

## BEDROCK GEOLOGIC MAP OF THE CHESTER QUADRANGLE, WINDSOR COUNTY, VERMONT

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### INTRODUCTION

The bedrock of the Chester quadrangle consists largely of Middle Proterozoic gneisses that form the core of the Chester dome. The Chester dome, an Acadian feature, is flanked to the east by mantling rocks of Late Proterozoic(?), Cambrian(?), Ordovician, and Silurian to Devonian age. Along the western side of the dome, a narrow, tightly pinched belt of probable Ordovician rocks occurs in what previously has been referred to as the Star Hill fold of Thompson (1950), but is here termed the Spring Hill fold (fig. 1). On Hawks Mountain and in a narrow belt that extends southward along the west side of the dome, schists of the Cavendish Formation crop out. These schists were previously correlated with rocks of the Hoosac Formation by Thompson and others (1990, 1993) and interpreted as infolds of cover rocks younger than the core gneisses. To the north in the Cavendish quadrangle, the type Cavendish has been reinterpreted as Middle Proterozoic schist within the Mount Holly Complex (Ratcliffe, 1994, 1995). The dominant planar features (either a foliation, schistosity or gneissosity) dip steeply to the west along the western side of the dome and moderately steeply southeast along the eastern side of the map. Throughout the center part of the dome, foliation dips gently to the north or to the south. The dominant structure is that of a rather low-amplitude, doubly plunging dome.

### PREVIOUS WORK

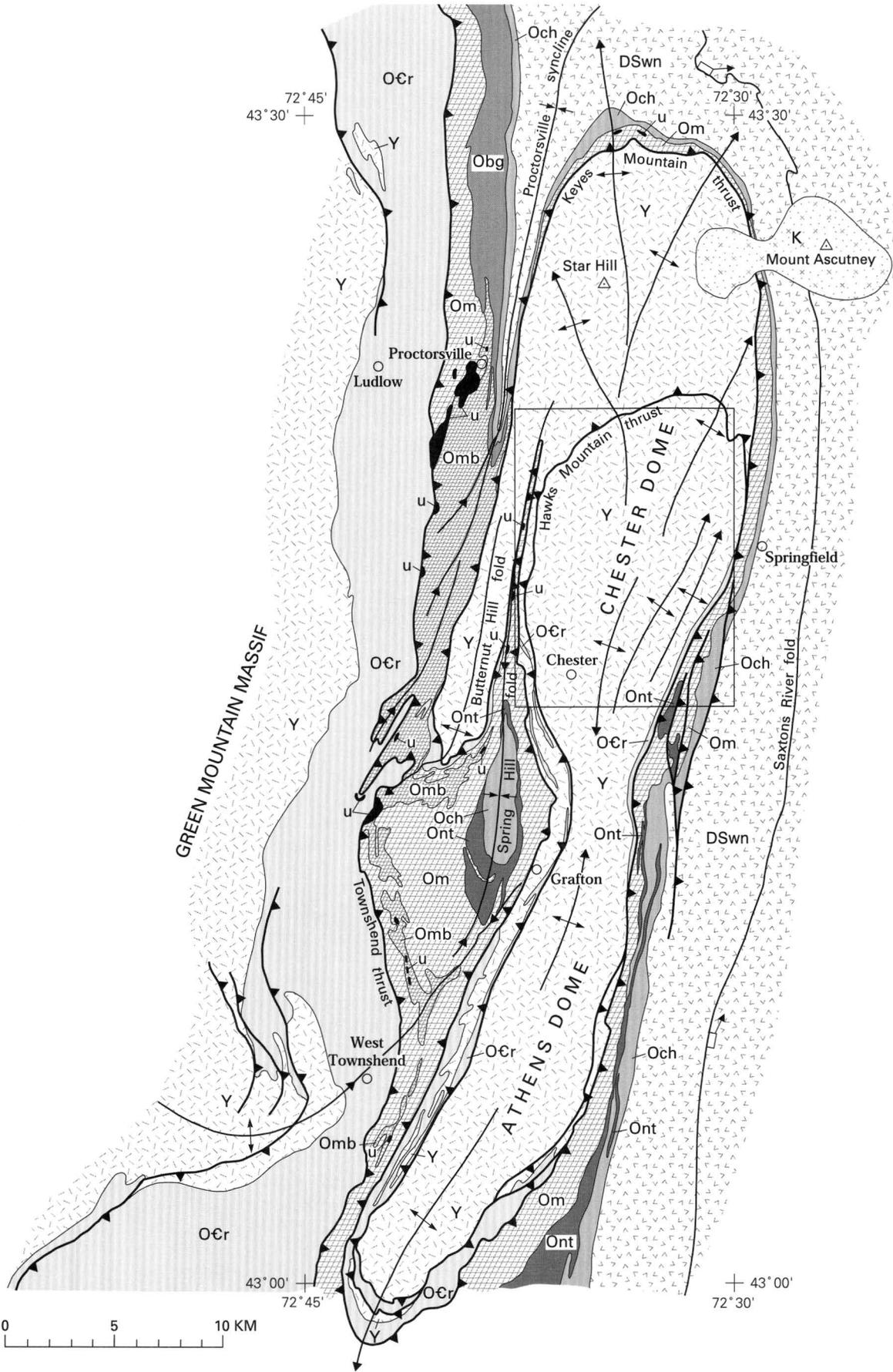
Bedrock of the Chester quadrangle was previously mapped by Thompson (1950) at a scale of 1:62,500. His subsequent studies were incorporated into the Centennial Geologic Map of Vermont at a scale of 1:250,000 (Doll and others, 1961), and more recently in Thompson and others (1990) at a scale of 1:250,000, and in Thompson and others (1993) at a scale of approximately 1:125,000. Numerous petrologic studies principally dealing with the metamorphic petrology of the Gassetts Schist and calc-silicate rocks have been conducted by Thompson (1975); Thompson, Lyttle, and Thompson (1977); Thompson, Tracy, and others (1977); Thompson, Cheney, and Robinson (1986); and Vance and Holland (1993). Geochronologic investigations by Faul and others (1963) and Karabinos and Aleinikoff (1990) have helped determine the Middle Proterozoic ages of the Mount Holly Complex in the Chester dome. Recent U-Pb zircon studies by John N. Aleinikoff (*in* Ratcliffe and others, 1996; Ratcliffe, Armstrong, and Aleinikoff, 1997) have determined that the Middle Proterozoic

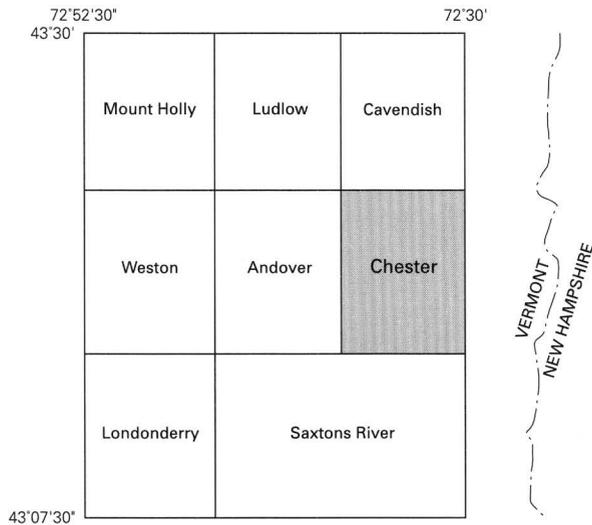
ages of tonalitic gneisses in the Chester dome are as great as 1.4 Ga and that metamorphic overgrowth ages are about 1.1 Ga and at 950 Ma.

Regional compilations and interpretations of the Chester dome and adjacent areas have been conducted by Thompson and others (1990, 1993) and by Thompson, Rosenfeld, and Downie (1986). The structural models for the Chester dome, according to previous studies, involve complex overturned nappes of basement and cover rocks that formed either during the Taconian or Acadian orogenies, followed by subsequent doming during the Acadian.

The regional geology is shown in figure 1. According to Doll and others (1961), the axial trace of a major antiformal structure (their Star Hill fold, which is in the position of the Spring Hill fold of this report) brings up cover rocks from beneath inverted Middle Proterozoic rocks in the Cavendish quadrangle. The axial trace of the Spring Hill fold is outlined in part by the distribution of cover rocks along the western border of the quadrangle. West of this fold (fig. 1), Doll and others (1961) thought that Middle Proterozoic rocks formed the core of a major downward-closing, north-plunging synform, which they called the Butternut Hill fold. The western limb of the Butternut Hill fold lies outside the Chester quadrangle. The Butternut Hill synform and Star Hill antiform form the Star Hill sigmoid of Rosenfeld (1968); however, in this report and in Ratcliffe and Armstrong (1995), these folds are interpreted in a completely opposite sense. The Butternut Hill fold of this report is considered to be essentially antiformal and the Spring Hill fold to be synformal, although there is abundant local evidence for reclined folds that plunge to the northwest. If the major folds are reclined, the terms antiform or synform are, strictly speaking, incorrect.

