BEDROCK GEOLOGIC MAP OF THE WEST DOVER AND JACKSONVILLE QUADRANGLES, WINDHAM COUNTY, VERMONT

By Nicholas M. Ratcliffe and Thomas R. Armstrong

INTRODUCTION

The oldest rocks in the West Dover and Jacksonville quadrangles are Middle Proterozoic gneisses that are exposed in the cores of complex antiformal structures in the Rayponda and Sadawga domes, which are about 10 km east of the Green Mountain massif (fig. 1 on sheet 2). In the adjacent Mount Snow and Readsboro quadrangles to the west, the Sadawga dome is a complex, highly irregular domal structure of folded imbricate thrust sheets (Ratcliffe, 1993a). Middle Proterozoic rocks in the hanging wall and footwall of the combined Wilmington and Cobb Brook thrusts (fig. 1) form the core rocks of the Sadawga dome. A complex succession of metasedimentary and metavolcanic cover rocks of Late Proterozoic, Cambrian, and Ordovician age overlie the domes. These younger rocks were highly thrust faulted during the Taconian orogeny. This sequence includes the basal Hoosac Formation, the Rowe(?) Schist, the Rowe Schist proper, and the overlying Moretown Formation. East of the domes, this succession forms a homoclinal section of steeply dipping rocks that were interpreted previously by Doll and others (1961) and Skehan (1961) as a nonfaulted, eastward-younging section. Furthermore, they had assigned these rocks to the Hoosac, Pinney Hollow, Ottauquechee, Stowe, and Moretown Formations of Cambrian through Middle Ordovician age. Our detailed mapping shows that our map units are more complexly distributed and that the classical names should not be applied here.

A thrust fault separates the Moretown Formation from the North River Igneous Suite of possible Late Ordovician to Silurian age first described in this report. The age of the North River Igneous Suite is Ordovician and possibly Lower Silurian; it intrudes the Middle Ordovician Cram Hill Formation. The Northfield Formation of possible Silurian or Devonian age is exposed in the southeastern corner of the map above what previously was regarded as a major structural décollement produced by movement along an unconformity (Chidester and others, 1967). We find no evidence for this décollement.

In summary, the succession of rocks in the West Dover and Jacksonville quadrangles extends from the Middle Proterozoic basement of the Rayponda dome and Sadawga Lake antiform, eastward through a thick belt of tectonically layered Cambrian and Ordovician rocks, to Silurian and Devonian rocks in the southeast part of the map. The Silurian and Devonian rocks are younger than the Taconian orogeny of Middle and Late Ordovician age, and therefore only contain structural and metamorphic effects of the Acadian orogeny of Early to Middle Devonian age.

Previous maps in this area are by Skehan (1961) and Hepburn and others (1984) at the scale of 1:62,500 and by Doll and others (1961) at 1:250,000. Maps at the scale of 1:24,000 include the Mount Snow and Readsboro quadrangles (Ratcliffe, 1993a), the Jamaica-Townshend area (Ratcliffe, 1997), the Heath quadrangle (Hatch and Hartshorn, 1968), the Williamstown-North Adams area (Herz, 1961; Ratcliffe and others, 1993), and the Rowe quadrangle (Chidester and others, 1967). Comprehensive discussions of the stratigraphy and structural geology of the Rowe Schist, Moretown Formation, Hawley Formation, and Goshen Formation in Massachusetts are in Stanley and Hatch (1988) and Hatch and Stanley (1988). Hepburn and others (1984) present a comprehensive discussion of the geology of the Brattleboro quadrangle, which is immediately east of this area.

Ratcliffe (1993a) defined the term Lithotectonic Unit to describe a fault-bounded sequence of rocks differing from other Lithotectonic Units by tectonic juxtaposition. Five Lithotectonic Units are recognized in this area (fig. 1). From west to east they are the Green Mountain, Mount Snow, Wilmington, Moretown and Rowe, and South Newfane Lithotectonic Units. Major fault zones separating these units are the Clarksburg and Searsburg thrust, the Wilmington and Cobb Brook thrust, the Whitcomb Summit thrust, and the South Newfane thrust.

AGE OF THE COVER SEQUENCE ROCKS

Recent work north of this area (Ratcliffe and others, 1997) supports the concept that rocks of the Pinney Hollow, Ottaquechee, Stowe, and Moretown Formations of Doll and others (1961) are fault-bounded lithotectonic units. Middle Ordovician conodonts (Ratcliffe and others, 1997 and in press) found in a dolostone lens within the upper part of the Plymouth Formation of Ratcliffe (1994) indicate that the base of the Pinney Hollow Formation at its type locality, 67 km north of this quadrangle, is a thrust fault. A new U-Pb zircon age of 571±5 Ma from a probable metafelsite within the Pinney Hollow Formation (Walsh and Aleinikoff, 1999) suggests that the Pinney Hollow Formation may, in part, be Late Proterozoic and suggests overlap in age with the Hoosac Formation that also contains rift-stage basalts. These results suggest that rock that we map as Rowe(?) Formation and as Rowe Formation may also be as old as Late Proterozoic. The major fault now required at the base of the Pinney Hollow Formation projects into the general position of the Ellis Brook and Dover faults of this quadrangle.

U-Pb zircon ages from tonalite of the North River Igneous Suite and trondhjemite of the Barnard Gneiss (*of* Richardson, 1924) which intrude the Moretown Formation outside this area indicate that the Moretown Formation is at least as old as Lower Ordovician. The U-Pb zircon age of felsic volcanic rocks in the Cram Hill suggests that the Cram Hill Formation is, in part, Middle Ordovician (Ratcliffe and others, 1997).

