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BEDROCK GEOLOGIC MAP OF THE WILLIAMSTOWN AND NORTH ADAMS QUADRANGLES, MASSACHUSETTS AND VERMONT, AND PART OF THE CHESHIRE QUADRANGLE, MASSACHUSETTS

By Nicholas M. Ratcliffe, Donald B. Potter, and Rolfe S. Stanley

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BEDROCK GEOLOGIC MAP OF THE WILLIAMSTOWN AND NORTH ADAMS QUADRANGLES, MASSACHUSETTS AND VERMONT, AND PART OF THE CHESHIRE QUADRANGLE, MASSACHUSETTS

By Nicholas M. Ratcliffe,[1] Donald B. Potter,[2] and Rolfe S. Stanley[3]

INTRODUCTION

The map area and vicinity (fig. 1) is located near the termination of two prominent highlands of Middle Proterozoic gneiss, the Green Mountain massif of Vermont and the Berkshire massif of Massachusetts. The lowlands surrounding the southern end of the Green Mountain massif are underlain by lower Paleozoic carbonate rocks that are continuous to the north with carbonate rocks of the Vermont Valley sequence and to the south with carbonate rocks of the Stockbridge Valley. At the latitude of Williamstown, Mass., the north-plunging core of the Berkshire massif and the south-plunging core of the Green Mountain massif are separated by carbonate and schistose rocks, in an area known as the North Adams Gap. Rising above the valley carbonates are high ridges of the Taconic Range to the west, and Mount Greylock and associated ridges that are all underlain by phyllitic and schistose rocks of various Taconic allochthons. Major faults, important geographic features, and major lithotectonic units are identified in figure 1.

Mapping was conducted in 1976, 1977, and 1978 as part of the U.S. Geological Survey's (USGS) preparation of the new bedrock geologic map of Massachusetts (Zen and others, 1983), where regional map relations and cross sections incorporating data from this map area may be found. Major geologic problems in the map area include the following: (1) the structure of the south-plunging end of the Green Mountain massif, (2) the structure of the North Adams Gap, (3) the complex structure of the Greylock slice of the Taconic allochthon, and (4) the chronological development of these features during the Taconian (~450 Ma) and Acadian (~390 Ma) orogenies.

Previous geologic maps of the Cheshire 7.5-minute quadrangle at 1:31,680 scale and of the North Adams 7.5-minute quadrangle at 1:24,000 scale were published by Herz (1958, 1961), and parts of both quadrangles have been remapped and are included on this map. The Williamstown quadrangle was last studied by Prindle and Knopf (1932) as part of the old Taconic quadrangle at 1:125,000 scale.

Detailed remapping of the northern part of the Cheshire quadrangle and of the cover sequence rocks in the North Adams quadrangle was conducted during this study, but contacts of Herz (1958, 1961) locally were retained, principally in the southwestern part of the Cheshire quadrangle. On that quadrangle the area on North Mountain, southeast of the Cheshire Reservoir, was remapped by Cullen (1979); his data, supplemented by reconnaissance work of Ratcliffe, were used on the bedrock geologic map of Massachusetts (Zen and others, 1983). These new data suggest that the North Mountain mass is underlain by a thrust fault that carries Middle Proterozoic gneiss, Cheshire Quartzite, and Dalton Formation rocks westward across the Stockbridge Formation exposed in the lowlands. The major tectonic features and geology of North Mountain are shown in figure 1. On Hoosac Mountain[4] and elsewhere in the central, eastern, and southern areas of the North Adams quadrangle, structure symbols taken from Herz's data are plotted on the geologic map. These symbols are indicated by the letter "H" placed next to them. Schistosity or foliation symbols taken from Herz cannot be correlated with certainty with the symbology adopted in this report, although the crenulation cleavage shown by Herz correlates with the F_3 or F_4 structures mapped here. Geology in the Rowe Schist along the eastern border of the map is taken from Chidester and others' (1967) revision of Herz's geology as shown in the North Adams quadrangle, but is modified to include newly recognized thrust faults.

MAJOR LITHOTECTONIC UNITS

Bedrock of the map area is divided into five lithotectonic units that are arranged here in their original west-to-east (restored) positions relative to the foreland of the Taconide deformation belt, which formed in Middle and Late Ordovician time. They are as follows:

1. Autochthonous sequences consisting of Middle Proterozoic gneiss in the core of the Green Mountains and its Late Proterozoic through Middle Ordovician metasedimentary cover sequence (see correlation of map units);
2. Rocks of the parautochthon, which are the Middle Proterozoic core of the Berkshire massif and its unconformable cover sequence of Hoosac Formation and Dalton Formation rocks (and minor Cheshire Quartzite);
3. Allochthonous Hoosac Formation rocks located above the Hoosac Summit thrust;
4. Allochthonous Greylock Schist (of the Greylock slice) and other Taconic allochthons; and
5. Allochthonous rocks of the Rowe Schist located above the Whitcomb Summit thrust. This sequence of rocks is believed to be a tectonic melange unit, and original stratigraphic relations of the mapped units are no longer decipherable.

The south-plunging antiformal termination of the Green Mountain massif is a complex, folded duplex consisting of: (1) a western low-angle thrust fault (Lake Hancock-Thompson Pond thrust, fig. 1), (2) a composite fault slice of recumbently folded cover sequence rocks (Eph Pond slice) and the overlying Stone Hill slice, and (3) the Clarksburg fault along the eastern edge of the

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[4]The term Hoosac Mountain, although not used on the topographic base map, is used in the text to refer to the southern one-third of the Hoosac Range in the North Adams quadrangle. Wolff (1894), working in the present map area and south of it, used the term to refer to high ground east of the town of Cheshire.

Green Mountain massif. Locally, normal faults, such as the Phelps Knoll fault and the Clarksburg fault, cut the packages of nested thrust faults, downdropping rocks to the east, in part along reactivated low-angle thrust faults. Thrust faults bounding the Greylock allochthon and other Taconic allochthons as well as the nested thrust faults on Hoosac Mountain are highly deformed and are locally overturned. The Whitcomb Summit thrust forms the roof of the tectonic packages. It dips moderately to the east, but just east of the North Adams quadrangle (Chidester and others, 1967) it bends steeply downward into a subvertical position in response to severe Acadian deformation.

STRATIGRAPHY

Middle Proterozoic rocks of the autochthon and parautochthon

Middle Proterozoic gneisses consist here of undifferentiated biotite-quartz-plagioclase gneiss (Ybg) and hornblende-biotite-plagioclase gneiss (Ybhg). These units are intruded by the large masses of Middle Proterozoic Stamford Granite of the Cardinal Brook Intrusive Suite (Ratcliffe, 1990) on Clarksburg and Hoosac Mountains. Clarksburg Mountain, northeast of Williamstown, is not labelled on the topographic map but is identified in figure 1. These older gneisses are highly deformed and contain a well-developed gneissosity expressed by granoblastic high-grade minerals, oligoclase, brown hornblende, and locally green diopside. Outside the area to the north, rusty-weathering paragneiss interlayered with these rocks contains coarse sillimanite, microcline perthite, garnet, and biotite; and mafic rocks contain hornblende and relict hypersthene. Gneissosity in these gneisses is folded into isoclinal folds that define a high-grade dynamothermal fabric that is 1 Ga or older (Sutter and others, 1985; Ratcliffe and others, 1988). In the Berkshire massif south of Hoosac Mountain, granitic orthogneiss dated at about 1 Ga is highly folded, containing hornblende-granulite facies minerals and tectonic lineations older than the Early Cambrian and Late Proterozoic Dalton Formation (Ratcliffe and Zartman, 1976). In the North Adams quadrangle, gneisses containing these old fabrics are intruded by the Stamford Granite, as they are in the Stamford, Vt., area of the Green Mountains. These relations indicate that the high-grade Grenvillian event, probably at about 1 Ga, occurred prior to intrusion of the Cardinal Brook Intrusive Suite (Ratcliffe, 1990).

Conversely, the coarse-grained biotite granite of the Stamford Granite contains no relict fabric from this older event and differs markedly in appearance from the granitic orthogneiss such as the Tyringham Gneiss (Emerson, 1898; Ratcliffe and Zartman, 1976) that is widespread in the Berkshire massif, and which contains Middle Proterozoic gneissosity.

The Stamford Granite (Hitchcock and others, 1861) crops out west of Stamford, Vt. (1.6 km north of the Massachusetts-Vermont State line), where it forms the core of the south-plunging Green Mountain massif. It is a coarse-grained porphyritic biotite granite that contains large (1–5 cm) rectangular to ovoidal phenocrysts of microcline perthite partly enclosed in rims of sodic plagioclase. Large anhedral grains of blue-gray quartz as much as a centimeter in diameter form undeformed areas commonly lacking evidence of ductile deformation. Near the border of the pluton the granite becomes finer grained and less biotite-rich, and passes gradationally into a white, medium-grained quartz-microcline-plagioclase aplite. Locally, inclusions of well-layered biotite- and (or) hornblende-quartz-plagioclase gneiss are found within the aplitic facies. Tabular microcline perthite phenocrysts and biotite schlieren define a subtle igneous flow structure in many outcrops, as do irregular intrusive dikes of either more mafic or more felsic rock. Cognate xenoliths of fine-grained aplite and ferrodiorite 0.5–2 m in diameter are found as inclusions within the coarse-grained granite.

Where deformed, the rock is strongly foliated, well lineated, and mylonitic, and consists of abundant muscovite, epidote, and highly recrystallized quartz. The low-grade mineral assemblages of the shear zones indicate that the mylonitic and augen texture characteristic of the rock is the result of Paleozoic deformation, as noted by Prindle and Knopf (1932).