Recent studies along the southern closure of the Butternut Hill fold in the adjacent Andover and Saxtons River quadrangles suggest that the basement and cover rocks are not inverted and do not plunge to the north (Ratcliffe, 1993; Ratcliffe and Armstrong, 1995). Mapping of the Cavendish quadrangle to the north (Ratcliffe, 1995, *in press*) indicates that the dominant regional foliation, said to be the axial surface of the nappe stage folds (Thompson, Rosenfeld, and Downie, 1986), is not the axial surface to major deflections of the basement units in the core of the dome at its northern end. The detailed structural geology of the map units in the Mount Holly Complex, in the core of the dome, does not permit large-scale isoclinal or recumbent folding along the projection of the Butternut Hill and Star Hill folds in the Cavendish quadrangle (Ratcliffe, 1994, 1995; Ratcliffe, Armstrong, and Aleinikoff, 1997). Likewise, at the northern end of Spring Hill in the Saxtons River quadrangle, Ratcliffe and Armstrong (1995) show that folds plunge to the south and not to the north; therefore, the Spring Hill fold is a normal, doubly





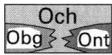
**EXPLANATION**



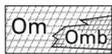
**Alkaline intrusive rocks (Cretaceous)**



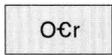
**Waits River and Northfield Formations, undivided (Devonian and Silurian)**—Includes volcanogenic members of Waits River Formation (Standing Pond Volcanics of Doll and others, 1961)



**Cram Hill Formation (Och), igneous rocks of North River Igneous Suite (Ont), and Barnard Gneiss (Obg) of Richardson (1929) (Ordovician)**



**Moretown Formation (Ordovician)**—Includes rocks previously mapped as Whetstone Hill member of Doll and others (1961) of Missisquoi Formation. Also includes rusty schist member (Omb)



**Hoosac, Pinney Hollow, Ottauquechee, and Stowe Formations, and Rowe Schist, undivided (Ordovician to Cambrian)**



**Core gneisses and schists of Green Mountain massif and Chester and Athens domes (Middle Proterozoic)**—Includes units of Mount Holly Complex, Cardinal Brook Intrusive Suite, and Cavendish Formation



**Ultramafic rocks (age uncertain)**—Found within units O€u, Om, and Omb



**Contact**

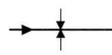


**Thrust fault**—Teeth on upper plate

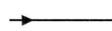
**Acadian folds**



**Antiform**—Showing direction of plunge



**Synform**—Showing direction of plunge



**Axial trace of fold**—Showing plunge only



**Inclined fold**—Barb shows dip direction of axial surface. Arrow shows approximate plunge direction

**Figure 1.**—Simplified regional geologic and tectonic map of the Chester and Athens domes showing the location of the Chester quadrangle.

plunging synform rather than a north-plunging antiform containing inverted rocks, as shown by Doll and others (1961).

## PURPOSE OF PRESENT MAPPING

Previous geologic maps by Thompson (1950), Doll and others (1961), and Thompson and others (1990, 1993) do not show subdivisions of the Mount Holly Complex within the core of the Chester dome, either in the Cavendish or Chester quadrangles. Because the relationship of cover rocks to the basement rocks is important to determining the internal structure of the dome, an effort was made to separate rock types within the core of the dome. Separating the rock types is necessary in order to evaluate the whether the Cavendish Formation is cover rock or part of the Mount Holly Complex.

Key questions that can be addressed in this quadrangle are

1. Are the core rocks of the dome comparable to Mount Holly rocks of the Green Mountain massif?
2. Are the schists of the Cavendish Formation part of the basement rocks or are they cover rocks assignable to the Late Proterozoic and Lower Cambrian Hoosac Formation?
3. Is the internal structure of the dome compatible with isoclinal and recumbent folding of the basement and cover into nappes?, and
4. Are the cover rocks east and west of the dome in depositional contact with the core rocks and is the stratigraphy intact, or are these rocks bounded by faults?

## STRATIGRAPHY

Rocks of the Chester quadrangle range in age from Middle Proterozoic to Cretaceous. The core rocks of the dome, including the Cavendish Formation or the Hoosac Formation of Thompson and others (1993), on Hawks Mountain are here all regarded as Middle Proterozoic. The core rocks include intrusive and layered gneisses of the Mount Holly Complex and the younger intrusive Bull Hill Gneiss of the Cardinal Brook Intrusive Suite.

A 0.5- to 0.75-km-thick section of cover rocks overlies the Mount Holly Complex and the Bull Hill Gneiss on the eastern side of the dome. The ages of the rocks and formation assignments are highly uncertain in this belt but they are thought to range from possibly Late Proterozoic to Early Devonian. The lower part of the section consists of schists, amphibolites, granofels, and metavolcanic or intrusive rocks previously assigned to the Hoosac, Pinney Hollow, and Ottauquechee Formations, and the overlying Moretown Formation and associated Barnard Gneiss as shown by Thompson and others (1993).

Previous maps show these cover rocks as continuous, through-going parallel units. The present mapping does not support that interpretation because the mapped units are neither continuous, nor are they in a regular succession. Internal faulting and folding, as well as a major fault detachment along the base of the section, are indicated. On the present map, the lower part of the section is assigned to the Moretown Formation and interpreted to be in fault contact with the basement rocks.

The top of the exposed section consists of a sequence of interlayered greenstones, quartzites, coticule, and schist here assigned to the Ordovician Cram Hill Formation. Overlying

these are rocks of the Northfield and Waits River Formations of Silurian and Devonian age.

Cover rocks west of the dome, in the Spring Hill fold, appear to correlate with the lower parts of the eastern cover sequence but do include, locally, rocks of the Hoosac Formation. Abundant faults along the basement-cover contact enter the area from the south. Cover rocks of the Moretown Formation in the core of the Spring Hill fold extend from the southern edge of the map northward to their closure at the Baltimore-Chester town line. Some of the cover rocks in the southwestern corner of the map shown as questionable Moretown are mapped as units of the Rowe Schist in the adjacent Saxtons River quadrangle (Ratcliffe and Armstrong, 1995, in press).

## STRATIGRAPHY OF THE MOUNT HOLLY COMPLEX

Rocks of the Mount Holly Complex crop out within the core of the dome and on both flanks of the Spring Hill fold along the western edge of the map. As mapped here, the Mount Holly Complex consists of paragneisses and intrusive rocks. The dominant rock type of the paragneiss section consists of well-layered biotite-quartz-plagioclase gneiss (Ybg) that is the host for a variety of other distinctive rocks, including rusty-weathering schists or gneisses (Yrs, Yrg) that are closely associated with thin layers of quartzite, calc-silicate, and marble (Ycs, Ym). Abundant layers of amphibolite (Ya) can be mapped locally. The calc-silicate rocks and marbles (Ycs, Ym) and schists (Yrs, Yrg) are generally discontinuous, but locally continuous belts that are associated with very garnet rich biotite gneiss or schist (Yrgt) can be mapped. One belt of such rocks extends along the eastern side of the map from the North Springfield Reservoir south almost to State Route 11, where it disappears in a belt of granite gneiss (Ygg). South of State Route 11, a very persistent but thin belt of rusty muscovite-chlorite schist (Yrs) and associated garnetiferous biotite gneiss (Yrg) extends southwestward to the map border. The belt returns in the southwestern part of the map as garnet-biotite gneiss (Yrgt) and extends northward for about 3 km to a point north of State Route 103.

A parallel belt of similar rocks (Yrg, Yrs, Ym, Ycs) extends from the Black River at the eastern margin of the map southwestward through Whitney Hill to the southern border of the map. This belt of rocks has been mapped previously by Thompson and others (1993) and Doll and others (1961) as the equivalent of the Cambrian Tyson Formation, which is normally found near the base of the cover sequence in the Green Mountains. They therefore interpreted this belt of rock as the base of the cover sequence. The present mapping indicates that these calc-silicate and associated schists are all well within the Mount Holly Complex. In the present map, the contact of these schists with cover sequence rocks is placed east of the belt of Bull Hill Gneiss that runs northeast from Bond Hill to the Black River.

In the northwestern part of the map, narrow belts of schist, calc-silicate rocks, and marble (Yrs, Ycs, Ym) interlayered in biotitic gneiss (Ybg) enter the map from the adjacent Cavendish quadrangle. The westernmost belt of schist and gneiss (Yrs, Yrgt, Yrg) and associated marble and calc-silicate rocks (Ym, Ycs) were mapped by Thompson and others (1993) as the base of their cover sequence in the Spring Hill fold. On this map, the rocks east of this belt are assigned to the Mount Holly Complex. Thus, in the present mapping, schists and calc-silicate rocks recognized by Thompson and others (1993) as the base of the cover section

east and west of the dome are here all placed within the Mount Holly Complex.

Discontinuous amphibolites are common within the Mount Holly Complex and occur within or are associated with all rock types; clearly, they occur at different positions. The larger, more persistent bodies are mapped separately. Rusty-weathering schist containing biotite-muscovite-garnet-kyanite-plagioclase and quartz-rich schist or gneiss (Yrs) also occur within the center of the dome where they are associated with belts of amphibolite (Ya) and biotite-quartz-plagioclase gneiss (Ybg). A large belt of such rocks, almost 4 km long, is present north of State Route 10. The schists within this belt, as elsewhere, that are mapped as Yrs closely resemble schist within the Cavendish Formation (Ycg, Ycfs) (see section on Cavendish below).

The well-layered paragneiss units of the Mount Holly are extensively intruded by two different varieties of felsic rocks. The oldest intrusive rocks are tonalitic and trondhjemitic to granodioritic and are here mapped as the Baileys Mills Tonalitic Gneiss (Yt), and the Felchville Gneiss (Ygp)

The Baileys Mills Tonalitic Gneiss is a coarse-grained, biotite-spotted gneiss locally having relict phaneritic texture resembling coarse-grained tonalite or trondhjemite. The unit is named for exposures along State Route 103 north and south of Baileys Mills and on the hill of 1,183 ft elevation west of Trebo Road. These rocks closely resemble unnamed rocks in the Mount Holly Complex in the core of the Green Mountain massif dated at 1.35 to 1.31 Ga (Ratcliffe and others, 1991) that were referred to informally as the Rawsonville and Cole Pond facies of an unnamed metatrondhjemite suite. In the absence of clear crosscutting relations with other units of the Mount Holly Complex, they were interpreted as older than the paragneiss units of the Mount Holly (Ratcliffe and others, 1991). In the core of the Chester dome, however, both in the Cavendish quadrangle (Ratcliffe, 1995) and in the Chester quadrangle, these rocks appear to intrude the biotite-quartz-plagioclase gneiss (Ybg) and associated units (Ya, Yrs, Yrg). Enclaves of amphibolite (Ya) and biotite gneiss (Ybg) are common within the tonalites and trondhjemites. In the Cavendish quadrangle, the Felchville Gneiss (Ygp) is a trondhjemite gneiss broadly intrusive into most rocks of the Mount Holly Complex and into the Cavendish Formation (Ratcliffe, 1995). Two samples of the Felchville Gneiss from the Cavendish quadrangle yielded  $^{207}\text{Pb}/^{206}\text{Pb}$  single high-resolution ion-microprobe (SHRIMP) ages for cores of zircons of  $1424 \pm 22$  Ma and  $1379 \pm 23$  Ma (John N. Aleinikoff, *in* Ratcliffe and others, 1996). The same zircons have ages of zircon overgrowths dated at 1111 and 950 Ma. These dates are interpreted as the age of intrusion of the Felchville Gneiss, and the times of subsequent metamorphism in the Middle Proterozoic.