Taken together these data suggest that the cover sequence rocks east of the Green Mountain massif and structurally above the Hoosac Formation constitute a tectonic assemblage rather

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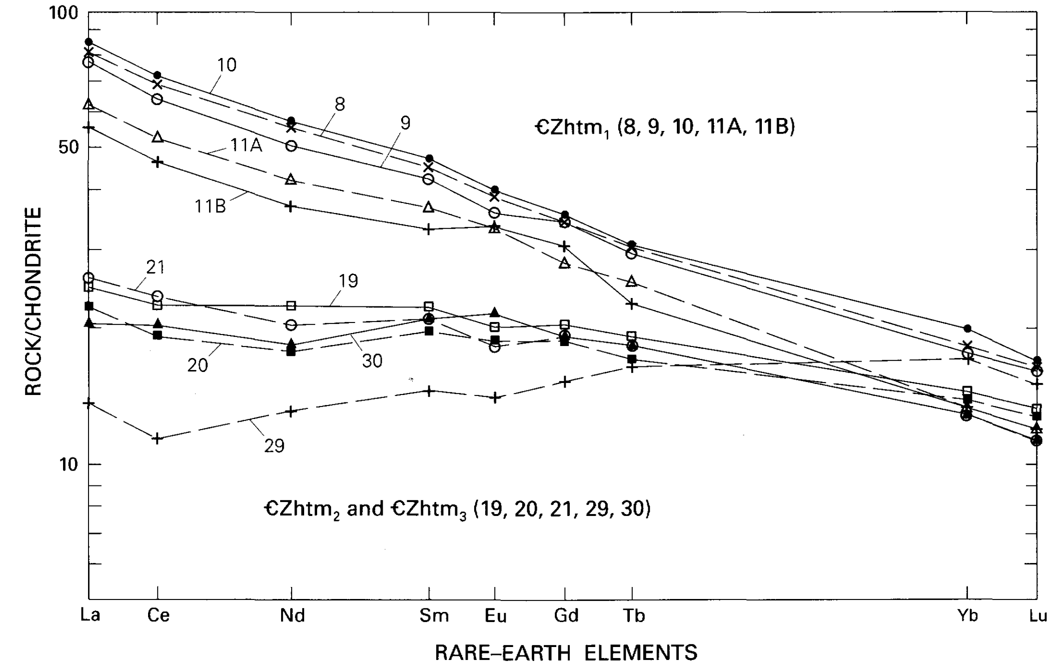


Figure 2.—Chondrite-normalized to rare-earth-element (REE) abundance diagram of amphibolite from the Hoosac Formation in the West Dover and Jacksonville quadrangles. Sample analyses shown in table 2 and located in geologic map. Data normalized to CI chondrite of Anders and Ebihara (1982). Gadolinium (Gd) estimated by extrapolation.

than a stratigraphic sequence, consistent with the interpretation of the Rowe Schist and Moretown Formation as used by Stanley and Hatch (1988) in Massachusetts.

STRATIGRAPHY

Middle Proterozoic rocks

Gneissic rocks of the Mount Holly Complex are so poorly exposed in the cores of the Rayponda and Sadawga domes that distribution and recognition of units are somewhat uncertain. Well-layered gneisses (map units Ybg, Ycs, and Yrg) contain unequivocal beds of metasedimentary rocks, although hornblende-plagioclase gneiss and amphibolite within the biotite gneiss unit (Ybg) represent metavolcanic beds. These paragneiss units are in contact with a distinctive granitic gneiss (Ygg) and aplite (Yap) that are interpreted as intrusive. All of these rocks are typical of the Mount Holly Complex in the Green Mountain massif to the west. On the basis of U-Pb zircon studies (Ratcliffe and others, 1991), the age of the Mount Holly Complex ranges from as old as 1.35 Ga for tonalites and trondhjemites exposed north of here, to about 1.24 Ga for granites that intrude older rocks and the paragneiss units in the Mount Holly Complex. Deposition of the paragneiss units is older than 1.24 Ga, but younger than 1.35 Ga because they appear to nonconformably overlie the tonalites and trondhjemites (Ratcliffe and others, 1991).

Coarse-grained biotite-plagioclase-microcline megacrystic granite of the Harriman Reservoir Granite of the Cardinal Brook Intrusive Suite (map unit Yhr) is in contact with layered gneisses of the Mount Holly Complex in the Rayponda dome and eastern half of the Sadawga dome where it is entirely above the Wilmington fault system. U-Pb zircon upper intercept ages and geologic studies indicate the Cardinal Brook Intrusive Suite intruded at approximately 960–950 Ma and is post-tectonic to the Mount Holly Complex and the Grenville orogeny (Karabinos and Aleinikoff, 1990; Ratcliffe, 1991b). Poor exposures of igneous contacts and extensive mylonitization have obscured the intrusive nature of the Harriman Reservoir Granite in the West Dover and Jacksonville quadrangles.

Conglomerates and feldspathic quartzite at and near the base of the Hoosac Formation contain clasts of both the Cardinal Brook Intrusive Suite and the Mount Holly Complex, thus indicating an unconformity beneath the Hoosac Formation.

Hoosac Formation

Albitic granofels, conglomerate, quartzite, and schist of the Hoosac Formation unconformably overlie the Mount Holly Complex and Harriman Reservoir Granite. Rocks of the Hoosac Formation outline the form of the gneiss domes. All rocks between the Wilmington fault system and the Whitcomb Summit thrust belong to the Wilmington Lithotectonic Unit. The Hoosac in this Unit differs from the Hoosac of the underlying Mount Snow Lithotectonic Unit exposed to the west (Ratcliffe, 1993a); here, the Hoosac has more rusty-weathering muscovite-biotite-albite-quartz schist (€Zhrab), especially near the top of the Wilmington Lithotectonic Unit.

To the west the Hoosac interfingers with the Dalton Formation, which rests unconformably on Middle Proterozoic basement rocks of the Green Mountain massif (fig. 1) (Ratcliffe, 1993a, 1997). This interfingering suggests that the Dalton and Hoosac Formations constitute a westwardly transgressive sequence. Facies relations between the Dalton and Hoosac Formations are illustrated in figure 2 in the Mount Snow and Readsboro map (Ratcliffe, 1993a). The Hoosac of the West Dover and Jacksonville area is generally older than much of the Hoosac exposed to the west and north. A key observation in this relative age interpretation is that metabasalts of the Turkey Mountain Member of the Hoosac Formation are always found below the first occurrences of dolomites and associated vitreous quartzites that probably mark the initial establishment of the carbonate-shelf facies. Furthermore, metabasalts occur within the Hoosac that rests on the Mount Holly Complex in the Chester and Athens domes to the northeast, suggesting that the Hoosac there is also older than to the west. Most importantly, metabasalts are absent from the Hoosac and Dalton Formations resting on the Green Mountain massif, as well as from sections of Hoosac, or the equivalent Tyson or Plymouth Formations, which rest on basement to the north near Ludlow and Plymouth; however, Late Proterozoic diabase dikes are common in the Mount Holly Complex of the Green Mountains. These regional relationships suggest south-to-north as well as east-to-west transgression of the basal sequences of the Hoosac onto the Middle Proterozoic basement; much of the Hoosac Formation in this area was deposited during pre-Iapetan rifting. The albitic granofels, quartzite, quartz-rich schists, and, locally, coarse metaconglomerates of the Hoosac suggest proximal marine deposition in a submarine rift environment well before the formation of the Cambrian through Middle Ordovician shelf sequence exposed west of the Green Mountain massif.

