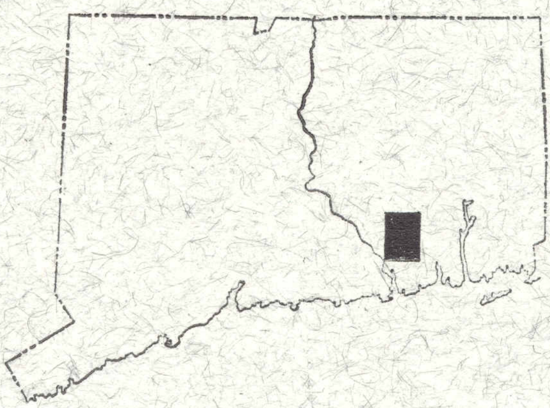
The Bedrock Geology of the Hamburg Quadrangle

WITH MAP

Open Map

BY LAWRENCE LUNDGREN, JR.



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

A DIVISION OF THE DEPARTMENT OF AGRICULTURE
AND NATURAL RESOURCES

1966

QUADRANGLE REPORT NO. 19

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by

Lawrence Lundgren, Jr.

ABSTRACT

Bedrock in the Hamburg quadrangle comprises the following units, from oldest to youngest: Plainfield Formation (quartzite, schist, gneiss); Mamacoke Formation (schist, marble, calc-silicate rocks, biotitic quartz-feldspar gneiss); Ivoryton Group (new name), which includes the New London Gneiss (granitic gneisses including the Joshua Rock Gneiss Member, an aegerine-augite granite gneiss), the Monson Gneiss (plagioclase-quartz gneiss and alaskite gneiss), and the Middletown Formation (anthophyllitic gneiss and amphibolite); Tatnic Hill and Brimfield Formations (laterally equivalent facies of a major biotite-muscovite schist unit); Canterbury Gneiss (biotitic augen gneiss); Hebron Formation (calc-silicate gneiss and quartz-biotite schist). Granitic gneisses designated as the Sterling Plutonic Group are associated with rocks of the Plainfield and Mamacoke Formations. Modal analyses accompany the descriptions of each rock unit.

The age of these rocks ranges from Cambrian (?) (Plainfield Formation) to Ordovician or Silurian (Hebron Formation). The age of the granitic gneisses of the Sterling Plutonic Group is uncertain; they definitely antedate the thermal peak of metamorphism and the later stages of deformation.

Rocks below the base of the Brimfield and Tatnic Hill Formations are exposed in complicated anticlines designated as the Colchester nappe, the Selden Neck dome, and the Lyme dome. Rocks above the base of these formations are exposed in the recumbent Chester syncline, which overlies the Selden Neck dome, and in the Hunts Brook syncline, which separates the Selden Neck dome from the Lyme dome. Both synclines are major isoclinal folds with folded axial surfaces. The Tatnic Hill, Brimfield, and Hebron Formations display blastomylonitic facies reflecting their proximity to the Honey Hill Fault, a major fault that here coincides with the contact between the Tatnic Hill Formation and the Monson Gneiss. A sillimanite-orthoclase isograd crosses the area from the southwestern corner of the quadrangle to its east-central ninth, separating rocks containing sillimanite-muscovite assemblages from equivalent rocks to the southeast that contain sillimanite-orthoclase assemblages.

The present structures apparently developed in two or more stages. Major isoclinal and recumbent folds were formed first; these were deformed at the thermal peak of metamorphism. Displacement on the Honey Hill fault continued after the thermal peak of metamorphism.

INTRODUCTION

The Hamburg quadrangle (fig. 1) is underlain by an exceptionally varied suite of rock units that includes representatives of nearly all the major stratigraphic and granitic units known in eastern Connecticut. This suite of rocks is unusually well exposed, particularly in extensive tracts of forested land enclosed in the boundaries of the Nehantic State Forest, Devil's Hopyard State Park, Stone Ranch Military Reservation, and the Yale Engineering Camp. However,

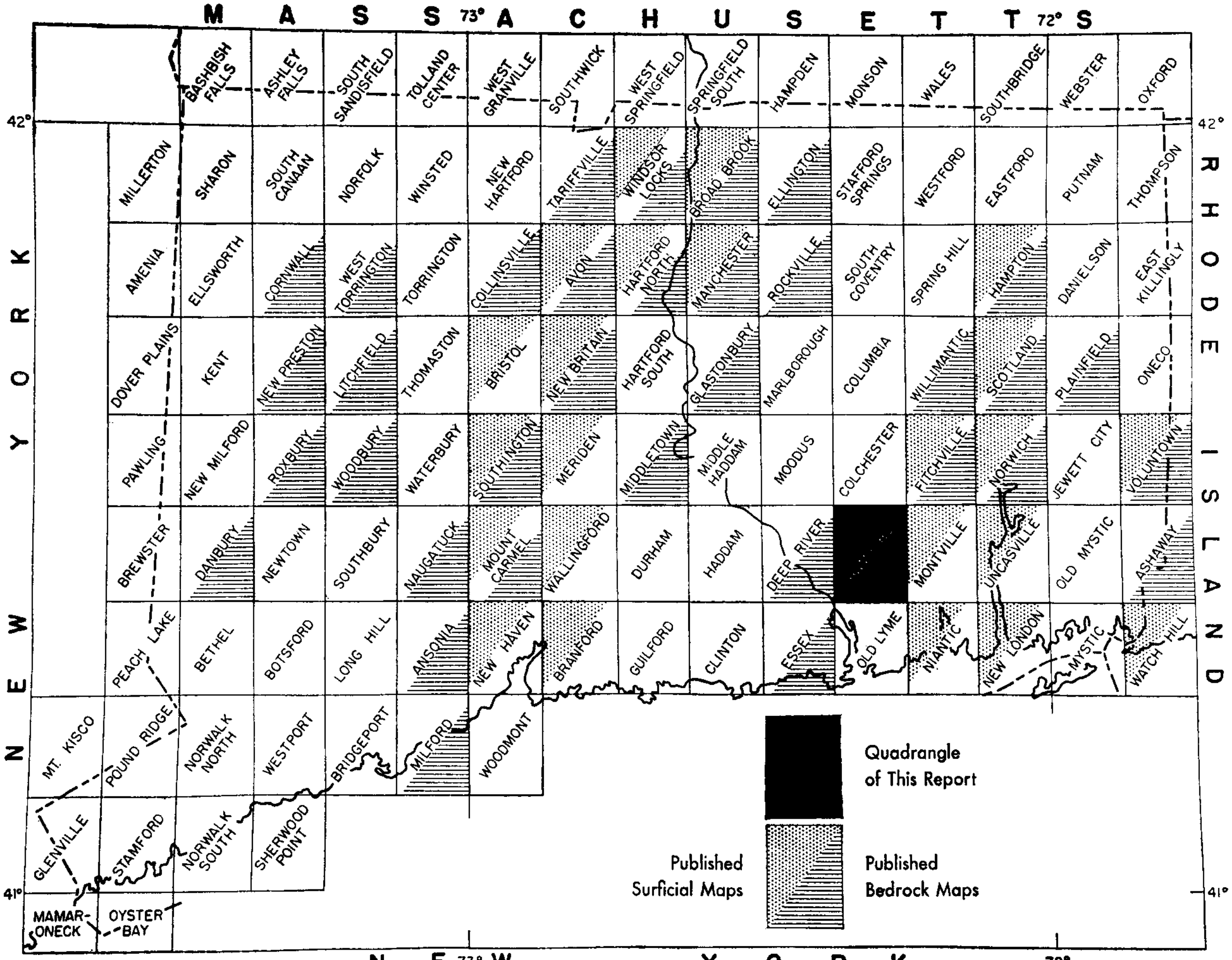

Fig. 1. Index map of Connecticut showing the location of the Hamburg quadrangle and of other published quadrangle maps.

the year-round cover of mountain laurel (*Kalmia latifolia*) is a considerable hindrance to mapping detailed relationships in some of these tracts. The structural complexity and stratigraphic variety displayed in the bedrock are such that earlier small-scale mapping (Percival, 1842; Rice and Gregory, 1906; Gregory and Robinson, 1907; Foye, 1949; Rodgers and others, 1956) was not successful in outlining the essential features of the local bedrock geology.

Although the bulk of the mapping for the present report was done during the summers of 1957 and 1958, some time was spent in 1959, 1961, and 1963 as the mapping of the contiguous Lyme, Colchester, and Montville quadrangles (the last by Richard Goldsmith) progressed. Field work and the cost of thin sections was supported by the Connecticut Geological and Natural History Survey; reconnaissance in the Colchester quadrangle and the cost of thin sections of the Brimfield Formation were supported by Geological Society of America Grant 799-58. I am grateful to Richard Goldsmith of the U.S. Geological Survey for extensive cooperation and discussion of the problems of stratigraphic mapping in the coastal fringe of eastern Connecticut, to Lawrence Ashmead for able assistance in 1958, to H. R. Dixon and G. L. Snyder for information on the relationships of the younger units in areas to the northeast, and to John Rodgers for helpful discussion of many problems.

ROCK UNITS

Descriptive procedures

Bedrock exposures are exceptionally abundant throughout most of the quadrangle; the density of foliation symbols on the map is an index of the ratio of bedrock exposure to Pleistocene cover. The mineral assemblages are typical of the sillimanite-almandine-muscovite and sillimanite-almandine-orthoclase subfacies of metamorphism (Turner and Verhoogen, 1960, p. 548-549) except where obviously retrograde assemblages are present, particularly along the Honey Hill fault. The high metamorphic grade must be considered in comparing these stratigraphic units with their counterparts in areas to the north where the metamorphic grade is lower.

The descriptions of the rock units are based on a study of approximately 400 thin sections. Throughout this report, colors of minerals as seen in thin sections of standard thickness, as well as colors of hand specimens of rocks, are described by citing the most nearly similar color on the Rock Color Chart distributed by the Geological Society of America (Goddard and others, 1948). The modal analyses in the tables were made on thin sections in which both plagioclase and potassium feldspar were stained (Bailey and Stevens, 1960). The modal analyses or modes were obtained by counting 1,000 points on a grid of points 0.5 x 1.0 mm. This insured that the stated mode is an accurate and reproducible indication of the composition of the thin section and, for all but the coarser grained rocks, that the mode is an accurate estimate of the composition of the hand specimen. As most of the rocks are layered, the hand specimen represents the composition of a single bed or layer and not necessarily the composition of the outcrop from which it was taken. Thus, the modes indicate the composition of the most important kinds of rocks found in a particular unit or outcrop; other types of rock may be present, as indicated in the descriptions.

Where the mineralogy of a rock is indicated by a series of hyphenated mineral names (for example, hornblende-plagioclase-epidote amphibolite), 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 by using the name(s) of accessory mineral(s) as adjectives placed before the hyphenated terms (for example, epidotic hornblende-plagioclase amphibolite; sillimanitic biotite schist).

Outcrop locations

Throughout the report, locations of outcrops are indicated by citing the ninth of the quadrangle in which each is to be found. The numbering convention followed in designating these ninths is indicated in figure 2. Locations are also identified by citing the structural feature in which the particular rock unit is found; the positions of these features are indicated on plate 1. The location of outcrops from which modally analyzed specimens were taken is indicated in each table in terms of two coordinates, *XN* and *XE*. The *XN* number is the distance of an outcrop (in thousands of feet) from the southern boundary of the quadrangle (lat 41°22′30″ N); the *XE* number is the distance of an outcrop (also in thousands of feet) from the western boundary of the quadrangle (long 72°22′30″ W).

Hebron Formation

The belt of Hebron Formation that crosses the northwestern quarter of the quadrangle can be traced westward and northward to the type locality of the Hebron Formation (see Lundgren, 1963a, p. 4). In the Hamburg, as in the Deep River quadrangle, the Hebron consists of interbedded quartz-biotite schist and gneiss and calc-silicate gneiss. The two rock types generally are found together in any large outcrop, the calc-silicate layers in resistant beds, with a thickness measured in inches, lying between thicker layers of quartz-biotite

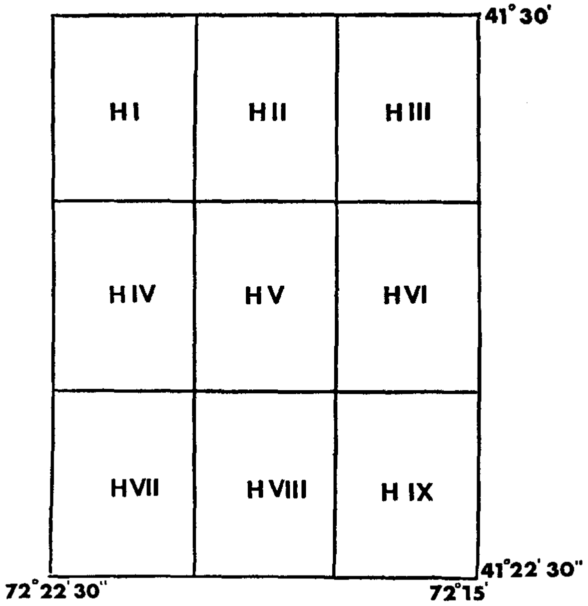

Fig. 2. Index map showing the division of the Hamburg quadrangle into ninths.

schist or gneiss. The Hebron lies in the axial zone of the recumbent Chester syncline and immediately above the Honey Hill fault zone as well, with the result that small folds are widespread in the Hebron and a fabric at least moderately cataclastic is extensively developed.

The quartz-biotite schist layers are medium-dark-gray to brownish-gray, medium-fine-grained (½ to 1 mm), equigranular rocks, notably uniform except for scattered augen of plagioclase and thin laminae of quartz. These layers (table 1, samples 1-3) normally consist of 30 to 40 percent quartz, 20 to 40 percent biotite (Z = moderate reddish brown), and 25 to 35 percent plagioclase (oligoclase or andesine). Microcline is present in many layers and muscovite in a few. Zircon, apatite, and graphite are the only common accessory minerals; garnet is not present.

These biotitic layers commonly display a moderately to strongly developed cataclastic fabric, particularly within a few hundred feet of the Brimfield Formation or the Canterbury Gneiss. This fabric is best developed in rock from outcrops in which dark-greenish-gray laminae of aphanitic ultramylonite or bluish-gray plagioclase augen are conspicuous. It is characterized by laminae of very fine-grained quartz and biotite and by round plagioclase grains enclosed in a sheath of very fine-grained minerals.

