Stratigraphic and Structural Relationships of the Brimfield Group in Northeast-Central Connecticut and Adjacent Massachusetts

GEOLOGICAL SURVEY BULLETIN 1389

Prepared in cooperation with the Connecticut State Geological and Natural History Survey and the Massachusetts Department of Public Works

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By JOHN D. PEPER, M. H. PEASE, JR., *and* VICTOR M. SEIDERS

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A revision of the stratigraphy of rocks of the Brimfield Schist of Emerson in and about the type area

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By JOHN D. PEPER, M. H. PEASE, JR., and VICTOR M. SEIDERS

ABSTRACT

A thick sequence of Ordovician(?) to Devonian(?) eugeosynclinal strata, metamorphosed to sillimanite-muscovite and sillimanite-orthoclase grades, is exposed immediately east of the Bronson Hill anticlinorium in the Brimfield area of northern Connecticut and southern Massachusetts. These rocks dip northwest in a largely homoclinal sequence, isolated in a fault-bordered and fault-imbricated wedge, which includes and extends south of the type locality of the Brimfield Schist of Emerson in Massachusetts. Complicated internal structural relationships and structural isolation made it difficult to correlate rocks in the wedge with established stratigraphic sequences to the south, west, and southeast. In this area the name Brimfield is elevated to group status to include the Bigelow Brook Formation and the newly named overlying Hamilton Reservoir and Mount Pisgah Formations.

The Bigelow Brook Formation gradationally overlies the Southbridge Formation of M. H. Pease, Jr. The contact is largely a low-angle thrust fault, however, in the southeastern part of the area. The Bigelow Brook is about 16,000 feet (4.9 km) thick; it includes a lower gneiss member of largely gray-weathering sillimanite gneiss with minor calc-silicate gneiss, sulfidic schist, and amphibole gneiss; a middle calc-silicate member, less than 300 feet (92 m) thick, of calc-silicate gneiss and schist; and an upper gneiss member of rusty-weathering sillimanite schist and gneiss with persistent lenses of gray granular gneiss and calc-silicate rocks.

The Hamilton Reservoir Formation, which is in the central part of the area, overlies the Bigelow Brook Formation along a major thrust fault, the Kinney Pond fault. The Hamilton Reservoir may be as much as 30,000 feet (9.2 km) thick; it includes lower, middle, and upper schist members of predominantly fissile sulfidic sillimanite schist. The upper schist member includes the type locality of the former Brimfield Schist. The schist members are separated by a lower gneiss member and an upper gneiss member that contain laterally extensive lenses of intermediate to mafic quartz-poor to quartz-rich gneiss.

The Mount Pisgah Formation overlies the upper schist member of the Hamilton Reservoir Formation in two isoclinal synclines in a fault wedge along the western border of the area. About 2,000 feet (600 m) of Mount Pisgah rocks is exposed; these rocks consist of massive gray garnetiferous sillimanite schist and gneiss as well as cyclically interlayered schist and gneiss.

INTRODUCTION

A sequence of high-grade metamorphic rocks has been mapped at 1:24,000 scale in northeast-central Connecticut and adjacent Massachusetts, herein termed the Brimfield area (fig. 1, area 1). Quadrangles pertaining to this report are outlined on the geologic

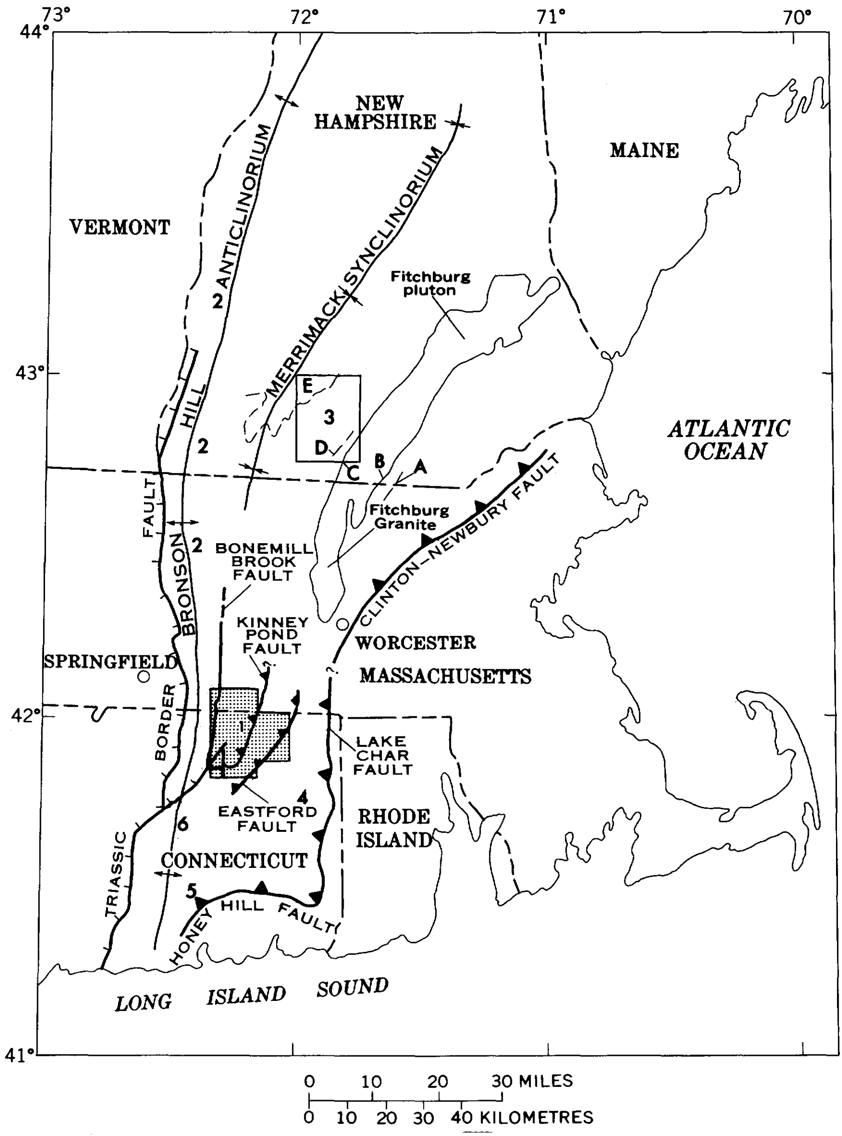

FIGURE 1.—Index map showing the regional geologic setting of the Brimfield area in southern New England.

EXPLANATION

Location of areas of recent study in southern New England:

1. **Brimfield area (this report)**
2. **Bronson Hill anticlinorium (Thompson and others, 1968)**
3. **Peterborough quadrangle (Greene, 1970)**
4. **Plainfield-Danielson area (Dixon, 1964)**
5. **Deep River area (Lundgren, 1962)**
6. **Marlborough quadrangle (Snyder, 1970)**

Letters delimit rocks east and west of Fitchburg pluton of Billings (1956) in southern New Hampshire. These rocks are possibly correlative with rocks in the Brimfield area:

A-B Upper part of Merrimack Group (Billings, 1956)
C-D Souhegan Member of Littleton Formation (Greene, 1970)
D-E Peterborough, Francestown (dashed lines), and Crotched Mountain Members of Littleton Formation (Greene, 1970)

Normal fault—Tick marks on downthrown block

Steeply dipping fault

Thrust fault—Sawteeth on upper plate

FIGURE 1.—Continued.

map (pl. 1). Mapping has been completed by geologists of the U.S. Geological Survey in the Wales, Westford, Eastford, Stafford Springs, and Monson quadrangles and is in progress in the Southbridge and Warren (north of the Wales) quadrangles.

Rocks of the Brimfield area occupy a largely fault-bordered wedge in the southern part of a large area mapped as Brimfield Schist and Paxton Quartz Schist on the geologic map of Massachusetts and Rhode Island (Emerson, 1917). These rocks are also shown as Brimfield Schist and Hebron Gneiss on the preliminary geologic map of Connecticut (Rodgers and others, 1956) and as Brimfield Schist on generalized geologic maps of eastern Connecticut (Dixon and Lundgren, 1968).

Our recent mapping has demonstrated that the names Paxton, Brimfield, and Hebron, as previously defined or used, are inadequate to deal with the stratigraphy of the Brimfield area, owing largely to the smaller scale and lack of detail of the earlier mapping. Consequently, we propose to raise the rank of Emerson's Brimfield Schist to group status in this area and to include in the Brimfield Group the Bigelow Brook (Pease, 1972) and the newly named Hamilton Reservoir and Mount Pisgah Formations. The name Southbridge Formation (Pease, 1972) has been assigned to the bulk of the rocks that are on strike with the Paxton Quartz Schist of Emerson (1917).

ACKNOWLEDGMENTS

Fieldwork in Massachusetts was carried out in cooperation with the Massachusetts Department of Public Works, and in Connecticut with the Connecticut State Geological and Natural History Survey. Lincoln R. Page and H. Roberta Dixon introduced the authors to major geologic problems to be solved in the area and provided stimulating critical analysis and discussion during many field visits as the mapping progressed. Professor Janet M. Aitken (University of Connecticut) made available to the authors unpublished data on the bedrock geology of the Spring Hill and South Coventry quadrangles and gave freely of her knowledge in discussions of geologic interpretations during the authors' field visits in the northern third of these quadrangles. G. E. Moore, Jr., (Southbridge quadrangle) and John S. Pomeroy (Warren quadrangle) gave freely of their geologic knowledge as work progressed in those quadrangles. D. W. O'Leary served as field assistant in the Wales and Monson quadrangles and helped outline and draft illustrations for this report. R. V. Guzowski served as field assistant in the Wales and Stafford Springs quadrangles.

REGIONAL SETTING AND PREVIOUS WORK

The Brimfield area has not been mapped since Emerson's time (late 19th century). Knowledge of stratigraphic and structural relationships in the strike belt in which the Brimfield rocks lie has been largely speculative and tentative, based on inferences drawn from Emerson's earlier works and modern work in peripheral areas. Emerson (1917, p. 60, 62) considered the Paxton Quartz Schist to underlie the Brimfield Schist. He regarded the Brimfield as being probably of Carboniferous age, on the basis of a tentative correlation with fossiliferous rocks at the "coal mine" at Worcester, Mass. (fig. 1). Grew (1973), however, suggested that the coal mine rocks are in a fault sliver enclosed by older rocks.

West of the Bonemill Brook fault (fig. 1 and pl. 1), a sequence of Middle Ordovician to Lower Devonian metasedimentary and metavolcanic rocks has been mapped from northern New Hampshire to Long Island Sound along the Bronson Hill anticlinorium, a series of elongate gneiss domes and mantling metasedimentary rocks called the Bronson Hill anticline in New Hampshire (Billings, 1956). The Monson Gneiss, chiefly layered plagioclase-quartz-biotite gneiss and amphibolite of probable Middle Ordovician or older age, extends in a belt along the east side of the anticlinorium from northern Massachusetts to southern Connecticut.

