domed-up mass of basement complex. The granite core is surrounded by concentric envelopes of Plainfield formation, New London (?) granite gneiss, Monson gneiss, and Putnam formation. These units structurally overlie the core on the north side of the dome (pl. 1, section AA'), but they wrap around the core and dip north under it along the south side of the dome. The rocks that form the dome are evenly banded and display few minor folds on the north side of the dome. West of the Connecticut River the same rocks show numerous minor folds, most of them overturned to the west, with fold axes plunging gently to the north. These folds are particularly well displayed in the vicinity of Chester; an excellent example may be seen immediately north of Hearse Hill Cemetery on the southwest slope of Story Hill.

MONSON ANTICLINE

The Turkey Hill belt of Monson gneiss has long been regarded as the core of an anticline (Emerson, 1898, 1917; Rodgers and others, 1959, p. 20; Lundgren, 1962), an interpretation which hinges on the stratigraphic equivalency of the two belts of schist that flank the Monson gneiss outcrops. The structure is designated in the present report as the Monson anticline.

KILLINGWORTH DOME

The Cedar Lake belt of Monson gneiss lies on the east flank of the Killingworth dome (fig. 2). It is a large mass of quartz-plagioclase gneiss (Haddam or Monson) whose general structure was first described by Mikami and Digman (1957), who showed the northward continuation of the Cedar Lake belt of Monson gneiss as simply the outer part of the dome. However, in the Deep River and Essex quadrangles (fig. 2) the Cedar Lake belt of Monson gneiss is separated from both the Monson anticline and the main part of the Killingworth dome by a narrow belt of mica schist (Pine Ledge belt of the Brimfield formation) and contiguous anthophyllitic gneiss (Middletown formation). Thus the Cedar Lake belt must be involved in some sort of structural complication on the east flank of the dome; the nature of this complication is not yet clear. Possible interpretations of the structural relationship between this belt and the dome are presented in figure 4. The information necessary to determine which, if either, of these interpretations is correct must come from detailed mapping in the Haddam and Middle Haddam quadrangles.

The Cedar Lake belt of Monson gneiss may simply represent a digitation or subsidiary anticline on the east flank of the Killingworth dome (fig. 4a). This interpretation places the Pine Ledge belt of the Brimfield formation in the keel of an isoclinal syncline, which is itself a folded fold. Eaton and Rosenfeld (see Rodgers and others, 1959, p. 22 and their fig. 3) have shown the northward extension of this belt of Brimfield (their Collins Hill formation) as a syncline lying between the Killingworth dome and the Monson anticline.

Another interpretation is permissible if the Pine Ledge belt of mica schist is not equivalent to the Brimfield formation but is simply a schist layer within the Middletown formation. Given this assumption, the Cedar Lake belt of the Monson gneiss may be interpreted as the core of a syncline. (fig. 4b). This interpretation requires that all the rocks in this syncline be designated as Middletown formation. It remains to be seen whether this interpretation can be reconciled with relationships in the Middle Haddam quadrangle.

Structural relationships of the Putnam gneiss and the Brimfield and Hebron formations

The Putnam gneiss and the Hebron and Brimfield formations dip north at a low angle off the Selden Neck dome (pl. 1, section