The calc-silicate gneisses are resistant, greenish-gray to moderate-gray layers, coarser grained (1 to 3 mm) and less uniform than the quartz-biotite schist layers. They commonly outline small folds, particularly toward the contacts between the Hebron and the adjacent units. Near these contacts the calc-silicate gneisses display a strongly developed laminar structure marked on weathered surfaces by the contrast between white plagioclase laminae and dark-green hornblende-diopside laminae. Although these laminar gneisses are interbedded with cataclastic schist, they do not generally display an obviously cataclastic fabric.

Table 1.—Modal analyses (in volume percent)[1] and mineral assemblages of the Hebron Formation

Sample no.	1	2	3	4	5	6
Field no.	H14-8	H7-8	H57-1	H55-7	H37-9	H29-9
quartz	39.2	38.2	31.2	38.9	x	x
microcline	—	8.4	0.2	—	x	x
plagioclase	34.0	34.0	23.8	32.8	x	x
biotite	27.0	19.0	44.5	5.1	x	x
hornblende	—	—	—	22.5	x	x
diopside	—	—	—	—	x	x
calcite	—	—	—	—	x	x
non-opaque accessory	x	0.2	0.3	0.7	x	x
opaque accessory	x	0.2	x	x	x	x
XN[2]	32.65	28.9	32.5	42.2	33.25	32.25
XE[2]	13.0	6.8	12.3	20.65	8.9	8.3

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

The mineral assemblage of the calc-silicate gneisses (table 1, samples 4-6) is exceptionally varied. However, virtually all of them contain the following minerals: 30 to 60 percent quartz, 20 to 30 percent plagioclase (labradorite), 10 to 20 percent hornblende (Z = dusky yellow green), and relatively small amounts of diopside, biotite (Z = moderate reddish brown), and sphene. Many that contain all these minerals also contain potassium feldspar, calcite, and scattered garnet.

Canterbury Gneiss

The Canterbury Gneiss in the Hamburg quadrangle is part of a body of quartz-feldspar gneiss that extends northeastward into the Fitchville quadrangle where Snyder (1964) has mapped it as Canterbury Gneiss. This body of gneiss is on strike with and similar to the type Canterbury Gneiss (Dixon and Shaw, 1965; Snyder, 1961), but it is not continuous with type Canterbury at the surface (Snyder, 1964).

The best sections across the Canterbury may be seen along traverses across Dolbia Hill (fig. 2, HV) or along the more easily accessible power transmission line north of Route 82 (HIV). Traverses across any such area of good outcrop illustrate that the belt mapped as Canterbury is underlain by at least two distinct types of granitic rock. The more common and more distinctive sort, which is regarded as typical of this belt, is heterogeneous medium- to dark-gray augen gneiss (table 2, samples 1-3) in which augen of feldspar ½ cm to 5 cm long lie in a medium-grained (1 to 2 mm) matrix of quartz, feldspar, and biotite. These augen are orange-pink Carlsbad-twinned microcline crystals and light-gray Carlsbad-twinned plagioclase crystals. Although the abundance and size of these augen vary markedly, they give the Canterbury Gneiss its distinctive appearance here as in the Deep River quadrangle. The less common type of rock is pink or gray muscovite gneiss containing less biotite than the augen gneiss and lacking conspicuous feldspar augen. The two types are interleaved with one another and with layers of calc-silicate gneiss mapped as Tatnic Hill Formation.

The Canterbury Gneiss lies entirely within the zone of blastomylonitic rocks

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

Sample no.	1	2	3	4
Field no.	H126A-5	H17-7	H78-7	H125-5
quartz	22.1	28.8	40.0	32.0
plagioclase	46.2	39.6	34.8	39.6
microcline	16.9	9.7	14.0	20.0
biotite	14.2	20.2	10.5	x
muscovite	0.2	1.4	—	8.4
non-opaque accessory	0.3	0.2	0.5	x
opaque accessory	0.1	0.1	0.2	—
XN[2]	30.0	44.8	22.75	33.2
XE[2]	11.75	28.15	3.1	14.95

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

above the Honey Hill fault, and generally displays cataclastic features. Therefore, the distinctive attributes evident here may in part be related to cataclasis and may not be present in Canterbury Gneiss away from the fault zone. Because of this, thin sections are described in some detail.

Thin sections of most specimens of augen gneiss have the following characteristics: The augen are Carlsbad-twinned crystals of microcline or plagioclase (calcic oligoclase) set in a matrix of quartz, plagioclase, microcline, biotite (Z = dusky brown, 5YR 2/2), together with variable, although minor, amounts of muscovite, epidote, zircon, apatite, garnet, and opaque minerals. The Carlsbad-twin composition plane of the augen is parallel to the foliation. The augen have irregular boundaries as seen in cross-section, and are spotted with inclusions of the matrix minerals. The microcline augen generally show well developed albite and pericline twins also, and the borders typically are embayed by myrmekite (plagioclase-quartz intergrowth), which rims the crystal and is evident in hand specimens as a white rim around the microcline. The plagioclase augen generally display weakly developed albite and pericline twins and an indistinct zonal structure is evident between crossed polars.

These augen are set in a matrix cut by laminae of exceptionally fine-grained material (maximum grain size 0.05 mm) in which biotite forms a delicate network between quartz and feldspar grains. These laminae are crushed matrix material; they generally are parallel to the foliation but are warped around the borders of the augen.

The muscovite gneiss is a medium-grained rock consisting of more than 85 percent antiperthitic plagioclase (oligoclase), quartz, and perthitic microcline; muscovite constitutes as much as 10 percent of the rock (table 2, sample 4); garnet and biotite are the principal accessory minerals. The feldspars in this rock are distinctly different from those in the augen gneiss; the rock may be younger than and essentially unrelated to the Canterbury Gneiss.

Brimfield Formation[1]

NOMENCLATURE AND AREAL DISTRIBUTION

The Brimfield and the Tatnic Hill Formations are believed to be approximate equivalents, but they are mapped as separate units wherever they are separated physically by the Hebron Foundation (see Lundgren, 1963a, 1964; Snyder, 1964). The assignment of units to one or the other of these formations is more difficult in the narrow belt where they are exposed in the Hunts Brook syncline (fig. 2, HVI, HVIII). The conventions followed in mapping these units are based on those used in mapping the Essex quadrangle (Lundgren, 1964). Where there is no basis for mapping Brimfield as distinct from Tatnic Hill, as in the Hunts Brook syncline northeast of Grassy Hill Road (HVI), a single hyphenated symbol (Ot-b) is used on plate 1 to indicate the schist unit that overlies the Monson Gneiss.

The Brimfield Formation in the northwestern quarter of the quadrangle can be traced northward to the type locality of the Brimfield Schist (Emerson, 1898, 1917; Callaghan, 1931; Lundgren, 1963a, p. 6) or westward and southward

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[1] The term *Brimfield Formation* is used here in preference to the original designation, *Brimfield Schist,* because the Brimfield comprises many types of metasedimentary rocks.

around the Selden Neck dome to link up with the belt of Brimfield in the Hunts Brook syncline (Lundgren, 1964, fig. 2). The Brimfield in the northwestern quarter of the quadrangle — described first because the metamorphic grade is lower and the exposures more extensive than in the southeastern quarter of the quadrangle — consists largely of biotite-muscovite schist and interbedded layers of garnetiferous quartz-biotite schist, calc-silicate rock, and amphibolite, which locally constitute mappable units. All of these rock types are exceptionally well displayed in a section along the valley of the Eight Mile River in Devil's Hopyard State Park (HI); this section lies on the overturned limb of a recumbent syncline and is assumed to be inverted. The descriptions that follow supplement those in the Deep River quadrangle report, as the rock units are continuous with the Bashan Lake belt of Brimfield (Lundgren, 1963a, p. 7-8).

BIOTITE MUSCOVITE SCHIST (Obm)

The biotite-muscovite schists are medium-grained, lustrous medium-dark-gray rocks, generally spotted with small (2 mm) crystals of very dark-red garnet and larger (1 to 2 cm) augen of plagioclase and muscovite. These schists commonly are coated with light-brown to dark-yellow-orange iron oxides, particularly in man-made exposures. The best exposed and probably most common type of schist (table 3, samples 1-6) consists of 35 to 45 percent quartz, 40 to 50 percent micas, 10 to 15 percent plagioclase (oligoclase), and 1 percent garnet, and accessory graphite, tourmaline, iron sulfides (pyrite and pyrrhotite), and sillimanite. Biotite is the more abundant mica in these schists; the ratio of biotite to modal muscovite generally lies between 2/1 and 1/1.

Outcrops of these resistant schists commonly are undercut along layers of less resistant schist that is not well exposed in natural outcrops. These less resistant schists (table 3, samples 7-9) contain less plagioclase (0 to 5 percent) and more mica (30 percent biotite and 30 to 40 percent muscovite) than the more resistant schists. Muscovite commonly is more abundant than biotite, and iron sulfides probably are even more abundant than in the resistant schists, as suggested by the deeply rust-stained character of the micaceous-schist outcrops.

The biotite-muscovite schist in a zone 20 to 30 ft thick, above the contact of the Brimfield with the Hebron Gneiss, generally is moderately cataclastic, displaying the same attributes in outcrop and thin section as those of the biotite-muscovite schists of the Tatnic Hill Formation along the Honey Hill fault. This cataclastic Brimfield facies is exceptionally well exposed for approximately 2 mi. along the contact with the Hebron Gneiss west of the entrance to Devil's Hopyard State Park (fig. 2, HI). In outcrop this Brimfield facies typically displays thin laminae of fine-grained quartz and plagioclase, as well as plagioclase augen with highly attenuated ends. The facies differs from normal schist, as the augen of plagioclase and muscovite are set in a matrix of fine-grained quartz and biotite with much of the biotite in a network of extremely ragged grains, 0.1 to 0.5 mm across rather than the normal 0.5 to 1.0 mm. These differences appear to have resulted from the crushing and recrystallization of quartz and biotite that now appear as a matrix in which deformed crystals of muscovite and plagioclase are set.

AMPHIBOLITE (Oba)

Amphibolite layers occur in a zone in the lower half of the Brimfield Formation. Outcrops of these amphibolites (Devil's Hopyard State Park, fig. 2, HI) are distinctively rounded and pitted and are spotted locally with nodules of

Table 3.—Modal analyses (in volume percent)[1] and mineral assemblages of the Brimfield Formation

	Biotite-muscovite schist (Obm)									(Obqb)			(Obm, Ot-b)		Amphibolite (Oba)[2]			
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Field no.	H44-0	H73-1	H76-1	H71-7	H35-8	H54-7	H38-9	H51-1	H30-9	H21-8	H37-9	H70-1	H6-0	H17-0	D20a9	D20b9	D23-9	H457
quartz	40.3	43.9	39.1	33.9	36.3	38.0	37.4	29.3	23.6	42.0	24.4	x	24.2	43.7	—	—	0.8	0.8
plagioclase	16.4	14.4	13.9	17.4	9.8	26.2	0.4	3.2	1.8	31.2	44.8	x	35.0	28.6	23.9	65.2	28.2	37.2
K feldspar	—	—	—	—	—	—	—	—	—	—	21.2	—	22.2	9.6	—	—	—	—
biotite	29.6	20.2	22.3	30.6	29.3	22.0	27.6	33.8	25.0	21.0	4.8	—	12.4	15.4	—	—	—	—
muscovite	11.4	12.9	22.6	16.4	15.6	13.2	33.8	29.7	43.4	4.4	2.4	—	—	—	—	—	—	—
garnet	1.2	6.0	0.6	0.3	1.4	0.4	—	1.7	5.6	0.4	x	x	1.1	2.2	—	—	—	—
sillimanite	—	—	—	—	6.3	—	—	—	—	—	—	—	x	0.4	—	—	—	—
hornblende	—	—	—	—	—	—	—	—	—	—	—	x	—	—	75.1	34.4	42.0	61.0
diopside	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	27.6	—
non-opaque accessory	x	0.8	0.1	0.3	x	x	x	1.1	x	0.8	0.4	x[3]	0.1	0.1	x	x	1.0	0.8
opaque accessory	1.2	1.8	1.5	1.1	1.4	0.2	0.8	1.2	0.6	0.2	2.0	—	x	x	1.0	0.4	1.4	0.2
XN[4]	35.65	37.25	30.55	37.15	44.25	44.9	42.6	40.9	32.4	40.8	33.6	36.25	17.8	16.2	40.5	40.5	36.7	38.35
XE[4]	9.6	8.85	4.2	9.8	10.5	19.7	19.0	17.65	8.2	8.85	8.85	9.45	31.5	21.2	26.3	26.3	28.7	31.4

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Samples 15, 16, and 17 are amphibolite from the Deep River quadrangle; they are from the same amphibolite layer (Oba) as sample 18, which is from the Hamburg quadrangle (fig. 2, HI). The modal analyses of samples 15, 16, and 17 were incorrectly labelled in the Deep River Quadrangle Report (Lundgren, 1963a, p. 8) and are reprinted here in correct form.

[3] Epidote and sphene.

[4] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

epidote-garnet-plagioclase aggregate. Hand specimens have a distinctive appearance, with lustrous black hornblende grains (1 to 3 mm) scattered through a matrix of finer grained plagioclase (andesine and labradorite), accompanied by minor sphene, calcite, and epidote. The amphibolites are interbedded with biotite-muscovite schist and garnetiferous quartz-biotite schist. Modal analyses of samples of this unit are listed in table 3 (samples 15-18) where typographical errors in an earlier publication (Lundgren, 1963a, table 2, samples 15-17) are corrected.

GARNETIFEROUS QUARTZ-BIOTITE SCHIST AND GNEISS (Obqb)

The stratigraphically lower half of the Brimfield Formation contains numerous layers of well bedded, light-gray, granular quartz-biotite schist and gneiss. These rocks (table 3, samples 10 and 11) consist of quartz (30 to 40 percent), plagioclase (30 to 40 percent), biotite (5 to 20 percent), and variable although minor amounts (less than 5 percent) of muscovite and garnet. These rocks are similar to Hebron quartz-biotite schist except for the presence of garnet.

CALC-SILICATE GNEISS

Thin layers of calc-silicate rock having a variety of mineral assemblages occur throughout the formation but are too thin to map. The most typical outcrops of this rock are located in Eight Mile River (fig. 2, HI) where white calc-silicate rock (table 3, sample 12) is interbedded with typical Brimfield schist.

