Correlation of the Oakdale Formation and Paxton Group of Central Massachusetts with Strata in Northeastern Connecticut

U. S. GEOLOGICAL SURVEY BULLETIN 1796

Correlation of the Oakdale Formation and Paxton Group of Central Massachusetts with Strata in Northeastern Connecticut

By M.H. PEASE, JR.

U.S. GEOLOGICAL SURVEY BULLETIN 1796

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1989

For sale by the Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225

Library of Congress Cataloging in Publication Data

Pease, Maurice Henry, 1922-

Correlation of the Oakdale Formation and Paxton Group of central Massachusetts with strata in northeastern Connecticut.

(U.S. Geological Survey bulletin ; 1796)

Bibliography: p.

Supt. of Docs. no.: I 19.3:1796

1. Geology, Stratigraphic—Devonian. 2. Geology, Stratigraphic—Silurian. 3. Geology—Massachusetts. 4. Geology—Connecticut. 5. Paxton Group. 6. Oakdale Formation. I. State Geological and Natural History Survey of Connecticut. II. U.S. Nuclear Regulatory Commission. III. Title. IV. Series.

QE75.B9 no. 1796 [QE654] 577.3 s [551.7'4'09744] 87-600340

CONTENTS

Abstract 1
Introduction 1
    Acknowledgments 2
Historical background 3
Regional tectono-stratigraphic setting 6
    Terrane distribution 6
    Tectonic mechanisms 6
Stratigraphic units 9
    Oakdale Formation 9
        Distribution 9
        General description 9
        Thickness 12
    Paxton Group 12
        Dudley Formation 12
            Distribution 12
            General description 13
            Thickness 13
        Southbridge Formation 14
            Distribution 14
            General description 14
            Thickness 14
    Hebron Formation 14
        Distribution 14
        General description 15
        Thickness 15
Summary of structure 15
Metamorphism 16
Age relations 17
Conclusions 18
References cited 19
Appendix: Description of localities 21
    Oakdale Formation 21
    Dudley Formation 24
    Southbridge Formation 25
    Hebron Formation 25

PLATE [Plate is in pocket]

1. Generalized geologic map showing the correlation of strata in eastern Connecticut with the Oakdale-Paxton sequence of adjacent Massachusetts

FIGURES

1, 2. Diagrams showing:
    1. Stratigraphy pertinent to the interpretation of this report **2**
    2. Evolution of stratigraphic terminology for central Massachusetts and northeastern Connecticut prior to this report **3**
3. Generalized geologic map of part of eastern Connecticut **5**
4. Map of structural terranes of northeastern Connecticut and adjacent Massachusetts **7**
5. Diagrammatic geologic cross section across the Willimantic dome, eastern Connecticut **8**
6. Geologic map of the Halls Pond area, eastern Connecticut **10**

Correlation of the Oakdale Formation and Paxton Group of Central Massachusetts with Strata in Northeastern Connecticut

By M.H. Pease, Jr.[1]

Abstract

Correlation of the Oakdale Formation and Paxton Group of Massachusetts with strata in northeastern Connecticut has necessitated revision of earlier stratigraphic and structural interpretations. In Massachusetts, the Oakdale Formation and overlying Paxton Group are apparently right side up beneath the Brimfield Group. These units are contiguous with strata beneath the Brimfield in Connecticut that have been mapped as Hebron Formation and Scotland Schist.

The Oakdale Formation is an unusually homogeneous, calcareous metasiltstone that maintains its lithologic character from New Hampshire to as far south as the Honey Hill fault in southeastern Connecticut. The Scotland Schist, formerly mapped as the youngest formation, is here shown to be a member of the Oakdale. In northeastern Connecticut and adjacent Massachusetts, the Paxton Group, formerly mapped as the Hebron Formation in Connecticut, is divided into the Dudley and Southbridge Formations. Northward in east-central Massachusetts, the Paxton is undivided. The Connecticut term "Hebron" is retained in the area south and west of the Willimantic dome; this area includes the type Hebron in east-central Connecticut. The Oakdale-Paxton sequence in Connecticut is separated from rocks of the Brimfield Group on the west by the Black Pond fault.

The Clinton-Newbury fault zone, a major structural discontinuity in Massachusetts across which no stratigraphic correlation has been possible, separates the Oakdale, Paxton, and Brimfield succession from rocks of the Nashoba and underlying Marlboro Formations to the east. Equivalents of the Nashoba and Marlboro continue into Connecticut as the Putnam Group. The trace of the Clinton-Newbury fault zone is difficult to delineate in Connecticut because it has been obscured by syntectonic intrusion and, in part, cut out by later faults.

Previous maps of the bedrock geology of eastern Connecticut show a simple stratigraphy in a regional recumbent fold, the axis of which traces a sinuous path from southwest to the northeast corner of the State. The Scotland Schist, considered the youngest formation according to that interpretation, is in the axis of the inferred fold, and the Hebron Formation is on either limb; stratigraphic units northwest of the axis are considered to be overturned. Recognition that the Scotland is a member of the Oakdale Formation in the lower part of what evidence herein indicates is a continuously west-topping sequence west of the Clinton-Newbury fault zone is incompatible with this earlier interpretation.

INTRODUCTION

This report proposes a reinterpretation of part of the bedrock geology in northeastern Connecticut and adjacent Massachusetts. It is concerned with the stratigraphic and structural relations of strata previously mapped as Oakdale Quartzite and Paxton Quartz Schist (Emerson, 1917) in Massachusetts and Hebron Formation and Scotland Schist (Dixon and Lundgren, 1968) in Connecticut. The purpose is to demonstrate that Oakdale and Paxton strata extend into northeastern Connecticut, where they are generally contiguous with and stratigraphically equivalent to the Hebron and Scotland. Figure 1 is a schematic diagram showing the stratigraphic relations pertinent to the geologic interpretation presented in this report.

The geologic map, plate 1, primarily shows my interpretation of the stratigraphic and structural relations of these specific stratigraphic units, and secondarily orients this stratigraphy in the context of an apparently conformable sequence. The Oakdale Formation has been traced into Connecticut, where it adjoins eastern exposures of rocks previously mapped as Hebron Formation. The Scotland Schist, formerly mapped as a separate formation younger than the Hebron, is shown to be a member of the Oakdale.

The Paxton, which was raised informally to group status by Pease and Barosh (1981) and which is raised

Manuscript approved for publication, March 26, 1987.

[1]Present address: P.O. Box 386, Waterville Valley, NH 03223.

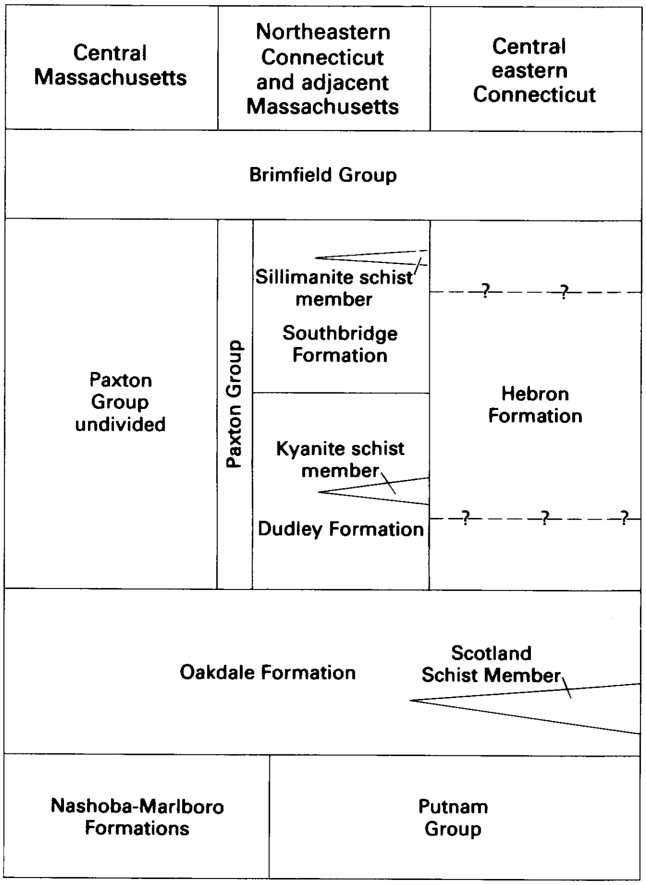


Figure 1. Stratigraphy pertinent to the interpretation of this report.

formally to group status by Barosh and Moore (in press), is shown on plate 1 to consist of the Dudley Formation overlain by the Southbridge Formation. The Dudley was formerly named the "lower Paxton" (Barosh, 1977; Barosh and Pease, 1981; Pease and Barosh, 1981). The Southbridge was named by Pease (1972). Barosh and Moore (in press) formally define the Paxton Group and Dudley Formation and describe, in detail, type sections of the Dudley and Southbridge Formations. The Hebron Formation, which in Connecticut previously had included all of the Oakdale Formation except the Scotland Schist and all of the Paxton Group, is formally restricted herein to that part of the Hebron of Dixon and Lundgren (1968) that lies south of the Wangumbaug Lake fault and west of a fault in the Fitchville Quadrangle delineated by an arcuate band of the Lebanon Gabbro (pl. 1).

The protoliths of these strata appear to have been a continuous stratigraphic sequence that generally coarsened upward in the section from siltstone to coarse sandstone and wacke, but which also included, throughout, numerous pelitic lenses and several more extensive intervals in which claystone and mudstone predominated. The characteristic lithology of the Oakdale is a somewhat calcareous metasiltstone. Lenses of schist occur at several intervals within the formation; the largest of these is the Scotland Schist Member, a micaceous schist.

The Dudley Formation, at the base of the Paxton Group, is transitional from the Oakdale to the Southbridge Formation. It consists chiefly of fine-grained granular schist and granofels. The term "granofels" is used in this report for a fine- to medium-grained metamorphic rock that consists mostly of quartz and feldspar, that contains less than 10 percent micaceous minerals, and that has a dominantly granoblastic texture. Where micaceous foliation becomes conspicuous, the rock is termed a "granular schist." Lenses of schist are also present within the Dudley, and a kyanite schist member has been mapped (pl. 1).

The Southbridge Formation is more heterogeneous than the Dudley and is generally coarser grained. It consists mostly of well-layered, medium- to coarse-grained gneiss and schist and includes interlayers of sulfidic schist, calc-silicate-rich schist and granofels, and amphibolite. References in this report to calc-silicate-rich rocks mean rocks that contain calcic plagioclase and various amounts of one or more of the following minerals—diopside, green amphibole, scapolite, and accessory epidote, clinozoisite, and sphene. A sillimanite schist member of the Southbridge has been mapped (pl. 1).

The Hebron Formation includes two principal rock types: (1) calc-silicate-rich granofels and schist and (2) feldspathic hornblende-bearing gneiss and schist. Also present are rusty-weathering mica schist and massive plagioclase gneiss.

The interpretation in this report is based on detailed and reconnaissance geologic mapping carried out by me and by colleagues at the U.S. Geological Survey between 1965 and 1979. Although several informal reports having a bearing on this geology have been published (Barosh, 1974, 1977; Barosh, Fahey, and Pease, 1977; Barosh, Pease, and others, 1977; Pease and Fahey, 1978; Pease and Barosh, 1981), a definitive presentation of the data has been delayed until this report.

State maps showing the bedrock geology of Connecticut (Rodgers, 1985) and Massachusetts (Zen and others, 1983) did not incorporate the interpretation presented in this report as it had not yet been formally accepted. The compilers of these maps did use several of the newly named formations, but their basic concept of stratigraphy and structure (fig. 2) shows little change from that of Dixon and Lundgren (1968). Therefore, no attempt is made herein to discuss these maps in detail.

Acknowledgments

Most of my research for this study was done for the U.S. Geological Survey under a cooperative agreement

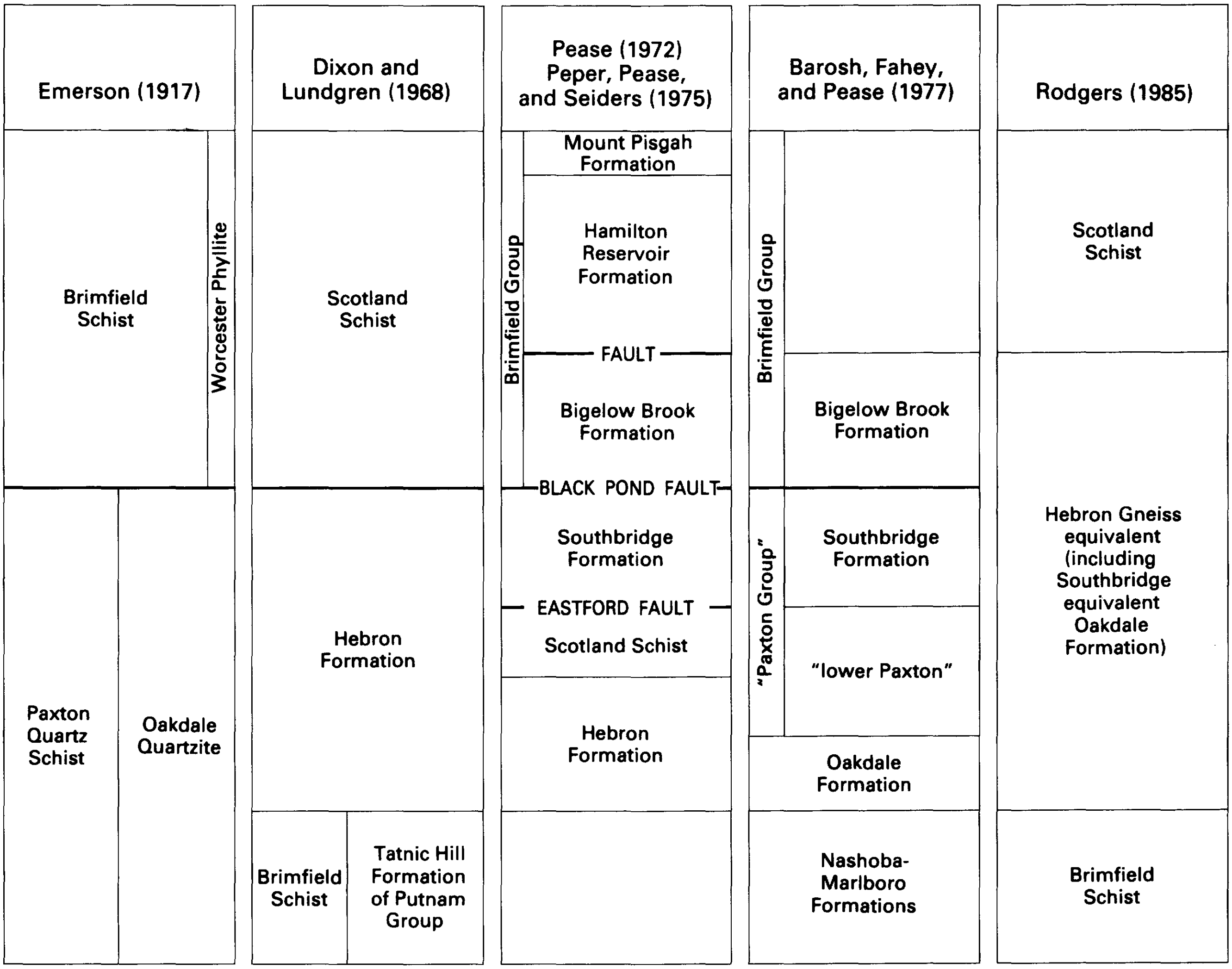


Figure 2. Evolution of stratigraphic terminology for central Massachusetts and northeastern Connecticut prior to this report.

with the Connecticut Department of Environmental Protection, Geological and Natural History Survey. The final report was completed after my retirement from the Survey, and partial financial assistance came from the U.S. Nuclear Regulatory Commission under contract number AT(49–24)–0291.