Turkey Mountain Member of the Hoosac Formation

Greenish hornblende-epidote-plagioclase amphibolite occurs as layers throughout the Hoosac Formation. Four relatively continuous metabasalt layers (shown as **€Zhtm$_1$** through **€Zhtm$_4$**) are mapped here. Individual outcrops show parallel layering of volcaniclastic basalt beds and the enclosing sediments. Minor but distinctive beds of magnetite-epidote quartzite (map unit **€Zhq**), are interbedded with the amphibolite. The along-strike continuity of the relatively thin amphibolites, clear interlayering with volcaniclastic rocks, and the basaltic chemistry discussed below suggest a series of basaltic lava flows.

Ten samples of the Turkey Mountain Member were analyzed for major, trace, and rare-earth elements (tables 1, 2; tables 1–8 follow References Cited). The basalts have a weight percent of SiO_2 between 44 and 51 and a weight percent of TiO_2 between 4.7 and 1.4. Samples lower in the stratigraphic section are higher in TiO_2 and have moderate light-rare-earth-element (REE) enrichment of lanthanum (La) at 90 to 55 times chondrite abundances (fig. 2). Samples stratigraphically higher (**€Zhtm$_2$** and **€Zhtm$_3$**) have a TiO_2 content about 2 weight percent and light-REE enrichment of 20 to 25 times chondrite abundances.

Samples 29 and 30 from the Turkey Mountain Member **€Zhtm$_3$**) contain 1.9 to 1.3 weight percent of TiO_2 and have slightly depleted light-REE abundances having La 15 to 20 times chondrite (fig. 2). The chemistry of basalts from the Hoosac exposed in other areas is similar, namely that basalt lower in the stratigraphic section is alkalic and closely resembles the chemistry of dikes from the Green Mountain massif, whereas basalts stratigraphically higher in the Hoosac are less alkalic, are more similar to mid-ocean-ridge basalts (MORB-like), and closely resemble amphibolites in the overlying Rowe Schist(?) and Rowe Schist proper (Ratcliffe, 1991a). Plots of Turkey Mountain Member basalts on triangular tectonic discrimination diagrams (figs. 3, 4) show the similarity of lower units to within-plate basalts and that the upper units are chemically MORB-like.

This upward chemical variation from alkalic basalt to MORB-like basalt is independent of east-to-west geographic position and suggests that the Hoosac basalts evolved towards MORB with progressive rifting and subsidence (Ratcliffe, 1991a). The Turkey Mountain Member is discussed further in the Mount Snow-Readsboro report (Ratcliffe, 1993a).

Rowe(?) Schist and Rowe Schist proper

The belt of rocks between the top of the Hoosac Formation and the base of the Moretown Formation thins from greater than 9 km wide at the northern border of the map to about 1 km wide at the southern border. This tapering wedge of rocks is in the general position of the Pinney Hollow, Ottauquechee, and Stowe Formations mapped to the north by Doll and others (1961) and in this area by Skehan (1961). Rather than forming parallel belts, individual map units within this wedge are discontinuous or pinch out by fault truncation along the Whitcomb Summit thrust or the Goose City fault zone. At the southern end of the map the belt is coextensive with rocks mapped as Rowe Schist by Chidester and others (1967) and by Hatch and Hartshorn (1968). Nonetheless, the same belt between the Hoosac and Moretown at the northern edge of the map is coextensive with the belt of rocks to the north that contains the type Pinney Hollow and Ottauquechee Formations and with the Stowe Formation as mapped by Chang and others (1965). However, detailed and reconnaissance mapping south of the Woodstock area mapped by Chang and others has revealed important truncation of map units due to thrust faulting.

In this map, rocks above the Goose City fault are mapped as Rowe Schist proper, because these rocks are similar to and coextensive with Rowe Schist mapped to the south. The Rowe Schist proper generally appears to be equivalent to the Stowe Formation to the north. Rocks beneath the Goose City fault but above the Hoosac Formation are mapped here as Rowe(?) Schist. Further studies to the north may resolve the regional extent and continuity of the Pinney Hollow and Ottauquechee Formations southward from their type localities. The Rowe(?) Schist does contain rock types characteristic of the Pinney Hollow and Ottauquechee Formations, however, the heterogeneous distribution of these rocks does not coincide with rock types as mapped previously.

Rocks of the Rowe(?) Schist and Rowe Schist proper are shown in fault contact with adjacent units in most areas of the map. However we show a normal stratigraphic contact between rocks of the Hoosac Formation and rocks of the Rowe(?) Schist in the northwestern part of the map and in two areas west of the Stacey Mountain thrust on figure 1. The discovery in 1997 of Middle Ordovician conodonts in a fault sliver beneath the Pinney Hollow Formation near Plymouth indicates that the Pinney Hollow Formation at its type area is in fault contact with Late Proterozoic through Cambrian rocks that underlie it (Ratcliffe and others, 1997 and in press). Because rocks of the Rowe(?) Schist are lithic correlatives with the Pinney Hollow Formation, a fault may also separate the Hoosac Formation from the Rowe(?) Schist in the two areas mentioned above. However, F_2 fault structures are not present along these contacts and the faults, if present, would have to date from an earlier generation of faulting.

Rowe(?) Schist

A dominant belt of lustrous green schist and phyllite (**€r?**) enters the northwestern part of the map from a wider belt in the Jamaica quadrangle (Ratcliffe, 1997). This schist overlies green albite schist and granofels of the Hoosac Formation (**€Zhgab**). Amphibolite (**€Zhtm$_3$** or **€Zhtm$_4$**) and a dark, garnet-nubbled schist (**€rgt?**) are irregularly distributed along the contact. Here the lower contact is sinuous and folded, and in the Jamaica area it may be normal and nonfaulted (Ratcliffe, 1997). Farther south