BIOTITE-GARNET-ORTHOCLASE-SILLIMANITE SCHIST (Obm, Ot-b)

The Brimfield in the core of the Hunts Brook syncline probably includes high-grade equivalents of all the rocks described above. However, the exposures are poor, and only a part of the section is exposed. The principal type of rock here is friable, rust-stained, graphitic biotite-garnet-orthoclase-sillimanite schist, which superficially resembles some of the biotite-muscovite schist. It differs from the latter, however, as it is coarser grained and migmatitic and contains sillimanite and orthoclase (table 3, samples 13 and 14) rather than muscovite. Although muscovite is present in some samples, it apparently occurs only as an alteration product of plagioclase and sillimanite. These non-resistant schists are interleaved with more resistant migmatitic gneisses consisting largely of granitic and pegmatitic folia that are spotted with large garnets and interleaved with biotite-sillimanite schists.

Tatnic Hill Formation

AREAL DISTRIBUTION

The Tatnic Hill Formation occupies two narrow belts, one along the Honey Hill fault, the other in the Hunts Brook syncline. The northern belt can be traced westward around the Selden Neck dome to meet the belt in the Hunts Brook syncline. The northern belt can also be traced northeastward through the Fitchville and Norwich quadrangles (Snyder, 1961, 1964) to the Scotland and Danielson quadrangles (fig. 1) where equivalent rocks have been mapped as Tatnic Hill Formation (Dixon, 1964; Dixon and Shaw, 1965) and described as the upper part of the Putnam Group (Putnam Gneiss of Rice and Gregory, 1906). Therefore the unit that is mapped as Putnam Gneiss in the Deep River and Essex quadrangles (Lundgren, 1963a, 1964) is hereafter to be regarded as Tatnic Hill Formation. The rocks in the belt north of the Honey Hill fault are described first, as the metamorphic grade is lower there than in the Hunts Brook syncline. However, the rocks in this belt have been modified by crushing and partial recrystallization of the primary metamorphic minerals.

North of the Honey Hill fault, the Tatnic Hill Formation can be divided informally into upper and lower parts; these are not distinguished on the map (pl. 1). The upper part consists largely of a biotite-schist unit capped by a calc-silicate gneiss that is mapped separately (Otcm); the lower part consists of highly sillimanitic and garnetiferous schists. The best sections across these units are exposed south of Dolbia Hill (fig. 2, HII, HV) or in the vicinity of Malt House Brook (HIV).

UPPER PART (Otm, Otcm)

The principal unit in the upper part of the Tatnic Hill Formation comprises medium-dark-gray biotite schist and gneiss (Otm) in which isolated lenses of dark-gray amphibolite and thin layers of lustrous gray but rust-stained muscovite-biotite schist are present. This unit may be equivalent to the Yantic Member of Dixon (1964, p. 4) or to the upper part of the lower member of the Tatnic Hill Formation (Dixon, 1964; Dixon and Shaw, 1965). The biotite schists are medium-grained (1 to 3 mm) rocks that typically consist of 65 to 70 percent quartz and plagioclase (oligoclase), 20 to 25 percent biotite ($Z =$ brownish black or moderate brown), and 5 to 10 percent muscovite (table 4, samples 1-3). Magnetite is the most common accessory mineral; garnet and sillimanite are rarely present and then only in trace amounts. The biotite gneisses are more nearly equigranular than the schist; they consist of quartz and plagioclase (>80 percent), biotite (10 to 15 percent), and little or no muscovite (table 4, sample 4). The muscovite-biotite schist layers (table 4, sample 5) contrast with the biotite schist and gneiss, because they contain more muscovite (15 to 20 percent) and more garnet, and in outcrop generally are rust stained rather than gray. The amphibolites are dark-gray rocks consisting of approximately equal amounts of hornblende and plagioclase (labradorite); they generally are in isolated lenses, which in some places are widely separated boudins, or in isoclinal folds involving layers that cannot be traced more than a few feet.

The thin calc-silicate unit (Otcm) that caps this schist unit consists of well bedded gray or greenish-gray diopsidic and hornblendic quartz-plagioclase gneiss (table 4, sample 10) interleaved with the schist below and with Canterbury Gneiss above. This unit is mapped as part of the Tatnic Hill Formation because it is interleaved with the schists; it may be in the same stratigraphic position as the Fly Pond Member described by Snyder (1961, 1964).

LOWER PART (Otm)

The lower part of the Tatnic Hill Formation is not well exposed. It apparently consists of sillimanitic and garnetiferous biotite schist containing layers of amphibolite and gray biotite schist. Presumably it is equivalent to the lower member mapped by Dixon (1964, p. 4). The sillimanitic schists are medium-coarse-grained rocks in which sillimanite prisms constitute up to 20 percent of some samples (table 4, sample 6). The garnetiferous schists are distinctive, well foliated rocks in which large garnets (5 to 10 mm) are arrayed between laminae of fine-grained quartz, plagioclase, and biotite. Garnet commonly constitutes up to 20 percent of the rock (table 4, sample 7); sillimanite generally is present in the garnet and in the larger prisms, which are largely altered to an aggregate of fine-grained white mica.

Table 4.—Modal analyses (in volume percent)[1] of the Tatnic Hill Formation

	Schist (Otm, Ot-b)									Otcm	Otg	Otc
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12
Field no.	H12-8	H24-9	H83-7	H81-7	H82-7	H18-8	H64-1	H2-9	H16-0	H54-1	H69-8	H68-8
quartz	37.8	37.1	43.0	22.2	29.7	7.6	32.3	44.2	31.3	34.3	31.6	39.2
plagioclase	28.6	32.8	33.7	59.3	25.6	9.2	34.3	23.9	12.7	31.6	53.0	31.2
microcline	—	—	—	—	1.1	—	—	3.6	x	5.8	1.2	—
biotite	22.8	22.9	19.2	16.2	14.0	54.8	14.0	25.8	37.3	5.8	13.1	5.2
muscovite	9.0	6.3	4.0	1.5	18.5	0.6	0.9	—	—	—	—	3.4[2]
sillimanite	—	0.1	—	—	—	26.4	x	—	14.0	—	—	—
garnet	—	0.2	—	—	3.1	—	12.6	2.2	1.5	—	—	—
chlorite	—	—	—	—	7.7[2]	—	4.2[2]	—	—	—	—	2.6[2]
hornblende	—	—	—	—	—	—	—	—	—	21.0	—	16.4
non-opaque accessory	0.3	x	x	0.6	0.4	0.4	0.2	0.3	0.1	1.5	0.2	2.0[3]
opaque accessory	1.5	0.3	x	0.2	x	0.2	1.6	x	3.1	x	0.9	x
XN[4]	30.1	28.1	26.6	27.3	27.15	26.65	24.1	21.1	4.25	31.0	0.25	0.25
XE[4]	15.3	11.1	8.4	8.3	8.4	12.60	6.7	12.75	16.2	14.6	13.45	13.45

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Mineral is an alteration product.

[3] Sample contains 1.6 percent diopside, included as an accessory mineral.

[4] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

BLASTOMYLONITIC ROCKS

All of these rocks display a partially cataclastic fabric. The schists and gneisses contain conspicuous plagioclase augen up to 2 cm long and the schists contain muscovite grains up to ½ cm in length. Most specimens contain laminae and lenses of very fine-grained (less than 0.05 mm) quartz and biotite; these laminae are parallel to the foliation in the coarser grained layers and are curved around the plagioclase augen, quartz and plagioclase lenses, and garnet crystals. Muscovite flakes in these laminae generally are twisted and show tapered ends in cross section. They are the same size, however, as muscovite flakes in adjacent layers. Garnets are fractured and sheathed in finer grained material. These laminae clearly represent crushed but recrystallized material developed along planes of slippage parallel to the existing foliation. Therefore, these rocks are considered as blastomylonitic schists or gneisses. Locally, layers and dikes of aphanitic dark-greenish-black ultramylonite are present; this ultramylonite consists of angular fragments of quartz and feldspar set in a matrix of fine-grained micas and other minerals not identifiable in thin section.

Calc-silicate beds can be traced into dark-greenish-black laminar blastomylonite gneiss and ultramylonite in which may be seen a complete gradation from layers containing fractured minerals to layers displaying scattered angular fragments of quartz, plagioclase, and microcline in a nearly isotropic matrix of fine particles.

All of the blastomylonitic rocks contain minerals that represent alteration products of the primary metamorphic minerals. Plagioclase is clouded by a mesh of fine muscovite flakes and granules of opaque material. Biotite is interleaved with chlorite, which is laced with rutile needles and with granules of potassium feldspar and epidote (table 4, sample 5). Sillimanite prisms in the lower Tatnic Hill Formation are found as cores in masses of fine-grained muscovite, and garnets are cut by chlorite along fractures. Hornblende in the amphibolite and calc-silicate layers is cut by chlorite veins.

ROCK UNITS IN THE HUNTS BROOK SYNCLINE (Otm, Otc, Otg, Ot-b)

The Tatnic Hill Formation in the Hunts Brook syncline includes rock units that are high-grade counterparts of the units described above, but it also includes gneissic rocks not known to the north although they are present in the Essex quadrangle to the southwest.

Dark-gray, magnetite-bearing sillimanitic schists (table 4, samples 8-9) are found in contact with the Monson Gneiss. These schists are migmatitic rocks containing closely spaced folia of quartz, orthoclase, and myrmekitic plagioclase. Sillimanite is abundant in prisms up to 2 mm square and 5 mm long; garnet occurs in crystals up to 1 cm across. Rust-stained biotite-garnet-sillimanite-orthoclase schists are interleaved with the gray schist, but are not well exposed. All of the schists contain orthoclase; they do not contain muscovite except as a later alteration product. These schists differ in detail from the Brimfield schists but they can be mapped separately only where separated from the Brimfield by the gneissic units described below.

The gneissic rocks that occupy the central part of the Hunts Brook syncline are mapped as Tatnic Hill Formation because they are similar to gneissic units mapped in the Essex quadrangle as part of the Putnam gneiss (upper part). The best exposed and most distinctive unit is light-gray, medium-grained, equigranular plagioclase-quartz-biotite gneiss (Otg, table 4, sample 11) containing numerous thin layers of amphibolite. This unit is exposed along a line of small hills where its outcrops display complicated small folds. It is interleaved with widely spaced calc-silicate layers and biotitic-schist folia. The quartz-plagioclase gneiss is separated from the schists of the Brimfield Formation by gneisses (Otc) consisting of well bedded gray to greenish-gray calc-silicate rock (Otc, table 4, sample 12) and garnetiferous quartz-biotite schist or gneiss. The calc-silicate rocks are indistinguishable from Hebron calc-silicate gneiss; they are mapped as Tatnic Hill Formation because they are interbedded with garnetiferous gneiss not known to occur in the Hebron Formation. This is the mapping convention followed in the Essex quadrangle (Lundgren, 1964). The calc-silicate rocks consist of 50 to 60 percent quartz and plagioclase, 5 to 10 percent biotite ($Z =$ moderate red), together with variable amounts of hornblende ($Z =$ moderate olive brown) and diopside. The garnetiferous quartz-biotite schist is a granular quartz-plagioclase biotite rock spotted with large red garnets and interleaved with closely spaced white pegmatitic folia. The plagioclase in these rocks is extensively altered to sericite, the biotite and hornblende to chlorite.

Ivoryton Group

NOMENCLATURE

The Ivoryton Group is named here as a major unit comprising the following formations: Middletown Formation, Monson Gneiss, and New London Gneiss. This new group, called "the plagioclase gneisses" in the Deep River area by Lundgren (1962, p. 6), is so named because its three formations and their mutual relationships are exemplified in exposures within a circle of 5-mi. radius centered at Ivoryton in the Essex quadrangle (Lundgren, 1964). These exposures lie in quadrangles for which large-scale geologic maps are available (Lundgren, 1963a; 1964). The group is given formal status because the Middletown, Monson, and New London appear to constitute parts of a major stratigraphic unit that originally consisted of volcanic rocks together with associated intrusive rocks whose original relationships to the volcanics have been masked by the pervasive effects of high-grade metamorphism. The Ivoryton Group consists largely of plagioclase gneisses (Lundgren, 1962), although microcline-bearing gneisses do occur within it.

No one section displays all three formations. The Middletown Formation, which overlies the Monson Gneiss, generally is restricted to a north-south belt lying west of long 72°22′30″ W, whereas the New London Gneiss, which underlies the Monson, is restricted to an east-west belt lying east of long 72°22′30″ W. The Monson Gneiss, which occurs throughout most of eastern Connecticut and much of east-central Massachusetts, forms the unifying element of the Ivoryton Group. The Middletown Formation and the New London Gneiss display somewhat less continuity, and locally it is difficult to separate either of them from the Monson. Because of this, and because it is convenient to group the three units on small-scale maps or in discussions of regional structure, the group designation seems appropriate.

The upper boundary of the group is placed at the base of the Brimfield (Partridge Formation in Massachusetts, Robinson, 1963) or Tatnic Hill Formations, the lower boundary at the contact between the Mamacoke Formation and the overlying New London or Monson Gneiss. The relationships at these contacts are described in this report and in other publications by Lundgren (1963a, 1964).

MIDDLETOWN FORMATION (Omig, Omia)[2]

Interbedded amphibolite, anthophyllitic, or cummingtonitic gneiss and quartz-feldspar gneisses lying within a northward-plunging trough at the northern edge of the quadrangle (fig. 2, HI) are mapped as Middletown Formation. These rocks are indistinguishable physically from the type Middletown (Lundgren, 1963a, p. 11) and they lie in the same stratigraphic position in contact with the Brimfield Formation. However, the Middletown Formation in the Hamburg quadrangle (HI) lies on the inverted limb of the recumbent Colchester nappe (Dixon and others, 1963; Lundgren, 1963a, p. 28), where it structurally overlies and is isolated within an area of younger Brimfield Formation.

The rocks (Omia) that give the Middletown Formation its distinctive character are sharply banded gneisses consisting of black hornblende-plagioclase (labradorite)-(epidote)-amphibolite layers interleaved with light-colored anthophyllitic or cummingtonitic quartz-plagioclase layers (table 5, samples 2 and 3). The quartz-feldspar layers commonly are spotted with garnets (1 to 2 cm) or with prisms of light-brown anthophyllite or pale-green cummingtonite. Where these layers are folded the anthophyllite and cummingtonite are conspicuous; in unfolded layers they are less conspicuous and may be seen only by careful examination of foliation surfaces, particularly on light-colored layers adjacent to amphibolite. This unit also contains coarse-grained schistose layers consisting of anthophyllite and biotite, anthophyllite and cummingtonite, or cummingtonite and hornblende (see table 5 for representative assemblages).

