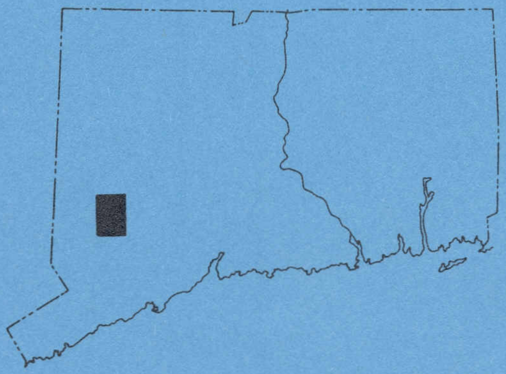
The Bedrock Geology of the Newtown Quadrangle

WITH MAP

Open Plate 1

Open Plate 2

ROLFE S. STANLEY AND KATHERINE G. CALDWELL



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

DEPARTMENT OF ENVIRONMENTAL PROTECTION

1976

QUADRANGLE REPORT NO. 33

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AND
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The Bedrock Geology of the Newtown Quadrangle

by

Rolfe S. Stanley and Katherine G. Caldwell

ABSTRACT

Detailed mapping of 18 units reveals a complex geologic history beginning with deposition of shales, graywackes, and basalts oceanward of the continental platform during the Early Paleozoic, culminating in orogenic activity during Middle to Late Ordovician (Taconic orogeny) and Middle to Late Devonian (Acadian orogeny), and terminating with rifting and continental sedimentation during Upper Triassic time. The minor deformation (F4 folds) and chlorite-grade metamorphism may have occurred in post-Acadian time, possibly during the Alleghenian orogeny. Uplift and continuing erosion dominated Mesozoic and Cenozoic activity.

The 15 metasedimentary and igneous units are grouped into three formations: Hartland II, Hartland I, and the Collinsville Formation in ascending order, and two intrusive complexes: the Brookfield-Newtown Gneiss and the foliated and massive granites. Based on the Silurian and Devonian age of the Straits Schist, the Brookfield-Newtown complex, which is confined to Cambrian and Ordovician rocks, is thought to represent intrusive activity of the Taconic orogeny. These units are fairly widespread throughout southwestern Connecticut and may be related to the mafic intrusives along Cameron's line (Hodges' Mafic Complex and the Mt. Prospect Complex). Metamorphism during this time may have reached garnet grade. Major folds of F1 age appear to have formed prior to the intrusive activity.

Foliated and massive granites represent two distinct intrusive events that accompanied kyanite- to sillimanite-grade metamorphism of the Acadian orogeny. The foliated granites either formed during or possibly slightly before F2 folding, whereas massive granites and pegmatites cut the Straits Schist and may be younger than F3(?) folds. Metamorphism may have preceded F3(?) deformation because the first sillimanite isograd appears to be folded by F3(?) structures.

Economic deposits are confined to sand and gravel for construction purposes, foliated granite for dimension stone, and amphibolite and gneiss for road ballast, riprap, or coarse construction aggregate.

The nature of the bedrock and surficial geology of Newtown requires careful land-use planning with regard to ground-water resources, septic discharge, and foundation and road construction. Rocky areas with "bird's-eye-maple" topography have limited

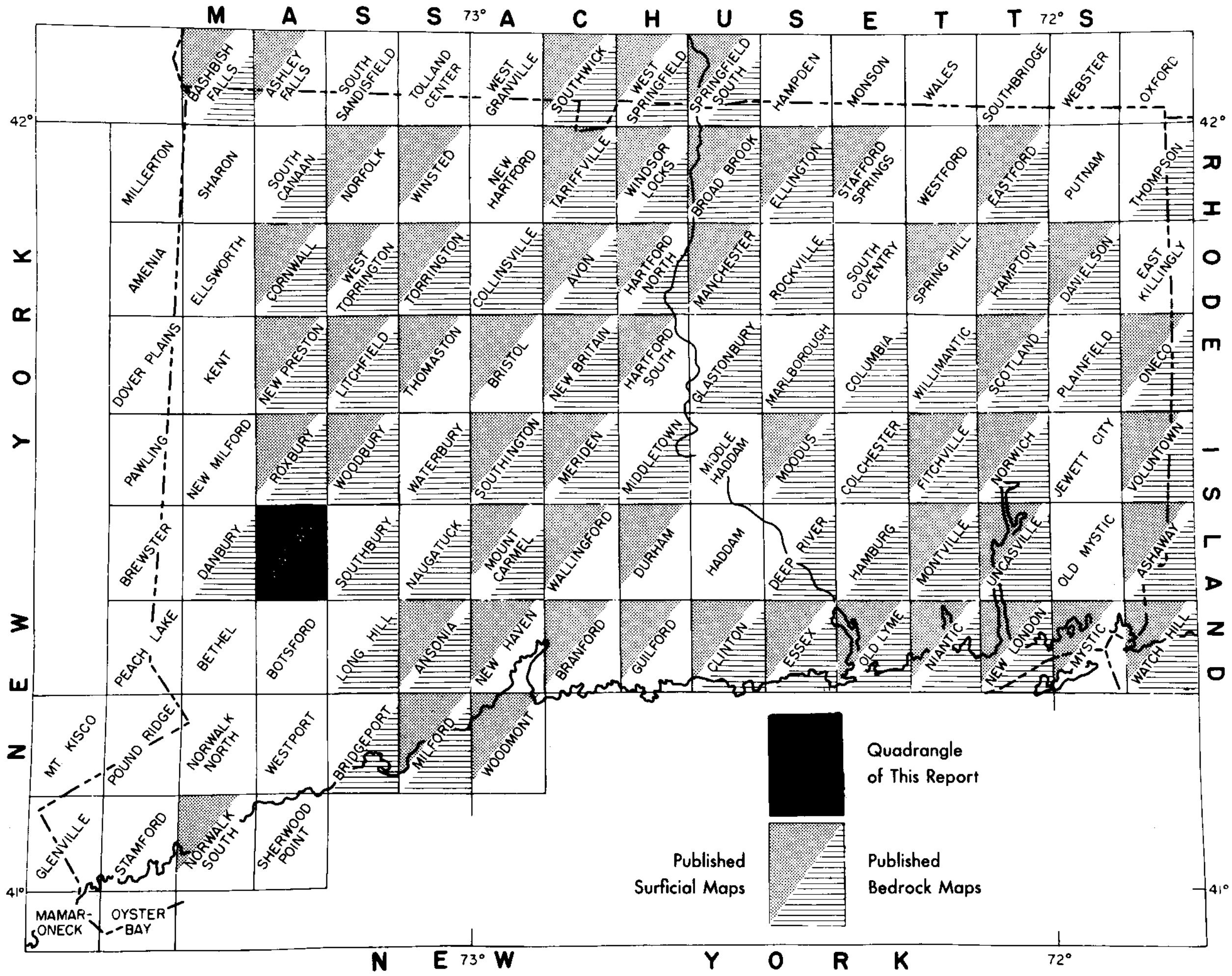

Fig. 1. Index map of Connecticut, showing the location of the Newtown quadrangle and of other published quadrangle maps.

and expensive ground water, many are poorly drained, and they are costly to develop for suburban housing. Areas with extensive surficial cover and smooth, elongate topography are generally more suitable for the suburban development that has characterized the Newtown quadrangle during the last 20 years. With these generalizations as a guide, however, proper development of any area requires on-site analysis of the bedrock, surficial, and ground-water geology before construction begins.

INTRODUCTION

Location and accessibility

The Newtown quadrangle is located at the junction of New Haven, Litchfield, and Fairfield Counties, 10 km east of Danbury, Connecticut (fig. 1). It covers approximately 145 sq km, and is bounded by latitudes 41°22′30″N and 41°30′N and longitude 73°22′30″W and 73°15′W. Principal population centers are Newtown, Sandy Hook, and South Britain.

The quadrangle is readily accessible by such routes as I-84, U.S. Route 202, and State Routes 25, 34, 133 and 172. A network of minor paved and dirt roads provides convenient access to most parts of the quadrangle.

Topography and drainage

The map area is located in the crystalline uplands of western Connecticut but includes in the northeastern corner a narrow strip of the Pomperaug basin containing Upper Triassic sedimentary and igneous rocks. Within the quadrangle the topography ranges from slightly lower than 120 ft (37 m.) along the eastern part of the Housatonic River to a maximum of 830-840 ft (about 250 m.) on Taunton Hill in the southwestern part. The average relief is approximately 250 ft (77 m.).

The topography of Newtown results from differential erosion controlled by rock type and structure, modified by glacial deposition which has essentially filled in major depressions (south of Sandy Hook) or smoothed out irregularities (Flat Hill).

Throughout much of the area the hills and valleys have a fairly well developed NE-SW grain that is largely the result of glacial motion from the northwest as confirmed by glacial striations (pl. 1) and boulder trains. In the western part of the quadrangle, for example, the elongate hills are glacially-molded features (drumlins) possibly cored with bedrock. In contrast, the more irregular, "bird's-eye-maple" topography between the Housatonic River and Cavanaugh Pond to the south is largely bedrock controlled. Here the dominant ridges generally parallel the strike of schistosity or bedding whereas the less prominent features are controlled by joint orientation and rock type (pl. 1). Where the schistosity strikes to the northwest, for example, the ridges are elongate in that direction, and where it trends eastward the ridges follow suit.

The major rock types in the area exert a less obvious control over the general topography. The Newtown and Brookfield gneisses are commonly more erodible than the schist and gneiss of Hartland I and Hartland II and, therefore, form the shallow basins with broad hills and valleys near the town of Newtown and a much smaller basin in the Hawleyville area.

The Housatonic River with its many tributaries (Pomperaug, Pootatuck, Shepaug Rivers) flows southeastward across the quadrangle and drains both the northern and southern uplands. The location and path of many of the smaller brooks are controlled by bedrock structure and illustrate how well the topography and drainage are adjusted to this control. For example, Fred Beers Brook, Dingle Brook, and part of Pond Brook southeast of Brookfield are strongly influenced by the amphibolite that snakes its way through the area.

Swamps are abundant in the areas underlain by the Newtown Gneiss, the Brookfield Gneiss, and the feldspathic schist of Hartland II. Although these rocks have been a major factor in controlling the topography, the relatively poor drainage implied by the swamps results from the "tightness" of the surficial material. Much of the area appears to be underlain by a clay-rich till.

Acknowledgments

Financial support for mapping this quadrangle during the summers of 1965 through part of 1968 was provided by the Connecticut Geological and Natural History Survey. I gratefully acknowledge this support and thank Joe Webb Peoples, then the Survey's Director, for his encouragement and advice. Field assistance was provided by Arthur Sarkesian in 1965 and by William Acker in 1966 and 1967. Field conferences with Robert Scott, William Crowley, Leo Hall, John Rodgers, Robert Gates, and Norman Hatch were helpful and stimulating, as were the summer conferences held by the Connecticut Geological and Natural History Survey. Leo Hall and John Rodgers reviewed the manuscript.

During 1970 and 1972, the junior author, Katherine G. Caldwell, made a petrographic and microprobe study of the quadrangle's metamorphic rocks as the subject of her Master of Science thesis at University of Vermont, the results of which are incorporated in this report.

Publication of this Quadrangle Report was delayed until Robert Scott's (1974) work on the bedrock geology of the adjoining Southbury quadrangle was completed and until my regional studies were largely finished, in order to take advantage of new information or new interpretations which they provided.

Previous work

Percival (1842) was the first to study the rocks in the Newtown area in his classic work on the geology of Connecticut. In 1906 Rice and Gregory subdivided the crystalline rocks into four units, the Hartland Formation, the Brookfield Diorite, the Danbury Granodiorite Gneiss, and the Thomaston Granite Gneiss. The Brookfield Diorite essentially correlates with the Brookfield Gneiss of this report. The Danbury Granodiorite Gneiss appears to be the same as the Newtown Gneiss, although the internal details of the formation are not described in the 1906 report. Little published work on the area has appeared since then.

Regional setting

The Newtown quadrangle lies just southwest of the small basin of Upper Triassic rocks of the Pomperaug Valley in the western part of the eugeoclinal rocks of western Connecticut (fig. 2). The boundary between the eugeoclinal sequence of recrystallized clastic and volcanic rocks and the miogeoclinal or platform sequence of metamorphosed carbonates and quartzites is just to the west in the Danbury quadrangle.

The generalized regional geology of western Connecticut has been reviewed by Stanley (1964, p. 6-7; 1968a, 1969) as well as others (Rodgers, 1970, p. 92-102; Hall, 1968, for example) and need not be repeated here. During the last six years, as the mapping of many quadrangles has been completed, the United States Geological Survey has been tracing and modifying the well-documented geology of eastern Vermont south to western Connecticut. Although these are alternative solutions, Hatch and Stanley (1970, 1974) have suggested that the Straits Schist, which threads its way in and around the domes in the eastern part of western Connecticut (fig. 2; Stanley, 1964, fig. 2), is equivalent to the Goshen Formation of western Massachusetts. This correlation, with its related corollaries, has substantially changed the interpretation of the structure of the eugeoclinal belt. The belts of Straits Schist are now interpreted as keels of several isoclinal synclines, surrounded by older Cambrian and Ordovician rocks, that have subsequently been refolded by the rise of felsic rocks of the gneiss domes during the Acadian orogeny. It is thought that, prior to doming, these felsic rocks represented the cores of major east-facing isoclinal folds or nappes.