I am indebted to the many workers of the U.S. Geological Survey who provided the groundwork for this study. Foremost among these are H.R. Dixon and G.L. Snyder. P.J. Barosh furnished most of the recent geologic data for Massachusetts and was a major contributor to the compilation of the Massachusetts part of the regional geologic map. I am particularly grateful to A.S. Shride, who reviewed two original manuscripts and insisted that they be combined into this single report. His detailed critical reviews of these preliminary drafts were essential to the completion of this final report. Discussions and field conferences with P.J. Barosh, S.S. Quarrier, J.D. Peper, Jelle de Boer, and R.P. Wintsch, among others, are also gratefully acknowledged. Lastly, I owe my sincere gratitude to L.R. Page, Dennis O'Leary, and Richard Goldsmith, who worked through the final technical reviews of this report.

HISTORICAL BACKGROUND

The evolution of changes in stratigraphic terminology preceding this report is shown in figure 2 and is summarized below. The Oakdale Quartzite, Paxton Quartz Schist, and Brimfield Schist were defined by B.K. Emerson (1917) in central Massachusetts (fig. 2). According to Emerson, the Oakdale is a fine-grained, even-textured flaggy quartzite commonly tinted reddish brown by biotite and greenish by actinolite. The Paxton is more flaggy, includes more abundant and more visible biotite, and has distinct greenish lenses containing a variety of calc-silicate minerals. The Brimfield Schist, according to Emerson, is a uniform, coarse, red-brown muscovite schist containing much biotite, fibrolite, and graphite; characteristically, it is highly weathered as it contains an abundance of pyrite.

On Emerson's geologic map (1917), the Oakdale, Paxton, and Brimfield units extend south to the Connecticut State line. The Oakdale lies east of and structurally beneath the Paxton; the Brimfield lies mostly west of and structurally above the Paxton, although belts of Brimfield also are shown within the western part of the Paxton. Emerson (1917, p. 62) stated that "The Paxton passes in pitching folds beneath the Brimfield" in this area. He considered the Paxton to be a more highly metamorphosed equivalent of the Oakdale. He considered the Brimfield Schist, on the other hand, to be the high-grade equivalent of an exposure of graphitic phyllite and slate in a coal prospect north of Worcester, which he included in the Worcester Phyllite shown on his map as a lens passing through Worcester.

The Brimfield Schist was earlier recognized in Connecticut by H.E. Gregory and H.H. Robinson (1907), but the Oakdale and Paxton were not differentiated in eastern Connecticut. Gregory and Robinson named stratigraphically equivalent strata in Connecticut "Hebron Gneiss"; Snyder (1961) appears to have been the first to use the term "Hebron Formation."

From 1955 to 1968, much of eastern Connecticut was mapped at a scale of 1:24,000 by the U.S. Geological Survey in cooperation with the Connecticut Geological and Natural History Survey. This work was summarized by Dixon and Lundgren (1968), who described a stratigraphic sequence for northeastern Connecticut in which the Scotland Schist was considered the youngest formation lying along the axial surface of a recumbent syncline that traces a sinuous path across eastern Connecticut from southwest to northeast (fig. 3). East of this axis, the Scotland was interpreted to lie in normal stratigraphic sequence above the Hebron, which overlay the Tatnic Hill and Quinebaug Formations of the Putnam Group. West of the axis, the sequence was interpreted to be inverted: the Hebron structurally above the Scotland was correlated with that below, and the Tatnic Hill Formation was correlated with the Brimfield Schist (fig. 2).

Detailed geologic mapping of the Brimfield area in Connecticut and Massachusetts under continuing cooperative programs with these States from 1966 to 1975 resulted in revision of the Hebron Formation and the Brimfield Schist. Strata formerly mapped as the Hebron Formation were divided on the geologic map of the Eastford Quadrangle (Pease, 1972) into two formations separated by the northeast-trending Eastford fault. Strata northwest of the fault were named the "Southbridge Formation"; strata southeast of the fault were assigned to the Hebron Formation and Scotland Schist.

Strata previously mapped as Brimfield Schist were subdivided, on the basis of detailed mapping in the Eastford, Westford, and Stafford Springs Quadrangles, into several formations and members (Pease, 1972, 1975; Peper and Pease, 1975, 1976). The name "Brimfield Schist" was changed to "Brimfield Group," and the formations were named, from oldest to youngest, the Bigelow Brook, Hamilton Reservoir, and Mount Pisgah Formations (Peper, Pease, and Seiders, 1975). The Brimfield Group is separated from the Southbridge Formation by the Black Pond fault (fig. 2).

Geologic mapping of the Oakdale and Paxton strata of adjacent Massachusetts was started in the Webster area in the early 1970's under the direction of P.J. Barosh, then with the US. Geological Survey. Reports on this work include three U.S. Geological Survey open-file reports: a preliminary bedrock geologic map of the Webster Quadrangle (Barosh, 1974), a preliminary bedrock geologic map of the Boston 2° sheet (Barosh, Fahey, and Pease, 1977), and a report on the geology of the Worcester region (Barosh, 1977). A preliminary geologic map of the Clinton Quadrangle by J.H. Peck (1975) also significantly influenced the present interpretation of the stratigraphy in this region.

In these reports, the Oakdale Quartzite was changed to Oakdale Formation (Barosh, 1974; Peck, 1975) because the unit contains little or no true quartzite and is primarily a metasiltstone. The Paxton Quartz Schist was informally raised to group status to include the Hebron and Southbridge Formations (Barosh, Fahey, and Pease, 1977) because the Southbridge-Hebron division that had been recognized in the Eastford Quadrangle, Conn. (Pease, 1972), was also recognized in the Paxton in contiguous southern Massachusetts. The term "Southbridge Formation" was retained for the upper part of the Paxton, and the remainder of the Paxton above the Oakdale was informally assigned to the "lower Paxton" (fig. 2).

Another significant result of this mapping in the early 1970's was the correlation of the Nashoba-Marlboro sequence of Massachusetts with the Putnam Group of Connecticut (pl. 1). The continuity of these strata along strike, though severely disrupted by faulting near Webster, is clearly demonstrated on the map of the Worcester area (Barosh, 1977) that shows the bedrock geology superposed on the aeromagnetic map; the continuity is also shown on the aeromagnetic lineament map of southern New England (Barosh, Pease, and others, 1977).

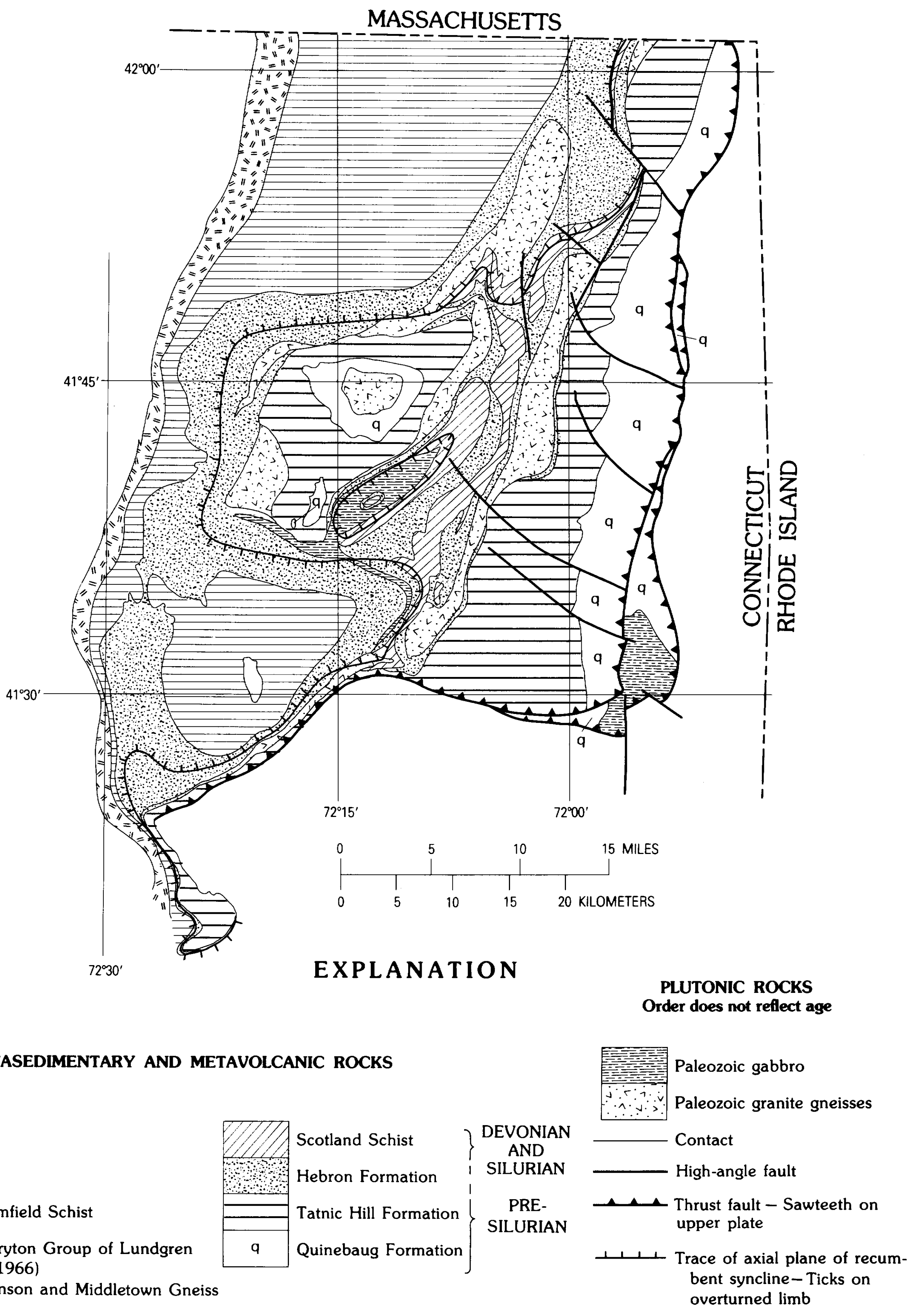


Figure 3. Generalized geologic map of part of eastern Connecticut modified from Dixon and Lundgren (1968). Map unit names and symbols have not been altered.

REGIONAL TECTONO-STRATIGRAPHIC SETTING

Terrane Distribution

According to the interpretation proposed in this report, northeastern Connecticut and adjacent Massachusetts can be divided into four principal structural terranes (fig. 4), separated by fault zones of regional extent across which no reliable stratigraphic correlation is possible. The basement terrane of southeastern New England is separated from the Putnam-Nashoba thrust belt terrane by the Honey Hill-Lake Char-Bloody Bluff fault complex. Rocks of the basement terrane consist mostly of the Sterling Plutonic Suite of Rhode Island and their apparent equivalents that extend into southeastern Connecticut. The thrust belt terrane includes rocks of the Putnam Group in Connecticut and of the Nashoba Formation and associated rocks in Massachusetts. The stratigraphy of these formations has been highly disrupted by imbricate thrusting subparallel to the belt.

The thrust belt terrane (fig. 4) is separated from the geosyncline terrane by the Clinton-Newbury fault zone except in the northern part of the area mapped in plate 1, where the Wekepeke fault forms the western boundary of a graben of younger phyllitic rocks that lies between the two terranes. The geosyncline terrane consists of a thick stratigraphic sequence that, although severely disrupted by faulting, appears to be in normal upright position. It includes the Oakdale Formation at the base, overlain by the Dudley and Southbridge Formations of the Paxton Group, which, in turn, are overlain by strata of the Brimfield Group.

The geosyncline terrane is separated from the gneiss dome terrane by the Bonemill Brook fault zone (Peper, Pease, and Seiders, 1975). Rocks of the gneiss dome terrane are generally equivalent to rocks included by Dixon and Lundgren (1968, fig. 16–1) in their Bronson Hill anticlinorium sequence; rocks of the geosyncline terrane are generally equivalent to rocks of their Merrimack synclinorium.

The Willimantic dome is a window through the geosyncline terrane (fig. 4), exposing in its core rocks of the basement terrane separated by the Willimantic fault zone from encircling rocks of the thrust belt terrane. Figure 5 is a cross section across the Willimantic dome showing the interpretation of this structure.

Tectonic Mechanisms

Tectonic transport along the various thrust faults in the area shown in plate 1 is believed to have begun with ductile deformation during the late stages of regional metamorphism accompanied by, or closely followed by, syntectonic intrusion, and to have continued through late retrograde metamorphism accompanied by brittle fracture. The ductile character of these thrust faults was recognized by R.P. Wintsch (1979) in his study of the Willimantic fault. In an extensive series of roadcut exposures 4 km west of Willimantic, Conn., on U.S. Highway I-84, Wintsch observed large lenticular blocks of gneiss and schist as much as 30 m long by 15 m high that have been rotated at various angles to each other and are enclosed by anastomosing shear zones. He noted that sillimanite needles are present within these shear zones even where they cut rocks that otherwise do not contain sillimanite and that the needles are aligned parallel to the variously oriented shear surfaces. He also noted the presence of large feldspar porphyroblasts associated with these shear zones and concluded that both minerals had grown during the deformation (Wintsch, 1975, 1977). He ascribed these features to ductile deformation in the amphibolite facies of metamorphism. Wintsch was able to show that these tectonic blocks occur in a relatively broad structural interval, the base of which is approximately the base of the Putnam Group rocks exposed in the Willimantic dome. He termed this zone the "Willimantic fault."

Similar ductile features have been recognized locally in other regional thrust zones of eastern Connecticut. For example, in the Brimfield area, sillimanite needles are aligned with the "a" direction of asymmetric folds in shear zones, thus indicating the direction of ductile movement along thrust faults (Peper, Pease, and Seiders, 1975). Rotated tectonic blocks enclosed by anastomosing shear zones also are present in thrust faults other than the Willimantic fault, but the magnitude of these structures makes them difficult to recognize except in large outcrops such as the roadcuts along U.S. Highway I-84. Isolated tectonic blocks can be recognized in some places where shear foliation on the face of a block crosscuts metamorphic layering and foliation within the block. An apparent random orientation of attitudes of layering and foliation between closely spaced outcrops may also indicate the presence of rotated tectonic blocks.

Deformation features associated with retrograde muscovite and chlorite commonly are superposed on ductile features, suggesting that deformation within these thrust zones persisted into lower metamorphic grades where brittle fracture dominates over ductile flow. Wintsch (1979, p. 378) described deformation features ranging from blastomylonite to ultramylonite on the Willimantic fault and reported that retrograde muscovite and chlorite occupy bands where mylonitization is relatively intense. On other faults, such as the Honey Hill fault, mylonitization (Lundgren and Ebblin, 1972) is so pervasive that it obscures, along much of the fault trace, whatever ductile deformation structures might once have been present.

