The Bedrock Geology of the Clinton Quadrangle

WITH MAP

Open Map

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and

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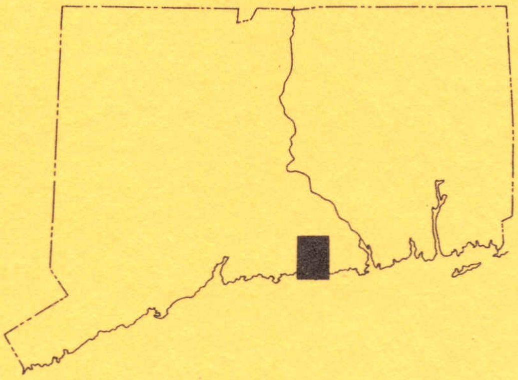

STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

DEPARTMENT OF ENVIRONMENTAL PROTECTION

1973

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The Bedrock Geology of the Clinton Quadrangle

by

Lawrence Lundgren, Jr. and Robert F. Thurrell

ABSTRACT

The Clinton quadrangle is largely underlain by the monotonous Monson Gneiss, a rock consisting chiefly of plagioclase and quartz with subordinate biotite or biotite and hornblende. The Monson Gneiss is part of the large Killingworth dome, which is surrounded by the orthoamphibole-bearing Middletown Gneiss and the mica schists of the "Brimfield" Formation. These units are exposed in areas in the northeastern part of the quadrangle and in a belt across the middle of the quadrangle, where they lie in synformal belts between or within Monson Gneiss. A dome of Clinton Granitic Gneiss is exposed in the southeastern part of the quadrangle. The entire quadrangle displays sillimanite-zone rocks, and the southern part lies within the sillimanite-orthoclase zone. There are no significant quarrying operations in the quadrangle, and none of the rocks appears to be of particular economic interest. The distribution of the Middletown Gneiss may be of importance to anyone proposing to tap ground-water supplies within the Middletown, or planning to tunnel within the quadrangle, because much of the Middletown appears to consist of carbonate-bearing rocks and sulfide-bearing schists that disintegrate rapidly on exposure. Bedrock is close to the surface in the areas of Monson Gneiss, and the terrain within areas of Monson does not seem to lend itself to large-scale housing development.

INTRODUCTION

The map of the bedrock geology of the Clinton quadrangle shows bedrock exposures (outcrops) and an interpretation of the types of bedrock believed to underlie areas where no exposures are present. The map does not differ greatly in its broad outlines from part of a smaller-scale map by Mikami and Digman (1957) but it does provide more information on a better base map and the descriptive material is more complete. Approximately two thirds of the mapping was done by R.F. Thurrell III in 1969 and 1970, assisted by Jeff Halka in 1970. This mapping was reviewed in the field by Lundgren with Thurrell at intervals throughout 1969-1970. The remaining one third of the mapping was done by Lundgren, who also reviewed older mapping in parts of the adjoining Essex and Guilford quadrangles. The text was written by Lundgren. All the work was supported by the Connecticut Geological and Natural History Survey. Richard Goldsmith, John Rodgers, and Jelle de Boer provided helpful editorial comment.

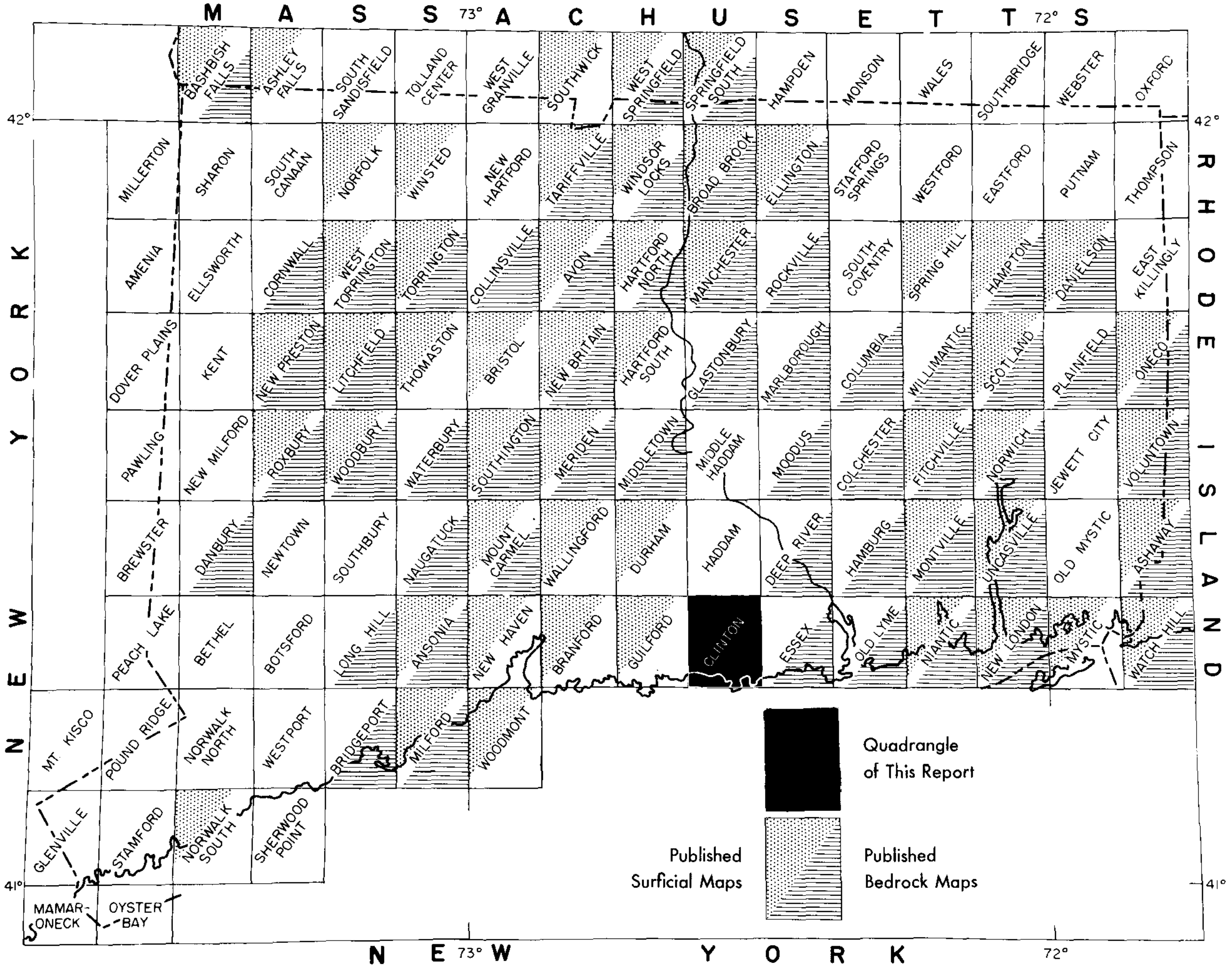


Fig. 1. Index map of Connecticut showing the location of the Clinton quadrangle and of other published quadrangle maps.

