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Bedrock geologic map of the Weston quadrangle, Windsor, Windham, Bennington, and Rutland Counties, Vermont

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Introduction

Bedrock of the Weston quadrangle consists entirely of Middle Proterozoic rocks of the Mount Holly Complex except for a small area of albite- or chloritoid-bearing schists west of Moses Pond. The age of these rocks is uncertain; they may be Late Proterozoic and Cambrian cover rocks, although in this report they are assigned a questionable (Y?) Middle Proterozoic age.

Exposures range from excellent to very poor. Abundant outcrop is found on the south-facing slopes in the northern and central part of the map. South of Peabody Hill and Markham Mountain, exposures are widely scattered and generally of minor extent. There abundant glacial till covers the slopes, and the valley bottoms contain extensive deposits of sand and gravel.

All of the Mount Holly Complex rocks are highly foliated and are retrograded to contain greenschist-facies minerals. Alteration of biotite and garnet to chlorite is widespread, and abundant fine-grained muscovite and/or paragonite, clinozoisite or epidote, and albite are common minerals. Relict high-grade assemblages, such as hornblende and garnet, diopside-calcite, coarse tremolite-phlogopite and dolomite, and perthitic alkali feldspar plus garnet-microcline, are preserved locally. Re-metamorphism in the Taconian (Middle to Late Ordovician) and Acadian (Middle Devonian) orogenies is responsible for the retrogression of the hornblende-granulite assemblages originally formed in the Middle Proterozoic. Because of the almost complete retrogression, the schistose rocks of the Mount Holly Complex contain the same minerals (chlorite-muscovite-albite or chloritoid, for example) as prograde Late Proterozoic through Ordovician rocks exposed east of the Green Mountain massif (Ratcliffe, 1992a). Despite the physical resemblance of schistose rocks in this quadrangle to late Proterozoic and Cambrian cover rocks of the Tyson, Hoosac, and Pinney Hollow Formations, the geologic mapping and limited geochronology indicate that most or all of the schistose rocks of the quadrangle are really part of the Mount Holly Complex.

Previous mapping

The only large-scale geologic map of this area is the reconnaissance map of Slack and Sabin (1983) that covers the area within the Green Mountain National Forest in the western and north central part of the map. The generalized geology at 1:250,000 is given by Doll and others (1961) and by Thompson, McLelland, and Rankin (1990). Recent maps of contiguous areas are those of the Mount Holly area to the north (Ratcliffe, 1992a; Walsh and others, 1994), Andover to the east (Ratcliffe, 1996), and the Londonderry to Stratton Mountain area to the south (Ratcliffe and others, 1991; Ratcliffe and Burton, 1989). The area immediately to the west was mapped by Peper and Downie (1992) at 1:48,000 for a mineral resource assessment of the Green Mountain National Forest Wilderness Area at Big Branch, Peru Peak, and Wilder Mountain. An open-file digital version of this map, lacking the text, cross sections, and structural data was released in 1996 (Ratcliffe and Burton, 1996).

Regional Setting and Metamorphism

The Weston quadrangle lies near the center of the Green Mountain massif immediately south of the Mount Holly quadrangle that contains the type section of the Mount Holly Complex of Middle Proterozoic age (Whittle, 1894a; Ratcliffe, 1992a). A generalized map (Fig. 1) shows the location of the area in relation to Late Proterozoic and Cambrian cover rocks of the Tyson Formation.

Retrogression of the Proterozoic rocks was contemporaneous with formation of a regionally important foliation that is coplanar with a strongly developed second generation foliation (S_2) (Fig. 2) in Paleozoic cover rocks east of the massif. The (D_2) structural event produced discrete shear zones in the southern part of the massif as well as a penetrative foliation there and to the north (Ratcliffe and others, 1988; 1992). Minor folds are commonly reclined† within this S_2 foliation. In the southern part of the

† A reclined fold has a hingeline that plunges nearly directly in the dip direction of the axial surface regardless of the amount of dip of the axial surface. The term is not to be confused with either a recumbent or an inclined fold which are distinguished by having a subhorizontal to inclined axial surfaces.

massif, these folds plunge to the south-southeast down the dip of the southeast dipping (S_2) foliation. The map distribution of S_2 foliation within the area of figure 1 is given in figure 2. S_2 forms a north-plunging cleavage arch that extends north-north-westerly through the Weston quadrangle. The crest corresponds approximately with the positions of Holt and Peabody Hills and the Devils Den area. To the north of Devils Den, the trend is more to the northeast. Plunges of folds of S_2 are generally gentle to the north or locally to the south-southeast, and folded S_2 locally describes domes and basins. A very important observation supported by detailed mapping is illustrated by figure 2. The trace of the retrogressive foliation S_2, transects units and folds in the Mount Holly. S_2 is not the axial surface of major symmetrical repetitions of units within rocks of the Mount Holly. These older folds are Middle Proterozoic and commonly have steeply dipping axial surfaces as well as steep plunges, whereas the S_2 foliation dips gently east and northeast as well as to the west.

Retrogressive minerals muscovite, chlorite, chloritoid, ilmenite, tremolite-actinolite, and biotite all lie within the S_2 foliation. Aggregates of albite and epidote commonly overgrow and include the S_2-oriented minerals. In figure 1, quartzite (Yq), schistose rocks (Ys), and calc-silicate rocks (Ycs) of the Mount Holly Complex are distinguished from other rocks of the Mount Holly, which are nonpatterned and designated as Mount Holly Complex undifferentiated (Ymhu). Belts of chloritoid-bearing aluminous schist and garnet quartzites are distinguished by the darker of the two (Ys) patterns. In these rocks, chloritoid is a retrograde mineral that is aligned in the penetrative (S_2) regional foliation. The foliation is arched to form the major antiform. Belts of chloritoid-bearing schist (darker Ys pattern in Fig. 1) west of the Weston quadrangle have textures that clearly indicate derivation of chloritoid from retrogression of coarse Middle Proterozoic garnets, which are as much as 2 cm in diameter. Iron-rich chlorite derived from the garnet forms elliptical to rod-shaped spears lying in the S_2 foliation. In the eastern and northern part of the quadrangle, and on Ludlow Mountain in the Mount Holly quadrangle (Fig. 1), garnet is uniformly retrograded to chlorite. Abundant chloritoid is found in the Ys unit (lighter pattern) there as well. Garnet and biotite in the nonchloritoid-bearing Ys unit are retrograded and commonly replaced throughout the Weston quadrangle. Clinozoisite and albite are common retrograde minerals in these schists. Garnet is not present in the cover rocks along the eastern side of the massif. The first occurrence of Acadian prograde garnet in cover rocks occurs approximately 3 km east of the quadrangle (Fig. 1) boundary in the Pinney Hollow Formation (Ratcliffe, 1992a).

From the above relationships, it is clear that rocks of the massif were retrograded to biotite-grade after hornblende-granulite facies Middle Proterozoic metamorphism. The coexistence of garnet and chloritoid in some of these rocks could be regarded entirely as disequilibrium if it were not for the fact that chloritoid is found locally as inclusions within euhedral garnet in the schist units. These localities occur within the Y?cms unit west of Moses Pond and in the belt of Ymcs east southeast of Moses Pond, extending towards Weston (Fig. 1). Localities where inclusions of chloritoid in garnet have been found also are shown on the geologic map and on figure 1. Outside, the garnets, chloritoid, and ilmenite are aligned in the S_2 retrogressive foliation. This indicates that in certain areas, garnet grew after S_2. These slightly higher, garnet-grade conditions are preserved only within the core of the massif, approximately along the crest of the post-S_2 cleavage arch, which probably is an Acadian structure.

One possible interpretation is that the garnet that contains the ilmenite and chloritoid inclusions resulted from Taconian re-metamorphism of Middle Proterozoic schists (Ys) and that these rocks were brought closer to the surface by later (Acadian) arching (fig. 3). Judging from form line maps of the folded S_2 foliation (Fig. 2), the structural relief on the antiform may be 3 to 4 km (fig. 3). Therefore, the rocks exposed in the core of the massif may correspond to a pre-arching position 3 to 4 km beneath the non-garnet-bearing cover rocks at the east edge of the massif.

Throughout the area, late crenulation cleavages lack a metamorphic fabric, except for minor chloritization of garnet. Chloritoid-ilmenite-white mica, and retrogressive clots of chlorite, after older garnet, all are kinked or warped by the later folding that accompanied the crenulation cleavages.

Acadian metamorphism of garnet grade and higher did affect areas east of the quadrangle, where there is abundant evidence that garnet grew during and after the formation of multiple Acadian crenulation cleavages (Ratcliffe and Armstrong, 1995; Ratcliffe and others, 1992). These crenulation cleavages are similar in orientation and in their related fold styles to the F_3 and F_4 folds in this quadrangle.

The arguments above suggest that Acadian metamorphism in the Weston area never reached the garnet- to biotite-grade expressed by the minerals in the regional S_2 retrogressive foliation. Therefore, it is plausible that the S_2 fabric and the garnet-chloritoid inclusion structure are relicts of Taconian metamorphism.