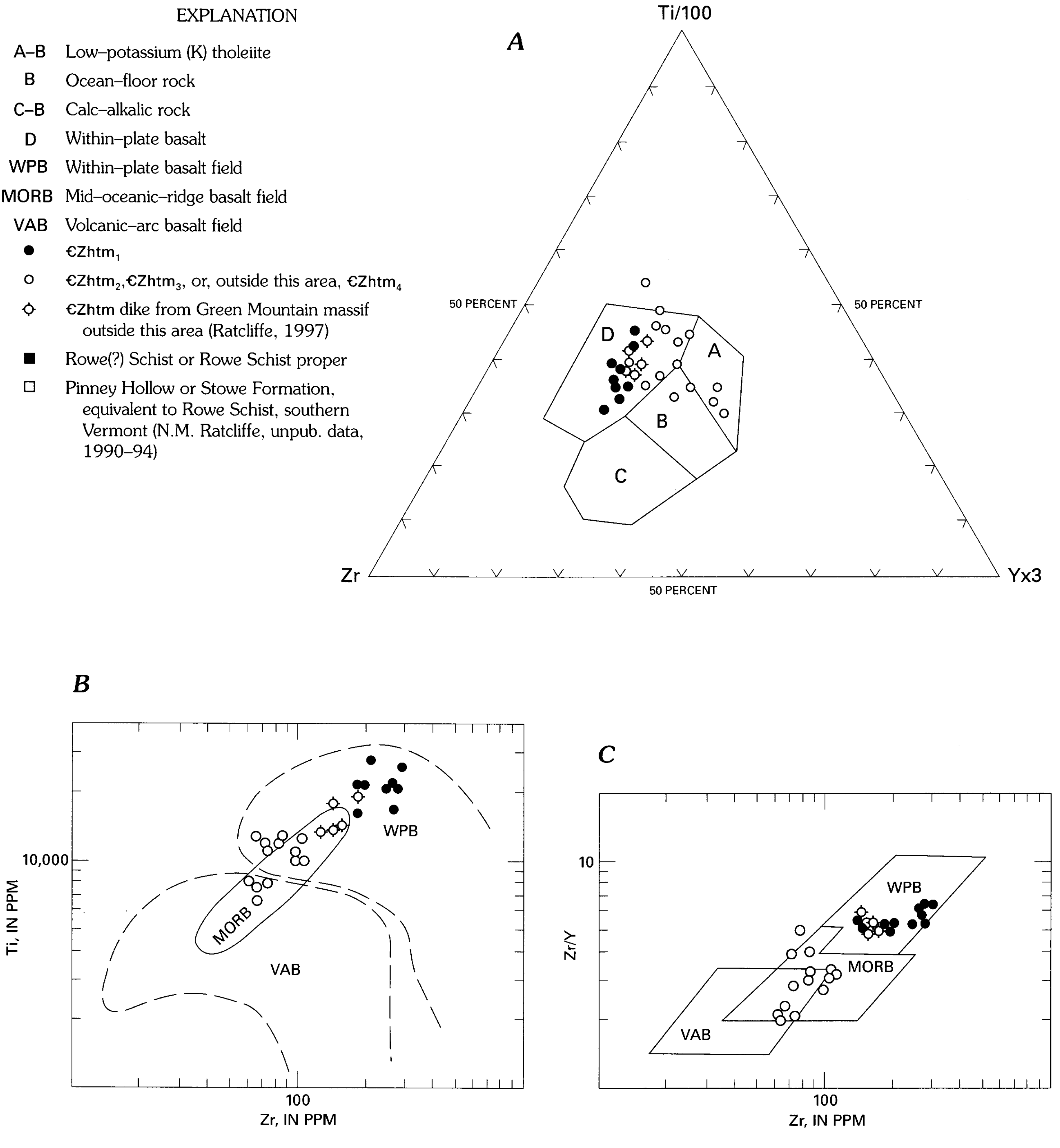
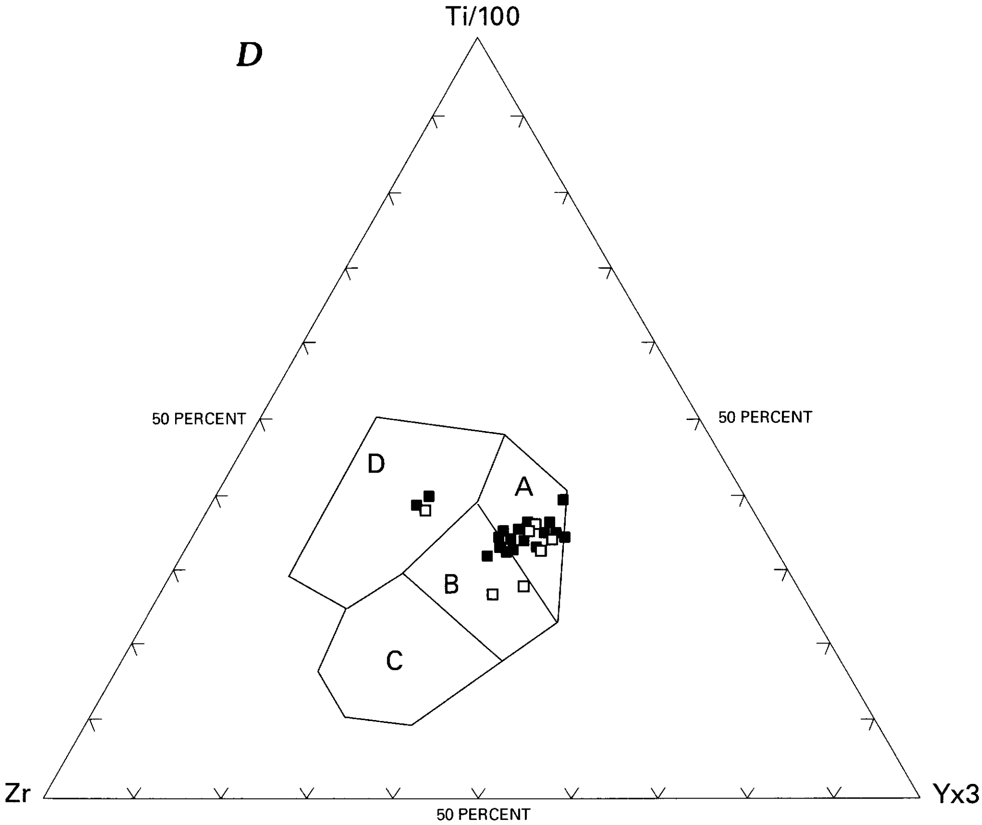
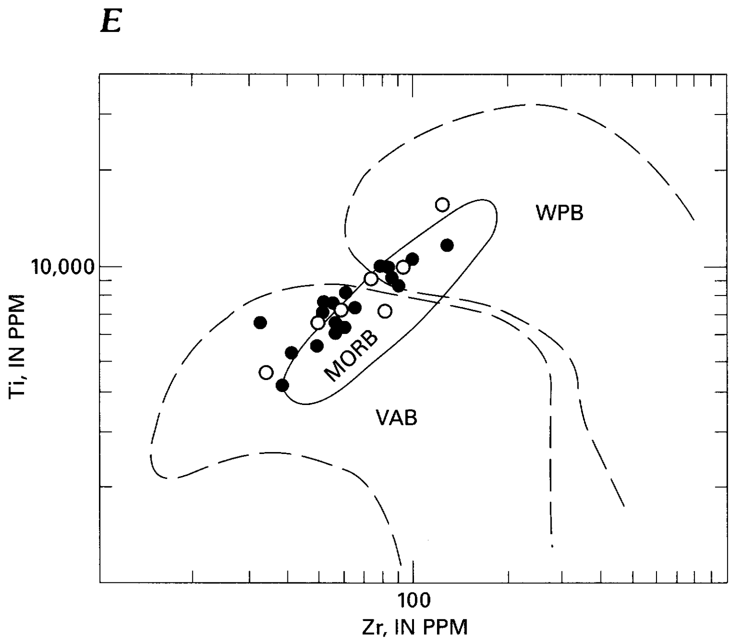
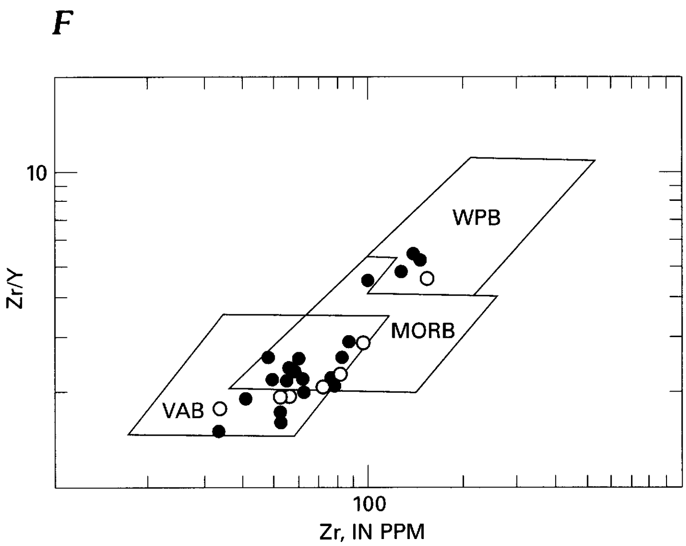