The status of bedrock mapping in the quadrangles that surround the Clinton quadrangle is shown in figure 1. A generalized geologic map, combining the older work indicated in figure 1 and the remapping noted above, is presented as figure 2. We believe that little improvement of the Clinton map can result from more detailed mapping because there are so few outcrops in key areas. Further analysis of structural models different from the one we follow might, however, lead to improved interpretation.

ROCK UNITS

General remarks

There are only three major rock units in the Clinton quadrangle: Monson Gneiss, Middletown Gneiss, and Clinton Granitic Gneiss. Because they all have been described in the reports on the adjoining Essex quadrangle (Lundgren, 1964, 1966a) and the Guilford quadrangle (Bernold, 1962), this report only notes some of the major variations within units in the quadrangle. In addition, a small area of "Brimfield" Formation has been mapped.

Locations of outcrops and samples discussed in this report are expressed as shown in figure 3. Thus the general location of an outcrop lying in the Clinton quadrangle within the ninth designated by Roman numeral III is indicated in the text by the designation (C III). The location of an outcrop lying in the central part of the adjoining Essex quadrangle is indicated by the designation (E V). In addition, any or all of the following are cited where appropriate: a geographic name, a Connecticut State Highway number, and Connecticut Grid System coordinates, which are marked on the edges of topographic map sheets. Coordinates given as 28.83N/31.75E indicate that the outcrop is located at the intersection of coordinate lines 288,300 ftN and 317,500 ftE.

Descriptions and modal analyses of thin sections are based on a study of sections in which potassium feldspar and plagioclase were stained for easy identification. Colors of minerals as seen in unstained thin sections of standard thickness (magnification 50X, plane polarized light) and colors of hand specimens of rocks or minerals are described throughout by citing the most nearly similar color on the Rock Color Chart distributed by the Geological Society of America.

Monson Gneiss

GENERAL RELATIONSHIPS

The Monson Gneiss underlies over half of the quadrangle; it is continuous with the Monson of the Essex quadrangle and therefore with the type Monson in Monson, Massachusetts (Lundgren, 1964, p. 15). The Monson Gneiss, as mapped in Connecticut at least, comprises a variety of gray quartz-feldspar rocks, mostly but not entirely gneissic, that characteristically are one-feldspar (plagioclase) rocks containing little or no potassium feldspar. The Monson consists of metamorphosed igneous rocks, both intrusive and volcanic, and the variety of rocks now

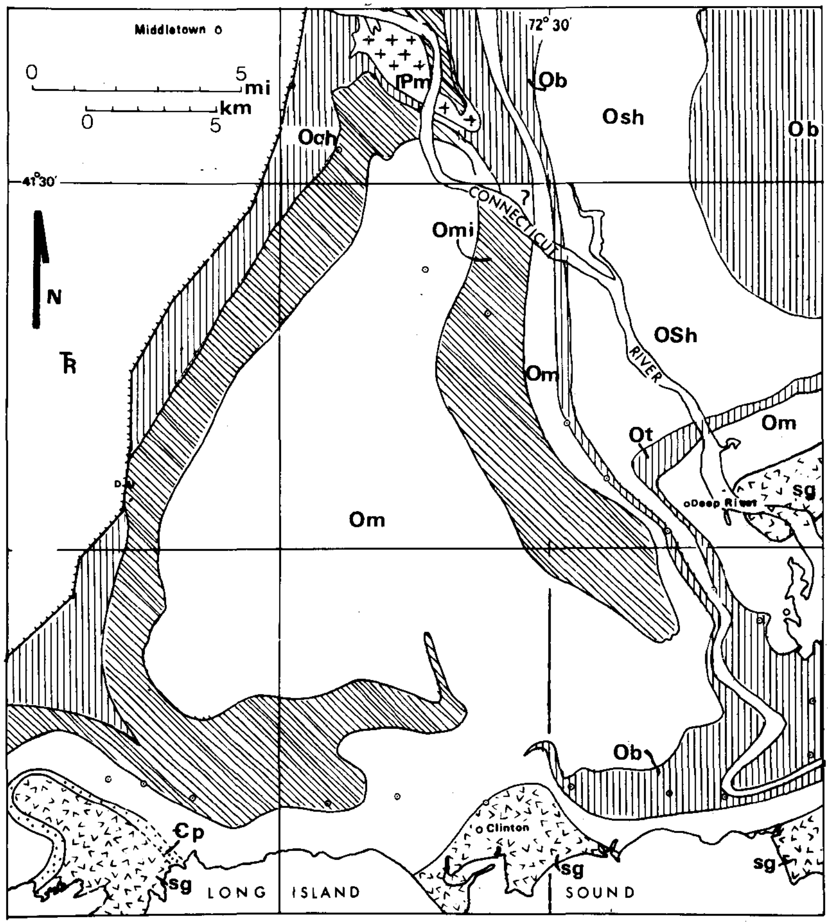
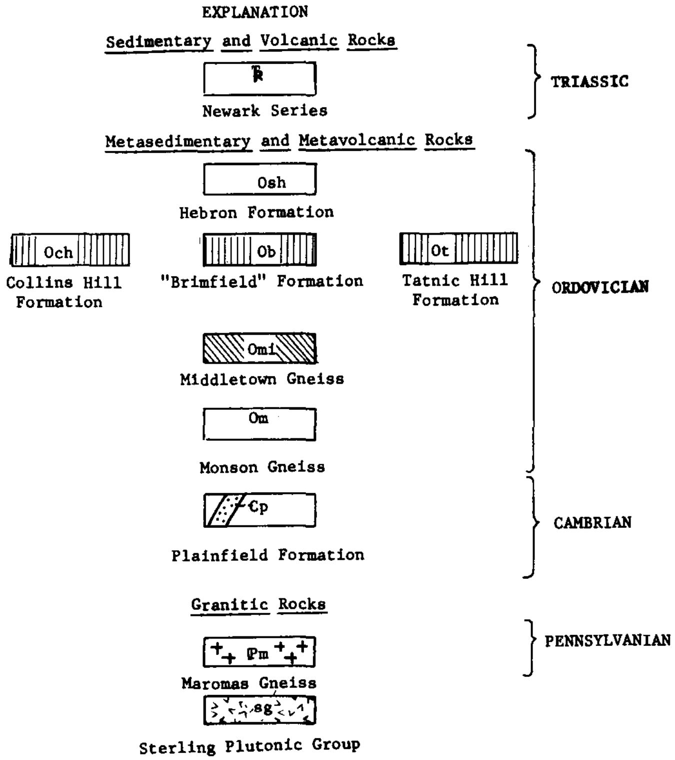


Fig. 2. Geologic map of the Killingworth dome showing major structural features. The explanation of the geologic formations is on the facing page. (Based on published geologic maps and on the U. S. Geological Survey open-file map of the Middle Haddam quadrangle by Gorgon Eaton and John Rosenfeld.)

included in the Monson reflect both the original variation in the antecedent volcanic-plutonic complex and metamorphic modifications. The basic differences among different types of Monson are determined by the following types of variation:

Degree of development of foliation: Massive rock is well represented in CV and VIII; the remainder of the Monson displays at least some degree of mineral orientation.