Table 5.—Modal analyses (in volume percent)[1] and mineral assemblages in the Middletown Formation

Sample no.	1	2	3	4	5	6
Field no.	H31-9	H33-9	H32-9	H11-0	H12-0	H48-8
quartz	36.8	58.1	x	—	x	—
plagioclase	38.9	6.0	x	x	x	x
microcline	16.1	—	—	—	—	—
biotite	8.2	14.5	—	x	x	—
anthophyllite	—	13.0	—	x	x	—
cummingtonite	—	—	x	x	—	—
hornblende	—	—	x	—	—	x
garnet	—	8.3	x	—	x	—
non-opaque accessory	x	0.1	x	x	x	x
opaque accessory	x	x	x	x	x	x
XN[2]	44.8	44.25	44.3	44.1	45.25	45.1
XE[2]	9.85	9.6	10.6	9.8	7.7	10.2

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

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[2] The term *Middletown Formation* is used here in preference to the original designation, *Middletown Gneiss*, because the Middletown comprises many types of metasedimentary and metavolcanic rocks.

The Middletown also includes a unit (Omig) consisting of medium-grained equigranular quartz-feldspar-biotite-garnet gneiss (table 5, sample 1), light gray on fresh surfaces but characteristically rust stained in outcrop. Thin beds of pale green quartz-diopside-garnet rock, amphibolite, and anthophyllitic gneiss and schist are interleaved with the quartz-feldspar gneiss.

MONSON GNEISS (Om, Oma, Omga)

The bulk of the Monson Gneiss is exposed in two belts on the flanks of the Selden Neck dome; these are continuous with the Hadlyme belt (DRQ) of Monson Gneiss (Lundgren, 1963a, p. 14-15). A narrow belt of Monson Gneiss is also exposed along the southeast limb of the Hunts Brook syncline; this belt is continuous with Monson Gneiss along the southern coast of the Essex quadrangle (Lundgren, 1964) that is continuous with the Monson Gneiss at the type locality.

The Monson Gneiss consists of light- to dark-gray, medium-grained (1 to 3 mm) biotitic and hornblendic plagioclase-quartz gneisses (Om) in which amphibolite layers (Oma) and pink alaskitic granite-gneiss layers (Omga) are common. Although the gneiss in some of the largest exposures is only weakly foliated or indistinctly layered, the bulk of the Monson apparently is well foliated and moderately to strongly layered. Amphibolite beds, which range from inches to 1 ft or more in thickness, give the gneiss a sharply banded appearance in those outcrops where they are present; they typically display boudinage. The pink granitic layers are particularly abundant in plagioclase gneiss close to the contact between the Monson and the adjacent Brimfield Formation and New London Gneiss; the narrow belt of Monson along the southern flank of the Hunts Brook syncline consists almost entirely of sharply interleaved gray plagioclase gneiss and pink granitic gneiss.

The typical plagioclase-quartz gneisses generally contain 25 to 35 percent quartz and 10 to 15 percent mafic minerals (table 6, samples 1-3). The layers

Table 6.—Modal analyses (in volume percent)[1] of the Monson Gneiss[2]

Sample no.	1	2	3	4	5
Field no.	H1-9	H129-1	H116-1	H25-8	H123-5
quartz	30.5	50.6	24.3	41.1	40.7
plagioclase	55.5	34.7	58.0	21.1	31.6
microcline	0.4	8.8	0.3	36.6	27.0
biotite	10.4	2.9	9.5	0.3	0.8
hornblende	1.9	3.0	6.5	—	—
non-opaque accessory	0.3	x	1.1	x	x
opaque accessory	0.8	x	0.3	0.8	0.2
XN[3]	1.2	11.5	15.05	35.15	20.0
XE[3]	11.2	22.0	17.0	24.6	7.25

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Samples 1-3 are from biotitic and hornblendic plagioclase-quartz gneisses (Om); samples 4 and 5 are from alaskitic granite-gneiss layers (Omga).

[3] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

with less biotite and hornblende contain up to 50 percent quartz. The mafic minerals are biotite (Z = olive gray), hornblende (Z = dusky grayish green to olive green), magnetite, and ilmenite. Both biotite and hornblende generally are present, but the ratio of biotite to hornblende varies widely; most of the differences apparent in adjacent gneiss layers in outcrop reflect differences in the relative abundance of biotite and hornblende. Plagioclase generally is calcic oligoclase or andesine; potassium feldspar is generally a minor constituent or is absent.

The alaskite gneiss mapped as part of the Monson Gneiss is well foliated or lineated, gray-pink to very pale-orange granitic gneiss consisting of quartz, microcline, and albite (table 6, samples 4-5) and traces of biotite and magnetite-ilmenite. The foliation is produced by the parallel arrangement of platy grains of quartz and the few grains of mafic minerals present in any one sample. The major alaskite gneiss member is exposed in scattered outcrops east and west of Salem (fig. 2, HIII). This unit has been mapped in the Montville, Fitchville, Norwich, and Uncasville quadrangles to the northeast and east (Goldsmith, 1963; Snyder, 1961, 1964, p. 11-12); it may also be represented by the alaskitic gneiss layers mapped south of Route 82 (HIV).

NEW LONDON GNEISS

Areal distribution. The New London Gneiss consists of pink or gray granitic gneisses, amphibolite, and aegerine-augite granite gneiss. It forms a discontinuous rim around the Selden Neck dome and has been traced eastward along the southern flank of the dome to the type locality of the New London Granite Gneiss of Gregory (Rice and Gregory, 1906; Goldsmith, 1961, and personal communication, 1964). Throughout the eight 7½-min. quadrangles in which the New London has been mapped it maintains a consistent stratigraphic position between the Monson Gneiss and the Mamacoke Formation, and it is therefore treated as a stratigraphic unit.

Of all the rock types found in the New London Gneiss, only one, the aegerine-augite granite-gneiss unit, is unique to it. This unit, the Joshua Rock Gneiss Member (Lundgren, 1963, p. 16), is the key to mapping the New London here as in the area to the east (Goldsmith, 1961), although it is not areally as extensive as the associated rocks. Therefore, the Joshua Rock Gneiss Member is described in some detail, and the stratigraphic relationships at two places where this member is well exposed are also described.

Joshua Rock Gneiss Member (nj). The Joshua Rock Gneiss Member is a light-to-medium-gray, medium-grained (1-2 mm) weakly foliated granite; it is extremely resistant and therefore is well exposed in long rounded outcrops along such ridge crests as Nickerson Hill (fig. 2, HVIII). Where fresh and fairly rich in aegerine-augite (as in the quarry east of Route 156 on the northern side of the Hamburg Fair Grounds, HVII), it has a distinctive appearance characterized by folia of smoky quartz, gray feldspars, and indistinctly aligned granules of lustrous black aegerine-augite and magnetite-ilmenite. Red hematite spots are conspicuous against this gray background, and are fairly characteristic of the Joshua Rock gneiss. Where finer grained and less fresh the rock is not easily recognized and can be identified with assurance only in thin section.

In thin section the aegerine-augite granite displays attributes that make it unique among the variety of granite gneisses in southeastern Connecticut. The

Table 7.—Modal analyses (in volume percent)[1] of the New London Gneiss

	Joshua Rock Gneiss Member (nj)					Granitic gneisses (n)						
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12
Field no.	H87-1	H101-1	H96-7	H81-8	H106-1	H19-9	H20-9	H407	H121-1	H81-1	H130-1	H112-5
quartz	43.1	42.4	43.6	40.0	34.1	49.6	47.4	40.5	42.6	38.9	39.4	17.3
plagioclase	21.7	25.4	20.8	5.6	26.3	10.5	6.1	24.6	21.4	31.5	27.4	45.8
microcline	25.6	27.2	27.4	48.4	33.6	36.0	41.2	29.7	31.2	27.0	29.8	—
aegerine-augite	5.8	2.2	7.4	1.0	2.5	(0.2)	—	—	—	—	—	—
amphibole	—	—	—	—	—	0.5	—	2.2	1.0	—	—	18.6
biotite	—	—	—	—	—	—	4.4	—	0.6	2.5	2.8	11.8
non-opaque accessory	x	1.0	0.4	0.8	0.5	0.9	0.2	1.7	1.0	0.1	x	1.6
opaque accessory	3.8	1.8	0.4	4.4	3.1	2.3	1.6	1.3	2.2	x	0.6	4.9
XN[2]	17.4	17.65	17.35	11.25	2.95	13.8	13.8	1.25	16.0	14.9	11.6	1.5
XE[2]	18.75	17.05	19.45	20.95	4.45	5.8	5.8	1.4	19.0	14.8	21.8	0.7

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

alkali feldspar occurs as a coarse mesoperthite, consisting of microcline and albite intergrown in the so-called flame perthite, and as separate grains of albite. The microcline-albite intergrowth in the perthite is so coarse that this albite is included with the separate grains of albite in the modal analyses (table 7, samples 1-5; see table 5 in Lundgren, 1963a). The aegerine-augite is easily recognized where it is abundant, but where present only as isolated grains it might be mistaken for green hornblende on cursory inspection. Although it displays variable optical properties, those shown in table 8 are representative.

The suite of accessory minerals is itself varied and distinctive; it includes magnetite and ilmenite rimmed with sphene; zircon in large irregularly shaped grains and in clusters of small euhedral crystals; rare-earth-bearing sphene; and conspicuous allanite. The accessory minerals commonly constitute 3 to 4 percent in the modal analyses (table 7).

Granitic gneisses (*n*). The granitic rocks accompanying the aegerine-augite granite include alaskite, hornblende granite-gneiss, and gray magnetite-bearing granite gneiss through which 3 to 4 percent biotite is evenly disseminated. Generally, these rock types are each finer grained than are similar rocks in other major map units, and all commonly display a suite of accessory minerals that makes them appear to be related to the aegerine-augite granite, plus monazite and xenotime. None of these rocks displays a perthite comparable to the mesoperthite in the aegerine-augite granite; instead, the microcline and albite or oligoclase are in separate grains. Modal analyses illustrate the character of each of these types of rock (table 7, samples 6-11; see also table 5 in Lundgren, 1963a).

Amphibolite (*na*). Although amphibolite layers are common in the New London Formation, they have not been examined in detail. Most of them are dark-gray hornblende-plagioclase rocks in sharply bounded layers a few inches to a few feet thick. They appear to be mineralogically simple rocks containing none of the minerals, such as diopside, garnet, cummingtonite, or epidote, that characterize many amphibolites in other units. The biotitic amphibolite listed in table 7 (sample 12) is not representative; it is exceptionally rich in biotite and quartz.

Section at Hamburg Cove. The best section across the New London Gneiss and adjacent units is exposed north of the southern part of Hamburg Cove (fig. 2, HVII). This section is overturned. Its stratigraphically lower half consists of aegerine-augite granite-gneiss (table 7, sample 5), which may lie directly on

Table 8.—Optical properties of aegerine-augite in Joshua Rock Member of the New London Gneiss

Pleochroism	Optical orientation
X = Dark yellowish green	X:c = 5°
Y = Light olive	Y = b
Z = Light olive brown	Optic axial angle
Absorption X > Y = Z	2V = 63° (negative)

the sillimanitic schists of the Mamacoke Formation; the contact is not exposed. The principal layer of aegerine-augite granite appears to be completely separated from an overlying layer of the same rock by a layer of biotitic amphibolite (table 7, sample 12). The upper half of the section consists of interleaved layers of gray granite-gneiss (table 7, sample 8), pink alaskite, pink microcline-rich pegmatite, and amphibolite. At least 25 percent and perhaps as much as 40 percent of the thickness of the upper half of the section consists of amphibolite layers, none of them thick enough to map separately. The overlying Monson Gneiss here consists of interbedded amphibolite and gray plagioclase-biotite-hornblende gneiss.

The Joshua Rock Gneiss Member (nj) can be traced in nearly continuous outcrop for 5 mi. east of this section. East of Nickerson Hill (HVIII) the Joshua Rock decreases in thickness and within the quadrangle it has not been recognized east of Beaver Brook (HVIII). Where the Joshua Rock is thin, as in the easternmost outcrops in this belt, it is not readily distinguished from the associated granitic gneisses and can be mapped only on the basis of careful petrographic work. As a consequence, the Joshua Rock Gneiss Member is likely to be unrecognized wherever it or the New London Gneiss as a unit is thin. East of Beaver Brook, the New London is less easily separated from the adjacent Monson Gneiss, as the New London consists of abundant amphibolite and subordinate alaskite and gray granite gneiss.

Section near Cedar Lake. The belt of New London Gneiss on the northern flank of the Selden Neck dome is best exposed west and northwest of Cedar Lake (fig. 2, HV, HVI). The most complete section is crossed on a traverse northward from the 180-ft hill north of Beaver Brook Road (HVIII) at coordinates XN 14.7, XE 19.0. The Mamacoke Formation on this hill is overlain by the characteristic interleaved amphibolite, pink alaskite, and gray granite gneiss, which are overlain by and interfinger with red-spotted light-gray aegerine-augite granite-gneiss (table 7, sample 3), which is in turn overlain by more of the interleaved amphibolite and granite. The upper part of the New London Gneiss here includes hornblendic plagioclase-quartz-biotite gneiss and thin quartzite; because of this and because of the tight folds in which these rocks are involved, the contact mapped (pl. 1) between the New London and the Monson here is schematic.

The elements of this section can be recognized as far west as Mt. Archer where the Joshua Rock Gneiss Member may be represented by rock in which the aegerine-augite has been completely altered (table 7, sample 6). North of the Cedar Lake section, the New London is involved in a fold outlined by the Joshua Rock Gneiss Member. That member here (table 7, samples 1-2) is particularly difficult to map, as it forms a narrow band in broad outcrops of relatively massive granite (table 7, samples 9-10) having much the same appearance as the aegerine-augite granite. The Joshua Rock Gneiss Member cannot be traced west of the 450-ft hill (HV), and it has not been recognized in the belt of New London Gneiss north of Darling Road. This belt consists of interleaved alaskite, amphibolite, and gray granite gneiss; it cannot be distinguished from the Monson Gneiss east of the Middlesex County Line.

Mamacoke Formation[8]

NOMENCLATURE

The upper part of the pre-New London sequence consists of one or more quartz-feldspar gneiss units and calc-silicate rocks and biotitic schists adjacent to the gneiss units. This part of the pre-New London sequence is mapped here as Mamacoke Formation, the gneiss and associated rocks having been traced eastward (see unit *bf* mapped by Goldsmith, 1963) to Mamacoke Island in the Thames River, the type locality of the Mamacoke Gneiss of Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907). The name Mamacoke Formation designates a unit overlain by the New London Gneiss and underlain by the Plainfield Formation, although it interfingers with the upper Plainfield. The contact between the Mamacoke and the New London generally can be placed without ambiguity; the contact between the Mamacoke and the Plainfield is more difficult to place. Where the uppermost Plainfield consists of a major quartzite unit, as in HIII (fig. 2) and eastward, the base of the Mamacoke is placed at the top of the quartzite. Where the uppermost Plainfield consists of gneisses in which quartzite is present only in thin discontinuous beds, the base of the Mamacoke is placed at the horizon that appears to represent that of the major Plainfield quartzites in the area to the east. This convention leads to some uncertainty in areas of complicated structure such as that in the central part of the quadrangle.