The structure of the belt has been considered anticlinal in southern and central Connecticut (Lundgren, 1962) but is synformal at its northern end in Massachusetts (Thompson and others, 1968).

Geologists, working along the Bronson Hill anticlinorium which extends into the eastern uplands of central Massachusetts and southern New Hampshire (fig. 1, area 2), suggested that rusty-weathering "Partridge-like" schist in Emerson's Brimfield may be Ordovician in age; they mapped both Ordovician and Devonian rocks in a narrow belt east of the Bronson Hill anticlinorium, which they suggested is a root zone of recumbent folds overturned from east to west (Thompson and others, 1968, p. 214, and map and cross sections, pls. 15–1a, b). The distance that these structures extend southeastward into the Merrimack synclinorium is the subject of continuing study in central Massachusetts. Recent mapping by Greene (1970), however, in the Peterborough quadrangle of New Hampshire (fig. 1, area 3) placed the axis of the Merrimack synclinorium asymmetrically to the north of the north-northeast-trending belt of Emerson's Brimfield Schist in central Massachusetts (Greene, 1970, discussions and map p. 52–53, and discussions of age p. 15–16). Greene's work suggests that most rocks extending southward into Massachusetts are on the homoclinal southeast limb of the Merrimack synclinorium and are Silurian and Devonian in age.

Rocks immediately southeast of the Eastford fault (fig. 1 and pl. 1) include the Lower(?) Devonian Eastford Gneiss (intrusive gneissoid quartz monzonite) and the Ordovician(?) to Silurian(?) Hebron Formation (calcareous metasedimentary rocks) mapped by Pease (1972). These rocks have been interpreted as lying on the overturned limb of a major recumbent syncline (Dixon and Lundgren, 1968).

Evidence for the syncline is the tracing of the Tatnic Hill Formation of Dixon (1964), which underlies the Hebron in the Plainfield-Danielson area (fig. 1, area 4) west of the Lake Char fault, southward then westward, along the Honey Hill fault into the Deep River area (fig. 1, area 5). Here the Tatnic Hill and its proposed equivalent, the Brimfield Formation of Lundgren (1962), are on opposite sides of a major syncline (Chester syncline).

STRUCTURAL FRAMEWORK AND METAMORPHISM

The formations shown on the geologic map and cross section (pl. 1) form a largely homoclinal sequence of westward-dipping metasedimentary rocks. The stratigraphic positions of the many lithologic units in the sequence mapped at 1:24,000 scale are shown on plates 2 and 3. Large-scale isoclinal folds have been identified only in the western part of the area. Major westward dipping high-angle reverse and thrust faults internally complicate and locally separate formations. These faults diverge northeastward subparallel to the strikes of bedding and regional foliation. The fault relationships at depth, as shown on the cross section of plate 1, are interpretive, based on a down-plunge projection of surface relationships of mapped faults. Beyond this sort of extrapolation there are no drill-hole data or other firm information of relationships at depth along the line of section.

Rocks of the area have been recrystallized at the sillimanite-potassium feldspar and sillimanite-muscovite grades of metamorphism (isograd shown on pl. 1) and have been extensively deformed locally by small-scale drag folding and small- and large-scale thrust faulting. Intrusions of thin (6 in) (15 cm) to thick (300 ft) (92 m) concordant and semiconcordant tabular bodies of foliated pegmatite are locally abundant. In this type of terrane, primary sedimentary structures are seldom well preserved, and interpretation of the direction of bedding tops from these relict structures is often difficult.

The Bigelow Brook Formation overlies the Southbridge Formation (Pease, 1972) in the southeastern part of the area (pl. 1). The contact is the Black Pond fault, a thrust fault of variable degree of westward dip, in the Eastford quadrangle (Pease and Peper, 1968, stop 8). The Keach Pond fault, probably a steeply dipping reverse fault, cuts the Black Pond fault and forms most of the contact in the Westford quadrangle. Detailed stratigraphic analysis (pl. 2 and discussion below) suggests that displacement on these faults decreases northeastward. In addition, the formations share similar lithologies, but in differing proportions, near the fault contact in the Southbridge quadrangle (G. E. Moore, Jr., written commun., 1970), suggesting that the faults displace an originally gradational sedimentary contact between the two formations.

The predominance of relict sedimentary structures in the two units, whose tops face west, including graded bedding (fig. 2) and low-angle cross lamination, suggest that these formations become younger westward. Facing directions or dips are locally reversed on the limbs of small overturned or open folds. The stratigraphic succession of the Bigelow Brook Formation is interrupted by the Boston Hollow fault, Bigelow Pond fault, and many unnamed oblique faults. Minor folds visible in individual outcrops, and larger folds, show a dextral sense and plunge gently north-northeast. Some of the larger folds are outlined by map configurations of the middle calc-silicate member of the Bigelow Brook Formation (pl. 1, unit bc) and show west-over-east drag sense sympathetic to directions of movement on faults. Movement on the faults evidently began during late stages of the regional metamorphism and continued after folding; sillimanite needles, quartz rods, and small asymmetric folds are alined in the fault planes, and the faults cut major folds. The sense of minor folds and direction of lineations in the fault planes suggest that upper plates moved east-southeast (Pease and Peper, 1968) in the eastern and central parts of the area.

The Hamilton Reservoir Formation overlies the Bigelow Brook Formation along the Kinney Pond fault, a major regional thrust fault (pl. 1). The attitude of shear surfaces along the fault in a narrow valley in the northeastern part of the Westford quadrangle (Pease and Peper, 1968, stop 6A) suggests that the fault dips steeply west here. Regionally, however, the fault appears to be a low-angle thrust fault; it dips gently north where it trends across the South Coventry quadrangle and truncates steeply west-dipping units of the Hamilton Reservoir Formation. Along this segment the fault is openly warped around north-trending axes and locally is offset by a major normal fault west of Route 32 (pl. 1). Narrow zones of gneiss, made schistose by shearing, follow closely and splay off gently north-dipping relict bedding and foliation planes in the Bigelow Brook rocks underlying the fault. Similar but discordant zones cut, offset, and drag the steeply west-dipping relict bedding and regional foliation of Hamilton Reservoir rocks overlying the fault and are sporadically distributed as far north as the latitude of the middle of the Westford quadrangle (Pease and Peper, 1968, stops 4 and 5).

The stratigraphic sequence of the Hamilton Reservoir Formation is complicated by steeply dipping faults that trend subparallel to the strike of bedding and regional foliation—the Rock Meadow, Pinneys Pond, and Hollow Brook faults. The Hollow Brook fault ends in the northern part of the Warren quadrangle (J. S. Pomeroy, oral and written communs. 1970).

Between the Kinney Pond and Hollow Brook faults, relict sedimentary structures are most abundant in the gneiss members and upper schist member of the Hamilton Reservoir Formation, and most indicate tops to the west (figs. 7–9). Although these top indicators are sparsely distributed through the section, the predominance of west-facing top indicators and the lack of detectable repetition of map units or mappable fold hinges suggest that the rocks of the Hamilton Reservoir form a west-facing homocline between these two major faults.

In the fault wedge between the Hollow Brook fault and the Bonemill Brook fault to the west, the Mount Pisgah Formation overlies the Hamilton Reservoir Formation in two major synclines identified chiefly on the basis of facing direction of graded beds in the lower part of the Mount Pisgah Formation (figs. 10–13). The axis of the easternmost syncline (Mount Pisgah syncline) is offset and repeated by the Alden Brook fault. The axis of another syncline is breached by intrusion of the foliated diorite including porphyritic quartz monzonite (fqd on pl. 1), which is equivalent to the Hardwick and Coys Hill Granites of Emerson, 1917.

The amount of relative displacement on the Hollow Brook and Bonemill Brook faults is unknown. Minor folds of dextral sense, with west- and southwest-plunging axes, are abundant in the narrow wedge between the two faults in the Stafford Springs quadrangle. These folds have steep dips and suggest largely strik-slip movement on the faults, rather than the largely dip-slip movement inferred to characterize faults in the eastern part of the area.

STRATIGRAPHIC CORRELATION AND TENTATIVE AGE

The sequence of rocks in the Brimfield area (fig. 1, pl. 1) is separated from recently mapped sequences in surrounding areas by major faults on the southeast (Eastford fault) and west (Bonemill Brook fault). Bordering areas that have not been mapped in detail include the Spring Hill and South Coventry quadrangles (to the south) and the general area of central Massachusetts (to the north). In addition, no fossils have been found in, or radiometric age determinations done on, rocks in the Brimfield area. Thus, correlation of formations of the Brimfield Group in the as yet poorly deciphered stratigraphic framework of southeastern New England can be tentatively suggested only on the basis of lithologic similarity and long-range stratigraphic projection.

In general, the thickness and order of succession of lithologic units in the Brimfield area are not recognizably duplicated in the stratigraphic section across strike to the west on the Bronson Hill anticlinorium, nor across strike to the east in the Tatnic Hill and Quinebaug Formations of the Putnam Group (Dixon, 1964) immediately west of the Lake Char fault, nor to the southwest in the Putnam Group of Snyder (1970) in the Marlborough quadrangle (fig. 1, area 6).

The trends of aeromagnetic anomalies on the recent aeromagnetic map of southern New England (Zietz and others, 1972) parallel the strike of map units in the Brimfield area and suggest, moreover, that these units trend northeast and north into southeastern and south-central New Hampshire (Peper, 1972). In addition, reconnaissance investigations by two of us (Pease and Peper) suggest a possible general lithologic correlation of stratigraphic units in the Brimfield area with units in southern New Hampshire (fig. 1). In general, the lithology of the Southbridge Formation is similar to metasedimentary rocks of the upper part of the Merrimack Group (interval A–B, fig. 1); the Bigelow Brook is similar in lithology to Greene's (1970) Souhegan Member of the Littleton Formation (interval C–D, fig. 1), and the Hamilton Reservoir and Mount Pisgah Formations in large part resemble rocks of his Peterborough, Francestown, and Crotched Mountain Members of the Littleton Formation (interval D–E, fig. 1).

These similarities favor the thesis that most units in the Brimfield area are continuous with part of the thick homoclinal west-facing succession of metasedimentary rocks on the east limb of the Merrimack synclinorium in southern New Hampshire. On this basis, the rocks of the Brimfield Group would be considered Silurian(?) to Early Devonian(?) in age. However, the possibility that the sequence contains rocks of Ordovician age cannot be ruled out at present because of the geographical remoteness of the relevant fossiliferous rocks in Waterville, Maine, and Littleton, N.H., and the incomplete knowledge of stratigraphy and structure in intervening areas, particularly northeast-central Massachusetts. Thus, rocks of the Brimfield Group are considered to be Ordovician(?) to Early Devonian(?) in age.