Relative abundance of biotite and hornblende: All rocks contain biotite



and many contain only biotite; others contain more hornblende than biotite.

Degree of development of granite-pegmatite folia: All Monson contains folia, dikes, and pods of pink granite pegmatite. Where these are abundant the essential character of the Monson is almost obscured.

These attributes vary markedly from place to place, so it is convenient to describe the Monson in four areas. The rock in each of the areas seems to grade into the rocks in the others, yet rock within any one area has an identity of its own. The areas are C I-III (Hammonasset Reservoir area), C VI-VIII, (Boulder Lake area), C III-VI (Camp Hadar area), C VI-VIII-IX (Clinton dome area). Modal analyses of rocks from the first two areas are presented in table 1.

HAMMONASSET RESERVOIR AREA

The Monson in the vicinity of the Hammonasset Reservoir area and Chatfield Hollow State Park lies in the central part of the Killingworth dome, where, because the foliation is weak and nearly horizontal, most good exposures are seen on prominent, steeply dipping N-S and E-W joint faces.

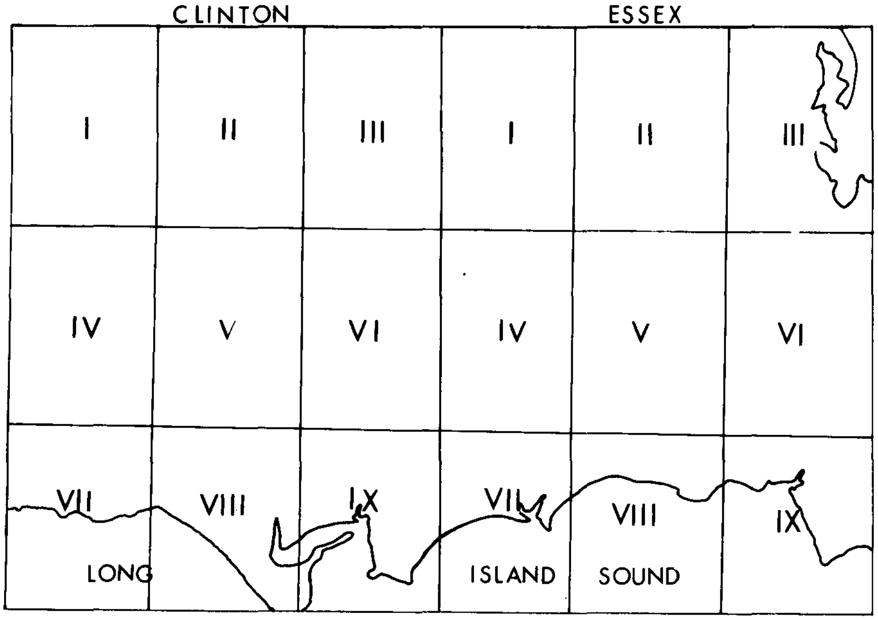


Fig. 3. Division of the Clinton quadrangle (and the adjoining Essex quadrangle) into ninths for the purpose of easily locating outcrops and sampling sites mentioned in this report.

The rocks are uniformly light gray, weakly foliated quartz-plagioclase biotite-rocks (table 1), with numerous thin folia of pure biotite and sparse amphibolite layers. Some of these folia can be traced for several feet, others for only inches. The rock has a tendency to break along nearly horizontal surfaces controlled by the parallel orientation of biotite flakes, which are scattered throughout the rock. However, the more prominent and continuous biotite folia are folded about this horizontal plane, and recumbent isoclinal folds in biotite folia and amphibolite layers are evident in numerous large outcrops. The effect of this is to give most outcrop faces a curious pitted appearance that apparently reflects differential weathering controlled by intersecting foliation and schistosity. The weak schistosity typically is nearly horizontal and it intersects the folded biotite folia. The schistosity and the biotite folia are hardly visible in biotite-poor rock containing no layers of amphibolite but even such rock displays the characteristic pitted surfaces.

Throughout this area the Monson contains relatively few layers of black amphibolite that display any degree of continuity. However, it does contain blocklike masses of amphibolite that now appear to float in the dominant gray rock. They may be isolated boudins or blunt fold crests but this is not at all clear from many exposures.

The only other type of rock within this area of Monson is pink alaskite

Table 1. — Modal analyses of Monson Gneiss[1]

Sample No.	Quartz	Plagioclase	Biotite	Hornblende	K-feldspar	Non-opaque	Opaque	Coordinates
K101	24.2	48.7	26.1	0.0	0.0	0.1	0.6	18.30N/64.56E
K352	32.5	54.4	11.6	0.0	1.0	0.2	tr	19.62N/65.99E
K512A	35.0	48.6	13.0	2.9	0.5	tr	tr	17.08N/64.90E
K512B	36.4	46.5	12.8	2.6	0.2	0.1	1.4	17.08N/64.90E
K550	30.2	36.5	8.4	15.3	9.4	0.2	tr	17.26N/64.75E
K850	26.2	44.4	7.5	8.4	12.6	0.1	0.5	16.65N/65.12E
K851B	25.6	43.6	8.2	19.2	3.2	0.2	tr	16.61N/65.24E
K806D	36.5	33.4	12.6	3.6	12.5	tr	tr	16.59N/65.33E

[1] Modal analyses by H. Dygert and L. Lundgren. Each analysis based on 1000 points spread uniformly over a standard thin section. First digit of sample number indicates the ninth of the Clinton quadrangle from which the specimen was taken. Non-opaque minerals include zircon, apatite, and chlorite; opaque mineral is magnetite. The letters *tr* indicate that mineral is present in thin section but was not intersected in any counting traverse. All but K101 and K352 are *Omh* (Boulder Lake variety). K512A and K512B are separate thin sections from a single hand specimen.

(equigranular quartz-microcline-plagioclase rock), much finer grained than the pegmatite folia that are present throughout. The alaskite is rare, and has been seen only in isolated layers several feet thick.

The gray gneissic rocks are cut by pink, K-feldspar-rich pegmatite dikes, 5-10 cm wide, that typically contain large K-feldspar crystals and a contact selvage of biotite. In spite of the abundance of these dikes, the gray rocks do not contain much, if any, K-feldspar (table 1).

BOULDER LAKE AREA

The Monson Gneiss in the vicinity of Boulder Lake (C V, VII, VIII, fig. 3) is a distinct type, characterized by a lack of foliation or layering. This rock contains hornblende (table 1) in contrast to the rock in C I-III. Small inclusions of black amphibolite are common (fig. 4) but they constitute less than 5 percent of the total rock. Inclusions of garnet calc-silicate rock are also common. The outcrops are rounded, reflecting the relative homogeneity of this hornblendic rock.