Zircon from the Baileys Mills Tonalitic Gneiss collected from site 13 on State Route 103, 1 km south of State Route 10, yielded an ion-microprobe (SHRIMP) age of  $1382 \pm 15$  Ma (John N. Aleinikoff, U.S. Geological Survey, 1998, written commun.). Because both the Felchville Gneiss and the Baileys Mills Tonalitic Gneiss intrude the paragneisses of the Mount Holly Complex and the Cavendish Formation, both of the latter are older than 1.379 Ga.

Chemical analyses of tonalitic and trondhjemitic gneisses from the Chester and Cavendish quadrangles are given in table 1. Major-oxide, trace-element, and rare-earth-element chemical analyses of the Baileys Mill Tonalitic Gneiss and the Felchville

Gneiss in the Cavendish quadrangle are also given in table 1. Sample locations of the specimens from the Chester quadrangle are identified on the map.

Samples 1 through 7 in table 1 come from the Cavendish quadrangle and are thought to be characteristic of the belts of Felchville Gneiss (Ygp) that enter the quadrangle from the northwest corner of the map. Samples vary from medium-grained biotite-plagioclase-quartz gneiss having as much as 20 percent microcline, to finer grained, aplitic variants (samples 5, 6, and 7) that are typical of the contact zones between the Felchville Gneiss and the Cavendish Formation or other units of the Mount Holly. Samples 1 and 5 yielded the  $^{207}\text{Pb}/^{206}\text{Pb}$  zircon ages discussed previously.

Samples 10 through 15 are from the Baileys Mills Tonalitic Gneiss in the Chester quadrangle. The Felchville Gneiss tends to be higher in  $\text{SiO}_2$  (67 to 72 percent) and lower in CaO (0.79 to 3.69 percent) than the Baileys Mills Tonalitic Gneiss. Plots of normative An-Or-Ab compositions (fig. 2) show the Felchville rocks to be trondhjemite and sodic tonalite, whereas the Baileys Mills samples tend to be more tonalitic.

The tonalitic and trondhjemitic gneisses of the Chester dome closely resemble, in major oxide chemistry and age, rocks from the Green Mountains belonging to the Rawsonville, Cole Pond, and Bondville facies of the Green Mountain massif identified by Ratcliffe and others (1991); therefore, correlation with those facies is indicated.

In general, the Felchville Gneiss and its aplitic facies resemble the Rawsonville and Bondville facies. The Baileys Mill Tonalitic Gneiss is comparable to both the Cole Pond and Rawsonville facies.

Rare-earth element characteristics of the two groups of rocks from the Chester dome are compared in figure 3. The Felchville samples 1, 2, 4, 5 and 6 have quite similar chondrite-normalized patterns with La values of 28 to 42 X chondrite, and Lu values of 1.9 to 3 X chondrite. Samples 3 and 7 contain sharply higher rare-earth abundances. These two samples are more siliceous, contain significant normative corundum, and are probably slightly contaminated rocks. The Baileys Mills Tonalitic Gneiss samples are similar to those of the Felchville, but have higher chondrite-normalized La values at 112 to 25 X chondrite and Lu values of 1.3 to 3.3 X chondrite, respectively. Both sets of rocks exhibit no Eu anomalies and have chondrite-normalized ( $\text{La}_c/\text{Lu}_c$ ) ratios of approximately 20.

The Baileys Mills and Felchville rocks chemically closely resemble the Rawsonville and Cole Pond trondhjemitic and tonalitic facies of the Green Mountain massif and similar rocks cropping out on Terrible Mountain in the Weston quadrangle which were not included in Ratcliffe and others (1991). Five samples from Terrible Mountain, not shown in table 1, closely resemble, in their coarse-grained, biotitic character, the Baileys Mills Tonalitic Gneiss. This is especially significant because the rocks appear at the easternmost edge of the Green Mountain massif at the same latitude as the Chester quadrangle and may well be the identical rocks which reappear in the Chester dome. Figure 1 of Ratcliffe and others (1991) shows that correlatives of the tonalite-trondhjemite suite of the Green Mountain massif appear at similar latitude and are on strike with rocks identified by McLelland and Chiarenzelli (1990) in the Adirondack Mountains of New York; these rocks are here extended into the Chester and Athens domes.

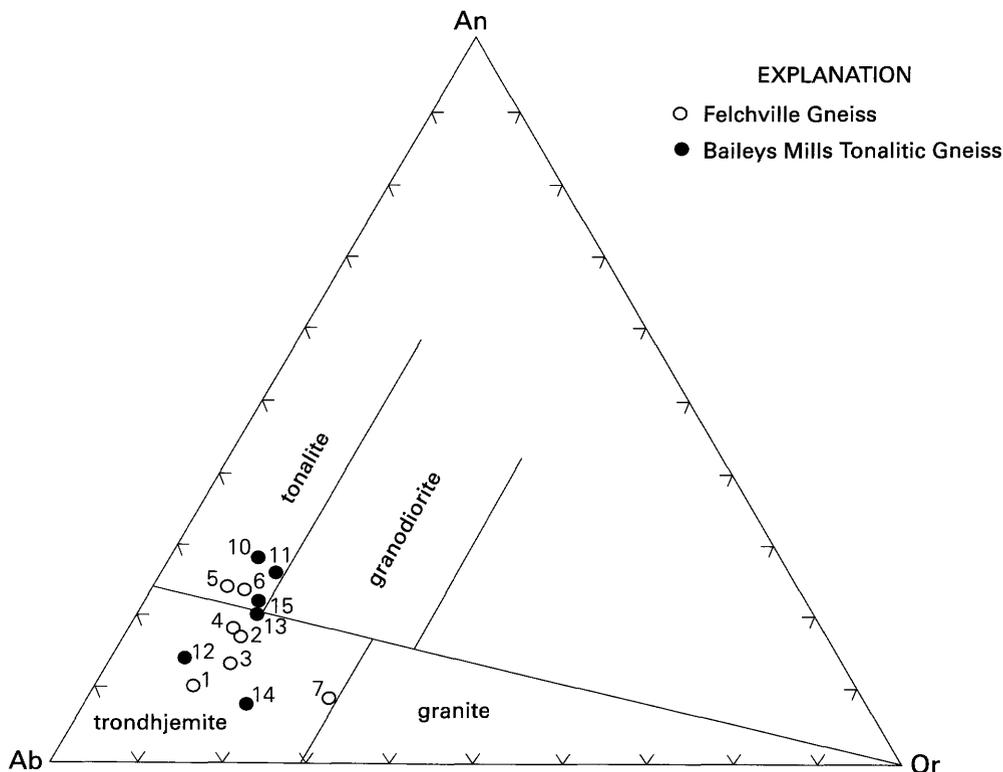
**Table 1**—Major-oxide compositions, CIPW normative mineral compositions, and minor- and trace-element abundances of trondhjemite and tonalitic gneiss of the Chester dome.

[Samples 1 through 9 are from the Cavendish quadrangle; samples 10 through 15 are from the Chester quadrangle. Ybg, biotite-quartz-plagioclase gneiss; Ygg, granite and migmatitic gneiss. Major oxides were determined by x-ray spectroscopy at the U.S. Geological Survey (USGS); J.E. Taggart, Jr., A. Bartel, and D.F. Siems, analysts. Minor- and trace-element concentrations were determined by instrumental neutron activation analysis (INAA) at the USGS; Curtis Palmer, analyst. INAA error limits in percent (%) are 1 standard deviation based on counting statistics]