The Stamford Granite on Hoosac Mountain closely resembles the type Stamford Granite of Vermont, except for the greater amount of Paleozoic deformation and foliation present on Hoosac Mountain. Nonetheless, coarse-grained oligoclase-mantled microcline perthite phenocrysts up to 5 cm long are locally preserved on Hoosac Mountain. Internal igneous flow structure is locally present but could not be mapped owing to subsequent deformation.

The contact with layered, biotite-hornblende-plagioclase gneiss is well exposed along the western side of Hoosac Mountain. A narrow selvage of aplitic biotite granite (Ysa) that contains xenoliths of country rocks and that locally resembles an intrusive breccia is mapped on Hoosac Mountain. The transition into coarser grained Stamford takes place over a distance of 0.25 km. The exact location of this contact is difficult to map because abundant irregular pods and stringers of pegmatite are present in the finer grained aplite, and the aplite itself contains great variations in grain size and a widely varying percentage of microcline phenocrysts.

The intrusive contact between Stamford Granite and well-layered biotite-hornblende-plagioclase gneiss and minor amphibolite is exposed at an elevation of 1850 ft in small cliffs 91 m north of the power line, east of the village of Zylonite in the North Adams quadrangle. Here a small Paleozoic isoclinal syncline with limbs of Stamford Granite and a core of biotite gneiss is exposed. Along the limbs of the syncline, layers in the biotite gneiss are truncated by the granite contacts. In exposures 61 m north, fragments of biotitic gneiss are included in porphyritic Stamford. Both the Stamford and the biotite gneiss are folded together in tight isoclines having nearly vertical axial surfaces, and a parallel foliation is expressed in both rocks. Because subvertical folds are present in nearby cover rocks, this later folding is regarded as Paleozoic. The pre-intrusive gneissosity, however, is of Middle Proterozoic age.

Chemical analyses of the Stamford Granite from Clarksburg Mountain and Hoosac Mountain show that the rock in both areas consists of similar peraluminous granitic and quartz monzonite based on O'Connor's (1965) normative feldspar classification. Chemical analyses are given in table 1. Mafic enclaves, as much as 5 m thick, consisting of brown hornblende, biotite, plagioclase, and microcline perthite ± augite ± hypersthene, form irregularly shaped to straight-walled bodies within the Stamford Granite in the Green Mountains. These dike-like features show capturing of microcline perthite phenocrysts and flow orientation of feldspar phenocrysts. They are interpreted as cogenetic ferromonzonitic segregations within the Stamford. One of these dikes (sample 172), exposed at the eastern margin of the massif near sample locality 1, was incorrectly referred to as a probable Late Proterozoic diabase dike by Ratcliffe and so shown on the Massachusetts bedrock geologic map as €Zd (Zen and others, 1983). On the basis of chemistry and mineralogy this dike and other inclusions found north of the map area are not diabasic in texture or composition (see table 1).

Uranium-lead dating of zircon obtained from sample locality 1 in the North Adams quadrangle yields a nearly concordant upperintercept concordia age of 959±4 Ma (Karabinos and Aleinikoff, 1988, 1990). Likewise a uranium-lead-dated zircon age of about 950 Ma from the Stamford Granite, collected in the north-central part of the Windsor 7.5-minute quadrangle (which adjoins the North Adams quadrangle on the south), was obtained by Beth Harding and Samuel Mukasa (written commun., 1988). These data and field relations indicate that Middle Proterozoic deformation of rocks of the Green Mountain massif and of the Berkshire massif occurred prior to about 960 Ma, thus establishing the young or upper age-limit for the Grenville orogeny in this area.

Late Proterozoic and Early Cambrian clastic rocks of the autochthon and parautochthon

Two generally similar quartzofeldspathic stratigraphic sections of Late Proterozoic and Early Cambrian age unconformably overlie Middle Proterozoic rocks, one on the Green Mountains and the other on Hoosac Mountain. The latter section is dominated by abundant schist and lesser amounts of quartzite in all of the units of the Hoosac and Dalton Formations; for example, quartzite of the Dalton (€Zd) on Hoosac Mountain contains more than 70 percent dark schistose feldspathic quartzite. The Dalton of the Green Mountains, however, contains only localized beds of schist in a predominantly quartzofeldspathic section of quartzite, feldspathic quartzite, and schistose quartzite. Comparative stratigraphic sections and thicknesses (fig. 2) show that the abundance of schist increases eastward as the abundance of quartzite decreases. Vitreous quartzite of the Cheshire Quartzite is present in each section, but the quartzite is markedly thinner in eastern exposures.

The well-developed unconformity on the Stamford Granite on Clarksburg Mountain is marked by a continuous belt (see map) of schistose conglomerate that locally contains fragments of Stamford and pebbles of blue quartz; most of the pebbles and cobbles, however, are milky-white to gray, fine-grained quartzite. The Stamford Granite immediately beneath the Dalton is epidotic, magnetite studded and muscovite rich in a zone up to 5 m thick, that is interpreted as a metamorphosed Late Proterozoic weathering profile. The Dalton Formation passes upward into vitreous quartzite of the Cheshire Quartzite, and the Cheshire is interpreted to pass upward into dolomite marble of the Stockbridge Formation in the lowlands at the foot of Clarksburg Mountain, although the contact is not exposed. Subsurface data from water wells in the vicinity of White Oaks, north of Williamstown (Freeman Foote, oral commun., 1979), indicate dolomite marble in that area.

The basal part of the stratigraphic section on Hoosac Mountain differs markedly from that on the Green Mountains. The well-exposed unconformity on the north end of Hoosac Mountain has albitic granofels (€Zhdab) and conglomerate (€Zhdc) of the Hoosac Formation resting directly on Stamford Granite (Herz, 1961). Distinctive albitic conglomerates and granofels up to 200 m thick are typical of the basal Hoosac Formation. These gray and white albitic rocks are overlain disconformably by a prominent but thin, dark-gray, muscovite-biotite-plagioclase-garnet-quartz schist (€Zhdg) that rests directly on Middle Proterozoic gneiss on the western slopes of Hoosac Mountain. This garnet schist unit has been traced by Norton (1969) southeastward into the Windsor quadrangle, where it also marks the base of the Late Proterozoic and Paleozoic section on the overturned limb of the Hoosac nappe (Christensen, 1963).

Rusty-brown to dark-gray, albite-spotted granofels and schist (€Zhd) overlies the garnet schist unit and includes thin gray and white pinstriped feldspathic quartzite layers 1–10 cm thick and locally beds of pebbly quartzite thick enough to map (€Zhdp). Overall unit €Zhd resembles dark-colored schists mapped by Skehan (1961) within the Heartwellville Schist in the Wilmington, Vt., area to the north. On Hoosac Mountain unit €Zhd passes upward into silvery-gray, muscovitic and lustrous schist typical of the darker schists (€Zds) of the Dalton Formation on Clarksburg Mountain. On the slope east of Adams, unit €Zds passes upward into feldspathic quartzite and vitreous quartzite typical of the Dalton Formation. Feldspathic quartzite of the Dalton Formation (€Zd) beneath the Hoosic thrust at Adams passes upward through interbedding into a thin, 75-m-thick belt of Cheshire Quartzite (€c), as shown by Herz (1961), that is overlain by unit A of the Stockbridge Marble.

The unconformable cover on Hoosac Mountain, above the Hoosic thrust as described above, contains beds typical of the Dalton Formation overlying a section of albitic schists typical of the Hoosac Formation. These observations lead to the general conclusion that the Hoosac Formation is an eastern and somewhat older equivalent of the Dalton Formation. The Dalton and Hoosac are therefore viewed as the basal part of a transgressive sequence that becomes younger westward and that was deposited unconformably on the Middle Proterozoic basement of the Green Mountains and Hoosac Mountain.

The age of the Cheshire Quartzite and Dalton and Hoosac Formations is given by Lower Cambrian *Olenellus* and *Hyolithes* fossils found in vitreous quartzite of the Cheshire Quartzite, on the west flank of the Green Mountains in the Pownal 7.5-minute quadrangle (Walcott, 1888, p. 235). Walcott (1888, p. 236) also reported *Olenellus*(?) fragments from the western side of Clarksburg Mountain, from a point 30 m above the unconformity on the western summit. According to his description, the latter locality actually occurs within the Cheshire Quartzite on the slopes north of Mason Hill. At this locality in the south-central part of the Pownal quadrangle, the contact relations with the gneiss are complicated by faulting and by excessive attenuation in an overturned section in the hanging wall of the Thompson Pond thrust (Ratcliffe and others, 1988). The suggestion that the fragments were obtained from 30 m above the unconformity is suspect, and therefore the data do not rule out the possibility of a Late Proterozoic age for some of the Dalton Formation.

Because rock types common to the Dalton and Hoosac Formations interfinger, the Lower Cambrian age of the Cheshire and the inferred Late Proterozoic age of the Dalton suggest a comparable age range for the Hoosac Formation as well.

Cambrian to Lower Middle Ordovician autochthonous carbonate and pelite sequence

Lower Cambrian to Lower Ordovician carbonate rocks of the Stockbridge Formation crop out on the northwestern flank of Clarksburg Mountain in the Eph Pond and Stone Hill slices, and in the North Adams and Adams area. A narrow, southwest-trending belt of marble in the Cheshire Harbor area connects the carbonate rocks of the Williamstown area to the type area of the Stockbridge Formation to the south (see Ratcliffe, 1984). The narrow belt of carbonate rocks in the northwestern part of the Williamstown quadrangle (fig. 1) is traceable northward into the Vermont Valley sequence of Vermont.