A representative large exposure of this rock type may be seen in C VIII at River Road, east of Interchange 62 north of the Connecticut Turnpike (fig. 4A). The rock is uniform, almost massive, medium-grained, medium-gray, plagioclase-quartz-hornblende-biotite rock with conspicuous black granules of magnetite and reddish sphene. Here the rock contains irregular isolated masses of amphibolite, which do not display a strong dimensional orientation (fig. 4B). It is cut by remarkably planar pegmatite dikes 2-8 cm thick. These give the outcrop a gneissic appearance (fig. 4A), which is misleading, as foliation in the hornblendic rock is not parallel with them. This rock is the most uniform unit seen in the Monson anywhere in the four quadrangles previously mapped by Lundgren (1963, 1964, 1966a, 1967) but it does gradually become less uniform away from the immediate vicinity of Boulder Lake.

To the west, in the belt between the Hammonasset Connector (the divided highway extending S from Interchange 62) and Madison as far west as the quadrangle boundary (C VII), this hornblendic unit is readily identifiable because it retains its mineralogy, contains scattered amphibolite inclusions, and is relatively uniform. However, it *is* foliated and displays a planar orientation of biotite. More significantly, the amphibolite inclusions generally form flat lenses 2-3 cm thick and 20-30 cm long (fig. 4C) and are probably disc shaped in three dimensions. These lenses are aligned parallel to the biotite schistosity. It seems probable that the primary rock is the massive type described first. If so, then the foliated type has formed from this massive type as a result of deformation of the massive type in the coastal belt and the foliation is a younger foliation. Alternatively, a weak foliation may initially have been present in all Boulder Lake type rock, and deformation (folding) in the immediate vicinity of Boulder Lake may have made the original foliation less conspicuous.

The eastern limit of the Boulder Lake type of rock is not clear because there are no exposures in the critical area. It is possible that the Boulder Lake type extends farther east to connect with somewhat simi-

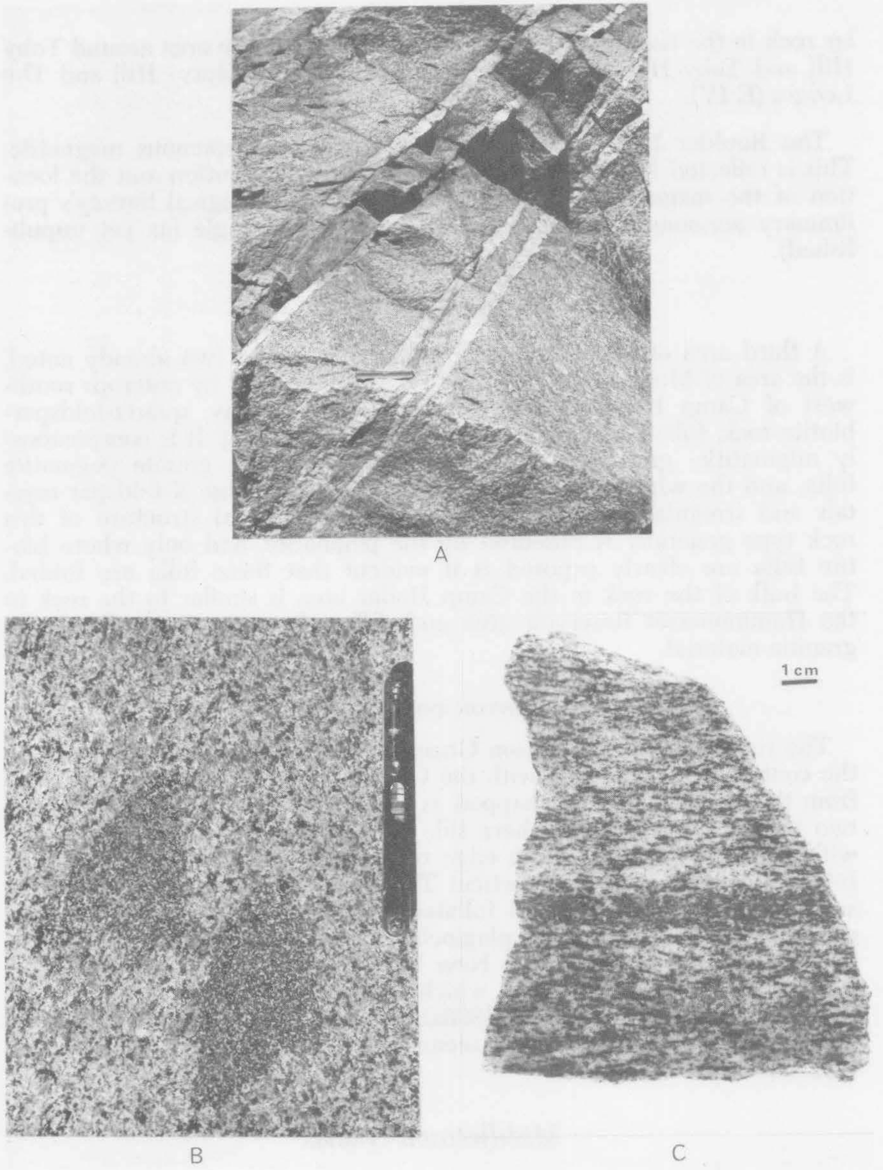


Fig. 4. Boulder Lake variety of Monson Gneiss. *A*, Nearly massive hornblendic rock. Pegmatite sheets are *not* part of a gneissic structure. 16.65N/65.12E on C VIII. *B*, Inclusions of amphibolite (black) in rock shown in *A*. Inclusions are angular and show no apparent orientation. *C*, Planar amphibolite inclusion (black) in well foliated hornblende gneiss. (Compare with fig. 5B.) 16.30N/63.90E on C VII.

lar rock in the Essex quadrangle, as represented in the area around Toby Hill and Toby Hill Road (E V, fig. 3) and even at Horse Hill and The Ledges (E IV).

The Boulder Lake type of Monson contains conspicuous magnetite. This is reflected in the correlation between its distribution and the location of the magnetic high shown on the U. S. Geological Survey's preliminary aeromagnetic map of the Clinton quadrangle (as yet unpublished).

CAMP HADAR AREA

A third area of Monson Gneiss, different from the two already noted, is the area of Monson in C VI (fig. 3), as exemplified by outcrops southwest of Camp Hadar. The bulk of the rock is gray, quartz-feldspar-biotite rock, foliated but without conspicuous layering. It is conspicuously migmatitic; gray folia are interleaved with pink granite pegmatite folia, and the whole rock complex is spotted with large K-feldspar crystals and irregular masses of pegmatite. The internal structure of this rock type generally is obscured by the pegmatite, and only where biotite folia are clearly exposed is it evident that these folia are folded. The bulk of the rock in the Camp Hadar area is similar to the rock in the Hammonasset Reservoir area and differs from it principally in the granitic material.

CLINTON DOME AREA

The rock mapped as Monson Gneiss in a belt 1000-1500 ft wide along the contact of the Monson with the Clinton Granitic Gneiss differs most from the bulk of the rock mapped as Monson. It is well exposed at only two places: one on the northern side of the Clinton dome and in a belt within 1000 ft of the eastern edge of the quadrangle and the other at Interchange 63 of the Connecticut Turnpike. Within this belt the rocks are sharply layered and well foliated pink alaskite, black amphibolite, gray plagioclase gneiss, and plagioclase-microcline gneiss. This association is similar to parts of the New London Granite Gneiss (Lundgren, 1966a, 1967; Goldsmith 1966), which constitutes the lowest unit in the Ivoryton Group of Lundgren (1966a). In the absence of the distinguishing unit of the New London it seems best to include these rocks in the Monson.