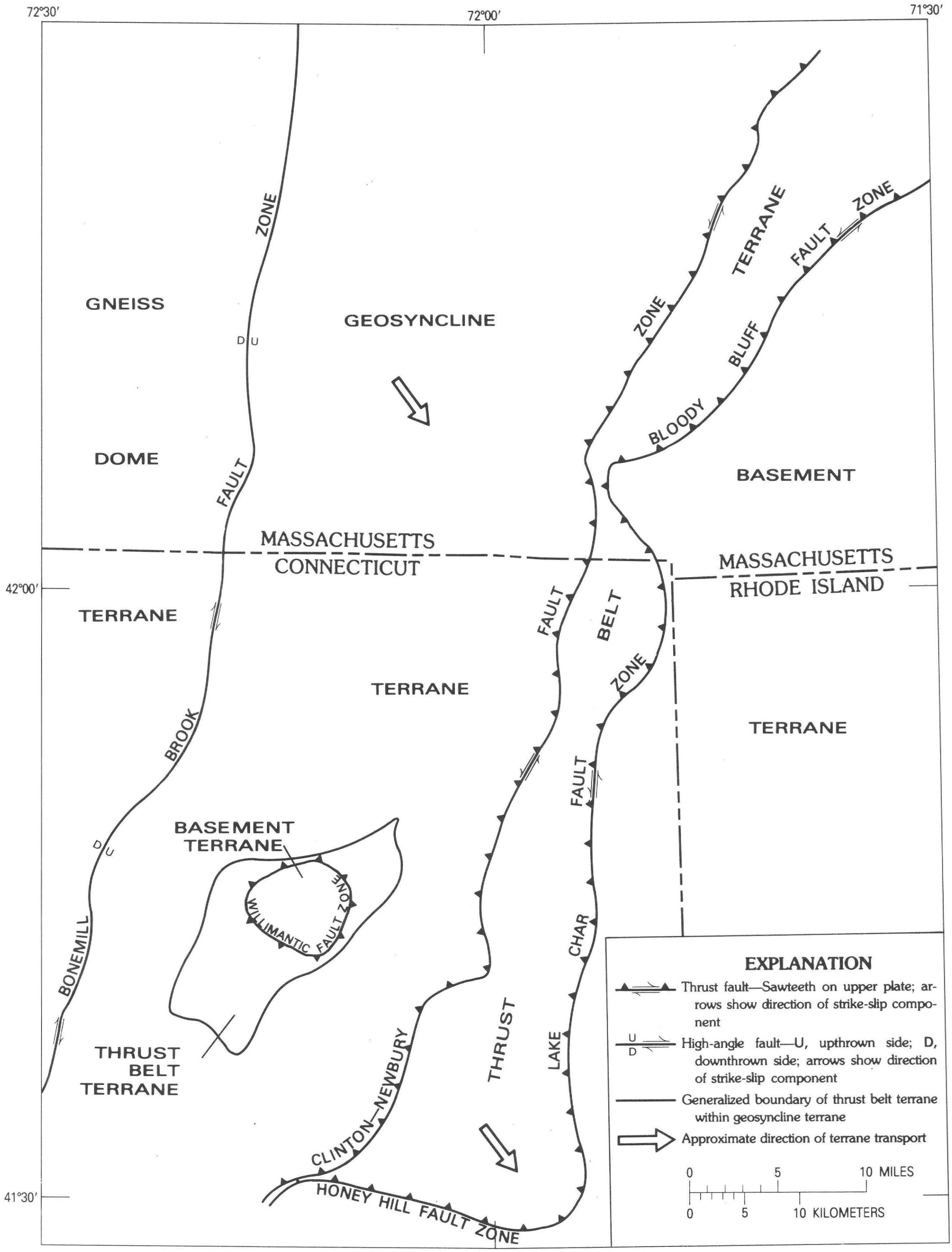
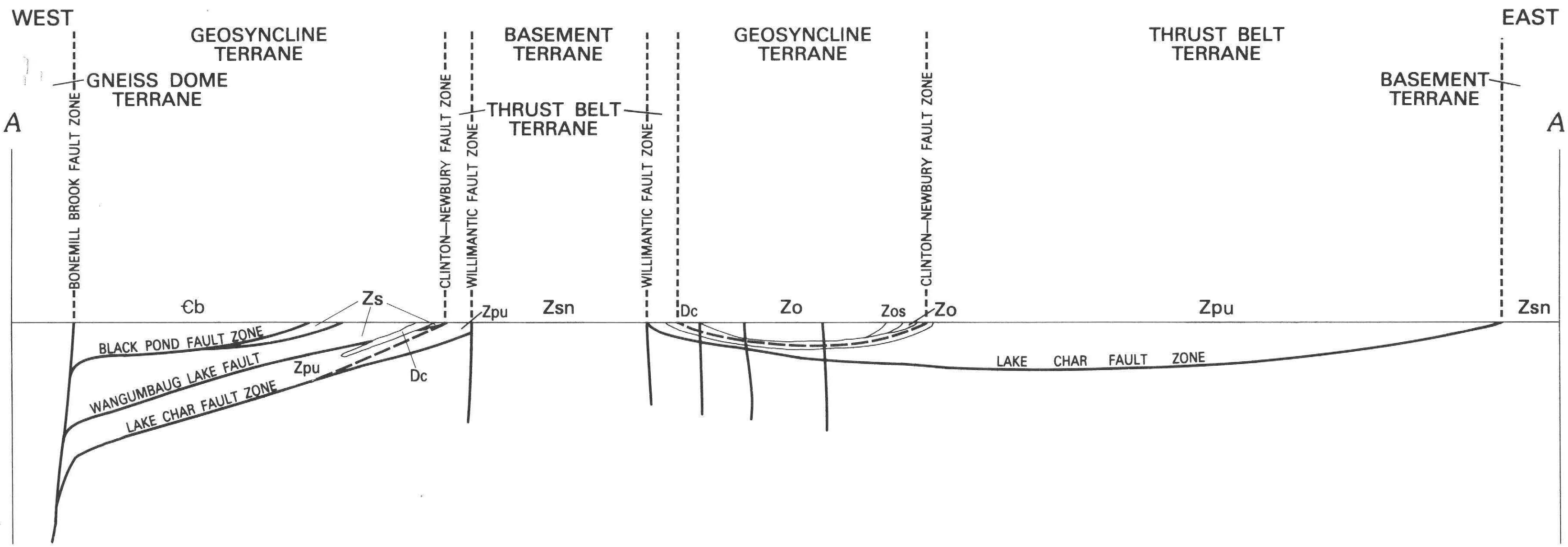


Figure 4. Structural terranes of northeastern Connecticut and adjacent Massachusetts.



EXPLANATION

- Dc Canterbury Gneiss
- €b Brimfield Group
- Zs Southbridge Formation
- Zo Oakdale Formation
  - Zos Scotland Schist Member
- Zpu Putnam Group
- Zsn Southeast New England Platform

- Contact
- Fault
- Assumed position of Clinton–Newbury fault zone

Figure 5. Diagrammatic geologic cross section across the Willimantic dome, eastern Connecticut. Location of section *A–A′* shown on plate 1.

STRATIGRAPHIC UNITS

The lithology and stratigraphic relations of the Oakdale Formation, Paxton Group, and Hebron Formation as defined herein are described in order from oldest to youngest. The character and distribution of the Oakdale Formation are described in greatest detail because recognition of this formation in Connecticut is the key to stratigraphic correlation between Massachusetts and Connecticut.

The discussion of each formation includes a description of its areal distribution and general lithologic character and an estimation of stratigraphic thickness. Representative exposures and critical localities discussed below are described in the appendix, and their locations are shown in plate 1 (locs. 1–23) or figure 6 (locs. 1–12). Localities 1–12 in figure 6 are different from localities 1–12 in plate 1.

Oakdale Formation

Distribution

The Oakdale Formation extends from its type locality (Emerson, 1917) in Oakdale, Mass., southward into Connecticut along the east side of the Willimantic dome to the Honey Hill fault (pl. 1). The formation also is exposed north of the area mapped in plate 1, and it extends across Massachusetts into New Hampshire, as shown by Barosh, Fahey, and Pease (1977). The Scotland Schist Member of the Oakdale, as revised by Pease (U.S. Geological Survey, 1980), extends from the Honey Hill fault zone in the Fitchville Quadrangle north to the eastern edge of the Hampton Quadrangle, Conn., where it is cut off against the Canterbury Gneiss; it has not been recognized farther north. Other strata formerly mapped as Scotland Schist are now included within the Oakdale (U.S. Geological Survey, 1980). Lenses of aluminous schist present within the Oakdale at several stratigraphic intervals above the Scotland Schist Member are not shown in plate 1.

The Oakdale Formation is conformably overlain by the Paxton Group in the fault block at the northern end of the eastern belt of Canterbury Gneiss (pl. 1). The lower part of the Oakdale, including the part that would contain the Scotland Schist Member, appears to be cut out along the structural position of the Clinton-Newbury fault zone, which has no surface expression in this area.

Rocks considered to represent the lowest exposed part of the Oakdale Formation crop out in two small areas in Connecticut east of the Canterbury Gneiss and west of the belt of Putnam Group rocks (locs. 1 and 2, pl. 1). These strata appear to be slivers of the Oakdale caught at the base of the Canterbury Gneiss in the upper plate of the Clinton-Newbury fault zone and exposed by later high-angle faults of minor displacement.

The width of exposure of the Oakdale is greatly reduced by faulting and syntectonic intrusion in the Webster Quadrangle and the southern part of the Leicester Quadrangle, and locally the Oakdale is cut out entirely. The Oakdale reappears to the north in the Worcester area, and from there, its belt of exposure widens northeastward (Barosh, Pease, and others, 1977). The Oakdale from the southern part of the Worcester North Quadrangle to the north border of the area mapped in plate 1 appears to rest conformably beneath the Paxton Group undivided. The lower part of the Oakdale is cut out along the Clinton-Newbury fault zone.

Intervals of muscovite schist lithologically similar to the Scotland Schist Member are present throughout the Oakdale; they range from lenses less than 1 m thick to mappable units tens of meters thick, but their relative stratigraphic positions within the Oakdale are uncertain. Like the Scotland Schist Member of the Oakdale, the Gove Member of the Berwick Formation of New Hampshire and the Gonic Formation of Maine consist predominantly of micaceous schist; they lie within strata apparently correlative with the Oakdale (P.J. Barosh, oral commun., 1982).

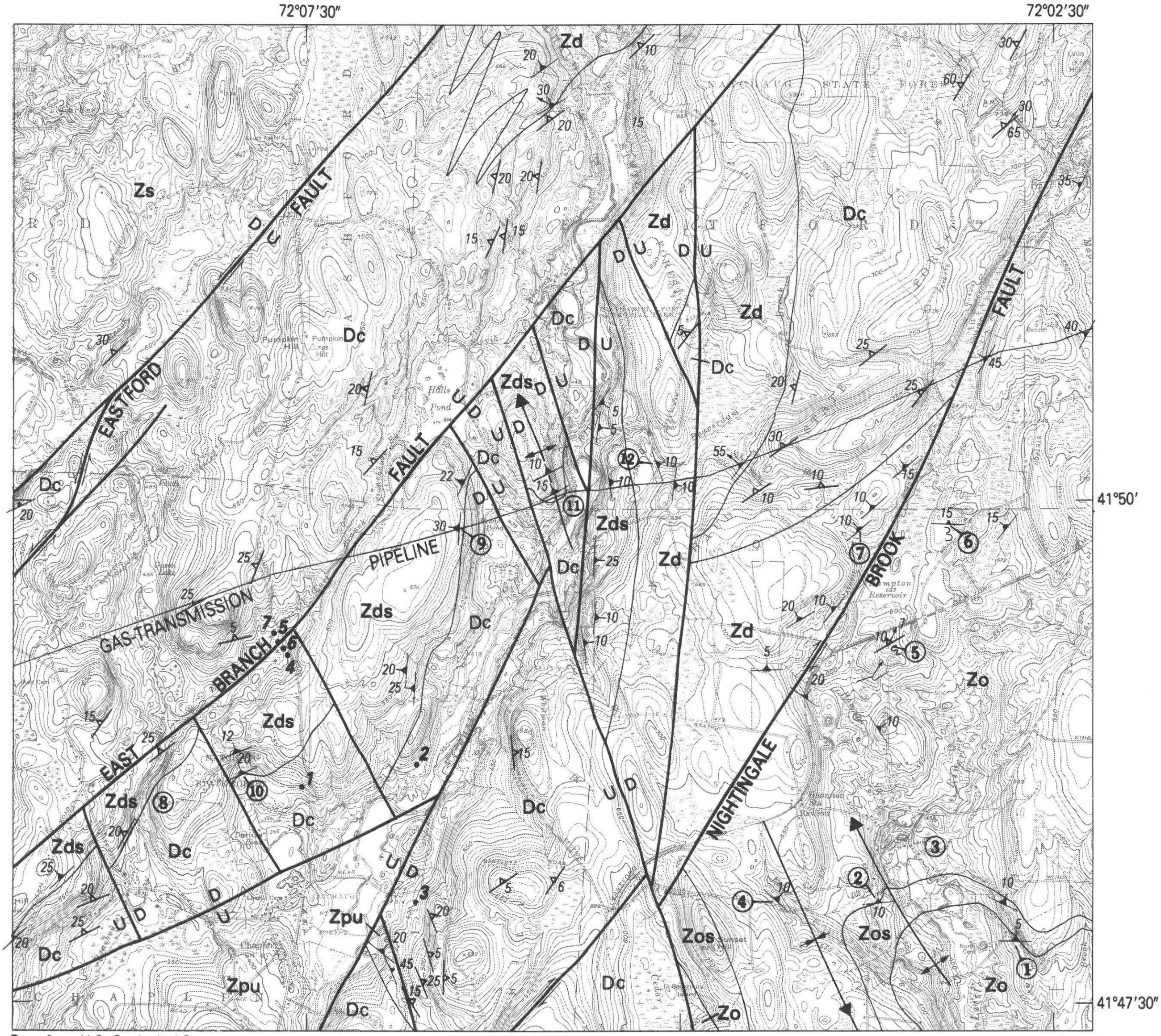
General Description

The characteristic and most common rock type of the Oakdale Formation is a medium- to dark-gray, greenish-gray, and purplish-gray metasiltstone that weathers light to medium gray, light greenish gray, or brownish gray. Included in this dominant rock are thin greenish-gray calcareous lenses and brownish-gray lenses of staurolite-bearing muscovite schist of pelitic origin. The Scotland Schist Member is a thick interval of muscovite biotite schist commonly containing garnet and staurolite and rarely containing kyanite.

The metasiltstone is well bedded in thin to medium beds that are commonly laminated, are rarely cross laminated, and contain a few graded beds. Phyllitic layers are typically present, and a fine micaceous sheen is characteristic of the fresh rock. The weathered rock typically splits in flaky sheets parallel to layering. The rock consists mostly of quartz, plagioclase, and biotite. Fine-grained muscovite is a minor but diagnostic constituent. Accessory minerals are chlorite, garnet, calcite, and calc-silicate minerals.

The metasiltstone shows no appreciable coarsening in grain size even where it is metamorphosed to amphibolite grade or where it forms xenoliths within plutons. In contrast, more aluminous rocks coarsen conspicuously as clay minerals are recrystallized during metamorphism.