BRIMFIELD GROUP

BIGELOW BROOK FORMATION

The Bigelow Brook Formation consists mostly of quartzo-feldspathic schist and gneiss that contain biotite, garnet, and sparse sillimanite (figs. 2, 4). Equigranular calc-silicate gneiss with diopside, scapolite, or actinolite (fig. 3), fissile sulfidic sillimanite schist, amphibolite and amphibole-bearing gneiss containing biotite and garnet form marker lenses that intertongue with one another and with the quartzo-feldspathic schist and gneiss. A thin (100–250 ft) (31–76 m) unit of schist and calc-silicate gneiss forms the middle calc-silicate member of the formation (pls. 1 and

2, unit bc) and separates a thick (12,000 ft) (3.7 km) lower gneiss member of predominantly gray-brown-weathering gneiss from a thick (6,000 ft) (1.8 km) upper gneiss member of mostly rusty-orange-weathering gneiss.

Pease (1972) designated the hills south and west of the upper reach of Bigelow Brook in the Westford quadrangle as the type area of the Bigelow Brook Formation, where the upper and middle parts of the formation are exposed. The lower part of the formation is exposed in the Eastford quadrangle northwest of Crystal Pond where the lowest rocks of the formation are between the Keach Pond and Black Pond faults (pl. 1, section lines 2–13, 2–14, and 2–15; pl. 2, cols. 2–13, 2–14, and 2–15).

LOWER GNEISS MEMBER

Rocks between the Keach Pond and Black Pond faults.—The Black Pond separates the lower gneiss member (pl. 1, unit bl) of

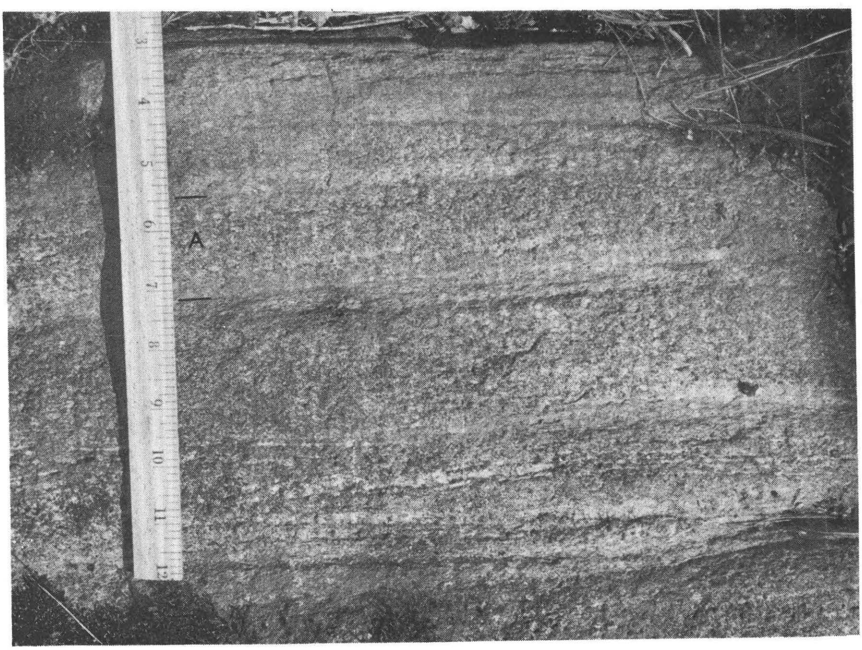

FIGURE 2.—Relict graded bedding in the lower gneiss member of the Bigelow Brook Formation. Rock is sparsely sillimanitic plagioclase-quartz-biotite-garnet schist and gneiss of unit blgg (pl. 2), about 300 feet (92 m) stratigraphically below base of middle calc-silicate member. Biotite content and grain size increase gradationally upward in layer (A), reflecting probable gradation of recrystallized psammitic to pelitic contents of original graded bed. Ruler in inches.

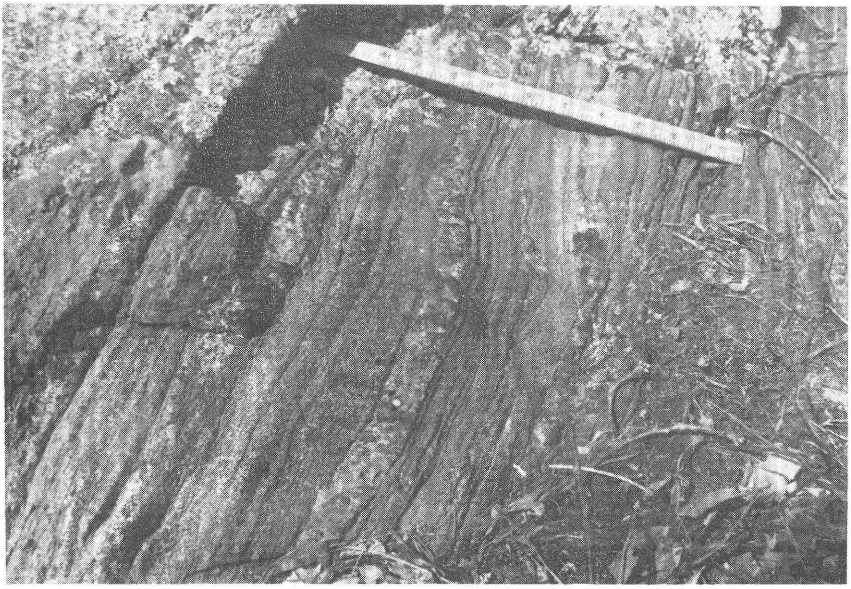

FIGURE 3.—Layers of the calc-silicate gneiss in lower gneiss member of Bigelow Brook Formation. The calc-silicate gneisses form mappable lenses (pl. 2, unit blc). Ruler in inches.

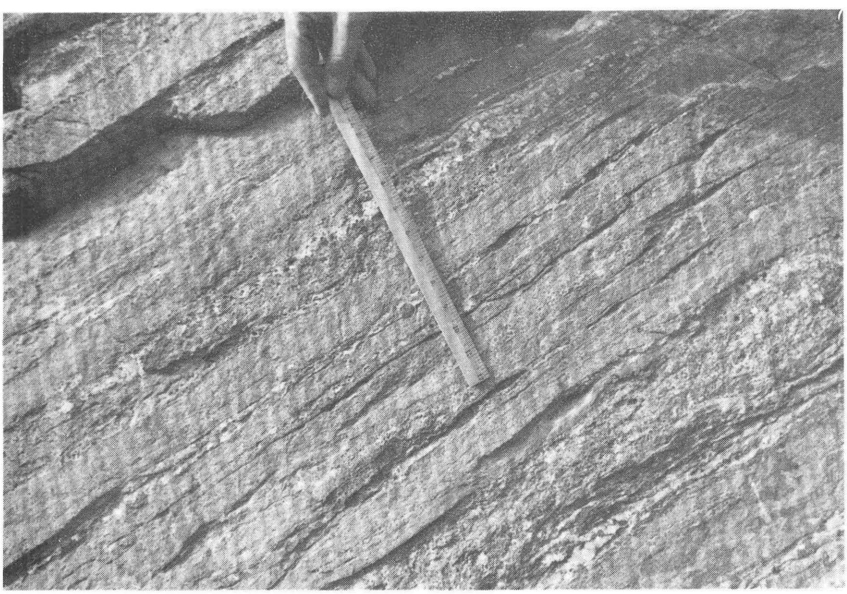

FIGURE 4.—Regularly parted and evenly layered gneiss (pl. 2, unit blgg) of lower gneiss member of Bigelow Brook Formation. Ruler in inches.

the Bigelow Brook Formation from the Southbridge Formation in the Eastford and Southbridge quadrangles. The Keach Pond fault, which coincides with the sillimanite-potassium feldspar isograd (pl. 1), forms the boundary between the two formations in most of the Westford quadrangle and in the Spring Hill quadrangle. Rusty-weathering schists in the fault sliver between the Keach Pond and Black Pond faults in the Westford and Eastford quadrangles contain prograde muscovite and are considered to be the lowest exposed rocks in the Bigelow Brook Formation. The rocks in the fault sliver between the two faults in the Westford quadrangle are assigned to this same stratigraphic interval on the basis of a lithologic similarity between rusty-weathering schist containing prograde muscovite in the Westford quadrangle (pl. 2, col. 2–3, unit bls) and a similar schist (pl. 2, col. 2–15, unit blr_1 of Pease, 1972) in the Eastford quadrangle.

The contrast between rocks of the Bigelow Brook Formation and rocks of the Southbridge Formation along the Keach Pond fault in the Westford quadrangle is more distinct than it is in the Eastford and Southbridge quadrangles. Bigelow Brook rocks here are stratigraphically higher in the Bigelow Brook Formation and are mostly northwest of the sillimanite-orthoclase isograd. The Bigelow Brook units (pl. 2, blsc, blgf, bls, and blgg) are distinctly coarser grained and more schistose than the gneisses of the Southbridge Formation.

Rocks west of the Keach Pond fault.—Above or west of the Keach Pond fault, the lower gneiss member of the Bigelow Brook Formation consists predominantly of gray- to brown-weathering schist and gneiss (pl. 2, units blgg and bl). These rocks are sparsely sillimanitic, slightly calcareous, and locally contain abundant garnet. Individual layers are quite variable in mineral content (table 1, modes 5–8, unit blgg) and have compositions and structures appropriate for metamorphosed beds of siltstone (modes 6 and 8), calcareous siltstone (modes 5 and 7), and shale. Relict graded bedding (fig. 2) and crossbedding occur locally, but most discernible relict bedding is parallel and nongraded (figs. 3 and 4).

The calc-silicate gneisses (fig. 3) form local marker units of small lateral extent (pl. 1, unit bld; pl. 2, units blc, bld).