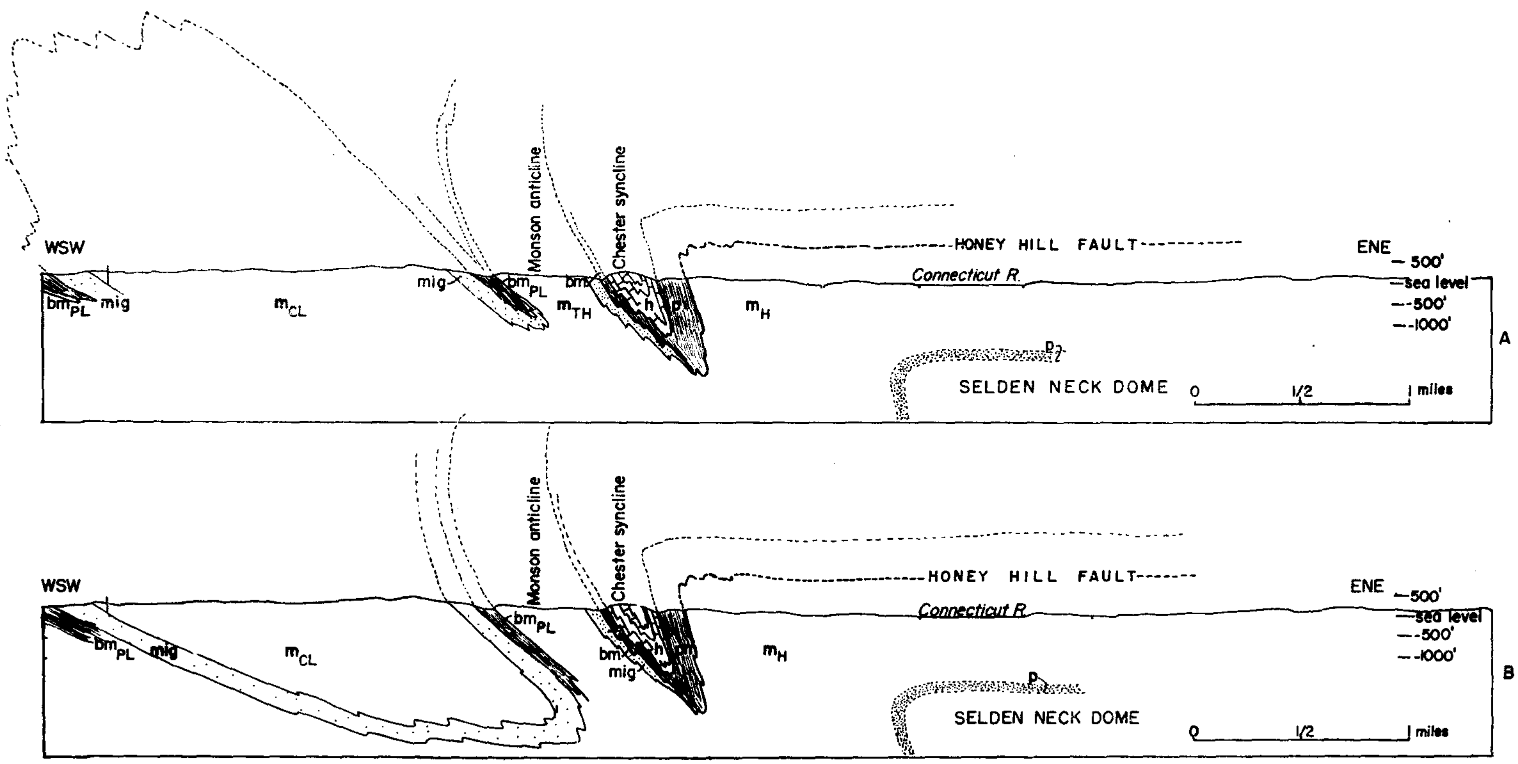


Fig. 4. Structure sections across the Cedar Lake belt of the Monson gneiss, illustrating alternative interpretations of the structure. *A*, the Cedar Lake belt as an anticline; *B*, the Cedar Lake belt as a syncline.

AA'), and, in most of the northern half of the quadrangle east of the Connecticut River, the Hebron and Brimfield dip gently toward a point at the northeast corner of the quadrangle. These units may be said to *mantle* the Selden Neck dome and may also be described as the *mantle or mantle sequence.* West of the Connecticut River the same units undergo an abrupt flexure so that they are vertical or dip steeply to the east in a narrow belt bordering the Monson anticline.

Two interpretations of these relationships might be considered. One is to regard the whole sequence as an overturned homocline in which successively younger units are crossed in passing from east to west. The other is to regard the sequence as one in which units are repeated by isoclinal folding. This interpretation is required if the Turkey Hill belt of Monson lies along an anticline (Rodgers and others, 1959, p. 21) ; it is regarded as the most satisfactory interpretation of the relationships in the Deep River quadrangle. The first interpretation does not appear to be satisfactory for the local relationships, but it has been advanced as an interpretation of the structural relationships among many of the same units along the strike to the north (Collins, 1954; Aitken, 1955).

CHESTER SYNCLINE

South of Chester the mantle lies along a narrow belt in which the dips of the bedding and foliation are steep (60°- 90°E). This belt has been interpreted as an isoclinal syncline, the Chester syncline (Lundgren, 1962), separating the Selden Neck dome from the Monson anticline. North of Chester the axis of this syncline lies along the belt of steeply dipping, tightly folded Hebron formation.

The principal evidence for this interpretation is the symmetrical disposition of rock units about a mid-line drawn along the narrow belt of Hebron formation. The Hebron is flanked by biotite-muscovite schists (Putnam and Brimfield) of similar appearance and mineralogy. Farther from the axis it is flanked by plagioclase-quartz-biotite-hornblende gneisses that are physically identical except for the occurrence of anthophyllitic layers on the west side of the axis. Further evidence of this symmetry is shown in the Old Lyme and Hamburg quadrangles (Lundgren, 1962) where the structure is cut deeply enough so that both the New London (?) granite gneiss and Plainfield formations are exposed along both sides of the axis (fig. 2). This symmetry has also been recognized by Goldsmith (1961, p. 54) in the Montville quadrangle, along the eastward extension of the Chester syncline, which he named the Hunts Brook syncline.

The dip of the bedding on opposite sides of the axis west and northwest of Chester implies that the Putnam and Brimfield converge beneath the Hebron. Minor folds are notably abundant in the Hebron along the axis; they are particularly well displayed on the south side of hill 211, west of Chester. These features also suggest that the Hebron lies along a fold axis, but they have no independent value in interpreting the structure.

The Chester syncline appears to be a major recumbent syncline overturned to the east. The necessity for this interpretation, if the approximate equivalence of the Putnam gneiss and Brimfield formation is accepted, has been recognized by all geologists who have recently worked in the general region. The Hebron formation occupies the core of this recumbent fold; the Putnam gneiss forms the normal limb, and the Bashan Lake belt of the Brimfield formation forms the inverted limb (fig. 5 and pl. 1, section AA'). The axial plane of this recumbent syncline is nearly horizontal throughout the area east of the Connecticut River; it lies somewhere within the Hebron formation, so that part of the Hebron formation must also be inverted.