Figure 3.—Triangular tectonic discrimination diagrams of titanium (Ti), zirconium (Zr), and yttrium (Y) comparing amphibolite from the Turkey Mountain Member of the Hoosac Formation (*A*, *B*, and *C*) with amphibolite from the Rowe(?) Schist and Rowe Schist proper (*D*, *E*, and *F*). Samples from West Dover and Jacksonville quadrangles unless otherwise noted. Triangular Ti/100–Zr–Yx3 diagrams from Pearce and Cann (1973), and Ti–Zr and Zr/Y–Zr diagrams from Pearce (1982) and Pearce and Norry (1979). Ppm, parts per million.







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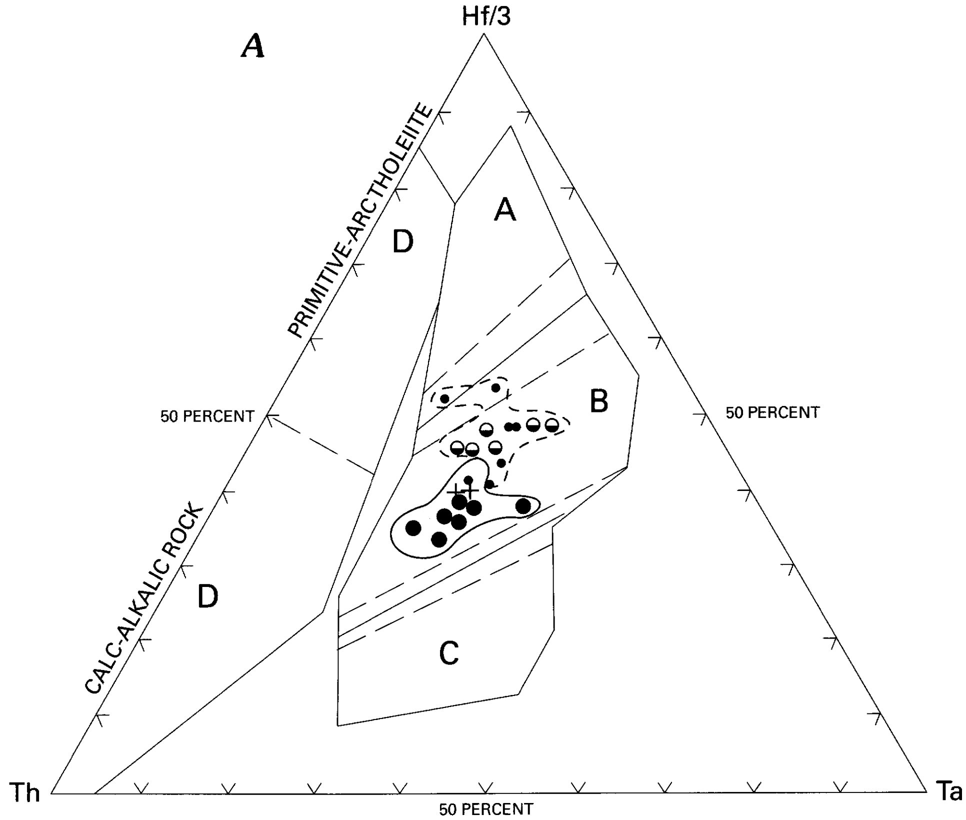

EXPLANATION

- A Normal (N-type) mid-oceanic-ridge basalt
- B Enriched (E-type) mid-oceanic-ridge basalt and within-plate tholeiitic basalt
- C Within-plate alkalic basalt
- D Destructive-plate-margin basalt
- ● ꞒZhtm$_1$
- ◒ ꞒZhtm$_2$ or, outside this area, ꞒZhtm$_4$
- • ꞒZhtm$_3$
- + ꞒZhtm dike from Green Mountain massif (Ratcliffe, 1997)
- ■ Rowe(?) Schist or Rowe Schist proper. Sample numbers identified in tables 3 and 4
- □ Pinney Hollow or Stowe Formation, equivalent to Rowe Schist, southern Vermont (N.M. Ratcliffe, unpub. data, 1990–94)