Middletown Gneiss

GENERAL REMARKS

Two separate areas of Middletown Gneiss are shown, one in C III (fig. 3), the other in C IV and V and contiguous parts of adjoining ninths. The distinguishing feature of the Middletown Gneiss is that rust-stained anthophyllite gneisses are present throughout. However, the rock associations in the two areas of Middletown noted above are sufficiently distinctive that each is described separately. It is important to note that the two belts of Middletown are physically continuous with each other around the Killingworth dome (fig. 2) and that they therefore are part of the original Middletown Gneiss of Rice and Gregory (1906).

C III AREA

The descriptions of the Middletown Gneiss in Essex (E I, Lundgren, 1964, p. 13-15) apply in detail to the Middletown in C III. Roadcuts on Route 145 and exposures just west of these illustrate the typical association of thin layers of black amphibolite, gray plagioclase gneiss, and rust-stained anthophyllitic gneiss. This association is indicated in the map explanation (pl. 1) as the plagioclase gneiss-amphibolite association (Omig).

C IV-V AREA

The rocks mapped as Middletown in the area centered on C IV-V include all the types seen in C III, but other distinctive rock units are well represented, if poorly exposed. These other rock units are designated as the calc-silicate gneiss-sillimanite schist association. They abound in most of the area of C IV.

The calc-silicate gneiss and sillimanite-schist association (Omic) forms the majority of outcrops in C VI and contiguous C VII. Anthophyllitic gneiss is rare here; only three outcrops have been found. The calc-silicate gneiss and sillimanite-schist association is well displayed in an area in C V around triangulation station "Pritchard" (16.88N/63.63E). Most outcrops display tightly folded layers of the two types of rock. The calc-silicate layers tend to be resistant to weathering and layers of folded calc-silicate granofels are conspicuous. The sillimanite schists also are folded, and quartz-sillimanite nodules in them commonly have an axial-plane orientation. This schist commonly forms a matrix in which isolated folds of calc-silicate granofels are evident.

The individual layers of calc-silicate rock are greenish-gray granofels, consisting of diopside in a granular matrix of microcline and biotite in some layers and plagioclase, quartz, and biotite in others. Calcite is present and many beds show pitted outcrops. Some marble layers are present.

The sillimanite schists and gneisses are largely gray, biotite quartz-feldspar (both plagioclase and microcline) rocks that contain disseminated fibrous white sillimanite or, more conspicuously, the resistant nodules of quartz-sillimanite aggregate so common in coastal eastern Connecticut. These rocks also contain garnet, either in disseminated small, round, red grains or in large red masses.

The stratigraphic relationship of *Omig* to *Omic* is not clear because there are no outcrops in critical areas. They are distinguished on the map (pl. 1) only where good outcrops are present, and the rest of the area of Middletown is simply designated as *Omi.* It may be underlain by both *Omig* and *Omic.* Lundgren had earlier considered *Omic* to be part of the Mamacoke Gneiss (Goldsmith, 1966; Lundgren, 1966a), but this conclusion was rejected because *Omic* lies above, not below, the Monson.

"Brimfield" Formation

Plate 1 (C IX) shows a small belt designated as "Brimfield" Formation. This unit is continuous with schist in the Essex quadrangle mapped as Brimfield Formation (Lundgren, 1964, p. 5-9). The quotation marks indicate that the rocks mapped by Lundgren as Brimfield have not been satisfactorily established as equivalent to the Brimfield schist in Massachusetts. Because they are of minimal importance in Clinton, nothing is to be gained by introducing another name at this time.

The "Brimfield" Formation in the Clinton quadrangle is exposed in only a few outcrops. It consists of bedded garnet (spessartite)-quartz rock (coticule), rusty calc-silicate gneiss with graphite, thin amphibolite, and schistose gneisses. No genuine micaceous schist is exposed, however. Isolated outcrops of these rocks also are found on hilltops of Monson Gneiss north of the mapped belt of "Brimfield." These all lie within a few hundred feet of the eastern edge of the quadrangle.

Clinton Granitic Gneiss

The Clinton Granitic Gneiss consists of massive to well foliated pink granitic rock (quartz monzonite to granodiorite) exposed within the Clinton dome. It is part of the Sterling Plutonic Group (Goldsmith, 1966) of pink granitic rocks, which are an important element of the bedrock all along the coast of eastern Connecticut. The Clinton is well displayed in a long cut on the Connecticut Turnpike. This has been partly described by Lundgren (1966, p. 17-18). This description is repeated here with accompanying illustrations.

The western half of the cut displays the equigranular, rather massive variety of Clinton (fig. 5A), which typically is in rather sharp contact with the gray hornblendic gneisses. These contacts locally cut across the foliation in the gneiss. This variety is pink except along contacts, where it is gray. Eastward along the cut the Clinton is better foliated, more biotitic, and is spotted with red hematite (fig. 5B). This rock is interleaved with a variety of gneissic units. It gradually becomes migmatitic (fig. 5C), and this migmatitic unit forms a transition unit between the Clinton and the gneissic units in which the Clinton appears. It is not clear whether these gneissic units belong to the Monson or the Mamacoke (Goldsmith, 1966). They are better layered than most of the Monson, but not enough of the total Mamacoke association was seen to justify mapping them as Mamacoke.

This cut shows that the Clinton comprises three types of rock, all of them interleaved with other types of rock. It also shows that the contact between the Clinton and the surrounding units is complicated and lies within a zone of intermixed granitic rocks and plagioclase gneisses. Outcrops within the Clinton show that amphibolite is present, and the aeromagnetic high within the Clinton dome suggests that amphibolite or other magnetite-bearing rocks underlie 10 percent or more of the area shown as *cg*.