Gregory and Robinson (1907) mapped as Mamacoke some units, such as the Monson Gneiss, that are not equivalent to the type Mamacoke. Therefore, the present map (pl. 1) shows the Mamacoke Formation to be less widely distributed than the older maps indicate. The Mamacoke occupies three distinct belts, two on opposite flanks of the Selden Neck dome and the third on the northwestern flank of the Lyme dome. These belts are described first, followed by a description of the rock types occurring in them.

CANDLEWOOD LEDGE BELT

The belt of Mamacoke Formation on the southern flank of the Selden Neck dome is designated informally as the Candlewood Ledge belt. This belt has been traced eastward to the type locality at Mamacoke Island (R. Goldsmith, personal communication, 1965). A section across this belt at Candlewood Ledge (fig. 2, HVII) serves as a local standard section, as no section has been described at the type locality. Although the section at Candlewood Ledge is overturned, it clearly illustrates the sequence of rock units.

The stratigraphically lowest unit in the section is biotitic quartz-feldspar gneiss (mb) that constitutes more than half the thickness of the formation in most sections. Here the gneiss unit is estimated to be 300 to 400 ft thick. This gneiss lies against folded quartzite of the Plainfield Formation or against Sterling alaskite where the quartzite is not present. The gneiss is interleaved with pink alaskitic granite in the many outcrops displayed south of Candlewood Ledge. The upper part of the Mamacoke Formation is here a distinctive, extremely heterogeneous unit (mc) less than 300 ft thick. This unit consists of the following sharply contrasting types of rock: sillimanitic biotite schist (ms), sillimanitic nodular gneiss (mn), epidotic amphibolite and calc-silicate rock

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[8] The term *Mamacoke Formation* is used here in preference to the original designation, *Mamacoke Gneiss,* because the Mamacoke comprises many types of metasedimentary rocks.

(ma), and garnetiferous gneiss (kinzigite). All of these rocks are interbedded with one another and generally mapped collectively as a single unit (mc). This ensemble of distinctive rocks provides an excellent basis for separating the Mamacoke Formation from the quartz-feldspar gneisses of the New London. However, this unit (mc) is not well exposed, and the contact between the Mamacoke and the New London generally is covered.

East of Candlewood Ledge, the Mamacoke in this belt is less than 500 ft thick and not well exposed. The same sequence of units can be seen in several places, notably in cleared land south of Colt Cemetery (HVIII) or east of Beebe Cemetery (HIX). Farther to the northeast along this belt it is difficult to separate the Mamacoke Formation from the granitic units of the Sterling, as the biotitic quartz-feldspar gneisses (mb) are streaked with layers and lenses of pink granitic rock, and single outcrops appear to consist more of granite than of biotite gneiss.

BEAVER BROOK BELT

The Mamacoke Formation can be traced westward from Candlewood Ledge around the core of the Selden Neck dome, where it was previously mapped as part of the Plainfield Formation (?) (Lundgren, 1963a, 1964), into a narrow belt on the northern flank of the dome, a belt referred to as the Beaver Brook belt after Beaver Brook, which drains Cedar Lake (fig. 2, HV). Between Mt. Archer (HVII) and Cedar Lake the formation is not well exposed and the lower contact is difficult to place. North of Cedar Lake the formation is involved in fairly complicated folds so that all the principal rock types are well exposed over a considerable area on either side of Gungi Road (HV, HVI) and along the power-transmission line crossing that road. Although the stratigraphic sequence is obscured in this area by structural and possibly stratigraphic complications, the rocks are well exposed, so that the descriptions of some of the units are focused on samples from this area.

The Mamacoke is shown (pl. 1) as extending westward to the vicinity of Pleasant View Cemetery (HIV) and from there northeastward along the valley of the East Branch to Salem Four Corners (HIII). The section across the formation east of Salem Four Corners is much like that at Candlewood Ledge.

GRASSY HILL BELT

This belt, named for Grassy Hill (fig. 2, HVIII, HVIX), rims the Lyme dome. The Mamacoke Formation is less than 500 ft thick in this belt and not well exposed. This belt is not continuous at the surface with the other two belts, being separated from them by the Hunts Brook syncline.

BIOTITIC QUARTZ-FELDSPAR GNEISS (mb)

At least half the thickness of the Mamacoke Formation is made up of light-to-medium-gray, layered to indistinctly layered, equigranular (1 mm) biotitic gneisses consisting of 30 percent quartz, 50 to 60 percent feldspar (plagioclase/microcline ratio generally greater than 4/1), 5 to 10 percent evenly disseminated biotite, and conspicuous accessory magnetite (table 9, samples 1-6). Some layers contain hornblende as well as biotite. The gneiss unit is well exposed wherever foliation symbols are shown (pl. 1) in belts mapped as (mb); where this symbol is underscored ($\underline{\text{mb}}$) exposures are few but the gneiss is assumed to be the principal unit beneath the surficial cover.

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

	Biotitic quartz-feldspar gneiss (mb)					Nodular gneiss (mn)				Biotite schist			
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13
Field no.	H425	H96-1	H13-9	H14-9	H109-1	H49-1	H422	H94-7	H3-0	H43-0	H47-1	H2-0	H16B-9
quartz	27.6	32.6	33.6	34.1	31.6	32.6	40.0	26.5	34.2	38.9	26.5	32.0	38.0
plagioclase	55.8	51.1	47.9	53.4	29.2	40.1	22.8	35.6	23.4	39.8	39.1	38.2	32.5
microcline	7.4	8.0	10.2	0.3	32.6	15.3	27.2	31.2	37.8	—	—	x	—
biotite	7.4	6.6	4.2	11.4	4.9	8.0	1.0	3.9	3.4	19.4	10.3	28.4	20.9
muscovite	x	1.5[2]	2.4[2]	0.2[2]	0.2[2]	—	7.2	0.9	—	1.4	2.8	—	—
chlorite	—	—	0.9[2]	—	—	—	0.6	0.7	—	—	9.3[2]	—	—
garnet	—	—	—	—	—	—	—	—	—	—	—	0.2	8.5
sillimanite	—	—	—	—	—	—	0.4	x	0.4	x	8.4	x	—
hornblende	—	—	—	—	—	2.2	—	—	—	—	—	—	—
non-opaque accessory	0.7	x	x	0.2	0.1	0.7	x	0.6	x	0.5	0.3	0.1	x
opaque accessory	1.1	0.2	0.8	0.4	0.5	1.1	1.0	0.3	0.8	x	3.3	1.2	x
XN[3]	19.5	17.4	7.5	6.75	9.2	34.65	21.9	18.3	15.55	25.7	37.0	31.45	4.45
XE[3]	16.7	21.25	6.2	5.75	11.2	27.4	21.85	18.65	31.0	23.25	31.2	15.1	3.9

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Mineral is an alteration product.

[3] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

The gneiss generally is interleaved with sharply bounded layers of alaskite and less regular layers of pegmatite that appear as pink streaks on outcrop surfaces. Thin layers of black amphibolite are present locally. The gneiss generally is associated with granitic gneiss included in the Sterling Plutonic Group and, where granitic material is abundant, it is difficult to separate Mamacoke gneiss (mb) from Sterling gneiss (sgb).

CALC-SILICATE ENSEMBLE (mc)

General description. The upper part of the Mamacoke Formation and, less widely, the lower part as well, is a distinctive ensemble of rocks that includes interbedded layers of sharply contrasting mineralogy and bulk composition. It is characterized by calc-silicate rocks (ma) of great variety, sillimanitic biotite schist (ms), and nodular gneiss (mn). Each of these is mapped separately where feasible; elsewhere they are grouped in a single unit (mc).

Amphibolite and calc-silicate rocks (ma). The rocks most characteristic of the calc-silicate ensemble are amphibolites and calc-silicate rocks interleaved with schist and nodular gneiss. The amphibolites and calc-silicate rocks display extreme mineralogic and textural variability; most of them developed from carbonate-bearing sedimentary rocks, and their peculiar structural relationships (in HV, fig. 2) may have resulted in part from flowage of carbonate rocks in early stages of metamorphism and folding.

The amphibolites are well bedded to massive, granular, dark-gray rocks consisting of hornblende and plagioclase; they are streaked with lenses of epidote. Delicately laminar amphibolite composed of black hornblende laminae and white or gray quartz laminae is a characteristic but minor part of the amphibolite units. The amphibolites interfinger with coarse-grained black and white rocks consisting of quartz and plagioclase streaked with large black hornblende grains.

Coarse-grained calc-silicate rocks form layers and lenses in the amphibolite; some consist of large, dark-greenish-black hornblende prisms and massive aggregates of greenish-gray diopside. Others are granular aggregates of brown garnet, quartz, and diopside, while still others consist of quartz, epidote, hornblende, and calcite. Calc-silicate marble, not known to be exposed in natural outcrops but seen in an excavation on the power-transmission line east of Gungi Road (HV), is a coarse-grained aggregate of light-brown calcite spotted with greenish-gray diopside, light-olive-green epidote, dark-greenish-black hornblende, red garnet, and light-gray lenses of quartz. The marble apparently underlies the topographically low areas adjacent to outcrops of amphibolite and calc-silicate rock.

Nodular gneiss (mn). The amphibolites and calc-silicate rocks interfinger with light-colored quartz-feldspar gneisses (nodular gneisses, mn) containing ellipsoidal nodules of quartz-sillimanite aggregate. Isolated outcrops of nodular gneiss are indicated by small ellipses on the map (pl. 1). These gneisses are rust stained in some outcrops, nearly white in others; they are conspicuous because the nodules are resistant and stand out on weathered surfaces. Much of the nodular gneiss is rather uniform, resistant, and only weakly foliated; it is interleaved, however, with schistose micaceous layers in which the quartz-sillimanite aggregate occurs in flat lenses. A typical outcrop is located west of Gungi Road at the point (fig. 2, HV) where the power-transmission line crosses that road.

The matrix of the nodular gneisses generally is a granular aggregate of quartz, plagioclase, and microcline (table 9, samples 7 and 8). Minor biotite and muscovite are disseminated through this matrix. Plagioclase generally is clouded with fine particles of white mica and opaque minerals; biotite generally is interleaved with chlorite formed from the biotite. The nodules are smooth elongated ellipsoids aligned parallel to one another. Nodules up to 12 in. in length occur locally; nodules 3 to 4 in. long are common. The nodules consist of coarse-grained quartz in which sillimanite needles and muscovite flakes are dispersed. The sillimanite needles are perfectly fresh; they are randomly oriented in quartz, but in muscovite they occur as sheaves of needles in the centers of large flakes. The outer surface of the nodules commonly is coated with a silvery sheath of muscovite.

The nodular gneiss in the Lyme dome is similar to the rock described above except that muscovite is not present and the sillimanite occurs in quartz and in contact with microcline or orthoclase (table 9, sample 9).

Sillimanitic and garnetiferous biotite schist (*ms*). Sillimanitic biotite schist and garnetiferous biotite schist are intercalated with the amphibolites and nodular gneisses. The sillimanitic schists are lustrous light- to dark-gray, coarse-grained (2-4 mm) micaceous rocks consisting of 60 to 70 percent quartz and plagioclase, 20 to 30 percent biotite, and minor, although locally abundant, muscovite, sillimanite, and magnetite (table 9, samples 10 and 11). Kyanite is present in one sample. Potassium feldspar is found in the schists south of the isograd but muscovite is lacking (table 9, sample 12). Sillimanite is common and conspicuous in sheaves and irregular aggregates of white or light-brown needles that stand out on weathered surfaces; the sillimanite generally is intergrown with coarse aggregates of magnetite and is also common in biotitic foliation surfaces on which it appears as a mat of unoriented prismatic crystals.

Garnetiferous biotite schist generally is finer grained than the sillimanitic schist; it consists of quartz, plagioclase, biotite, garnet, and magnetite (table 9, sample 13). Garnet is in uniformly disseminated crystals 1 to 3 mm in diameter, commonly constituting 10 percent or more of the rock. Such rocks have been called *kinzigites.*

Plainfield Formation[4]

NOMENCLATURE AND DISTRIBUTION

The quartzites and associated rocks below the Mamacoke Formation clearly are comparable to, and in the same stratigraphic position as, the quartzites to which the name Plainfield quartz schist was given by Loughlin (1910; see also Rice and Gregory, 1906). Therefore, the principal quartzites in the quadrangle and the metasedimentary units found with or below them are mapped (pl. 1) as Plainfield Formation.

This formation is exposed in the axial region of the Selden Neck dome and

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[4] The term *Plainfield Formation* is used here in preference to the original designation, *Plainfield Quartz Schist,* because the Plainfield comprises many types of metasedimentary rocks.

on the northwestern flank of the Lyme dome. The stratigraphic relationships of the Plainfield units are obscured by abundant interleaving of granite and by the imperfectly understood structures which involve these units. Furthermore, it appears that the Hamburg quadrangle is located along a zone in which the sedimentary antecedents of the Plainfield quartzite units thinned abruptly or terminated: each of the thick quartzite units known to occur to the east (R. Goldsmith, personal communication, 1965) pinches out just east or west of the eastern edge of the Hamburg quadrangle.

In the Hamburg quadrangle the best section across the Plainfield Formation is exposed in Salem (fig. 2, HIII), on the north side of the axial surface of the Selden Neck dome, along a line extending southward from a point with coordinates XN 34.6, XE 29.0. This line is west of and approximately parallel to Shingle Mill, the stream that drains Shingle Mill Pond. A similar section may be seen along the eastern edge of the quadrangle north and south of Fairy Lake (HIII).

In the Salem section the contact between the Plainfield Formation and the overlying Mamacoke Formation is not exposed; the 1,000-ft section of Plainfield immediately below the Mamacoke consists largely of well bedded, vitreous, gray to white micaceous quartzite and feldspathic quartzite. Several beds of white calc-silicate quartzite also are present. A dark-gray biotite schist unit, 10 to 20 ft thick, occurs in the middle of this quartzite sequence and there are thinner layers of similar schist throughout. Some of these schists, as well as the micaceous bedding-plane folia in the quartzites, contain sillimanite.