If this interpretation is correct, the Turkey Hill belt of Monson gneiss must represent the root zone of a recumbent anticline that has been eroded away in the Deep River quadrangle, although a remnant (fig. 2) may be present just to the east in the Hamburg and Colchester quadrangles (Lundgren, 1962). Detailed mapping in the quadrangles to the north may provide enough information to determine whether the Brimfield formation is actually inverted, as the interpretation of the Chester syncline as a recumbent fold requires.

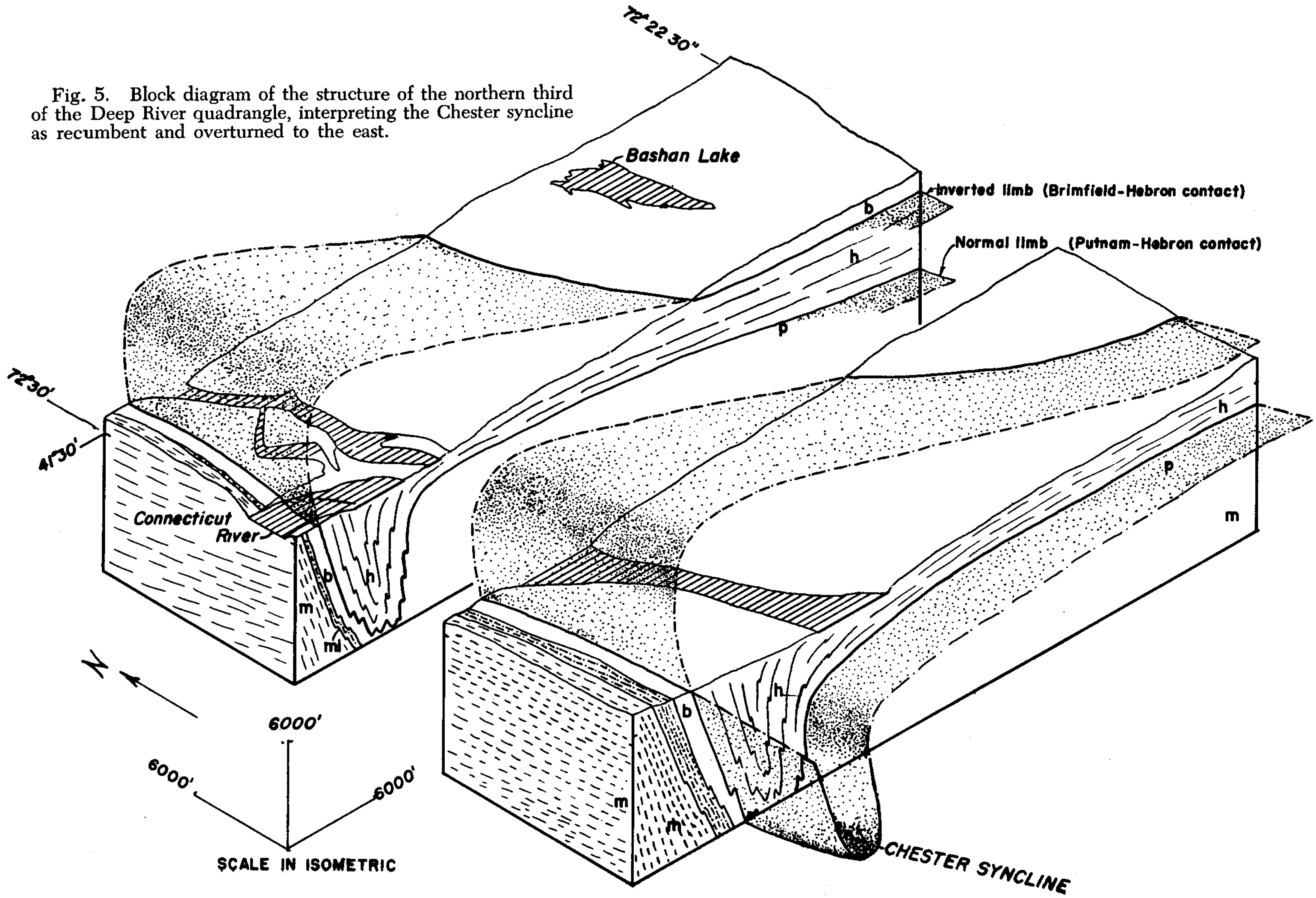
The only evidence within the Deep River quadrangle indicating that the Brimfield formation was displaced east over the Hebron formation is the orientation of numerous recumbent folds in the Hebron calc-silicate gneisses near the contact with the overlying Brimfield schist. These folds are generally overturned to the east with axial planes dipping gently west. The only further observation that may be taken to indicate the same sense of movement is the presence of anthophyllitic gneisses in the northwest Hamburg and southwest Colchester quadrangles. As anthophyllitic gneiss normally is restricted to the Bronson Hill anticline this may indicate displacement of these rocks from west to east.