Rock unit Field no. Sample no.	Felchville Gneiss							Ybg 132B 8	Ygg C-679 9	Baileys Mills Tonalitic Gneiss metatrondhjemite and metatonalite					
	Aplitic border facies				Aplites					CSt-1B 10	CSt-5 11	CSt-12 12	CSt-13 13	CSt-14 14	CSt-15 15
	C-609 1	C-607 2	C-408 3	C-666 4	C-490 5	C-718 6	132A 7								
<b>Major-oxide composition, in weight percent</b>															
SiO <sub>2</sub> ---	70.7	69.4	71.3	72.7	67.6	67.0	70.3	70.7	72.2	63.7	68.3	66.0	68.6	72.1	69.7
Al <sub>2</sub> O <sub>3</sub> --	16.1	16.9	15.4	15.3	17.7	17.8	15.5	14.6	14.10	18.8	16.1	18.1	17.1	16.0	16.6
FeO ---	.86	.62	1.62	.71	.85	.77	1.22	1.41	1.20	1.76	1.67	1.83	.97	.58	.77
Fe <sub>2</sub> O <sub>3</sub> --	.57	.99	.62	.81	1.04	1.28	.98	1.13	.66	.91	1.18	.70	0.93	0.38	0.98
MgO --	.79	.75	1.02	.42	.82	.90	1.09	1.29	.43	1.39	1.59	1.36	.89	.39	.65
CaO ---	1.75	2.55	2.07	2.28	3.61	3.69	1.37	1.85	.79	4.65	3.58	2.52	3.28	2.52	3.24
Na <sub>2</sub> O --	6.52	5.64	5.13	5.17	5.62	5.50	4.58	3.59	3.16	5.61	4.69	6.88	5.37	5.62	5.17
K <sub>2</sub> O ---	1.55	1.82	1.47	1.49	1.23	1.34	2.99	3.40	6.13	1.26	1.55	1.39	1.63	1.14	1.64
TiO <sub>2</sub> ---	.17	.22	.26	.16	.10	.26	.27	.31	.26	.39	.39	.31	.23	.14	.20
P <sub>2</sub> O <sub>5</sub> --	.08	.1	.08	.07	.03	.11	.10	.07	.09	.16	.12	.14	.10	.08	.08
MnO --	.04	.04	.04	.04	.69	.03	.05	.05	.04	.04	.05	.26	.04	.01	.03
H <sub>2</sub> O+ --	.40	.60	.61	.45	.62	.84	.84	.90	.42	.57	.59	.47	.71	.34	.05
H <sub>2</sub> O- --	<.01	.01	.02	.02	.03	.03	.03	.03	.03	.02	.05	.04	.03	.03	.02
CO <sub>2</sub> ---	<.01	<.05	.11	<.05	.10	<.05	<.05	<.05	<.05	.08	<.05	<.05	.13	.07	<.05
Total _	99.53	99.64	99.75	99.62	99.94	99.55	99.32	99.33	99.51	99.34	99.87	100.0	100.01	99.40	99.13
<b>CIPW normative mineral composition, in weight percent</b>															
Q -----	22.10	23.67	29.70	31.8	21.86	21.35	28.00	31.32	28.07	14.19	25.03	12.78	23.25	29.52	25.88
C -----	.88	1.38	2.07	1.33	1.04	.98	2.63	2.10	1.17	.33	.63	1.16	1.09	1.31	.74
or -----	9.23	10.86	8.77	8.88	7.35	8.02	17.94	20.40	36.55	7.54	9.23	8.27	9.70	6.80	9.78
ab -----	55.62	48.17	43.80	44.10	48.07	47.14	39.34	30.84	26.98	48.07	39.97	58.62	45.77	48.02	44.14
an -----	7.78	11.79	9.13	10.62	16.80	17.49	5.92	8.15	3.04	21.79	16.72	11.35	14.91	11.65	15.37
hy -----	2.89	1.92	4.69	1.50	2.43	2.27	3.85	4.51	2.40	5.44	5.54	5.78	2.94	1.53	1.96
mt -----	.84	1.45	.91	1.19	1.52	1.85	1.45	1.69	.96	1.34	1.73	1.02	1.36	.55	1.44
il -----	.33	.42	.50	.31	.46	.50	.52	.60	.50	.75	.75	.60	.44	.27	.38
hem -----	.0	.0	.0	.0	.0	.03	.0	.0	.0	.0	.0	.0	.0	.0	.0
ap -----	.19	.24	.19	.18	.24	.26	.24	.17	.22	.38	.31	.33	.24	.19	.19
cc -----	.16	.11	.25	.11	.23	.12	.12	.25	.11	.18	.11	.11	.30	.16	.11
Total _	100.02	100.01	100.01	100.02	100	100.01	100.01	100.03	100.00	100.01	100.02	100.02	100.00	100.00	99.99

**Table 1.**—Major-oxide compositions, CIPW normative mineral compositions, and minor- and trace-element abundances of trondhjemite and tonalitic gneiss of the Chester dome—Continued.

Rock unit	Felchville Gneiss							Ybg	Ygg	Baileys Mills Tonalitic Gneiss metatrondhjemite and metatonalite					
	Aplitic border facies				Aplites					CSt-1B	CSt-5	CSt-12	CSt-13	CSt-14	CSt-15
	C-609	C-607	C-408	C-666	C-490	C-718	132A								
Field no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<b>Minor- and trace-element abundances</b>															
[In parts per million (ppm) except for Fe, which is in percent (%)]															
Replicates	(1)	(1)	(1)	(1)	(1)	(1)	(2)	(1)	(2)	(1)	(1)	(1)	(1)	(1)	(2)
Sc	2.37±2%	2.34±2%	3.71±2%	1.84±2%	2.52±2%	2.21±2%	3.44±2%	5.96±2%	2.8±2%	3.75±3%	4.56±4%	3.32±2%	2.57±2%	2.01±2%	2.08±2%
Cr	1.8±10%	5.8±5%	7.1±6%	1.28±13%	3.16±7%	5.3±5%	6.83±4%	21.5±4%	2.29±11%	5.12±6%	15.1±8%	4.72±6%	3.14±7%	5.18±5%	2.26±6%
Fe (%)	1.086±2%	1.173±2%	1.69±2%	1.119±2%	1.407±2%	1.443±2%	1.576±2%	1.88±2%	1.378±2%	2.01±3%	1.97±4%	1.73±2%	1.312±2%	0.663±2%	1.212±2%
Co	2.71±3%	3.11±3%	4.25±3%	1.61±3%	3.99±2%	3.95±2%	3.84±2%	5.85±2%	1.95±3%	6.95±4%	8.7±4%	5.75±4%	3.59±2%	1.96±3%	2.81±3%
Ni	<12	<9	<11	<8	<9	<11	15±32%	<21	20±33%	<14	20±21%	<13	<8	8.2±28%	<8
Zn	34.6±4%	31.7±4%	32.7±7%	31.8±4%	47±3%	33±4%	48.1±3%	38.6±5%	55.9±3%	46±7%	37.9±6%	31.8±5%	25.7±4%	24.9±4%	34.4±3%
Rb	31.8±4%	39.5±3%	55±3%	31.1±7%	27.5±4%	27.6±7%	117.9±2%	129±3%	220±2%	32.3±8%	43.3±6%	33.7±4%	30.7±4%	39.4±3%	33.9±3%
Sr	492±4%	638±3%	214±6%	605±4%	911±3%	970±3%	250±4%	295±8%	166±6%	980±3%	512±4%	532±4%	951±3%	527±3%	854±2%
Cs	0.94±4%	1.02±3%	5.93±3%	1.4±3%	0.94±4%	0.9±6%	2.5±2%	2.6±3%	2±2%	0.383±6%	1.24±4%	0.665±4%	0.29±6%	1.06±3%	0.55±3%
Ba	528±3%	546±4%	171±12%	635±3%	450±7%	906±3%	504±2%	499±4%	677±3%	346±4%	323±4%	399±3%	612±3%	314±5%	572±2%
La	11±3%	10.6±3%	19±3%	13.1±3%	8.94±3%	9.17±3%	16.1±2%	31.8±3%	58.8±2%	10.5±3%	34.6±3%	17.8±3%	9.77±3%	8.88±3%	8±4%
Ce	20.6±3%	22±2%	34.2±3%	23.2±2%	16.9±3%	16.6±4%	29.7±2%	61.5±2%	126.6±2%	18.8±2%	62.3±4%	34±3%	17.9±3%	16.9±3%	14.5±3%
Nd	8.5±7%	8.6±7%	13.4±6%	9.8±8%	7.4±12%	5.9±13%	12.1±4%	25.5±12%	45.8±3%	8.8±6%	18.8±5%	13.1±7%	8±6%	8±7%	5.7±10%
Sm	1.69±3%	1.84±3%	2.8±2%	1.87±3%	1.3±3%	1.27±3%	2.9±2%	6.4±2%	8.95±2%	1.79±2%	3.09±2%	2.13±2%	1.71±3%	1.84±3%	1.15±4%
Eu	0.491±3%	0.488±3%	0.8±5%	0.499±3%	0.452±3%	0.467±6%	0.579±2%	0.77±3%	0.71±2%	0.619±4%	0.775±3%	0.649±3%	0.515±3%	0.414±3%	0.435±3%
Tb	0.149±5%	0.167±8%	0.399±4%	0.185±5%	0.111±12%	0.114±10%	0.417±3%	0.95±3%	0.921±2%	0.142±18%	0.287±4%	0.173±10%	0.156±8%	0.142±5%	0.095±5%
Yb	0.306±10%	0.43±16%	1.68±5%	0.63±15%	0.304±9%	0.288±10%	1.38±3%	3.44±7%	1.59±4%	0.29±13%	0.82±11%	0.43±23%	0.291±10%	0.243±12%	0.14±17%
Lu	0.053±7%	0.054±6%	0.232±6%	0.089±7%	0.046±15%	0.046±8%	0.194±3%	0.484±4%	0.209±4%	0.042±13%	0.106±8%	0.066±7%	0.048±9%	0.037±12%	0.033±10%
Hf	2.11±2%	2.13±3%	3.74±3%	2.28±2%	2.59±6%	2.3±3%	3.55±4%	4.54±3%	4.77±4%	1.77±5%	2.59±5%	2.47±2%	2.48±2%	2.51±4%	2.55±12%
Ta	0.122±6%	0.135±5%	0.658±3%	0.146±8%	0.095±8%	0.098±7%	0.442±4%	0.661±3%	0.553±5%	0.075±10%	0.179±12%	0.131±10%	0.125±10%	0.051±9%	0.06±8%
Th	2.14±3%	1.4±5%	5.11±5%	1.68±3%	1.19±3%	1.29±7%	6.28±2%	13.81±2%	25.8±2%	0.243±8%	9.4±5%	4.78±2%	1.6±3%	2.52±2%	0.59±9%
U	1.58±9%	0.241±12%	0.59±15%	0.32±14%	0.24±15%	0.192±16%	0.91±6%	3.62±5%	2.29±3%	<0.2	0.21±16%	0.23±17%	0.19±17%	1.03±6%	0.111±16%



**Figure 2.**—Normative An-Or-Ab plots of samples of the Felchville Gneiss and the Baileys Mills Tonalitic Gneiss. Sample numbers refer to analyses in table 1. Classification scheme of O'Connor (1965).