The terminology used for the Stockbridge Formation follows that established by Zen (1966) in southwestern Massachusetts, which has been here extended to cover the Stockbridge in all of western Massachusetts. Dolomitic units A, B, and C are fairly easily recognized and distinguished. Especially notable is the lithic variation in unit B described in the stratigraphy of the Stone Hill and

Table 1A.–Major-oxide and normative mineral composition of the Stamford Granite (Ysg) from the Green Mountain massif and from Hoosac Mountain, in the Williamstown, North Adams, and Stamford quadrangles, Massachusetts and Vermont

[Data in weight percent. Analyses by rapid-rock techniques described by Shapiro (1975). Analysts: N. Rait and H. Smith, U.S. Geological Survey, Reston, Va. — , no data]

	Green Mountains										Hoosac Mountain			
	Coarse facies						Biotite-hornblende granite		Fine-grained border facies (aplite)	Mafic dike	Coarse facies			Emerson (1917, p. 151)
Sample No.	2	3E	18A	170	171	173	6	11	149	172	102-32	176	174	
Major-oxide and total sulfur composition														
SiO_2	68.3	70.8	70.0	67.6	69.2	70.7	64.5	66.4	72.5	50.5	68.0	69.4	69.2	67.12
Al_2O_3	16.4	14.2	14.4	16.0	16.4	14.9	14.8	14.7	14.1	14.9	15.4	14.0	14.7	14.97
Fe_2O_3	1.0	1.0	1.5	1.5	1.1	.90	1.8	1.3	1.1	2.6	2.0	1.9	2.1	2.61
FeO	1.5	2.1	2.4	1.7	1.2	1.7	4.8	4.6	1.5	8.5	2.2	2.6	1.6	2.19
MgO	.12	.17	.15	.17	.12	.20	1.1	.92	.38	3.5	.36	.82	.40	.54
CaO	2.1	1.7	1.8	2.4	2.2	2.1	3.1	3.1	1.3	7.7	2.0	.83	1.3	1.69
Na_2O	3.5	3.1	3.1	3.5	3.5	3.2	3.2	2.8	2.8	2.2	3.6	2.8	3.1	3.92
K_2O	6.6	5.3	5.7	5.9	6.4	5.8	4.2	4.3	5.9	3.7	5.4	5.8	5.9	5.15
H_2O+	.36	2.3	.54	.55	.32	.37	.62	.56	.33	1.0	.16	.04	.60	.19
H_2O-	.05	.03	.03	.02	.02	.08	.03	.02	.06	.06	.04	.03	.02	—
TiO_2	.21	.32	.36	.29	.23	.24	1.1	.98	.24	2.5	.39	.42	.34	.37
P_2O_5	.15	.17	.18	.15	.14	.14	.45	.40	.21	1.0	.19	.18	.18	.14
MnO	.04	.05	.05	.04	.03	.04	.07	.06	.03	.15	.06	.04	.04	.02
CO_2	.02	.06	.07	.01	.08	.03	.07	.08	.05	1.5	.01	.03	.04	—
ZrO_2	—	—	—	—	—	—	—	—	—	—	—	—	—	.03
BaO	—	—	—	—	—	—	—	—	—	—	—	—	—	.19
Total	100.35	101.3	100.28	99.83	100.94	100.40	99.84	100.22	100.50	99.81	99.81	98.89	99.52	99.13
Total S	.10	.14	.088	.12	.09	.077	.093	.11	.14	.97	.027	.14	.13	—
Normative mineral composition														
Apatite	0.37	0.40	0.44	0.36	0.34	0.34	1.08	0.94	0.50	0.43	0.44	0.44	0.44	.34
Zircon	—	—	—	—	—	—	—	—	—	—	—	—	—	.04
Ilmenite	.39	.61	.68	.56	.44	.45	2.09	1.87	.45	.74	.80	.65	—	.39
Orthoclase	39.02	31.67	33.79	35.0	37.80	34.3	25.05	25.55	34.9	31.9	34.5	35.2	35.2	30.8
Albite	29.63	26.49	26.33	29.9	29.6	27.1	27.06	23.7	23.7	30.5	23.9	26.5	26.5	33.5
Anorthite	9.51	6.62	8.56	10.5	10.3	9.1	13.8	14.9	6.32	9.8	3.87	6.40	6.40	8.1
Corundum	0.0	.98	0.0	0.0	0.0	0.0	0.0	0.0	1.2	.03	1.72	.9	.90	—
Magnetite	1.46	1.45	2.19	2.2	1.59	—	2.64	1.9	1.60	2.9	2.75	3.08	3.08	3.8
Diopside	.68	0.0	.27	1.14	.43	1.02	1.11	.24	0.0	0.0	0.0	0.0	0.0	.51
Hypersthene	1.59	3.52	2.90	1.80	1.52	2.8	7.86	8.06	2.61	2.70	4.6	.86	.86	2.69
Quartz	17.85	27.55	25.07	18.43	18.98	24.1	20.0	23.25	29.66	20.78	27.10	25.61	25.6	19.68
Total	100.5	99.29	100.23	99.89	101.0	99.21	100.69	100.41	100.94	99.78	99.68	99.64	98.98	99.85

Table 1B.–Major-oxide and normative mineral composition of mafic inclusions and unusual enclaves in the Stamford Granite (Ysg) from the Stamford quadrangle, Vermont, and from the Vermont part of the Williamstown and North Adams quadrangles

[Data in weight percent. Analyses by rapid-rock techniques described by Shapiro (1975). Analysts: N. Rait and H. Smith, U.S. Geological Survey, Reston, Va. — , no data]

Field No.	W-1236	W-1239B	W-1237B	W-1237A	W-1237D	W-1238A	W-1233	W-517B
			Major-oxide composition and loss on ignition (LOI)					
SiO_2	47.7	49.2	44.8	46.5	68.7	54.3	70.6	71.9
Al_2O_3	15.1	15.0	18.1	17.6	14.3	14.3	15.7	13.3
Fe_2O_3*	14.5	13.2	14.4	15.1	4.97	13.2	1.35	2.95
MgO	7.82	6.37	7.13	8.22	.20	3.25	.45	.56
CaO	10.3	9.67	9.14	7.63	2.25	7.53	2.60	1.57
Na_2O	1.45	2.60	1.30	1.29	2.84	2.88	4.66	2.49
K_2O	1.44	1.91	1.26	1.68	2.27	1.33	2.57	5.62
TiO_2	1.62	1.47	3.88	1.64	.44	2.28	.12	.46
P_2O_5	.24	.23	<.05	<.05	.11	.45	.07	.10
MnO	.18	.1	.24	.19	.05	.19	<.02	<.02
LOI at 900°C	.14	.11	.34	.35	.34	.65	.78	.48
			Normative mineral composition					
Apatite	0.6	0.5	0.1	0.1	0.3	1.1	0.2	0.2
Zircon	—	—	—	—	—	—	—	—
Ilmenite	3.1	2.8	7.5	3.2	.9	4.4	.2	.9
Orthoclase	8.6	11.5	7.5	10.1	31.6	8.0	15.5	33.7
Albite	12.4	22.4	11.1	11.1	24.4	24.8	40.2	21.4
Anorthite	30.8	24.0	40.3	37.9	10.6	22.5	12.7	7.2
Corundum	0.0	0.0	0.0	0.0	.1	0.0	.7	.5
Magnetite	4.6	4.4	7.9	4.6	2.4	5.6	.7	1.4
Diopside	15.8	19.0	4.2	.2	0.0	10.3	0.0	0.0
Hypersthene	20.4	6.2	20.5	26.0	4.0	12.3	2.1	3.2
Olivine	4.0	9.5	0.0	7.1	0.0	0.0	0.0	0.0
Quartz	0.0	0.0	1.4	0.0	26.0	11.5	27.7	31.6
TOTAL	100.3	100.3	100.5	100.3	100.3	100.5	100.0	100.1

*Total iron as Fe_2O_3.

Eph Pond slices. Elsewhere unit B cannot be as finely subdivided and is shown only as Ꞓsb on the map.

Calcitic marble units E and G contain discontinuous sandy beds which locally are distinguished as units D and F. The distinction between calcitic marbles of unit E and unit G is not always easy to make; in certain areas near Cheshire Harbor and west of the Cheshire Reservoir, rocks mapped as unit G and as Bascom Formation by Herz (1961) may not be correctly assigned in this work because of poor exposure.

Dark- to medium-blue-gray, glistening calcite marble (unit G), containing boudins of beige dolostone, crops out at the western foot of Mount Greylock in pastures north of Hopper Brook. Walcott (1888, p. 238) reported gastropods from these outcrops.

The Walloomsac Formation consists of a thick section of dark-gray to black carbonaceous schist or phyllite which regionally rests unconformably on older carbonate rocks, and which locally rests directly on basement (Norton, 1969). Near the base of the Walloomsac Formation a thin, discontinuous, dark-blue-gray- and light-gray-mottled calcite marble occurs, which locally contains abundant bryozoan fragments, cup corals, pelmatozoan hash, and conodonts that indicate the base of the Walloomsac is Rocklandian (middle and late Caradocian) or younger (Zen and Hartshorn, 1966; Ratcliffe, 1974).

The base of the Walloomsac Formation is no older than Black Riverian, as determined from shelly macrofossils (Zen and Hartshorn, 1966), but probably is younger (Rocklandian and (or) Kirkfieldian), as determined from conodonts from the basal beds near No Bottom Pond in the State Line 7.5-minute quadrangle (Ratcliffe, 1974) and near Queechy Lake in the Pittsfield West 7.5-minute quadrangle (Ratcliffe, 1978). At these two localities, conodonts indicative of conodont zone 8 are present on the basis of reports to Ratcliffe from John Huddle (USGS, written commun., 1968) and from John Repetski and Anita Harris (USGS, written communs., 1984). The upper age limit for the Walloomsac is given by graptolites (Potter, 1972) belonging to the *Climacograptus bicornis* Subzone (originally defined by Berry, 1960) but subsequently redefined by Finney (1986) to be correlative with the British *Diplograptus multidens* Zone, or Caradocian. Utilizing the time scale of Tucker and others (1990) places the time of deposition of the Walloomsac Formation in the map area between about 454 Ma (age of the Rocklandian Stage of the U.S. Mohawkian Series) and the top of the *C. bicornis* Subzone, or Middle Caradocian. The end of the Caradocian is estimated by Tucker and others (1990) to be 450 Ma. A $^{39}Ar/^{40}Ar$ model age of 446±6 Ma (Hames and others, 1990) on hornblende at staurolite grade from the Walloomsac Formation, in southwestern Massachusetts in the same strike belt as the map area, further limits the time of deformation and deposition of the Walloomsac as Caradocian. The age of the Walloomsac Formation, therefore, based on the time scale of Ross and others (1982), is upper Middle Ordovician.