Although the Newtown quadrangle is west of the domes, it is important structurally because it may contain still older Taconic structures that were redeformed by the nappe formation during the early phases of the Acadian orogeny. Other important evidence includes the determination of two generations of Paleozoic intrusive activity and evidence for post-Acadian metamorphism which may possibly be late Paleozoic in age.

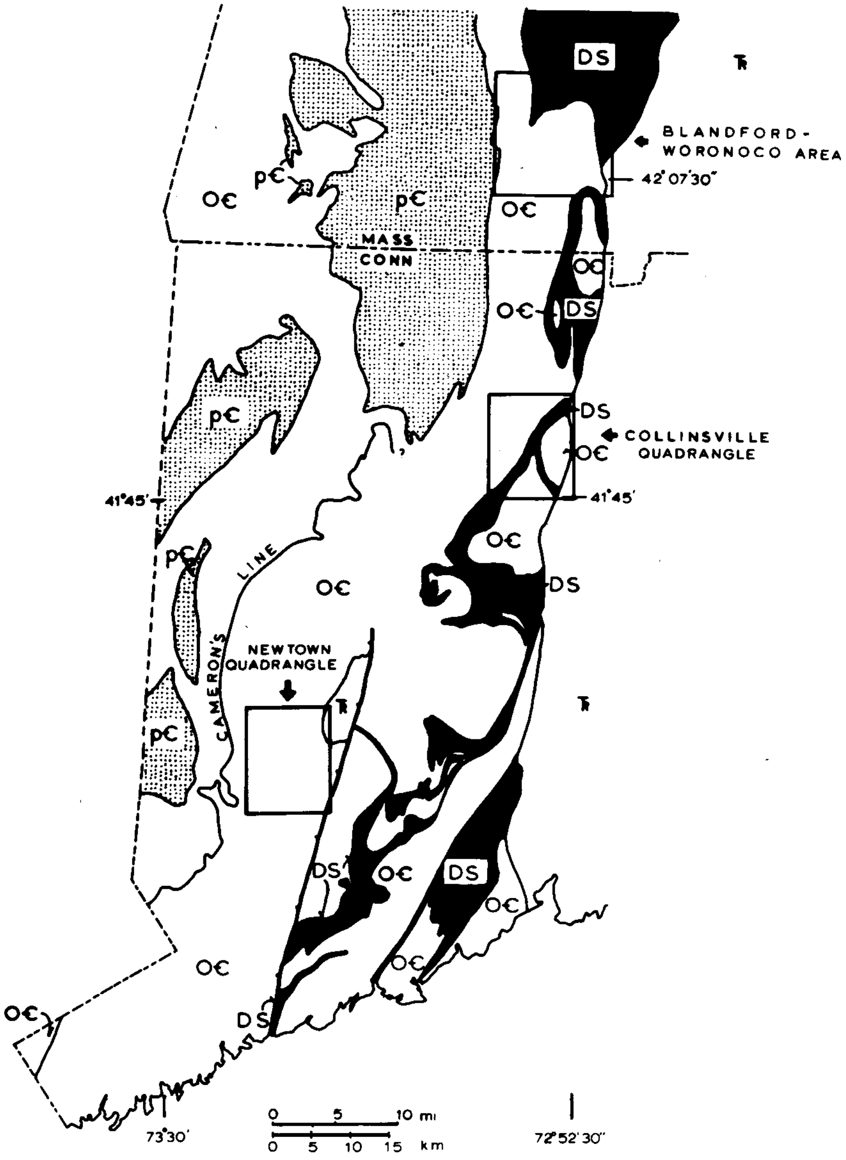

Fig. 2. Generalized geologic map of southwestern Massachusetts and western Connecticut, showing the distribution of major areas of Precambrian rocks (pꞒ), Cambrian and Ordovician rocks (OꞒ), Silurian and Devonian rocks (DS: Goshen Formation in Massachusetts, and the Straits Schist, Cooks Pond and Wepawaug formations in Connecticut), and Triassic rocks (TR). Cameron's line separates the carbonate rocks to the west from the pelitic and volcanic rocks to the east. The three areas mapped by the author (with Hatch in Massachusetts) are indicated on the map.

ROCKS OF LOWER AND MIDDLE PALEOZOIC AGE

Introduction

The Newtown quadrangle is largely underlain by sedimentary and igneous rocks that have been metamorphosed to the kyanite and sillimanite grades during the Acadian orogeny. Intrusion of granite and pegmatite accompanied and postdated deformation. Unmetamorphosed Upper Triassic sedimentary and igneous rocks rest with profound unconformity on the Paleozoic rocks in the northeastern part of the quadrangle.

The pre-Triassic rocks are divided into 15 mappable units of varied continuity. These are combined into six major units; four of them underlie a major part of the quadrangle. Three of the six, Hartland II, Hartland I, and the Collinsville Formation, were originally marine shales of varying composition: graywackes (some turbidites), felsic volcanics, carbonate sandstones, and basalts. The abundance of plagioclase (in parts of Hartland I, for example) indicates that some of the graywackes possibly contained abundant volcanic detritus. The other three units are metamorphosed intrusives and of these the Brookfield Gneiss and Newtown Gneiss represent metamorphosed diorite, quartz diorite, and granodiorite that have been deformed along with the country rocks. Younger granites and pegmatite cut across the older intrusives and the adjacent metasedimentary units. One of these granites is foliated; it was deformed and metamorphosed when the regional schistosity developed. The unfoliated granites and pegmatites are unmetamorphosed.

The stratigraphic sequence, Hartland I younger than Hartland II, in the Newtown quadrangle is based on regional correlation in which the main parameters are stratigraphic sequence and lithic similarity (Stanley and Hatch, in press; Hatch and Stanley, 1974). This arrangement differs from that proposed by Gates (1959), Gates and Christensen (1965, p. 18), Gates and Martin (1967), and Martin (1970, p. 26), who consider Hartland II to be younger than Hartland I, primarily for structural reasons enumerated by Martin (1970, p. 26). The terms Hartland Unit I and Hartland Unit II, although invalid according to the stratigraphic code (1961), are used in this report (referred to as Hartland I and Hartland II) to avoid confusion generated by new names. Hopefully, these names will be abandoned when the geology of western Connecticut is completed and tied in with areas to the north.

The field methods and general procedures used in describing map units are similar to those employed in the Collinsville quadrangle (Stanley, 1964, p. 10, 15-17). The only exception is in the manner of listing the minerals modifying textural names (for instance, a quartz-biotite-kyanite-microcline schistose gneiss). In the present report, the most abundant mineral is given first and is followed by the next two or three minerals in decreasing order of abundance.

Metasedimentary rocks

HARTLAND II

Hartland II was defined originally by Gates (1959) in the Roxbury quadrangle and later found by Martin (1962) to extend throughout the central part of western Connecticut. In the Newtown quadrangle Hartland II is a heterogeneous unit consisting of schist, gneiss, amphibolite, and calc-silicate rocks which underlie a wide belt extending northward across the quadrangle. Five mappable rock types have been separated from the main body of the formation and have clarified its internal structure. Two of the five units are compositionally distinct, the amphibolite and the calc-silicate rocks. The remaining three are dominantly schists that differ in mineralogy or in relative mineral percentages. These five units are discussed in order of approximate decreasing age.

Main body of Hartland II (O€hII): The bulk of Hartland II consists of light-brown to gray, rusty to nonrusty-weathering, medium-grained, bedded to nonbedded, muscovite-biotite-quartz-plagioclase schist with prominent porphyroblasts of garnet, staurolite, and/or kyanite. The garnet commonly appears as well developed dodecadedra, particularly in the mica-rich, silvery schist along Brown Brook Road just south of the Roxbury quadrangle. Chlorite porphyroblasts cut randomly across the schistosity and are more common in the northeastern part of the area. Beds of plagioclase-quartz-mica gneiss and granulite are interbedded with the schist, and appear to be more numerous southeast of Flat Hill and east of Little Pootatuck Brook. Five reference localities are indicated on plate 1.

The thickness of Hartland II cannot be determined with any degree of confidence because its base is not exposed in the Newtown quadrangle and the unit is structurally complex. In the west-central part of the area near Pond Brook, however, Hartland II appears to be at least 2,500 m. thick.

Representative mineral assemblages in the schist and gneiss are:
muscovite-biotite-quartz-plagioclase
quartz-plagioclase-muscovite-biotite
plus one of the following assemblages:
staurolite
garnet-staurolite
garnet-staurolite-kyanite
staurolite-kyanite
garnet-kyanite
garnet

Opaque minerals include magnetite and ilmenite. Chlorite was observed with these assemblages. West of the first sillimanite isograd, fibrolitic sillimanite and coarser grained sillimanite are found with kyan-

Table 1.–Modal analyses in volume percent of three samples, from the main body of Hartland II in the Newtown quadrangle.[1]

Sample number	*Ms*	*Bio*	*Q*	*Chl**	*Pl*	*St*	*Ilm*	*Gt*	*Sph*	*Mt*	*Ky*	*Z*
1176N	37.3	23.4	18.7	6.5	6.2	4.6	T	T	T	–	–	–
731N	9.6	16.7	46.3	5.2	5.2	5.9	–	3.9	–	1.4	5.9	–
846N	35.5	10.0	9.7	2.9	11.0	10.1	–	18.3	T	2.3	–	T

[1]/Abbreviations used in tables 1-6:

Bio = biotite
Cal = calcite
Chl* = chlorite (retrograde)
Clz = clinozoisite
Di = diopside
Ep = epidote
Gt = garnet
Hb = hornblende
Hem = hematite
Ilm = ilmenite
Ky = kyanite
Mi = microcline
Ms = muscovite
Mt = magnetite
Or = orthoclase
Pl = plagioclase
Q = quartz
Sill = sillimanite
Sph = sphene
St = staurolite
Tr = tremolite
Z = zircon
T = trace (<1 percent)

ite-bearing rocks. Selected modes are shown in table 1.

The contact with the overlying Hartland I is gradational by interbedding and a change in composition over a horizontal distance of 50 m. These relations are best seen just east of Cooper Road in the northwestern part of the quadrangle.

Amphibolite (*OЄhIIa*): Hartland II in the north-central part of the quadrangle contains an irregular but very continuous zone of black to dark-gray amphibolite (hornblende>> plagioclase> quartz) which is texturally and mineralogically uniform. Because the amphibolite body parallels the bedding in adjacent outcrops of metasedimentary rocks it is interpreted as a metamorphosed layer or layers of basalt, originally deposited as conformable flows or possibly intruded as sills. On the scale of the map this is confirmed somewhat by the general conformability of the calc-silicate rocks to the general trend of the amphibolite.

The nature of the original configuration of the basalt is unclear. As shown on the geologic map, the main part of the basalt was probably a single unit west of Hanover Road. To the east, however, the configuration is different. One belt trends eastward across the quadrangle and the other bends northward and pinches out across the Housatonic, suggesting a highly simplified picture of a thick basalt flow bifurcating into two thinner flows. One alternative could be two flows, one less extensive than the other. Although the outcrop control is excellent, there are covered areas with sparce outcrop where connections between amphibolite outcrops are tenuous at best. One such area, critical to the above problem, extends across Hanover Road just south of its junction with Brook Road. A second alternative, and one favored in this report, is that the amphibolite is a single layer deformed into a tight major fold and then redeformed by two generations of major folds.

The contacts of the amphibolites are sharp and the grain size in the adjacent metasedimentary rock is no larger or smaller than in areas far from the amphibolite. The thickness of the main amphibolite unit varies from zero to 200 m.

Calc-silicate rocks (*O€hIIcs*): In the central and northeastern parts of the quadrangle, light-colored, slightly rusty, fine-to-medium-grained, calc-silicate gneiss and granulite are found in layers, 5-15 cm thick, interstratified with partly rusty to rusty-weathering schist. Together these rocks form mappable units. Although these belts are relatively thin, their distinctive mineralogy provides an excellent "marker bed" for partly unraveling Hartland-II structure. In such places as Flat Hill, west of Rocky Glen, and near Parmalee Hill Road several series of asymmetrical folds indicate still larger scale folds. Whether these areas are connected is highly problematical, since surficial material covers this thin unit in the intervening areas. The available data, however, suggest that there are at least two stratigraphically distinct belts of calc-silicate rock in the central part of the quadrangle. The most persistent belt is found outside of or stratigraphically above the amphibolite. The other, much smaller, belt is within or below the amphibolite. The relationship of the calc-silicate rocks on Flat Hill to the amphibolite is largely unknown since glacial cover is abundant and normal faults may possibly be fairly important here.

The lithic character of the calc-silicate unit is displayed particularly well in the reference locality near Parmalee Hill Road. Although the belts of this unit range from 0 m. to 150 m. in thickness, they are commonly less than 50 m. thick. The contacts are less gradational than the aluminous schist and can be confined to within 10 m. in most places.

Representative modal analyses are listed in table 2.