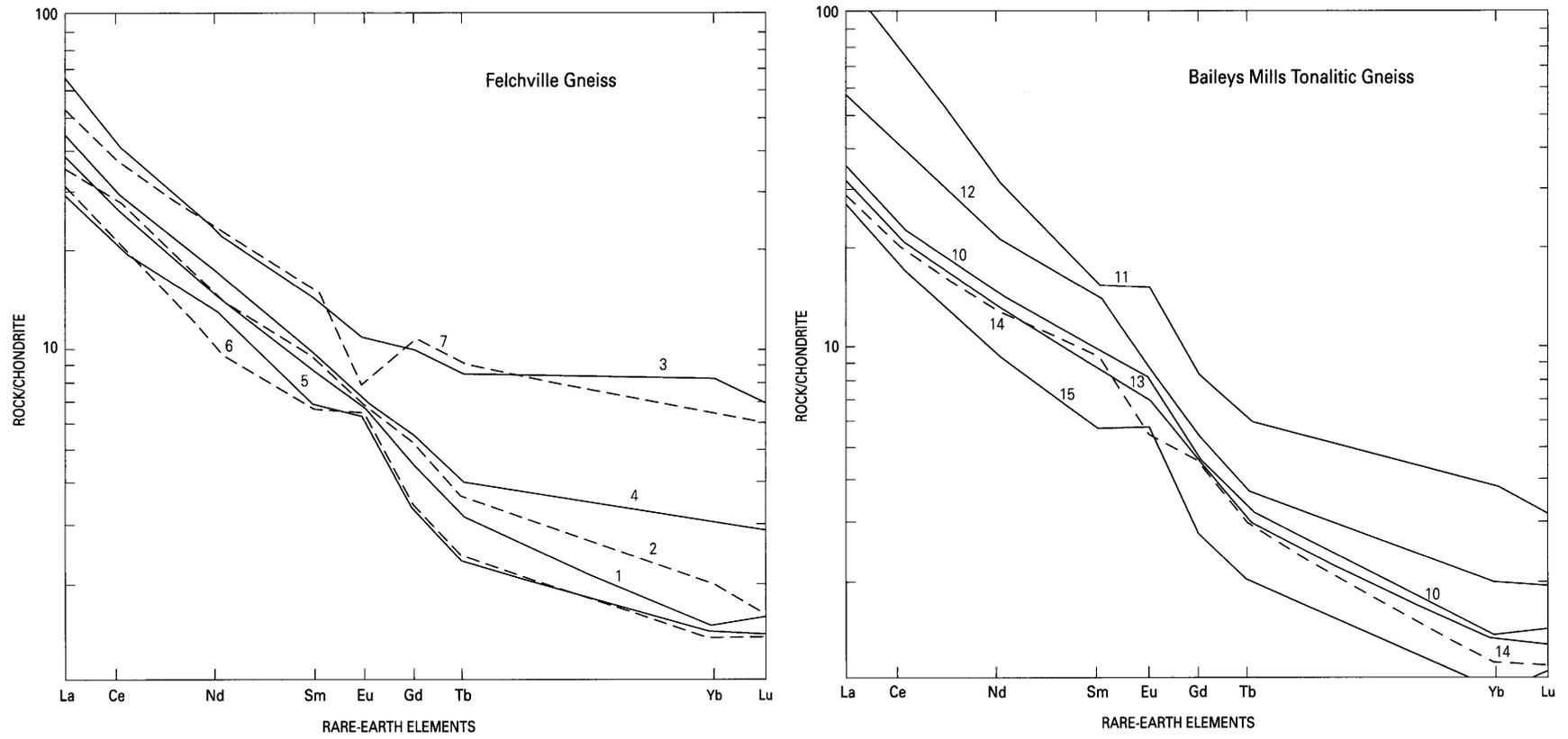
Other intrusive or migmatitic granitic gneisses (Ygg) are found within the Baileys Mills Tonalitic Gneiss, the Felchville Gneiss (in the Cavendish quadrangle), and in the paragneiss units of the Mount Holly Complex. These rocks appear to locally intrude other units of the Mount Holly Complex, but in other cases appear to be migmatitic or anatectic rocks perhaps replacing or derived from older microcline-rich, perhaps metarhyodacitic rocks. The origin of this rock unit is probably highly complex both in terms of the original protolith and the degree of anatectic remobilization. Similar granitic gneisses are common throughout the Mount Holly Complex of the Green Mountain massif and clearly crosscut both the tonalite-trondhjemite gneisses and the paragneiss units of the Mount Holly. Preliminary data suggest that these granitic gneisses are intruded or formed in place at about 1.25 Ga (Ratcliffe and others, 1991). Still younger granite pegmatite (Yp) and aplite (Yap) of uncertain age intrude all rocks of the Mount Holly. Distinctive diopside-bearing biotite-granite pegmatite occurs in the southern part of the quadrangle.

Near the eastern margin of the Chester dome, and adjacent to the contact with the eastern cover of the dome, medium- to coarse-grained biotite-microcline augen granite gneiss of the Bull Hill Gneiss (Ybh) of the Cardinal Brook Intrusive Suite appear. These rocks extend from the type area on Bull Hill immediately south of the quadrangle where Karabinos and Aleinikoff (1990) obtained a U-Pb upper intercept age of  $955 \pm 5$  Ma on zircon

from their sample 1-85. The Bull Hill of this quadrangle, shown on the eastern edge of the map, is continuous on the ground with rocks they sampled. The Bull Hill Gneiss of this belt terminates near the eastern margin of the map and is absent from this point northward in the Springfield, Ascutney, and Cavendish quadrangles.

A similar belt of augen gneiss enters the quadrangle along the southwestern margin of the dome and extends about 2 km northward before terminating against the fault that carries rocks of the Moretown Formation over the Mount Holly. Along the eastern side of this belt, at the south end of the map, and from that point south to the southern closure of the Athens dome in the Newfane quadrangle, narrow belts of Bull Hill Gneiss, gneisses of the Mount Holly Complex, and the Hoosac Formation are tectonically interlayered along a zone of intense faulting (Ratcliffe and others, 1992; Ratcliffe, 1991).

Along the eastern side of the dome in the Chester quadrangle, the Bull Hill Gneiss occurs entirely beneath the cover contact and does not exhibit interlayering with the Hoosac Formation. The Bull Hill Gneiss intrudes the core gneisses of the Athens dome in the Newfane, Townshend, and Saxtons River quadrangles (Ratcliffe, 1991; Ratcliffe and others, 1992). At the type locality on the western slopes of Bull Hill in the Saxtons River quadrangle, the contact of the Bull Hill Gneiss with the Mount Holly Complex locally is an intrusive breccia that contains rotated



**Figure 3.**—Chondrite-normalized rare-earth element diagrams of the Felchville Gneiss and the Baileys Mills Tonalitic Gneiss. Sample numbers refer to analyses in table 1.

xenoliths of gneiss in a fine-grained granite (Ratcliffe and Armstrong, 1995). Both the xenoliths and the intrusive rock contain later (that is, post-intrusion) foliations. The contact of the Hoosac Formation with the Bull Hill Gneiss is interpreted as an unconformity in the northern part of the Townshend quadrangle.

### Cavendish Formation

The name Cavendish Schist was first applied by Richardson (1929) to the large mass of biotite-quartz-plagioclase schist and more lustrous garnet-kyanite-staurolite-biotite-muscovite-quartz schist exposed near Gassetts and on Hawks Mountain in the towns of Chester and Baltimore. The more lustrous unit, well exposed in roadcuts on State Route 103, 0.5 km west of the village of Gassetts, was identified as Gassetts schist (Richardson, 1929). The term Gassetts schist has been informally used by many authors (for example, Thompson, 1975). A regional compilation by Doll and others (1961) did not show the Gassetts as a separate unit but used the name Cavendish Formation instead. The Cavendish as used by Doll and others (1961) included three discontinuous members; in ascending order they were an unnamed marble member, the Readsboro Schist Member (equivalent to the Gassetts schist and Cavendish Schist of Richardson, 1929), and the Bull Hill Gneiss member.

In subsequent reports (Thompson, Lyttle, and Thompson, 1977a; Thompson and others, 1990, 1993), the name Cavendish was abandoned and the name Hoosac Formation was used to refer to the schistose rocks, the basal marble was retained as an unnamed member, and the Bull Hill Gneiss was viewed as a metavolcanic member, all of the Hoosac Formation.

The results of mapping of the Cavendish (Ratcliffe, 1995) and Chester quadrangles, as well as regional studies outside these areas (Ratcliffe and Armstrong, 1995) have shown that the Bull Hill Gneiss is not interlayered with the Hoosac Formation (Ratcliffe, 1991) but is instead intrusive into the Mount Holly Complex. Furthermore, rocks previously mapped as schists of the Cavendish Formation now appear to be part of the Mount Holly Complex. The name Cavendish Formation is herein reinstated. The formation is assigned to the Mount Holly Complex on the basis of 1) the intrusive contact of the Felchville Gneiss against the Cavendish, and 2) the similarities between schistose units (Yrs, Yrg, Yrgt) and calc-silicate rocks or marbles (Ycs, Ym) of the Mount Holly Complex and the comparable marbles, calc-silicate rocks, and schists of the Cavendish Formation (as here revised). The Cavendish Formation includes three members: (1) an unnamed marble and calc-silicate member (Ycm); (2) Gassetts Schist Member (Ycg), an aluminous garnet-rich schist; and (3) an unnamed feldspathic schist or granofels member (Ycfs).

These three members of the Cavendish Formation (Ratcliffe, in press) extend into the Chester quadrangle from the large mass on Hawks Mountain. The Gassetts Schist Member is locally bordered on the west by a belt of feldspathic schist and granofels (Ycfs) less than 50 m thick and a narrow belt of marble and calc-silicate rock (Ycm). These marbles and calc-silicate rocks are discontinuous and the contact with biotite-quartz-plagioclase gneiss (Ybg) of the Mount Holly Complex, without the intervening schist and granofels (Ycfs) or calc-silicate rock or marble, can be observed along the western slopes of Hawks Mountain about 1 km south of the northern border of the quadrangle. In the large roadcuts west of Gassetts, a narrow zone of highly mylonitic phlogopite-calcite schist and calcite

marble 0.5 m thick occurs at the contact between the Gassetts Schist Member (Ycg) and the schist and granofels member (Ycfs).