The Scotland Schist Member of the Oakdale lies in the lower part of the formation exposed in Connecticut. Oakdale strata west of the Canterbury Gneiss and stratigraphically below the Scotland (locs. 3 and 4, pl. 1) consist of thinly laminated calcareous metasiltstone much less



Base from U.S. Geological Survey
Hampton, 1:24,000, 1953; and
Spring Hill, 1:24,000, 1953

1 ½ 0 1 MILE

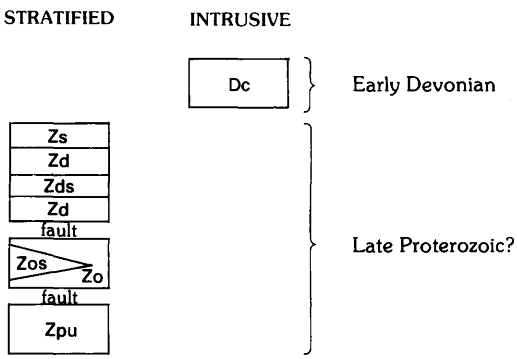
1 .5 0 1 KILOMETER

Figure 6. Geology of the Halls Pond area, eastern Connecticut.

resistant to weathering than the overlying micaceous schist of the Scotland. As a result, the contact commonly is marked by a sharp break in slope. Lenses of quartzite are common within the Scotland, particularly near the base (locs. 5 and 6, pl. 1), and quartzite as much as 2 m thick is discontinuously present in the Oakdale at the basal contact with the Scotland. Lenses of micaceous schist and of quartzite also appear to be present within the Oakdale in a stratigraphic interval several meters thick beneath the Scotland (locs. 5 and 6, pl. 1).

The most complete section of the Scotland Schist Member is exposed in the Shetucket River valley from Merrick Brook to the western boundary of the Scotland Quadrangle (loc. 7, pl. 1). The lower part of the section, exposed in roadcuts along Station Road, is characterized by an interlayering of finely granular metasiltstone with the predominant micaceous schist. The upper part of the section, best exposed in railroad cuts at the dam in the Shetucket River, is mostly highly micaceous schist containing few metasiltstone interlayers. The top of the

EXPLANATION



MAP UNITS

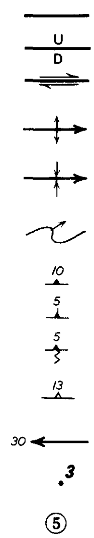
STRATIFIED ROCKS

Zs	Southbridge Formation of Paxton Group (Late Proterozoic?)
Zd	Dudley Formation (Late Proterozoic?)
Zds	Kyanite schist member of Dudley Formation (Late Proterozoic?)
Zo	Oakdale Formation (Late Proterozoic?)
Zos	Scotland Schist Member of Oakdale Formation (Late Proterozoic?)
Zpu	Putnam Group (Late Proterozoic?)

INTRUSIVE ROCKS

Dc	Canterbury Gneiss (Early Devonian)

MAP SYMBOLS



Contact

High-angle fault—U, upthrown side; D, downthrown side

Strike-slip fault—Arrows indicate relative sense of movement

Anticline—Shows trace of axial plane and direction of axial plunge

Syncline—Shows trace of axial plane and direction of axial plunge

Asymmetric fold—Shows sense of fold and direction of plunge

Strike and dip of foliation

Strike and dip of foliation parallel to bedding

Strike and dip of bedding—Shows shape of folds in bedding that is not parallel to foliation

Strike and dip of foliation in orthogneiss

Bearing and plunge of lineation—May be combined with foliation symbol

Drill hole

Locality discussed in text and described in appendix

Figure 6. Geology of the Halls Pond area, eastern Connecticut—Continued.

Scotland is not exposed in the Shetucket River valley outcrops, but it has been observed to the southwest in the Fitchville Quadrangle, where the contact appears to be gradational, as mica schist is interlayered with metasiltstone throughout an interval of several meters (loc. 8, pl. 1).

The Scotland Schist Member thins and becomes less pelitic northward. It has not been recognized north of the southeast corner of the Halls Pond area (fig. 6), where the member is less than 100 m thick. The lowest part of the member is exposed at locality 1 (fig. 6), and exposures in Fuller Brook at locality 2 (fig. 6) appear to be very near the top of the member.

The thick section of Oakdale strata above the Scotland Schist Member in Connecticut consists almost entirely of typical, platy-bedded to flaggy, quartz-plagioclase-biotite metasiltstone that weathers brownish gray. Lenses of muscovite schist within this interval resemble the Scotland lithologically, but none are more than 2 m thick and all lie stratigraphically well above the Scotland Schist Member.

Representative exposures of typical Oakdale metasiltstone above the Scotland Schist Member are present in the Willimantic Quadrangle in railroad cuts along the Shetucket River (loc. 9, pl. 1) and in the Halls Pond area in the Little River (loc. 3, fig. 6) and in Fuller Brook (loc. 4, fig. 6). In contrast, at localities 5 and 6 (fig. 6), the metasiltstone is commonly phyllitic, and interlayers of muscovite schist are present.

Dixon mapped a muscovite schist unit at locality 5 (fig. 6) within her Hebron Formation and evidently correlated this unit with several exposures of rusty muscovite schist to the north (Dixon and Pessl, 1966). She showed locality 6 (fig. 6), on the other hand, to lie within her Scotland Schist (Dixon and Pessl, 1966). She considered both localities to lie on the hinge of the regional recumbent syncline shown in figure 3. According to my interpretation, both exposures lie at about the same stratigraphic position in the upper part of the Oakdale Formation. The schists at both localities are indistinguishable from schists in the Oakdale elsewhere and are readily accommodated within the Oakdale as mapped.

G.L. Snyder (1964) included localities 10 and 11 (pl. 1) in a western band of Scotland Schist on the basis of the presence of muscovite schist. The field evidence, however, indicates that the muscovite schist is a minor constituent in this western band and that its stratigraphic position is well above the Scotland Schist Member (pl. 1).

Snyder (1964) considered the exposures at Kick Hill (loc. 12, pl. 1) to represent an overturned klippe containing his Brimfield Schist over younger Hebron Formation. His justification for this geologic interpretation appears to have been the presence of rusty schist on top of calcareous metasiltstone, but this relationship is common in the Oakdale, and the metasiltstone is more compatible with the Oakdale than with the Hebron. These exposures at Kick Hill are entirely surrounded by Lebanon Gabbro, and I think that they are stratigraphically in the upper part of the Oakdale Formation.

The Oakdale is poorly exposed north of the Scotland Schist Member in the northeast corner of Connecticut and immediately adjacent Massachusetts. Where observed, the dominant rock type appears to be the typical flaky metasiltstone that weathers olive gray to brownish gray. In rare exposures of fresh rock, the metasiltstone is medium gray, tinted lavender in some places and green in others owing to the respective dominance of biotite and actinolite or chlorite. Carbonate and calc-silicate minerals are common minor constituents, and pitting by differential weathering gives a woody-textured appearance to some outcrop surfaces. Phyllitic interlayers and thin micaceous schist intervals, mostly less than 1 m thick, are common in this upper part of the Oakdale. Thin quartzite layers, commonly forming lenticular pods, are present in many outcrops.

The alternation of phyllitic metasiltstone and micaceous schist was best exposed in a trench cut for the gas pipeline where it extends across the southern part of the Putnam Quadrangle (Pease, 1980, 1982b). As the trench is now refilled, localities 13, 14, and 15 (pl. 1) are designated representative exposures of this stratigraphic interval.

The micaceous sheen on layered surfaces that is characteristic of the phyllitic facies of the metasiltstone is well expressed in abandoned roadcuts along Route 44 in the northeast corner of the Hampton Quadrangle (loc. 13, pl. 1). These outcrops are in an area mapped as Scotland Schist by Dixon and Pessl (1966), but, although thin interlayers of micaceous schist are present in the metasiltstone, the exposures show little resemblance to the Scotland in its type area where aluminous schist predominates.

A rusty-weathering muscovite schist representative of the schist in the upper part of the Oakdale is poorly exposed in an abandoned gravel pit off Blake Road close to the Connecticut State line in the Webster Quadrangle (loc. 14, pl. 1). An outcrop 3–4 m high and as much as 200 m long is exposed in an abandoned railroad cut (loc. 15, pl. 1) in the Massachusetts part of the Webster Quadrangle. Although the cut is subparallel to the strike of layering, it provides the most representative sample of the Oakdale in this area, where natural outcrops are small and sparse. The extensive exposures in the roadcuts at exit 10 on the Massachusetts Turnpike (loc. 16, pl. 1) are representative of the Oakdale in the northern part of the area mapped in plate 1.

Thickness

Stratigraphic thicknesses of exposed sections of the Oakdale are estimated below, but nowhere is a complete section exposed nor has it been possible to measure accurately even partial sections of the formation. The maximum exposed apparent stratigraphic thickness of Oakdale strata that lie beneath the Scotland Schist Member and above the Canterbury Gneiss is probably less than 500 m, but exposures are so poor and dips so gentle that no estimate of thickness is reliable. The Scotland Schist Member attains a maximum apparent stratigraphic thickness of about 600 m in the section exposed along the Shetucket River at the west edge of the Scotland Quadrangle (loc. 7, pl. 1), but intraformational folding is so pervasive in this member that a true stratigraphic thickness is difficult to assess. The member thins stratigraphically to less than 100 m in its northern exposures in the Halls Pond area. The maximum exposed apparent stratigraphic thickness of Oakdale strata above the Scotland is on the order of 1 km. In southern Massachusetts, including the type area, the total exposed thickness of the Oakdale may be as much as 1,500 m.

Paxton Group

The Paxton Quartz Schist of Emerson (1917) has been formally raised to group status by Barosh and Moore (in press). The Paxton Group includes the Southbridge Formation (Pease, 1972) at the top and a new formation, the Dudley, to represent strata beneath the Southbridge that had been informally termed the "lower Paxton" (Barosh, 1977; Barosh, Pease, and others, 1977; Barosh and Pease, 1981; Pease and Barosh, 1981). The Paxton Group conformably overlies the Oakdale Formation and conformably underlies the Brimfield Group.

Dudley Formation

Distribution

The Dudley Formation (Barosh and Moore, in press) extends across the Connecticut-Massachusetts State line as shown on plate 1. It is recognized in Massachusetts as far north as the southern part of the Leicester Quadrangle (pl. 1). The formation is intruded by the Canterbury Gneiss toward the southwest and occurs only as xenoliths in the Canterbury in much of the Halls Pond area northwest of the East Branch fault (fig. 6). A kyanite schist member of the Dudley has been recognized southeast of this fault on an anticlinal nose in the Halls Pond area. The member probably pinches out stratigraphically to the northeast, as it is not exposed north of the Halls Pond area. Lenses of schist have been observed at localities farther north within the Dudley, but these are too small and discontinuous to correlate with the kyanite schist member. A sliver of biotite granofels caught between Canterbury Gneiss and Lebanon Gabbro in the Willimantic Quadrangle is the southernmost extent of the Dudley.

General Description

The Dudley Formation is chiefly a homogeneous sequence of medium- to dark-olive-gray, layered, very fine to fine-grained biotite granofels and granular schist composed mostly of quartz, plagioclase, and black biotite. Calc-silicate minerals are ubiquitous in minor amounts. The Dudley is generally more biotitic and less quartzitic than the Oakdale and contains fewer calc-silicate minerals and calc-silicate-rich layers. Muscovite, though locally present in trace amounts, is generally absent except in the kyanite schist member.

The Dudley commonly exhibits a finely granular salt-and-pepper texture, which is distinct from the micaceous sheen characteristic of the metasiltstone of the Oakdale Formation. The contact with the underlying Oakdale is traced across the southwest corner of the Webster Quadrangle and the northwest corner of the Putnam Quadrangle. Outcrops, though sparse, suggest that this contact is gradational and that interlayering occurs across a broad stratigraphic interval. The Dudley Formation is transitional in grain size and composition between the finer grained metasiltstone of the Oakdale and strata of the Southbridge Formation, which generally are coarse grained and more varied in composition and thickness.

Strata near the base of the Dudley are exposed in the Connecticut part of the Webster Quadrangle (loc. 17, pl. 1). The Dudley also is well exposed in the northeast corner of the Eastford Quadrangle (loc. 18, pl. 1). In the Halls Pond area, good outcrops of the Dudley are present in a series of exposures in the hills just north of Hampton Reservoir (loc. 7, fig. 6). The salt-and-pepper texture of the granofels and granular biotite schist in these outcrops is clearly distinguishable from the characteristic micaceous sheen of the Oakdale metasiltstone, exposed to the south across the Nightingale Brook fault.

The kyanite schist member of the Dudley Formation consists of layered biotite-muscovite schist locally containing staurolite and kyanite interbedded with fine- to medium-grained granular schist composed chiefly of quartz, plagioclase, and biotite with minor muscovite and staurolite. The muscovite schist layers, which are diagnostic of the member, occur as folia and as beds several millimeters to as much as 1 m in thickness; they amount to no more than 30 percent of the member. Garnet and sulfides, present throughout, break down on weathering to stain most outcrops rusty brown.

The kyanite schist member of the Dudley is almost continuously exposed for about 500 m along Stonehouse Brook, downstream from the mouth of the East Branch (loc. 8, fig. 6). Fresh samples of the kyanite schist member were obtained from coreholes 4 and 6 (fig. 6) drilled into bedrock along Pumpkin Hill Road (Pease, 1980). These samples are mostly brownish-gray granular schist containing muscovite, kyanite, sillimanite, and garnet; sulfides are ubiquitous minor constituents.

The exact stratigraphic position of the kyanite schist member within the Dudley is not known because no complete Dudley section is known to exist. The member is, however, overlain and underlain by granofels and granular schist of the Dudley.

The contact at the base of the kyanite schist member has been observed at three locations in the Halls Pond area: (1) in a trench excavated for a gas-transmission pipeline (Pease, 1980) (loc. 9, fig. 6); (2) in a natural outcrop about 3 km southwest of Reeds Pond on a steep slope that extends from just west of the pond (loc. 10, fig. 6); (3) on the pipeline right-of-way on the fault block where the kyanite schist member plunges northward on the nose of an anticline (loc. 11, fig. 6). In all three localities, the Canterbury Gneiss appears to have intruded the Dudley beneath the kyanite schist member, and all that remains of the Dudley beneath the member are a few thin lenses of calc-silicate-rich granofels.

The kyanite schist member was mapped as Scotland Schist by Dixon and Lundgren (1968; see fig. 3, this report). However, as mentioned above, aluminous schist amounts to less than 30 percent of the kyanite schist member, making it markedly less pelitic than the Scotland Schist Member of the Oakdale. According to my mapping, the kyanite schist member is structurally and stratigraphically separate from the Scotland Schist Member. It more closely resembles the lithology of strata in the Brimfield Group (Peper, Pease, and Seiders, 1975), from which it also is structurally and stratigraphically separated.

Dudley strata that overlie the kyanite schist member are exposed in the streambed of Beaverdam Brook (loc. 12, fig. 6). Exposures are indistinguishable from outcrops of the Dudley to the north. North of the Halls Pond area, the strata are well exposed in Bigelow Brook (loc. 19, pl. 1) in the Eastford Quadrangle. The top of the Dudley Formation is everywhere cut out by faulting in Connecticut and adjacent Massachusetts, but farther north in Massachusetts, the contact is known to be conformable and gradational (Barosh and Moore, in press).