Staurolite schist (*O€hIIs*): Near Valley Field Road north of Newtown a thin (50-m.) zone of nonrusty-weathering staurolite-bearing mica schist forms a lens, 1 km long, that is bent similarly to the calc-silicate rocks and amphibolite (pl. 1). This unit is gradational into the garnetiferous schist of Hartland II and, to clarify the structure in this area, it has been mapped separately.

Aluminous schist (*O€hIIas*): In the northwestern part of the area are a number of outcrops of gray, medium-grained, mica-quartz-plagioclase schist with porphyroblasts or clusters of kyanite and/or sillimanite which, upon weathering, produce a very knobby outcrop surface. These out-

Table 2.—Modal analyses in volume percent of samples of calc-silicate rocks in the Newtown quadrangle.[1]

Sample number	*Clz*	*Tr*	*Q*	*Sph*	*Mt*	*Cal*	*Pl*	*Bio*	*Chl**	*Z*	*Mi*	*Di*	*Gt*
1523N	69.08	21.09	12.94	1.67	T	–	–	–	–	–	–	–	5.09
393N	10.92	3.47	–	T	T	–	43.67	–	–	–	–	41.22	–
1071N$_1$	–	21.14	34.60	0.70	T	28.91	15.45	T	–	–	–	–	–
1071N$_2$	T	T	20.29	0.87	1.92	1.63	41.35	33.27	T	T	–	–	–
1146N	2.57	T	5.42	2.66	T	–	19.47	–	–	–	27.66	42.11	–
570N	44.46	–	46.61	4.51	4.42	–	–	–	–	–	–	–	–

[1] For meaning of abbreviations see footnote to table 1.

crops appear to be in two belts several kilometers in extent. This configuration, however, may be more complex or even less continuous than indicated on the geologic map because the outcrop control is rather poor as a result of fairly extensive surficial cover. Good exposures of the unit are found at reference locality 1 (pl. 1), north of State Route 133.

In the eastern belt, north of the Housatonic River, there are several outcrops of a coarser grained muscovite-plagioclase-quartz-chlorite-kyanite-biotite schist identical to the somewhat unusual, kyanite-rich rocks just south of Berry Road in the Roxbury quadrangle (Gates, 1959).

The thickness of the aluminous schist is as great as about 40-50 m. Its contacts with the main body of Hartland II are gradational, primarily by a decrease in kyanite and/or sillimanite.

Feldspathic schist (*O€hIIf*): In the southeastern part of the quadrangle the schist and gneiss of Hartland II become quite feldspathic. The rocks are medium grained to coarse grained, nonrusty weathering, with the feldspar crudely segregated into irregular layers that give many of the rocks a distinctive "marble-cake" appearance. Microcline accompanies plagioclase in some feldspar-quartz-mica gneiss. Granite, both foliated and unfoliated, and pegmatite are plentiful throughout the feldspathic schist. Typical exposures are found in the reference locality just west of Sugar Lane.

The thickness of the feldspathic schist appears to vary from 0 to about 2,000 m., although the latter figure is highly suspect because of the intrusive contact along the eastern side of the unit.

The predominant lithic type is: plagioclase-muscovite-biotite-quartz-magnetite-chlorite plus one of the following assemblages, which comprises less than 10 percent:

garnet
garnet-staurolite ± kyanite
staurolite
sillimanite-garnet-staurolite (west of sillimanite isograd)

The contact with the main body of Hartland II is gradational by a change of mineral percentages over a distance of 200 m. This relationship is exposed most clearly north of Sunset Hill in the center of the quadrangle.

HARTLAND I

Hartland I was originally defined by Gates (1959) in the Roxbury quadrangle and has since been recognized elsewhere in western Connecticut by Gates and Christensen (1965), Gates and Martin (1967), Martin (1970), and Scott (1974). This unit is lithically similar to and probably correlative with the Taine Mountain Formation in the Collinsville quadrangle (Stanley, 1964).

In the Newtown quadrangle, Hartland I is found in two large areas, one in the northern part, continuous with the same unit in the Roxbury quadrangle. The other, in the western part, was included in Hartland II to the north by Gates (1959) but is compositionally quite similar to Hartland I to the east. A small area of Hartland I is mapped in the northeastern part of the quadrangle.

Main body of Hartland I (OhI): Hartland I is a fairly homogeneous unit composed of nonrusty-weathering, quartz-plagioclase granulite or gneiss interlayered with mica-quartz-feldspar schist containing garnet and, locally, kyanite. Granulite and gneiss beds are less than 20 cm thick. In outcrops such as those in the reference locality a poorly developed "pin-striped" pattern is formed by thin laminae of schist in the more granulitic rocks. In other areas some of the rocks are covered by a light, rust-colored stain.

The thickness of Hartland I is uncertain because the upper contact with the overlying Collinsville Formation is absent. Near Shepaug River, however, it appears to be at least 300 m., based on one-half of the dip-corrected distance between outcrops of Hartland II.

Representative mineral assemblages are:
  quartz-plagioclase-biotite-muscovite
  biotite-muscovite-quartz-plagioclase
plus one of the following assemblages:
  garnet
  garnet-kyanite

Biotite gneiss (OhIbg): Medium- to dark-gray, biotite-rich, quartz-plagioclase gneiss with subordinate schist forms a fairly continuous belt of rocks extending westward into the Danbury quadrangle, where there are outcrops of quartz-plagioclase gneiss lithically identical to Hartland I west of the Shepaug River. In the Newtown quadrangle the biotite gneiss differs from the main body of Hartland I; it contains less muscovite and a few beds of calc-silicate gneiss. Despite these minor differences the two belts are correlated with each other because they consist predominantly of biotite-quartz-plagioclase gneiss, a feature

Table 3.—Modal analyses in volume percent of three samples from the biotite gneiss of Hartland I from the Newtown quadrangle and sample D.Q.$_1$ from the Danbury quadrangle.[1]

Sample number	*Bio*	*Ms*	*Sill*	*St*	*Mt*	*Gt*	*Q*	*Chl**	*Hem*	*Pl*	*Or*	*Z*
605N	31.6	28.2	24.9	6.9	5.2	1.6	1.4	T	T	T	–	T
602N	20.7	T	6.9	17.3	3.3	1.8	41.4	T	T	7.6	–	T
575N	53.2	–	14.6	–	6.3	T	22.0	–	–	3.9	–	T
D.Q.$_1$	44.6	2.6	10.7	–	T	T	34.8	–	–	4.3	3.0	T

[1] **For meaning of abbreviations see footnote to table 1.**

typical of both the Hartland I (Gates and Christensen, 1965, p. 15) and the Taine Mountain Formations (Stanley, 1964, p. 19).

The biotite gneiss, along with its subordinate rock types, are well displayed in reference locality 6 (pl. 1) north of the junction of Kenan and Currituck Roads. The total thickness of this unit cannot be calculated in Newtown because its western boundary is undefined. The contact with Hartland II is gradational by a change in composition over a distance of 100 m. Typical mineral assemblages are shown in table 3. Kyanite may be present with any of the assemblages in the Newtown quadrangle.

Miscellaneous rock types (*Ohlgs*): Less than a dozen small lenses of garnetiferous schist are scattered throughout the Hartland I east of the sillimanite isograd. These rocks are identical to the dominant schist in Hartland II. The large belt of Hartland II in the middle of Hartland I can be traced to the main body of Hartland II in the southern part of the Roxbury quadrangle. For this reason it is not included in the garnetiferous schist (Ohlgs) of Hartland I. Small lenses of amphibolite (Ohlbga) are also present in the biotite-gneiss facies of Hartland I north of the Housatonic.

COLLINSVILLE FORMATION

The small area of aluminous schist of the Collinsville Formation (Oca) shown along the east-central part of the quadrangle is based on mapping by Scott (1974) in the Southbury quadrangle. No outcrops of this unit are found in the Newtown quadrangle.

Intrusive rocks

Three major groups of Paleozoic intrusive rocks are distinguished on plate 1. Two of these, the Brookfield Gneiss and the Newtown Gneiss, are genetically related but are designated differently because of previous work in adjacent quadrangles. The term *Brookfield* is used for the two intrusives on the western boundary of the quadrangle because they are continuous with two bodies called "Brookfield Plutonic Series" in the Danbury quadrangle (Clarke, 1958). The specific term "Plutonic Series" has not been used because of its genetic connotation. Although the mafic facies of the Newtown Gneiss is continuous with a small section of Brookfield in the Danbury quadrangle, the term *Newtown Gneiss* is used because a large part of this unit is a granitoid gneiss, with large megacrysts of microcline, continuous with the Newtown Gneiss as defined by Crowley (1968) in the Long Hill quadrangle. Although this rock type occurs in the Brookfield Plutonic Sequence (Clark, 1958), it has not been separated there from the other hornblende-bearing rocks. This nomenclature problem is complicated further by the fact that the Brookfield may be continuous with the Harrison Gneiss to the south. Furthermore, the Newtown Gneiss proper is lithically and texturally very similar to the porphyroblastic gneiss of the Pumpkin Ground Member of the Prospect Formation of Crowley (1968, p. 11). Obviously these nomenclature problems must be simplified in the final compilation of the geology of Connecticut. The genesis and regional relations of the aforementioned rocks with the mafic intrusives to the north along Cameron's Line may well provide an important chapter in the tectonic history of western New England.

BROOKFIELD GNEISS

The Brookfield Gneiss (Ob) is generally poorly exposed, forming subtle topographic depressions relative to the surrounding metasedimentary rocks of Hartland I and II. Clarke (1958, p. 32) reports granodiorite; however, well foliated and lineated plagioclase-biotite-hornblende gneiss is the only rock type exposed in the Newtown quadrangle. This dominantly dark-colored gneiss cuts the contacts between Hartland II and the biotite-gneiss facies of Hartland I. Several fairly large lenses of Hartland II crop out within the Brookfield and are interpreted as inclusions, although the schistosity and mineral lineations are parallel in both. The contact of the Brookfield with the surrounding rocks is sharp, with no apparent features that could be attributed to chemical interaction during emplacement. The Brookfield Gneiss can be distinguished from the amphibolites in Hartland I and II because it contains texturally distinctive megacrysts of plagioclase.

The typical assemblage is shown in table 4.

Table 4.—Modal analysis in volume percent of a sample from the Brookfield Gneiss.[1]

Sample number	*Bio*	*Pl*	*Hb*	*Ep*	*Sph*	*Chl°*	*Mt*
499N	32.5	44.6	15.4	3.0	2.4	1.6	T

[1]For meaning of abbreviations see footnote to table 1.

NEWTOWN GNEISS

The Newtown Gneiss was formally defined by Crowley (1968, p. 9-12) for the megacrystic two-feldspar mica gneiss in the northwestern part of the Long Hill quadrangle. Although recognizing its discordant relations with the Collinsville Formation, Crowley favored a volcanic origin, and hence placed the Newtown Gneiss stratigraphically below the Collinsville Formation. Subsequent mapping by Scott (1974) in the Southbury quadrangle shows that this unit cuts isoclinal folds outlined by Hartland I and the Collinsville Formation.

In the Newtown quadrangle, the Newtown Gneiss consists of three mappable units; a megacrystic two-feldspar gneiss, minor lenses of medium-grained feldspar-biotite gneiss, and medium-grained hornblende-bearing gneiss that varies from amphibolite to feldspar-hornblende gneiss. These types are well exposed in reference locality 9 (pl. 1) south of Cedar Hill Road.

Newtown Gneiss (*On*): Medium to coarse-grained plagioclase-microcline-quartz-biotite gneiss, with megacrysts of microcline, underlies much of the southeastern part of the Newtown quadrangle. Except for that formed from the alteration of plagioclase, muscovite is almost totally absent. This unit cuts across the more mafic rocks and is rarely in contact with Hartland II in Newtown. To the east in the Southbury quadrangle it is continuous with the Newtown Gneiss of granitic composition (Scott, 1974, p. 26-27). In the western part of the Newtown Gneiss area, however, it forms conformable bodies interlayered with the hornblende gneiss. The contact with the surrounding mafic rocks is gradational; microcline in both small and large grains is possibly present in the hornblende gneiss, although its abundance diminishes away from the contact. The contact with Hartland II is sharp.

The representative mineral assemblage is:

plagioclase-microcline-quartz-biotite with varying amounts of chlorite.

Modal analyses are given by Crowley (1968, p. 10, LH513a) and Scott (1974, p. 27).

Mafic facies (*Onm*): This unit is considerably more varied than the felsic gneiss. Hornblende ranges from 10 percent to almost 70 percent; feldspar and biotite are other important phases. The hornblende-poor rocks are interlayered with feldspar-biotite gneiss, with hornblende-rich rocks and, in places, with the felsic gneiss. South of Longview Road much of the feldspar-hornblende-biotite gneiss is spotted with larger grains of plagioclase and is identical to the Brookfield Gneiss to the north on George Hill Road. It is this rock type that appears to be continuous with the Brookfield in the southeastern part of the Danbury quadrangle.