This thick quartzite sequence is underlain by 200 to 300 ft of massive dark-gray biotitic quartz-feldspar gneiss (pbc) and additional schistose gneiss having thin, parallel folia of biotite. Thin layers of black amphibolite (table 10, sample

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

Sample no.	1	2	3	4	5	6	7	8	9
Field no.	H45-8	H5-7	H12-9	H10-0	H9-0	H1-0	H42-8	H41-8	H126
quartz	80.6	86.2	93.4	60.0	56.0	45.4	37.2	37.0	1.0
plagioclase	5.4	5.0	3.8	16.4	21.4	23.4	44.8	35.8	40.0
microcline	11.1	—	0.5	14.8	x	—	—	10.6	—
biotite	2.4	4.4	0.8	7.0	22.4	31.2	17.6	16.2	x
muscovite	0.7	2.8	1.5	—	—	—	—	—	—
chlorite	—	1.4	x	—	—	—	—	—	—
hornblende	—	—	—	—	—	—	—	—	57.0
sillimanite	—	—	—	x	0.4	—	—	—	—
non-opaque accessory	x	x	x	x	x	x	x	x	0.8
opaque accessory	—	—	—	0.4	0.2	—	0.2	0.4	1.4
XN[2]	1.3	33.65	10.8	3.7	0.1	33.95	6.6	4.0	32.35
XE[2]	25.6	28.8	8.3	26.7	23.9	33.7	28.15	25.0	28.95

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

9), dark-greenish-gray diopsidic gneiss, and quartzite occur within the feldspathic gneiss. A fairly continuous quartzite separates this gneiss from the underlying alaskitic granite mapped on plate 1 as Sterling (sga). The alaskite is underlain by an additional 200 to 300 ft of biotitic gneiss in which quartzite beds are present. The gneiss is itself underlain by biotitic alaskite and biotite granite, mapped (pl. 1) as Sterling. Although it is possible that another thin quartzite occurs within the biotite granite gneiss, no quartzite is exposed along or near the line of section. Therefore, the biotitic gneiss and quartzite possibly are the basal units in the Plainfield Formation.

Although the units described above do not appear to be repeated by folding, it is possible that the axial planes of one or more isoclinal folds are hidden within the sequence. In the absence of concrete evidence of repetition, however, it is assumed that the units in the sequence are in normal order. This sequence is well represented east of the quadrangle (R. Goldsmith, personal communication, 1965), but it cannot be traced westward around the Selden Neck dome because the major quartzite terminates in a region of complicated structure in HV (fig. 2). Thus, the contact between the Mamacoke and the Plainfield is easily mapped where the major quartzite is present, but this contact is difficult to map accurately where the quartzite is thin or absent. Unfortunately, the major Plainfield quartzite unit in the Lyme as well as in the Selden Neck dome does not continue across the quadrangle. Therefore, where the structure is obscure, units that properly belong to the Plainfield Formation may have been mapped as Mamacoke.

QUARTZITE (pq, pcq)

Quartzite is exposed in each belt of Plainfield Formation, and in each belt it displays well bedded, massive, and calc-silicate facies, and is interbedded with a variety of other rocks.

Most of the quartzite is a well bedded, light-gray to white, vitreous rock consisting of more than 80 percent quartz, with minor plagioclase, microcline, biotite, and muscovite (table 10, samples 1-3). Individual beds are 1 to 6 in. thick; they are separated by biotite-muscovite folia that locally contain sillimanite (outcrops east and west of Route 85, north of Fairy Lake, HIII). Quartz occurs in large (3 to 5 mm) grains filled with planar arrays of liquid inclusions. Small (0.5 mm) biotite flakes and rounded granules of feldspar are scattered through the quartz matrix. The feldspar commonly is matted with an aggregate of muscovite; because of this alteration the feldspar is conspicuous in hand specimen as lusterless granules set in a vitreous quartz matrix. Muscovite occurs in isolated flakes in the quartzites in the Selden Neck dome; most of the muscovite in the quartzites in the Lyme dome appears to be an alteration product of feldspar.

The well bedded quartzites grade into less micaceous, nearly massive, white, vitreous rocks in which bedding is scarcely, if at all, discernible. The massive quartzites generally appear to be lenses in well bedded quartzite but they may partly represent quartzite recrystallized in the hinge region of isoclinal folds.

Lenses and beds of calc-silicate quartzite (pcq) are conspicuous, although of minor importance. Outcrops are spotted with large (1 to 4 cm) poikilitic grains of red garnet, calcic plagioclase (labradorite), greenish-black hornblende, and pale-green diopside that stand in relief against the white quartz matrix. Biotite, muscovitic alteration on plagioclase, and iron sulfides are also present (see outcrops on north side of Powers Lake, HIX).

SILLIMANITIC BIOTITE SCHIST (ps)

The quartzites are interbedded with coarse-grained, black-and-white, sillimanitic quartz-plagioclase-biotite schist containing matted sillimanite needles in biotitic folia. Garnet is locally abundant but generally not present. The modes (table 10, samples 5 and 6) illustrate that these schists are similar to those in the Mamacoke Formation.

GARNETIFEROUS BIOTITIC GNEISS (pgs)

Well foliated migmatitic gneisses consisting of 70 percent or more quartz and plagioclase and 15 to 20 percent biotite (table 10, samples 7 and 8) occur with the schists in the Lyme dome. These gneisses are coarser grained, more heterogeneous, and better foliated than the biotitic gneisses of the Mamacoke

NODULAR GNEISS (pn)

Light-colored quartzo-feldspathic nodular gneiss (table 10, sample 4), named "the nodular gneiss" because of the nodules of quartz-sillimanite aggregate which it contains, occurs adjacent to the sillimanitic schist (ps) described above. The nodular gneisses are granular rocks consisting of quartz, plagioclase, microcline, and minor biotite; the nodules are ellipsoidal masses and flat lenses of quartz filled with sillimanite needles. These gneisses are similar to the nodular gneisses of the Mamacoke Formation.

BIOTITIC QUARTZ-FELDSPAR GNEISS (pb, pbc)

Gray biotitic quartz-feldspar gneisses similar to the gneisses in the Mamacoke Formation occur throughout the section. The northernmost belts of this gray gneiss (pbc) contain thin beds of amphibolite, diopside, and quartzite; the remainder of the gneiss (pb) does not. These gneisses appear to grade into the Sterling biotite granite gneiss.

Sterling Plutonic Group

NOMENCLATURE

Pink, gray, or orange biotitic and hornblendic granite-gneisses and associated alaskite gneisses interleaved with units of the Plainfield and Mamacoke Formations are mapped here as parts of the Sterling Plutonic Group. This is the convention followed in the Deep River quadrangle (Lundgren, 1963a). It is clear that the rocks to which Loughlin (1910, 1912) and Gregory (Rice and Gregory, 1906) applied this name were similar gneissic granites within the Plainfield quartz schist. This broad designation is used in this report although it is recognized that some of the granites included here in the Sterling Group may be of different age or origin from the bulk of the Sterling rocks.

All of the biotitic and hornblende rocks are designed as granite-gneisses, because all the modal analyses fall within the composition field for granites as outlined by Chayes (1957). They are largely type II* granites in his classification. Although gneissic on a large scale, they are only weakly foliated or nearly massive in many outcrops. The term alaskite gneiss is used here to designate granite-gneiss containing less than 2 percent mafic minerals. The term leucogranite is preferred by some as an appropriate name for rocks having this low content of mafic minerals.

As mapped on plate 1, the Sterling includes granites of three different, although seemingly related, types. Most large outcrops, for instance those on the eastern slopes of Mt. Archer (fig. 2, HVII), display all types, interleaved with and gradational into one another, so that it is not generally feasible to show the distribution of each type. Alaskite gneiss has been mapped as a separate facies in those places where it occurs in a well exposed layer or mass that appears to contain only minor biotitic or hornblendic granite. The modal analyses give some indication of the distribution of the various facies; however, extensive sampling of the granites would be required to portray the distribution of these facies.

BIOTITE GRANITE-GNEISS (sgb)

The biotite granite-gneisses are medium- to coarse-grained (2 to 5 mm) gray-pink to moderate-orange-pink rocks in which black biotitic folia, gray laminae of platy quartz grains, and pink laminae rich in microcline all contribute to the foliation. The modal analyses (table 11, samples 1-3) indicate that the gneisses generally consist of approximately equal amounts of quartz, plagioclase (oligoclase), and microcline. The analyses also show that these three minerals together constitute 90 to 95 percent of the volume of most samples. Biotite (Z = brownish black) generally makes up 5 percent of the volume, and magnetite-ilemite, zircon, garnet, and apatite are common accessory minerals. The biotite granite-gneiss is the least uniform facies of the Sterling and it grades into biotitic quartz-feldspar gneisses of the Plainfield and Mamacoke Formations as the microcline content becomes equal to or greater than modal plagioclase.

HORNBLENDE GRANITE-GNEISS (sgb)

The hornblende granite-gneisses are medium-grained (1 to 3 mm), grayish-orange-pink to moderate-orange-pink rocks streaked with black hornblende-rich laminae or spotted with black hornblende and magnetite-ilmenite grains. They apparently are more uniform and more nearly equigranular than the biotitic granites and they appear to occupy distinct belts within the biotite granite-gneiss. The modal constitution of the hornblende granite-gneisses is similar to that of the biotite granite-gneisses: quartz, plagioclase (oligoclase), and microcline are nearly equal in amount and together constitute more than 90 percent of the volume of most samples (table 11, samples 4-6). Hornblende (Z = greenish black or dusky green; 5 percent or less) and biotite (Z = dark black to nearly opaque; 3 percent or less) generally occur together. Magnetite-ilmenite, sphene, and zircon are common accessory minerals; hematite occurs in spots centered on mafic minerals. The hematite-spotted hornblende granite-gneiss is easily mistaken for aegerine-augite granite-gneiss in outcrop.

ALASKITE GNEISS (sga)

The alaskite gneisses are medium-grained to coarse-grained orange-pink rocks containing more than 30 percent each of quartz and microcline (table 11, samples 7-13). Modal plagioclase commonly makes up 30 percent of the rock, although it amounts to less than 15 percent in some samples. Biotite and magnetite-ilmenite together constitute less than 2 percent in modal analyses of alaskite gneiss. Foliation generally results from the parallel orientation of platy quartz grains and microcline-plagioclase laminae. Alaskite commonly occurs in layers between biotite granite-gneiss and quartzite in a variety of rocks and as independent mappable layers at Shingle Mill Pond and Grassy Hill Road.

MIXED GRANITIC GNEISSES (sgm)

The southeastern corner of the quadrangle appears to be underlain by several

Table 11.—Modal analyses (in volume percent)[1] of the Sterling Plutonic Group

	Biotite granite gneiss			Hornblende granite gneiss			Alaskite gneiss (Salem belt)				Alaskite gneiss (Lyme dome)		
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13
Field no.	H28-0	H133-1	H114-1	H-29-0	H41-0	H119-5	H408	H2-7	H11-7	H401	H44-8	H430	H97-8
quartz	32.5	44.0	28.0	36.5	41.1	30.1	33.8	33.7	47.6	33.1	36.4	42.2	35.2
plagioclase	31.2	40.9	30.9	31.5	26.9	29.9	32.9	31.4	14.9	30.8	26.2	10.9	14.6
microcline	32.3	10.9	30.0	27.4	29.3	33.8	32.5	34.9	36.4	33.7	37.0	46.6	48.0
biotite	3.8	2.4	9.0	0.4	0.7	1.4	0.3	—	—	1.7	—	0.2	1.6
muscovite	—	1.6	1.4	—	—	—	—	—	x	—	—	—	—
hornblende	—	—	—	3.4	1.5	4.5	—	—	—	0.2	—	—	—
garnet	—	—	0.7	—	—	—	0.3	—	—	—	—	—	—
non-opaque accessory	x	0.1	x	x	0.3	0.2	x	x	0.2	x	0.2	0.2	—
opaque accessory	x	0.1	x	0.8	0.3	x	0.2	0.1	0.8	0.6	0.2	0.2	0.6
XN[2]	18.8	17.25	21.25	17.65	15.1	12.7	31.3	31.55	31.55	28.35	1.3	5.4	1.75
XE[2]	28.2	27.4	27.5	27.3	24.45	2.0	28.55	28.65	32.4	25.0	25.9	30.25	31.35

[1] The symbol x indicates volume percent of mineral is less than 0.1.

[2] Sample-location coordinates: XN numbers are thousands of ft N of S boundary of quadrangle; XE numbers are thousands of ft E of W boundary of quadrangle.

types of granitic gneiss, interleaved with one another and with sillimanitic biotite schist of the Plainfield Formation. The few available outcrops suggest that the most prominent type of granite is an alaskite (table 11, sample 13), deeply rust stained and friable. This rock type is associated with biotitic quartz-feldspar gneiss containing conspicuous garnets and with granitic gneiss containing nodules of quartz-sillimanite aggregate.

Pegmatite

Granitic pegmatite is abundant in most of the rock units in the quadrangle. The map (pl. 1) cannot convey the true abundance of pegmatite because the bulk of this material is in layers, lenses, and folia too intimately interleaved with metamorphic rock units to be mapped separately. Most of the pegmatites shown on the map are in masses large enough to display some topographic expression, enabling them to be located with fair assurance.

Most of the mappable pegmatites in the Brimfield Formation lie north of the sillimanite-orthoclase isograd. These are white or light-gray quartz-perthite-oligoclase-muscovite-tourmaline rocks. Some of their contacts with the adjacent schist are sharply discordant, although every pegmatite displays partly concordant contacts with the surrounding rocks. The major pegmatites in the Brimfield are within the biotite-quartz schist unit (Obqb) in HI and HII (fig. 2) and in a fairly well delineated N-S belt in biotite-muscovite schist in HII.