In summary, certain units (Y?mab, Y?cms, and Ymcs) contain mineralogy like that in the cover sequence rocks at garnet grade east of the quadrangle. However, this resemblance does not indicate that the rocks should be correlated. The widespread occurrence of schists that contain chlorite, muscovite, chloritoid, ilmenite, and rutile throughout the known Mount Holly Complex (Ratcliffe, 1992b) weakens the mineralogic arguments for such a correlation. Moreover, the close association of these schists with quartzite, calcsilicate rock, and even dolomite marble of the Mount Holly Complex argues against lithologic similarity as a sole reason for correlation.

The Devils Den structure and the basement-cover problem

Near the area known as Devils Den in the adjacent Danby quadrangle, labeled DD in figure 1, excellent exposures of albite-muscovite-biotite-quartz schist (Ymab), a microcline-muscovite quartzite and cream- to beige-weathering dolostone crop out (Dale, 1915, p. 21). The entire section, totalling approximately 40 feet in thickness, dips northeasterly beneath granitic and plagioclase- and tourmaline-rich gneisses of the Mount Holly Complex. Below the road (country Route 10), and in exposures above the road to the north, migmatite gneiss underlies the dolostone and quartzite. A subvertical belt of albitic schist (Y?mab) can be traced from the dolostone at Devils Den 1 km to the north in the core of a northerly plunging antiform (Fig. 1). The western limit of the albitic rocks can be traced 0.5 km south from this road cut where what superficially appears to be a gneiss-cobble conglomerate dips to the west beneath a migmatitic gneiss. In reality, this rock is a strongly sheared pegmatitic gneiss that contains elliptical clots of quartz and gneissic granite. It is not a metasedimentary rock. Thus, the rocks that could be considered to underlie Proterozoic gneiss on the northeast and northwest limbs of a fold both seem to underlie and overlie these gneisses in the northern hook-like termination shown in figure 1. Therefore, whatever the age assignment of these rocks, they are tightly infolded and generally underlie rocks of the Mount Holly Complex. A simplified and enlarged cross section through the structure described is shown in figure 3.

The dashed lines in figure 3 show the form of the folded S_2 foliation, which depicts the axial region of the main Green Mountain antiform. This structure is quite simple. Comparison of the geologic map (Fig. 1) with the formline map (fig. 2) shows that the geologic units in the Mount Holly do not conform to the trend lines of the S_2 foliation. In outcrops, gneissosity in the Mount Holly Complex is subvertical to steeply inclined, and the S_2 foliation is axial planar to numerous minor folds that have gently dipping axial surfaces, either to the northwest or northeast. It is clear regionally (figs. 1 and 2) that the S_2 foliation transects belts of rocks and folds in the Mount Holly Complex. These older folds, which regionally trend across the Green Mountain massif in a general east-west orientation, are Middle Proterozoic.

In cross section A-A' (fig. 3), the Mount Holly units do not conform to the S_2 foliation. The section A-A' (fig. 3) illustrates the closed nature of the fold of the proposed cover rocks at Devils Den and shows the compatibility in fold form to the rocks of the Mount Holly Complex. If the Y?mab unit is cover rock, then major recumbent folds are required. These are very incompatible with the observed lack of the basement-cover folding along the western and eastern limbs of the Green Mountain massif. On the other hand, as can been seen from figure 1, fold patterns in the Middle Proterozoic rocks are quite similar to patterns within the questionable cover rocks (Y?mab and Y?cms). On balance, structural, petrologic, and field observation suggest the rocks labeled Y?mab and Y?cms in this quadrangle are part of the Mount Holly Complex. It remains possible however, that the quartzite, dolostone and some of the albitic schists at Devils Den may be true cover rocks infolded into the Mount Holly Complex. This synformal F_2 fold would have to open to the south and be somewhat sheath-like, judging from the orientation of the hingelines of the F_2 folds.

Mount Holly Complex

The Mount Holly Complex is named for exposures immediately north of the Weston quadrangle, in the vicinity of the town of Mount Holly (Whittle, 1894a; Ratcliffe, 1992a). The term recently has been redefined to include all those metaigneous, metasedimentary, and metavolcanic rock and granite pegmatite in the Green Mountain massif, Chester-Athens dome, and Rayponda and Sadawga domes in Vermont that are older than the Ottawan phase of the Grenville orogeny. In Vermont, the minimum age of the Ottawan phase is ≈950 Ma as determined by the U-Pb zircon age (Karabinos and Aleinikoff, 1990) of post-tectonic intrusive rocks of the Cardinal Brook Intrusive Suite (Ratcliffe, 1991). These rocks include the Stamford Granite, Harriman Reservoir Granite, Sherman Reservoir Granite, and the Bull Hill Gneiss (Ratcliffe, 1991). The maximum age of the rocks in the Mount Holly Complex is unknown; however, the oldest dated rocks are intrusive metatonalite and metatrondhjemite (based on textures and chemical composition). These have U-Pb zircon ages of about 1.3 to 1.35 Ga in the Green Mountain massif (Ratcliffe and others, 1991). Because we could not determine clear intrusive relations with surrounding metasedimentary rock, we chose in the 1991 study (Ratcliffe and others, 1991) to interpret the metatrondhjemites and metatonalites as volcanic and hypabyssal intrusive rocks older than the metasedimentary rocks of the Mount Holly Complex. However, Ratcliffe and Burton now favor the idea that the tonalites and trondhjemites intrude the paragneiss units of the Mount Holly Complex. Granitic gneisses younger than the tonalites and trondhjemite intrude all units of the Mount Holly Complex. Aplitic granite (Ygg, Fig. 1) on Ludlow Mountain intrudes the schists and quartzite there and has been dated at approximately 1.3 Ga. This indicates that the metasedimentary rocks of the Mount Holly Complex must be older than 1.3 Ga (Ratcliffe and others, 1991). In addition, new mapping (since 1991) of trondhjemite gneisses of the Chester dome reveals that the trondhjemite gneisses intrude metasedimentary rocks of the Mount Holly Complex there. Ages obtained by ion microprobe, $^{207}Pb/^{206}Pb$ (SHRIMP) analyses of zircons from these trondhjemites are approximately 1.4 Ga† (Ratcliffe, Aleinikoff, and Hames, 1996). If the tonalitic and trondhjemitic gneisses also intrude the metasedimentary rocks of the Green Mountain massif, some, if not all, of the metasedimentary rocks of the Mount Holly Complex also may be older than 1.4 Ga. These results suggest that the paragneiss units of the Mount Holly Complex are older than 1.3 Ga and possibly older than 1.4 Ga.

In the Weston quadrangle the Mount Holly Complex is divisible into three major groups of rocks (see Correlation of Map Units) these include:

(1) well-layered paragneisses and schists (for example, Ybg, Yrs, Yq, Ycs, Ym, Yd, Ycms)

(2) intrusive rocks, including trondhjemite gneiss (Yt), biotite granite gneisses (Ygg), fine-grained felsic gneiss (Yfg) and hornblende dioritic gneiss (Yhd, Yhda), and pegmatite (Yp)

(3) metasomatic or fine-grained aplitic gneisses (Yap), albitic gneiss (Yab) possibly related to one or more of the intrusive rocks, and migmatitic gneiss (Ymig). The latter may be in part intrusive and derived by anatexis of original felsic volcanic protoliths.

†One Ga or gigiannum equals 1 billion years

Schists and paragneiss of the Mount Holly Complex

The dominant paragneiss unit of the Mount Holly Complex is a heterogeneous, well-layered, biotite-quartz-plagioclase gneiss (Ybg) that contains abundant layers of amphibolitic gneiss, amphibolite and minor layers of quartzite, schist and calc-silicate gneiss. Where these rocks are wide enough to be shown, they are mapped separately. As indicated in the Correlation of Map Units, the Ybg unit is thought to include many layers of these different rocks, which may be found throughout Ybg. From examination of the map, it is clear that rocks of metasedimentary origin, such as quartzites (Yq, Ydq), schists (Yrs, Yrgt, Ymcs), and calc-silicate rocks and marble (Ycs, Ym, Ydm), tend occur in parallel belts within or adjacent to major belts of Ybg. These observations suggest that the biotite gneiss unit (Ybg) probably also is metasedimentary or metavolcanic. This association is consistent throughout all of the Mount Holly Complex in the core of the Green Mountain massif and in the Chester and Athens domes to the east.