A thick lens of rusty-weathering felsic gneiss and schist (pl. 2, unit blrg) forms an extensive marker unit through the Westford quadrangle. Most of this unit is rusty felsic gneiss having a composition appropriate for metamorphosed siltstone, but thin lenses of rusty calc-silicate gneiss (unit blrc, table 1, mode 9,

TABLE 1.—*Modes of the Southbridge Formation and the lower gneiss member of the Bigelow Brook Formation*

	Southbridge Formation		Lower gneiss member of the Bigelow Brook Formation											
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Unit (symbols used on pl. 2)	S	Sa2	bla	blgf	blgg	blgg	blgg	blgg	blrc	blrs	blr	blrc	blg	blg
Location [1]: XN	381.02	384.65	393.30	381.05	386.30	382.45	382.45	404.17	380.27	380.09	389.70	389.60	381.95	391.15
XE	764.53	768.30	766.70	756.25	759.15	756.05	756.05	765.25	753.27	753.20	760.28	760.20	751.10	759.13
Points counted	518	536	602	489	535	406	555	540	525	563	538	491	374	526
Quartz	38.5	12.5	7.5	39.0	18.7	54.5	.9	19.5	24.8	36.3	36.9	16.7	7.2	14.3
Plagioclase	36.7	46.1	21.6	30.7	32.0	20.4	45.6	35.8	25.0	.9	30.7	29.8	43.9	41.8
Anorthite content [2]	(32)	-----	(36)	(35)	(45)	(30)	(45)	(32)	(54)	(35)	(34)	(47)	(15)	(47)
Potassium feldspar	.6	[3].0x	.8	10.6	-----	-----	-----	-----	-----	16.7	-----	-----	-----	-----
Biotite	21.2	4.8	-----	17.8	5.2	24.4	8.7	38.2	1.3	13.8	23.8	.0x	5.9	9.7
Muscovite	.6	-----	-----	*1.6	-----	.0x	-----	-----	-----	-----	-----	-----	-----	-----
Pyroxene [4]	-----	-----	.0xD	-----	1.0D	-----	24.7D	-----	21.0D	-----	-----	22.6D	14.7D	15.8H
Amphibole [5]	-----	34.1B	57.5B	-----	32.6B	-----	4.3G	-----	7.8B	-----	-----	9.4G	23.0B	13.2P
Amphibole [5]	-----	-----	-----	-----	8.7A	-----	12.8A	-----	-----	-----	-----	-----	.0xA	-----
Garnet	1.9	.9	-----	.1	-----	.8	-----	4.6	5.7	20.0	7.3	-----	-----	-----
Sillimanite	.0x	-----	-----	.0x	-----	-----	-----	-----	-----	8.0	-----	-----	-----	-----
Chlorite	-----	-----	7.1	-----	-----	-----	-----	-----	-----	2.1	-----	-----	-----	-----
Scapolite	-----	-----	-----	-----	-----	-----	-----	-----	10.1	-----	-----	6.7	-----	-----
Epidote	-----	1.1	-----	-----	-----	-----	-----	-----	-----	-----	-----	11.2	-----	-----
Apatite	.2	.2	.3	-----	.9	-----	-----	-----	-----	-----	.7	.0x	.5	.4
Sphene	-----	-----	-----	-----	-----	-----	-----	-----	2.3	-----	-----	3.7	-----	-----
Zircon	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Sulfide	-----	.0x	-----	-----	-----	-----	-----	-----	-----	.7	.6	-----	-----	-----
Opaque oxide	.2	-----	5.0	-----	.9	-----	3.1	-----	-----	-----	-----	-----	4.8	5.0
Graphite	.1	-----	-----	-----	-----	-----	-----	2.4	.0x	1.2	-----	-----	-----	-----
Total	100.0	99.7	99.8	99.8	100.0	100.1	100.1	100.5	98.0	99.7	100.0	100.1	100.0	100.2

[1] Connecticut grid system: XN, thousands of feet north; XE, thousands of feet east.
[2] Number in parentheses shows anorthite content of plagioclase in mole percent.
[3] 0.0x indicates mineral present in rock but not present in mode. Abundance estimated to be less than 0.10 percent.
[4] D, calcium-rich clinopyroxene; H, orthopyroxene.
[5] B, brown hornblende; G, green hornblende; A, tremolite-actinolite; P, pale-grayish-brown amphibole.
* Retrograde.

metamorphosed calcareous siltstone) and fissile sulfidic sillimanite schist (unit blrs, table 1, mode 10, metamorphosed euxinic shale) are abundant. Relatively thin but extensive lenses of biotite and amphibole-bearing gneiss form marker units at two positions in the lower member in the Westford quadrangle (pl. 1, unit blg; pl. 2, units bla and blg). In both units, weakly layered relatively quartz-poor gneiss (table 1, modes 3, 13, and 14), containing hornblende, or pale-brown amphibole in prismatic aggregates probably pseudomorphic after pyroxene, is interleaved with more strongly banded biotite gneiss and amphibolite. The general quartz-poor compositions of this gneiss and its interlayering with the thickly banded mafic gneiss suggest that the rocks in these units were derived from waterworked volcanic debris.

MIDDLE CALC-SILICATE MEMBER

The middle calc-silicate member of the Bigelow Brook Formation is shown as a narrow continuous band (pls. 1 and 2, unit bc) that extends for at least 9 miles (14 km) in the Westford, Eastford, and Southbridge quadrangles.

The member is characterized by thin lenses of gray-green-weathering calc-silicate gneiss containing diopside and scapolite (table 2, modes 1–3). These laminated to thinly parted gneisses have compositions appropriate for metamorphosed calcareous siltstones. Gray- to light-brown-weathering schist, compositionally similar to schist of the lower member, is the most abundant rock type throughout the member. The calc-silicate member resembles calc-silicate-bearing units blc and bld in the lower member, but it is thicker and laterally more extensive than these units and gradationally underlies rusty-brown-weathering silimanite gneiss of the upper member.

UPPER GNEISS MEMBER

The upper gneiss member of the Bigelow Brook Formation is mapped east of (below) the Kinney Pond fault from the four-corner area of the Wales, Southridge, Eastford, and Westford quadrangles into the Spring Hill and South Coventry quadrangles (pl. 1, units bu, buk). Rocks in the lower part of the member are exposed in the Westford and Eastford quadrangles between the middle calc-silicate member and the Boston Hollow fault.

These rocks are cut out by the Boston Hollow fault southwest of the town of Westford (pl. 1) where rocks of the middle part of the upper gneiss member are in fault contact with rocks of the lower gneiss member. Toward the southern border of the Westford

TABLE 2.—*Modes of the middle calc-silicate and upper gneiss members of the Bigelow Brook Formation*

	Middle calc-silicate member			Upper gneiss member								
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
Unit Symbols (used on pl. 2)	bc	bc	bc	bur	bugr	bugg	bugg	bugg	bugg	bugg	bugg	bugg
Location [1]: XN	399.25	408.88	404.32	397.52	420.70	420.12	420.85	420.76	420.75	420.37	429.35	431.55
XE	759.60	767.85	765.20	757.40	765.03	764.08	764.15	764.55	764.92	764.92	769.60	768.35
Points counted	518	503	512	551	422	419	516	547	543	513	632	690
Quartz	22.3	11.7	16.4	50.7	26.8	40.8	40.9	47.1	45.3	38.2	22.0	37.7
Plagioclase	26.1	36.8	34.8	-----	13.1	8.8	24.7	34.4	34.1	41.1	2.4	38.7
Anorthite content [2]	(46)	(48)	(45)	-----	(52)	(33)	(54)	(57)	(38)	(32)	-----	(84)
Potassium feldspar	3.3	-----	2.0	17.4	16.8	30.3	.8	-----	-----	-----	-----	-----
Biotite	.2	-----	6.5	13.4	11.6	10.7	21.7	12.3	9.4	17.4	17.7	14.9
Muscovite	-----	.2	-----	-----	-----	-----	2.5	[3] 0.0x	-----	-----	-----	-----
Clinopyroxene [4]	25.0	30.2	26.0	-----	-----	-----	-----	-----	9.4	-----	-----	.3
Green hornblende	5.8	8.5	7.4	-----	-----	-----	-----	-----	-----	-----	-----	-----
Garnet	-----	-----	-----	13.4	11.4	3.3	7.0	5.5	-----	2.9	20.3	8.1
Sillimanite	-----	-----	-----	4.2	19.4	5.3	-----	-----	-----	-----	24.1	-----
Cordierite and pinite	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.9	-----
Scapolite	12.5	6.6	5.1	-----	-----	-----	-----	-----	-----	-----	-----	-----
Carbonate	2.5	2.0	.4	-----	-----	-----	-----	-----	-----	-----	-----	-----
Chlorite	-----	-----	-----	-----	-----	-----	2.5	-----	-----	-----	5.8	-----
Epidote	.0x	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Apatite	-----	.2	.4	-----	-----	-----	-----	.5	.7	.2	-----	.1
Sphene	1.5	3.0	1.4	-----	-----	-----	-----	-----	-----	-----	-----	-----
Zircon	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.3
Sulfide	-----	.8	.0x	.2	-----	.5	-----	-----	1.1	-----	-----	-----
Opaque oxide	-----	-----	-----	-----	-----	-----	-----	.0x	-----	-----	5.8	-----
Graphite	1.0	.0x	.0x	.7	.9	.0x	-----	.0x	-----	-----	-----	-----
Total	100.0	100.0	100.4	100.0	100.0	99.7	100.1	99.8	100.0	99.8	100.0	100.1

[1] Connecticut grid system: XN, thousands of feet north; XE, thousands of feet east.
[2] Number in parentheses shows anorthite content of plagioclase in mole percent.
[3] 0.0x indicates mineral present in rock but not present in mode. Abundance estimated to be less than 0.10 percent.
[4] Calcium-rich.

quadrangle, most of the upper member is cut out by displacement on the Bigelow Pond and Boston Hollow faults.

The upper gneiss member consists predominantly of rusty-weathering schist and gneiss (pl. 2, unit bur). Quartz-feldspar schist in this unit (table 2, mode 4) is mineralogically similar to rusty gneiss and schist of the lower gneiss member and has a composition appropriate for metamorphosed shale. Units of gray sillimanitic schist (pl. 2, bugg), granular quartz-plagioclase-calc-silicate gneiss (pl. 2, buc), fissile sulfidic schist (pl. 2, bus), and a distinctive sillimanite-megacryst gneiss (pl.2, busl) are lenticular units of metamorphosed sedimentary rock that intertongue with the rusty-weathering schist and gneiss. These lenses typically grade by interbedding through vertical distances of tens of feet (3–27 m) and lateral distances of hundreds of feet (30–270 m) into surrounding rocks of unit bur.

In addition to metasedimentary rock types, rocks of probable volcanic origin were noted north of the mapped area between the Kinney Pond and Bigelow Pond faults in the Southbridge quadrangle (G. E. Moore, Jr., oral commun., 1970). These consist of moderately foliated medium- to dark-gray quartz-plagioclase-biotite gneiss with 12 to 25 percent biotite, locally minor hornblende, and local trace amounts of garnet.

A relatively thick unit of gray granular gneiss and schist near the middle of the upper member (pls. 1 and 2, unit buk) forms an important stratigraphic marker, although it is lithologically complex and of irregular thickness. This unit, which fingers northward and southward into rusty gneiss, is truncated, offset, and repeated by movement along the Bigelow Pond fault. The top of the unit is present locally east of (below) the Bigelow Pond fault and also west of (above) this fault (pl. 2, cols. 2–10). The stratigraphic interval repeated by the fault is about 500 feet (150 m). A sill of foliated quartz diorite (pl. 2, cols. 2–10 and 2–11, unit fqd) is present on both sides of the fault 100–200 feet (30–61 m) above the granular gneiss and schist unit (buk). However, the sill, which is of uncertain age and is not part of the Bigelow Brook Formation, is not shown at these locations on the geologic map (pl. 1).