Honey Hill fault

The zone of blastomylonitic gneisses marks the trace of the Honey Hill fault, named for Honey Hill (fig. 3, DR VI). This major fault extends east of the quadrangle for at least 25 miles (Lundgren and others, 1958). The contact between the Monson gneiss and the Putnam formation is considered to be the fault surface, as the maximum displacement apparently took place along this contact. The contact is exposed on the southwest slope of Honey Hill where blastomylonitic biotite-muscovite schist (Putnam) lies on plagioclase-quartz-biotite-hornblende gneiss (Monson) with a conspicuously developed laminar structure seen only at the contact. Pink pegmatites along the contact are also partially crushed.

As the mylonitic foliation in each of the units is parallel to the bedding and foliation in adjacent relatively uncrushed layers, the fault surface must be parallel to the contacts between the various

Fig. 5. Block diagram of the structure of the northern third of the Deep River quadrangle, interpreting the Chester syncline as recumbent and overturned to the east.



stratigraphic units. The fault surface dips gently north between Honey Hill and Chester. The fault does not cut across the Chester syncline. At Chester the blastomylonitic units are bent sharply in conformity with the fold structure, and they extend south along the steeply dipping east limb of the Chester syncline for at least one mile.

Lundgren and others (1958) described the Honey Hill fault as a thrust fault (with respect to its present attitude), following an earlier interpretation of Foye (1949). The evidence for a north-side-south thrust sense is displayed in quadrangles to the east mapped by Snyder (1961) and Goldsmith. Within the quadrangle there is little evidence of this sense of movement. The orientation of recumbent isoclinal folds in Hebron calc-silicate gneiss in and above the fault zone suggests a stage in which movement was from west to east.

Most of the small-scale structural features in the blastomylonitic rocks indicate a late stage of movement in which the Monson was displaced southward relative to the overlying Putnam, Canterbury, and Hebron. This last stage represents essentially down-dip movement. Most of these small-scale features are small folds or faults in laminar mylonitic gneiss, and they clearly are younger than the deformation that produced the laminar gneisses. They are well displayed in the cliffs of Hebron calc-silicate gneiss along the east bank of the Connecticut River (Gillette Castle State Park, north of the ferry landing—fig. 3, DR V). Lamination in these gneisses is folded and offset along shears filled with aphanitic, dark-green ultramylonite; the sense of movement indicated is that the hanging wall was displaced northward. The same sense of movement is indicated by rotated boudins of pegmatite in blastomylonitic augen gneiss in an old quarry just south of the east landing of the Chester ferry (DR IV—hill on the north side of Whalebone Creek where it joins the Connecticut River).

STRATIGRAPHIC SEQUENCE AND AGE RELATIONSHIPS

The interpretation of stratigraphic sequence and structure is based in large part on the evidence that the two belts of schist shown as Brimfield formation and the belt of Putnam gneiss are all parts of a single major stratigraphic unit and thus are to be regarded as approximate equivalents. Part of the argument for this interpretation is based on regional relationships (Lundgren, 1962), and part is based on the observation that the schists of both the Putnam gneiss and the Brimfield formation (Haddam Neck belt) are arranged in similar sequence with respect to adjacent quartz-plagioclase gneisses (Monson and Middletown) and adjacent calc-silicate gneiss (Hebron). As this argument is of regional importance, some well exposed sections across the Putnam and across each of the two belts of Brimfield are described in some detail below (see also fig. 6). Essential features of these sections are summarized in a discussion that follows the detailed descriptions.