In eastern exposures throughout the Stockbridge Valley, a somewhat thicker, more impure schistose and albitic marble replaces the thin basal limestone present in the western exposures. This unit, Owm, is dominant in the map area and locally forms exposures or belts as much as 100 m thick. Contacts with the normal schist of the Walloomsac Formation are gradational and the boundary between schistose marble (Owm) and schist (Ow) is drawn at about 50 percent calcite. Well-laminated, hematite-spotted quartzite (Owq) forms thin beds in unit Owm as well as individual exposures up to 20 m thick consisting primarily of quartzite. Unit Owq is best developed in areas east of Mount Greylock in and around The Bellows Pipe, where it laterally replaces Owm as the basal unit of the Walloomsac Formation. The Walloomsac rests on unit G down to unit B of the Stockbridge Formation in the map area; elsewhere it rests on all units of the Stockbridge.

Stone Hill and Eph Pond slices

A well-exposed, apparently continuous section from the Dalton Formation up to unit C of the Stockbridge Formation is exposed on Stone Hill and in the pastures extending south to South Williamstown. This section is marked by abundant schist (ꞒZdbs) in the Dalton, a very thin Cheshire Quartzite and a markedly thin Stockbridge section. The total thickness from unit Ꞓsc (Clarendon Springs Dolomite of the Vermont Valley sequence) down to the base of the exposed Dalton measures approximately 1,000 m, whereas a similar section in the Vermont Valley sequence in the Bennington, Vt., area totals about twice that value. Exposed contacts show Cheshire Quartzite grading into unit A of the Stockbridge Formation on the southwestern slopes of Stone Hill near the southern termination of the quartzite. Four subunits of Stockbridge unit B are mapped, including a thin quartzite at the contact with unit C ($Ꞓsb_4$) that may represent the southernmost and greatly thinned occurrence of the Danby Formation (Keith, 1932) of the Vermont Valley sequence.

The overall thinness of the section, the abundant schist in the Dalton Formation, and the very thin Cheshire Quartzite of the Stone Hill slice resemble characteristics present in the Dalton, Cheshire, and Stockbridge rocks east of the Green Mountains, in the Adams area. On the basis of these data and structural arguments, the Stone Hill section is interpreted to be a thrust slice of shelf-sequence rocks that rooted east of the Green Mountains.

Allochthonous rocks

Allochthonous rocks that are believed to be in far-travelled thrust slices consist, from west to east on the map, of the Nassau(?) Formation of Berlin Mountain and ridges south of South Williamstown (fig. 1), the Greylock Schist of the Greylock allochthon, including rocks as far west as the Clarksburg fault, the Hoosac Formation above the Hoosac Summit thrust, and the Rowe Schist above the Whitcomb Summit thrust. The name Nassau Formation has been applied to green and purple chloritic slates and phyllites of the Giddings Brook slice (Potter, 1972; Ratcliffe and Bahrami, 1976) and to the rocks of the Chatham slice (Ratcliffe, 1974) in the State Line 7.5-minute quadrangle. Similar greenish and purple phyllites of the Perry Peak slice that overlie the Chatham slice have been correlated with the Nassau Formation by Ratcliffe (1974). These phyllites are coextensive with rocks of the Brodie Mountain area in the extreme southwestern part of the Williamstown quadrangle. On this basis, greenish phyllites on Brodie Mountain are here referred to as the Nassau(?) Formation (ꞒZng?). This usage follows that of the bedrock geologic map of Massachusetts (Zen and others, 1983). With increasing metamorphic grade eastward, purplish (hematitic) phyllites of the Nassau Formation change gradually into dark-dusty-red and finally dark-gray phyllites with only a faint purplish cast. This metamorphic change probably is responsible for the general absence of purplish phyllite in the Greylock Schist in the map area.

In the correlation of map units, these rocks are arranged in their inferred, relative west-to-east depositional positions. The Hoosac Formation above the Hoosac Summit thrust closely resembles the Hoosac beneath the Dalton Formation on Hoosac Mountain. In addition, the Nassau(?) Formation and Greylock Schist lack the abundant gray albitic rocks present in the Hoosac Formation.

Therefore the rocks of the Hoosac Summit slice are not considered the source of the Greylock or other Taconic allochthons. The abundant greenstones and the lack of albitic rocks in the Rowe Schist indicate that the Taconic allochthons were most probably derived from a now-missing or nonrepresented section rooted between the rocks of the Hoosac Summit slice and the Whitcomb Summit slice (Ratcliffe, 1979b).

The Hoosac Formation above the Hoosac Summit thrust consists predominantly of two units, a light-gray to rusty-brown, albitic granofels and albitic muscovite-biotite±garnet schist (€Zhab), and a lustrous, silvery-green to gray-green, ilmenite-chlorite-sericite-quartz±garnet±chloritoid phyllite or schist (€Zhg). This latter unit resembles closely unit €Zg of the Greylock Schist and €Zng? of the Nassau(?) Formation. A minor unit consisting of distinctly green, magnetite-studded, chlorite-sericite-white-albite granofels or quartz-garnet schist (€Zhgab) replaces €Zhab at or near the contact with €Zhg. This green albitic Hoosac resembles the green albite schist and granofels present in the Greylock Schist (€Zgab) and that within the Nassau(?) Formation (€Zna?). The distribution of units in the allochthonous Hoosac Formation suggests either rapid facies changes or low-angle internal discordances, perhaps premetamorphic thrust faults.

Rocks of the Greylock allochthon appear to have greater variability than those of the Hoosac Formation, but a more regular stratigraphy. In particular, gray and gray- and white-spotted, biotite-albite granofels so characteristic of the Hoosac Formation are all but absent from the Greylock Schist (Ratcliffe, 1979a). Distinctive blue-quartz pebble conglomerate and green vitreous quartzite (€Zgq) form minor beds in the Greylock Schist. Although not necessarily correlative, the vitreous quartzites in the map area very closely resemble quartzites mapped as Curtis Mountain Quartzite or as the Zion Hill Quartzite Member of the Nassau Formation of Columbia and Rensselaer Counties, N.Y. (Bird, 1962; Potter, 1972).

On Mount Greylock, rare thin beds of salmon- to pink-weathered dolomite marble as much as 1 m thick are associated with the pebbly quartzite (€Zgq) and the dark-gray, quartz-knotted schist (€Zgb) of the Greylock Schist. These marble beds occur at: (1) the east side of The Bellows Pipe, (2) the south end of Ragged Mountain, (3) in unit €Zgb at the west foot of Saddle Ball Mountain near the Cheshire-Williamstown quadrangle border, and (4) in the main body of Greylock Schist (€Zg) near the contact with €Zgb in steep stream valleys feeding into The Hopper from the east at 2800 ft elevation. At the latter locality, centimeter-thick beds of yellowish-beige laminated dolostone occur interbedded in soft, silvery-green chloritoid-chlorite-sericite-quartz phyllite that is pitted from weathered ankerite.

The bulk of the Greylock Schist is characterized by soft, lustrous green phyllite and quartz phyllite, locally rich in chloritoid, and rare beds of purplish-gray phyllite (€Zg). At lower metamorphic grades these purplish beds may have had the green and purple mottling characteristic of the Nassau Formation or Mettawee Member of the Nassau Formation of the Giddings Brook slice. The Greylock Schist lacks the greenstones present regionally in the Hoosac Formation and abundant in the Rowe Schist. It also lacks graywackes and metabasaltic rocks contained in the Nassau Formation of Rensselaer and Columbia Counties, N.Y. Rocks mapped as Nassau(?) Formation (€Zng? and €Zna?) are indistinguishable from the Greylock Schist, and the change in symbology is arbitrarily drawn at the Hemlock Brook fault.

At the north end of Brodie Mountain, the Walloomsac Formation contains hundreds of thin slices of rocks of the Berlin Mountain slice: green phyllite (€Zng?) and albite phyllite (€Zna?) of the Nassau(?) Formation. Slices are 0.5 m to several meters thick and as much as 500 m long. Together they constitute 10–30 percent of the Walloomsac terrane. That they are tectonic slices and not clasts in a wildflysch breccia is indicated by the similarity between the rocks that constitute these slices and those present in the Berlin Mountain slice. Also, the contacts between some of these slices and the enclosing Walloomsac are silicified, although some slices have sharp contacts with the Walloomsac and show no evidence of faulting.

STRUCTURAL GEOLOGY

Thrust faults demark the boundaries between the lithotectonic units. The lithotectonic units and packages of rocks contained within the units have all been multiply deformed. In addition, the structures developed from point to point across the map area are variably affected by post- to late-metamorphic thrust faulting. Folding of early emplaced faults bounding the Taconic allochthons is extreme. The Taconic allochthons, and the Greylock allochthon, for example, are highly folded into post-emplacement recumbent folds. The intensity of this post-thrust deformation decreases to the west. Although we have assigned relative ages to cleavages and to axial traces across the map area, we cannot be entirely certain of the correctness of the ages. Because of the multiple generations of thrust faulting and the observed progressive increase in folding near thrust faults, structures may have developed in part within lithotectonic units or been produced during repeated and noncoeval faulting across the map area. It is likely that both the duration and complexity of folding and of faulting are far greater in the eastern part of the map area than in the western part. Table 2 presents the correlation of structural features as we interpret them.