The uppermost exposed part of the upper member is immediately east of (below) the Kinney Pond fault and consists of a unit of interlayered quartz-plagioclase-biotite gneiss and gray sillimanite schist (pl. 2, unit bugg). The gneiss is medium grained, equigranular, and locally contains small amounts of diopside or garnet (table 2, modes 6–10); layers are 1–3 inches (3–8 cm) thick. A sample from the Wales quadrangle contains plagioclase as calcic as bytownite (table 2, mode 12). The contrasts in biotite content and distinct parting are suggestive of primary nongraded beds, with only minor graded bedding and crossbedding. These compositions and structures suggest that the gneiss is metamorphosed siltstone and calcareous siltstone. Coarse-grained layers of rusty-weathering sillimanite schist are locally interbedded with the gneiss in the Westford quadrangle. Sillimanite- and cordierite-bearing gneiss occur in the unit in the Wales quadrangle (table 2, mode 11).

HAMILTON RESERVOIR FORMATION

The Hamilton Reservoir Formation is herein named and adopted for a thick sequence of schist and gneiss that trends across the western half of the Westford quadrangle and underlies most of the Wales quadrangle (pl. 1). The type area of the Hamilton Reservoir Formation is designated as the low hills in the vicinity of Hamilton Reservoir in the Wales quadrangle (pl. 1), where middle parts of the formation are well exposed. The lower parts of the formation are best exposed on the low hills north of the town of Union (pl. 1, section lines 3–7, 3–8; pl. 3, col. 3–8) and around Mashapaug Pond in the Wales quadrangle. Upper parts of the

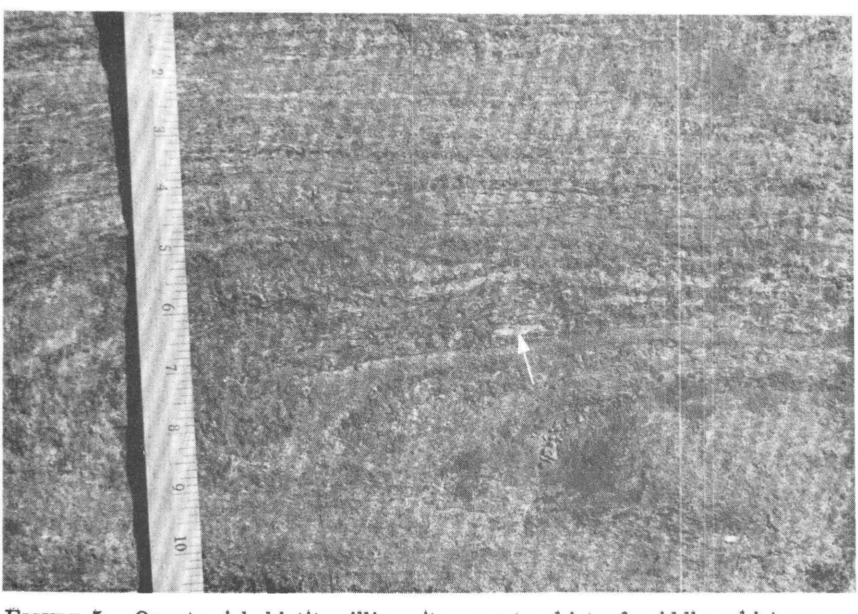

FIGURE 5.—Quartz-rich biotite-sillimanite-garnet schist of middle schist member of Hamilton Reservoir Formation. Note elongate white patches of fibrolitic sillimanite (arrow). Ruler in inches.

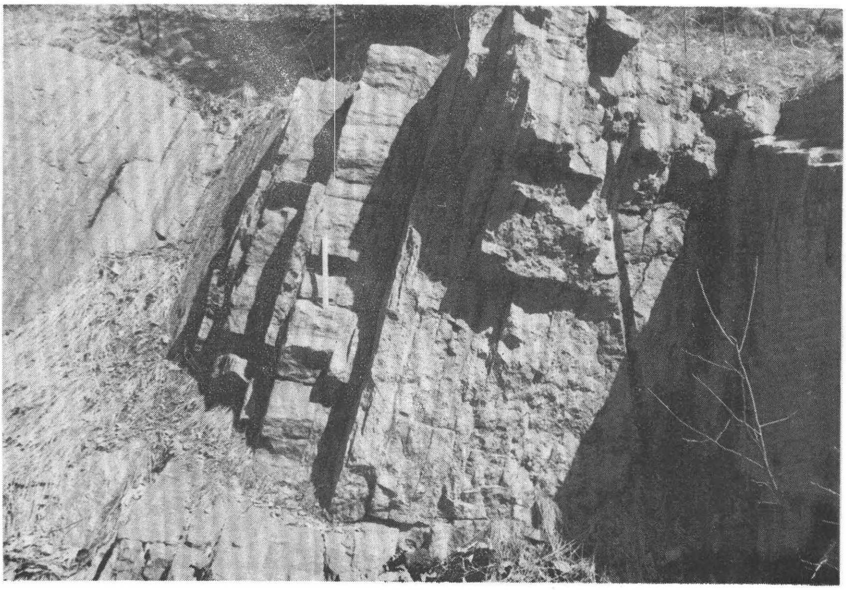

FIGURE 6.—Regularly layered schist and gneiss of upper schist member of Hamilton Reservoir Formation. Ruler is 1 foot (30 cm) long.

FIGURE 7.—Regularly alternating relict beds in upper schist member of Hamilton Reservoir Formation. Beds consist of metamorphosed calcareous (light-gray) and sulfidic (medium-gray) metasiltstone. Ruler is 1 foot (30 cm) long.

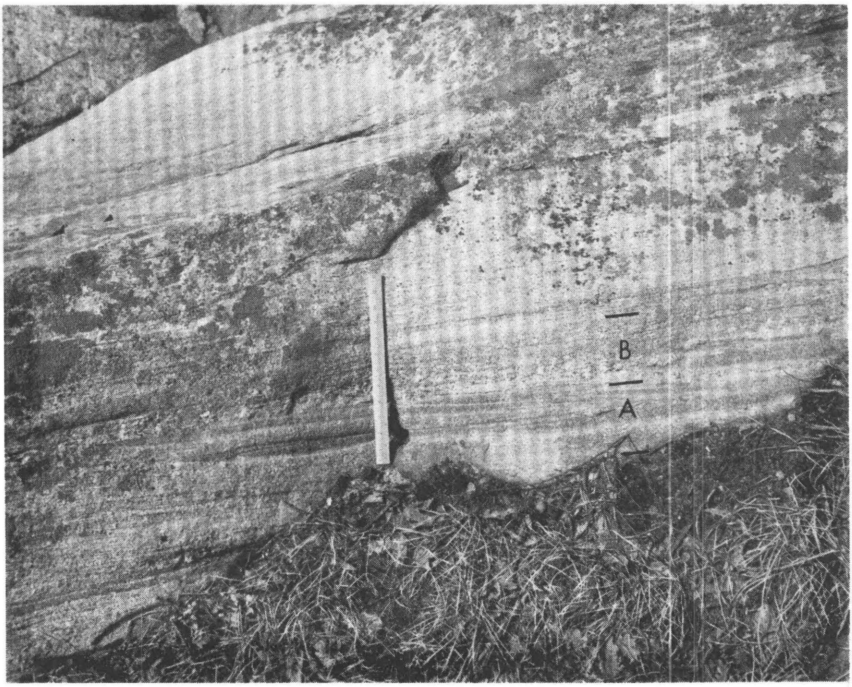

FIGURE 8.—Metavolcanic gneisses in lower gneiss member of Hamilton Reservoir Formation (unit hlgl of pl. 3). Stepwise truncation of relict beds of banded gneiss (A) by base of upwards-fining coarse-textured gneiss (B) suggests top is up. Ruler is 1 foot (30 cm) long.

formation are exposed in the west-central part of the Wales quadrangle (pl. 1, section lines 3–7 through 3–11; pl. 3, col. 3–11).

The formation is divided into the following five informal members: a lower, a middle, and an upper schist member separated by a lower and an upper gneiss member. The schist members are composed of predominantly rusty-weathering pelitic and semipelitic schist and gneiss (figs. 5, 6) and appreciable fissile sulfidic sillimanitic schist having composition and relict primary structures appropriate for metamorphosed siltstones and shales, and euxinic mudstones. The schist members also contain thin lenses and mappable units of granular gneisses including rocks with compositions and structures appropriate for metamorphosed quartzose siltstones and calacreous siltstones (fig. 7) as well as gneisses poorer in quartz and having more mafic compositions, probably indicative of metamorphosed volcaniclastic sediment.

The gneiss members include mappable units of complexly interfingering gneiss and contain only subordinate amounts of fissile sulfidic schist. Many of the gneisses are well-layered rocks that

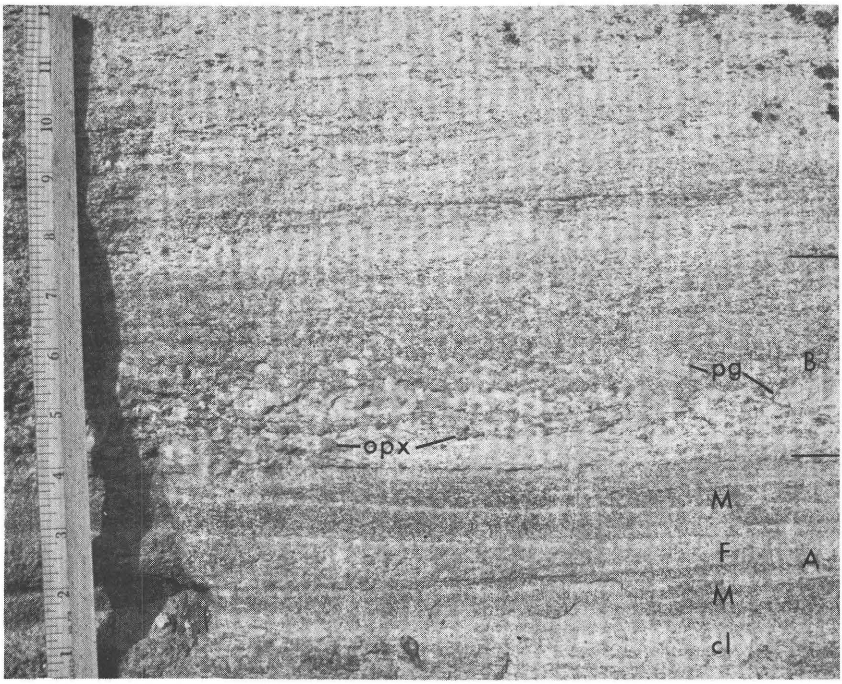

FIGURE 9.—Enlarged view of relict beds (A and B) of figure 8. Coarse-textured gneiss (B) contains large subhedral crystals of plagioclase (pg) and coarse aggregates of plagioclase, orthopyroxene (opx), and biotite in a groundmass of similar composition. Size of aggregates (probable relict clasts) fines upwards. Relict beds in the banded gneiss are shown by an even-textured granular gneiss (A), alternately richer, more mafic (M), and poorer, more felsic (F), in hornblende and biotite. Relict beds in the banded gneiss are also shown by an uneven-textured gneiss representing a probable metamorphosed clastic texture (cl). Ruler is in inches.

contain appreciable feldspar and biotite and small to large amounts of quartz, garnet, hornblende, orthopyroxene, and clinopyroxene. Their compositions and probable relict sedimentary structures (figs. 8, 9) suggest derivation largely from waterworked volcaniclastic debris. Subordinate amounts of layered and massive amphibolite, and massive mafic gneisses in the sequence, also suggest derivation of these rocks from the metamorphism of volcanic-derived material. Massive gneiss having generally conformable contacts with surrounding rocks may represent metamorphosed hypabyssal sills or less extensively reworked volcaniclastic material.