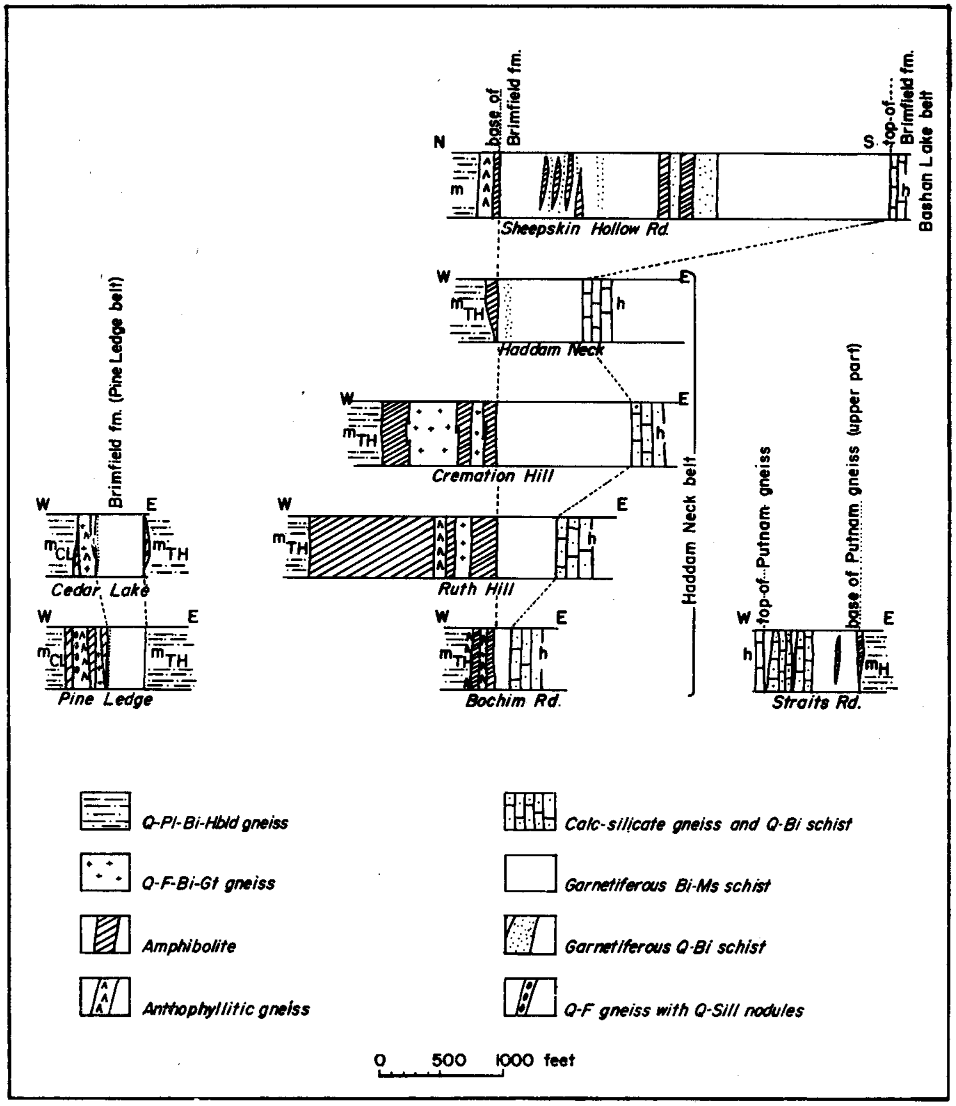


Fig. 6. Stratigraphic cross sections across the Brimfield and Putnam formations and adjacent units.

Stratigraphic sections, Brimfield formation and Putnam gneiss

BRIMFIELD SECTIONS

Sections across the Haddam Neck belt are described first; then a section across the supposedly inverted Brimfield is compared with them. Two sections across the Pine Ledge belt of the Brimfield are also described. The rocks designated here as Middletown were included in the Brimfield formation in an earlier description of the essential features of these sections (Lundgren, 1962).

Cremation Hill section. This section is exposed along the power-transmission line crossing the south end of Cremation Hill (fig. 3, DR I).

The base of the Middletown formation is marked by laminar, diopsidic amphibolite in contact with quartz-plagioclase gneiss (Monson) to the west. Similar amphibolites occur within the Monson. The next 400 ft of section consists of isoclinally folded garnetiferous quartz-plagioclase-biotite gneisses with amphibolite and a few thin beds of quartzite. To the east, these gneisses are interbedded with tightly folded, sharply layered amphibolite gneiss, considered to be the top unit in the Middletown. The next 1,000 ft of section consists largely of the coarse-grained garnetiferous biotite-muscovite schist typical of the Brimfield. This schist is apparently in sharp contact with calc-silicate Hebron gneisses to the east. However, both north and south of this section, biotite-muscovite schist layers occur within the calc-silicate gneisses of the Hebron formation, possible evidence that the Hebron lies conformably on the Brimfield.

Ruth Hill section. This section is exposed along an east-west line just north of Roaring Brook (fig. 3, DR IV). Similar sections are exposed just south of Roaring Brook.

The essential features of this section are the same as those of the Cremation Hill section, but the apparent thickness of various units is notably different. Coarse anthophyllite rocks are common along the contact between the basal amphibolite of the Middletown formation and the quartz-plagioclase Monson gneisses. Anthophyllitic gneisses also occur within the amphibolite. The entire section of Middletown formation consists of interbedded amphibolite, garnetiferous amphibolite, and garnetiferous quartz-feldspar gneisses. The overlying Brimfield consists entirely of biotite-muscovite schist.

Bochim Road section. This section is exposed along a line striking N. 50°E. and crossing Bochim Road at its intersection with the boundary between DR VII and DR VIII (fig. 3).

Here the section is less than 400 ft thick. The base of the Middletown is marked by thin, laminar amphibolite and interbedded anthophyllitic quartz-plagioclase gneiss in contact with Monson quartz-plagioclase gneiss to the west. The amphibolite is overlain by well bedded, gray, garnetiferous quartz-feldspar gneiss with some cummingtonitic quartz-plagioclase layers. The upper 200 ft of the section consists of rust-stained biotite-muscovite schist (Brimfield) here containing coarse sillimanite. This schist has layers of calc-silicate gneiss and it is in contact with calc-silicate gneiss and quartz-biotite schist of the Hebron formation.

Sheepskin Hollow Road section. This section is exposed in a broad belt along a north-south line drawn north from Urban Pond (fig. 3, DR VI). The section crosses a sequence of Brimfield considered to be inverted; it is described from north to south.

The base of the section is not exposed in the Deep River quadrangle, but just to the east amphibolite and anthophyllitic gneisses, shown on figure 2 as Middletown formation, are considered to be the upper part of the Middletown formation (fig. 2). There are virtually no good exposures along the line of section from the north edge of the quadrangle south to Martin Pond. This part of the section probably consists of sillimanitic biotite-muscovite schist with many layers of amphibolite and many more layers of garnetiferous quartz-biotite gneiss, all of which are well exposed in the Hamburg quadrangle to the east. This part of the section is included in the Brimfield, but it contains rocks similar to those mapped as Middletown in the belt west of the Connecticut River. The first good exposures along this line of section are the exposures of diopsidic amphibolite and interbedded quartz-feldspar gneiss east and west of Martin Pond. The remainder of the section from Martin Pond south to Urban Pond is garnetiferous biotite-muscovite schist. This schist lies in sharp contact with structurally underlying calc-silicate gneiss of the Hebron formation.