The contact of the mafic rocks with Hartland II is sharp, and dis-

Table 5.—Modal analyses in volume percent of samples from the mafic facies (Onm) of the Newtown Gneiss.[1]

Sample number	*Pl*	*Mi*	*Hb*	*Sph*	*Ep*	*Chl**	*Mt*	*Bio*	*Hem*
1733N$_3$	69.1	–	26.6	1.9	T	T	T	T	T
107N	60.9	T	10.9	4.7	2.3	3.6	T	17.6	T

[1]For meaning of abbreviations see footnote to table 1.

cordant with the boundaries of Hartland II and the feldspathic schist. The drastic change in thickness of the rocks lying between the mafic facies and the calc-silicate rocks of Hartland II north of Newtown also supports a discordant relationship (pl. 1). A fairly large discordant body of amphibolite originating from the main area of mafic rocks is mapped just northwest of the junction of Sugar Lane and Head-of-Meadow Road.

By comparing the geologic maps of Newtown (pl. 1) and Southbury (Scott, 1974, pl. 1), it can be seen that the Newtown Gneiss has intruded Hartland II, Hartland I, and the Collinsville Formation (fig. 11).

Representative mineral assemblages in the mafic facies are shown in table 5.

Biotite gneiss (Onb): Several small lenses of medium-grained plagioclase-quartz-biotite-gneiss are mapped south of Fairfield State Hospital. Smaller unmapped layers are found west and south of Sugar Lane. This unit is gradational with the felsic gneiss and the plagioclase-rich hornblende gneisses.

The representative mineral assemblage is:
plagioclase-quartz-biotite-microcline-sphene.

Foliated granite

Foliated microcline-plagioclase-quartz-muscovite-biotite-granite (DSgf) intrudes Hartland II and the Newtown Gneiss. The intrusive relations are most clearly shown east of Sandy Hook and north of Dodgingtown. Foliation in the granite is parallel to the schistosity of the Newtown Gneiss and Hartland II. Thus the granites were emplaced prior to the development of the dominant schistosity of the quadrangle.

Unfoliated granite and pegmatite are included with this unit because they form only a minor part of the granitic rocks of the area. They are chiefly confined to the southwestern part of the quadrangle in the area underlain by the feldspathic schist of Hartland II.

The foliated granite of Newtown is identical to the "Younger Granite" of Clarke (1958, p. 38) in the Danbury quadrangle, and may be equivalent to the Mine Hill Granite Gneiss of Roxbury (Gates, 1959). A historical review of this unit appears in Clarke's report.

The contacts with the surrounding rocks are sharp and in the field no effects were observed on the fabric or mineralogy.

ROCKS OF UPPER TRIASSIC AGE

Isolated outcrops of continental sedimentary rocks and basalt flows are present along two west-flowing brooks and a northward-trending ridge northeast of South Britain. The rocks form the western edge of the Triassic basin of the Pomperaug Valley. Their contact with Paleozoic metamorphic rocks is totally covered by surficial material along Transylvania Brook. The moderate eastward dip that appears to be nearly parallel with the moderate eastward hill slope on the metamorphic rocks to the west, however, suggests that the contact may well be an angular uncomformity. The age of these rocks is based on their similarity to the rocks of the Connecticut Valley where fossils are found. Descriptions of these units are given in the Explanation accompanying the geologic map (pl. 1). The geology of the Pomperaug Valley is covered in detail by Scott (1974, p. 30-35) and interested readers are referred to his report.

CORRELATION AND AGE OF THE METAMORPHIC ROCKS

Metasedimentary rocks

Figure 3 shows the inferred stratigraphic relationship of Hartland II and Hartland I to other stratigraphic units recognized throughout a large part of western Connecticut. Since fossils are absent and consistently reliable primary sedimentary top data are scarce, this correlation scheme is based on stratigraphic sequence, lateral continuity, and lithic similarity. The justification for the arrangement of units in columns 2, 3 and 6 is based on an extensive discussion of the metamorphic stratigraphy in western Massachusetts and western Connecticut by Hatch and Stanley (1974) and Stanley and Hatch (in press). Columns 3 and 6 are arranged quite differently from the schemes proposed by Gates and Martin (col. 3) and Crowley (col. 6) in the quadrangle reports listed in the figure caption. Column 2 differs from that of Stanley (1964, p. 42-50) but is in general agreement with Stanley (1968b, table 1). The rocks of western Connecticut are in turn correlated with the rocks in the southern part of western Massachusetts (col. 1). Column 5 is unchanged from that of Scott (1974, fig. 3). Readers interested in the detailed arguments for these rearranged sequences are referred to Hatch and Stanley (1974).

As shown in figure 3, Hartland II in Newtown (col. 4) is correlative with the Breezy Hill Member of the Satan's Kingdom Formation and the Slashers Ledges Formation in the Collinsville quadrangle (col. 2). These in turn are equivalent to the Rowe Formation of Massachusetts (col. 1). As this stratigraphic interval is traced southward, several

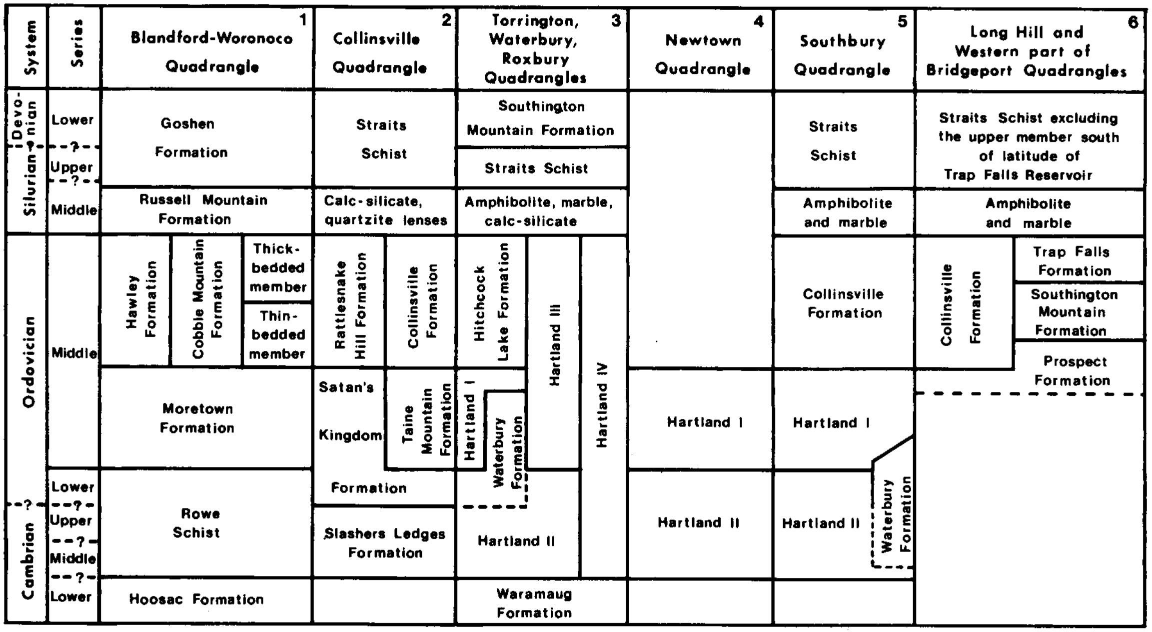

Fig. 3. Stratigraphic correlation chart for western Connecticut and western Massachusetts. Column 1 is taken from Hatch and Stanley (1974); column 2 is from Stanley (1964, 1968b) and Hatch and Stanley (1974); column 3 is modified from Martin (1970), Gates and Martin (1967), and Gates (1959); column 5 is taken from Scott (1974); column 6 is from Crowley (1968), as modified by Hatch and Stanley (1974). Quadrangles are located on figure 1.

changes appear. In Newtown, Hartland II contains pelitic schists with the common assemblages garnet-staurolite and garnet-staurolite-kyanite, characteristic of the corresponding units to the north. Kyanite-rich schist, which is more extensive in the Rowe and Slashers Ledges formations, is present in Newtown, but it is somewhat different lithically and occurs on a much more limited scale. The characteristic greenish-colored, kyanite-rich schist with thin but prominent quartz segregations and irregular pods of altered ultramafics, which is so typical of the kyanite-schist member of the Slashers Ledges Formation and parts of the Rowe, is totally absent from the Newtown quadrangle. These rock types either do not extend this far south or are not exposed, since formations older than Hartland II do not occur in Newtown. Massive quartz-plagioclase-mica schist with garnet and a trace of staurolite, characteristic of the upper part of the Satan's Kingdom Formation (Ratlum Mountain Member) in Collinsville, is present here and there in Hartland II and may suggest that the upper boundary of Hartland II in Newtown should be higher up in column 4 as compared to column 2 of figure 3.

The main difference in Hartland II in Newtown as compared to correlative units to the north is the presence of calc-silicate rocks and associated rusty schists. These lithic types are not present in correlative units to the north (col. 1, 2) and are found only in the upper part of the Satan's Kingdom Formation in Collinsville, where, however, the calc-silicate rocks are hard, quartz-rich, carbonate-free gneiss, quite different from those in Newtown. In summary, Hartland II appears to undergo a facies change with the presence of calc-silicate rocks as it is traced southward. Furthermore, Hartland II in Newtown represents a slightly higher and perhaps more restricted stratigraphic position compared to the Collinsville quadrangle (fig. 3, col. 2) and southwestern Massachusetts (fig. 3, col. 1).

Hartland I in Newtown is very similar to Hartland I to the north (fig. 3). It differs from the Taine Mountain Formation in Collinsville by lacking the mappable rusty-weathering schist and gneiss of the Scranton Mountain Member of the Taine Mountain Formation (Stanley, 1964, p. 20-21), although rusty rocks are present here and there in Hartland I in Newtown.

Intrusive rocks

Figure 4 is a simplified correlation chart of the Newtown and Southbury quadrangles, showing the intrusive relations of the Brookfield Gneiss, the Newtown Gneiss, and the granite which includes both foliated and nonfoliated varieties as well as pegmatites. The Brookfield-Newtown complex intrudes all the metamorphic rocks up to the base of the amphibolite and marble which is found discontinuously along the base of the Straits Schist (fig. 2). As these latter units represent the basal Silurian rocks deposited on an eroded, highly deformed basement following the Taconic orogeny, the Brookfield-Newtown gneisses

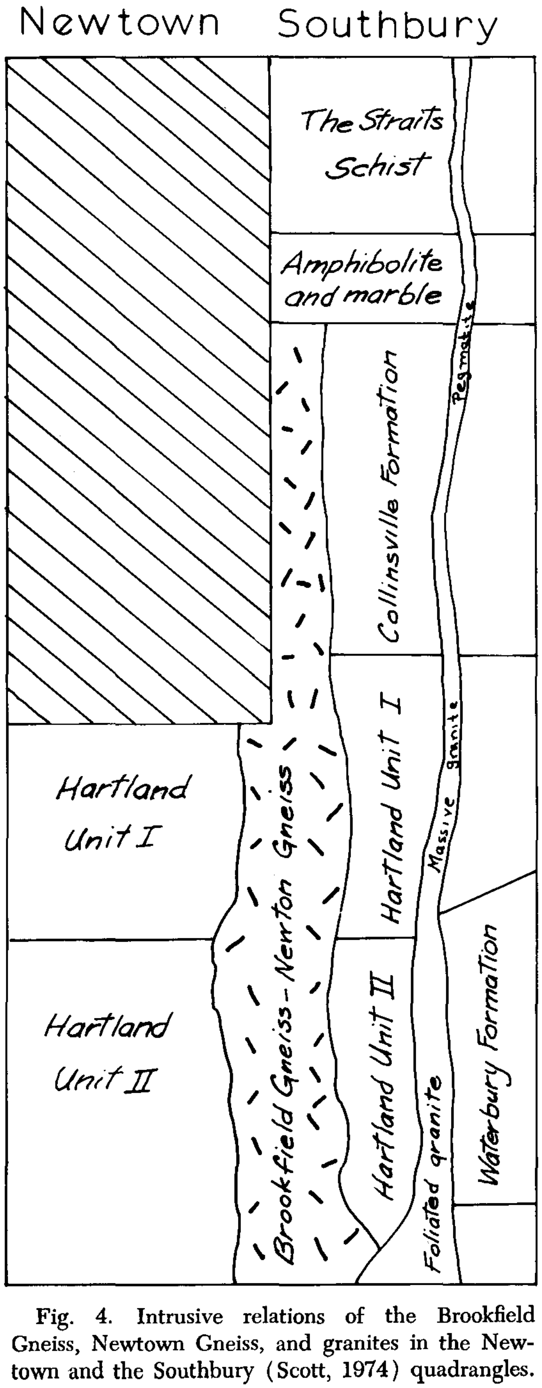

Fig. 4. Intrusive relations of the Brookfield Gneiss, Newtown Gneiss, and granites in the Newtown and the Southbury (Scott, 1974) quadrangles.

may represent a fairly extensive intrusive complex emplaced during the Taconic orogeny and subsequently deformed in the Acadian orogeny when the dominant schistosity was impressed throughout the metasedimentary rocks of south-central Connecticut (Stanley, 1975).

As mapped in this report, the granite includes foliated granite, unfoliated granite, and pegmatite. Although these rocks are found throughout the metasedimentary section including the Straits Schist, detailed radiometric work and future mapping may show them to be of more than one age. At present, however, they are thought to represent intrusive activity of the Acadian orogeny. The foliated granites were emplaced early in the orogenic cycle before the dominant schistosity was fully developed. The unfoliated granites and pegmatite occurred after peak-deformation and may well be equivalent to the Nonewaug Granite, radiometrically dated as 382 ± 64 m.y. (Besancon, 1970, p. 1).