The schistose rocks (Yrs, Yrgt, Ymcs) appear to be retrograde variants of originally more garnetiferous gneisses or schists that are closely associated with belts of calc-silicate rocks and garnet-bearing quartzite. The Ymcs unit, which is quite phyllitic and chloritic, appears to be a more thoroughly retrograded variety of Yrs. Both Yrs and Ymcs contain pegmatite (Yp). Exposures of lustrous silvery-green retrograde garnet-chlorite-muscovite-quartz±chloritoid±ilmenite±paragonite schist (Ymcs) west of Weston have been correlated with Cambrian cover rocks by Doll and others (1961), Slack and Sabin (1983), and by Thompson, McLelland and Rankin (1990). This more aluminous unit resembles some chloritoid-rich beds in the Pinney Hollow and Tyson Formations in the cover rocks east of the Green Mountain massif (Ratcliffe, 1992a). Examination of the map shows that the Ymcs unit is closely associated with garnetiferous quartzite (Yq), amphibolite (Ya), and calc-silicate rock (Ycs). The calc-silicate unit (Ycs) contains mappable beds of orangish tan- to beige-weathering, phlogopite-dolomite marble, scapolite gneiss, and tremolite rock. It is associated with albite-muscovite-biotite-quartz schist and a clinozoisite-biotite-actinolite gneiss (Ybcg) and with pegmatite (Yp). The more aluminous schist (Ymcs) passes gradationally into a less lustrous, rusty weathering, more biotitic schist (Yrs). Pegmatite dikes (Yp) intrude the Yrs, Ycms, Yq, and Ycs units. Despite the fact that the schistose units contain no minerals indicative of high-grade Proterozoic metamorphism, the rocks interbedded with them do. This, in combination with the overall map relations and the intrusion by pegmatite (Yp), require that these schistose rocks be part of the Mount Holly Complex. The Yrs unit associated with the large quartzite that enters the northeastern corner of the quadrangle is continuous on the ground with lustrous chloritoid-muscovite-ilmenite±kyanite-bearing schists in the Ludlow Quadrangle (Fig. 1, loc. 1) that there are intruded by kyanite-bearing tourmaline pegmatite and granodiorite gneiss (Ygg) (Ratcliffe, 1992a). This granodioritic gneiss (Ygg on figure 1) contains zircons that yield U-Pb ages of about 1.3 Ga as mentioned previously. The chloritoid-bearing phyllite there contains relict large 2- to 5-mm porphyroclasts of muscovite that have yielded $^{39}Ar/^{40}Ar$ laser extraction ages as great as 950 Ma (Hames, personal communication to Ratcliffe, 1990; Ratcliffe, Aleinikoff and Hames, 1996). The geologic and isotopic data therefore indicate that the retrograded aluminous schists in the central and eastern part of the quadrangle are Middle Proterozoic in age and not cover sequence rocks, despite their general resemblance to the latter.

Chloritoid-bearing, chloritic-muscovite schists like Ymcs and more biotitic (non-chloritoid-bearing) rocks like Yrs are widely developed throughout the Mount Holly Complex. They are associated with large-garnet quartzite, dolomitic marble, and coarse-grained tremolite±talc calc-silicate rocks (Fig. 1). This association has been reported from the type Mount Holly Complex in the Mount Holly quadrangle (Ratcliffe, 1992a) and from the College Hill area in the Stratton Mountain and Jamaica quadrangles (Ratcliffe and Burton, 1989; Ratcliffe, in press). The Wilcox Formation, as redefined by Ratcliffe (1992b) within the Rutland and Killington Peak quadrangles, closely resembles rocks mapped here as Yrs, Ymcs, Y?cms, and Y?mab. A newly discovered belt of coarse-grained to fine-grained dolomite marble and tremolite-talc calc-silicate rock is interlayered with an extensive belt of lustrous chloritoid chlorite-muscovite-quartz phyllonite on Blue Ridge Mountain in the Chittenden quadrangle (Ratcliffe, [1995], unpub. data). This schist contains 3- to 5-mm elongated rosettes of intergrown chlorite, muscovite, and chloritoid, which constitute as much as 35 percent of the rock. In some cases, the chlorite-muscovite-chloritoid clots have equant, dodecahedral outlines of the original garnet. In other cases, the chloritoid rosettes grew across the prominent retrogressive foliation. The schist is intruded by coarse pegmatite and is included as screens within pegmatite on the slopes north of Chittenden Reservoir along the southern border of the Mount Carmel quadrangle. These rocks all contain abundant coarse rutile, and the chloritoid contains abundant ilmenite as described by Whittle (1894b) and by Brace (1953).

In general, these more aluminous schists of the Mount Holly Complex are very titaniferous (like Ymcs of this quadrangle), alkali-poor rocks. They may owe their unusual chemistry to titanium and alumina enrichment and resulting alkali depletion during anatexis in either a pre-Grenville or Grenville metamorphic event. The general occurrence of migmatitic gneiss (Ymig), aplitic gneiss (Yap) and diopside, and other calc-silicate gneiss and pegmatite suggests the possibility of widespread exchange of mobile elements such as K, Na, Ca, Mg, and Si during Proterozoic metamorphism.

Schist and granofels units of uncertain age (Y?cms and Y?mab)

Two broad areas of lustrous schist (Y?cms) and albite-biotite-muscovite schist (Y?mab) crop out on the hills west of Moses Pond and extending to the western border of the map. The more aluminous, greenish lustrous schist (Y?cms) contains chloritoid, garnet, rutile, ilmenite, and abundant chlorite and muscovite. This unit overlies the more albitic Y?mab unit in a late synform on the hills due west of Moses Pond (Plate 1). The biotite-muscovite-plagioclase-quartz-schist (Y?mab) has a gradational contact with Y?cms. The basal contact of the Y?mab unit however is problematic. The contact with Yrs is very difficult to map because albitic layers also occur within Yrs, and Y?mab passes locally into garnetiferous schists that are identical to Yrs elsewhere. On the east and west flanks of the adjacent upright antiform, which is cored by felsic and probably intrusive gneiss (Yfg), very coarse-albitic muscovite granofels (Yab) contains sills of felsic gneiss and also exhibits gradational contacts into the Y?mab. Likewise, the Y?mab schist unit is gradational into garnet quartzite (Yq), hornblende-garnet amphibolite (Ya), and calc-silicate rock (Ycs). Despite very thorough examination, no evidence for an unconformity between Y?mab and known Proterozoic gneisses could be determined. A conglomerate or quartzite that locally might mark the contact between basement rocks and cover sequence was not discovered. Normally, the contact between basement rock and cover rock across the region is a marked angular unconformity both on the eastern and western borders of the Green Mountain massif. Schist units (Yrs, Ycms and Yq) are clearly truncated by the basal units of the Dalton Formation on the west, and by the basal units of the Tyson Formation on the east (Fig. 1) in the adjacent Andover quadrangle (Ratcliffe, 1996). The strong structural concordance west of Moses Pond therefore suggests that Y?cms and Y?mab do not rest unconformably above the Mount Holly Complex.

Figure 1 shows the distribution of schistose rocks (Ys) of the Mount Holly Complex to the questionable schists (Y?cms and Y?mab) discussed above. The map data confirm that chloritoid-bearing schists (shown by darker shading) are associated with garnet quartzite (Yq) and calc-silicate rock (Ycs) in the area north and west of the Weston quadrangle. Figure 1 also shows the profound angular unconformity between all units of the Mount Holly Complex and the Tyson Formation. The map pattern of the schist units defines the general east-west trending, but broadly folded, Middle Proterozoic structural grain of the Mount Holly Complex. The concurrence between map units in the Devil Den-Moses Pond area and belts of schistose rocks of the known Mount Holly units outside that area suggests strongly that the Y?mab and Y?cms units actually are part of the Mount Holly Complex. The dolostone and quartzite in a narrow north-south belt at Devils Den (locality 2, Fig. 1), which are too small to show at scale, remain very problematic and may be indeed exposures of cover rock.

Intrusive rocks of the Mount Holly Complex

Trondhjemite gneiss (Yt) occurs in six areas on the map in contact with a wide variety of units, and the map relations suggest that the unit may be intrusive. No exposures within the quadrangle, however, demonstrate the intrusive relations. The best exposures are on the south slopes of Terrible Mountain where the contact with Ybg is nearly exposed. At or near the contact is a pinkish, medium- to fine-grained trondhjemite that is too thin to map. At the borders elsewhere, aplitic gneiss (Yap) or a fine-grained felsic magnetite-biotite gneiss (Yfg) is present. Both the Yap and Yfg units could be the intrusive border facies of the trondhjemite that is contaminated by mixing with country rocks. The trondhjemite gneiss has yielded U-Pb zircon discordia ages of 1.35 to 1.31 Ga. A similar rock in the core of the Chester dome has yielded $^{207}Pb/^{206}Pb$ ion microprobe (SHRIMP) ages for zircon cores as old as 1.4 Ga, and this is interpreted as the age of intrusion there (Ratcliffe, Aleinikoff and Hames, 1996). North of Terrible Mountain, a narrow sill or folded dike-like mass of hornblende-diorite gneiss (Yhd) appears to intrude Yrs and has a narrow selvage of fine-grained amphibolite along the contact. The spatial association of these mafic rocks with the trondhjemite gneiss may indicate that the felsic and mafic intrusive rocks are cogenetic. Dioritic rocks like the hornblende-diorite gneiss form a minor but important part of the tonalite-trondhjemite suite throughout the Mount Holly Complex (Ratcliffe and others, 1991).

Three areas of granitic gneiss (Ygg) have been mapped. The wide belt in the southwestern part of the map is traceable to a sample locality about 1 mile south of the border that yielded zircon with a U-Pb discordia age of about 1.25 Ga (Ratcliffe and others, 1991).

A widely distributed felsic gneiss (Yfg) has a map distribution that suggests the unit is intrusive. It forms an irregular border around the migmatite gneiss unit (Ymig) in the north central part of the map and also appears to be a border facies of the trondhjemite gneiss (Yt). The unit appears to intrude or enclose paragneiss units. Along the western limb of the small anticlinal exposure of Yfg northwest of

Moses Pond, numerous small lit par lit sills of aplite occur within the albitic schist Y?mab; similar lit par lit sills occur in garnet-quartzite (Yq) and in albitic-muscovite schists interlayered with garnet-hornblende-amphibolite (Ya).