Thickness

The total stratigraphic thickness of the Dudley Formation is not known because in each fault block, either the top or the bottom of the formation is cut out by faults or by gneissoid intrusive rock. The maximum exposed apparent stratigraphic thickness is on the order of 1,000 m (Barosh and Moore, in press); the maximum for the kyanite schist member is about 250 m.

Southbridge Formation

Distribution

The Southbridge Formation, which forms the upper part of the Paxton Group, is mapped in a belt 10–15 km wide that extends from the southern part of the Leicester Quadrangle, Mass., to the Rockville Quadrangle, Conn. (pl. 1). The outcrop belt bends from a southwesterly to a westerly trend across the north flank of the Willimantic dome to where it is truncated by the Bonemill Brook fault. The base of the Southbridge is cut out by the Eastford fault on the southeast and by the Wangumbaug Lake fault on the south (pl. 1). The top is truncated by the Black Pond fault. A complex of low-angle thrusts and high-angle tear faults (Fahey and Pease, 1977; Pease, in press) breaks the stratigraphic continuity of the Southbridge north of the Wangumbaug Lake fault, but, in general, the strata dip northward at a relatively low angle subparallel to the thrusting. Strata of the Hebron Formation exposed south of the fault dip westward and strike generally normal to the fault trace.

Two members have been identified in the Southbridge Formation. A lower member characterized by augen-shaped feldspar porphyroblasts was mapped in the Eastford Quadrangle (Pease, 1972); it could not be mapped separately beyond this quadrangle and is not shown on plate 1. A sillimanite schist member is restricted to the Spring Hill (Pease, in press) and South Coventry (Fahey and Pease, 1977) Quadrangles (pl. 1).

General Description

The reader is referred to the geologic maps of the Eastford Quadrangle (Pease, 1972) and the Southbridge Quadrangle (Moore, 1978) for detailed descriptions of the Southbridge Formation. The type section was designated by Pease (1972) as "a line extending N. 48° W. from the point where Dudley Hill Road leaves the [Southbridge] quadrangle (388,700 ft. N.; 464,225 ft. E.) to Cady Brook northwest of Carlton Street School (394,700 ft. N.; 457,225 ft. E.)." The type section has been extended to include the lower part of the Southbridge and is described in more detail by Barosh and Moore (in press). Strata within the type section are well exposed in a large outcrop at the eastern border of the Southbridge Quadrangle (loc. 20, pl. 1).

The Southbridge Formation is more heterogeneous than the Dudley Formation. It consists mostly of distinctly layered, medium- to coarse-grained quartz-plagioclase-black-biotite gneiss and schist but includes interlayers of rusty-weathering muscovite schist and biotite schist and gneiss, calc-silicate-bearing granular schist, and amphibolite. The minor rock types occur as thin lenticular bodies of local extent, and most are not shown separately on plate 1. The heterogeneity of the Southbridge Formation is well shown in exposures extending about 1,000 m along Bigelow Brook on the northwest side of the Eastford fault in the Eastford Quadrangle (loc. 21, pl. 1).

Strata of the sillimanite schist member are very similar to strata within the Brimfield Group but cannot be part of the Brimfield Group because they are conformably overlain by a thick sequence of biotite schist and gneiss of the Southbridge Formation. The member is restricted to the Spring Hill and South Coventry Quadrangles. Its base is everywhere cut out by a fault that is subparallel to layering and foliation. The sillimanite schist member and contacts with rocks above and below it are exposed in the Spring Hill Quadrangle along Chaffeeville Road and in the hills to the east (loc. 22, pl. 1).

Thickness

The total stratigraphic thickness of the Southbridge Formation is not known because of faults cutting the section. The maximum exposed apparent stratigraphic thickness in the Eastford Quadrangle probably is on the order of 3.5 km rather than the 4 km I estimated (Pease, 1972) when I mapped a lower member. To the south and west, however, the exposed thickness appears to be no more than 1 km and may be considerably less as a result of loss of section by overthrusting of the Brimfield. The maximum apparent stratigraphic thickness of the sillimanite schist member is on the order of 150 m.

Hebron Formation

Although the Hebron Formation, as restricted herein, almost certainly lies within the stratigraphic interval of the Paxton Group, it is mapped as a separate formation because the Hebron is separated from all other stratigraphic units by fault or intrusive contacts across which no internal stratigraphy can be correlated. The name "Hebron Formation" is retained because the area of exposure includes the original type area of the Hebron Gneiss of Gregory and Robinson (1907).

Distribution

The Hebron Formation lies west and south of the Putnam Group in the Willimantic dome; it is separated from the Southbridge Formation by the Wangumbaug Lake fault and from the Oakdale Formation by an arcuate thrust fault along which is intruded a thin band of

Lebanon Gabbro (pl. 1). Brimfield Group rocks are thrust over the Hebron on the west and south.

General Description

The Hebron Formation south of the Wangumbaug Lake fault is mostly a homogeneous sequence of medium- to dark-gray, fine-grained, thinly layered quartz-plagioclase-black-biotite schist intercalated with thicker and coarser, biotite-poor, internally laminated felsic gneiss layers. Calc-silicate-rich layers are present in beds 2–8 cm thick.

David London (oral commun., 1982) stated that the Hebron Formation in the Moodus area consists of four different rock types. The two principal types are (1) calc-silicate-rich granulite and schist and (2) more feldspathic, hornblende-bearing gneiss and schist. The third rock type is rusty-weathering mica schist that occurs in thin layers at various stratigraphic intervals. The fourth is massive, gray plagioclase gneiss, of possible volcanic origin. This is interlayered throughout the formation.

Calc-silicate-rich layers account for less than 5 percent of the formation just south of the Wangumbaug Lake fault, but they become increasingly abundant to the south and particularly to the east, where they characterize the Hebron. Good exposures along Route 2 in the Moodus Quadrangle described by Lundgren (Lundgren, Ashmead, and Snyder, 1971) contain varied proportions of "calc-silicate granulite" and quartz-plagioclase-biotite schist. Farther east along Route 2, in the Fitchville Quadrangle, between the eastern end of the Brimfield Group and the Lebanon Gabbro (pl. 1), the Hebron is almost entirely medium-grained, granular, greenish-gray, calc-silicate-bearing biotite schist interlayered with biotite-poor "calc-silicate granulite" (loc. 23, pl. 1).

In his Hebron Formation, Snyder (1964) included metasiltstone of the Oakdale Formation that lies east of the narrow arcuate band of Lebanon Gabbro in the Fitchville Quadrangle. Although he did not recognize the presence of the Oakdale in Connecticut, he did observe a lithologic difference between rocks on either side of this boundary. He defined it as a difference in ratio between "calc-silicate rock, calcareous biotite schist rock, and noncalcareous biotite schist," that west of the Lebanon having a much greater proportion of calc-silicate rock (Snyder, 1964, p. 18).

Thickness

Exposed sections of the Hebron Formation vary greatly in thickness. As these sections are bounded by faults, the original aggregate thickness of the Hebron Formation is impossible to determine. Both top and bottom are cut out by faults. The maximum exposed continuous apparent stratigraphic thickness may be on the order of 3 km in the Marlborough and Columbia Quadrangles.

SUMMARY OF STRUCTURE

Major structures relevant to correlation of the Oakdale Formation and Putnam Group with strata in eastern Connecticut are shown on plate 1. A brief interpretation of pertinent relationships is given below, but no definitive analysis of the total structure has been attempted in this stratigraphic paper.

Most of the eastern margin of the area of concern is delineated by the Clinton-Newbury fault zone, along which the Oakdale Formation appears to have been thrust over the Putnam-Nashoba thrust belt terrane (pl. 1, fig. 4) and to have had its lower part cut out. The principal sense of displacement on this fault zone evidently was left-lateral, as the entire geosyncline terrane moved south and east relative to the thrust belt terrane (fig. 4). In the northern part of the area mapped in plate 1, the Wekepeke fault splays northward from the Clinton-Newbury zone and separates the Oakdale from a graben of younger phyllitic rocks. The trace of the Clinton-Newbury fault zone is generally well defined in the northern part of the area mapped in plate 1, but from about the middle of the Putnam Quadrangle southward in Connecticut, the surface trace of the fault is entirely obscured by igneous intrusive rock and younger high-angle faults.

Plutonic rocks intruded extensively along the Clinton-Newbury fault zone include the Ayer Granite along the northern part and the Canterbury Gneiss from the northwest corner of the Danielson Quadrangle south. Both suites of plutonic rock have been foliated during regional metamorphism of the country rock. Where the Ayer is exposed within the fault zone, it is mylonitic and accentuates the trace of the zone. The belt of Canterbury that is exposed in the structural position of the Clinton-Newbury fault zone, between the Oakdale and the Putnam Group rocks (pl. 1), shows no evidence of mylonitization, and the trace of the fault is not apparent.

The Canterbury Gneiss surrounds much of the Willimantic dome (pl. 1), here, too, masking the boundary between rocks of the thrust belt terrane and rocks of the geosyncline terrane. This boundary also represents the structural position of the Clinton-Newbury fault zone, along which the principal body of Canterbury Gneiss appears to have been emplaced. Strata of the geosyncline terrane on the flanks of the dome are in the upper plate of the Clinton-Newbury thrust sheet (fig. 5).

The arcuate band of Lebanon Gabbro exposed south of the Willimantic dome in the Fitchville Quadrangle (pl. 1) intruded along a fault zone that separates the Oakdale Formation from the Hebron Formation; the Oakdale Formation was thrust beneath the Hebron. Local shearing in the base of the gabbro suggests that at least minor displacement occurred along this fault zone after emplacement of the gabbro.

The stratigraphic sequence in the geosyncline terrane appears to be essentially homoclinal, and younger rocks are toward the west. No evidence indicates repetition of stratigraphic sequences. Topping evidence consists of metamorphosed graded beds and cross lamination in quartzite (Peper and Pease, 1975); it shows that bed tops are consistently to the west except locally in minor folds and around the Willimantic dome, where the structure flattens and is warped up by doming. Radiometric ages, as described in a later section of this report, support the interpretation of strata younging to the west.

The geosyncline terrane is sliced by numerous thrust faults, most of which are subparallel to foliation and layering. Only a few of these are shown on plate 1. The principal movement on these faults appears to have been by ductile transport during the late stages of regional metamorphism. They show the same features of ductile deformation, aligned sillimanite needles, feldspar growth, and rotated blocks that are present along the boundaries between major structural terranes (Wintsch, 1979). Many local units in the terrane are cut out at low angles against one side of a fault and cannot be found on the opposite side, suggesting significant apparent strike-slip displacement.

Stratigraphy in the geosyncline terrane north of the Willimantic dome is complicated by the north- west-plunging anticline exposed in the center of the Halls Pond area (fig. 6). It is defined by the attitude and distribution of the kyanite schist member of the Dudley Formation in several fault blocks. The east flank of the anticline is exposed in a north-trending fault block where the member dips gently eastward beneath fine-grained granofels and granular schist of the Dudley. The base of the member is cut out by a fault along the Natchaug River to the west. Rusty-weathering micaceous schist of the kyanite schist member plunges gently down the nose of the anticline in the central fault block. The kyanite schist member in this block rests directly on the Canterbury Gneiss, and all that remains of the Dudley Formation beneath this member are calc-silicate-bearing xenoliths in the Canterbury. On the west flank, the member dips gently northwest against the East Branch fault (fig. 6). Calc-silicate-bearing granofels of the Dudley is also present discontinuously between the kyanite schist member and the Canterbury Gneiss in this fault block. The granofels has a maximum thickness of less than 2 m and is not shown separately on figure 6.

The sense of transport along the Wangumbaug Lake and Black Pond fault zones is similar to that along the Clinton-Newbury fault zone in that the west side moved south relative to the east. Both are gently north dipping thrust faults in the Rockville and South Coventry Quadrangles; strata of the Southbridge Formation are warped into subparallel alignment between the fault surfaces. The Wangumbaug Lake fault cuts across west-dipping strata assigned to the Hebron Formation and Brimfield Group in its lower plate; the Black Pond fault cuts out the entire Brimfield section in its upper plate. The surface trace of the Wangumbaug Lake fault is cut out by a younger fault, the Eastford fault, in the Spring Hill Quadrangle (pl. 1), but the fault zone itself is believed to bend northeastward, as does the Black Pond fault. North of the Spring Hill Quadrangle, the two fault zones are subparallel to regional foliation and layering, and the principal displacement is left-lateral. The continuity of these fault zones with faults in Massachusetts is uncertain, but the Black Pond fault is considered to represent the upper boundary of exposed Paxton Group rocks.

The Bonemill Brook fault zone forms the western boundary of the thick stratigraphic sequence of the geosyncline terrane where it has been squeezed against the gneiss dome terrane (Pease, 1982a). The sense of transport along this zone appears to be right-lateral, as the geosyncline terrane has moved southward and upward relative to the gneiss dome terrane.

Near-vertical, mostly normal faults of relatively small displacement are common throughout the area. The most conspicuous of these intersect the structure as they trend northeast to northwest; others, such as the Eastford fault, are subparallel to structure and, in many places, obscure or cut out the traces of earlier ductile thrust faults. Age relations among these normal faults are not known, but all the faults appear to be younger than the late syntectonic ductile displacement.

METAMORPHISM

Regional metamorphic isograds in the geosyncline terrane increase generally in a southwest direction across central Massachusetts; farther south in eastern Connecticut, the increase is almost due west. The easternmost formation in the geosyncline terrane, the Oakdale Formation, is at the lowest grade; in Massachusetts, it shows scarcely any evidence of metamorphism. The principal rock type of the Oakdale characteristically retains most of the sedimentary features of a siltstone and does not possess a distinctly metamorphic fabric. Thus, the Oakdale is more aptly referred to as a metasiltstone than as a higher grade granofels.

The increase in metamorphic grade across the geosyncline terrane appears to be progressive with no evidence of any significant reversal in grade across the strike. This progression is best shown by the numerous alumino-silicate schist members and lenses. The Scotland Schist Member of the Oakdale (pl. 1) is a muscovite-rich garnet staurolite schist; the kyanite schist member of the stratigraphically higher Dudley Formation (pl. 1) contains kyanite and staurolite, and the sillimanite schist member of the still higher Southbridge Formation (pl. 1) contains sillimanite as well as muscovite. There is no conspicuous contrast in metamorphic grade across the Black Pond fault that separates the Paxton Group from the Brimfield Group (Peper, Pease, and Seiders, 1975); rather, the transition from first sillimanite to second sillimanite grade is well up in the Brimfield section.

An apparently anomalous relationship exists in eastern Connecticut and adjacent Massachusetts because the persistently right-side-up homoclinal sequence exhibits a gradual increase in regional metamorphic grade upward in the section. This appears to result from the position of these strata within the regional framework of the geosynclinal basin and from slicing and shortening of this terrane during ductile transport. The present erosion surface in eastern Connecticut and adjacent Massachusetts exposes a cross section of the eastern flank of a major geosynclinal basin that extends across New Hampshire and Maine. The axis of this geosyncline lies north of the area mapped in plate 1, probably in the approximate position of the axis of the Merrimack synclinorium as shown by R.C. Greene (1970) in the vicinity of Mount Monadnock and Crotchet Mountain. The geosyncline axis apparently is cut out against the projected position of the Bonemill Brook fault zone so that the west flank of the geosyncline does not appear in Connecticut, where sillimanite-grade strata of the geosyncline terrane are turned on end and jammed against mostly lower grade rocks of the gneiss dome terrane.