METAMORPHISM

Introduction

The pelitic rocks of the Newtown quadrangle contain a fairly wide range of mineral assemblages and fabrics. It is, therefore, possible to work out the metamorphic facies and corresponding isograds with some degree of clarity. Compositional zoning is widespread in garnet and plagioclase and "retrograde" relations are well displayed, particularly in Hartland II. For example, electron microprobe traverses by the junior author indicate discontinuities in the CaO, FeO, MnO, MgO content of porphyroblastic garnet, which are interpreted as two separate periods of growth followed by partial alteration to chlorite. Such data indicates at least two pulses of metamorphic recrystallization and possibly three, depending on how the garnet information is interpreted.

Mineralogical field mapping, detailed petrographic study of 275 thin sections, and microprobe analysis of mineral assemblages from six pelitic samples showing zoning and "retrograde" features provide the data base for the following discussion. The petrographic and microprobe work was done by Caldwell (1972) and interested readers are referred to her work.

Isograds

The kyanite-sillimanite isograd, commonly known as the first sillimanite isograd, is controlled by abundant data from diverse mineral assemblages in the western part of Newtown. East of this isograd only kyanite is present, whereas to the west sillimanite (some fibrolite) is dominant, although kyanite persists. The critical reaction involves the development of sillimanite from muscovite and biotite. Magnetite is common where sillimanite developed from biotite and probably is formed by the release of iron during the breakdown of biotites. In all these rocks sillimanite is oriented parallel to the cleavage traces of muscovite and biotite.

Approximately 200 m. west of the Newtown-Danbury boundary and 1,200 m. south of U.S. Route 6, Caldwell (1972, fig. 16, table 7, pl. 1) found the assemblage biotite-quartz-sillimanite-plagioclase-potash feldspar-muscovite with a trace of magnetite and garnet in three thin sections stained for potash feldspar. Both fibrolite and coarse-grained sillimanite are present. Muscovite in these samples is so fine grained that it is difficult to determine if the sillimanite is oriented parallel to the cleavage traces. Potash feldspar has not been previously reported in these rocks and this assemblage suggests that the rocks in this part of Danbury and a small area in the western part of Newtown have been metamorphosed to the second sillimanite isograd, where the critical reaction is muscovite→ sillimanite + potash feldspar + quartz + water. The isograd is indicated on plate 1 and figure 5C.

Diagrams A and B, figure 5, are graphic projections according to Thompson (1957) of pelitic mineral assemblages for the rocks on either side of the first sillimanite isograd. These diagrams are based on touching assemblages observed in the field and under the microscope and represent a composite of information for the respective areas. Lists of the mineral assemblages are given in the description of each mappable unit and are not repeated here. Microprobe data and modal analyses for sample 731 (located on pl. 1) are shown in table 6. The positions of each phase in the respective projections are only approximate, although exact locations can be made for sample 731.

Zoning

Chemical zonation was observed petrographically in many of the garnet, plagioclase, and staurolite grains in Newtown. It was investigated by Caldwell, using the Action-Cameca microprobe at Yale Uni-

Table 6.—The composition in oxide-weight percent of the garnet, staurolite, plagioclase, biotite, and chlorite in sample 731N from Hartland II in the Newtown quadrangle.[1]

Oxide	*Gt rim*	*Gt core*	*St*	*Pl*	*Bio*	*Chl*
FeO	28.35	28.94	12.89	–	18.59	21.40
MnO	7.96	8.46	0.50	–	–	–
MgO	2.84	2.26	1.74	–	12.53	19.84
CaO	1.95	1.80	–	5.35	–	–
K_2O	–	–	–	–	7.49	–
SiO_2	35.76	34.90	26.89	63.18	18.59	24.22
Al_2O_3	20.99	20.73	52.67	24.46	17.82	22.59
Na_2O	–	–	–	9.74	–	–

[1] See table 1 for modal analysis of this sample; see footnote to table 1 for meanings of mineral abbreviations.

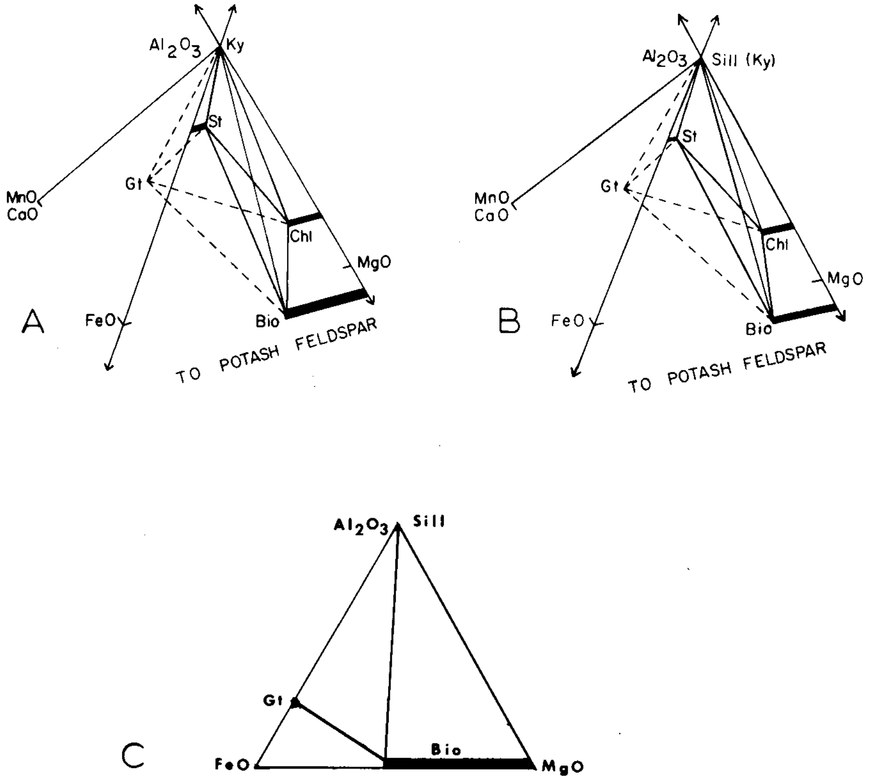

Fig. 5. Diagrams A and B are modified Thompson projections for pelitic schist in the Newtown quadrangle. Mineral regions in the face Al_2O_3, FeO, MgO are determined by lines projected through muscovite in the compositional tetrahedron K_2O, Al_2O_3, FeO, MgO. Minerals shown are coexisting with quartz, plagioclase, muscovite, and magnetite. Chlorite in both projections is retrograde, which explains the crossing tie lines kyanite-biotite and staurolite-chlorite. Phase regions for staurolite, biotite, and chlorite are hypothetical. Numerous theoretical tie lines exist between all minerals, providing they do not cross. These are not shown because the appropriate bulk compositions were not observed. Diagram A shows assemblages east of the first sillimanite isograde and diagram B contains assemblages to the west. The schematic phase regions are different in B because sillimanite develops from both muscovite and biotite, thus contributing K_2O, MgO, and FeO to coexisting minerals. Data for diagram A is based in part on sample 731 of table 1. Diagram C is projected through potash feldspar in the same compositional tetrahedron as diagrams A and B for samples west of the second sillimanite isograd. Minerals are kyanite (Ky), staurolite (St), garnet (Gt), chlorite (Chl), biotite (Bio), sillimanite (Sill).

versity. The method and data-reduction procedures are described in her report (Caldwell, 1972, p. 42-46). The results showed sharp chemical zonation in garnet and plagioclase but none was observed in the oxides FeO, MgO, SiO_2, Al_2O_3 in staurolite.

GARNET

The garnet porphyroblasts of sample 846 from a thin belt of Hartland II between Skyline Ridge Road and the Shepaug River are optically zoned; the very small inclusions of quartz and mica are far more abundant in the cores than in the rims. Commonly the inclusions are even larger or more numerous at the contact between the two zones. Representative core-rim chemical data by weight percent and modal analysis of the sample containing the garnet are given in table 7. Microprobe oxide profiles show a symmetrical zonation of FeO, MgO, MnO, and CaO about the central point of the garnet (point 1.28, fig. 6). In all the profiles there is a marked change in slope in the intervals 0.6—0.9 mm and 1.7—2.0 mm, which correspond to the fabric boundaries seen under the petrographic microscope. These profiles are interpreted to be the result of two distinct periods of garnet growth (Caldwell, 1972, p. 72-73). Note that the ends of both growth periods are marked by a slight increase in MnO resulting in an upturn in the MnO profile.

Table 7.—An electron microprobe analysis of (oxide-weight percent) of a garnet from sample 846N of Hartland II.[1]

OXIDE	RIM	CORE
FeO	44.18	38.68
MnO	1.14	12.61
CaO	4.37	2.46
MgO	1.78	0.90
SiO_2	27.68	27.58
Al_2O_3	18.90	18.60
TOTAL	98.05	100.83

[1] The modal analysis of the thin section containing this garnet is given in table 1 (sample 846N).

Table 8.—Compositions in oxide-weight percent of the cores and rims of three plagioclase grains in sample $1733N_3$ of the mafic facies of the Newtown gneiss.

OXIDE	RIM 1	CORE 1	RIM 2	CORE 2	RIM 3	CORE 3
CaO	1.58	3.37	1.34	3.15	1.55	3.53
Na_2O	10.71	10.02	11.23	10.38	10.38	9.83
SiO_2	65.32	64.28	67.39	64.54	68.09	63.50
Al_2O_3	21.15	22.35	21.12	22.36	21.08	22.85
TOTAL	98.76	100.02	101.08	100.43	101.10	99.71

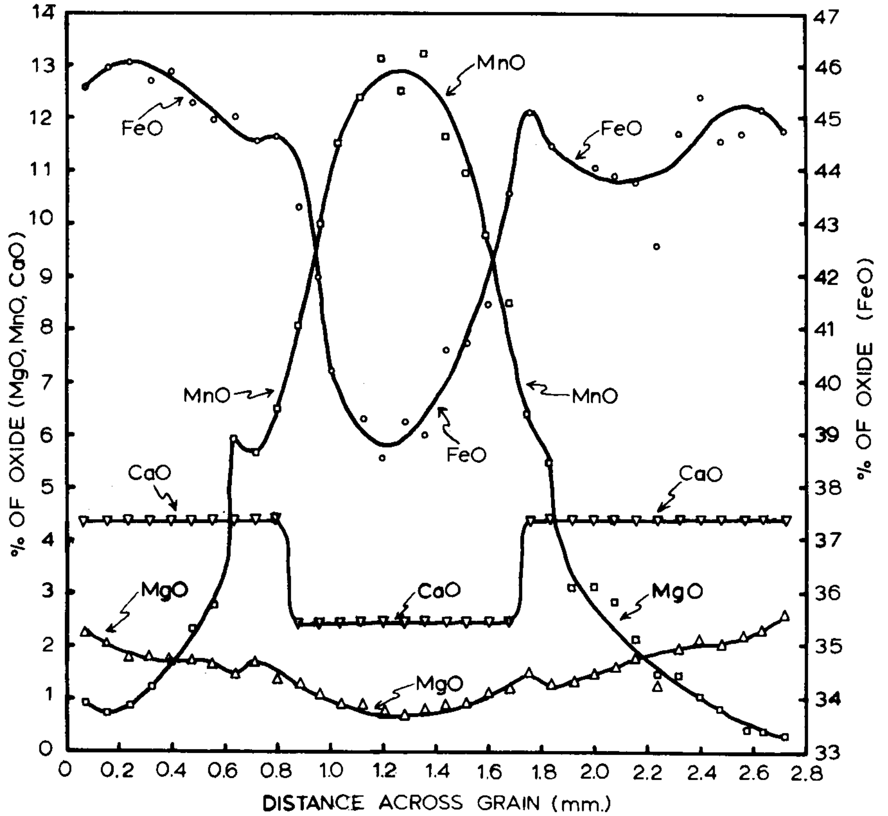

Fig. 6. MnO, CaO, FeO, and MgO microprobe profiles across a garnet from Sample 846N. Profiles constructed from 34 point analyses made at 0.08-mm intervals across the diameter of the garnet grain. Garnet standard is Sample 61-1492, Knowles and co-workers (1969), provided by A. E. Bence.

PLAGIOCLASE

Plagioclase zoning in Newtown is marked by a difference in extinction angles and in the degree of sericitization between core and rims. Microprobe analyses on three plagioclase grains in a hornblende-bearing gneiss of the Newtown Gneiss show calcium-rich cores and sodium-rich rims (table 8). The rims of all the grains were sericitized, whereas the cores are clean. The calcium x-ray-scanning pictures show that the core-rim boundary is sharp; not gradational as one might expect for a plagioclase grain growing in a melt of changing composition. One possible explanation is the metamorphism of an older calcium-rich plagioclase formed during crystallization of the intrusive. The geology of the Newtown-Southbury quadrangles certainly supports this suggestion.