Biotite-muscovite and biotite-tourmaline pegmatite (Yp) intrude most units in the Mount Holly Complex but are particularly abundant in the schistose and quartzitic rocks. Gneissic layering in the rocks of the Mount Holly Complex is cross cut by the pegmatites but the pegmatites, also are foliated strongly. The pegmatites have not been dated, but judging from field relation they may range from about 1.2 Ga, the age of some granitic gneisses in the Mount Holly Complex (Ratcliffe and others, 1991) to about 1 Ga, the approximate time of the Ottawan Phase of the Grenville Orogeny, which was the last Middle Proterozoic dynamothermal event.

Metasomatic and migmatitic rocks of the Mount Holly Complex

The units Yap and Ymg are interpreted as the products of anatectic melting and interaction of mobilized liquids with country rocks. The protoliths of these rocks are highly uncertain, and the age of the anatexis unknown. They certainly were associated with a high-grade hornblende granulite metamorphism and contemporaneous intrusion of the granitic gneisses (Ygg).

A white fine-grained aplitic gneiss (Yap), consisting of microcline, oligoclase, quartz, and epidote, is widespread and occurs as tiny nonmappable and larger mappable masses in and near calc-silicate rocks (Ycs) and amphibolite (Ya). Accessory minerals are albite, magnetite and very minor biotite, and either hornblende or diopside. Grains of sphene as much as 3 mm in length are fairly common. The only masses of this rock large enough to map are located in the northeastern corner of the map. The largest area of aplitic gneiss (Yap) is in contact with marble (Ydm), calc-silicate rock (Ycs), and amphibolite (Yhg), and irregular knots of partially reacted amphibolite, plagioclase-hornblende gneiss, or diopside-hornblende rock appear within the aplitic rock. The field observations suggest that this rock (Yap) is the result of carbonate-wall rock interaction and caused by metasomatic enrichment of Na and perhaps depletion of Si during the decarbonization and silicification that produced the calc-silicate rocks. Very minor occurrences of large-albite schists and finer grained albite schist occur as a contact phase at the border of Yfg and along the contact between dolomitic marble (Ydm) and Ybg respectively.

A large area of migmatitic gneiss (Ymig) of uncertain origin is mapped in the northern part of the map. Although quite massive appearing, the rock contains abundant irregular stringers, veins, and amorphous knots of microcline-rich granitic rock. The unit contains abundant microcline and plagioclase, and the parent rock before migmatization may have been a felsic volcanic or intrusive rock. The contact with Yfg, which forms a partial border around the mass, is gradational. The interpretation favored here is that the migmatite gneiss (Ymig) was mobilized locally and intruded the country rocks. The gradational contact with Yfg, which is spatially and mineralogically similar to the trondhjemite gneiss, suggests that migmatization may have been related to intrusion of the trondhjemite. Alternitively, both Ymig and Yfg may have been the result of migmatization that affected all the rocks well after intrusion of the trondhjemite.

Structural Geology

The dominant structural feature in most rocks of the quadrangle is an intensely developed schistosity or phyllitic foliation (S_2) produced by remetamorphism of higher grade gneisses, schists, and igneous rocks. This retrogressive or diapthoritic foliation may totally transpose older Middle Proterozoic gneissosity in minor ductile shear zones or it may be aligned subparallel to older gneissic layering, as commonly occurs on the limbs of the later Paleozoic folds. The dominant schistosity is expressed by fine-grained muscovite, aligned chlorite, or other retrograde minerals such as tremolite-actinolite and talc in calc-silicate rocks. Relict Middle Proterozoic gneissosity is locally well preserved, particularly in the more feldspathic and granitic gneisses. Minor pegmatitic or aplitic seams of Middle Proterozoic age cross cut this gneissosity throughout the area and provide clear evidence that the gneissosity is

Grenvillian or older. A special strike and dip symbol shown by double strike lines identifies this gneissosity on the map. Overall, relict gneissosity is subparallel to contacts of units and trends east-west across the map. The dips of gneissosity vary from vertical to gently dipping. Gneissosity commonly dips more steeply than the associated penetrative diapthoritic (S_2) foliation.

The intense Paleozoic foliation is the regional S_2 foliation referred to above. It describes a mostly northwest-trending, northeast dipping pattern that is crenulated by later fold events. The S_2 foliation pattern in this quadrangle forms the eastern limb of a major antiformal-S_2-foliation arch whose crest appears at or along the western border of the quadrangle (fig. 2). In the adjacent quadrangles to the west and northwest, this S_2 foliation dips to the northwest and north. The foliation arch describes the antiformal structure of the Green Mountain massif. The S_2 foliation is regarded as Taconian, and the age of the arching of the later crenulation cleavages are probably Acadian, Late Taconian, or both.

F_2 folds

F_2-generation folds are second order features on the map; they commonly are en echelon folds of limited extent. Axial surfaces dip gently northeast except where warped by later folds. The F_2 folds are overturned and isoclinal in outcrop; fold hinges commonly plunge down the axial surface in reclined style. F_2 folds cross both limbs of the older Middle Proterozoic folds. This relation is shown on Markham Mountain and in the central part of the map. The minor thrust faults exposed near Weston and the West River thrust are F_2-generation faults. Both elongation (size and shape) lineations and intersection lineations trend generally east-west. In or near shear zones the lineation is intense and both hingelines of minor folds and chlorite or biotite spears plunge down the dip of the foliation. The F_2 lineation approximates the transport direction of Taconian faults.

Crenulation cleavage and F_3 and F_4 folds

A prominent set of overturned, west-verging folds (F_3) trends to the north-northwest across the western and central part of the map. These folds have greater amplitude and are more continuous features than the F_2 folds. These folds of the S_2 surfaces plunge gently northwest or southeast. Where they cross subvertical gneissic layering, the fold forms are suppressed, and plunges of F_3 folds on the Proterozoic gneissic layering are very steeply plunging (in contrast to gentle plunges of folds of the S_2 foliation). The F_3 folds are particularly well developed in the area west of Moses Pond.

A prominent crenulation cleavage forms the axial surface of the F_3 folds. Little mineralization occurs in this crenulation cleavage except for minor retrogression of garnet to chlorite, and thin seams of muscovite and chlorite. F_3 folding and the related crenulation cleavage post date all of the major retrogression and formation of the S_2-oriented minerals such as muscovite, chlorite, ilmenite, chlorite, garnet, and albite. The F_3 event was accompanied by sub-biotite grade metamorphic conditions.

Post F_3 folds

North-south and north-east trending upright folds, which are expressed by a weak crenulation cleavage or only by simple flexures lacking a cleavage, post date the F_3 folds. The structures are broad open features. Only limited data are available for these folds, and age relationships between the northeast and north trending folds is not known. Both are referred to as F_4 folds.

Age of the fold sets and metamorphic events

The F_2 folds and the age of the retrogression of the Middle Proterozoic rocks are thought to be Taconian based on limited data. F_2-related shear zones, in the southern part of the massif, contain new biotite aligned in the S_2 foliation. Sutter and others (1985) reported cooling ages of 436 and 446 Ma for this biotite. We are reasonably certain that the S_2 foliation in this area is coextensive with the S_2 foliation dated by them because all of the area between the former locality and the present area has been mapped recently by us (see Ratcliffe and others, 1988). $^{40}Ar/^{39}Ar$ data from muscovite from S_2 in this area also suggest the possibility of a Taconian age for S_2 and the retrogressive foliation here (Burton and others, 1990, 1991).

Cooling ages of approximately 410 to 390 Ma were obtained from four samples of muscovite in S_2 from localities 2, 3, and 4 (Fig. 1; localities 3 and 4 also shown on the geologic map). At several of the localities sampled, some garnets contain inclusions of chloritoid and ilmenite aligned in S_2. Temperatures of 450° to 500°C are needed to form the equilibrium chlorite-chloritoid-garnet textures, based on temperatures determined for similar garnet- and chloritoid-bearing rocks associated with garnet-biotite rocks in western Massachusetts (Hames and others, 1991).

Assuming temperatures of 450°C to 500°C, or 100 to 150°C above muscovite closure temperature, it is unlikely that the muscovite ages of 410 to 390 Ma could be Acadian. We therefore conclude that the 410 to 390 Ma cooling ages ages reported by Burton and others (1990) indicate a pre-Acadian (or Taconian) origin of the S_2 foliation and the F_2 fold event.

Because the muscovite sampled for $^{40}Ar/^{39}Ar$ dating came from the center of the S_2 foliation arch, it is reasonable to assume that these rocks were brought closer to the surface during the F_3 and subsequent Acadian fold events. The structural relief on the Green Mountain antiformal arch is approximately 3 to 4 km (fig. 3), and, therefore, in a Taconian event the rocks in the core of the arch could have been subjected to temperatures 100°C above, and pressures approximately 1 kb greater than, the comparable non-garnet bearing cover rocks on the east limb of the massif. The structural argument therefore makes rapid unroofing of Acadian muscovite an unlikely explanation for the 410 to 390 Ma ages. Both the structural and petrologic arguments support a Taconian age for the S_2 and F_2 fold event.