Cedar Lake section. This section extends east from Cedar Lake (fig. 3, DR VII) on the grounds of Camp Hazen, a Y.M.C.A. camp.

Gneiss at the west end of the section is dark-gray, hornblendic plagioclase gneiss (pl. 1, m_{CL}) with interbedded amphibolite, some of it garnetiferous. These gneisses are capped by an amphibolite separating them from an overlying sequence (Middletown formation) of interbedded amphibolite and rust-stained coarse-grained gneisses with abundant dark-brownish-black prisms of anthophyllite, large (10 to 20 mm) red garnets, pods of quartz-tourmaline aggregate, and pods of garnet-anthophyllite rock. These rocks are overlain by thin-bedded quartz-plagioclase-biotite-muscovite gneiss and muscovitic quartzite containing lenses of garnet-quartz rock. These quartzites are taken as the base of the Pine Ledge belt of Brimfield. They are structurally overlain by rusty-weathering, muscovite-biotite schist. This schist may lie in the keel of an isoclinal fold. The schist is structurally overlain by biotitic and hornblendic plagioclase gneiss (pl. 1, *mhg*), much of it garnetiferous and containing numerous amphibolite layers and a few layers of anthophyllitic gneiss. The contact between the schist and these gneisses is not exposed.

Pine Ledge section. This section crosses Pine Ledge (fig. 3, DR VII).

West of Pine Ledge the Monson gneiss (pl. 1, m_{CL}) is banded hornblendic quartz-plagioclase gneiss capped by a thin amphibolite. The amphibolite is overlain by a 6-ft-thick layer of muscovitic feldspathic gneiss, spotted with quartz-sillimanite nodules. This is overlain by a sequence of interbedded amphibolite, rust-stained anthophyllitic gneiss, cummingtonitic amphibolite gneiss, and garnetiferous quartz-feldspar gneiss. Tourmaline-quartz lenses are conspicuous; flat lenses of garnet-quartz aggregate are common. These anthophyllitic gneisses are overlain by rusty-weathering graphitic quartzite and muscovite-biotite schist exposed along the road just west of Pine Ledge. The schists are structurally overlain by the hornblendic plagioclase gneisses well exposed in Pine Ledge. The contact is not exposed.

PUTNAM SECTIONS

Roaring Brook section. This is a composite section representing the sequence along the Honey Hill fault (fig. 3, DR VI).

The lower part of this section is best exposed at Honey Hill (DR VI). The lower 200 to 300 ft of Putnam consists of dark-gray biotite-quartz-plagioclase schists and schistose gneisses in which muscovite and garnet generally are minor constituents. Subordinate garnetiferous muscovite-biotite schist and thin lenses of amphibolite are interbedded with the biotitic schists. The Putnam schists are in sharp contact with the underlying Monson gneiss, here a dark-gray hornblendic plagioclase gneiss with many amphibolite layers. The contact is a fault contact, and the rocks on both sides are blastomylonitic.

The middle part of the section, representing an apparent thickness of approximately 100 ft, consists of rusty-weathering garnetiferous biotite-muscovite schist interbedded with gray biotite-muscovite schist. This is best exposed at about the 100-ft contour on the north side of Roaring Brook due east of the intersection of the Middlesex-New London County boundary line with Rt. 82.

The upper part of the section (50 to 100 ft) consists of thin-bedded calc-silicate gneiss and quartz-biotite-plagioclase gneiss with thin layers of amphibolite and rusty schist. The calc-silicate gneisses generally are interleaved with layers of dark-gray augen gneiss (Canterbury gneiss), and the position of the upper contact of the Putnam cannot be located as precisely as the lower contact. This part of the section is well exposed on the west and south sides of the 120-ft hill southeast of the east landing of the Chester Ferry (DR V).

Straits Road section. This section is parallel to, but a few hundred feet north of, the Chester-Deep River town boundary line where it crosses Straits Road (fig. 3, DR VIII).

The Monson gneiss (pl.. 1, m_H) near the contact with the Putnam is dark-gray hornblendic plagioclase gneiss with many thin amphibolite layers. It is separated from the basal Putnam schists by a unique banded granite gneiss *(mg)* consisting of layers of pink granite interleaved with sharply bounded layers of black biotitic amphibolite. The base of the Putnam is marked by thin, discontinuous amphibolites, overlain by 300 ft of dark-gray biotitic schistose gneiss with a generally small muscovite content. Interbedded with this are thin layers of quartzite, amphibolite, and rust-stained sillimanitic schist.

Toward the top of the section, calc-silicate gneiss interbedded with biotitic quartz-feldspar gneiss is predominant. The calc-silicate gneiss is interleaved with thin layers of granitic gneiss (Canterbury). It is separated from similar calc-silicate Hebron gneiss by a thin, rusty-weathering muscovite-biotite schist.