Late metamorphism

Clear-cut, definitive evidence for a metamorphic event at much lower pressure-temperature conditions is found throughout the pelitic rocks in Newtown. Specific data are:

a) Chlorite interdigitated with biotite.

b) Chlorite halos around garnet.

c) Large, inclusion-free chlorite porphyroblasts, randomly oriented across the schistosity.

d) Chlorite with the muscovite-quartz-plagioclase assemblages, both the biotite-garnet-staurolite and the biotite-garnet-staurolite-kyanite ones (for example, see fig. 5). Both these assemblages occur in interbedded rocks.

e) Probe data (Caldwell, 1972, tables 15, 22) indicate that the iron oxide and magnesium oxide are nearly equivalent in amount: approximately 22 percent FeO and 19 percent MgO (by weight). Chlorite in equilibrium with kyanite and biotite in pelitic rocks should be rich in magnesium. Although chlorite is slightly more magnesium-rich than biotite in the same samples, the probe data suggest that the chlorite is retrograde, especially in the light of other data.

f) Muscovite halos around staurolite. One sample has a chlorite halo around muscovite.

g) Muscovite halos around kyanite.

h) Sericitization of plagioclase.

Most of the above data could be interpreted as retrograde metamorphism, possibly occurring during the waning stages of the kyanite-sillimanite-grade metamorphism. Although this may have taken place, two facts argue for a renewed pulse of metamorphism: randomly oriented porphyroblasts of chlorite, and chlorite selectively replacing biotite along kink bands. In the laboratory, kink deformation of biotite is a form of intracrystalline gliding that occurs in chemically inert systems undergoing deformation (Borg and Handin, 1966, p. 277). Thus, the kinked biotite in Hartland II indicates deformation at temperatures sufficiently low that recrystallization did not occur. This event, although apparently not widespread, clearly took place after the Acadian metamorphism (382 ± 64 m.y. age of the Nonewaug Granite, Besancon, 1970). Selective replacement of the deformed biotite in the kink band in larger biotite grains indicates a renewed pulse of metamorphism. Much of the so-called retrograde features listed in this section, perhaps developed at this time. This event in Newtown might represent the periphery of late Paleozoic metamorphism and plutonism along the Connecticut coast, discussed by Lundgren (1968).

STRUCTURAL GEOLOGY

Introduction

The structural configuration of the rocks in the Newtown quadrangle represents a long and complex history that appears to begin in the Taconic orogeny, reaches its maximum development in the Acadian orogeny, and terminates with high-angle faulting in the Palisades disturbance during the Upper Triassic. Minor structures are grouped into three Paleozoic fold generations that can be related to major folds and chronologically correlated with the two periods of plutonic activity.

The following section concentrates on the major structures with emphasis on the map pattern of the amphibolite and calc-silicate rocks in the north-central part of the quadrangle. A comprehensive discussion of the minor-fold generations, their regional correlation, and their significance is covered by Stanley (1975) and, therefore, their characteristics are merely summarized here.

Method of study and description of structural elements

The structural methods and definitions employed throughout this study are described by Stanley (1964, p. 60-69; 1975). Descriptive information and orientation data were collected at each outcrop and plotted on equal-area diagrams. Collective diagrams for homogeneous subareas based on schistosity attitudes were contoured on an XDS Sigma-Six computer using the Warner (1969) program as modified by Morse (1973). Too numerous to include in this report, these diagrams are available from the senior author on request. Equal-area nets are shown only for the hinges and axial surfaces of F2 and F3.

Section A-A^1 (pl. 2) is a profile section drawn perpendicular to the F2 fold-axis maximum (fig. 7B) which plunges to the west at 35°. This method assumes that the projection axis remains unchanged throughout the quadrangle. The hinges of F2 generally obey this rule, although there is some variation from place to place. F2 folds were used for the projection axis because they are the most abundant fold generation in the area. Although the intrusive contact of the Newtown Gneiss appears to be similar in the profile section and map, there is really no compelling reason to assume that the geometry of this contact remains constant, as projected into the section. The contact has, however, been folded during F2 time because the Newtown Gneiss contains the same schistosity that is parallel to the axial surface of F2 folds.

The structural elements are described briefly in the Explanation sec-

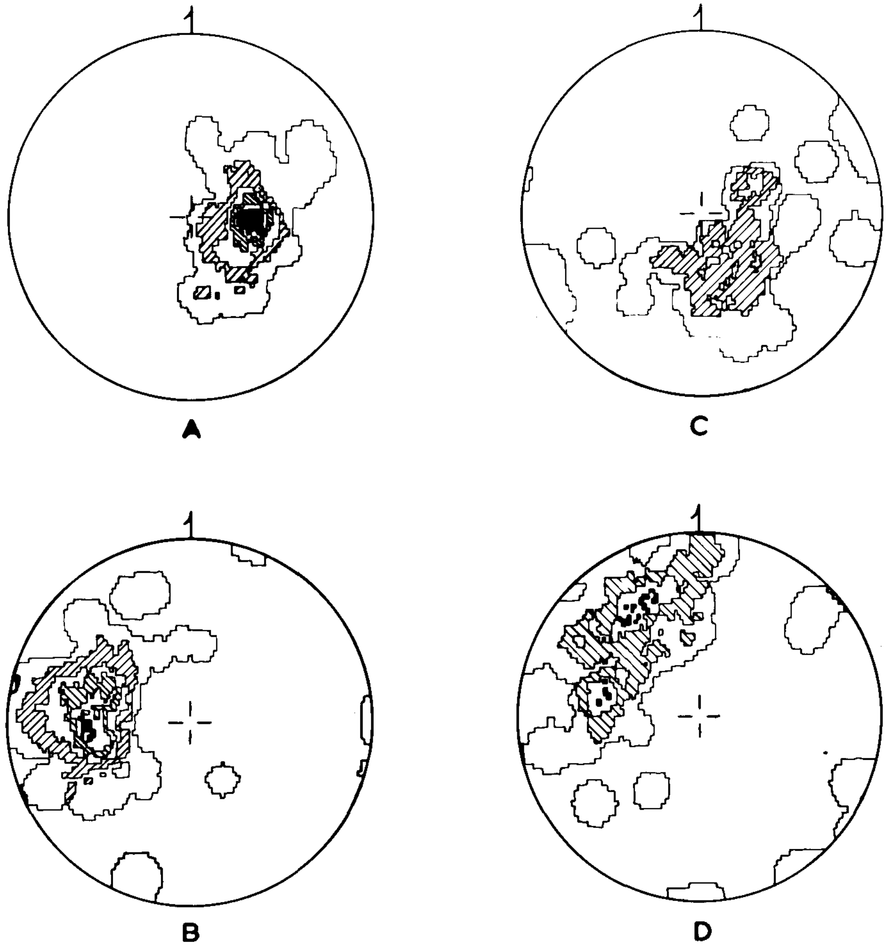

Fig. 7. Lower hemisphere equal-area projections of F2 (A,B) and F3(?) (C,D) folds in the Newtown quadrangle. Diagram A contains 107 poles to axial surfaces of F2 folds. Diagram B contains 99 F2 fold axes. Contour intervals for A and B are 1.0, 4.0, 8.0, 12.0, 16.0, 18.0 percent per 1-percent area. Diagram C contains 65 poles to axial surfaces of F3(?) folds. Contour intervals are 1.0, 4.0, 9.0 percent per 1-percent area. Diagram D contains 64 F3(?) fold axes. Contour intervals are 1.0, 4.0, 9.0, 12.0 percent per 1-percent area. Plane of projections is horizontal, with north indicated by arrow.

tion of the geologic map (pl. 1). In this report, the term schistosity is used instead of the term foliation which was employed in the Collinsville area (Stanley, 1964).

Minor folds

A variety of minor-fold styles are prevalent in the metasedimentary rocks of the Newtown quadrangle. These folds are seen most readily in outcrops consisting of relatively thin beds of interlayered gneiss, granulite, and schist. Using techniques developed in the Collinsville quadrangle and the Blandford-Woronoco areas of western Massachusetts (Stanley, 1975), the minor folds are separated into three generations based on superposed relations observed in a number of outcrops in the quadrangle. These generations are designated F2, F3(?) and F4, according to a regional scheme proposed for western Connecticut and southwestern Massachusetts (Stanley, 1975). Folds of F3 age are queried, since their correlation with a generation of post-F2 folds to the east near the gneiss domes is questionable. Minor folds of F1 age were not observed in this study but are represented by a major fold outlined by the amphibolite and calc-silicate rocks of Hartland II. The characteristics of each generation are described in the following sections.

F2 FOLDS

Minor folds of F2 age deform bedding and are well developed throughout the quadrangle. They are commonly similar in profile, with tight to isoclinal limbs and a well developed axial-surface schistosity which forms the dominant schistosity of the region. Generally the fold limbs are severely thinned and in many places they are pinched off, leaving isolated hinges or fold mullions. Quartz rods and elongate minerals in Hartland I and II parallel F2 fold axes (pl. 1). The pervasive hornblende lineation which is well developed in the Brookfield Gneiss and the Newtown Gneiss is also parallel to the hinges of F2 folds (pl. 1). F2 folds probably deformed an earlier schistosity of F1 age. Evidence of this schistosity is rare; presumably, it has been largely obliterated by intense F2 deformation.

The axial-surface and hinge attitudes of 127 F2 folds, from throughout the entire quadrangle, are shown in figure 7A, B. The contoured data locate an axial-surface-pole maximum that defines a surface striking N and inclined 35° W (fig. 7A). The contoured fold-axis data outline a maximum that plunges 35° W (fig. 7B). Although there is variation in the data, the folds of F2 age are essentially reclined.

F3(?) FOLDS

Minor folds of F3(?) age are confined largely to the areas marked by F3(?) axial symbols in figure 9 and are far more restricted geographically than are those of F2 age. They deform either bedding or schistosity (or both) and are generally more open and concentric in profile. Their axial surfaces are generally not marked by a cleavage or a schistosity. In a few places, such as the junction of Route I-84 and Papoose Hill Road, a crenulate cleavage is developed in schistose rocks.

The attitude of the hinges and axial surfaces is more varied than comparable elements of F2 (fig. 7C, D) because: a) the minor folds included in F3(?) are possibly of different ages, although stylistically they look the same; b) the bedding and schistosity that they deform are not parallel; and c) they were produced by a stress field with heterogeneities generated primarily by existing mechanical anisotropies in the rocks. Generally the axial surfaces trend NE or E (fig. 7C), whereas the fold axes plunge gently NW. Neither of these elements forms a unique

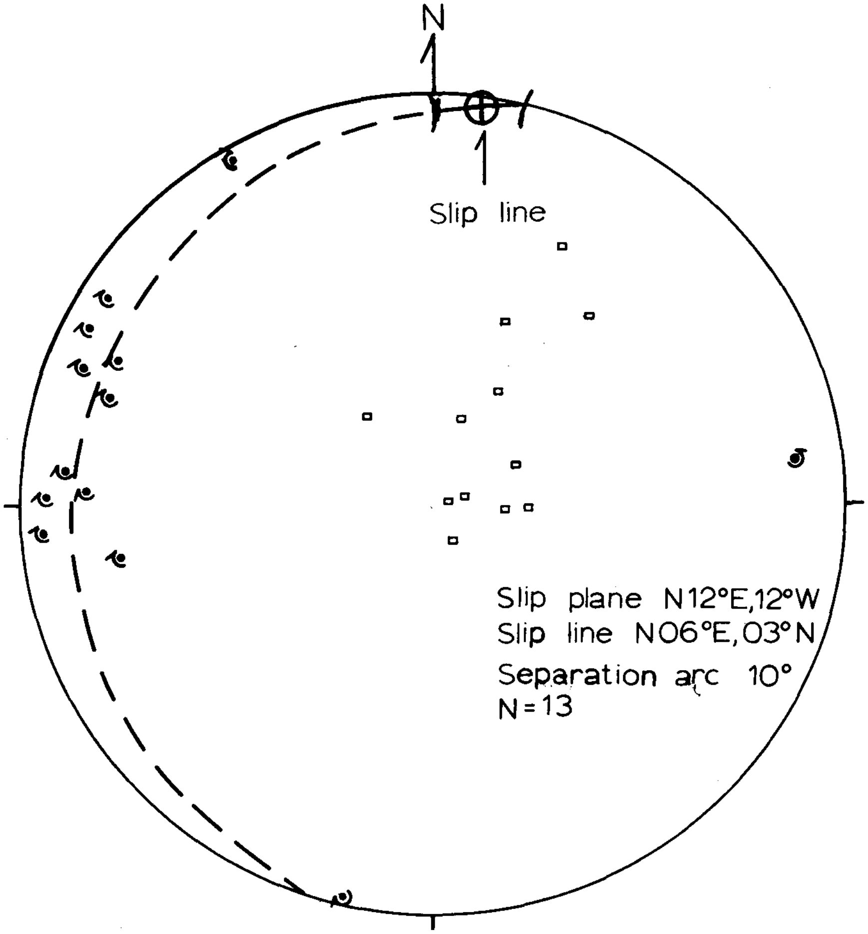

Fig. 8. Drag folds from locality A (pl. 1), 1 km north of South Britain. The deduced slip line trends slightly east of north and is confined by a 10° separation arc.

point maximum as do similar elements of F2 age (fig. 7).