The F_3 and F_4 crenulation events occurred at very low metamorphic grade and commonly have little or no mineralogic expression. Folds to the east of this quadrangle that arch the regional S_2 foliation are demonstrably Acadian based on garnet inclusion fabrics and $^{40}Ar/^{39}Ar$ ages for hornblende that have cooling ages as old as 389 Ma from staurolite-kyanite grade rocks in the Chester dome (Spear and Harrison, 1989). Based on the data presented here, the F_3 and F_4 crenulation cleavages and arching of the Green Mountain massif are Acadian, and all Acadian deformation in this quadrangle occurred under sub-garnet grade conditions. On Markham Mountain and Terrible Mountain near the eastern border of the map, new biotite grows across the S_2 fabric. This may indicate Acadian-biotite grade metamorphism extended this far to the west. Proterozoic garnet is extensively retrograded in the S_2 foliation there as it is throughout the quadrangle ruling out granet or higher grade in the Acadian orogeny in much of the area.

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Caption

Figure 1. Simplified geologic map of the central part of the Green Mountain massif in the Wallingford, Danby, Weston, Mount Holly, Ludlow and Andover Quadrangles. Map shows the distribution of aluminous chlorite-muscovite chlorite-quartz±chloritoid±garnet schists (Ys, dark gray), nonchloritoid-bearing chlorite-muscovite±biotite±garnet±plagioclase schists (Ys, light gray), quartzite on Ludlow Mountain (Yq, ruled), and calc-silicate rocks (Ycs, black), all belonging to the Mount Holly Complex (Mount Holly undifferentiated, Ymhu, white); possible cover rocks of the Tyson Formation (ЄZt) including albitic granofels and dolostone at Devils Den (loc. 2), in relation to rocks of questionable age Y?mab (circles), and Y?cms (dotted) between Devils Den (DD) and Moses Pond (MP). Patterned intrusive rock granodioritic gneiss of the Mount Holly (Ygg) intrudes Yq and Ys on Ludlow Mountain (near loc. 1), where the retrograde schists contain chlorite, chloritoid, muscovite, ilmenite and quartz as well as relict kyanite.

Figure 2. Generalized F_2-formline map of the central part of the Green Mountain massif shown in figure 1. Barbs point in dip direction of the Taconian S_2 foliation. Antiforms and synforms are Acadian F_3 and F_4 folds identified by subscript.

Figure 3. Schematic cross section through the Devils Den area (DD) based on geologic map in figure 1.

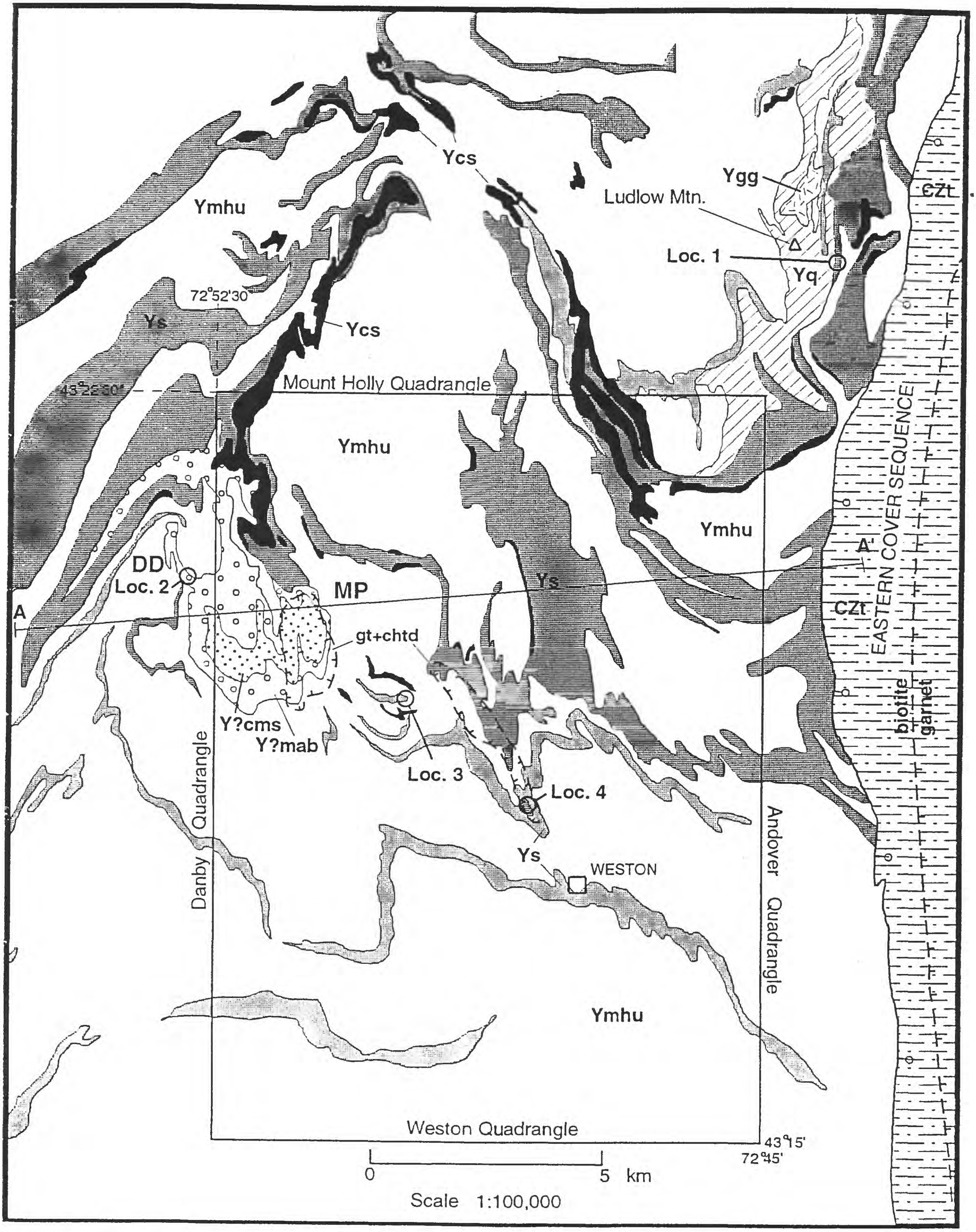
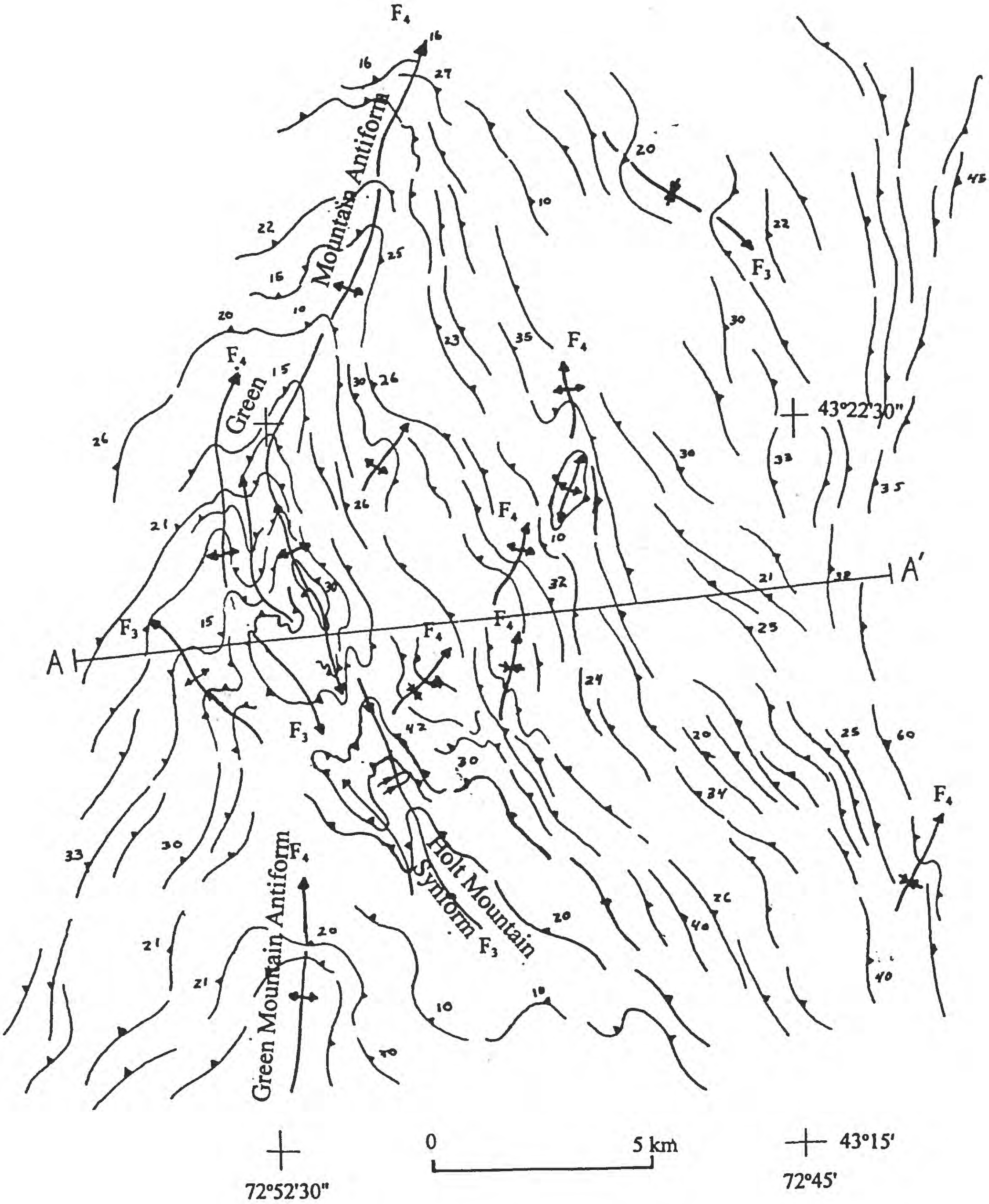