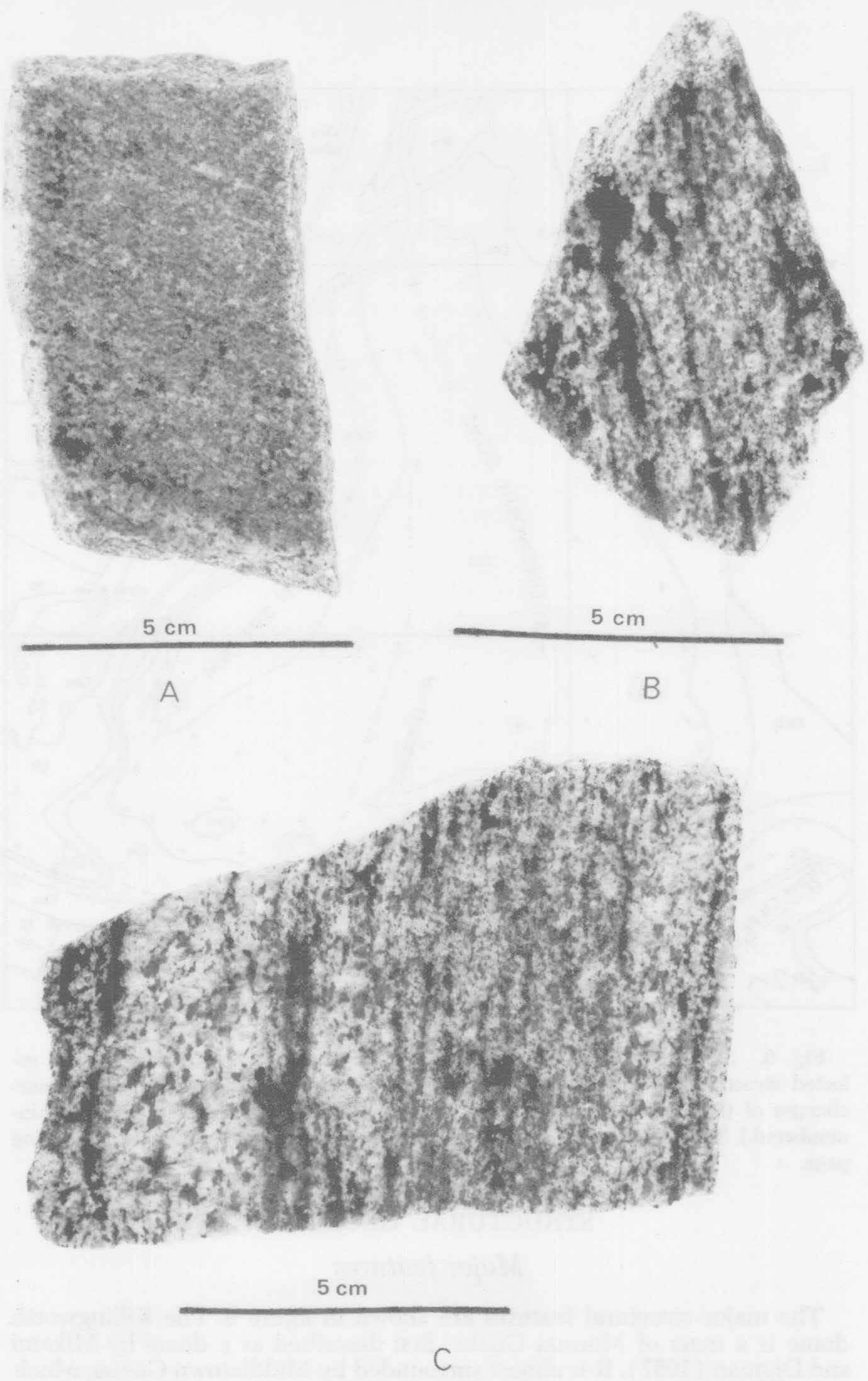


Fig. 5. Polished slabs of Clinton Granitic Gneiss. All samples are from the Connecticut Turnpike cut at the eastern edge of the quadrangle (C IX), listed in order from west to east. *A*, Nearly massive, finer grained variety. Pink to gray. *B*, Foliated and migmatitic variety. Pink with red hematite spots. *C*, Foliated and migmatitic variety. Pink and gray.

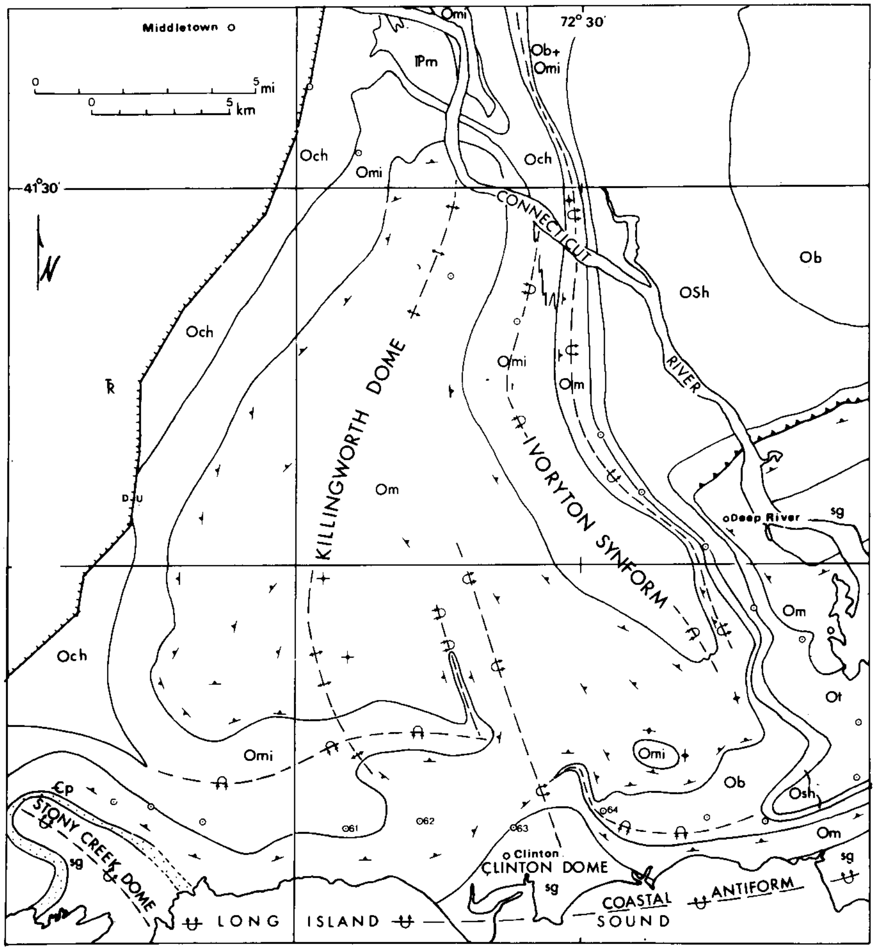
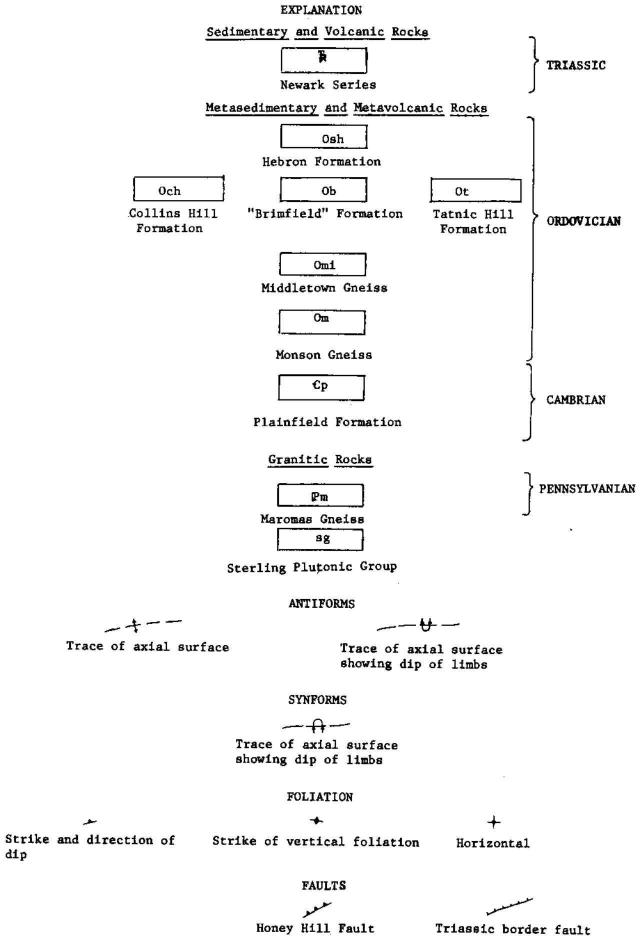


Fig. 6. Structure map of the Killingworth dome and its surroundings. Only selected structural features are indicated. Small circles with dots in center are interchanges of the Connecticut Turnpike (numbered) and of Connecticut Route 9 (unnumbered.) The explanation of geologic formations and structures is on the facing page.