The formation is structurally separated into two parts by the Rock Meadow fault, which extends across the mapped area (pls. 1, 3). Rock east of (below) the fault is considered to be stratigraphically beneath the rock west of (above) the fault. No details of the internal stratigraphic succession can be correlated across the fault. Consequently, the actual direction and amount of displacement on the fault cannot be determined. It is entirely conceivable, however, that rocks on the two sides of the fault are at least in part lateral facies equivalents, the rocks on the west having been thrust over those to the east.

A sill near the base of the upper schist member is mapped as foliated quartz diorite (fqd on pl. 1) in the Westford and Stafford Springs quadrangles and includes orthopyroxene-bearing gneiss in the Wales quadrangles. It has also been included in plate 3, but it is not part of the Hamilton Reservoir Formation.

LOWER SCHIST MEMBER

The lower schist member is mapped as a belt from the northeast corner of the South Coventry quadrangle through the center of the Westford quadrangle and across the southeast corner of the Wales quadrangle (pl. 1, unit hls).

The member has an apparent thickness of 4,000–6,000 feet (1.2–1.8 km), but this is a minimum thickness, as the base of the member is not exposed in the Brimfield area. The lowest exposed rocks of the member crop out on the west side of the Kinney Pond fault, where they are in fault contact with the Bigelow Brook Formation. This fault contact is particularly well exposed in a fault-controlled topographic lineament along an unnamed brook that flows southwestward into Kinney Pond in the northeastern ninth of the Westford quadrangle (Pease and Peper, 1968, stop 6A about 0.6 mile (1 km) east of the town of Union). Outcrops of Hamilton Reservoir rocks near the fault consist chiefly of rusty-weathering sillimanite-rich schist and gneiss and include rare dark-gray very fine grained quartz-rich biotite gneiss in layers a few inches (10 cm) thick.

A stratigraphic marker unit of dark-gray mafic granular gneiss with orthopyroxene and appreciable colorless amphibole occurs near the middle of the member in the Wales quadrangle (pl. 3, unit hlsb, col. 3–8; table 3, mode 1). Discontinuous thinner lenses of granular plagioclase-quartz-biotite gneiss containing small amounts of clinopyroxene occur at a similar stratigraphic position in the Westford quadrangle (pl. 3, unit hlsc, col. 3–1). Fissile graphitic and sulfidic schist is the dominant rock type of the member above the general stratigraphic position of these granular gneisses.

TABLE 3.—*Modes of the lower schist, lower gneiss, and middle schist members of the Hamilton Reservoir Formation*

	Lower schist member	Lower gneiss member							Middle schist member									
Sample No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Unit (symbol used on pl. 3)	hlsb	hlgm	hlgf [2]	hlgi	hlgg	hlgg	hlgr	hlgl	hms	hms	hms	hms	hms	hms	hmsb	hmsb	hmsb	hmsb
Location [1]:																		
XN	438.90	402.00	428.75	428.90	436.40	435.60	431.80	427.45	464.80	464.80	437.90	432.70	427.60	399.70	409.15	428.60	446.20	441.00
XE	768.70	750.00	761.40	761.10	766.35	765.30	760.95	757.85	769.30	769.30	760.85	755.75	755.95	744.65	750.45	754.15	762.75	760.35
Points counted	65.5	490	685	2122	706	688	618	719	590	513	885	951	576	534	608	1356	539	545
Quartz	15.7	14.3	64.1	42.7	3.8	.6	33.8	8.5	-----	36.3	53.3	38.9	5.0	51.5	46.3	23.0	46.6	35.0
Plagioclase	43.5	42.2	24.1	-----	38.5	39.0	8.7	47.4	-----	-----	-----	-----	8.3	9.2	33.1	57.4	28.0	34.7
Anorthite content [3]	-----	(38)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	(35)	(31)	(11)	-----	-----
Potassium feldspar	-----	2.0	-----	-----	2.0	.9	8.4	-----	-----	-----	19.3	9.9	-----	7.3	-----	4.1	-----	19.8
Biotite	14.7	25.4	.4	3.4	-----	47.0	12.3	-----	50.0	16.8	13.1	16.8	34.3	9.9	11.8	12.2	11.1	7.3
Orthopyroxene	4.6	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.1	-----	3.1
Clino-pyroxene [4]	-----	11.8	-----	-----	35.9	-----	-----	36.3	-----	-----	-----	-----	-----	-----	7.4	-----	12.6	-----
Amphibole [5]	17.7C	[6] 0.0xG	-----	-----	8.2G	.2G	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.4G	-----
Garnet	-----	-----	-----	47.7	-----	-----	24.3	5.2	-----	-----	2.7	20.5	9.8	12.6	-----	-----	-----	-----
Sillimanite	-----	-----	1.3	-----	-----	-----	7.9	-----	36.8	-----	5.0	12.4	37.5	8.4	-----	-----	-----	-----
Cordierite	-----	-----	2.8	-----	-----	-----	2.3	-----	-----	*38.9	3.4	-----	-----	-----	-----	-----	-----	-----
Pinite	-----	-----	2.8	-----	-----	-----	1.0	-----	-----	2.5	1.8	.6	-----	-----	-----	-----	-----	-----
Chlorite	-----	-----	-----	.9	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Apatite	-----	1.2	-----	3.9	.1	2.9	-----	.1	-----	-----	-----	-----	-----	-----	.5	-----	-----	-----
Sphene	-----	.0x	-----	.1	3.0	-----	-----	1.7	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Zircon	-----	-----	-----	-----	-----	-----	-----	.1	-----	-----	-----	.4	-----	-----	-----	-----	-----	-----
Opaque	-----	1.8	-----	-----	-----	.3	1.3	.7	13.2	-----	-----	-----	-----	-----	-----	-----	1.3	-----
Iron sulfide	3.8	-----	-----	.2	-----	-----	-----	-----	-----	4.3	-----	-----	-----	.4	.1	-----	-----	-----
Graphite	-----	-----	3.5	1.1	-----	-----	-----	-----	-----	1.2	1.2	.4	3.3	.6	-----	-----	-----	-----
Carbonate	-----	.8	-----	-----	2.8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Scapolite	-----	-----	-----	-----	6.4	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total	100.0	99.5	99.0	100.0	100.7	100.0	100.0	100.0	100.0	100.0	99.8	99.9	98.2	99.9	99.2	99.8	100.0	99.9

[1] Connecticut grid system: XN, thousands of feet north; XE, thousands of feet east.
[2] Mode includes 1.0 percent red iron oxide. Plagioclase mode includes potassium feldspar.
[3] Number in parentheses shows anorthite content of plagioclase in mole percent.
[4] Calcium-rich.
[5] C, colorless amphibole; G, green hornblende.
[6] 0.0x indicates mineral present in rock but not present in mode. Abundance estimated to be less than 0.10 percent.
* Includes cordierite and plagioclase.

LOWER GNEISS MEMBER

The lower gneiss member is mapped in a band about 0.75 mile wide (1.2 km) (pl. 1, unit hlg) across the South Coventry, Stafford Springs, Westford, and Wales quadrangles. The member maintains a fairly constant apparent thickness of 1,900–2,300 feet (580–690 m) for a distance of at least 15 miles (25 km) along strike. It contains many tabular and lenticular heterogeneous units of distinctive mineralogy and texture that have been mapped separately in the individual quadrangles at 1:24,000 scale. The interlayering relationships and description of these units are shown in plate 3, and modes are given in table 3, modes 2–8.

The member consists predominantly of weakly to strongly layered granular plagioclase-(quartz)-biotite gneiss containing minor amphibole, clinopyroxene, and orthopyroxene (hlgg) in the southern part of the Westford quadrangle. Northward, the lower parts of this granular gneiss form the base of the member, and the upper parts of this gneiss intertongue complexly with other types of gneisses and schist, including rocks with compositions and structures appropriate for metamorphosed euxinic black shales (hlgs), metamorphosed layered tuffs and calcareous siltstones (hlgl), and semipelitic siltstones (hlgr). The granular gneiss also encloses lenses composed predominantly of ferruginous quartz-garnet gneiss (hlgi), amphibolite gneiss (hlga), and fissile graphitic and sulfidic schist (hlgf). The garnet in a sample of hlgi has a composition near almandine 71.6, andradite 10.2, grossularite 1.5, pyrope 13.4, and spessartite 3.3, as calculated by V. M. Seiders from modal analysis and chemical rock analysis; the rock locally contains 19.4 percent FeO.

A massive to weakly layered hypersthene-megacryst gneiss (unit hlgm) occurs as discontinuous lenses in the lower part of the granular gneiss in the Westford quadrangle and may represent metamorphosed hypabyssal sills or lava.

MIDDLE SCHIST MEMBER

The middle schist member is mapped in a belt, 0.75–1.25 miles (1.2–2 km) wide, that trends northeastward from the northeast corner of the South Coventry quadrangle through the southeast corner of the Stafford Springs quadrangle, the west-central part of the Westford quadrangle, and the east-central part of the Wales quadrangle (pl. 1, unit hms). The member has an apparent thickness of 4,200 feet (1.3 km) in the most complete section, which is the southern part of the Wales quadrangle (pl. 3, col. 3–8, units hms, hmsb). The uppermost part of the member is cut out by the

Rock Meadow fault in the Westford quadrangle (pls. 1 and 3, cols. 3–2, 3–4), and by the Pinneys Pond fault in the Stafford Springs and South Coventry quadrangles. The middle schist member consists chiefly of red-orange, rusty-weathering coarse-grained quartz-feldspar schist and gneiss in which sulfidic and graphitic schist is characteristic. South of the central parts of the Westford quadrangle, layers of thinly laminated aluminous schist containing megacrysts of sillimanite are abundant (fig. 5). The schist and gneiss are generally quartz rich. They contain biotite, sillimanite, and variable amounts of feldspar, cordierite, and garnet (table 3, modes 11–14). Individual layers are locally rich in biotite and sillimanite (table 3, modes 9 and 13) or cordierite and biotite (table 3, mode 10).