Strata of the Oakdale Formation apparently were deposited along the eastern margin of the basin, where any overburden, now eroded, was so thin that the strata were essentially unaffected by regional dynamothermal metamorphism. The highly metamorphosed rocks of the Brimfield Group, in contrast, evidently were deposited in the center of the geosynclinal basin beneath a thick sequence of younger rocks that have since been eroded. A remnant of these younger strata is exposed in the graben between the Clinton-Newbury fault and the Wekepeke fault in the northern part of the area mapped in plate 1.

The continuity of increasing metamorphic grade is more apparent than real. Rocks of highest metamorphic grade evidently represent strata that have been carried up from the deepest part of the geosynclinal basin along a series of northwest-dipping fault surfaces. Each fault from east to west evidently brought up a slice of slightly higher grade rocks from deeper in the basin. The change in metamorphic grade between each fault slice, however, was so small as to give the appearance of a continuous increase in metamorphic grade from east to west.

AGE RELATIONS

No fossils have been found in the geosyncline terrane of eastern Connecticut and adjacent Massachusetts. Emerson (1917) considered the entire Oakdale, Paxton, and Brimfield sequence to be Carboniferous in age on the basis of plant fossils found in the Worcester Phyllite, which consists of black carbonaceous graphitic schist exposed in a small "coal mine" (pl. 1) in the city of Worcester, just north of Millstone Hill. He considered the Oakdale to be about the same age as the Worcester Phyllite and inferred that the Oakdale grades up into the Worcester "by an easy transition without visible unconformity or interruption" (Emerson, 1917, p. 27). Emerson then equated the Worcester with the Brimfield and the Oakdale with the Paxton as being the same lithofacies at higher metamorphic grade. The structure and stratigraphic relationship of the Worcester in the coal mine to the surrounding Oakdale Formation is not certain (Grew, 1973), and a substantial body of radiometric age data assembled in recent years indicates that the Oakdale-Paxton sequence must be considerably older than Carboniferous.

R.E. Zartman of the U.S. Geological Survey has obtained radiometric dates of many samples of the foliated intrusive rocks of the area. Using both the Rb-Sr whole-rock and the U-Th-Pb zircon techniques, Zartman and Naylor (1984) obtained the following ages (in millions of years) for foliated intrusive rocks pertinent to this report:

Intrusive rock	*Age based on Rb/Sr ratio*	*Age based on U-Pb concordia intercept*
Canterbury Gneiss..........	392±9	395±10
Fitchburg Complex—		
at Malden Hill............	402±11	...
at Rollstone quarry.......	...	390±15
Ayer Granite................	...	433±5

The Canterbury Gneiss intrudes rocks of both the Oakdale Formation and the Paxton Group. The Ayer Granite includes foliated rocks that intrude the Oakdale (pl. 1). The Fitchburg intrudes the Paxton in the northern part of the area mapped in plate 1. The dates above thus provide at least a minimum age for the Oakdale and Paxton rocks.

A critical radiometric age, however, and one that Zartman (written commun., 1980) feels to be a reliable primary age within a small margin of analytical error, is 440±10 Ma, which was determined by $^{207}Pb/^{206}Pb$ ratios for the Hedgehog Hill sill (Peper and Pease, 1975). This informally named foliated gneiss is emplaced near the top of the Hamilton Reservoir Formation of the Brimfield Group (fig. 2). Thus, according to our regional interpretation of a homoclinal section younging to the west, the entire Oakdale-Paxton sequence must be at least as old as Ordovician.

Aleinikoff, Zartman, and Lyons (1979) assigned $^{207}Pb/^{206}Pb$ ages of 1,188 Ma and 1,237 Ma, respectively, to detrital zircons collected from localities north of the area mapped in plate 1, one in the Oakdale Formation of northern Massachusetts and the other in the Paxton Group of southern New Hampshire as mapped by Barosh, Fahey, and Pease (1977). These ages provide maximum possible ages for these formations. A younger, Late Proterozoic age is suggested by a date of approximately 650 Ma (Lyons, Boudette, and Aleinikoff, 1982) from rocks of the Massabesic Gneiss that intrude the Paxton Group (Barosh, Fahey, and Pease, 1977). Thus, although at least part of the Brimfield Group may be Ordovician or older Paleozoic, the Oakdale Formation and Paxton Group are herein assigned to the Late Proterozoic(?).

CONCLUSIONS

A sequence of metasedimentary and metavolcanic rocks many kilometers thick extends across central Massachusetts into eastern Connecticut. This geosyncline terrane is separated from terranes on the east, south, and west by major zones of ductile transport and brittle fracture across which no specific stratigraphic correlations can be made. The Oakdale Formation lies at the base of the sequence and is overlain in conformable succession by rocks of the Paxton and Brimfield Groups. This thick stratigraphic prism has undergone large-scale tectonic transport accompanied by syntectonic intrusion. The regional sense of movement is northwest over southeast. The surface traces of most stratigraphic boundaries are obscured by fault contacts or intrusive bodies, but the stratigraphic order of formational units does not appear to have been disrupted by this large-scale tectonic transport. Younger and higher grade rocks, in general, were transported over older and lower grade rocks. Stratigraphic thicknesses can only be estimated, owing to pervasive intraformational folding and faulting.

The Oakdale Formation maintains its distinctive metasiltstone character from east-central Massachusetts to its southern termination against the Honey Hill fault zone in Connecticut. The Scotland Schist Member lies near the base of the formation in Connecticut. Lenticular bodies of micaceous schist lithologically similar to the Scotland are present at several other stratigraphic levels in the Oakdale, but these are too small to map.

The Oakdale is separated from older rocks of the thrust belt terrane by the Clinton-Newbury fault zone. A graben of younger phyllitic rocks, dropped down on the west by the Wekepeke fault, lies at this boundary in the northern part of the area mapped in plate 1. Plutonic gneisses that have been intruded along much of this boundary south of the graben are the Ayer Granite in Massachusetts and northern Connecticut and the slightly younger Canterbury Gneiss farther south. These are syntectonic intrusive rocks believed to have been emplaced at the time of ductile transport along the Clinton-Newbury fault zone. The Ayer shows evidence of a near-vertical shearing along this tectonic boundary. The Canterbury shows none and obscures the trace of the fault zone, but near-vertical shearing has been observed at two localities in Connecticut where the boundary between the Oakdale and Putnam is exposed east of the Canterbury Gneiss. Evidently, high-angle shearing and mylonitic deformation occurred along this tectonic boundary in the time interval between emplacement of the Ayer and Canterbury intrusions, but the amount of tectonic transport accompanying this deformation is not known.

The Clinton-Newbury fault zone also is believed to enclose the window of older rocks in the Willimantic dome, but here, too, the surface trace of the fault zone has been either displaced by younger faults or obliterated by gneissic intrusive rock.

The Oakdale Formation conformably underlies the Paxton Group, but in most of the area mapped in plate 1, the upper part of the Oakdale is cut out either by faulting or by igneous intrusion. The Oakdale extends southward along the east side of the Willimantic dome into the Fitchville Quadrangle, where it is cut off by faults.

The Paxton Group, undivided north of the Webster Quadrangle, is divided to the south into the Dudley and Southbridge Formations. The Dudley Formation is a transitional stratigraphic unit between the Oakdale and Southbridge Formations, and, although the top of the Dudley is everywhere cut out by faulting, the contact with the overlying Southbridge also appears to be gradational. The kyanite schist member defines the limbs of a highly faulted, northwest-plunging anticline in the Halls Pond area. The precise stratigraphic position of this member within the Dudley, however, is uncertain, but it is stratigraphically and structurally separate from the older Scotland Schist Member with which it formerly had been correlated. The southernmost outcrop of the Dudley is exposed in a small fault sliver on the east side of the Willimantic dome in the Willimantic Quadrangle.

The Southbridge Formation lies between the upper plate of the Wangumbaug Lake fault and the lower plate of the Black Pond fault. From the Spring Hill Quadrangle northeastward, however, the surface trace of the Wangumbaug Lake fault is cut out by the Eastford and other younger faults. The Southbridge terminates westward against the Bonemill Brook fault. The sillimanite schist member, which closely resembles strata within the Brimfield Group, is a lens within the Southbridge occurring only within the Spring Hill and South Coventry Quadrangles (Fahey and Pease, 1977; Pease, in press).

The Hebron Formation apparently lies within the stratigraphic interval represented by the Paxton Group (pl. 1), but it is mapped as a separate formation because, in its overall lithologic appearance, it is recognizably distinct from both the Southbridge and Dudley Formations and because its precise stratigraphic relationship to these formations (pl. 1) is not known. The Oakdale east of the thin band of Lebanon Gabbro apparently lies lower in the stratigraphic section than the Hebron. The area of exposure of the Hebron as herein restricted includes the original type area.

The Paxton, Southbridge, and Hebron all structurally underlie rocks of the Brimfield Group. The contact is a fault in Connecticut and adjacent Massachusetts, but north of the area mapped in plate 1, the contact appears to be conformable, and the Paxton appears to grade upward into Brimfield Group rocks. South of the Wangumbaug Lake fault, extreme variations in thicknesses of the Hebron and Brimfield suggest that there also has been considerable tectonic transport along this contact.

Most folding is small scale and intraformational and the sense of asymmetry is in accord with the sense of transport along fault zones. The limbs of many of these folds are sheared, and the shears show a similar sense of transport. The north-plunging anticline in the Halls Pond area is the principal large-scale fold. This highly faulted anticline is predicated on recognition of the distribution in fault blocks of the kyanite schist member of the Dudley Formation.

The 440-Ma radiometric age of the Hedgehog Hill gneiss that is intruded almost at the top of the thick sedimentary prism of the geosyncline terrane indicates that the Oakdale-Paxton sequence can be no younger than Late Ordovician. The top of the Paxton, moreover, lies well below the strata of the Brimfield Group that were intruded by this gneiss, and rocks of probable Late Proterozoic age intrude the Paxton. Both the Paxton and the underlying Oakdale Formation, therefore, probably should be considered Late Proterozoic(?) in age. The ages assigned to the several regionally foliated intrusive bodies, ranging from about 390 Ma to 430 Ma, attest to a period of regional metamorphism extending from the Early Silurian to the Early Devonian.

The stratigraphy and structure as set forth in this report are not compatible with an earlier interpretation (fig. 3) that postulates a simple stratigraphy repeated on opposite limbs of a recumbent syncline.

REFERENCES CITED

Aleinikoff, J.N., Zartman, R.E., and Lyons, J.B., 1979, U-Th-Pb geochronology of the Massabesic Gneiss and the granite near Milford, south-central New Hampshire—New evidence for Avalonian basement and Taconic and Alleghenian disturbances in eastern New England: Contributions to Mineralogy and Petrology, v. 71, p. 1–11.

Barosh, P.J., 1974, Preliminary bedrock geologic map of the Webster Quadrangle, Massachusetts-Connecticut: U.S. Geological Survey Open-File Report 74–192, 2 p., 1 pl., scale 1:24,000.

———1977, Preliminary map showing bedrock geology superposed on an aeromagnetic base map of the Worcester region, Massachusetts, Connecticut, and Rhode Island: U.S. Geological Survey Open-File Report 77–131, 46 p., 2 pls., scale 1:125,000.

Barosh, P.J., Fahey, R.J., and Pease, M.H., Jr., 1977, Preliminary compilation of the bedrock geology of the land area of the Boston 2° sheet, Massachusetts, Connecticut, Rhode Island, and New Hampshire: U.S. Geological Survey Open-File Report 77–285, 142 p., 1 pl., scale 1:125,000.

Barosh, P.J., and Moore, G.E., Jr., in press, The Paxton Group of southeastern New England: U.S. Geological Survey Bulletin 1814.

Barosh, P.J., and Pease, M.H., Jr., 1981, Correlation of the Oakdale and Paxton Formations with their equivalents from eastern Connecticut to southern Maine [abs.]: Geological Society of America Abstracts with Programs, v. 13, no. 3, p. 122.

Barosh, P.J., Pease, M.H., Jr., Schnabel, R.W., Bell, K.G., and Peper, J.D., 1977, Aeromagnetic lineament map of southern New England showing relation of lineaments to bedrock geology: U.S. Geological Survey Miscellaneous Field Studies Map MF–885, 1 sheet, scale 1:250,000.

Dixon, H.R., and Lundgren, L.W., Jr., 1968, Structure of eastern Connecticut, *in* Zen, E-an, White, W.S., Hadley, J.B., and Thompson, J.B., Jr., eds., Studies of Appalachian geology—Northern and maritime: New York, Interscience, p. 219–230.

Dixon, H.R., and Pessl, Fred, Jr., 1966, Geologic map of the Hampton Quadrangle, Windham County, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ–468, scale 1:24,000.

Emerson, B.K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geological Survey Bulletin 597, 289 p., scale 1:250,000.

Fahey, R.J., and Pease, M.H., Jr., 1977, Preliminary bedrock geologic map of the South Coventry Quadrangle, Tolland County, Connecticut: U.S. Geological Survey Open-File Report 77–584, 30 p., 2 pls., scale 1:24,000.

Greene, R.C., 1970, The geology of the Peterborough Quadrangle, New Hampshire: New Hampshire Department of Resources and Economic Development Bulletin 4, 88 p.

Gregory, H.E., and Robinson, H.H., 1907, Preliminary geological map of Connecticut: Connecticut Geological Survey Bulletin 7, 39 p.

Grew, E.S., 1973, Stratigraphy of the Pennsylvanian and pre-Pennsylvanian rocks of the Worcester area, Massachusetts: American Journal of Science, v. 273, no. 2, p. 113–129.

Lundgren, L.W., Jr., 1966, The bedrock geology of the Hamburg Quadrangle, Connecticut: Connecticut Geological and Natural History Survey Quadrangle Report 19, 41 p.

Lundgren, L.W., Jr., Ashmead, Lawrence, and Snyder, G.L., 1971, The bedrock geology of the Moodus and Colchester Quadrangles: Connecticut Geological and

Natural History Survey Quadrangle Report 27, 24 p., 8 figs.

Lundgren, L.W., Jr., and Ebblin, Claude, 1972, The Honey Hill fault in eastern Connecticut—Regional relations: Geological Society of America Bulletin, v. 83, no. 9, p. 2773–2794.

Lyons, J.B., Boudette, E.L., and Aleinikoff, J.N., 1982, The Avalonian and Gander zones in central eastern New England, *in* St-Julien, Pierre, and Beland, J., eds., Major structural zones and faults of the northern Appalachians: Geological Association of Canada Special Paper 24, p. 43–66.

Moore, G.E., Jr., 1978, Preliminary bedrock, surficial, and structural data maps of the Southbridge Quadrangle, Massachusetts and Connecticut: U.S. Geological Survey Open-File Report 78–220, 16 p., 4 pls., scale 1:24,000.

Pease, M.H., Jr., 1972, Geologic map of the Eastford Quadrangle, Windham and Tolland Counties, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ–1023, 3 p., scale 1:24,000.

———1975, Preliminary bedrock geologic map of the Stafford Springs Quadrangle, Tolland County, Connecticut: U.S. Geological Survey Open-File Report 75–633, 30 p., 2 pls., scale 1:24,000.

———1980, Geologic data obtained from core samples drilled in the vicinity of Chaplin, Windham County, Connecticut: U.S. Geological Survey Open-File Report 80–933, 34 p.