Stratigraphic relationships of the Brimfield formation and Putnam gneiss

The sequence from each belt of quartz-plagioclase gneiss across the adjacent schist unit is summarized below to emphasize the similarities which initially suggested that the Brimfield formation and the Putnam gneiss are approximate equivalents.

A typical section from the Hadlyme belt of Monson gneiss across the adjacent Putnam is as follows:

a) The upper part of the Monson is hornblendic plagioclase gneiss, generally rather well banded and interbedded with numerous layers of amphibolite.

b) The Putnam gneiss lies on the Monson gneiss. This contact is a fault contact, but a structurally conformable one.

c) The lower half of this belt of the Putnam gneiss is gray biotitic and muscovitic schist and gneiss interbedded with subordinate amphibolite and conspicuously garnetiferous schist.

d) The upper part of the Putnam comprises calc-silicate gneiss interbedded with biotite-muscovite schist and garnetiferous quartz-biotite gneiss. Where the Canterbury gneiss is present between the Putnam and the Hebron, thin layers of calc-silicate gneiss are found in the Canterbury. Where the Canterbury gneiss is not present, the Putnam is separated from the overlying Hebron by rusty sillimanitic schist.

A typical section from the Turkey Hill belt of Monson gneiss *east* across the Brimfield differs from the section described above, because anthophyllitic gneisses occur along the contact between the Monson gneiss and the biotite-muscovite schist unit. The sequence may be summarized as follows:

a) The Monson gneiss along the east edge of the Turkey Hill belt is gray biotitic quartz-plagioclase gneiss. Thinly layered diopsidic amphibolite is common in the gneiss.

b) The contact between the Monson gneiss and the overlying Middletown formation is marked by persistent amphibolite interbedded with anthophyllitic gneisses. The gneisses are conspicuously rust stained in contrast to the gray outcrop surface of the Monson gneisses. Near this contact are lenses of garnet-anthophyllite rock. The contact is placed at the bottom of the first persistent amphibolite known to be associated with rust-stained anthophyllitic or garnetiferous gneisses. This contact is rather difficult to place; the sequence from Monson to Middletown presumably is gradational.

c) The Middletown formation is overlain by the biotite-muscovite schists of the Brimfield formation. These schists are interbedded with subordinate amphibolite and garnetiferous quartz-biotite schist. This contact is also difficult to place; it is drawn where biotite-muscovite schist is more abundant than interbedded amphibolite. The sequence from the Middletown to the Brimfield also appears to be gradational.

A typical section from the Turkey Hill belt of Monson *west* across the Pine Ledge belt of Brimfield is rather similar to the section east to the main belt of Brimfield. It is poorly exposed, however, and only the following statements may be made.

a) The Monson gneiss along the west edge of the Turkey Hill belt is banded hornblendic plagioclase gneiss with interbedded amphibolite.

b) Toward the Pine Ledge belt of the Brimfield formation, the Monson is progressively more heterogeneous; it includes well bedded, gray, garnetiferous quartz-feldspar gneiss, numerous layers of diopsidic amphibolite, and banded hornblendic gneiss. These rocks may actually be the counterpart of the rocks shown elsewhere as belonging to the Middletown. Only a thin sliver of anthophyllitic gneiss is exposed, however; it is shown as Middletown.

c) The contact between these rocks and the Pine Ledge belt of the Brimfield is not exposed.

A typical section from the Cedar Lake belt of Monson gneiss east across the Pine Ledge belt of Brimfield is as follows.

a) The Monson gneiss is gray, hornblendic plagioclase gneiss with interbedded amphibolite.

b) The contact between the Monson and the overlying Middletown is marked by a thin, but fairly persistent amphibolite, which in turn is overlain by and interbedded with conspicuously rust-stained anthophyllitic and garnetiferous gneisses, and gneiss with quartz-sillimanite nodules. The sequence from Monson gneiss to Middletown gneisses appears to be continuous and conformable.

c) The Middletown formation is overlain by biotite-muscovite schist, commonly separated from the anthophyllitic gneisses by thin, well bedded quartzites containing lenses of fine-grained garnet-quartz aggregate. This contact is generally sharp and is easily mapped.

A comparison of the sections described above shows an impressive similarity between sections from the Cedar Lake and

Turkey Hill belts of the Monson gneiss across the adjacent units. This similarity is taken as good, if not conclusive, evidence of the equivalence of the schist in the two belts shown as Brimfield formation.

Sections from the Hadlyme belt of the Monson gneiss across the Putnam gneiss are similar but not identical to the sections of Monson-Middletown-Brimfield. The absence of an anthophyllitic Middletown formation between the Monson and the Putnam is the most important difference. Less obvious differences are largely in modal composition of the Putnam schists as compared with Brimfield schists. Some of these differences may be related to involvement of the Putnam gneiss in the deformation along the Honey Hill fault. They may also imply a sedimentary-facies change in the major unit, to which the Brimfield and Putnam are considered to belong as laterally equivalent strata. Such a facies change would have taken place along the present axis of the Chester syncline. In spite of the differences, the sequence Monson-Putnam-Hebron is so much like the sequence Monson-Middletown-Brimfield-Hebron that the correlation of Brimfield with Putnam seems more plausible than considering them as non-equivalent parts of a homoclinal sequence.