Ycs
Ygg
Ludlow Mtn.
CZt
Ymhu
Loc. 1
Yq
72°52'30"
Ys
Ycs
43°22'30"
Mount Holly Quadrangle
Ymhu
EASTERN COVER SEQUENCE
Ymhu
DD
Loc. 2
A
MP
Ys
A'
CZt
gt+chtd
Y?cms
Y?mab
Loc. 3
Loc. 4
biotite
garnet
Danby Quadrangle
Ys
WESTON
Andover Quadrangle
Ymhu
Weston Quadrangle
43°15'
72°45'
0
5 km
Scale 1:100,000

Fig. 1



Taconian S_2 foliation form line; barb points in direction of dip

Axial Trace of Acadian fold (arrow shows direction of plunge; subscript shows age)

Antiform F_4

Synform F_3

Overturned synform F_3

Fig. 2

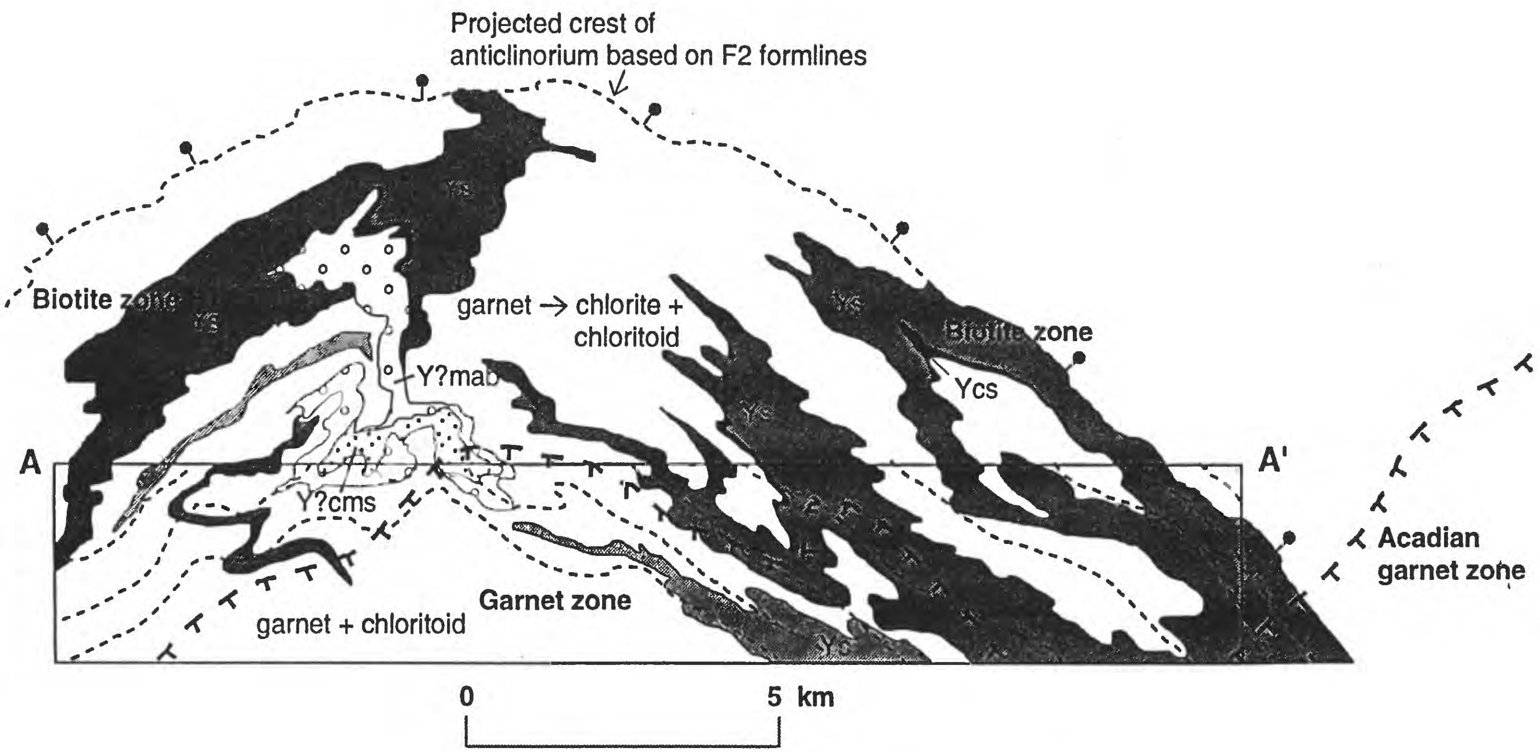
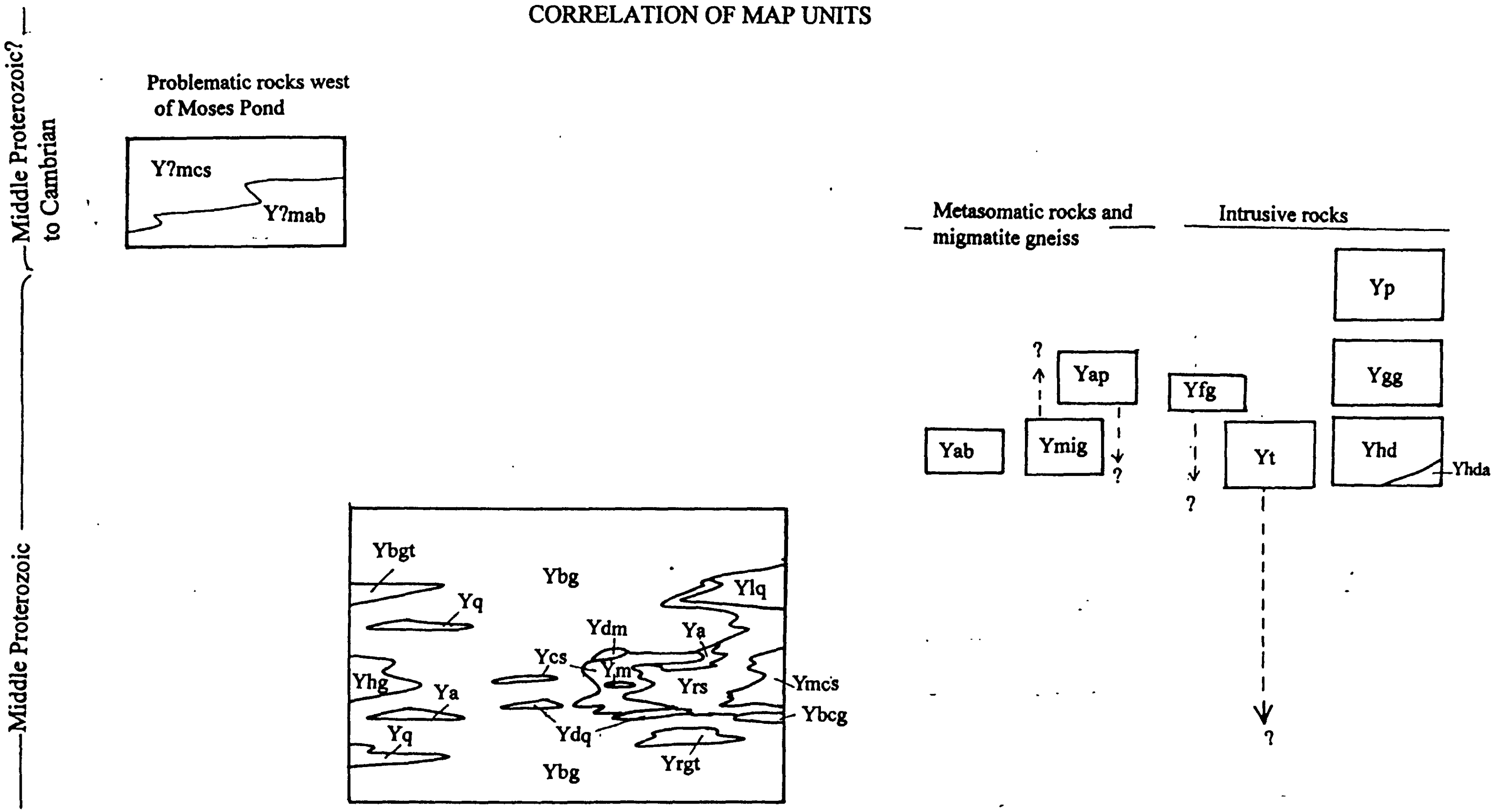


Figure 3. Cross section through fig. 1 showing formlines (dashed) and isograds (hachured)

CORRELATION OF MAP UNITS



Description of Map Units

Minerals are listed in order of increasing abundance

Mount Holly Complex?