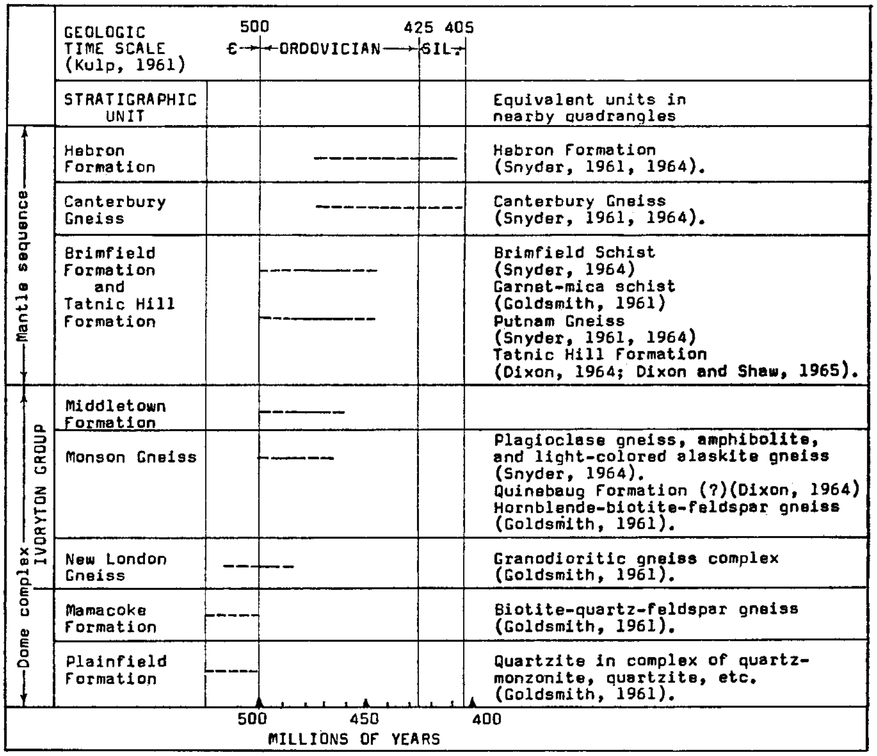
Field observations of the variety of other pegmatites suggest relationships similar to those described in the Essex quadrangle (Lundgren, 1964). Pegmatites in the Brimfield Formation south of the sillimanite-orthoclase isograd are quite different from those described above, being mineralogically simple and consisting of quartz and alkali feldspar with minor biotite, magnetite, and garnet. Muscovite is not present. They do contain sillimanite and orthoclase locally, consistent with their occurrence in sillimanite-orthoclase schists.

STRATIGRAPHIC SEQUENCE AND AGE RELATIONSHIPS

The stratigraphic sequence indicated in table 12 is inferred from the regional relationships of key units for which relative ages are reasonably well established. Because most of these relationships have been discussed previously (Dixon, 1964; Dixon and others, 1963; Lundgren, 1962, 1963a, 1964; Rodgers and others, 1959; Eaton and Rosenfeld, 1960; Snyder, 1962, 1964) the present discussion will be limited to new work bearing on this problem.

The key units are the Brimfield and Middletown Formations and the Monson Gneiss, which have been traced northward to Massachusetts by the author's reconnaissance mapping and by more detailed mapping for published Connecticut quadrangle reports. There they appear to be physically continuous with, and in the same sequence as, comparable units that Robinson (1963) has mapped as Partridge Formation (= Brimfield), Ammonoosuc Volcanics (= Middletown), and Monson Gneiss (= type Monson Gneiss). Robinson's use of the New Hampshire nomenclature for the two upper units is based on physical continuity or near continuity with units so mapped in New Hampshire. If the equivalence of the three Connecticut units and their counterparts in Massachusetts is accepted, the age of the Brimfield and Middletown may be considerd Ordovician, as the Partridge Formation and Ammonoosuc Volcanics are pre-Silurian and most probably Middle Ordovician (Billings, 1956, p. 94-96). The Monson Gneiss is then Ordovician or older. The remainder of the sequence

Table 12.—Stratigraphic sequence and possible ages of rock units in the Hamburg quadrangle. (Most probable age lies within the time span indicated by solid segment of line; possible age lies within time span indicated by solid and dashed line.)



	GEOLOGIC TIME SCALE (Kulp, 1961)	500 425 405 € ORDOVICIAN SIL.	
	STRATIGRAPHIC UNIT		Equivalent units in nearby quadrangles
Mantle sequence	Hebron Formation		Hebron Formation (Snyder, 1961, 1964).
	Canterbury Gneiss		Canterbury Gneiss (Snyder, 1961, 1964).
	Brimfield Formation and Tatnic Hill Formation		Brimfield Schist (Snyder, 1964) Garnet-mica schist (Goldsmith, 1961) Putnam Gneiss (Snyder, 1961, 1964) Tatnic Hill Formation (Dixon, 1964; Dixon and Shaw, 1965).
Dome complex — IVORYTON GROUP	Middletown Formation		
	Monson Gneiss		Plagioclase gneiss, amphibolite, and light-colored alaskite gneiss (Snyder, 1964). Quinebaug Formation (?)(Dixon, 1964) Hornblende-biotite-feldspar gneiss (Goldsmith, 1961).
	New London Gneiss		Granodioritic gneiss complex (Goldsmith, 1961).
Dome complex	Mamacoke Formation		Biotite-quartz-feldspar gneiss (Goldsmith, 1961).
	Plainfield Formation		Quartzite in complex of quartz-monzonite, quartzite, etc. (Goldsmith, 1961).
		500 450 400 MILLIONS OF YEARS	

must be worked out from the relationships of other units to these key ones — relationships which require considerable interpretation because the units are involved in isoclinal recumbent folds.

Occupying the core or double limb of the recumbent Chester syncline, the Hebron Formation is the youngest stratigraphic unit (Ordovician or younger). It may be equivalent to the Mine Brook Formation of the Bolton Group (Eaton and Rosenfeld, 1960), which is believed to be the Connecticut counterpart of the Fitch Formation (Silurian) in New Hampshire (Billings, 1956, p. 90). The Hebron is not physically continuous with the Mine Brook Formation, but the two units lie in comparable stratigraphic positions above the Brimfield Formation and therefore could be equivalent.

The Brimfield and Tatnic Hill Formations are considered to be approximate equivalents now on opposed limbs of recumbent synclines; therefore the Tatnic Hill Formation also is inferred to be Ordovician (?). The contact between the Brimfield and Tatnic Hill Formations and the underlying Middletown Formation and Monson Gneiss generally is sharp, although it is in part a fault contact. This contact may represent an important hiatus in deposition. The Middletown, Monson, and New London are assumed to be Ordovician but the New London could be Cambrian. This interpretation is supported by Rb-Sr isochrons of 440 ± 15 million years for the Middletown Formation and 472 ± 15 million years for the Monson Gneiss (Brookins and Hurley, 1965).

The break between the New London Gneiss and the underlying Mamacoke and Plainfield Formations is one of the major breaks in the sequence. It apparently marks the change from largely clastic sedimentation (deposition of the sedimentary antecedents of the Mamacoke and Plainfield rocks) to volcanism.

The mutual relationships of the units mapped as Mamacoke and Plainfield are not entirely clear. At the eastern edge of the quadrangle and farther east (Goldsmith, 1963) the Mamacoke is easily mapped as the unit immediately overlying the uppermost quartzite in the pre-New London sequence. The quartzites and the rocks interbedded with them are mapped as Plainfield. Although some of these interbedded rocks are physically similar to those of the overlying Mamacoke, the association with quartzite provides a satisfactory basis for mapping them as part of the Plainfield. As the two formations are traced westward, they become progressively more difficult to separate because the quartzites become thinner, and no single quartzite layer can be traced continuously. The two formations are mapped separately on the basis of the position of quartzite lenses considered as the top of the Plainfield. It is apparent that in the western part of the quadrangle the two formations might be mapped as a single formation containing lenses of quartzite. Thus, the two formations should be viewed as sedimentary facies of a larger unit that constitutes the pre-New London sequence. The youngest units in this pre-New London sequence are part of the Mamacoke Formation, which overlies or interfingers with the upper Plainfield; the oldest units in the pre-New London sequence are the lowest units in the Plainfield Formation.

The Plainfield Formation, and probably the Mamacoke Formation as well, can be traced eastward to Rhode Island (Goldsmith, 1963) where comparable rocks have been mapped as Blackstone Series (Moore, 1959; Quinn, 1949) or eastward and northward to Massachusetts where Emerson (1917) mapped quartzite comparable to the Plainfield as Westboro Quartzite. Quinn (1949) examined the evidence for the Precambrian age of the Blackstone Series and concluded that the Blackstone could be Precambrian but may be Cambrian or younger. At present a Cambrian age for the Plainfield and Mamacoke Formations seems probable but not well established.

The age of the Canterbury Gneiss and of the granite gneisses in the Sterling Plutonic Group is more difficult to evaluate. The Canterbury Gneiss maintains an apparently consistent stratigraphic position between the Hebron Formation and the Tatnic Hill Formation (Dixon and Shaw, 1965; Lundgren, 1963a; Snyder, 1961, 1964) and is interleaved with rocks mapped as Tatnic Hill (pl. 1) and lower Hebron (Dixon and Shaw, 1965; Snyder, 1961, 1964). The Canterbury could be a metamorphosed volcanic unit or a metamorphosed sill; its age may lie anywhere between the age of the Tatnic Hill Formation and the age of the metamorphism.

The granitic rocks included in the Sterling Plutonic Group are of uncertain age and origin. All are older than the thermal peak of metamorphism, as they were folded and recrystallized during deformation and metamorphism. As a consequence, it is difficult to evaluate the chronologic and genetic significance of apparent gradations of one granite into another or into definitely metasedimentary units. Furthermore, the final metamorphism was effected at temperatures sufficiently high for partial melting to be common, so that the chronologic significance of local discordance between granites and adjacent metasedimentary units is subject to more than one interpretation. As these granite-gneisses are restricted to a position below the New London Gneiss, the time of emplacement cannot be shown to postdate the time of deposition of any unit younger than the Mamacoke Formation. Therefore they are shown as post-Cambrian; they may be post-Ordovician, but isotopic studies accompanied by large-scale detailed internal mapping of these granites will be required to establish this.

The discrete pegmatite masses in the Brimfield and Hebron Formations were emplaced after, or during a late stage in, the metamorphism which took place prior to the formation of the mylonites marking the Honey Hill fault. If these pegmatites are contemporaneous with the well dated pegmatites in the Collins Hill Formation (Lundgren, 1963a, p. 38), a reasonable but unproved postulate, then the Hebron Formation and all the other units are more than 265 million years old. This suggests that all the units are Pennsylvanian or older.

STRUCTURAL RELATIONSHIPS

The Hamburg quadrangle lies across some of the major structural elements which involve the rocks of eastern Connecticut: the Colchester nappe, the Chester syncline, the Honey Hill fault, the Selden Neck dome, the Hunts Brook syncline, and the Lyme dome (Goldsmith, 1961; Lundgren, 1963a). The domes are complex anticlines in which the predominantly quartzo-feldspathic older rocks are exposed. They are mantled by younger rocks (Brimfield and Tatnic Hill Formations, Canterbury Gneiss, and Hebron Formation), which lie in the complexly folded Chester and Hunts Brook synclines. The Honey Hill fault is a surface of displacement that here coincides with the stratigraphic boundary between the dome rocks and the mantle of younger rocks.

Although the two-dimensional relationships of these structures are now fairly well illustrated by detailed maps (see Goldsmith, 1963, for a compilation), the three-dimensional relationships remain subject to varied interpretations. Because of this, the following discussion describes the possible large-scale configuration of the surface separating the dome complex (Ivoryton Group, Mamacoke and Plainfield Formations, and associated granitic rocks) from the mantle sequence and concerns relationships inside large-scale structures outlined by this surface. Smaller scale structural features are described only incidentally.

Because it has the most extensive outcrops, the surfaces separating the Ivoryton Group from the mantle of younger rocks is the best reference surface to consider in a discussion of major structural features. It is folded into two synclines (fig. 3), the Chester syncline (Dixon and others, 1963; Lundgren, 1962, 1963a, 1964) and the Hunts Brook syncline (Goldsmith, 1961). The axial planes of these synclines are complexly folded.

The name *Chester syncline* is restricted in this report to the recumbent syncline that lies on the north flank of the Selden Neck dome (Lundgren, 1963, fig. 5). The position of the hinge line of this syncline is not known with certainty, although it is apparently located in a narrow belt of steeply dipping Hebron Formation in the Deep River and Essex quadrangles, west of the Connecticut River. This belt can be traced into the belt of Hebron Formation that can be followed across the northern part of the Hamburg quadrangle. Therefore,

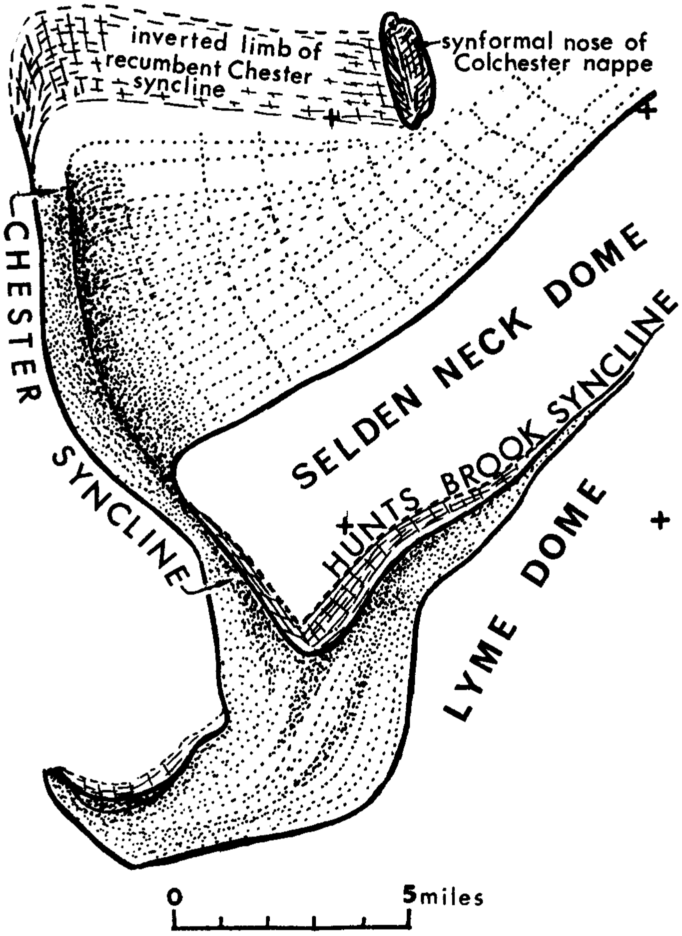


Fig. 3. Possible configuration of the surface separating the Ivoryton Group from the mantle of younger rocks. The diagram is schematic and shows the configuration of this surface beneath the present level of erosion except in the northern part where the inverted limb of the recumbent Chester syncline is shown above the present level of erosion. The heavy line is the present outcrop of the surface between the Ivoryton and the younger mantle; the stippled pattern indicates the upper face of this surface and the lined pattern its lower face. Small crosses mark the corners of the Hamburg quadrangle.

the segment of the Chester syncline in the Hamburg quadrangle is entirely recumbent. The Tatnic Hill formation constitutes the normal limb and the Brimfield Formation the inverted limb of the recumbent fold (pl. 1, section AA′). The Middletown Formation (fig. 2, HI) lies in a trough on this inverted limb, a trough which represents the nose of an inverted anticline, the *Colchester nappe* of Dixon and others (1963). The axial plane of the recumbent syncline lies within the belt of Hebron Formation that constitutes the double limb of the fold (Lundgren, 1964, p. 25).