If the equivalence of Brimfield and Putnam is accepted, the stratigraphic sequence can be constructed, starting with the lowest unit beneath the Putnam in the Selden Neck dome. It is as follows: (bottom) Plainfield formation—New London (?) granite gneiss—Monson gneiss (pl. 1, m_H)—Putnam gneiss—(Canterbury gneiss)—Hebron formation (top). West of the Chester syncline the Middletown formation overlies the Monson gneiss (m_{TH}) and is in turn overlain by the Brimfield formation. No clear evidence for unconformities can be found within this sequence.

Relative ages of the granitic rocks

The relationships between each of the granitic units and the units that are clearly metasedimentary are ambiguous, because the granitic units were all thoroughly deformed during metamorphism and folding.

The Sterling granite gneisses are conformably interleaved with the various rock types found in the Plainfield formation. Alaskite layers cut across the foliation of some of the adjacent rocks, but most of the granite gneiss shown as Sterling is structurally concordant with adjacent units. The Sterling granite gneisses may be metamorphosed intrusives emplaced in the original Plainfield sequence, and they may be regarded as being of the same age as, or of somewhat younger age than, the Plainfield formation. Some of the layers of granite gneiss within the Monson are also of Sterling type, and the Sterling may be younger than the Monson. However, granite gneisses of this type are not found in any unit above the Monson gneiss, so there is no evidence that the Sterling gneisses are younger than the Putnam gneiss or the Brimfield formation, while all the present evidence indicates that they are older.

The rocks tentatively assigned to the New London granite gneiss lie along, and are restricted to, the zone between the Monson gneiss and the Plainfield formation. The rocks of the New London(?) granite gneiss are in conformable contact with upper Plainfield and lower Monson and have been folded and metamorphosed in harmony with them. Thus the New London(?) granite gneiss is clearly younger than the Plainfield but does not appear to be younger than the Monson. The most satisfactory interpretation of these relationships is that the New London(?) granite gneiss is a true stratigraphic unit and is not an intrusive complex.

The Canterbury gneiss also forms a conformable layer in the zone between the Hebron and the Putnam. Thus it, too, may represent a stratigraphic unit in normal sequence with respect to the underlying Putnam and the overlying Hebron. There is no clear evidence that it is intrusive into the Hebron gneiss.

The pegmatites are the only granitic rocks that clearly cut across all of the stratigraphic units. The pegmatites in the Brimfield formation presumably are contemporaneous with pegmatites in the Collins Hill formation (= Brimfield), along the strike to the north, for which excellent age determinations are available (Eckelmann and Kulp, 1957, p. 1126; Rodgers, 1952, p. 413-415; Rodgers and others, 1959, p. 23-24). These age determinations, and one made on micas of the Collins Hill formation (Fairbairn and others, 1960, p. 8), fix the minimum age of the Hebron gneiss and all the other units at more than 265 million years, and imply that all the rocks are Pennsylvanian or older (Kulp, 1959; Faul, 1960).

GEOLOGIC HISTORY

The depositional history of the quadrangle began, probably in the Cambrian or even the Precambrian, with the deposition of a thick sequence of sedimentary and volcanic rocks. This sequence was largely quartzitic sandstone in the lower part (Plainfield formation) and volcanic (quartz keratophyre and andesite flows and pyroclastics) in the upper part (Monson gneiss). Rhyolitic flows and pyroclastics and concordant intrusives (Sterling granite gneiss and New London (?) granite gneiss) may have been deposited or emplaced at the same time. Basaltic volcanics (amphibolite) and andesite and hypersthene andesite (anthophyllitic gneiss), which together constitute the Middletown formation, were deposited on the Monson gneiss during the Ordovician. All these rocks may have been deformed, and ultramafic rocks emplaced in them, before the overlying units were deposited.

A major unit (Brimfield formation and Putnam gneiss) consisting largely of shale (now biotite-muscovite schist) was deposited on the volcanic sequence. A laterally uniform unit consisting almost entirely of siltstone and carbonate-bearing siltstone (Hebron formation) was deposited on the shale, forming the uppermost part of the local sequence.

All these rocks were then metamorphosed at high-amphibolite-facies level. During this metamorphism the quartzo-feldspathic rocks were thoroughly recrystallized and deformed, and domes of granitic gneiss and quartz-plagioclase gneiss were formed by the vertical movement of parts of the basement on which the shale and siltstone units had been deposited. The quartzo-feldspathic rocks within the domes flowed more readily than the quartzites and amphibolites interleaved with them, and complicated structures characterized by extensive boudinage and disharmonic folds were formed within the domes. The recumbent Chester syncline may have formed as a consequence of the eastward overturning of an isoclinal anticline (Monson anticline) in the Monson gneiss. Granitic liquids formed at the peak of metamorphism, and these were emplaced as pegmatites. Metamorphism reached its peak at approximately the same time as the pegmatites were emplaced, some 265 million years ago.

Movement on the Honey Hill fault may have begun during metamorphism as part of the eastward displacement of the recumbent Chester syncline. However, the movement on the fault that resulted in the formation of blastomylonitic gneisses must have taken place after the peak of metamorphism, since the mineral assemblages in these gneisses indicate low-amphibolite-facies conditions. This movement on the fault post-dates the emplacement of the pegmatites and is the youngest important event recorded in the bedrock of the quadrangle.

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