The designation F3 is questioned because the age of this minor folding relative to major folds in the central part of the Southbury quadrangle to the east is interpreted somewhat differently by Stanley than by Scott (1974). Following Dieterich (1968a,b), Scott (1974, fig. 8, p. 37-44) distinguishes four generations of folds based principally on the hypothetical evolution of the map pattern of the Straits Schist in the southeastern part of western Connecticut. Thus the problem of structural sequence is approached differently by Scott than by Stanley. Stanley agrees with Scott that the isoclinal syncline of Straits in Southbury is F2 in age (Scott 1974, pl. 1). To the west, however, Scott (1974, p. 41) considers the isoclinal folds outlined by the contact of Hartland I and the Collinsville Formation to be F3 in age, although he admits an F2 age is possible. Stanley prefers an F2 age for these folds because the dominant schistosity appears to be parallel to their axial surfaces and the tight F2 syncline of Straits Schist. Furthermore, in order for these folds to be of different ages yet have parallel schistosity, the older schistosity of F2 age must have been severely transposed during F3 folding, thus producing an identical younger schistosity over a distance of 1,000 m. There appears to be no evidence to support this sequence.

The subsequent deformation of the schistosity in Southbury by crenulate folds with westward-trending axial surfaces is associated with large-scale bending of the older isoclinal folds. These younger folds can be traced into the Newtown quadrangle where they become the F3(?) folds of this report.

F4 FOLDS

Scattered here and there in the schistose rocks of Newtown are kink folds which correspond in style to the kink folds produced experimentally by Patterson and Weiss (1966) and Donath (1968). These folds, with sharp hinges and planar limbs, deform the regional schistosity. They are probably, at least in part, coeval with the microscopic kink folds in biotite and the associated chlorite metamorphism discussed in a preceding section, "*Late metamorphism.*" The attitudes of the kink folds are not shown in equal-area projection because fewer than 10 were recognized during field work.

DRAG FOLDS

Approximately 1 km northwest of South Britain, the calc-silicate rocks of Hartland II contain numerous minor asymmetrical folds of F2 age with hinges that plunge at various azimuths to the west (pl. 1, locality A). All the folds have a clockwise sense of rotation. When plotted in equal-area projection according to the methods of Hansen (1971), they define a 10° separation arc containing a N-trending, nearly horizontal slip direction (fig. 8). This information suggests that an important direction of rock flowage in this area during F2 time was northerly. This conclusion assumes that subsequent folding and faulting have not rotated the folds appreciably.

Major structures

In order to understand the geological history of the Newtown area it is necessary to unravel the fold configuration in the northern part of the quadrangle. Information on minor folds summarized in the previous section and detailed geologic mapping of stratigraphic units provide a solution to this problem.

MAJOR FOLDS

Detailed mapping of the amphibolite and calc-silicate rocks of Hartland II indicates that the N-trending syncline of Hartland I in the north-central part of the quadrangle refolds an older fold with an axial surface that has been severely deformed by the younger folds (pl. 1). This configuration is further supported by the complex map pattern of Hartland I and Hartland II along the Roxbury-Newtown border. The profile section (pl. 2) shows these relations quite well. The axial surface of this older fold, here designated F1, would be located between the two belts of amphibolite (OЄhIIa) in Hartland II, intersecting them when they join, and would then wend its way northward into the Roxbury quadrangle where it was refolded in some complex manner so as to re-enter the Newtown quadrangle in the younger syncline of Hartland I (pl. 2 and fig. 9). In a sense, this F1 major fold, which would be an anticline on stratigraphic grounds, has been refolded into a flattened "jelly roll." The approximate position of this F1 axial surface in the Newtown quadrangle is shown on figure 9. A diagrammatic sketch of the "jelly roll" with its deformed axial surface is shown in figure 10. Although the configuration in the Roxbury quadrangle is based on reconaissance work, the form of the contact is questionable. This interpretation is quite different from the one shown by Gates (1959, fig. 1).

The younger generation of minor folds, F2 through F4, were then superimposed on the older F1 configuration. Two of these generations, F2 and F3(?) are represented by major folds. The F2 folds are intensely strained and dominate much of the northern half of the quadrangle. As shown on figure 9, the axial-surface schistosity of F2 minor folds parallels the geometric axial surfaces of many of the major folds outlined by the amphibolite and calc-silicate rocks of Hartland II. They are also parallel to the axial surface of the complex syncline of Hartland I in the north-central part of the quadrangle. Since the minor folds essentially parallel the geometry of these major folds, the two are coeval. The intense refolding and flattening of the older F1 major fold, then, took place during F2 time, when the dominant schistosity

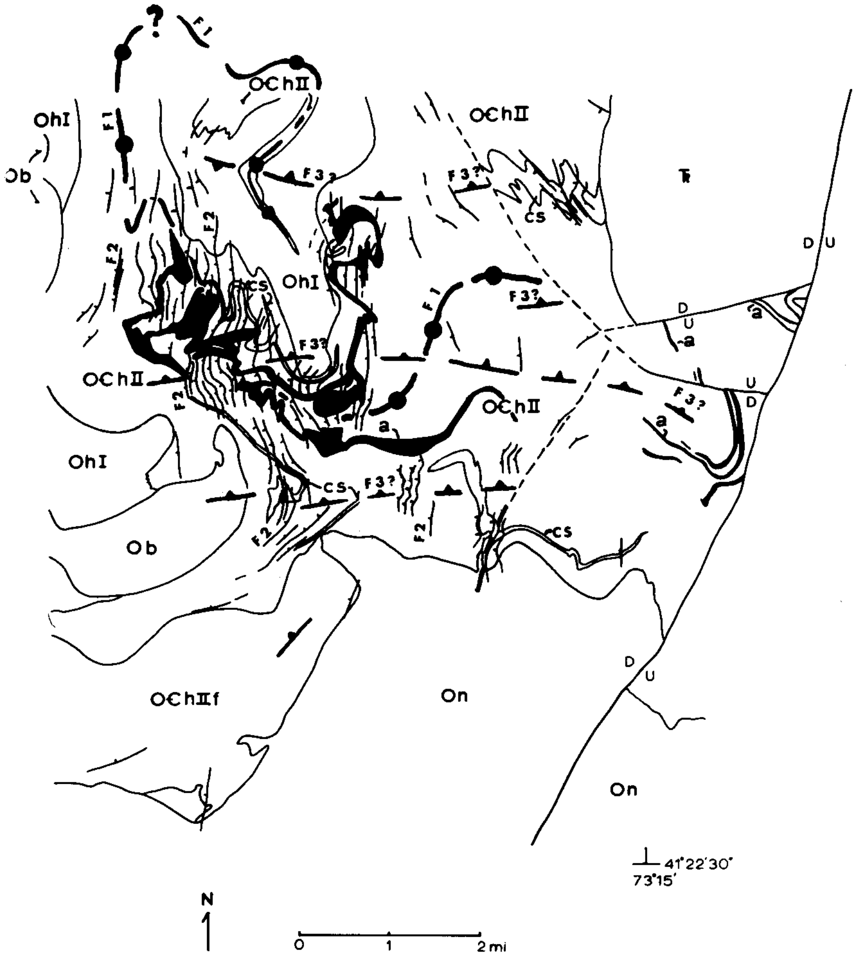

Fig. 9. Axial surfaces of fold generations F1, F2, and F3(?) in the Newtown quadrangle. Axial surface of F1 (heavy line with solid dot) is generalized for a stratigraphic anticline and is based on the map pattern of the amphibolite and calc-silicate rocks of Hartland II as well as the inferred configuration of Hartland I and Hartland II. Axial surfaces of F2 (light line with tick indicating dip) are based on 127 minor reclined folds and are coeval with many major folds outlined by the amphibolite and calc-silicate rocks in Hartland I and II. Axial surfaces of F3(?) (heavy line with triangle indicating dip) are based on 88 minor folds and are located in areas where F2 axial surfaces are folded. The geology east of longitude 73°15′ was mapped by Scott (1974). The geology east of the major NE-trending fault is not shown but is summarized in figure 11.

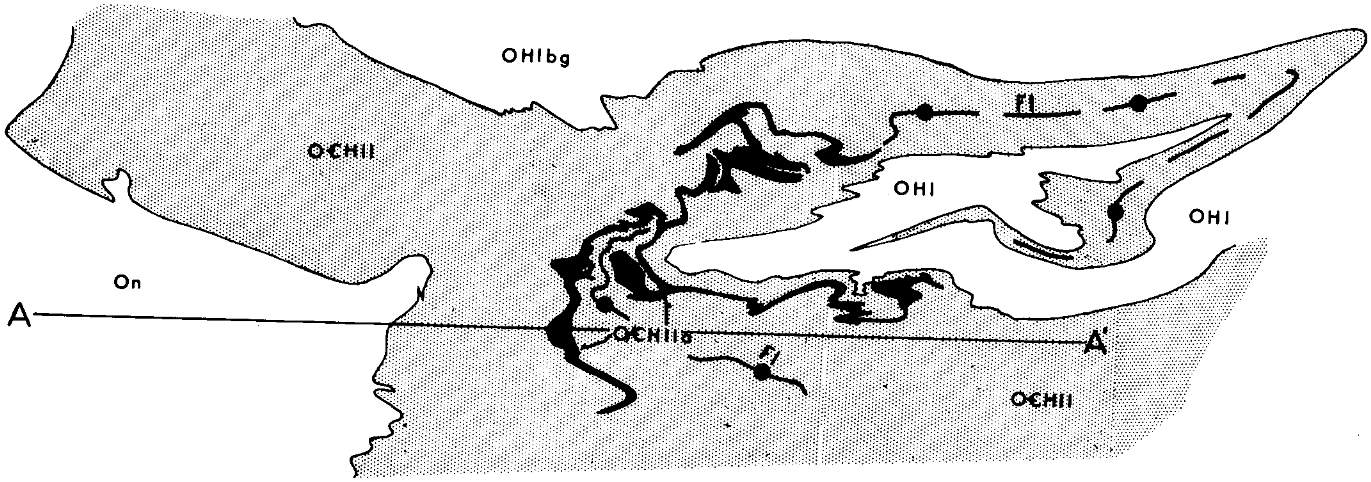

Fig. 10. Diagrammatic sketch of the inferred structure in the Newtown quadrangle and the southern part of the Roxbury quadrangle. The diagram is modified from the profile section (pl. 2) and is a view looking to the west. Line A-A′ corresponds to A-A′ on plates 1 and 2.

was impressed on the metasedimentary rocks, the Newtown Gneiss, the Brookfield Gneiss, and the foliated granite.

Folds of F3(?) age deform the axial-surface schistosity of F2 into broad, very open, antiforms and synforms (fig. 9). As shown on the geologic map (pl. 1) the systematic change in schistosity diagonally across the quadrangle and the warping of the syncline of Hartland I and the southern body of the Brookfield Gneiss are all a product of F3(?) deformation (fig. 9 and pl. 1). Furthermore, the curvature of the first sillimanite isograd appears to conform to the geometry of the major F3(?) folds, although it does cut across the schistosity and the axial surfaces of F2 folds. These relations suggest that the metamorphic isograds were set sometime between F2 deformation and F3(?) folding.

Compared to F2 folds the intensity of strain during F3(?) time was substantially less in Newtown, but to the east in the Southbury quadrangle it becomes more severe as the major F2 folds (F3 of Scott, 1974, fig. 8) in Hartland I, the Collinsville Formation, and the Straits Schist are folded into a major W-trending synform (fig. 11). Folds of F4 age do not occur on a major scale in the Newtown quadrangle.

The four generations of folds were developed during the Taconic and Acadian orogenies, and possibly during the Allegheny orogeny. The axial-surface schistosity of F2 is the regional schistosity that dominates most of the rocks of western Connecticut, including the Straits Schist of Silurian and Devonian age (Hatch and Stanley 1974; Stanley 1975). This surface formed during deformation and metamorphism of Acadian age. As a consequence, folds of F1 age may represent a still earlier Acadian event or a Taconic event. The earlier Acadian event would correlate with the F1 folds proposed by Dieterich (1968a,b) for the rocks to the southeast in the Naugatuck-Long Hill-New Haven-Westport area. A Taconic age, however, seems more likely because the contacts of the Brookfield Gneiss and the Newtown Gneiss, both possibly of late Ordovician age, are apparently not folded by F1. The presence of the regional schistosity and a penetrative mineral lineation parallel to F2 hinges in both these plutonic bodies indicates that they were emplaced before F2 time.

Folds of F3(?) age probably developed after the metamorphic peak during the Acadian orogeny because the first sillimanite isograd appears folded. The absence of an axial-surface cleavage seems to support this conclusion because recrystallization during metamorphism would certainly aid in developing a cleavage, even at fairly low levels of strain. The F3(?) folds in Newtown are probably younger than the F3 folds in the Long Hill-Naugatuck-New Haven-Westport area (Dieterich, 1968a,b) which are related to the development of the gneiss domes of western Connecticut and southwestern Massachusetts (Stanley, 1975). F3(?) in the Newtown-Southbury area form a W-trending synform which appears to fold F3, to the east (Stanley 1975, fig. 79).