Stratigraphic symmetry across the axial plane of the Chester syncline is imperfect; the Middletown Formation is present only on the inverted limb, the Canterbury Gneiss only on the normal limb. This lack of symmetry apparently was determined by the areal extent of each unit prior to folding. The Canterbury Gneiss on the normal limb does not extend west of Chester (Lundgren, 1963a), so its absence on the inverted limb is not surprising. The sedimentary and volcanic antecedents of the amphibolites and anthophyllitic gneisses of the Middletown Formation apparently were deposited west of long 72°22'30"W; the presence of the Middletown Formation as far east as the Hamburg quadrangle is anomalous. This anomaly was one of the first pieces of evidence to suggest that the rocks on the inverted limb originally lay much farther west (Lundgren, 1962, 1963a).

The name *Hunts Brook syncline* (Goldsmith, 1961) is restricted in this report to the syncline that separates the Selden Neck dome from the Lyme dome, where the surface separating the Ivoryton Group from the younger rocks is folded into an isoclinal syncline in which Tatnic Hill and Brimfield Formations are juxtaposed. The trace of the axial plane of this syncline must lie within the belt of Brimfield and Tatnic Hill rocks. The axial surface must dip northwest (pl. 1, section A'A") except at the east edge of the quadrangle where it must dip north. The axial surface is folded around the Lyme dome (Goldsmith, 1961).

Although the trace of the axial surface can be located with relative accuracy, the position of the hinge line cannot. One interpretation, shown in figure 3 and by Goldsmith (1961), is that the hinge line is oriented approximately parallel to the trace of the axial surface, although diverging from parallelism toward the southwest. In this interpretation the syncline is envisaged as opening toward the south and southeast over the Lyme dome. An alternative interpretation is that the hinge lines for each of the youngest units in the syncline are oriented more nearly northwest. Each such hinge line would thus be considered to plunge northwestward within the Hamburg quadrangle or to rise above the ground surface over the Lyme dome. In this interpretation the syncline is interpreted as opening toward the southwest. If this is the more nearly correct picture, the Brimfield and Tatnic Hill Formations extend well beneath the Selden Neck dome.

Stratigraphic symmetry across the axial plane of the Hunts Brook syncline is displayed by each of the major stratigraphic units except that the units are thinner on the side of the syncline which lies against the Lyme dome, and that the Joshua Rock Gneiss is not present on this side.

The relationships between the Hunts Brook and Chester synclines are not clear. If the Hunts Brook syncline is a folded overturned syncline with a nearly horizontal axis, then the axis of the Hunts Brook syncline probably meets the axis of the Chester syncline at nearly a right angle, as suggested by figure 3. This implies that the Hunts Brook syncline could have developed during or more probably after the formation of the recumbent Chester syncline. The Hunts Brook syncline might thus be viewed as a cross fold superimposed on the normal limb of the Chester syncline.

If the hinge of the Hunts Brook syncline plunges steeply to the northwest, then the Hunts Brook syncline could merge with the Chester syncline beneath the Selden Neck dome. This allows the Chester and Hunts Brook synclines to be considered as parts of a single syncline. North of the Selden Neck dome this syncline would open to the east; south of the dome it would open to the southwest. This picture is conjectural — it requires that the Selden Neck dome be viewed as a recumbent fold or nappe rooted to the east (Lundgren, 1964, p. 27).

The Selden Neck dome represents the anticline complementary to the Hunts Brook syncline. This dome is essentially an overturned, possibly recumbent, anticline, having a folded axial surface that dips north or northwest. The position of the hinge of this anticline is not known. Although the broad outline of the anticline is simple, as indicated by the pattern of the Monson Gneiss or the upper surface of the Monson (fig. 4), the internal structure of the dome is complicated and imperfectly understood, particularly on the north side of the trace of the axial surface.

The New London Gneiss (and its included Joshua Rock Member) outline a large sinistral fold on the north limb of the dome. This fold does not affect rocks younger than the Monson, nor does it affect rocks on the south side of the trace of the axial surface of the Selden Neck dome. The hinge of the anticlinal part of this sinistral fold is hidden beneath Pleistocene gravels along Eight Mile River west of Pleasant View Cemetery (fig. 2, HIV). The hinge of the synclinal part of this fold, which is in part outlined by the Joshua Rock Gneiess Member (pl. 1, cross section AA′, north of the bend in the section), is located in the area immediately northwest of Cedar Lake, HV). The hinges of anticline and syncline are assumed to plunge 20° to 25° WNW, as this is the plunge of all the linear features in rocks involved in these folds. These linear features include minor-fold axes, mineral aggregates, quartz-sillimanite nodules, and sillimanite needles.

The major elements of this sinistral-fold pattern appear to be reflected by the pattern of pre-New London units down to, but not beneath, the contact between the Plainfield (pb and pbc) and the Sterling biotite granite gneiss (sgb) in the axial region of the dome. The core of the anticline outlined by the New London Gneiss is occupied by a mass of tightly folded rocks mapped as Mamacoke Formation and the Plainfield quartzite unit. The structural (and stratigraphic) relationships both within the Mamacoke Formation and between the Mamacoke and the Plainfield Formations in this region are obscured by the abundant granite found with the metasedimentary units, by the lack of continuity of any of the units, by the apparent interfingering of units, and by the extensive surficial cover in some critical areas.

The difficulties in interpreting these relationships may be illustrated by tracing the major Plainfield quartzite unit (pq), the overlying Mamacoke (mb), and the underlying Plainfield gneiss (pbc) westward from Shingle Mill (HIII). The Mamacoke displays the sinistral-fold pattern, the quartzite terminates westward at about the point where the fold hinge should be located, and the Plainfield gneiss (pbc), although difficult to trace, apparently is not involved in the fold. Furthermore, the westernmost segment of the quartzite apparently is overlain by Mamacoke gneiss (mb) and underlain by rocks mapped as Mamacoke (ms, ma). The latter units are physically similar to the units generally found in, but apparently not restricted to, the *upper* part of the Mamacoke; they are on strike with the gneisses mapped as Plainfield (pbc).

Although these puzzling relationships might be accounted for purely in terms of complex folding and faulting, it appears more probable that they are partly a consequence of primary sedimentary-facies relationships between the Mamacoke and the Plainfield. The working hypothesis presented here is that the major Plainfield quartzite (sandstone) interfingered with the sedimentary antecedents of the schist, calc-silicate rock, and marble mapped as Mamacoke (ms, ma). Thus, the westward termination of the quartzite is viewed as being essentially a primary sedimentary feature. This quartzite is interposed between layers of Mamacoke-type rocks, some of which are sedimentary-facies equivalents of the Plainfield unit (pbc). If this interpretation is correct, the present pattern may be accounted for as follows.

The sinistral fold in the New London and the Mamacoke is located in a zone of marked sedimentary facies change. When this fold developed, the schists and carbonate rocks of the Mamacoke were tightly folded, flowing into the trough of the syncline and allowing the folding to be disharmonic. The deformation of the Mamacoke was accomplished independently of the deformation of the Plainfield gneiss unit, which does not display the fold pattern. The Plainfield quartzite unit lies on the long limb of the sinistral fold; if the horizon of this quartzite could be traced through HV it also would display the sinistral-fold pattern.

The Lyme dome appears to be a complex anticline similar to the Selden Neck dome. The segment that occupies the southeastern corner of the quadrangle includes all of the stratigraphic units seen in the Selden Neck dome. Although these units appear to be in normal order and unrepeated by isoclinal folding, the internal structure of the Lyme dome may be complex as that of the Selden Neck dome.

The Honey Hill fault is a surface of dislocation that in the Hamburg quadrangle coincides with the stratigraphic boundary between the Tatnic Hill Formation and the Monson Gneiss. As indicated in the descriptions of these units, blastomylonitic rocks and ultramylonitic layers and dikes are rather uniformly distributed throughout the Tatnic Hill Formation and the Canterbury gneiss above the fault. Blastomylonitic rocks are also developed in the Hebron Gneiss and in the Brimfield Formation, principally in zones close to contacts with adjacent units. These contacts also may represent surfaces of significant dislocation. The Monson Gneiss beneath the fault displays scattered layers of ultramylonite and lenses of crushed rock.

As the laminae of crushed rock are parallel to the pre-existing foliation and stratigraphic contacts, it appears that the rock units were displaced along the fault parallel to these contacts. The directions of movement are not known with assurance, although minor northwest-plunging dextral folds mapped in the Tatnic Hill Formation and in the Hebron Formation indicate at least one late stage of movement in which these units were displaced eastward relative to the rocks farther south. Some later structural features, such as minor slickensides, suggest a late stage when these units were displaced down the present dip of the fault.

BEDROCK CONTROL OF TOPOGRAPHY

The topography of much of the Hamburg quadrangle is notably fine textured (pl. 1) and reflects the structure and relative erodibility of the bedrock units in considerable detail. Where such resistant units as the Sterling alaskites or the Joshua Rock gneiss are interleaved with nonresistant units such as the upper part of the Mamacoke Formation or the schists of the Plainfield Formation (fig. 2, HIII, HVI, HVII, HVIII, HIX), ridges faithfully reflect the structure. Where the contrast in relative erodibility is less marked, for instance where the Hebron and Brimfield Formations are adjacent (HI, HII), the topography is a more subdued, yet accurate, reflection of the bedrock structure.

As in the Essex quadrangle, the contrast in relative erodibility of adjacent units varies with the grade of metamorphism. South of the sillimanite-orthoclase isograd the sillimanite-laden Brimfield schists are among the least resistant of rocks, and here the belt of high-grade Brimfield coincides with a narrow belt of lowland, traceable across the quadrangle, in which lie Hog Pond and Norwich Pond (HVIII).

Comparison of topographic and geologic maps of the quadrangle indicates that the cover of Pleistocene debris is quite thin — otherwise the topography could not so clearly reflect bedrock relationships. Only along the valleys of Eight Mile River (HI, HIII, HVII) or East Branch (HII, HIII, HV) is this cover thick enough to mask bedrock and structural characteristics. Eight Mile River and, on a smaller scale, Four Mile River (HIX) are the only geomorphic features that do not conform to the bedrock structure, cutting directly across the structural grain and traversing almost all of the bedrock units nearly at right angles to their strike. Falls are developed where Eight Mile River crosses resistant pegmatite-filled Brimfield (Chapman Falls, HI) and the thin sliver of Plainfield quartzite (Mt. Archer Road, HVII); rapids occur where it crosses relatively resistant but well jointed Canterbury Gneiss and Hebron Formation (HI).

GEOLOGIC HISTORY

The geologic history recorded in the Hamburg quadrangle probably commenced in Cambrian time with the deposition of the quartz sandstone, limestone, and dolostone, and the shale that were the sedimentary antecedents of the Plainfield and the Mamacoke Formations. Next, probably in Late Cambrian to Early or Middle Ordovician time, came the outpouring of a thick sequence of volcanic rocks, accompanied by intrusives, which constitute the Ivoryton Group. The uppermost unit of this volcanic sequence is the Middletown Formation, probably a composite of andesitic and basaltic volcanics. It was not deposited at the longitude where it is now exposed, but was brought there by structural displacement. Following this volcanic activity, and probably in Middle Ordovician time, the major shale unit, now represented by the Brimfield and Tatnic Hill Formations, was deposited. The Canterbury Gneiss may have been the next unit laid down; if so, it was deposited as a volcanic unit during the Ordovician or Early Silurian. The youngest stratigraphic unit, the Hebron Formation, was laid down during the Ordovician or Silurian as a sequence consisting of interbedded sandstone and siltstone and dolomitic sandstone and siltstone. The granitic rocks of the Sterling Plutonic Group probably were emplaced during Cambrian and Ordovician times, partly as volcanic units and partly as intrusives; some may have been emplaced during the Devonian. The discordant pegmatites were emplaced later, possibly as recently as the Pennsylvanian or Permian.

The sequence of structural events that affected these rocks is subject to varying interpretation; the following sequence is one of the more probable. The recumbent Chester syncline and Colchester nappe were developed during the post-Lower Devonian deformation and metamorphism. They were subsequently deformed during the development of the Hunts Brook syncline between the Selden Neck dome and the Lyme dome. All of these structures were further deformed during the thermal peak of metamorphism when folds represented by the folded Joshua Rock Gneiss Member developed and when the more pervasive lineations formed. The Honey Hill fault apparently was a locus of dislocation over a long period; the last movements took place after the thermal peak of metamorphism, resulting in the development of retrograde mineral assemblages in the blastomylonitic rocks formed at this time.

Metamorphism of all the rocks produced assemblages characteristic of the upper amphibolite facies. This metamorphism probably commenced in the Devonian, but the last episode of progressive metamorphism occuring at the thermal peak of metamorphism may have been as recent as Pennsylvanian or even Permian. The rocks south of the sillimanite-orthoclase isograd (pl. 1) were metamorphosed at temperatures higher than those to the north of it, with the result that muscovite was eliminated from originally muscovitic rocks and sillimanite and orthoclase formed in its place (Lundgren, 1963b). This metamorphism effected a pervasive recrystallization in all of the units and a partial melting of some of them. Therefore, many of the small-scale textural and structural features were superimposed on the older features and masked them.

ECONOMIC GEOLOGY

No significant use has been made of any of the rock units within the quadrangle. The Joshua Rock Gneiss Member was worked on a small scale in a minor quarry at the northern edge of the Hamburg Fairgrounds east of Route 156 (fig. 2, HVII) and on a much larger scale at the Joshua Rock Quarry, the southern tip of which lies within the southwestern corner of the quadrangle (Lundgren, 1963a, p. 16).

The alaskite unit (Omga) in the Monson Gneiss (HIII) is presently being quarried in the Fitchville quadrangle as a source of sized aggregate for use in road construction (Snyder, 1964, p. 31). The similar alaskites in the Sterling Plutonic Group are well exposed in HI, HIII, and HIX and presumably could serve as ample supplies of crushed stone, as could the Joshua Rock Gneiss Member in HVII and HVIII.

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