On the southwest side of the Williams River, 0.6 km west of the large roadcuts of Gassetts Schist Member in State Route 103 near Gassetts, a small quarry exposes a narrow belt of calc-silicate gneiss (Ycs) about 5 m thick. The gneiss is separated from the adjacent rocks of the Cavendish Formation, to the east, by a narrow zone of biotite-quartz-plagioclase gneiss (Ybg) in which thin seams of white-weathering trondhjemite gneiss (Ygp) occur. From this point south, and along the western contact of the Cavendish, calc-silicate rock is absent. At the crossing of the Williams River and from that point southward for about 2 km, highly mylonitic microcline augen gneiss of the Bull Hill Gneiss (Ybh) and highly sheared schists of the Cavendish Formation (Ycg and Ycfs) are in contact with biotite-quartz-plagioclase gneiss (Ybg) on the west and with tonalite gneiss (Yt) on the east. From a point about 1 km north of section line *B-B'* and continuing to the southern border of the map, slivers of Bull Hill Gneiss and Mount Holly rocks are tectonically interleaved with rocks of the Cavendish and Hoosac Formations.

The southern termination of the Cavendish Formation occurs just north of the small knob of elevation 1,235 ft. Just south of this knob, a narrow belt of rusty-weathering muscovite-biotite-garnet-plagioclase schist and garnet-bearing gneiss (Yrgt) appears. Although mapped as separate units, the sheared varieties of Yrgt resemble some of the feldspathic layers in Ycfs. The eastern and lower contact of the Cavendish is well exposed in a series of cliffs from a point west of Baileys Mills northward, on the east- and south-facing slopes of Hawks Mountain. All along this contact, the Cavendish has a transitional contact within the Baileys Mills Tonalitic Gneiss of the Mount Holly Complex (Yt) and with a biotitic-feldspathic plagioclase augen mylonite gneiss (Yta and Ytm) into highly sheared mylonitic schist of the Cavendish (Ycfs). The transition zone is 50 to 200 m thick. Photographs illustrating the structures within this zone can be found in Ratcliffe, Armstrong, and Aleinikoff (1997).

The lower transition into gneiss is exposed on the lower slopes of the western part of Hawks Mountain, below approximately 1,300 ft elevation. In this area, coarse-grained, biotite-spotted trondhjemite and tonalite gneiss (Yt) is recognizable despite an intense, penetrative, mylonitic foliation that dips approximately 15° to 10° to the north and northwest. Zones of mylonite, spaced meters apart, transect the coarse gneiss and weave around elongate blocks, knots, and sheared-off fold noses of the gneiss, producing marked zones of disarticulation in the plane of the mylonitization. This zone gradually passes to lower elevations of 1,100 ft at the east end of Hawks Mountain in the Cavendish quadrangle.

All along the south-facing cliffs of Hawks Mountain, there is a gradual transition upward from the above-mentioned basal zone into increasingly sheared, darker, finer grained biotite mylonite schist. This zone of mylonite schist contains two distinctive rocks. The first is a phacoidally sheared plagioclase- "augen" mylonite (Yta) in which 1- to 2-cm porphyroclasts of plagioclase account for 70 percent of the rock. The other is a dark, porphyroclastic, biotite mylonite schist (Ytm), which contains smaller (1 to 0.5 cm) mylonitic and milled composite "grains" of plagioclase, biotite, and quartz. The "grains" have distinctive growth tails and asymmetric shapes typical of mylonitic porphyroclasts modified by recrystallization and dynamic regrowth. The elongation direction of the augen within the

north-dipping mylonitic foliation generally is east to west (Ratcliffe, Armstrong, and Aleinikoff, 1997, fig. 7c).

Within about 20 m of the contact with the Cavendish, the rocks are fine grained, uniformly foliated schists and blastomylonite, in which less-deformed, elliptical to tabular pods, 5 to 10 cm thick, of less-deformed gneiss occur. The actual contact with the Cavendish can be located to within 2 m in the western part of the Chester quadrangle, where the aluminous Gassetts Schist Member (Ycg) is at the contact. From the crest of Hawks Mountain (a hill of 2,082 ft elevation) eastward and into the Cavendish quadrangle, the contact is more difficult to locate because the biotite feldspathic schist of the Cavendish (Ycfs) closely resembles and appears to be transitional into the mylonite derived from the tonalite gneiss.

At the east end of Hawks Mountain in the Cavendish quadrangle, the mylonitic foliation turns sharply to the south and undergoes intense plication in later folds that trend N. 25°-30° E. and have steeply southeast-dipping axial surfaces. Mylonitic, porphyroclastic gneiss, like that seen along the lower and intermediate slopes of Hawks Mountain, occurs at the 600- to 700-ft elevation of Quarry Road, 700 m southwest of Perkinsville in the Chester quadrangle. From this point southward, the mylonitic foliation extends southward to the vicinity of Kendrick's Corner. The lower contact of the Cavendish Formation on Hawks Mountain is therefore interpreted as a thrust fault here named the Hawks Mountain fault. The Hawks Mountain fault truncates the contact between the Gassetts Schist Member (Ycg) and the feldspathic schist member (Ycfs) of the Cavendish in the hanging wall.

Near the northeastern corner of the map, the feldspathic schist member (Ycfs) unit and a nearly continuous belt of marble and calc-silicate rock (Ycm) occur, forming the southern closure of the large masses of Cavendish Formation exposed on Pine Hill in the adjacent Cavendish quadrangle. The marble is in contact with the feldspathic schist above and the contact appears to be a normal, interbedded one. The contact with the underlying Baileys Mills Tonalitic Gneiss is not exposed but the gneiss is highly mylonitic and porphyroclastic like the gneisses along the lower slopes of Hawks Mountain.

In summary, the Cavendish Formation in the Hawks Mountain area of the Cavendish and Chester quadrangles is considered, therefore, either to have an intrusive contact with granodiorite gneiss of the Mount Holly Complex (Ygp or Yap), or to be interlayered with the biotite-quartz-plagioclase gneiss of the Mount Holly. The lower contact with the Baileys Mills Tonalitic Gneiss beneath the Cavendish Formation is interpreted locally as a fault, but this also may have been originally an intrusive contact.

## STRATIGRAPHY OF THE COVER SEQUENCE OF THE CHESTER DOME

### Cover sequence east of the dome

A sharp, highly strained contact marks the top of the Bull Hill Gneiss (Ybh) of the Cardinal Brook Intrusive Suite or gneisses of the Mount Holly Complex with overlying granofels and schists of the cover sequence. The contacts are well exposed in the bed of the Williams River 0.5 km south of the quadrangle in the Saxtons River quadrangle. In these exposures, biotite-plagioclase-granofels and strongly tectonically laminated Bull Hill Gneiss of the Cardinal Brook Intrusive Suite are interlayered over a

distance of approximately 30 m. In exposures 200 m north of the river, also in the Saxtons River quadrangle, enclaves of recognizable Bull Hill Gneiss appear within a highly sheared plagioclase-biotite mylonite (Ratcliffe and Armstrong, 1995). This zone extends for approximately 50 m east of the massive outcrops of Bull Hill Gneiss. This problematic and discontinuous zone is identified as the Hoosac Formation(?) (€Zh?) on this map. Because of the pronounced shearing and the enclaves of Bull Hill Gneiss, it is uncertain if this unit is mylonite derived entirely from the Bull Hill Gneiss, or a tectonic mixture of both Bull Hill Gneiss and Hoosac Formation. The sheared and transitional contacts of the blocks of Bull Hill Gneiss with the mylonite matrix suggest that enclaves of Bull Hill Gneiss are not sedimentary boulders or cobbles. Overlying this mylonitic zone (€Zh?) is a plagioclase granofels with large cross-foliation porphyroblasts of biotite (Omfg?) of the Moretown Formation.

Between the southern edge of the map and the Black River, different units, including amphibolite (Oma), green schist and granofels (Omgs?), hornblende fascicle schist (Omhs), and rusty schist and amphibolite (Omrs and Omra), all assigned to the Moretown Formation or Moretown Formation(?), occur in contact with the Bull Hill Gneiss. Although these basal units have been shown as parallel belts of Hoosac, Pinney Hollow, and Ottauquechee Formations by Thompson and others (1993), the rocks, when mapped in detail, are discontinuous and irregularly distributed along the contact. These data suggest that folding, faulting, or a combination of both is needed to account for the mapped distribution.

A fairly regular belt of very distinctive pinstripe granofels (Oml) of the Moretown overlies the lower rocks. This unit grades into a hornblende granofels and schist member (Omhg) that interfingers with a dark-black schist (Ombs) and amphibolite (Omd). At the eastern border of the hornblende-granofels and schist, beds of garnet-rich, gray-green schist and granofels increase in abundance and amphibolite beds decrease, suggesting that the next overlying unit (Omgg) is in depositional contact with the hornblende-granofels and schist member. The three major units of the Moretown (Oml, Omhg, and Omgg) therefore appear to be in stratigraphic conformity.

The rocks of the North River Igneous Suite (Armstrong, 1994; Ratcliffe and Armstrong, in press) (Ontr and Ont) appear in different positions within the Moretown and therefore are not the same masses of rock. Tonalite gneiss (Ont) appears to truncate all three major units of the Moretown and is intrusive. A U-Pb zircon upper-intercept age of  $486 \pm 3$  Ma has been determined by John N. Aleinikoff (in Ratcliffe, Walsh, and Aleinikoff, 1997) for this metaintrusive body. These results set a minimum age for the Moretown Formation of Middle Ordovician or older.