Four generations of folds are recognized in all the Paleozoic and Late Proterozoic cover rocks. From the youngest to the oldest they are as follows:

1. **F_4 folds**—Northwest-trending upright folds, expressed by a weak to moderately strong crenulation cleavage lacking mineral-growth fabric parallel to the cleavage;
2. **F_3 folds**—Northeast- to north-trending upright to overturned folds whose amplitude and frequency increase eastward. In the western part of the map area, folds are rather broad and upright and they lack foliation. At the foot of Hoosac Mountain and eastward, F_3 folds are intensely developed and have a strong foliation. The eastern margin of the Mount Greylock region, extending from the Farnams Hill synform (west of the Cheshire Reservoir) to North Adams, contains large-amplitude areally persistent F_3 folds that appear to have buckled the hanging wall of the Clarksburg fault. Near Constitution Hill in the southwestern part of the Cheshire quadrangle, the large right-handed bend of the garnet isograd that extends northeastward past North Adams reflects the sense of the F_3 folding in this area (fig. 1);
3. **F_2 folds**—Characterized by weak to well-developed axial surface foliation west of the Clarksburg fault. East of the Clarksburg fault, in the Greylock allochthon and on Hoosac Mountain, F_2 folds are intensely penetrative, and they almost completely transpose the earlier S_1 schistosity. Very high amplitude folds of F_2 generation are present on Mount Greylock and in the Hoosac Formation above the Hoosac Summit thrust. Locally on Mount Greylock, and on Hoosac

Mountain and throughout the Hoosac Range, F_2 folds possess strong transposition structure characterized by retrogression of garnets near thrust faults; F_2 folding is synchronous with thrust faulting and imbrication;

4. **F_1 folds**—Recognized in all lithotectonic units. They are truncated by major faults. F_1 folds commonly trend east over wide areas, have well-developed axial surface foliation, and are very highly refolded. Internal F_1 folds in the Eph Pond and Stone Hill slices, in the Greylock allochthon, and in the Hoosac Formation above and below the Hoosac Summit thrust, are truncated by regional thrust faults.

Foliation or schistosity is present in the axial surfaces of F_1, F_2, and (in eastern areas) F_3 folds. Elsewhere, F_3 and F_4 folds are commonly expressed by a slip or crenulation cleavage. Near thrust faults such as the Hemlock Brook fault, the Hoosic thrust, and the Hoosac Summit thrust, earlier F_1 schistosity (S_1) is plicated, and garnet or biotite locally is altered to chlorite-muscovite spears. Near the Clarksburg fault, F_1 and F_2 folds and (S_1–S_2) foliations are deformed. Brecciation along the Hemlock Brook and Clarksburg faults is responsible for development of gouge and for pulverization of S_1 and S_2 foliations.

Emplacement of the Taconic allochthons on Berlin and Brodie Mountains preceded development of the first regional foliation in those areas, whereas emplacement, or at least final emplacement, of the Greylock allochthon was accompanied by the formation of metamorphic structures of F_2 generation.

Eph Pond and Stone Hill slices

The large area of Stockbridge Formation carbonate rock lying northwest of Mount Greylock from Williamstown to South Williamstown is interpreted to be a composite thrust sheet consisting of two main slices, the Eph Pond and Stone Hill slices, that are truncated at their eastern boundary by the later Clarksburg fault and by subsequent normal-fault reactivation of the Clarksburg fault. The lower Eph Pond slice contains a large syncline, overturned to the north, that has an east-trending axial trace. The overturned southern limb of this syncline is overlain at Buxton Hill by the Stone Hill slice, which is marked by a thin sliver of mylonitic and highly folded Stamford Granite. The hanging wall of the Stone Hill slice is a truncated, right-side-up anticline consisting of a very thin section of Stockbridge Formation carbonate rocks and very thin Cheshire Quartzite. As mentioned previously, the stratigraphic section present in the Stone Hill slice resembles rock present on the eastern limb of the Green Mountain massif and in the Adams area east of Mount Greylock.

Intensely developed (F_1) east-trending isoclinal folds having east-trending hinge lines in the Eph Pond slice duplicate those found in the Dalton Formation and Cheshire Quartzite mantling the south-plunging end of the Green Mountain massif. Early minor structures are present within the Stone Hill slice but do not appear to be of large enough amplitude to affect the outcrop patterns in this slice.

Cross sections *B–B′*, *C–C′*, and *E–E′* best portray the interpretation of the Eph Pond and Stone Hill slices. These interpretations follow that used on section *A–A′* of the bedrock geologic map of Massachusetts (Zen and others, 1983). The slices root on the east side of the Green Mountains from a deeply buried, faulted anticlinal structure that involves basement rock beneath the Hoosic thrust. Because the buried fault is locally coplanar with the Clarksburg fault, as for example from the Hoosic River at North Adams northward to Clarksburg, the older fault trace does not appear in the hanging wall of the Clarksburg fault. An alternative interpretation, which was not adopted, would root the Eph Pond and Stone Hill slices in the Adams-North Adams area just beneath the Hoosic thrust, in the hanging wall of the Clarksburg fault. This would require that an unmapped fault be present in the Stock-

Table 2.–Chronology of Paleozoic structural events

Structural event	Fold phase	Metamorphism event	Expression	Crystalloblastic texture	Age or orogeny
Normal faulting	–	–	Breccias	–	Mesozoic?
Northwest cross folding	F_4	–	Slip or crenulation cleavage	None	Acadian.
Imbricate thrust faulting (Hemlock Brook and Clarksburg faults).	F_3	M_3	Crenulation cleavage; slickensides; textural overprinting of F_2 structures.	Muscovite-chlorite second garnet growth; late albite overgrowths.	Acadian?
Movement on Hoosic thrust	–	–	?	?	?
Final emplacement of Greylock slice and movement on Hoosac Summit and Whitcomb Summit thrusts, where latest movement may have been Acadian.	F_2	M_2	Mylonitic foliation; tight, strongly overturned folds having a late-generation schistosity as axial surface, superposed on multiple cleavages in or near thrust faults.	Muscovite-biotite in phyllonitic fabric; garnet retrogression to chlorite spears.	Taconian.
Emplacement of Eph Pond and Stone Hill slices.	–	–	Mylonite gneiss; mylonitic foliation along faults.	Synmetamorphic mylonitic fabrics; dynamic recrystallization of muscovite-biotite and plagioclase.	Taconian.
Regional folding on north-northeast trends; folding of early Taconic allochthons.	F_1	M_1	Strong foliation produced subparallel to bedding.	Chlorite-muscovite grade in west to garnet grade on Hoosac Mountain.	Taconian.
Initial emplacement of Taconic allochthons.	F_0	?	Early internal folds in Taconic allochthons west of map area.	–	–

bridge Formation in the valley of the Hoosic River, extending north from the village of Zylonite to North Adams.

Emplacement of the Eph Pond and Stone Hill slices probably postdated the earliest deformation of the cover sequence but predated thrust faulting on the Clarksburg and Hemlock Brook faults as well as buckling of the Green Mountain core. Late folds associated with this buckling event extend from the basement of the Green Mountain massif up into the stacked slices to the south. A slice of Walloomsac Formation locally carrying Taconic allochthonous rocks (Sweets Corner slice; see section *B–B′*) overlies the Eph Pond and Stone Hill slices and may represent a third and higher level detachment. Thrust faulting on the Clarksburg fault may have been followed by extensional or low-angle normal faulting late in the tectonic history, as shown by the zones of brecciation and retrogression found in the Clarksburg fault as well as along the unnamed fault along the northwestern base of Mount Prospect. Similar normal, late low-angle faulting is proposed for the Hemlock Brook fault and the Phelps Knoll high-angle fault west of Buxton Hill and Stone Hill.

Neither solution outlined above for the Eph Pond and Stone Hill slices is entirely satisfactory because the geometry of the buried slices and the throw on the Clarksburg fault are unknown. Both the Clarksburg and Hemlock Brook faults offset the Stone Hill and Eph Pond slices, and thus are late to post-metamorphic features. Both offset highly folded, probably overturned thrust faults, producing complex map relations. In addition, the fault between the Stone Hill slice and unit Ose in South Williamstown is completely conjectural, and it is possible that the entire belt of Stockbridge Formation west of the Phelps Knoll fault south of Sheep Hill may also be part of the Stone Hill-Eph Pond slice. In such an interpretation the contact between the Walloomsac and Stockbridge Formations may be a thrust fault carrying Stockbridge over Walloomsac, as suggested by the trace of the contact and the truncation of Stockbridge units there. This raises the possibility that much of the belt of Stockbridge rocks within the map area is really transported and detached cover. A minor, west-dipping thrust fault between the Walloomsac Formation and underlying Stockbridge Formation has been warping along the eastern slopes of Northwest Hill.

Hoosic thrust

The Hoosic thrust was first mapped by Herz (1961) as the western border of the Hoosac and Dalton Formations east of North Adams, extending through Briggsville and possibly connecting with a fault mapped by Skehan as the Hoosac thrust (Skehan, 1961, p. 152), located along the eastern margin of the Green Mountain massif in the position of the Clarksburg fault (fig. 1). Zen in 1967 (p. 61) suggested that the Hoosic thrust of Herz (1961) bends eastward on the sole of the Hoosac Formation just north of the area shown by figure 1, placing it in contact with the Readsboro Formation and Heartwellville Schist as mapped by Skehan (1961). Zen also proposed that the Hoosac thrust of Skehan (the original Hoosic thrust of Herz) forms the lower fault carrying the higher fault.