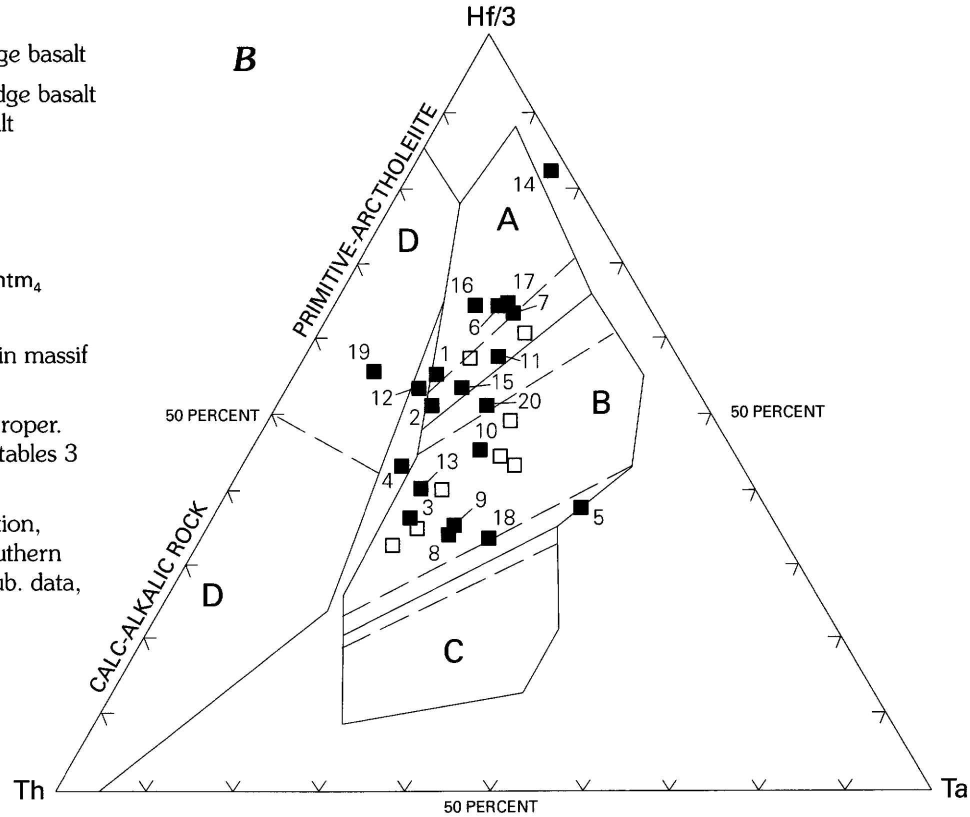

Figure 4.—Triangular tectonic discrimination diagrams (from Wood, 1980) of hafnium (Hf), thorium (Th), and tantalum (Ta) comparing amphibolite from the Turkey Mountain Member of the Hoosac Formation (*A*) with amphibolite from the Rowe(?) Schist and Rowe Schist proper (*B*). Samples from West Dover and Jacksonville quadrangles unless otherwise noted.

in this map area, the Hoosac Formation and Rowe(?) Schist are separated by faults, and the Rowe(?) Schist occurs only in two small fault slivers in the Jacksonville quadrangle. Garnet and chloritoid are present in map unit Ꞓr?, but commonly it contains abundant oligoclase, which is unlike much of the Pinney Hollow Formation exposed to the north. Two dark-colored schistose units are present also. The structurally lower unit, a plagioclase-rich, rusty-weathered chlorite-quartz schist (Ꞓrr?), is typically chloritic, muscovite-rich, and lacks abundant biotite. This unit is not easily distinguished from the rusty albite schist (ꞒZhrab) of the Hoosac, except that the Rowe(?) tends to be less feldspathic and more foliated. Although unit Ꞓrr? superficially resembles the Ottauquechee Formation, it lacks graphitic phyllite and quartzite that characterize the Ottauquechee.

Amphibolite (Ꞓra?) is interbedded throughout the Rowe(?) Schist (Ꞓr?) and is in contact with most of the other units within the Rowe(?) Schist. Most of these amphibolites probably were lava flows; however, some massive, more plagioclase-rich amphibolites may have been intrusive sills or even tectonic fragments of intrusive rocks. Light-gray, biotite-quartz-feldspar granofels and quartzite (Ꞓrfq?) are in contact with amphibolite (Ꞓra?), green schist (Ꞓr?), and the Cooper Hill Member (Ꞓrch?). The plagioclase-rich granofels or gneiss are interpreted as volcaniclastic deposits associated with basaltic volcanism and closely resemble the biotite-plagioclase schist and gneiss unit (Ꞓrfb) within the Rowe Schist proper.

Near contacts with the graphite schist and quartzite (Ꞓrchc?), green schist (Ꞓr?), and rusty chloritic schist (Ꞓrr?), well-bedded hornblende-plagioclase-epidote-quartz metawacke and epidote-knotted amphibolite are common in layers 0.5 to 1 m thick, suggesting the amphibolite originated as volcaniclastic deposits. Elsewhere, the amphibolites are highly foliated, but generally lack internal layers of metasedimentary rock.

Overall, the metasedimentary rocks of the Rowe(?) Schist suggest a marine sequence of rocks that were deposited in deeper water than the underlying rocks of the Hoosac Formation. Local carbonaceous schists and sparse coticule suggest local restricted basins and intermittent low rates of sedimentation in a marine basin or marginal sea. The wide belt of amphibolite on the west, south, and east slopes of Cooper Hill appears to be quite homogeneous except for talc-carbonate lenses. The amphibolites (Ꞓra?) are interpreted as metabasalt flows having the composition of MORB as discussed below.

Although the rocks mapped here as Rowe(?) Schist contain some rock units, such as the green schist unit (Ꞓr?) and the Cooper Hill Member (Ꞓrch?), which resemble the Pinney Hollow and Ottauquechee Formations of Doll and others (1961), the overall distribution and petrography do not duplicate relationships seen in the type sections of either formation near Plymouth (Walsh and Ratcliffe, 1993).