Felsic biotite gneiss (pl. 3, unit hmsb) forms a lens in the upper middle part of the member. This unit contains appreciable thinly banded light- and dark-gray medium- to fine-grained gneiss in the Westford quadrangle. The unit thickens northward, and in the Wales quadrangle it contains appreciable coarse-grained gneiss (table 3, modes 16 and 18) and less abundant thinly layered gneiss (table 3, mode 17).

UPPER GNEISS MEMBER

The upper gneiss member is mapped in a belt 1.0–1.5 miles (1.6–2.2 km) from the South Coventry quadrangle across the Stafford Springs, Westford, and Wales quadrangles (pl. 1, units hug, hugm). The member has maximum apparent thickness (6,000 ft) (1.8 km) near the northern border of the Wales quadrangle; southward units in the lower and middle parts of the member are cut out along the Rock Meadow and Pinneys Pond faults as shown in plate 3.

In general lithologic aspect, the upper gneiss member is similar to the lower gneiss member, containing marker units and lenses, predominantly of gneiss, that intertongue complexly with each other and with lenses of schist. This upper gneiss member, however, is about three times as thick as the lower gneiss member, and no satisfactory correlation can be made between the internal stratigraphy of the two members.

The base of the member is formed by a unit of quartz-poor, hornblende- and pyroxene-bearing gneiss, more than 500 feet (152 m) thick. This unit (pl. 3, unit hugb, cols. 3–5, 3–8, 3–11) is exposed east of (below) the Rock Meadow fault, north of the middle part of the Westford quadrangle. A thinner lens of similar gneiss (pl. 3, unit hugb, col. 3–12) forms the top of the member in the northern part of the Wales quadrangle, and very thin lenses of the gneiss (not shown) are present at five other localities in this member.

A thin marker unit composed predominantly of massive gneiss of generally mafic composition persists through the northern part of the Brimfield area and is the key to correlation of rocks between the Rock Meadow and Pinneys Pond faults. This unit (pls. 1 and 3, unit hugm) contains compositionally homogeneous mafic gneiss (possible lava or hypabyssal sill) sharply to gradationally intertongued with distinctly layered gneiss of intermediate and pelitic composition (possible metamorphosed tuffs and muds). The unit of mafic gneiss extends through the middle of a thick unit of undifferentiated gneiss in the Westford quadrangle and is near the top of the layered gneiss unit (pl. 3, unit hugt) in the Wales quadrangle.

Modes are given in table 4.

UPPER SCHIST MEMBER

The upper schist member (pl. 1, unit hus) forms a west-dipping homoclinal band of rock about 2.5 miles (4 km) wide extending through the west-central part of the Wales quadrangle and the four-corner area of the Westford, Stafford Springs, and Monson quadrangles. In addition, rocks in the upper part of the member form the limbs of isoclinal folds in the fault block bounded by the Hollow Brook and Bonemill Brook faults along the western edge of the area. The member has a maximum apparent thickness of about 15,000 feet (4.6 km) in the central homoclinal band (pl. 3, col. 3–11) and includes rocks in the type locality (Brimfield, Mass., pl. 1) of the Brimfield Schist of Emerson (1917).

The upper schist member consists chiefly of rusty-weathering schist and gneiss (pl. 3, unit hus) similar in composition (table 5, modes 1 and 2) to rocks in the other two schist members of the formation. The member includes a mappable lens of gray massive and well-layered quartz-feldspar-biotite metavolcanic gneiss on opposite sides of the Hollow Brook fault in the Stafford Springs quadrangle (pl. 1, unit husv) and a mappable lens of sulfidic schist in the Stafford Springs and Monson quadrangles (pl. 1, unit hs). In the Wales quadrangle, the member includes mappable lenses of calc-silicate gneiss and amphibolite (pl. 3, unit husa, cols. 3–10 and 3–11) and a gray-weathering gneiss (pl. 3, unit husn, col. 3–11). Six additional mappable lenses of distinctive gneiss in the upper schist member have been mapped in the Warren quadrangle (J. S. Pomeroy, written commun., 1970).

TABLE 4.—*Modes of the upper gneiss member of the Hamilton Reservoir Formation*

Sample No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Unit (symbol used on pl. 3)	hugu	hugu	hugc	hugc	hugt	hugt	hugl	hugl	hugh	hugm	hugm	hugm	hugg	hugr	hug[illegible]	hugo	hugc	hugb
Location [1]:																		
XN	407.90	410.95	399.50	410.75	441.50	466.25	464.95	464.95	468.45	426.16	455.30	466.15	430.30	444.55	459.00	460.75	460.75	426.20
XE	747.05	748.15	741.65	748.25	757.00	763.35	767.05	767.05	763.15	750.00	760.95	763.25	749.15	755.75	759.35	759.20	759.20	752.14
Points counted	537	550	677	555	503	708	1848	562	528	550	496	512	494	723	509	624	535	433
Quartz	24.1	25.1	26.6	28.8	32.8	28.7	34.6	8.7	31.3	.2	1.0	6.4	48.8	40.8	12.2	8.8	13.3	14.1
Plagioclase	19.5	5.6	37.4	44.5	38.8	-----	34.6	41.6	56.8	53.3	40.7	55.5	28.7	7.8	34.0	26.7	1.5	61.4
Anorthite content [2]	(34)	(33)	(42)	(31)	(68)	-----	(20–22)	(43)	(18)	(71)	(48)	(58)	(80)	-----	-----	-----	-----	(41)
Potassium feldspar	11.2	26.4	-----	-----	-----	16.7	24.5	-----	5.5	-----	-----	-----	-----	20.7	-----	10.9	3.7	-----
Biotite	6.1	10.7	.3	4.2	-----	-----	5.6	12.5	4.5	5.5	41.1	1.8	13.6	11.5	19.3	18.6	2.8	1.2
Orthopyroxene	-----	-----	-----	-----	-----	-----	-----	25.4	1.9	-----	-----	23.2	7.1	-----	31.0	-----	-----	22.0
Clino-pyroxene [3]	-----	-----	29.4	13.5	20.1	-----	-----	-----	-----	4.0	10.1	-----	-----	-----	-----	-----	23.0	-----
Amphibole [4]	-----	-----	4.3G	-----	-----	-----	-----	5.3I	-----	21.3I	-----	10.6I	-----	-----	-----	-----	15.9G	.5G
Amphibole	-----	-----	-----	2.9A	-----	-----	-----	-----	-----	13.6C	3.0C	-----	-----	-----	-----	-----	-----	-----
Garnet	27.8	13.5	-----	4.5	6.8	29.6	-----	-----	-----	-----	-----	-----	-----	11.9	-----	5.6	-----	-----
Sillimanite	9.9	18.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.8	-----	11.1	-----	-----
Corderite	-----	-----	-----	-----	-----	22.0	-----	-----	-----	-----	-----	-----	-----	2.8	-----	10.2	-----	-----
Pinite	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	2.2	-----	1.0	-----	-----
Scapolite	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	35.3	-----
Carbonate	-----	-----	1.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.4	-----
Apatite	-----	-----	.1	.1	-----	-----	-----	-----	-----	-----	1.2	-----	.4	-----	-----	-----	-----	-----
Sphene	-----	-----	1.5	-----	1.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.1	-----
Zircon	-----	-----	-----	-----	-----	-----	.1	-----	-----	.2	-----	-----	-----	.1	-----	.2	-----	-----
Opaque	-----	-----	-----	-----	.2	3.0	.5	-----	-----	1.6	2.8	2.5	1.4	1.4	3.5	6.9	-----	.9
Iron oxide	.9	-----	.1	.9	-----	-----	-----	6.4	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Iron sulfide	-----	.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Graphite	.4	[5] 0.0x	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total	99.9	100.3	100.7	99.4	100.0	100.0	99.9	99.9	100.0	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.1

[1] Connecticut grid system: XN, thousands of feet north; XE, thousands of feet east.
[2] Number in parentheses shows anorthite content of plagioclase in mole percent.
[3] Calcium-rich.
[4] G, green hornblende; I, green and brown hornblende; A, tremolite-actinolite; C, colorless amphibole.
[5] 0.0x indicates mineral present in rock but not present in mode. Abundance estimated at less than 0.10 percent.

TABLE 5.—*Modes of the upper schist member of the Hamilton Reservoir Formation and the Mount Pisgah Formation*

	Upper schist member of the Hamilton Reservoir Formation											Mount Pisgah Formation	
Sample No	1	2	3	4	5	6	7	8	9	10	11	12	13
Unit (symbols used on pl. 3)	hus	hus	hus	hus	husp	husp	husp	husa	husa	husb	husb	m	m
Location[1]: XN	444.00	457.50	457.25	413.35	432.90	439.25	451.05	432.10	432.90	429.95	438.95	451.15	452.85
XE	746.65	756.00	751.05	737.85	744.65	751.05	754.55	744.60	744.65	739.35	744.05	738.95	739.20
Points counted	639	515	589	600	485	617	574	745	667	509	632	704	692
Quartz	53.1	36.9	5.9	13.0	15.9	7.0	31.7	.9	-----	5.3	11.4	46.2	47.8
Plagioclase	9.5	29.1	65.7	57.6	55.7	51.4	43.4	43.6	30.2	48.5	27.1	10.0	7.7
Anorthite content[2]	-----	-----	-----	(33)	(55)	-----	-----	-----	-----	-----	-----	-----	-----
Potassium feldspar	7.8	4.9	-----	-----	.2	-----	-----	-----	-----	-----	-----	7.5	15.3
Biotite	6.0	16.5	.7	3.8	-----	-----	16.5	-----	-----	14.3	39.2	11.1	4.3
Orthopyroxene	-----	-----	19.2	-----	14.2	16.5	8.0	-----	-----	28.9	21.0	-----	-----
Clinopyroxene[3]	-----	-----	-----	24.0	12.8	24.6	-----	24.8	24.0	-----	-----	-----	-----
Amphibole[4]	-----	-----	4.2B	-----	.8G	-----	-----	7.8G	42.3B	-----	-----	-----	-----
Garnet	9.2	12.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	9.2	17.6
Sillimanite	2.8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	10.6	2.8
Cordierite	5.8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.6	1.6
Pinite	3.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	2.7	1.9
Scapolite	-----	-----	-----	-----	-----	-----	-----	6.7	-----	-----	-----	-----	-----
Calcite	-----	-----	-----	-----	-----	-----	-----	2.4	-----	-----	-----	-----	-----
Apatite	-----	-----	1.0	[5] 0.0x	.2	.5	.2	1.5	.1	.6	.2	-----	-----
Sphene	-----	-----	.2	-----	-----	-----	-----	8.1	-----	-----	-----	-----	-----
Zircon	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.2	-----	.1
Opaque	2.5	.6	-----	2.3	.2	-----	.2	4.6	3.4	2.4	.9	1.1	.9
Iron sulfide	-----	-----	3.1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total	100.0	100.0	100.0	100.7	100.0	100.0	100.0	100.4	100.0	100.0	100.0	100.0	100.0

[1] Connecticut grid system: XN, thousands of feet north; XE, thousands of feet east.
[2] Number in parentheses shows anorthite content of plagioclase in mole percent.
[3] Calcium-rich.
[4] B, brown hornblende; G, green hornblende.
[5] 0.0x indicates mineral present in rock but not present in mode. Abundance estimated at less than 0.10 percent.