Ratcliffe (1979b) portrayed the Hoosic thrust in the approximate position as mapped by Herz and located to the east a higher thrust fault, called the Hoosac Summit thrust, that carries aluminous Hoosac Formation over the parautochthonous Hoosac cover rocks in the Hoosac Range. In this report we also retain the original definition of Herz for the western and lower fault, that is, the Hoosic thrust. Thus the Hoosac Summit thrust of Ratcliffe (1979b) and of Stanley and Ratcliffe (1985) is in large measure equivalent to, and replaces, the upper or Hoosic fault as used by Zen (1967); it is not correlative with the Hoosac thrust of Skehan (1961) or the Hoosic thrust of Herz. Both the Hoosac Summit thrust and the Hoosic thrust are offset by the Clarksburg fault along the east side of the Green Mountain massif (fig. 1). In the map area, the Hoosic thrust forms a major thrust that carries Middle Proterozoic gneiss and cover rocks over the autochthon. From the southern edge of the North Adams quadrangle this fault is traceable from Adams toward the Hoosac Tunnel; near the tunnel it overlies Walloomsac Formation, and northward becomes highly folded into two tight folds having steeply dipping axial surfaces.

Hoosac Summit thrust

The Hoosac Summit thrust is well exposed along the southern end of Spruce Hill, where it truncates stratigraphic units in the parautochthonous Hoosac and Dalton Formations. About 1.5 km north of this point the Hoosac Summit thrust overrides and pinches out the lower Hoosic thrust. Along this contact, intensely developed retrograde (chlorite-muscovite-chloritoid) phyllonite contains a strong transposition foliation cutting the S_1 foliation. Marked elliptical smears of chlorite are probably retrograded from earlier garnet, and strong quartz rodding plunges east-southeast parallel to the spears of chlorite. For as much as 100 m above the thrust fault, intense plications and isoclinal reclined folds of schistosity having variable sense of rotation define a distinctive fold-thrust fabric.

North of the hairpin turn in State Route 2 and at a lower elevation, dark albitic-biotitic garnet schists similar to those riding above the Hoosic thrust to the south reappear from beneath the Hoosac Summit thrust. Together the nested Hoosac Summit thrust and the Hoosic thrust bend northwestward in the Stamford quadrangle, cross the North Adams Gap, and are truncated by the Clarksburg fault along the eastern margin of the Green Mountains (fig. 1). From this point northward, mylonitic Dalton Formation and mylonitic Hoosac Formation extend through the Stamford quadrangle where the dark albitic garnet schists are coextensive with rocks mapped by Skehan (1961) as the Heartwellville Schist.

Internal structures within the Hoosac Formation (that is, above the Hoosac Summit thrust) consist of early metamorphic folds having unusual downdip plunge terminations. These folds are overprinted by isoclinal and gently inclined, strongly foliated F_2 isoclines. Late F_2 small-scale folds are present immediately above the Hoosac Summit thrust. These latter folds plunge in reclined fashion down the dip of their axial surfaces (sections *A–A′*, *B–B′*, and *F–F′*).

Whitcomb Summit thrust and Rowe Schist

The upper contact of the Hoosac Formation, the Whitcomb Summit thrust, is remarkably planar and is characterized by hanging-wall truncations and footwall truncations of units €Zhab, €Zhgab, and €Zhg in the Hoosac Formation and O€rsg, O€r, and O€rc in the Rowe Schist. The Rowe immediately above the Whitcomb Summit thrust and for a distance of as much as 200 m above the fault consists of ultrafine-grained, paper-thin phyllite or phyllonite marked by very regular, 0.5- to 1-mm-wide bands colored dark greenish gray to light green. A very strong downdip lineation is present, consisting of dark-green chlorite-rich streaks, spears, and quartz rods. The lack of coarse-grained porphyroblasts and the ultrafine-grained silky sheen of the Rowe Schist along the fault contact suggest that this rock is a tectonically recrystallized mylonite schist and phyllonite. Compositional layering defined by quartz laminations and color banding within the lower 200 m of the Rowe Schist is discontinuous and marked by a pronounced anastomosing schistosity and numerous generations of quartz segregations and veins that are truncated by small shear zones. Many of the layers and quartz veins are deformed into reclined folds having sheared-off limbs. Axial surfaces are marked by the penetrative schistosity. Excellent pavement outcrops can be found along the north-trending road (Moore Road) directly west of Whitcomb Summit proper. The anastomosing fabric, which truncates compositional layers and quartz veins over a wide interval, indicates that the rocks along the Whitcomb Summit thrust and directly east have experienced a long history of repeated motion.

On the map the simple linear pattern of units OꞒrsg and OꞒrc, directly east of the thrust trace, contrasts markedly with the complex tectonic fabric seen in outcrop. This relation indicates that these units are either tectonic slivers or highly transposed segments of stratigraphic units whose original order has been thoroughly disrupted by fault-related deformation, because little vestige of a folded pattern can be mapped. Farther east, in the area mapped by Chidester and others (1967), the linear pattern of OꞒra compared to the more complex pattern of OꞒrc suggests that a ductile fault separates the two units. Thus the outcrop fabric and the pattern of map units support our interpretation that the Rowe Schist is a wide zone of ductile faults that developed throughout a significant part of Taconian history (Stanley and Ratcliffe, 1985).

Hemlock Brook fault

The Hemlock Brook fault is named for exposures in Hemlock Brook, 0.5 km west of Williamstown and north of U.S. Route 7, where highly cataclastic dolomite of the Stockbridge Formation (Ꞓsb) is exposed. Cataclastic zones and slickensided surfaces dip east at approximately 20°. Breccias infiltrated with nodular pyrite are abundant. Near the fault, plications of earlier schistosity form larger folds having a well-defined platy cataclastic foliation. The nature of the overturned folds and downdip slickensides spaced throughout the fault zone suggests a thrust fault. Extension of the fault to the southeast is problematic, although a major fault is required along the east side of Stone Hill and southwest of Sweets Corner. The Hemlock Brook fault is interpreted to merge with the complex zone of faulting east of Brodie Mountain, in which fault slivers of green, albitic phyllite of the Greylock Schist (ꞒZgab and ꞒZg) are intercalated with Walloomsac Formation and rarer slivers of Stockbridge Formation carbonates. The Hemlock Brook fault offsets the older Stone Hill and Eph Pond slices, which are folded into late north-trending folds at Buxton Hill in front of (west of) the fault. Although the compressional folds and foliated fault fabrics are consistent with thrust faulting, the brittle character of some of the breccias suggests the possibility of some extensional reactivation.

Clarksburg fault

The Clarksburg fault is named for exposures of cataclastic and mylonitic rocks northwest of Clarksburg, where units of the Dalton Formation are repeated by faulting and the basal unconformity with the Stamford Granite is mylonitized. In these rocks a strong second-generation foliation, strong rodding, and bands of ribbon quartz are aligned in a muscovite-biotite foliation. To the south the Clarksburg fault truncates rocks of the Eph Pond slice and passes into a zone of distributed thrust faults that merges with a similar zone at the south end of the Hemlock Brook fault. The Clarksburg fault truncates F_1 structures within the Eph Pond slice and in the hanging wall. Foliation is strongly crenulated, broken, and offset on slickensided surfaces, and locally pyrite mineralization of breccias in brittle-fractured dolomite is found. These distinctive breccias are found on the north side of Luce Road at the stream just east of Williamstown Reservoir and for 0.5 km in each direction northeast and southwest of that point along the fault. The brittle nature of these breccias and the presence of brecciated Dalton Formation quartzite northeast of Clarksburg, as far north as Searsburg, Vt., in the Mount Snow 7.5- minute quadrangle, suggest the possibility of significant extensional reactivation along the Clarksburg fault.

Phelps Knoll fault

From Phelps Knoll 3 km northward to exposures in Hemlock Brook, highly brecciated and quartz-veined dolostone crops out or is found in float. Faults seen in outcrops at Hemlock Brook show faulting of metamorphic folds and a down-to-the-east drag sense. This fault is interpreted as a down-to-the-east normal fault, possibly of Mesozoic age, although a late Acadian extensional fault cannot be ruled out.

METAMORPHISM

The rocks of the map area have been multiply deformed and multiply foliated during successive structural and metamorphic events certainly of Taconian age and probably also of Acadian age. The distribution of metamorphic minerals and the assigned grade at any one place are subject both to the maximum grade attained and to the degree of retrogression or remetamorphism. In general the grade ranges from chlorite-albite-epidote-muscovite-quartz subfacies of the greenschist facies of regional metamorphism in the west to almandine subfacies in the east.

Low-grade assemblages in the west, in metapelitic rocks, consist of muscovite, magnesium-rich chlorite, hematite, albite, and quartz of the Walloomsac Formation (Ow); and iron-rich chlorite, muscovite, chloritoid, ilmenite, and quartz ± paragonite (ꞒZg), or iron-rich chlorite, muscovite, ilmenite, albite, and quartz (ꞒZgab) of the Greylock Schist. Carbonate rocks contain dolomite and quartz. At the longitude of Williamstown, the schistose Dalton Formation (ꞒZds) and mylonitic Stamford Granite (Ysg) of the Stone Hill slice contain the assemblage muscovite-biotite-microcline-quartz. Biotite is aligned in the S_2 thrust fabric associated with emplacement of the Stone Hill slice. Biotite also occurs sporadically in schist (ꞒZdbs) and quartzite (ꞒZd) of the Dalton Formation on Pine Cobble east of Williamstown. Biotite is relatively abundant and chlorite is absent in the Walloomsac Formation in samples southeast of Pratt Hill in the Cheshire quadrangle and along a line extending northward to Buxton Hill in the Williamstown quadrangle. In zones of intense F_3 shearing, samples contain chlorite and no biotite, suggesting that original biotite has been destroyed. Biotite and chloritoid coexist with muscovite-albite and quartz in Greylock Schist (ꞒZg) on Savage Hill in Lanesborough (in the Cheshire quadrangle), where biotite is a late, post- S_2 mineral.