Cooper Hill Member of the Rowe(?) Schist

A southward tapering arcuate belt of distinctive rusty-weathering schist extends from Rice Hill and Cooper Hill eastward to the Goose City fault; rocks in this belt are here named the Cooper Hill Member (Ꞓrch?) of the Rowe(?) Schist. The unit is well exposed on Cooper Hill and the ridges northward to Rice Hill. The dominant rock type is a slabby, well-foliated, rusty-weathering, dull-gray muscovite-biotite-plagioclase-quartz schist and greenish-gray, more chloritic schist containing knots of milky-white quartz. Rare layers of dark-gray phyllite contain chloritoid and garnet. The unit is homogeneous and easily distinguished from the green schist unit (Ꞓr?) of the Rowe(?) by its dull-gray, rusty-weathering surfaces and its lack of distinctive greenish (chlorite-muscovite) schists that are typical of the green schist unit. Narrow belts of dark-gray to sooty-gray-weathering, carbonaceous plagioclase-quartz schist (Ꞓrchc?) are exposed north of Rice Hill. This carbonaceous schist locally contains beds up to 1 to 2 m in thickness of darker gray graphitic schist or 0.5-m-thick beds of dark-gray to black vitreous quartzite. A similar rock is interlayered with amphibolite (Ꞓrg) just above the Goose City fault 1 km south of the northern boundary of the map. These small occurrences of carbonaceous schist are the only rocks in the Rowe(?) Schist in these quadrangles that resemble those at the type locality of the Ottauquechee Formation in the Plymouth quadrangle.

The lower contact of the Cooper Hill Member (Ꞓrch?) with amphibolite (Ꞓra?) on Cooper Hill and Rice Hill is marked by serpentinite and talc-carbonate schist (OZu) within the amphibolite. Where the Cooper Hill Member overlies the green schist unit (Ꞓr?) 2 km northwest of Rice Hill, serpentinite (OZu) and amphibolite (Ꞓra?) occur within the Cooper Hill. The concentration of ultramafic rock near the contact of the Cooper Hill Member as well as at other positions within the Rowe(?) Schist suggests strongly the possibility of premetamorphic faults.

The southernmost exposures of the Cooper Hill Member (Ꞓrch?) are in two small areas along the Goose City and Rock River faults. To the north in the Jamaica quadrangle, the Cooper Hill Member trends northeasterly until it wedges out against the northern extension of the Goose City fault, there called the South Wardsboro thrust zone near West Townshend in the Townshend quadrangle (Ratcliffe, 1997). The total length of the outcrop belt of the Cooper Hill Member is about 20 km. The greatest exposed width is between Rice and Cooper Hills. Except for small exposures of graphite schist and quartzite (Ꞓrchc?) within the Cooper Hill Member, none of the other rocks resemble the type Ottauquechee.

Rowe Schist proper

The Rowe Schist, as used by Hatch and others (1966) and Chidester and others (1967), refers to rocks between the top of the Hoosac Formation and the base of the Moretown Formation in Massachusetts. At the Massachusetts State line, the Rowe Schist occupies the same general structural position as rocks mapped as Pinney Hollow, Ottauquechee, and Stowe Formations by Skehan (1961) and Doll and others (1961) in Vermont. However, southward into Massachusetts, the distinct Vermont units could not be mapped by Hatch and others (1966). Instead, the Rowe Schist was used to describe a very heterogeneous, nonpersistent assemblage of rocks having no regular stratigraphic sequence (Chidester and others, 1967). Hatch and Stanley (1988) and Stanley and Hatch (1988) summarize the Rowe belt in Massachusetts as a tectonic mélange of Taconian origin that has rock types characteristic of the Pinney Hollow, Ottauquechee, and Stowe, but that they have no regular stratigraphic succession.

The tectonic nature of the Rowe belt in Massachusetts is supported here by the tectonic thinning and elimination of rocks in the zone that we have mapped as Rowe(?) Schist and Rowe Schist proper. Here the Rowe Schist proper forms a tapering wedge of rock dominated by a large-garnet schist (Ꞓrgs) overlying lesser amounts of amphibolite greenstone (Ꞓrg) to the north and by abundant amphibolite (Ꞓrba) interlayered with little large-garnet schist (Ꞓrgs) in the south. Small pods of serpentinite occur within the Rowe. At or near the top of the Rowe is a large ultramafic body (OZd) at East Dover that is associated with a distinc-