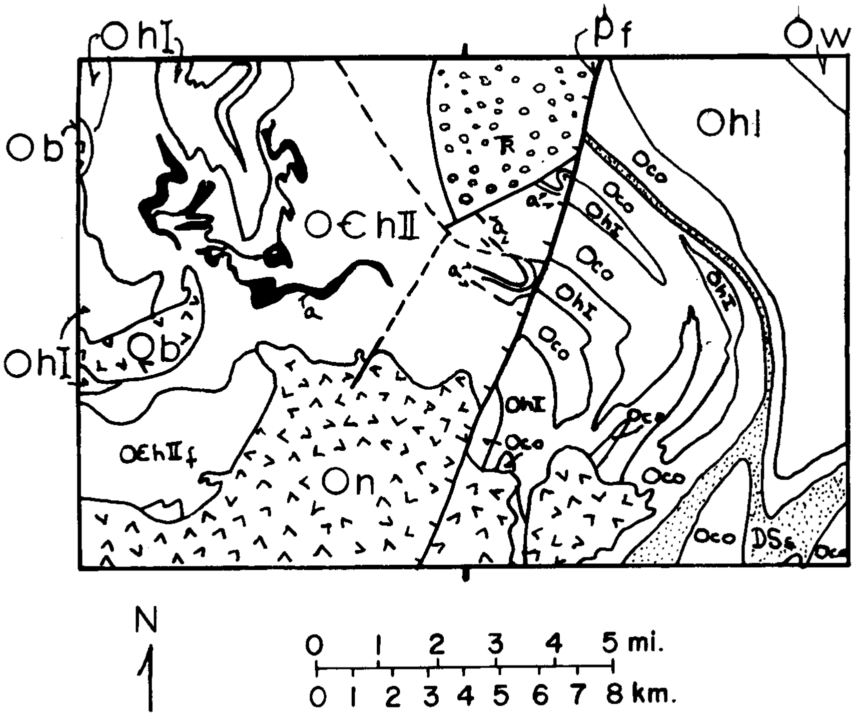

Fig. 11. Geologic map of the Newtown and Southbury quadrangles, showing distribution of Hartland II (O€hII), the amphibolite in Hartland II (a), the feldspathic schist in Hartland II (O€hIIf), the Waterbury Formation (Ow), Hartland I (OhI), the Collinsville Formation (Oco), the Straits Schist (DSs), the Brookfield Gneiss (Ob), the Newtown Gneiss (On), and the rocks of Triassic age (₸). The faults correspond to those on plate 1. The Pomperaug fault is marked *pf*.

The kink folds of F4 represent a post-Acadian event in which the rocks behaved brittley as compared to earlier fold generations. During this time micas in many of the rocks were kinked and subsequently replaced in part by chlorite. Although no definitive proof has yet been recognized, it is possible that F4 represents an Allegheny pulse in southern Connecticut.

FAULTS

Many of the faults in the eastern part of the quadrangle are based on mapping by Scott (1974) in the Southbury quadrangle. All these faults offset the Upper Triassic rocks in the Pomperaug basin. Some of the key evidence for them is shown in figure 9, where the lateral continuity of the amphibolite (O€hIIa) and calc-silicate gneiss (O€hIIcs) in Hartland II is disrupted. The location of these faults in Newtown, however, is very speculative because outcrop is relatively sparse and, where it is abundant, key map units are absent. Many of the quartz-filled joints shown on plate 1 are probably associated with this period of faulting.

Along the Pootatuck River in Sandy Hook the calc-silicate rocks and schist of Hartland II are intensely brecciated and altered. This belt of fractured rocks is thought to be part of a NE-trending fault which parallels the Pomperaug fault (fig. 11) to the east. The location of this fault northeast of Sandy Hook is doubtful because mappable units are absent in Hartland II north of Berkshire Estates.

The Pomperaug fault, which forms the main boundary fault of the Pomperaug basin, is located quite accurately in the older metamorphic terrain. As shown in figures 9 and 11, the boundary of the Newtown Gneiss is offset by the fault, whereas the major folds in the Southbury quadrangle abruptly terminate against it. The fault appears to dip steeply since it cuts across the topography. The western block is downdropped; the E-dipping Triassic rocks are only found to the west of the Pomperaug fault (fig. 11). In the metamorphic rocks, however, the older rocks compose the hanging-wall block. This fact is consistent with Dieterich's (1968a,b) and Scott's (1974) regional picture of a large E-facing anticlinal nappe rooting in the Newtown area and terminating to the east in the Bridgeport (anticlinal) synform of Crowley (1968). The younger rocks on the footwall block to the east would then extend westward beneath the older rocks of Hartland II.

GEOLOGIC HISTORY

The bedrock geology in the Newtown quadrangle is the result of a complex set of Paleozoic and Mesozoic events. During Early Paleozoic time the metasedimentary rocks of Hartland II were deposited oceanward of a continental platform that received carbonate sediments and is now represented by many of the rocks west of Cameron's line (fig. 2). In Early and Middle Ordovician time, and perhaps even before, an island-arc complex with its mass of volcanic rocks and volcanically derived sediments formed to the east, possibly as a result of plate subduction along the eastern coast of North America. These rocks are now represented by the Collinsville Formation and its correlative units in and around the gneiss domes of central New England. As Ordovician time progressed, the interbedded graywacke-shale turbidite sequence of Hartland I, which was forming off the arc complex, was gradually replaced by the felsic and mafic volcanic rocks and sediments of Middle Ordovician age that spread westward, inundating the basin between the island-arc system and the continent.

The chronological events of the Taconic and Acadian orogenies here given are deduced on the basis of a Silurian and Devonian age for the Straits Schist and on the structural sequence of fold generations. During the Late Ordovician the island arc-to-platform complex was compressed, forming large-scale folds and extensive thrust faults of the Taconic orogeny (Zen, 1972). Folds of F1 age formed at this time and were later cut by dioritic and granitic intrusives of the Brookfield-Newtown complex. Metamorphism during Taconic time may have reached the garnet grade, as suggested by the inner cores of sharply-zoned garnets in Hartland II.

Subsequent uplift and erosion at the end of the Taconic orogeny was followed by widespread deposition of carbon-rich muds with thinly bedded sands (Straits Schist and Goshen Formation, fig. 3). Deformation during the Middle and Late Devonian involved at least four generations of folds associated with large-scale isoclinal folds, E-facing nappes and mantled gneiss domes (Dieterich, 1968a,b; Stanley, 1975). Two of these generations, F2 and F3(?), are well developed in the Newtown-Southbury areas. The F2 folds are part of the regionally persistent isoclinal folds and E-facing nappes of southwestern New England, which appear to result from partial decoupling and underthrusting along Cameron's line (fig. 2). Generation F3(?) is far more restricted and apparently developed after the gneiss domes were emplaced (Stanley, 1975). Metamorphism began during intrusion of the foliated granite and reached its peak during or slightly after the formation of the regional schistosity of F2 age. The pegmatites and unfoliated granites in Newtown possibly represent a subsequent pulse of granitic activity that is perhaps younger than F3(?) folds and correlative with the Nonewaug Granite to the north in the Woodbury and Litchfield quadrangles (Gates 1951, 1954). Whole-rock Rb-Sr work on the Nonewaug gives a date of 382 ± 64 m.y., which is considered a minimum age for the Acadian orogeny in southern New England (Besancon, 1970).

Sometime after the Acadian orogeny and before the Palisades disturbance, a new metamorphic pulse developed chlorite and retrograded kyanite, staurolite, and garnet throughout the Newtown area. The kink folds of F4 age preceded this event, which may possibly represent Late Paleozoic Allegheny deformation.

Subsequent uplift and erosion at the end of the Paleozoic set the stage for continental rifting and deposition of the coarse clastic rocks of the Pomperaug basin. Continued faulting in the Triassic and prolonged erosion since then has isolated the Pomperaug rocks from the main Triassic basin of central Connecticut and Massachusetts.

ECONOMIC GEOLOGY

The economic deposits in the Newtown quadrangle are quite limited; the greatest revenues are from surficial deposits. There are active sand-and-gravel pits southeast of Sandy Hook in the low hills on either side of the Pootatuck River. The terrace sediments adjacent to the Housatonic River may contain other usable sand and gravel. Deposits of peat and clay were not found in the present study.

Bedrock deposits of economic value are even more limited. Many of the rocks of Hartland II are possibly rich enough in garnet to be mined for abrasive material. One such area is east of Brook Road near the northern boundary of the quadrangle. It is continuous with an area southeast of Roxbury Falls (labeled *hb* on the Roxbury quadrangle geologic map, Gates, 1959) that was once actively mined for garnet.

The foliated granite has been locally quarried as a building stone. The larger plutons east of Sandy Hook and northwest of Dodgingtown are both suitable for this use, although the deposits are far more limited than the Mine Hill Granite Gneiss in Roxbury.

The massive parts of the Newtown Gneiss and the amphibolite would make suitable riprap, road ballast, or coarse construction aggregate. Most of the schist and gneiss in Hartland I and II have little use since they are rich in mica and strongly foliated.

ENVIRONMENTAL GEOLOGY

During the last twenty years there has been a marked increase in the residential population of Newtown and the surrounding area. Farms and wooded areas have been converted to suburban homesites with their networks of scenic and meandering roads. Water and septic service are generally provided by the owner, either on an individual basis or shared by a small group. This land-use pattern is still being followed and appears to be the trend for the future.

The bedrock and surficial geology of any area can provide constraints and guidelines for rational environmental decisions. In order to make specific recommendations, however, a geologist must know the sort of uses planned for the land. The following discussion centers on the geological constraints for suburban development. It is generalized, and applicable to fairly large segments of the quadrangle. An understanding of geologic maps, both bedrock and surficial, is highly desirable for a land-use planner, although not absolutely necessary. Those desiring specific recommendations for a selected homesite should consult the Soil Conservation Service and appropriate engineering firms with geological talent.

Three specific problems confront a prospective homeowner or developer in the Newtown quadrangle: finding an adequate water supply, constructing a satisfactory septic system, and the high costs of foundations and roads. Unstable soils and other geologic hazards are generally not a problem, except for sites located on exceptionally steep slopes, on river banks, or along floodplains. Such areas should be avoided if at all possible.

On-site water supply comes from three sources: a) surficial material, where shallow, inexpensive wells can be dug; b) at the interface between the surficial material and the bedrock; and c) from joints (fractures) in the bedrock. Depending on the depth and nature of the surficial material, the water supply from the first two categories may be adequate, but generally it is contaminated, particularly in areas of high population density. Areas of sand and gravel, such as those southeast of Sandy Brook, north of South Britain, and along many rivers and streams may contain high-yield wells with clean water. Much of the quadrangle, however, is covered with till; wells in this material have low yields and, possibly, water of poor quality. The presence of abundant swamps in the southern part of the quadrangle suggests poor drainage, with rather slow-moving subsurface water. High-density development in some of these areas may be risky unless some central water supply is available. Connecticut Water Resources bulletins should be consulted by those attempting to find an adequate water supply in surficial material. Surficial geology, being mapped by the U.S. Geological Survey, and appropriate maps of the Soil Conservation Service may also be consulted.

Many of the wells in the Newtown area are probably seated in bedrock. Except for the New Haven Arkose in the northeastern part of the quadrangle, the rocks of Newtown are so thoroughly recrystallized that pore spaces and interconnecting channels among individual grains, which carry the water in many sedimentary rocks, are totally absent. The success of a bedrock well in metamorphic rocks, which underlie most of the quadrangle, depends on the number, orientation, and continuity of joints; schistosity is also a factor. Areas of high bedrock-water yield cannot be predicted with any degree of confidence from the data on joints and schistosity shown on the geologic map (pl. 1). Such prediction requires a detailed, systematic survey of joints (spacing, orientation, continuity, width, and the like), coupled with a reliable inventory of existing wells. Until such information is available, joint surveys of specific areas must be done in order to select well sites intelligently. Site selection for bedrock wells in metamorphic rocks is extremely "chancy." Productive wells are found where a number of joint orientations intersect; the trick is to find such areas, using reliable predictive methods.

Many of the above comments apply also to on-site septic systems. Here the effluent must be carried away so rapidly that it does not become stagnant or contaminate nearby wells or streams. Suitable leach fields can be constructed in fairly thick, porous surficial material with a high percentage of sand and gravel. Thin soils in a rocky terrain are generally unsuitable, and there the fields are expensive to install and maintain. Such areas are easily identified on the geologic map (pl. 1) as areas with a "bird's-eye-maple" texture to the topography. Some of the more obvious of these areas are in the north-central part of the quadrangle: north of Cavanaugh Pond, in the Parmalee Road, Papoose Hill, Castle Hill, and Skyline Ridge areas, and just east of the Pomperaug River. Swampy areas are also unfavorable, although limited development might be accommodated in the surrounding hills.

The costly foundation and roadway problems are found in rocky areas with poorly drained soils. Many of those mentioned in the previous paragraph fall into this category. Generally, prospective homeowners must be prepared to pay for extensive blasting in the construction of foundations and road access. Water seepage from fractured bedrock must be anticipated and can be avoided by bringing in suitable fill and drainage tile before the cellars are constructed. Many of these problems are avoided in outcrop-poor areas covered with relatively thick surficial material and marked topographically by smooth elongate hills. Some of these areas are labeled *Qs* on the geologic map (pl. 1).

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