Garnet is absent from the Greylock Schist on Mount Greylock as far south as Kitchen Brook just west of Cheshire. South of Kitchen Brook to Savage Hill, garnet is abundant in the Greylock Schist. Garnet occurs in the Walloomsac Formation (Ow) 1 km south of The Noppet, near the western border of the Cheshire quadrangle, and on Constitution Hill 2.5 km to the south. In this area garnet postdates S_2 foliation. Coarse, 1–3 mm garnets are common in units ꞒZg and Ow on the ridge of schist that extends from Savage Hill northeastward to Cheshire Harbor. In this area the garnet statically overgrows both plicated S_1 and the S_2 foliation. Garnet in the schist of the Hoosac Formation above the

Hoosic thrust is syntectonic and contains rotated inclusions of S_1 foliation.

Extensive retrogression of biotite and of garnet occurs in a belt approximately 2 km wide, southeast of and parallel to a line extending from Constitution Hill northeastward through Ragged Mountain (in the Williamstown quadrangle) to North Adams. Unusual equant clots of chlorite possibly after garnet occur in Greylock Schist (€Zgab) at 2200 ft elevation in Pecks Brook on the southeast side of Mount Greylock, near the northern edge of the Cheshire quadrangle. Similar chlorite pseudomorphs after garnet occur in the Walloomsac Formation 2 km east of Houghtonville, in the North Adams quadrangle. Throughout this 2-km-wide zone of retrogression, chlorite lies in the late F_3 crenulation cleavage.

Metamorphic albite throughout the map area is a late-crystallizing mineral always including S_1 and S_2 foliation, although it is commonly texturally zoned. The cores of albite crystals contain helicitic inclusions of folded graphite dust or of folded S_1 foliation, and have inclusion-free rims. Early-formed albite may be flattened in S_1 and broken or bent in S_2, but commonly the clear rims overgrow S_2. Near F_3 faults in the western part of the map area, albite growth preceded formation of thrust faults.

Aluminous Hoosac Formation (€Zhg) above the Hoosac Summit thrust contains large garnets (up to 1 cm) having rotated inclusions of muscovite, quartz, and chloritoid. These large garnets are retrograded to chlorite in the thrust fabric associated with the Hoosac Summit thrust. In the same rocks a second generation of muscovite and chloritoid has grown across the F_2 (thrust-related foliation). Locally rocks from the fault zone have no early garnet, but do have extensive chlorite spears. Post-S_2-foliation garnet may be present overgrowing the thrust fabric. Based on metamorphic textures, the schist of the Hoosac Formation above the Hoosac Summit thrust contains two generations of garnet, chloritoid, muscovite, and biotite. The overgrowth textures across S_2 foliation probably are Acadian. The distribution of metamorphic assemblages and structures in the rocks suggests the possible relationship of foliation, structure, and metamorphism (table 2).

CHRONOLOGY OF TECTONIC EVENTS

Following high-grade dynamothermal metamorphism in Middle Proterozoic time, during the Grenville orogeny, gneisses of the Green Mountains and Berkshire massif were intruded by post-tectonic granites of the Cardinal Brook Intrusive Suite. These rapakivi granites, here represented by the Stamford Granite, form discordant plutons that were intruded at about 960 Ma.

A period of uplift and erosion preceded deposition of a sequence of Late Proterozoic and Lower Cambrian clastic sediments of the Dalton and Hoosac Formations that unconformably overlie the Stamford Granite and the older gneissic basement rocks. Facies relations indicate that the deeper-water and older sediments of the Hoosac Formation were deposited to the east, whereas more quartzofeldspathic rocks of the Dalton were deposited to the west. A basal albitic coarsely conglomeratic section of the Hoosac Formation on Hoosac Mountain (€Zhdab, €Zhdc) appears to be an early rift deposit that lies unconformably beneath the more argillaceous and typical Hoosac. A deepening basin to the east, of Late Proterozoic and Early Cambrian age, received deposits of the Nassau Formation and Greylock Schist, probably as continental slope deposits formed after drifting and during development of the Iapetan passive margin.

To the west, deposition of the transgressive Dalton Formation and Cheshire Quartzite was followed by stabilization of a carbonate platform that produced shallow-water marine deposits of the Stockbridge Formation from late Early Cambrian possibly into the early Middle Ordovician. During deposition of the carbonate platform, deeper-water slope and rise sediments of the Giddings Brook slice of the Taconic allochthon were deposited, east of and possibly above rocks of the Hoosac Formation.

Prior to the late Middle Ordovician (Rocklandian and Kirkfieldian), the carbonate shelf was uplifted and eroded. A major bathymetric reversal leading to deposition of the black muds of the Walloomsac Formation ensued. This deepening exogeoclinal basin received tectonic deposits of flysch, and wildflysch to the west of the map area, immediately before emplacement of the Giddings Brook slice during the late Trentonian and early Cincinnatian. Movement of the Giddings Brook slice across the map area took place within the *C. bicornis* Subzone of Finney (1986), based on graptolites from the Whipstock Breccia Member of the Walloomsac Formation (Potter, 1972). Based on correlation of the *C. bicornis* Subzone with *D. multidens* Zone of the British graptolite zonation (Finney, 1986) and recent uranium-lead zircon geochronology (Tucker and others, 1990), the Giddings Brook slice was transported across the map area at about 454 Ma. Final emplacement of the leading edge of the Giddings Brook slice to the west postdated the deposition of the Forbes Hill Conglomerate, dated by graptolites as basal *C. spiniferus* Zone (Finney, 1986; Rowley and Kidd, 1981) or lower Ashgillian. If a date for the middle Ashgillian is given by the 446-Ma uranium-lead zircon age of Tucker and others (1990), emplacement of the Giddings Brook slice was completed by between 454 and 446 Ma.

The higher slices of the Taconic allochthon in the map area, the Greylock and Berlin Mountain slices, were emplaced under a thickening tectonic cover probably under greenschist-facies conditions. During this stage, imbrication of shelf-sequence rocks of the autochthon gave rise to the Stone Hill and Eph Pond slices. This was followed by overriding of the rocks above the Hoosic thrust and the Hoosac Summit thrust. The peak of Taconian metamorphism postdated emplacement of the Greylock slice, which occurred as a result of the F_2 and M_2 (table 2) metamorphic events.

Regional Taconian metamorphism and the production of the F_2-M_2 mylonitization along thrust faults is believed to be best approximated by a $^{40}Ar/^{39}Ar$ hornblende plateau age of 446 ± 6 Ma from basement gneiss in a ductile shear zone at kyanite grade in the East Lee 7.5-minute quadrangle (sample BM-12 of Sutter and others, 1985), and by a hornblende model age of 445 ± 4 Ma from the Walloomsac Formation of southern Massachusetts (Hames and others, 1990).

These age estimates supersede the previous 466-Ma citation of Sutter and others (1985) for the age of Taconian metamorphism in Massachusetts, which now appears to be too old for the known age of the Middle and Upper(?) Ordovician Walloomsac Formation and the age of emplacement of the Taconic allochthon, based on absolute ages of the graptolite zones given above (Hames and others, 1990). The available data suggest that the orogenic phase of the Taconian orogeny, as expressed in eastern New York and western Massachusetts, occurred during a brief interval in the late Middle Ordovician to early Late Ordovician, between about 456 and 446 Ma. Late Taconian thrusting and imbrication on the Champlain thrust continued into the Late Ordovician but probably ceased by latest Silurian or earliest Devonian.

Late thrust faulting on the Hemlock Brook and Clarksburg faults postdated the F_2-M_2 events and may have been Acadian (table 2). A potassium-argon muscovite age of 375±13 Ma (Sutter and others, 1985) from one of these late fault zones southwest of the map area, in the Pittsfield West 7.5-minute quadrangle, suggests that the late muscovite in these faults may be Acadian. If this interpretation is correct, significant reactivation of Taconian faults may have occurred here and throughout western New England during the Acadian.

Garnets in the Hoosac Formation above the Hoosac Summit thrust in the central part of the North Adams quadrangle contain inclusion-free rims suggestive of late (Acadian) overgrowths. A $^{40}Ar/^{39}Ar$ biotite plateau age of 379±4.2 Ma from the garnet-biotite schist unit (€Zhdg) at locality 2 (sample BM-4 of Sutter and others, 1985) suggests significant Acadian overprint in the Hoosac Mountain area. Based on $^{40}Ar/^{39}Ar$ hornblende ages in adjacent areas (Sutter and others, 1985), the Acadian metamorphic peak occurred at about 389 Ma.

Late (F_4) cross folding and a prominent crenulation cleavage are not expressed by mineral growth and probably are late Acadian. Breccias and slickensided tectonite zones along the Clarksburg and Hemlock Brook faults suggest late, low-angle extensional faulting. Downdropping on the Clarksburg fault helps resolve the difficult space problems between the Eph Pond slice and carbonate rocks above the Clarksburg fault in the North Adams Gap. This normal faulting may be the result of late Acadian faulting or of Mesozoic extensional faulting. Zeolite-mineralized normal and strike-slip faults of probable Mesozoic age are known from the Pittsfield East area (Ratcliffe, 1984).

Uplift and erosion followed the Acadian orogeny, although the present topographic surface was not developed until well after the Cretaceous, based on the known, approximately 120-Ma age of plutonic rocks of the White Mountain Plutonic-Volcanic Suite that intrude rocks of the present crustal level in nearby parts of Vermont (McHone and Butler, 1984; Foland and others, 1986).