### Cram Hill Formation

Overlying the trondhjemite gneiss (Ontr) unit is a very well layered felsic and mafic volcanoclastic unit (Ochv) of the Cram Hill Formation that contains abundant beds of rusty-weathering schist, cotecule, and feldspathic granofels. This unit may consist of recycled volcanic or intrusive rocks from the underlying North River Igneous Suite (Armstrong, 1994; Ratcliffe and Armstrong, in press) and may disconformably overlie the older rocks. Near the top of this unit is a distinctive belt of papery thin schist and phyllite (Ochs), locally rich in 1- to 2-mm-diameter garnets. At one locality, a quartz-pebble conglomerate (Ochq) occurs near the base of the schist unit. This belt of schist and quartzite probably

correlates with a similar unit that overlies felsic and mafic layered gneisses south of Rockingham in the Saxtons River quadrangle, discussed by Trzcinski and others (1992, p. 298). At their locality, quartzite and quartz-pebble conglomerate are interbedded with dark-gray, lustrous schist containing small garnets identical to schist and phyllite (Ochs) as mapped in the Chester quadrangle.

The felsic and mafic volcanoclastic member (Ochv) and the paper-thin schist and phyllite member (Ochs) are overlain by a very distinctive light-gray hornblende-plagioclase granofels (Ochhg) containing abundant and very coarse, stubby porphyroblasts of hornblende. This unit is identical to the Marlboro unit of the Cram Hill Formation as mapped by Armstrong (1994) in the Newfane area.

Overlying ankeritic greenstone (Ochag), greenstone (Ochg), and coticule (Ochc) form a continuous and distinctive set of units. The greenstones and amphibolites commonly exhibit a fragmental appearance and contain clots, blebs, and irregular patches of more feldspathic rock enclosed in a more mafic and uniform amphibolite matrix. Beds of quartzite and coticule (Ochc) that occur near the top of the greenstone are similar to coticule beds that occur within the overlying black quartz phyllite and ironstone member (Ochb). This uppermost unit is discontinuous and is absent where the greenstone nearly abuts the overlying Northfield; this may indicate erosion or nondeposition of the quartz phyllite and ironstone member. An ion-microprobe  $^{206}\text{Pb}/^{238}\text{U}$  age of  $484 \pm 4$  Ma by John N. Aleinikoff (in Ratcliffe, Walsh, and Aleinikoff, 1997) for zircon from a 1-m-thick felsic volcanic layer in the volcanoclastic unit (Ochv) in the Springfield quadrangle indicates a Middle Ordovician age.

Mapping in the adjacent Saxtons River quadrangle to the south indicates that the Cram Hill contains many of the same units as in the Chester quadrangle. However, there is considerable heterogeneity in the formation both across and along strike.

### Northfield and Waits River Formation

Rocks of the Northfield Formation are characterized by dark-gray schist or phyllite and siliceous phyllite (DSn) that contains abundant small (1-2 mm) garnet. These small garnets produce distinctive bumps on the foliation surfaces, even though the garnets may not be obvious. Within the quadrangle, beds of limestone appear to be absent, the abundance of which normally distinguishes the Waits River Formation (DSw) from the Northfield. Two minor units, a grit member (DSng) and a calc-silicate member (DSnc), occur at the base of the Northfield. The grit member contains pebbly, tan to gray quartzites and small-pebble conglomerate in beds less than 0.5 m thick. The contact with the overlying Waits River is poorly exposed and is therefore largely conjectural. The presence of abundant layers of deeply weathered, punky-brown-weathering, calcareous quartzite and limestone distinguishes the Waits River from the Northfield.

The Northfield and Waits River Formations regionally overlie different units of the Cram Hill Formation and locally rest directly on interlayered felsic and mafic metavolcanic or volcanoclastic rocks of the Barnard Gneiss of Richardson (1929), as used by Thompson and others (1993). No pronounced angular unconformity appears to be present; however a low-angle truncation or a major disconformity is required. As stated previously, the bedded felsic and mafic volcanoclastic member of the Cram Hill (Ochv) may contain recycled volcanic detritus from

the underlying igneous rocks of the North River Igneous Suite (Armstrong, 1994; Ratcliffe and Armstrong, in press).

## STRUCTURAL GEOLOGY

### FOLDS

Axial traces of five generations of folds are shown on the geologic map. The oldest folds ( $F_1$ ), confined to the core gneisses of the dome, predate the dominant internal foliation in the dome. Relict gneissic layering in the Old Shincracker, Great Brook, and Baileys Mills folds is steeper than the regional foliation on the limbs of these folds, and the foliation transects both limbs of these folds. These folds are probably relict Middle Proterozoic folds that have steeply dipping axial surfaces. However, the true dip of these axial surfaces is indeterminable. Relict gneissic layering in the core of the dome commonly is subvertical to steeply dipping, suggesting that the internal structure of the Mount Holly Complex rocks is not in accordance with the antiformal shape of the dome. This is illustrated well by the belts of steeply dipping amphibolite (Ya) throughout the core of the dome.

The second set of folds ( $F_2$ ) have the older regional foliation as their axial surface. These folds commonly are reclined and plunge steeply down the dip of the west-dipping foliation on the west limb of the dome. One major fold contains the cover rocks in a tightly pinched structure west of Gassetts. The small fold of amphibolite (Ya) and biotite-quartz-plagioclase gneiss (Ybg) west of Baileys Mills may also belong to this generation because the foliation is parallel to the axial trace. These folds are interpreted as Taconian folds.

Folds that are younger than the regional foliation in the core of the dome belong to several intersecting sets of upright to inclined folds ( $F_3$ ,  $F_4$ , and  $F_5$ ). The oldest of these folds trends north-northwest. The North Chester antiform is a doubly plunging structure that has been refolded by later north- to northeast-trending, upright  $F_4$  folds. The  $F_3$  and  $F_4$  folds have a weakly developed axial-planar crenulation cleavage. East of the Spoonerville fault, the northeast-trending folds tend to be inclined to the southeast and the tightness of the folds, visible in outcrops, increases greatly in the Lacross Road folded zone. These folds are synmetamorphic structures that have a well-developed axial-surface schistosity. Granite dikes that normally are not well foliated in the core of the dome are here highly folded and strongly foliated. Locally north-trending upright folds ( $F_5$ ) fold the older  $F_4$  folds.

Structures within the cover rocks on the east limb of the dome are dominantly tight, west-verging folds whose axial surfaces dip moderately steeply to steeply southeast, subparallel to regional foliation and later crenulation cleavage in the Northfield and Waits River Formations. Folds in the pre-Silurian rocks probably are predominantly of the regional  $F_4$  generation but relict reclined folds of the  $F_2$  generation are present in rocks as young as the Cram Hill Formation. Later north-trending  $F_5$  crenulate folds are present in the belt as well.

Garnet-inclusion structures from the Northfield Formation in the southeastern part of the map clearly show that garnet growth was synchronous with the late crenulation-cleavage events and, therefore, that the peak of metamorphism on the eastern flank of the dome was younger than or coeval with the  $F_4$  event. The

time of the Acadian metamorphic peak can be estimated from the  $^{39}\text{Ar}/^{40}\text{Ar}$  hornblende-plateau cooling ages of  $379\pm 2$  and  $374\pm 2$  Ma from amphibolite in the Baileys Mill Tonalitic Gneiss (Yt) from roadcuts on State Route 103, 1 km south of Gassetts (Harrison and others, 1989). Fold events  $F_3$ ,  $F_4$ , and  $F_5$  are clearly Acadian. Fold event  $F_2$  is interpreted as Taconian, as is the Hawks Mountain fault. The  $F_1$  folds in the Mount Holly Complex are interpreted as Middle Proterozoic.

## DISCUSSION OF THE CROSS SECTIONS

The Chester dome is the main structural feature of the area. The form of the dome is a nearly symmetrical elongated dome over which the cover rocks and numerous faults are arched. Mapping of the internal foliation in the core of the dome reveals a rather simple pattern in the northwestern two thirds of the dome; foliation there is very broadly arched and dips gently north. Cross sections *A-A'* and *B-B'* depict the arching of the foliation. The units within the Mount Holly Complex trend generally east to west and gneissic layering is commonly steeply dipping. Numerous thin layers of amphibolite (Ya) and other rocks within the Baileys Mills Tonalitic Gneiss (Yt) are useful markers and define rather low levels of shortening strain within the core of the dome.

The belts of layered biotite-quartz-plagioclase gneiss (Ybg), granitic gneiss (Ygg), and associated schists and amphibolite (Yrs and Ya) that are surrounded by tonalite gneiss (Yt) probably define older Grenvillian upright structures. The plunges of these folds are uncertain and therefore projection in the sections is also uncertain. Regardless, the map patterns illustrate well the lack of tight folding in the core of the dome.

Along the eastern third of the dome, east-southeast of the Spoonerville fault, both the dominant foliation and the units of the Mount Holly Complex are strongly folded. The Spoonerville fault marks the western edge of a high-strain zone, in which northeast-trending, westward-verging folds are abundant. Mapping of folds in amphibolite marker units illustrates well the different level of strain southeast of the fault as opposed to northwest of it. Very tightly folded units also occur in the vicinity of the North Springfield Reservoir and on the slopes northeast of French Meadow Road.

Shortening by about five times appears to have affected the rocks immediately east of the Spoonerville fault (section *B-B'*). This folding folds the dominant foliation in the dome and clearly has been produced by a superposed late event. Synmetamorphic structures indicate that this folding was contemporaneous with the latest metamorphism; therefore, the deformation is certainly Acadian. Plunges of these folds are generally to the northeast. Granite dikes in this area are strongly foliated and highly folded, suggesting that the high level of strain seen here is younger than intrusion of the granite dikes. The Chester dome therefore appears to be a composite feature in which the level of Acadian strain is much greater along the eastern margin of the dome than in the core. Likewise, a zone of pronounced late shortening is responsible for the tightness of the Butternut Hill and Spring Hill folds on the western margin of the dome in the adjacent Andover quadrangle. Late-stage tightening of folds along the margins of the dome clearly is an important element in the overall structure of the dome. The dome is the result of fold interference as well as of a very heterogeneous distribution of strain across the structure.