Schists and granofels west of Moses Pond (previously mapped by Doll and others (1961) as the Hoosac-Pinney Hollow Formations, but here tentatively included in the Mount Holly Complex as lithic correlatives of Yab, Ycms, and Ymab)

Y?cms

Chlorite-muscovite-garnet schist (Middle Proterozoic(?))--Light-silvery green to gray-green, lustrous muscovite-chlorite-quartz schist±garnet±chloritoid±ilmenite±biotite±albite. Unit is highly variable both in texture and composition (from ultrafine-grained phyllonitic schist to medium-grained garnet-muscovite-biotite-chlorite schist). Unit passes gradationally into a very similar appearing, lustrous, greenish schist that contains abundant garnet and biotite, all throughly retrograded to chlorite and albite. Albitic varieties tend to contain more biotite and less muscovite and do not contain chloritoid. Rock is highly retrograded and contains abundant chlorite derived from the breakdown of poikiloblastic garnet that contained large anhedral grains of quartz, coarse muscovite, biotite, and robust grains of rutile. Irregular areas within the replaced garnets consist of fine grained sericite probably derived from original inclusions of plagioclase. Where found, chloritoid commonly occurs in the fine-grained sericitic matrix with ilmenite but locally both minerals are found within large subhedral nonretrograded garnets. The contact with adjacent Y?mab is gradational and determined by the higher abundance of biotite (commonly chloritized) and albite in Y?mab near Y?cms. Y?cms closely resembles rocks mapped as Ymcs elsewhere on the map

Y?mab

Biotite-muscovite-albite-quartz schist (Middle Proterozoic?)--A highly heterogeneous unit, distinguished from Y?cms by its rusty weathering, nonlustrous appearance and abundance of large albite and conspicuous large plates of muscovite and biotite. Locally contains tiny grains of fresh garnet and rutile as inclusions in albite, or abundant totally retrograded chlorite-sericite clots after original highly poikiloblástic garnet and chloritized biotite. Near the contact with Yfg, abundant sills of granitic gneiss, plagioclase-tourmaline veins and highly albitic, very coarse-grained schist (Yab) occur. Unit is interbedded near its base with either garnet-muscovite-plagioclase-quartzite (Yq) or a fine-grained, black hornblende-garnet amphibolite (Ya) or calc-silicate rock (Ycs), all of the Mount Holly Complex. Both Y?cms and Y?mab contain abundant veins of coarse-grained well-twinned sodic oligoclase or albite intergrown with quartz. Veins like this are common in the Yrs unit. Because of these relations and the overall similarity of these units to Yrs, Ymcs, and Ybgt of the Mount Holly Complex the above units (Y?cms and Y?mab) are here regarded tentatively as correlatives of similar units in the Mount Holly Complex and not assigned to the Hoosac and Pinney Hollow Formation as previously mapped by Slack and Sabin (1983).

The Mount Holly Complex (Middle Proterozoic)

The Mount Holly Complex contains a variety of layered gneisses in interdigitating lenses and discontinuous masses of rock, all intruded by granitic gneiss, aplite, pegmatite, as well as metatonalite and metatrondhjemite and migmatitic gneiss. Because of the irregular distribution of units and the complex folding, stratigraphy of the Mount Holly Complex is not well known. The intrusive rocks may range in age from approximately 1.4 Ga to about 1 Ga.

Paragneiss of the Mount Holly Complex

Ycs

Calc-silicate rocks--Consists of one or more of the following rock types, often occurring in close proximity and interlayered with one another on a scale of 0.5 to several meters: Light-green, coarse-grained, diopside-hornblende calc-silicate rock variably altered to actinolite-tremolite or talc; coarse-grained calcite marble; calcite-diopside (±actinolite) marble;

massive coarse-grained, white, calcite- or dolomite-tremolite marble; scapolite rock; beige- to orange-tan weathering medium-grained, dolomite-phlogopite±scapolite marble; light-gray to pinkish-green plagioclase microcline-diopside-quartz-calcite granofels or gneiss

Ydm

Dolomite marble--Light-yellowish gray, white- to beige-weathering dolomite±scapolite± phlogopite±talc marble, commonly veined with quartz. Occurs at 4 localities: at the contact between Y?mab and Ybg in the northwestern corner of the map, in Ybg near Ycs on northern edge of the map, 1.5 km west of Route 155 in the northern part of the map associated with Yab, Yrs, and Yq, and a fourth small occurrence of very coarse-grained, white-weathering dolomite marble associated with the contact between Ycs and Yap two kilometers west of the point Route 100 crosses the northeastern margin of the map

Ym

Calcite marble--Coarse-grained, white, calcite±diopside±graphite marble in layers less than 10 m thick. No large continuous belts of pure calcite marble occur within the quadrangle; however thin discontinuous layers occur throughout Ycs

Ydq

Diopside quartzite--Vitreous quartzite containing layers of green-diopside-spotted quartzite and knots of hornblende and diopside at contact with Ycs, mapped in only one area in the northeastern corner of the map

Ybcg

Clinozoisite-biotite-actinolite gneiss--Dark-gray, faintly layered, medium-grained mafic gneiss, interbedded at contact of Ymcs and Ybg 2 km east of the peak of Peabody Hill. Rock contains abundant biotite, chlorite, actinolite, sphene, and clinozoisite and relict highly chloritized garnet, and hornblende. Interpreted as an altered biotite-rich hornblende-garnet-plagioclase gneiss similar to, but more biotitic than either Yhg or Ya

Yrs Yq Ymcs

Rusty muscovite quartz schist--Rusty-brown to yellowish-gray weathering, coarse-grained, garnet-muscovite-spangled schist (Yrs), commonly lustrous and ultrafine-grained where highly foliated; contains layers of muscovite-biotite±garnet quartzite (Yq) and muscovite-biotite-plagioclase±garnet-schist (Yrgt), highly altered to chlorite, sericite, albite, clinozoisite or epidote. Contains abundant albite-quartz and tourmaline veins. Ranges from coarse-grained garnetiferous and biotitic rock to a highly retrograde rock containing clots of chlorite after biotite and garnet. Unit passes gradationally into a lighter colored, yellowish-greenish gray, lustrous chlorite and muscovite-rich schist (Ymcs) that may contain abundant deep-blue-green chloritoid. Clots of chlorite and muscovite as much as one cm in diameter are set in a very fine-grained matrix of muscovite±paragonite±ilmenite. Exposures in Greendale Brook 1 km southwest of Weston Priory are highly pockmarked with oriented, foliated clots of chlorite as much as 1 ½ cm long lying in the prominent retrogressive foliation, the clots are derived from chloritization of garnet and biotite. This distinctive structure is widespread throughout Ymcs in the belt extending from this point eastward into the Andover quadrangle, and is developed where strain in association with the retrogressive foliation is not high enough to produce the complete transposition that normally results in the more lustrous chloritic variety of Ymcs. Unit may contain secondary albite and or highly chloritized biotite rather than chloritoid. Both Ymcs and Yrs contain irregular lenses of pegmatite (Yp), beds of garnet-plagioclase-muscovite quartzite (Yq), and are closely associated with calc-silicate rocks (Ycs), marble (Yd or Ym), and garnet-hornblende-amphibolite (Ya). Overall, Ymcs is finer-grained and more chloritic and muscovitic than Yrs, however the distinction is difficult to make and appears to be, in part, the result of more extensive retrogression of relict garnets in Ymcs, or of alteration and alumina enrichment near large pegmatites (Yp), prior to retrogression

Yrgt

Garnet-muscovite-biotite-plagioclase-quartz schist--Dark-gray to rusty-brown weathering schist, containing abundant large ½ to 1 cm garnets, abundant biotite, oligoclase and coarse spangles of muscovite. Unit becomes highly muscovitic near beds of highly garnetiferous quartzite (Yq). Unit passes laterally into Yrs

Ybgt

Garnet-muscovite-biotite-plagioclase-quartz gneiss--Dark-gray to steely-gray, thinly layered gneiss containing abundant layers 2 to 5 cm thick rich in 0.25 to 0.5 cm-sized garnet, abundant epidote and magnetite, muscovite-rich layers like Yrs. Where highly sheared is transformed into a lustrous chlorite-muscovite-albite-quartz schist containing clots of chlorite after biotite and garnet and new large porphyroblasts of albite. Unit contains either thin layers, commonly 0.5 m thick, of vitreous muscovite±garnet quartzite or has anastomosing lacey layers of blue-gray quartz 0.25 to 2 cm thick

Ybg

Biotite-quartz-plagioclase gneiss--A highly heterogeneous and widespread unit, consisting predominantly of well-layered, white and gray to dark-gray gneiss marked by layers of hornblende amphibolite, rusty weathering schist and epidote-biotite-plagioclase-quartz±garnet±albite±chlorite schist. Locally retrograded to albite-chlorite-epidote schist. Unit overall is muscovite-poor in comparison to Yrs and Yrgt. Contains lens of or is in contact with most of the layered gneiss of the Mount Holly Complex