REFERENCES CITED

Berry, W.B.N., 1960, Graptolite faunas of the Marathon region, Texas: University of Texas Publications, no. 6005, 179 p.

Bird, J.M., 1962, Geology of the Nassau quadrangle, Rensselaer County, New York: Rensselaer Polytechnic Institute thesis, 204 p.

Cady, W.M., 1945, Stratigraphy and structure of west-central Vermont: Geological Society of America Bulletin, v. 56, no. 5, p. 515–588.

Chidester, A.H., Hatch, N.L., Jr., Osberg, P.H., Norton, S.A., and Hartshorn, J.H., 1967, Geologic map of the Rowe quadrangle, Franklin and Berkshire Counties, Massachusetts, and Bennington and Windham Counties, Vermont: U.S. Geological Survey Geologic Quadrangle Map GQ–642, scale 1:24,000.

Christensen, M.N., 1963, Structural analysis of Hoosac nappe in northwestern Massachusetts: American Journal of Science, v. 261, no. 2, p. 97–107.

Cullen, T.R., 1979, Bedrock geology of a portion of the Pittsfield East and Cheshire quadrangles, Massachusetts: The City College of New York, Masters thesis, 89 p.

Emerson, B.K., 1898, The geology of old Hampshire County, Massachusetts, comprising Franklin, Hampshire, and Hampden Counties: U.S. Geological Survey Monograph 29, 790 p.

———1917, Geology of Massachusetts and Rhode Island: U.S. Geological Survey Bulletin 597, 289 p.

Finney, S.C., 1986, Graptolite biofacies and correlation of eustatic, subsidence, and tectonic events in the Middle to Upper Ordovician of North America: Palaios, v. 1, no. 5, p. 435–461.

Foland, K.A., Gilbert, L.A., Sebring, C.A., and Chen, Jiang-Feng, 1986, $^{40}Ar/^{39}Ar$ ages for plutons of the Monteregian Hills, Quebec: Evidence for a single episode of Cretaceous magmatism: Geological Society of America Bulletin, v. 97, no. 8, p. 966–974.

Hames, W.E., Sutter, J.F., and Ratcliffe, N.M., 1990, Evidence for a 15 Ma duration of the Taconian collisional episode: Geological Society of America Abstracts with Programs, v. 22, no. 2, p. 21.

Herz, Norman, 1958, Bedrock geologic map of the Cheshire quadrangle, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ–108, scale 1:31,680.

———1961, Bedrock geologic map of the North Adams quadrangle, Massachusetts-Vermont: U.S. Geological Survey Geologic Quadrangle Map GQ–139, scale 1:24,000.

Hitchcock, Edward, Hitchcock, Edward, Jr., Hagar, A.D., and Hitchcock, C.H., 1861, Report on the geology of Vermont: Descriptive, theoretical, economical, and scenographical: Claremont, N.H., Claremont Manufacturing Co., v. 2.

Karabinos, Paul, and Aleinikoff, J.N., 1988, U-Pb zircon ages of augen gneisses in the Green Mountain massif and Chester dome, Vermont [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 1, p. 29.

———1990, Evidence for a major Middle Proterozoic, post-Grenvillian igneous event in western New England: American Journal of Science, v. 290, no. 8, p. 959–974.

Keith, Arthur, 1932, Stratigraphy and structure of northwestern Vermont: Washington Academy of Sciences Journal, v. 22, no. 13, p. 357–379, and no. 14, p. 393–406.

MacFadyen, J.A., Jr., 1956, The geology of the Bennington area, Vermont: Vermont Geological Survey Bulletin, no. 7, 71 p., map scale 1:62,500.

McHone, J.G., and Butler, J.R., 1984, Mesozoic igneous provinces of New England and the opening of the North Atlantic Ocean: Geological Society of America Bulletin, v. 95, no. 7, p. 757–765.

Norton, S.A., 1969, Bedrock geologic map of the Windsor [Massachusetts] quadrangle: U.S. Geological Survey Open-File Report, 151 p., scale 1:24,000.

O'Connor, J.T., 1965, A classification for quartz-rich igneous rocks based on feldspar ratios: U.S. Geological Survey Professional Paper 525–B, p. B79–B84.

Potter, D.B., 1972, Stratigraphy and structure of the Hoosic Falls area, New York-Vermont, east-central Taconics: New York State Museum and Science Service Map and Chart Series, no. 19, 71 p., scale 1:24,000.

Prindle, L.M., and Knopf, E.B., 1932, Geology of the Taconic quadrangle: American Journal of Science, 5th series, v. 24, no. 142, p. 257–302.

Ratcliffe, N.M., 1974, Bedrock geologic map of the State Line quadrangle, Columbia County, New York, and Berkshire County, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ–1142, scale 1:24,000.

———1978, Reconnaissance bedrock geologic map of the Pittsfield West quadrangle and part of the Canaan quadrangle, Berkshire County, Massachusetts, and Columbia County, New York: U.S. Geological Survey Miscellaneous Field Studies Map MF–980, scale 1:24,000.

———1979a, Age of the Greylock Schist in western Massachusetts, *in* Sohl, N.F., and Wright, W.B., eds., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1978: U.S. Geological Survey Bulletin 1482–A, p. A77–A78.

———1979b, Field guide to the Chatham and Greylock slices of the Taconic allochthon in western Massachusetts and their relationship to the Hoosac-Rowe sequence, *in* Friedman, G.M., ed., Joint annual meeting of the New York State Geological Association, 51st annual meeting, and the New England Intercollegiate Geological Conference, 71st annual meeting: New York State Geological Association Field Trip Guidebook no. 51, p. 388–425.

———1984, Bedrock geologic map of the Pittsfield East quadrangle, Berkshire County, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ–1574, scale 1:24,000.

———1991, Revisions to the nomenclature of some Middle Proterozoic granitic rocks in the northern Berkshire massif, Massachusetts, and in the southern Green Mountains, Vermont and Massachusetts, *in* Stratigraphic Notes 1989–90: U.S. Geological Survey Bulletin 1935, p. 9–26.

Ratcliffe, N.M., and Bahrami, Behshid, 1976, Chatham fault: a reinterpretation of the contact relations between the Giddings Brook and Chatham slices of the Taconic allochthon in New York: Geology, v. 4, no. 1, p. 56–60.

Ratcliffe, N.M., Burton, W.C., Sutter, J.F., and Mukasa, S.B., 1988, Stratigraphy, structural geology, and thermochronology of the northern Berkshire massif and southern Green Mountains, *in* Bothner, W.A., ed., Guidebook for field trips in southwestern New Hampshire, southeastern Vermont, and north-central Massachusetts: New England Intercollegiate Geological Conference, 80th annual meeting, Oct. 14–16, 1988, Keene, N.H., p. 1–23, 126–135.

Ratcliffe, N.M., and Zartman, R.E., 1976, Stratigraphy, isotopic ages, and deformational history of basement and cover rocks of the Berkshire massif, southwestern Massachusetts, *in* Page, L.R., ed., Contributions to the stratigraphy of New England: Geological Society of America Memoir 148, p. 373–412.

Ross, R.J., Jr., and others, 1982, The Ordovician System in the United States: correlation chart and explanatory notes: International Union of Geological Sciences Publication No. 12, 73 p.

Rowley, D.B., and Kidd, W.S.F., 1981, Stratigraphic relationships and detrital composition of the medial Ordovician flysch of western New England: Implications for the tectonic evolution of the Taconic orogeny: Journal of Geology, v. 89, no. 2, p. 199–218.

Shapiro, Leonard, 1975, Rapid analyses of silicate, carbonate, and phosphate rocks (revised edition): U.S. Geological Survey Bulletin 1401, 76 p.

Skehan, J.W., 1961, The Green Mountain anticlinorium in the vicinity of Wilmington and Woodford, Vermont: Vermont Geological Survey Bulletin, no. 17, 159 p., scale 1:62,500.

Stanley, R.S., and Ratcliffe, N.M., 1985, Tectonic synthesis of the Taconian orogeny in western New England: Geological Society of America Bulletin, v. 96, no. 10, p. 1227–1250.

Sutter, J.F., Ratcliffe, N.M., and Mukasa, S.B., 1985, $^{40}Ar/^{39}Ar$ and K-Ar data bearing on the metamorphic and tectonic history of western New England: Geological Society of America Bulletin, v. 96, no. 1, p. 123–136.

Tucker, R.D., Krogh, T.E., Ross, R.J., Jr., and Williams, S.H., 1990, Time-scale calibration by high-precision U-Pb zircon dating of interstratified volcanic ashes in the Ordovician and Lower Silurian stratotypes of Britain: Earth and Planetary Science Letters, v. 100, no. 1/3, p. 51–58.

Walcott, C.D., 1888, The Taconic system of Emmons, and the use of the name Taconic in geologic nomenclature: American Journal of Science, 3rd Series, v. 35, no. 207, p. 229–242.

Wolff, J.E., 1894, The geology of Hoosac Mountain and adjacent territory, *part 2 of* Pumpelly, Raphael, Wolff, J.E., and Dale, T.N., Geology of the Green Mountains in Massachusetts: U.S. Geological Survey Monograph 23, p. 35–118.

Zen, E-an, 1966, Stockbridge Formation, Walloomsac Formation, Egremont Phyllite, Everett Formation, *in* Cohee, G.V., and West, W.S., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1965: U.S. Geological Survey Bulletin 1244–A, p. A30–A32.

———1967, Time and space relationships of the Taconic allochthon and autochthon: Geological Society of America Special Paper 97, 107 p.

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

Zen, E-an, and Hartshorn, J.H., 1966, Geologic map of the Bashbish Falls quadrangle, Massachusetts, Connecticut, and New York: U.S. Geological Survey Geologic Quadrangle Map GQ–507, scale 1:24,000.

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