## STRUCTURES OLDER THAN THE CHESTER DOME

The cover rocks and highly foliated basement rocks along the western margin of the map contain abundant reclined folds here termed  $F_2$  folds. Fold axes in these rocks plunge to the northwest and west. A very comparable set of folds having east-west-trending hinge lines are present within the Hawks Mountain fault zone and in the pre-Silurian cover rocks along the eastern side of the dome. In the former case, the hinge lines of these folds pass through the horizontal, and in the latter they plunge east to southeast. The data, therefore, suggest that a set of pre-dome folds that are spatially associated with mylonite zones were widely developed in the basement gneisses and inner cover rocks of the dome. Regional relationships suggest that these fabrics may be Taconian. Rocks on the limbs of the tightly pinched Spring Hill fold northwest of the dome contain many of these folds, although the fold itself almost certainly is an Acadian feature.

## THE HAWKS MOUNTAIN FAULT

The origin of the Hawks Mountain fault is problematic. Detailed mapping in the area near Perkinsville suggests that the mylonitic fabric trends southward into the Baileys Mills Tonalitic Gneiss and that no great displacement is required by the map relations. Nonetheless, the mylonite zone can be traced continuously to the west and then to the south where it is associated with an intense zone of faulting along the western margin of the dome. The fault zone, therefore, grows from a widely dispersed zone of shearing in the north and east to a very discrete, well-defined zone of faulting in the west. In addition, no evidence for closure could be found in the area south of Chester, indicating that the fault does not continue to the south as an internal fault that frames an inner core of the dome.

The exposures along Hawks Mountain probably represent a widely dispersed zone of shearing that formed in the root of the originally east-dipping fault; the fault climbed up in section to the west to become a well-defined fault. The original updip part of the fault is now exposed as the west-dipping margin of the dome. The presence of a uniform lineation and foliation, both of which are arched over the dome, support the hypothesis that the Hawks Mountain fault and mylonite zone are pre-dome structures. The Hawks Mountain fault probably originally formed as a thrust fault in basement rock during Taconian imbricate thrust faulting and was later folded during the Acadian orogeny.

## ACADIAN GRANITES

About 50 dikes or small intrusive masses of biotite-muscovite granite (Dg) have been mapped. These dikes are narrow features, commonly less than 1 m thick, that crosscut foliations and folds in the center of the Chester dome. The dikes trend northeast, northwest, and approximately east to west and dip gently to vertically. Intersecting dikes with opposing dips are common, especially in the area near Gassetts and in the hills east of Baileys Mills and extending south to North Chester. Large, irregular, but shallow-dipping masses of granite occur on Old Shincracker and on Mount Flamstead. Abandoned granite quarries occur east of Dean Brook Road (2 km east of Gassetts) and on the east side of Trebo Road (1 km southeast of Baileys Mills). Locally, granite pegmatite (Dp) is found (for example, on Davidson Hill and on the spur that extends east from Hawks Mountain north of Dean Brook Road).

The Devonian pegmatite and granites are commonly nonfoliated to very weakly foliated and unfolded especially in the core of the dome. Along the eastern margin of the dome in the zone of highly deformed rocks of the Lacross Road folded zone, irregularly folded and foliated granite exist. Similar folded and foliated dikes of granite are present along the eastern flank of the dome in the Cavendish quadrangle (Ratcliffe, 1995) and in the Saxtons River quadrangle (Ratcliffe and Armstrong, 1995).

These relations clearly show that post-intrusive deformation was intense along the eastern folded zone, east of the Spoonerville fault. In addition, these data suggest that the  $F_4$  folding event along the eastern margin of the dome continued after intrusion of the granites in the Acadian. These data also suggest that late shortening produced a high-strain zone on the eastern flank of the dome. Detailed mapping in the core of the Butternut Hill fold, on the western flank of the Chester dome in the Andover quadrangle, indicates a comparable level of intense shortening that postdated the intrusion of granite dikes there.

An ion-microprobe (SHRIMP) age of  $392 \pm 6$  Ma on the rims of zircon grains (John N. Aleinikoff, U.S. Geological Survey, 1997, written commun.) has been determined for granite from the quarry on Dean Brook Road. At this locality, nondeformed but flow-oriented biotite-muscovite granite cuts across highly deformed and well-foliated Baileys Mills Tonalitic Gneiss. The dominant foliation within the core of the dome heretofore is older than  $392 \pm 6$  Ma, and the Acadian  $F_4$  folding that folds and foliates Devonian granite dikes outside the area is younger than  $392 \pm 6$  Ma.

## ECONOMIC GEOLOGY

Numerous small quarries are widely distributed across the area and include flagstone, granite, marble, and soapstone. Marble of the Cavendish Formation (Ycm) was quarried at Duttonsville Gulf and east of Perkinsville. Granite quarries were operated at Dean Brook Road and east of Trebo Road; both were small operations. Highly foliated gneisses were quarried as flagstone at Gassetts, 1 km west of Baileys Mills, and on the west slope of Mount Flamstead. The stone from the latter locality was used for local construction of houses and two churches in the Stone Village area of Chester. An additional small quarry is developed in the Bull Hill Gneiss of the Cardinal Brook Intrusive Suite, southwest of the Black River; the stone appears to have been used for local construction. Serpentine-chlorite-talc rock was quarried west of Perkinsville for soapstone. A small talc quarry was operated in black schist of the Moretown Formation (Ombs) near the western border of the map, 0.5 km north of the western end of section *B-B'*. All quarries are at present inactive, except for limited excavations for flagstone at the locality west of Baileys Mills; at the site of the old granite quarry off Dean Brook Road, where highly foliated tonalitic gneiss (Baileys Mills Tonalitic Gneiss) is being taken for flagstone; and at Gassetts where quarrying for flagstone has recently been resumed.

## SUMMARY AND CONCLUSIONS

Detailed mapping of the core gneisses of the Chester dome in the Cavendish (Ratcliffe, in press) and Chester quadrangles indicates that the rocks of the Mount Holly Complex closely resemble the Mount Holly in its type area in the Green Mountain

massif (Ratcliffe, 1992). The presence of tonalitic to trondhjemitic gneisses of the Baileys Mills Tonalitic Gneiss and the Felchville Gneiss closely resemble, both in age and chemical composition, an unnamed suite of metagneous rocks in the Green Mountain massif (Ratcliffe and others, 1991). It is noteworthy that these gneisses appear at about the same latitude in both areas and that the occurrences in the Chester dome appear to be an eastward extension of the same east-west belt found in the Green Mountain massif. This relationship suggests that the general east-west structural grain of the Middle Proterozoic rocks is consistent for the entire region.

Restudy of the Cavendish Formation in both the Cavendish and Chester quadrangles suggests that these schistose and feldspathic rocks, once considered part of the cover sequence, are best interpreted as part of the Mount Holly Complex. However, U-Pb total evaporation and ion-microprobe U-Pb and Pb-Pb ages of fragmental zircons from a quartzite layer at Cavendish Gorge, in the Cavendish quadrangle, range from 950 to about 1400 Ma (Karabinos and Thompson, 1997; John N. Aleinikoff, U.S. Geological Survey, written commun., 1997). If the dates of individual grains are the correct ages for detrital zircons, then the quartzite is younger than 950 Ma. These data suggest that some of the Cavendish at Cavendish Gorge is younger, not older, than the Felchville. Alternatively, if the fragments contain original detrital cores and varying amounts of zircon overgrowths, then the ages could represent mixing of metamorphic overgrowths and provenance ages. U-Pb and Pb-Pb ages for overgrowths of zircon from the Mount Holly Complex and from the Felchville Gneiss of the Chester dome have ages of 1250, 1100, and 950 Ma (Ratcliffe and others, 1991; Ratcliffe and others, 1996). Therefore, I am hesitant to accept the zircon age data cited above as demonstrating clearly the minimum age for the quartzite in the Cavendish Formation. Further study may be required to determine that the ages cited are true provenance ages of detrital zircons. Intrusive relations between the Felchville Gneiss and the Cavendish Formation in the Cavendish quadrangle (Ratcliffe, in press), and the U-Pb and  $^{207}\text{Pb}/^{206}\text{Pb}$  zircon ages of the Felchville Gneiss still suggest to me that the metasedimentary rocks of the Cavendish Formation are approximately 1.4 Ga or older.

The internal structure of the Chester dome in the Chester quadrangle indicates that the major folds and distribution of rock units to a significant extent predate the regional and strong  $S_2$  foliation in the core of the dome. This relationship suggests, as it does in the Cavendish quadrangle, that the regional foliation is not axial planar to isoclinal and once-recumbent folds. Detailed examination of the Late Proterozoic, Cambrian, and Ordovician cover rocks of the dome does not indicate a coherent stratigraphic package; significant internal folding and faulting is required to explain the distribution of the rock units.

A major Taconian fault is proposed to underlie the rocks of the Moretown Formation. The rocks between the Moretown Formation and the core gneisses of the dome are highly tectonized; only locally are the original sedimentary contacts preserved. The minor structures, mylonitic foliation, and reclined isoclinal folds within the zone are interpreted as Taconian features, consistent with east over west imbrication of basement and cover rocks generally exposed along the western margin of the Chester and Athens domes in the Saxtons River and Townshend quadrangles (Ratcliffe and Armstrong, 1996; Ratcliffe and others, 1992).

Formation of the Chester dome during the Acadian orogeny was the result of multiple compressional fold events and interference among those sets of folds. The peak of the regional metamorphism during the Acadian orogeny produced garnet inclusion structures that indicate garnet grew during the later crenulation or  $F_4$  event along the eastern margin of the dome. In this area and within the dome, zones of late shortening occur in areas where the deformation of Acadian granite dikes also is the greatest. Comparable but lower shortening strain is present along the western margin of the dome where garnet growth also accompanied shortening. Rocks within the core of the dome are broadly arched and Devonian granite dikes are only weakly deformed there. These data suggest that the level of Acadian strain was greatest along the flanks of the dome and is consistent with an entirely compressional origin for the dome.

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