———1982a, The Bonemill Brook fault zone, eastern Connecticut, *in* New England Intercollegiate Geological Conference, 74th, Storrs, Conn., Oct. 2–3, 1982, Guidebook for fieldtrips in Connecticut and south-central Massachusetts: Connecticut Geological and Natural History Survey Guidebook 5, p. 263–287.

———1982b, Correlation of Eastford Gneiss with Canterbury Gneiss, eastern Connecticut, *in* Stratigraphic notes, 1980–1982: U.S. Geological Survey Bulletin 1529–H, p. H95–H97.

———in press, Bedrock geologic map of the Spring Hill Quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ–1650.

Pease, M.H., Jr., and Barosh, P.J., 1981, Distribution and structural significance of the Oakdale Formation in northeastern Connecticut, *in* New England Intercollegiate Geological Conference, 73d, Kingston, R.I., Oct. 16–18, 1981, Guidebook to geologic field studies in Rhode Island and adjacent areas: Kingston, R.I., University of Rhode Island, p. 17–34.

Pease, M.H., Jr., and Fahey, R.J., 1978, A reinterpretation of the stratigraphy and structure in part of eastern Connecticut [abs.]: Geological Society of America Abstracts with Programs, v. 10, no. 2, p. 79.

Peck, J.H., 1975, Preliminary bedrock geologic map of the Clinton Quadrangle, Worcester County, Massachusetts: U.S. Geological Survey Open-File Report 75–658, 30 p., 3 pls., scale 1:24,000.

Peper, J.D., and Pease, M.H., Jr., 1975, Geologic map of the Westford Quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ–1214, scale 1:24,000.

———1976, Summary of stratigraphy in the Brimfield area, Connecticut and Massachusetts, *in* Page, L.R., ed., Contributions to the stratigraphy of New England: Geological Society of America Memoir 148, p. 253–270.

Peper, J.D., Pease, M.H., Jr., and Seiders, V.M., 1975, Stratigraphic and structural relationships of the Brimfield Group in northeast-central Connecticut and adjacent Massachusetts: U.S. Geological Survey Bulletin 1389, 31 p.

Rodgers, John, compiler, 1985, Bedrock geological map of Connecticut: Connecticut Geological and Natural History Survey, Connecticut Natural Resources Atlas Series, Bedrock Geological Map, 2 sheets, scale 1:125,000.

Snyder, G.L., 1961, Geologic map of the Norwich Quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ–144, scale 1:24,000.

———1964, Petrochemistry and bedrock geology of the Fitchville Quadrangle, Connecticut: U.S. Geological Survey Bulletin 1161–I, 63 p.

U.S. Geological Survey, 1980, Correlation of Oakdale and Paxton Formations of east-central Massachusetts with stratigraphy in eastern Connecticut, *in* Geological Survey Research, 1980: U.S. Geological Survey Professional Paper 1175, p. 62.

Wintsch, R.P., 1975, Feldspathization as a result of deformation: Geological Society of America Bulletin, v. 86, p. 35–38.

———1977, Syntectonic oxidation in the Tatnic Hill Formation of eastern Connecticut [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 7, p. 1232.

———1979, The Willimantic fault—A ductile fault in eastern Connecticut: American Journal of Science, v. 279, no. 4, p. 367–393.

Zartman, R.E., and Naylor, R.S., 1984, Structural implications of some radiometric ages of igneous rocks in southeastern New England: Geological Society of America Bulletin, v. 95, no. 5, p. 522–539.

Zen, E-an, editor, and Goldsmith, Richard, Ratcliffe, N.M., Robinson, Peter, and Stanley, R.S., compilers, 1983, Bedrock geologic map of Massachusetts: Reston, Va., U.S. Geological Survey, 3 sheets, scale 1:250,000.

APPENDIX: DESCRIPTION OF LOCALITIES

Representative exposures and critical localities are described below in the same order that they are discussed in the text. Localities are shown on the geologic map of eastern Connecticut and adjacent Massachusetts (pl. 1, locs. 1–23) or on the larger scale map of the Halls Pond area (fig. 6, locs. 1–12). Localities 1–12 on figure 6 are different from localities 1–12 on plate 1.

Most localities are in Connecticut; three Massachusetts localities are described to confirm the lithologic similarity of stratigraphic units correlated between Connecticut and Massachusetts. Site locations given below are based on the 10,000-ft grid of the Connecticut coordinate system and, where indicated, on the Massachusetts grid. These grids and the geographic features mentioned below are shown on topographic maps of 7½-min quadrangles published by the U.S. Geological Survey. Locations of relevant quadrangles are shown on plate 1.

Oakdale Formation

Locality 1, plate 1 (311,000 N.; 800,250 E.).—Near the eastern border of the Scotland Quadrangle about 300 m north of Kinne Road and just west of a small pond in Cory Brook. The intrusive nature of the contact between the Canterbury Gneiss and the Oakdale Formation is shown in these outcrops. Numerous inclusions of biotite-rich and calc-silicate-rich metasiltstone are in medium-grained granitic gneiss at the base of the Canterbury exposures. The inclusions are lens shaped and rotated into the plane of foliation by plastic flow at the time of intrusion. Country rock exposed less than 3 m from the contact is hard, flinty, very fine grained, calc-silicate-rich metasiltstone. No bedding was observed, and foliation is obscure, but several conspicuous planar joints that strike about N. 20° E. and dip 55° NW. appear to parallel the foliation. Foliation in the Canterbury is subparallel to this trend. The position of Canterbury and Oakdale outcrops indicates that the contact at this locality is offset several meters relative to the trend of foliation. The offset may be the result of a small displacement on a late minor fault or of a local warp in the regional foliation not observed in outcrop.

The trace of the Clinton-Newbury fault zone apparently is cut out by a steeply dipping fault that lies on the east side of Cory Brook. Sheared biotite schist probably derived from metasiltstone of the Oakdale is exposed in a small, low outcrop immediately north of Kinne Road and west of Cory Brook (310,150 N.; 800,350 E.). The shears are essentially vertical, steeper than the probable dip of the Clinton-Newbury fault zone; they appear to be the result of local displacement of the upper plate. Rusty-weathering schist and gneiss aligned subparallel to the trace of the fault zone are exposed in a small roadcut 150 m to the east (310,050 N.; 800,550 E.). The outcrop is assigned to the Putnam Group and is east of the near-vertical fault and on the east side of the structural position of the Clinton-Newbury fault zone.

Locality 2, plate 1.—Hampton Quadrangle about 800 m north of Stetson Corner and extending for about 500 m to the northeast. This is the second area of Oakdale exposed east of the Canterbury; the first is locality 1, plate 1. In a small stream on the west side of Cherry Hill Road (350,500 N.; 802,550 E.), abundant slabs of a calc-silicate-bearing metasiltstone lie immediately below exposures of a fine-grained granitic dike believed to be related to the Canterbury. Medium-grained gneiss more typical of the Canterbury is exposed just upstream. Layered calc-silicate-bearing metasiltstone crops out across Cherry Hill Road about 500 m to the northeast (352,000 N.; 803,350 E.). It strikes about due north and dips about 45° W., essentially parallel to foliation in the gneiss. Canterbury Gneiss having a more northeasterly trend in foliation is exposed to the north, directly on strike with the metasiltstone. There is apparently a local northeasterly warp in the intrusive contact in these exposures, although the regional trend of foliation continues due north.

An exposure about 450 m south of Stetson Corner on the east side of the road (346,500 N.; 802,550 E.) consists of sheared micaceous schist dipping steeply to the east. This schist is believed to represent rocks of the Putnam Group on the east side of the Clinton-Newbury fault zone exposed by a fault that is either the same as or similar to the near-vertical fault observed at locality 1, plate 1.

Locality 3, plate 1 (341,150 N.; 789,200 E.).—Roadcut on the north side of Route 6, Hampton Quadrangle. These strata of the Oakdale Formation lie west of the Canterbury Gneiss and immediately beneath the Scotland Schist Member. The outcrop is olive gray to greenish gray and strongly differentially weathered. It consists of weakly resistant, flaky-weathering biotitic metasiltstone alternating with ribs of calc-silicate-bearing rock, on a scale of 1–10 cm. Small-scale recumbent folds having amplitudes of 5–200 cm are stacked in this outcrop. Axial planes dip gently north parallel to layering; the asymmetry is indicative of internal transport toward the south.

Locality 4, plate 1 (305,375 N.; 781,250 E.).—Waldo Brook just east of Route 97, Scotland Quadrangle. Thinly bedded, differentially weathered, biotite-rich and calc-silicate-rich metasiltstone of the Oakdale Formation is exposed in the streambed. A thin-bedded quartzite less than a meter thick is exposed on the northeast side of the stream valley at this locality but could not be traced beyond these exposures. This is the lowest stratigraphic position of quartzite mapped in the Oakdale of Connecticut. Quartzite is most common just below the Scotland Schist Member and within the lower part of the Scotland.

Locality 5, plate 1 (274,000 N.; 763,000 E.).—Roadcuts on both sides of Route 87 about 2.5 km northwest of the intersection with Route 32, Fitchville Quadrangle. The contact between the Oakdale Formation and the Scotland Schist Member is exposed. The contact is placed at the top of an interval about 10 m thick of evenly layered, distinctly color banded metasiltstone; the alternating layers are brownish-gray, biotite-rich metasiltstone and greenish-gray, calc-silicate-rich metasiltstone. Scotland-like, rusty-weathering, crinkle-foliated micaceous schist is present at the base of the outcrops on the south side of the road. These strata are considered to lie beneath the Scotland Schist Member; they include layers of metasiltstone 2–10 cm thick and grade upward into the banded metasiltstone. The low area of no outcrop east of these roadcuts presumably is underlain by weakly resistant metasiltstone. The Scotland above the banded metasiltstone consists of nonlayered, thickly parted, strongly crinkle foliated, rusty- and sulfidic-yellow-weathering muscovite-biotite-garnet schist. Blobs and stringers of quartzite are common within the schist.

The base of the Scotland Schist Member is also exposed about 1.3 km to the north on the west wall of the valley of Susquetonscut Brook (278,400 N.; 763,000 E.). Here, a quartzite bed about 1.5 m thick is overlain by crinkle-folded mica schist containing numerous quartzite streaks less than 1 cm thick and is underlain by interlayered biotite-rich and calc-silicate-rich metasiltstone. Mica schist layers were not observed in the metasiltstone in this outcrop. The quartzite is offset along a vertical fault trending about 35° W.; the southeast side has moved up about a meter. The base of the Scotland is placed immediately above the quartzite.

Locality 6, plate 1 (283,400 N.; 765,100 E.).—An east-facing outcrop several meters high in back of the church at Franklin, Fitchville Quadrangle. The base of the outcrop consists of thinly and sharply layered metasiltstone of the Oakdale Formation, which contains alternating biotite-rich layers and biotite-poor, calc-silicate-bearing layers. The metasiltstone is overlain by a bed of quartzite 20 cm thick extending for at least 10 m along the outcrop. Poorly layered, thickly parted, brown-weathering, aluminous biotite-muscovite schist of the Scotland forms the upper part of this exposure. The outcrop is capped by gneissoid pegmatite. Graded bedding in the church yard above the main outcrop indicates that the beds are right side up. The base of the Scotland is placed above the quartzite bed.

The base of the Scotland is present but not exposed less than 1 km north of locality 6 on the west side of Route 32. Quartzite here lies within thin-bedded metasiltstone of the Oakdale Formation. This quartzite bed is extremely lenticular, ranging in thickness from a few centimeters to as much as 2 m. The Scotland Schist Member crops out on the hillside above but is not exposed within the roadcut. Aluminous schist also crops out below the road. It probably is Scotland in fault slivers, but it possibly represents thin lenses of schist stratigraphically beneath the Scotland.

Locality 7, plate 1 (302,400–303,900 N.; 771,700-775,025 E.).—Along the railroad and in roadcuts along Station Road from the dam in the Shetucket River to Merrick Brook, Scotland Quadrangle. Outcrops in Merrick Brook are within the Scotland Schist Member and must be very near its base because thinly layered metasiltstone intervals tens of centimeters thick are interlayered with mica-garnet schist. Exposures along Station Road to the west are typically poorly layered, strongly crinkle folded, muscovite-biotite-quartz-garnet schist of the Scotland Schist Member. The attitude of bedding and configuration of folding commonly are brought out by resistant layers, of finely granular metasiltstone 1–5 cm thick. Foliation and layering strike generally north-northeast and dip 15°–30° W. Crinkle folds and small-scale isoclinal folds having axial surfaces parallel to foliation plunge 5°–15° SW. Discontinuous quartzite stringers and lenses are common; they are folded with foliation and layering.

The upper part of the Scotland is exposed at the dam in the Shetucket River. The exposure extends along the railroad for 100 m and in vertical section about 20 m along a powerline right-of-way. The Scotland here is a more massive schist generally lacking the granular layers observed lower in the section. The schist is highly muscovitic and typically contains staurolite and garnet. Intrafolial chevron folds as much as 0.5 m in amplitude are ubiquitous. The top is not exposed.

Locality 8, plate 1 (282,175 N.; 753,300 E.).—Exposures in a south-flowing tributary to Pease Brook on Mason Hill in the Fitchville Quadrangle. Rusty-weathering sulfidic micaceous schist at the top of the Scotland Schist Member dips beneath exposures of thinly layered metasiltstone containing intervals of muscovite schist as thick as 0.5 cm. Downstream, this metasiltstone, in turn, grades upward into typical Oakdale metasiltstone lacking muscovite folia. The upper contact here dips about 15° SW. and is on the flank of an anticlinal warp plunging gently to the west.

Locality 1, figure 6 (351,900 N.; 792,000 E.).—A powerline right-of-way crossing a prominent southeast-trending ridge just north of the intersection of Kings Highway and North Bigelow Road, Hampton Quadrangle. The base of the Scotland is exposed discontinuously from North Bigelow Road for about 700 m along the base of the ridge. It dips gently north, subparallel to layering and foliation, and has been raised a few meters or less on the east side of several northeast-trending high-angle faults. Strata beneath the contact are mostly olive-brown-weathering metasiltstone composed of quartz, plagioclase, and biotite with minor amounts of calc-silicate minerals.

Conspicuously color banded metasiltstone, similar to that below the basal contact of the Scotland at locality

5 (pl. 1) in the Fitchville Quadrangle, is exposed in an outcrop just east of the powerline right-of-way. This outcrop, however, lies about 5 m below the base of the Scotland.

In this series of outcrops, the Scotland consists largely of garnetiferous micaceous schist but also includes numerous metasiltstone layers several meters thick. Quartzite lenses are common within the Scotland, and locally a quartzite bed a few centimeters thick marks the contact between the Scotland Schist Member above and metasiltstone of the Oakdale Formation. Tightly appressed recumbent folds having amplitudes of 10–20 cm are common within both schist and metasiltstone. It is quite likely that the contact itself has been folded. Thin granitic gneiss layers in the country rock along this contact also have been folded and faulted.

Locality 2, figure 6 (353,175 N.; 787,775 E.).—Stream-cut outcrops below Route 97, Hampton Quadrangle. Rusty-weathering muscovite-biotite schist of the Scotland dips gently north on the nose of a northwest-plunging anticlinal warp. Flaggy metasiltstone layers are increasingly common upward in the section exposed in Fuller Brook, and less than 15 m stratigraphically upsection, above the streambank on the northwest side, the ground is littered with slabs of metasiltstone, and no muscovite schist was found. The upper contact of the Scotland must be just above the exposed section.