STRUCTURAL GEOLOGY

Major features

The major structural features are shown in figure 6. The Killingworth dome is a mass of Monson Gneiss, first described as a dome by Mikami and Digman (1957). It is almost surrounded by Middletown Gneiss, which appears to lie in one or more folded synclines. One of these synclines separates the Killingworth dome from an anticlinal belt along the coast, in which the oldest rocks are exposed. This coastal belt is modified by



a small domelike structure that has a core of Clinton Granitic Gneiss.

The interpretation of the fold structure of the Monson and Middletown is made more difficult because parts of the Monson may originally have been Ordovician intrusives emplaced in volcanic units of the Monson and Middletown. If this is so, some of the isolated or nearly isolated belts of Middletown may represent inclusions or even so-called roof pendants of Middletown in the Monson. Thus the form and distribution of the Middletown within the Monson might not provide as useful a guide to possible structural interpretation as one might expect. The entire Ordovician intrusive-extrusive complex has, of course, been metamorphosed and deformed one or more times since it formed and thus the original relationships are quite obscure.

The fold structures have been cut by numerous joints and small faults but no major faults have been recognized. The major structures are not well understood, and information available in the Clinton quadrangle is not adequate to justify extensive speculation on these major structures. Some of the puzzles presented by these structures are noted, as we hope that work in the Haddam, Durham, and Guilford quadrangles will help to solve these puzzles.

Coastal belt

The Monson Gneiss along the coast marks the northern limb of an antiform that extends west to the Triassic border fault and east to the Connecticut River. This antiform is modified by the Clinton dome, which has a core of Clinton Granitic Gneiss.

The relationships in the Clinton dome seem to be similar to those described by Sanders (1968) for the Stony Creek Granite (fig. 6). The granitic core appears to show both conformable and cross-cutting relationships with the enclosing and intercalated rocks. Sanders (1968) and Hills and Dasch (1969) interpret the Stony Creek Granite as a Late Precambrian granite remobilized in a more recent (Devonian or younger) metamorphic event. This interpretation is plausible for the Clinton Granitic Gneiss as well but no comparable isotope work has been done on it.

Killingworth dome

Mikami and Digman (1957) described the main mass of Monson Gneiss (Haddam Gneiss) as a dome in which the Monson formed the core of a structural high over which Middletown Gneiss was arched. They believed that the core was an intrusive magmatic pluton. This interpretation is no longer acceptable, as the Monson Gneiss has been folded and metamorphosed. The Killingworth dome is not a simple dome and it must have reached its present form and acquired its complicated internal structure in several structural stages. The relationships in the Clinton quadrangle are not sufficient to provide a basis for completely interpreting the structure of the dome. However, a description of the internal structure will indicate some of the complexities of the dome and subsequent discussion of the structure of the Middletown Gneiss and the coastal belt will point out other complications.

The most conspicuous outcrop-scale structures in the Killingworth dome are recumbent isoclinal folds. These folds are evident only where amphibolite layers or biotite folia are present. Throughout the dome there are numerous isoclinal folds with amplitudes of 2 meters or more. The axial surfaces of these folds have the same orientation as the foliation represented by the symbols shown on the map (pl. 1). Thus, in the area around the Hammonasset Reservoir the axial surfaces of these folds are horizontal or gently dipping (5°-20°). The axial surfaces are commonly marked by biotite folia that cut across the folded biotite folia in the hinge region. Thus, there clearly are at least two distinct foliations but these commonly are about parallel with one another except in the hinge region of each fold.

The major foliation pattern has already been illustrated by Mikami and Digman (1957). It may be seen in plate 1 and also in figure 6. The foliation is *flat* in C I, which is close to the center of the dome. East of this it dips NE and E, away from the center. However, along the southern margin of the dome the foliation dips toward the center of the dome. Thus, an examination of the foliation pattern alone suggests that the southeastern quarter of the dome is not as simple as the name "dome" would suggest. This may be seen equally well by considering the structure of the Middletown Gneiss.

Regional relationships suggest that the Middletown, which partially separates the coastal anticline from the Killingworth dome, lies in a synform with an axial surface of E-W trend (fig. 6). The exact position of this axial surface within the synform is not known. In addition, the Indian River belt of Middletown, which branches N from the E-W belt, appears also to lie in a tight synform. The axial surface of this synform is oriented about N-S and must continue N into the Monson Gneiss. The synforms must be flanked by complementary antiforms. The axial surfaces of the N-S folds meet the axial surfaces of the E-W folds at right angles, and the two sets of folds thus interfere with one another. The following pattern emerges from these observations.

The southeastern part of the Killingworth dome consists of two antiforms with N-S axial surfaces. These are modified by, or modify, antiforms and synforms having E-W axial surfaces. As a result, the southeastern part of the Killingworth dome displays a crude interference pattern of smaller domes and basins. All these structures are apparently superimposed on recumbent isoclinal folds. The scale of these earlier folds is not known.

Other structural features

The small patch of Middletown Gneiss in the extreme northeastern corner of C III (fig. 3) lies on the western limb of the Ivoryton synform (fig. 6). Alternative interpretations of this structure are illustrated by Lundgren (1964, p. 22-29). The isolated patch of Middletown (Omi?) in C III might be an inclusion (roof pendant) of Middletown in intrusive Monson. However, it lies on strike with layers of varied metasedimentary rock in the Monson in the Essex quadrangle (Lundgren, 1964), which suggests that it either is an original layer within the Monson or is Middletown folded down into the Monson.

The "appendix" of "Brimfield" Formation in C VI apparently is isoclinally folded between Monson to the north and south. If this is so, then the axial surface of this isoclinal fold is folded sharply around the Clinton dome. The orientation of the hinge of the isocinal fold is not known.

The structural relationships within the Boulder Lake variety of Monson along the Hammonasset River and within the adjacent Middletown (Omic) have not yet been studied in detail. The Boulder Lake mass here appears to be antiformal. Within this antiformal mass the Boulder Lake rocks (Omh) show only a weak foliation, which has been folded and then disrupted by the planar pegmatite sheets. The units in contiguous *Omic* show isolated large (fig. 4) isoclinal folds, which have been folded by younger, more open folds. The orientations of fold axes shown in *Omic* are of the axes of the younger folds.