MOUNT PISGAH FORMATION

The Mount Pisgah Formation is herein named and adopted for a sequence of gray-weathering pelitic schist and semipelitic gneiss that gradationally overlies rocks of the upper schist member of the Hamilton Reservoir Formation west of the Hollow Brook fault (pl. 1, unit m; pl. 3, unit m, cols. 3–11 and 3–13).

The type area of the formation is defined as Mount Pisgah, in the Wales quadrangle, where rocks of the formation occupy the axial part and east limb of the overturned Mount Pisgah syncline. A minimum thickness of 2,700 feet (810 m) is estimated for the formation in the type locality, approximated on the basis of a half width of the Mount Pisgah syncline. The top of the formation is not exposed in the Brimfield area.

The formation in the type locality consists chiefly of thick- to

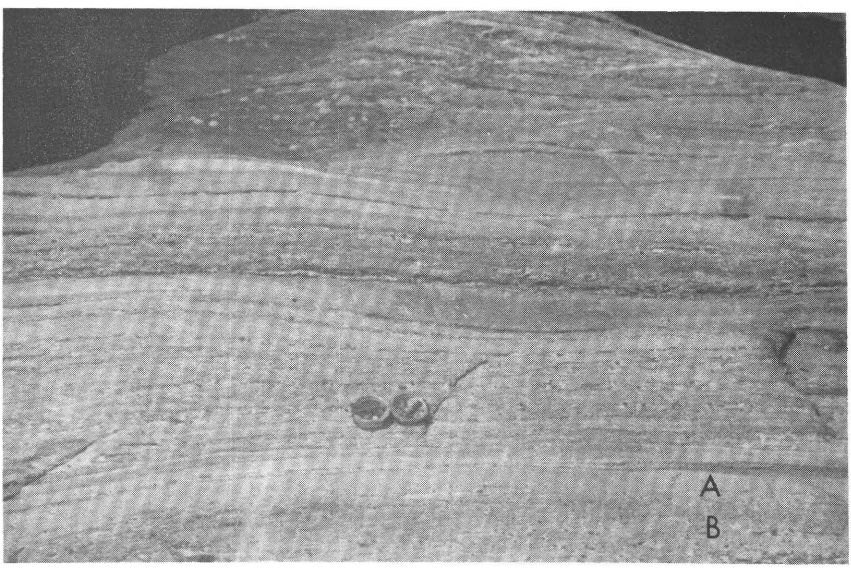

FIGURE 10.—Relict bedding in Mount Pisgah Formation on overturned limb of Mount Pisgah syncline. Note sharp contact at stratigraphic base of granular quartz-plagioclase-biotite gneiss (A, metasiltstone) and textural and compositional gradation into younger coarse quartz-plagioclase-potassium feldspar-biotite-garnet-sillimanite gneiss (B, coarsely recrystallized metashale).

thin-layered schist and gneiss in which sillimanite is sparse to absent in the gneiss and locally abundant in the schist (table 5, modes 12–13). Poikiloblastic garnets as coarse as 1 inch (2.5 cm) and rimmed with potassium feldspar are common in the gneiss.

Relict cyclic bedding, which is in part graded (figs. 10–13), and crossbedding are common locally in the schist and gneiss of the lower 300 feet (92 m) of the formation on the west (overturned) limb of the Mount Pisgah syncline in the Monson and Warren quadrangles. Differential weathering of the cyclic beds gives outcrops a characteristic "ribbed" appearance, the beds of granular gneiss forming ridges and the schist forming troughs.

Rare thin beds of fine-grained white to light-gray meta-orthoquartzite and light-gray calc-silicate gneiss occur in some exposures of the formation but are not conspicuous in the type locality.

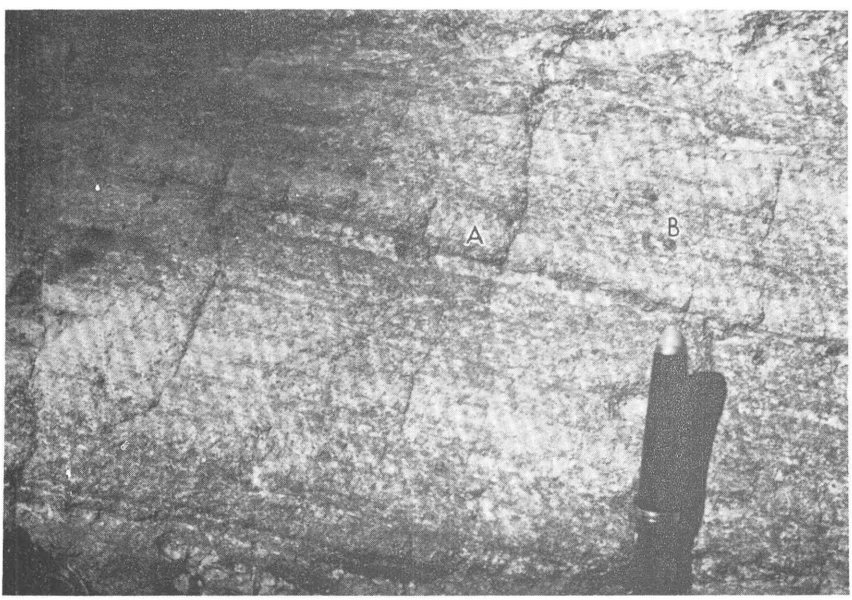

FIGURE 11.—Weathered gneiss of Mount Pisgah Formation on overturned limb of Mount Pisgah syncline showing typical ribbed texture of outcrop surfaces. Note relatively sharp contact (just above top of pen) at stratigraphic base of quartz-rich granular gneiss (A), and note gradation into younger coarsely crystalline pelitic gneiss (B). See figure 12 also.

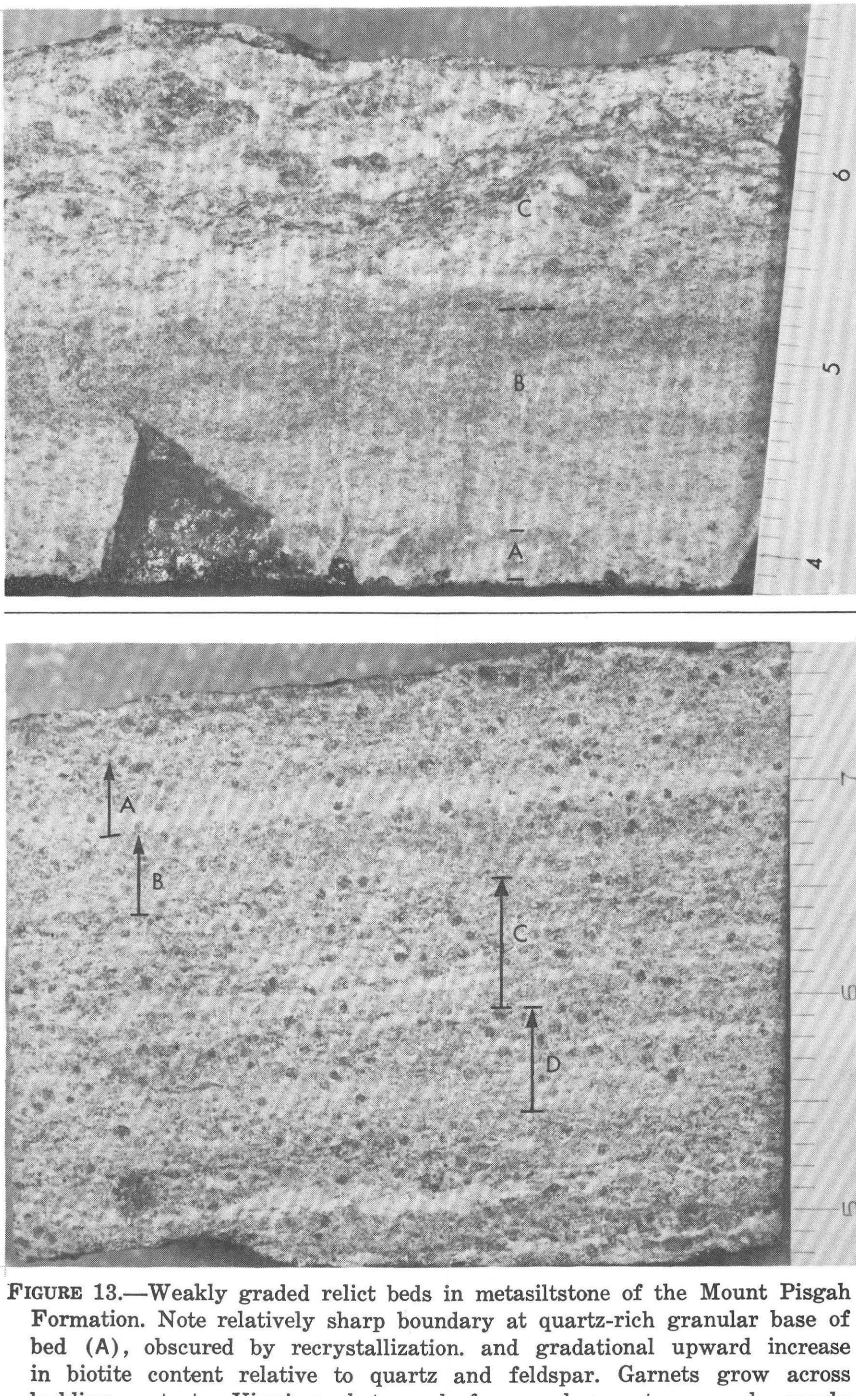

FIGURE 13.—Weakly graded relict beds in metasiltstone of the Mount Pisgah Formation. Note relatively sharp boundary at quartz-rich granular base of bed (A), obscured by recrystallization. and gradational upward increase in biotite content relative to quartz and feldspar. Garnets grow across bedding contacts. Viewing photograph from end on, at an angle nearly parallel to surface, brings out similar, but weaker, gradations in relict beds B, D, and (even less distinct) C. Scale in inches.

◀ FIGURE 12.—Cut slab of a single strongly graded relict in Mount Pisgah Formation, similar to beds in figure 11. Note sharp parting of slab along base of quartz-rich basal layer (A). Biotite and plagioclase content increase upward in granular gneiss (B). Very coarsely recrystallized pelitic zone (C) contains large irregular sieved garnets rimmed with potassium feldspar. Scale in inches.

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