Yhg

Hornblende-plagioclase gneiss--Dark-greenish gray to medium-dark-gray, hornblende streaked- to hornblende-spotted, well-layered gneiss; commonly consists of alternating dark-(hornblende-rich) and light-colored (plagioclase-rich) layers 1 to 5 cm thick. Contains layers of massive, dark-green amphibolite, unit includes a more plagioclase-rich gneiss having approximately 25 percent hornblende and biotite as porphyroblasts as much as 1 cm in length

Ya

Amphibolite--Dark-gray to dark-green, either medium-grained or a very fine-grained, aphanitic-appearing massive hornblende-plagioclase-amphibolite. Both the fine- and coarse-grained varieties contain relict garnet and hornblende largely retrograded to a fine-grained mixture of actinolite-epidote-albite-sphene and chlorite. The fine-grained varieties tend to be associated with beds of quartzite (Yq) or calc-silicate rock (Ycs) especially at or near contacts with Y?cms and Y?mab in the area northwest of Moses Pond, and in Greendale Brook 0.5 km north of the intersection with Jenny Coolidge Brook. At the latter locality, layers of chlorite muscovite schist in Yq adjacent to Ya contain as much as 40 percent chloritoid in a matrix of sericite-chlorite and quartz

Metasomatic rocks of the Mount Holly Complex

(These rocks are interpreted as altered rocks produced either by high grade metamorphism or contamination of intrusive rocks. The protoliths are highly uncertain)

Yap

Aplitic gneiss--White-weathering, massive to slightly gneissic, fine-grained, microcline-oligoclase-quartz±albite and epidote gneiss containing less than 5 percent biotite. Contains minor hornblende, sphene, or rarely diopside where in contact with marble (Ym) or calc-silicate rocks (Ycs). Interpreted as a metasomatic contact rock, perhaps the same age as Ygg

Ymig

Migmatite gneiss--Coarse-grained pinkish gray, epidote-biotite-plagioclase-quartz-microcline gneiss; massive in outcrop but well-foliated and marked by distinct clots, stringers and lenses of microcline-rich granite. Interpreted as a metamorphosed and anatectic rock produced by partial melting of a felsic volcanic or intrusive rock. Unit may be intrusive in part

Yab

Albite-muscovite-biotite quartz schist--A very coarse-grained muscovite schist distinguished by abundant albite up to 1 cm in diameter, epidote and tourmaline. Unit occurs at or near the contact between Yrs and Yfg in the area northwest of Moses Pond where it is associated with lit par lit injections of Yfg in Yrs and is here interpreted as a metasomatic rock associated with intrusion of Yfg in Yrs and Ybg. A more continuous belt of similar but finer grained albitic schist (Yab) is mapped adjacent to a nearly continuous belt of highly foliated fine-grained dolomitic marble (Ydm) at the north end of a large body of Yrs 4 km northwest of Weston Priory, near the northern edge of the map. At this locality, Yab is interbedded with biotite-quartz-plagioclase gneiss (Ybg)

Intrusive Rocks of the Mount Holly Complex

Yp

Pegmatite--Light-gray to pinkish-gray, biotite-muscovite granite pegmatite, or biotite-tourmaline granite pegmatite occurring as irregular masses within all units of the Mount Holly Complex, only mapped where of sufficient size to show on map. Particularly abundant in Yrs and similar rocks near quartzite (Yq). Cross cuts gneissosity in Mount Holly Complex but locally strongly foliated

Ygg

Granite gneiss--Light-gray to pinkish-gray weathering, medium- to coarse-grained, muscovite-biotite-plagioclase-quartz-microcline gneiss containing accessory garnet or magnetite. Well developed gneissosity present. Plagioclase to microcline ratios vary from 1:1 to 1:2. Interpreted as a metagranite to metagranodiorite. Coextensive with granite gneiss in the Londonderry quadrangle that contains zircons which have U-Pb discordia ages of approximately 1.25 Ga (Ratcliffe and others, 1991)

Yfg

Felsic magnetite-biotite gneiss--Massive to gneissic, white- to pinkish gray-weathering, fine-grained, biotite-magnetite-microcline-quartz-oligoclase-gneiss, distinguished by scattered octahedra of magnetite and only minor biotite. Strongly foliated varieties contain prominent muscovite and epidote and albite. Resembles Yap but is better layered and contains a higher percentage of magnetite and/or biotite. Microcline is subordinate and commonly ranges from about 5 to as much as 25 percent. Unit may represent an altered felsic volcanic rock or a contact phase of the trondhjemite gneiss (Yt)

Yhd

Yhda

Hornblende diorite gneiss--Medium-gray to greenish-gray weathering, coarse-grained biotite-hornblende-plagioclase metadiorite or mafic tonalite. Contains approximately 25 percent hornblende and 65 percent plagioclase and locally large retrograded metamorphic garnets as much as 2 cm in diameter, but most commonly only scattered small garnet. Although gneissic, rock has a relict diabasic to allotriomorphic granular texture. Adjacent to its contact with Yrs on Terrible Mountain passes gradationally into a very fine grained, dark-green to gray, hornblende plagioclase amphibolite (Yhda) that contains irregular patches and clots rich in plagioclase that is interpreted as fine-grained and perhaps more mafic border facies of Yhd. Unit may have genetic and temporal affinities with tonalites and trondhjemites (Yt) described below

Yt

Trondhjemite gneiss--Light-gray to chalky-white weathering, medium- to coarse-grained biotite trondhjemite containing minor, commonly 0 to 10 percent microcline. Interpreted as metaintrusive rocks, younger than some or all of the paragneiss. U-Pb zircon ages of 1.3 to 1.35 Ga have been determined for similar rocks in the Londonderry quadrangle (Ratcliffe and others, 1991) and $^{207}Pb/^{206}Pb$ ion microprobe (SHRIMP) ages of about 1.4 Ga (John Aleinikoff, written communication, 1995; Ratcliffe, Aleinikoff, and Hames, 1995) for cores of zircons in intrusive rocks of the Chester dome. If correctly interpreted as intrusive rocks, all of the paragneiss of the Mount Holly Complex may be older than 1.4 Ga.

Weston quadrangle

EXPLANATION

Approximate location of outcrop or area of abundant outcrop visited

Contact accurately located

Contact approximately located

Contact concealed by water

Thrust fault accurately located; teeth on upper plate

Thrust fault approximately located; teeth on upper plate

PLANAR FEATURES (may be combined; joined at point of observation)

Strike and dip of Proterozoic compositional layering in gneisses and coarse schistosity in schists of the Mount Holly Complex

70 Inclined

Vertical

Strike and dip of foliation or schistosity in Y?mab and Y?cms west of Moses Pond; either Taconian or Middle Proterozoic, age uncertain

30 Inclined

Vertical

Strike and dip of penetrative foliation or retrogressive schistosity expressed by fine-grained lepidoblastic muscovite, chlorite or retrograde minerals such as epidote, tremolite-actinolite, and talc derived from alteration of Middle Proterozoic biotite, hornblende, diopside, phlogopite, and plagioclase. Is the dominant foliation in most outcrops and is accompanied by minor thrust faults and reclined minor folds. Interpreted as Late Ordovician or Taconian, and correlated with a regionally developed retrogressive foliation

Inclined

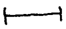
Vertical

Generalized strike and dip of inclined but highly plicated gneissosity

Generalized strike and dip of inclined, highly plicated foliation

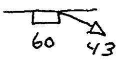
Crenulation cleavage, commonly not expressed by neomineralization and growth of new lepidoblastic minerals. Feature is spaced mm to cm apart and produces weakly to strongly developed fractures in outcrops. Although several sets of intersecting crenulation cleavage are present the relative age can rarely be determined in outcrop and different generations are not distinguished by separate symbols

Inclined

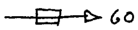


Vertical

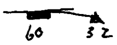
Strike and dip of axial surface of minor fold, showing plunge where observed



Inclined Middle Proterozoic fold

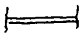


Vertical Middle Proterozoic fold

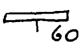


Inclined fold of gneissosity or compositional layering or gneissosity in Middle Proterozoic rocks, expressed by axial surface foliation. Formed during retrogressive metamorphism and formation of the regional foliation, probably Taconian

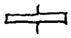
Inclined fold expressed by axial surface crenulation cleavage, probably Acadian



Upright Acadian fold expressed by axial surface crenulation cleavage, Acadian

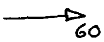


Inclined fold not expressed by axial surface crenulation cleavage or foliation, probably Acadian



Upright Acadian fold not expressed by axial surface crenulation cleavage or foliation

Linear Features



Azimuth and plunge of hingeline of fold of Middle Proterozoic fold, shown combined with symbol for axial surface

12

Azimuth and plunge of intersection lineation of compositional layering and retrogressive foliation or hingeline of folds. Generation determined by combination with the appropriate symbol for axial surface

cht

Locality where chloritoid has been identified in thin section, commonly associated with garnet, chlorite, ilmenite (or rutile), and muscovite

Locality where muscovite has been sampled for $^{40}Ar/^{39}Ar$ dating