Locality 9, plate 1 (305,150 N.; 767,100 E.).—Railroad cuts along the north side of the Shetucket River near the eastern border of the Willimantic Quadrangle. Brownish-gray-weathering, flaggy quartz-biotite metasiltstone, typical of the metasiltstone of the Oakdale above the Scotland Schist Member, is exposed in beds 5–10 cm thick.

Locality 3, figure 6 (355,000 N.; 789,175 E.).—Little River, Hampton Quadrangle. Exposures below the bridge at Route 97 are representative of Oakdale strata that overlie the Scotland Schist Member. The rock is brownish-gray-weathering, platy-bedded, quartz-plagioclase-biotite metasiltstone containing varied amounts of calc-silicate minerals that impart a greenish tint to some layers. Thin phyllitic layers are rare in these exposures.

Locality 4, figure 6 (353,050 N.; 784,950 E.).—Fuller Brook, Hampton Quadrangle. A series of small, low outcrops in the streambed is another representative exposure of Oakdale metasiltstone stratigraphically above the Scotland. The lithology is essentially the same as that at locality 3, figure 6.

Locality 5, figure 6 (360,950 N.; 787,975 E.).—Railroad cut south of Hampton Reservoir, Hampton Quadrangle. These exposures of the Oakdale Formation above the Scotland Schist Member consist of greenish- to olive-gray metasiltstone; it is commonly laminated, and the layers are 1–20 cm thick. The metasiltstone contains intervals of rusty-weathering muscovite schist 20 cm to as much as 1 m thick. The rock is deceptively massive looking, but weathered surfaces bring out the fine sedimentary layering. An intricate pattern of chevron folds that climb nearly vertically across the outcrop is well displayed in the muscovite schist intervals. Fold axes plunge 10°–25° NE.; the strike of axial surfaces ranges from N. 70° W. to N. 40° E., and dips that could be measured are 10°–20° N.

Locality 6, figure 6 (364,500 N.; 790,150 E.).—Small outcrop less than 1 m high and 3 m long exposed on the south side of a small hill on the Eastford-Hampton town line north of Kenyon Road, Hampton Quadrangle. A contact between finely micaceous, phyllitic metasiltstone and nonmicaceous biotitic metasiltstone is exposed in this outcrop of the Oakdale Formation above the Scotland Schist Member. As at locality 5 (fig. 6), the contact climbs nearly vertically in small-amplitude recumbent folds that cross the outcrop. Axial surfaces dip gently north. The phyllitic strata are graded and have tops to the east. They are on the east side of the contact and, thus, stratigraphically overlie the metasiltstone here.

The metasiltstone exhibits a distinctive woody-appearing texture in a stream-cut outcrop just below Kenyon Road (364,450 N.; 791,450 E.) about 400 m east of locality 6 (fig. 6). This texture apparently results from differential weathering of very thin calc-silicate-rich layers alternating with lamellae rich in quartz, feldspar, and biotite. The texture is much more conspicuous at exit 10 on the Massachusetts Turnpike (loc. 16, pl. 1).

Locality 10, plate 1 (306,700 N.; 764,400 E.).—About 1 km northwest of locality 9 (pl. 1) on the north side of Jerusalem Road, Willimantic Quadrangle. An interval of micaceous schist and phyllite about 2 m thick extends for several tens of meters along the crest of a ridge. The schist in these exposures is overlain and underlain by thin-bedded metasiltstone consisting chiefly of quartz and biotite and containing minor amounts of calc-silicate minerals. All the rocks exposed belong to the Oakdale Formation above the Scotland Schist Member.

Locality 11, plate 1 (296,000 N.; 750,800 E.).—The intersection of Kick Hill Road and Route 207, Willimantic Quadrangle. Lenses of muscovite schist and phyllite a few centimeters thick are interlayered with metasiltstone on the southwest side of the crest of a small knob. The rocks belong to the Oakdale Formation above the Scotland Schist Member.

Locality 12, plate 1 (301,050 N.; 750,700 E.).—Kick Hill, Willimantic Quadrangle. Rusty-weathering muscovite schist exposed in a knob at the crest of Kick Hill overlies metasiltstone containing varied amounts of calc-silicate minerals that is exposed in a small area extending from the crest of Kick Hill westward to the brook at Hayward Pond. Both the schist and the metasiltstone are in the upper part of the Oakdale.

Locality 13, plate 1 (374,800 N.; 798,200 E.).—Northeast corner of the Hampton Quadrangle. Quartz-feldspar-biotite metasiltstone typical of the Oakdale is exposed in a series of low outcrops in an abandoned part of Route 44 and in the field to the south; it dips gently northwest, weathers olive gray, and is thinly layered. The fine micaceous sheen on layered surfaces common to the Oakdale is well expressed in these outcrops, and muscovite laminae are rare.

Locality 14, plate 1 (429,350 N.; 819,500 E.).—An abandoned gravel pit on the south side of Blash Road in the Connecticut part of the Webster Quadrangle. Rusty-weathering micaceous schist containing metasiltstone beds 1–5 cm thick crops out in a rubble-covered slope on the east bank of the pit. The rocks are representative of the upper part of the Oakdale.

Locality 15, plate 1 (376,600 N.; 478,150 E., Massachusetts).—An abandoned railroad cut north of locality 14 (pl. 1) and just east of the end of Mill Road in the Massachusetts part of the Webster Quadrangle. A representative example of the Oakdale is well exposed in this extensive railroad cut in an area where natural outcrops are small and sparse. The rock is mostly medium- to dark-gray-weathering quartz-plagioclase-biotite metasiltstone, slightly more siliceous than the average metasiltstone of the Oakdale. Fine-grained muscovite gives a reflective sheen to partings along bedding surfaces. Predominance of biotite or calc-silicate minerals tends to tint the fresh rock lavender gray or greenish gray, respectively. A few mica schist lenses, as much as 10 cm thick, are interlayered with the metasiltstone. Thin quartzite stringers and lenses are common. Beds 1–15 cm thick are commonly laminated and dip gently northwest. Obscure grading suggests that beds are right side up. Minor intrafolial folds having sheared-out limbs show a west-over-east sense of transport.

Locality 16, plate 1 (434,250 N.; 504,100 E., Massachusetts).—Exit 10 of the Massachusetts Turnpike in the Worcester South Quadrangle, Mass., about 19 km north of the Connecticut State line. Outcrops representative of the Oakdale in Massachusetts are exposed extensively at this locality. The weathered rock is medium olive gray and has the bronze micaceous sheen characteristic of the Oakdale; fresh rock is medium gray and has tints of lavender or green caused by the respective dominance of biotite and actinolite or chlorite. Crinkled light-gray pods and stringers of quartzite and of quartz and feldspar accentuate the foliation in these outcrops. Compositional layering or bedding, parallel to foliation, is obscure in fresh exposures but is brought out on weathered surfaces by carbonate-rich laminae that become pitted and brown, giving the rock a woody texture. The rock is composed of quartz, feldspar, and biotite and contains notable amounts of carbonate and calc-silicate minerals; very fine muscovite occurs with the biotite. Foliation and layering strike about N. 40° E. and dip 35° NW. A conspicuous crinkle-fold lineation plunges to the north. Chlorite commonly is smeared out on the foliated surfaces.

Dudley Formation

Locality 17, plate 1.—Two roadcuts on side roads, one north and one south of Route 197, in the Connecticut part of the Webster Quadrangle. A low exposure on the east side of Duggs Hill Road (427,750 N.; 813,200 E.), about 650 m south of the Route 197 intersection, shows characteristics of the Oakdale and indicates that the Oakdale-Dudley boundary is gradational. The rock is brownish-gray, flaky-weathering, thin-bedded, very fine grained granular schist and granofels. It exhibits the granular salt-and-pepper texture characteristic of the Dudley, but many bedding surfaces also show a faint micaceous luster characteristic of the Oakdale, and a few calc-silicate-rich laminae form thin ridges on weathered surfaces.

More extensive outcrops of fine-grained granofels and granular schist typical of the Dudley are exposed on Converse Road about 200 m north of the Route 197 intersection (430,650 N.; 812,900 E.). They are slightly higher stratigraphically than the outcrops south of the intersection.

Locality 18, plate 1 (418,000 N.; 802,950 E.).—In and on the west side of Gravelly Brook about 100 m north of the Route 197 road crossing, Eastford Quadrangle. The rock is mostly olive-gray-weathering, thinly and evenly layered, fine-grained, compositionally homogeneous quartz-plagioclase-biotite metasandstone. A few thin calc-silicate-rich layers occur in the outcrop. Bedding strikes N. 40° E. and dips 20° W. A strong biotite lineation plunges downdip.

Locality 7, figure 6 (364,250 N.; 787,550 E.).—West of Cedar Swamp, Hampton Quadrangle. The rock is medium-gray, fine-grained granofels and granular schist having the salt-and-pepper texture characteristic of the Dudley. It is rich in biotite, and calc-silicate minerals are ubiquitous but sparse except in a few thin, resistant, calc-silicate-rich lenses. Muscovite is entirely lacking. Bedding, which dips gently north, is weakly expressed and is disrupted by small-scale intrafolial folds and low-angle shears.

Locality 8, figure 6 (355,900 N.; 765,500 E.).—Stonehouse Brook, Spring Hill Quadrangle. These exposures of the kyanite schist member of the Dudley Formation are mostly evenly layered granular schist and granofels composed chiefly of medium- to fine-grained quartz, plagioclase, and biotite. Muscovite is present in biotite-rich folia, and garnet is ubiquitous. Beds range in thickness from 0.5 to 10 cm, weather differentially, and are strongly parted along mica-rich folia. Intervals of biotite-muscovite-rich schist as much as several meters thick are interlayered with the granular schist and granofels. The muscovite schist contains kyanite blades as much as 1 cm long on some foliation surfaces, and sulfide-rich micaceous folia are common. Calc-silicate minerals are sparse in the granofels, and greenish-gray layers a few centimeters thick are rare.

Locality 9, figure 6 (363,300 N.; 772,450 E.).—Pipeline excavation west of Reeds Pond, Hampton Quadrangle. Greenish-gray, calc-silicate-bearing granofels is interlayered with and underlies brownish-gray kyanite-muscovite schist. The thickness of granofels and granular schist between the base of the kyanite schist member of the Dudley Formation and the Canterbury Gneiss appears to be no more than a few meters, too small to be shown in figure 6. Thin layers of Canterbury Gneiss intrude the kyanite schist member subparallel to layering.

Locality 10, figure 6 (356,750 N.; 768,350 E.).—About 600 m west of Pumpkin Hill Road in the Spring Hill Quadrangle. A small outcrop of calc-silicate-bearing granofels less than 0.5 m thick is exposed stratigraphically beneath outcrops of the kyanite schist member of the Dudley Formation; the outcrop apparently is on strike with outcrops of Canterbury Gneiss.

Locality 11, figure 6 (364,950 N.; 777,750 E.).—Pipeline right-of-way crossing knob on the west side of the Natchaug River valley, Hampton Quadrangle. Exposures of brownish-gray-weathering, garnet- and kyanite-bearing muscovite-biotite schist cap a prominent ridge above Route 198 on the pipeline right-of-way just north of the Eastford-Hampton town line. These strata are the kyanite schist member of the Dudley Formation; they plunge about 10° to the northwest along the ridge. Abundant slabs of medium-gray, fine-grained, calc-silicate-bearing biotite granofels and granular schist lie in the pipeline right-of-way stratigraphically beneath the schist outcrops. The excavation of the trench for the pipeline at this locality exposed a thin layer of greenish-gray calc-silicate-bearing granofels of the Dudley Formation resting on light-gray felsic Canterbury Gneiss.

Locality 12, figure 6 (366,650 N.; 780,650 E.).—Beaverdam Brook, Hampton Quadrangle. The rock is a homogeneous, thinly layered, olive-gray-weathering, fine-grained, quartz-plagioclase-biotite granular schist having the characteristic salt-and-pepper texture of the Dudley.

Locality 19, plate 1 (381,850 N.; 776,850 E.).—Bigelow Brook, Eastford Quadrangle. The principal rock type is medium gray to grayish olive when weathered and consists of thinly and evenly layered, very fine to fine-grained granofels and granular schist of the Dudley Formation. Several layers of muscovite-biotite-garnet schist, one of which is as much as 5 m thick, are interleaved with the granofels and granular schist in these exposures. Possibly these lie at the stratigraphic position of the kyanite schist member. Ultramylonite is present in exposures of these rocks at the Route 44 bridge just southeast of the Eastford fault.

Southbridge Formation

Locality 20, plate 1 (389,350 N.; 462,350 E., Massachusetts).—Intersection of Dudley Road and Dresser Road in the Massachusetts part of the Southbridge Quadrangle. The rock exposed on the north side of the intersection is typical of the Southbridge Formation. It is sharply layered, medium- to dark-gray granular schist and granofels consisting of quartz, plagioclase, and brown biotite. Grain size ranges from fine to coarse sand size; thin biotite-rich folia are sparse. Layers range from 5 to 70 cm in thickness. Lenses and pods of felsic gneiss and pegmatite as much as 1 m thick are interlayered with the granular schist and granofels.

Locality 21, plate 1 (384,000 N.; 774,700 E.).—Southwest corner of the Eastford Quadrangle. Medium- to dark-gray biotite schist containing lighter gray layers of feldspar-quartz gneiss in varied proportions compose the bulk of these exposures of the Southbridge Formation. Also present are thinly parted layers of biotite-muscovite schist, lenses of well-layered, dark-gray amphibolite, and greenish-gray layers bearing calc-silicate minerals.

Locality 22, plate 1 (356,650 N.; 744,150 E.).—Fenton River valley, Spring Hill Quadrangle. The sillimanite schist member of the Southbridge Formation here consists of brownish-gray-weathering, medium-grained, quartz-plagioclase-biotite-muscovite-sillimanite-garnet schist containing coarser grained stringers and lenses of feldspar and quartz. The basal contact of the member exposed on the south side of the hill opposite the Stone Mill Road intersection is a fault zone about 2 m wide. Within this zone, shears subparallel to foliation and Zlayering juxtapose lenticular slices of medium-gray biotite schist against brownish-gray sillimanite schist and cut off the limbs of flow folds in amphibolite.

The sillimanite schist member appears to grade upward through interlayering into biotite schist and felsic gneiss well exposed in a large outcrop about 150 m to the north along Chaffeeville Road. The member pinches out stratigraphically to the north.

Hebron Formation

Locality 23, plate 1 (268,200 N.; 744,900 E.).—Roadcuts along Route 2, Fitchville Quadrangle. These exposures, southwest of Gilman, are representative of the calc-silicate-rich rocks of the Hebron Formation. They consist of granofels and schist, which are uniformly gray to greenish gray, fine grained, granular, and rich in biotite and calc-silicate minerals. Compositional layering is weakly defined, but numerous lenses of light-gray felsic gneiss and pegmatite that conform generally to foliation and layering help display a complex pattern of deformation in these outcrops. The general strike of bedding is about N. 35° W.; the average dip is less than 10° to the southwest. Compositional layering is commonly recumbently folded. A conspicuous lineation that trends 5° E. to 15° N. and plunges gently north or south is axial planar to recumbent intrafolial folds showing a west-over-east sense of asymmetry. The folds commonly are sheared by low-angle undulatory thrusts along which compositional layering is also warped in a west-over-east sense.