PETROLOGY AND MINERALOGY

The rocks of the Clinton quadrangle are all high-grade metamorphic rocks. Lundgren (1964, 1966b) established the position of the sillimanite-orthoclase isograd in the adjacent Essex quadrangle and showed that rocks in the vicinity of this isograd must have been metamorphosed at a temperature of 650°C or more while at a depth of tens of kilometers. The position of this isograd cannot be located as easily in the Clinton quadrangle because the key rock types (muscovite schist and sillimanite-orthoclase schist) are not present in most of the area. However, sillimanite-orthoclase rocks are present in the Middletown in C IV and VII (fig. 3), indicating that the isograd trends E-W across about the middle of the quadrangle.

The mineral assemblages of greatest interest (Robinson and Jaffe, 1969; Stout, 1972) are the anthophyllite and cummingtonite assemblages in the Middletown Gneiss. Most of these are found in C II and V in the Indian River belt of Middletown. The assemblages represented here are shown in table 2.

ENGINEERING AND ECONOMIC GEOLOGY

General information

The map (pl. 1) shows the position of all bedrock outcrops located during field work. Within any area of closely spaced outcrops one can expect that the cover of unconsolidated material is very thin and that excavations will encounter bedrock.

The map also provides a guide to the type of bedrock for some tens of feet beneath the surface. Within the areas of Monson the unexposed bedrock may be expected to be much like that in the nearest exposures. However, within the area mapped as Middletown it is difficult to predict what types of rock will be encountered beneath the surface because the Middletown is so variable.

Most of the bedrock units are layered or foliated. The only significant area of relatively massive rock is the area around Boulder Lake. The frequency of jointing within the rocks probably does not vary greatly over the quadrangle but jointing is most conspicuous in C I-II and in the Boulder Lake area, where it is reflected in the topography. Engineering experience in the construction of the Genesee water tunnel that begins in C I (XN 19.73; XE 63.80) should be a guide to expected experience in tunneling within the Killingworth dome.

In general, one may expect that wells drilled in Monson will provide water of acceptable quality but wells drilled in Middletown may not, because sulfide and carbonate minerals are so common in that formation.

Table 2. – Mineral assemblages in the Middletown Gneiss[1]

	K202F	K505E	K503B	K504G	K505G
Anthophyllite	X	X	X	X	X
Refractive Index of Anthophyllite	1.668	1.688	1.664	1.676	1.666
Cummingtonite	X	—	X	X	—
Hornblende	—	—	—	X	—
Biotite	—	X	—	—	X
Garnet	X	X	—	—	—
Plagioclase	X	X	X	—	X
Quartz	X	X	X	X	X
Cordierite	—	—	—	—	X
Sillimanite	—	—	—	—	X
Coordinates	18.40N 65.30E	17.87N 64.88E	17.87N 65.50E	18.00N 64.66E	17.82N 64.84E

[1] From Thurrell, 1971. All rocks contain magnetite. All anthophyllite is the pleochroic, Fe-Al rich variety called *gedrite*. Some gedrite samples are iridescent blue in reflected light in hand specimen and thin section. These gedrites contain thin lamellae of anthophyllite of different composition. (See Ross, Papike, and Shaw, 1969).

None of the units in the Clinton quadrangle has been or is likely to be of economic interest. Several small quarries were started in the Clinton Granitic Gneiss and in the units surrounding the Clinton but none were developed to any size.

Bedrock control of topography

The topography of the Clinton quadrangle reflects first, the joint pattern and second, the map pattern of rock units of low resistance to weathering and erosion. The control exerted by joints is clearest in C I, II, III and IV, where valleys and cliffs are aligned along steep N-S and E-W joints. This relationship is clearest here because the rocks are relatively uniform, and the foliation is nearly horizontal. Elsewhere the topography is controlled as much by the type of underlying bedrock as by joints. This is especially true for some areas underlain by Middletown Gneiss, particularly the valley of Indian River (C II, V) and the area of Middletown in which the schists and calcareous units are dominant (C IV, V). This correlation between topography and bedrock geology requires that any rectilinear valley not obviously related to a weak rock unit be regarded as marking a belt of fractured, unstable rock, which generally will be highly permeable as well. This relationship was shown clearly during construction of the New Haven Water Company's Genesee tunnel that extends W from the Hammonasset Reservoir (C I). It is also evident in major roadcuts such as the Connecticut Turnpike cut in the Clinton Granitic Gneiss, where breccia and gouge along high-angle faults are rapidly weathered and eroded away.

GEOLOGIC HISTORY

The geologic development of the rocks of the Clinton quadrangle parallels the development of rocks in the coastal belt in the Essex (Lundgren, 1964) and Old Lyme (Lundgren, 1967) quadrangles. The major elements in the geologic development of the rocks of the Clinton quadrangle are as follows:

1) The oldest rocks in the quadrangle are the gneisses around the Clinton Granitic Gneiss. These may be as old as Cambrian or even Precambrian. These rocks, and all of the Monson Gneiss, were originally parts of a complex of volcanic rocks and intrusives, most of them dacites, altered andesites and quartz diorites. The intrusive parts of the original complex are best represented by units such as the Boulder Lake variety of Monson Gneiss.

2) The Clinton Granitic Gneiss was intruded into the lower part of this complex. If it, like the Stony Creek Granite to the west, is Precambrian (Hills and Dasch, 1969), then it was intruded before the Ordovician Monson Gneiss was in place.

3) The Ordovician Middletown Gneiss was deposited on top of the volcanic-intrusive complex described above. The Middletown was originally an extremely heterogeneous unit consisting of dacitic and altered andesitic volcanics, shale, calcareous sediments, and other types of rock.

4) The Ordovician "Brimfield" Formation was deposited on top of the Middletown. It consisted of shale and manganese-bearing chert.

5) The whole complex of rocks described above was metamorphosed at temperatures above 650°C. Most of the rocks in the southern half of the quadrangle are in the sillimanite-orthoclase zone (Lundgren, 1964, 1966b) but the position of the sillimanite-orthoclase isograd, marking the northern limit of this zone, is not established because the appropriate types of rock (mica schists containing muscovite) are not present in the northern half of the quadrangle. The gedrite assemblages in the Middletown Gneiss were also formed during this period of metamorphism. The metamorphism presumably began during the Devonian but may have continued into the Pennsylvanian or even Permian.

6) The structural development accompanying metamorphism presumably began with the formation of one or more N-trending anticlines of Monson Gneiss. These were modified by the formation of E-trending anticlines, notably the anticline that forms the coastal belt. This E-trending anticline and the complementary syncline modify the southern margin of the Killingworth dome, making it much broader than the northern end. The Clinton dome may have risen independently and may have been active more than once.

7) The subsequent structural history includes the formation of numerous small high-angle faults and joints. Some of these faults probably formed at the same time as the major Triassic faults in the area immediately to the west of the Clinton quadrangle. During this period the rocks of the Clinton quadrangle were uplifted many thousands of feet. An estimate of 15,000 ft to 20,000 ft of uplift between Permian and Late Triassic time seems reasonable.

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