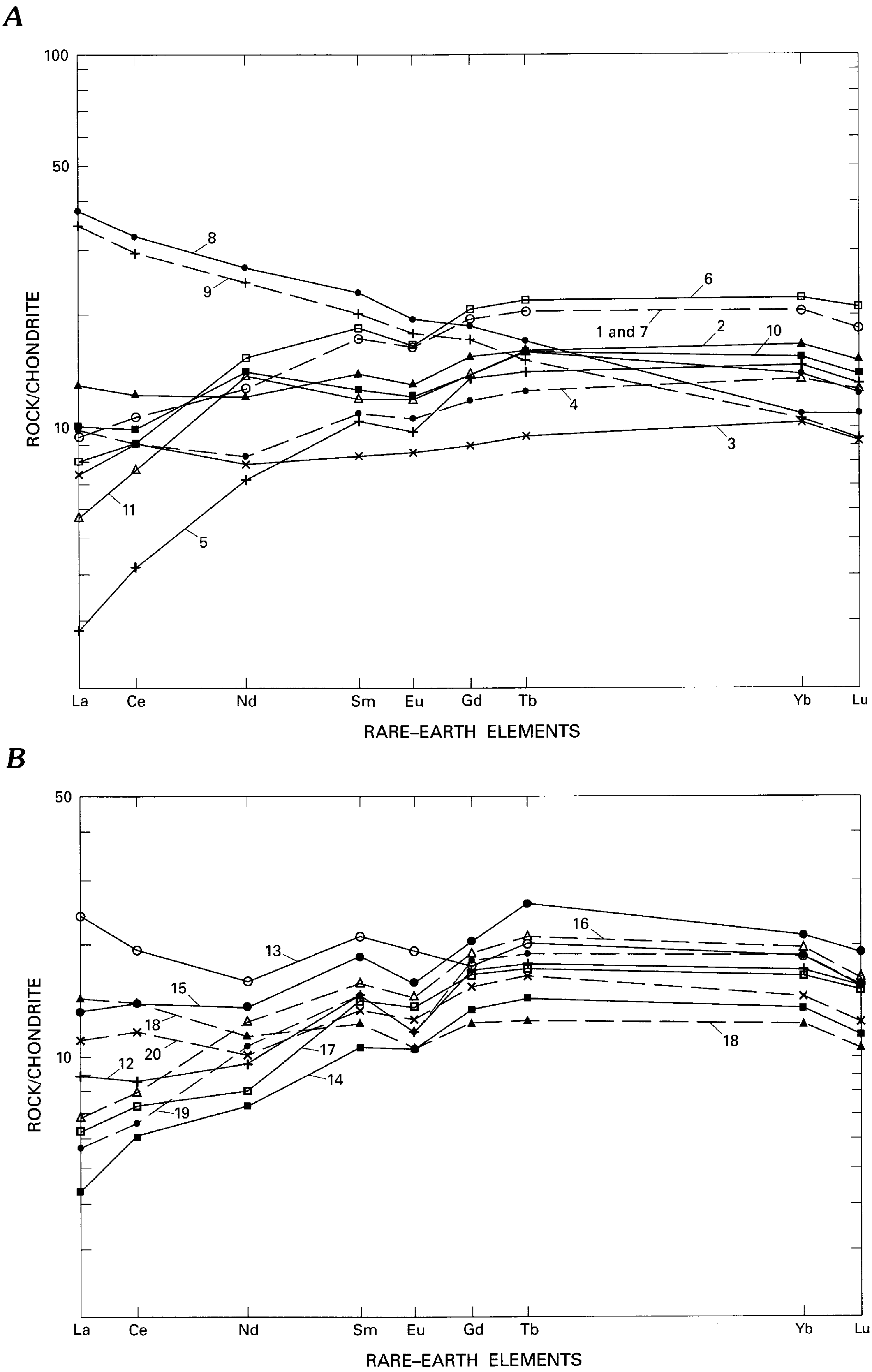

Figure 5.—Chondrite-normalized to rare-earth-element (REE) abundance diagrams of amphibolite from the Rowe(?) Schist and Rowe Schist proper from the (*A*) West Dover and (*B*) Jacksonville quadrangles. Samples identified in tables 3 and 4. Data normalized to CI chondrite of Anders and Ebihara (1982). Gadolinium (Gd) estimated by extrapolation.

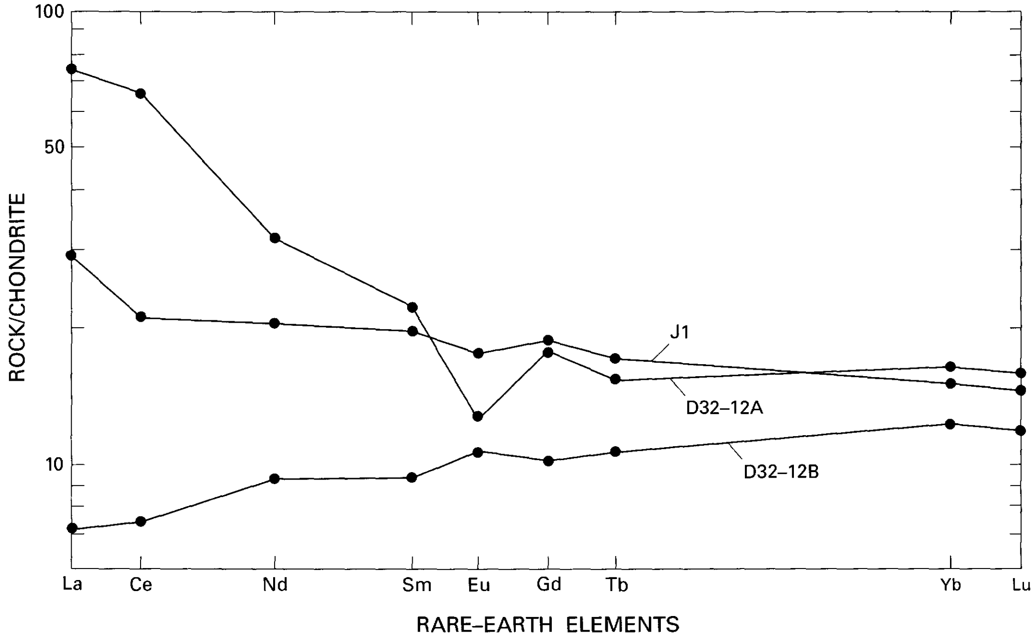

Figure 6.—Chondrite-normalized to rare-earth-element (REE) abundance diagram of mafic rocks from the Moretown Formation. Samples identified in tables 5 and 6. Data normalized to CI chondrite of Anders and Ebihara (1982). Gadolinium (Gd) estimated by extrapolation.

tive, tectonically laminated, green magnetite-chlorite-muscovite-quartz mylonite schist (Єrs). Major faults transect the formation and disrupt the stratigraphy. A distinctive biotite-plagioclase schist and gneiss (Єrfb) laterally replaces greenstones (Єrg) or amphibolite (Єrba) near the contact with the large-garnet schist (Єrgs). Large cross biotite is typical of the more feldspathic rocks of the Rowe Schist proper (Єrfb, Єrgf, and, to some extent, Єrgs), but not the rocks of the Rowe(?) Schist. Minor belts of carbonaceous to graphitic, dark-gray schist and quartzite (Єrcs and Єrcq), and feldspathic quartzite (Єrfq) form lenses within the upper amphibolite (Єrba); the carbonaceous units resemble the graphite schist and quartzite (Єrchc?) of the Cooper Hill Member of the Rowe(?) Schist. The light-green magnetite-chlorite schist (Єrs) unit somewhat resembles the green schist unit (Єr?) of the Rowe(?), but the Єrs unit overall is more chloritic, finer grained, and distinctly (tectonically) color banded. It lacks the quartz rods that are characteristic of the Єr? unit. Chlorite in the Єrs and Єrg units is more magnesium rich, whereas chlorite in the Єr? unit is more iron rich (see metamorphic mineral assemblage section).

Amphibolite and greenstone (Єrg) associated with the lower part of the Rowe commonly contain significant ankerite, and those greenstones weather to a dull-green-gray, deeply pitted surface. More typical hornblende-rich amphibolite is also present, especially in the upper part of the Rowe. These amphibolites tend to be dark-green to black and have fine quartz-epidote laminations.

Metasedimentary rocks of the Rowe Schist proper are generally more feldspathic and distinctly richer in biotite than rocks of the Rowe(?) Schist. The interlayered felsic schist and granofels (Єrfb) suggest, in part, a felsic volcanic source and, perhaps, tuffaceous sediments. In general, rocks of the Rowe Schist proper suggest deposition in a deepwater marine and distal setting where both mafic and felsic volcaniclastic deposits accumulated. In the tectonic model of Stanley and Ratcliffe (1985), the Rowe Schist may have been deposited during the early stages of the Taconian accretionary prism and oceanic-arc system into which tectonic slivers or olistoliths of ultramafic rock were incorporated.

Chemistry of metabasalts in the Rowe(?) Schist and Rowe Schist proper

Twenty samples of amphibolite from the Rowe(?) Schist and Rowe Schist proper were analyzed for major, trace, and rare-earth elements (REE) (tables 3, 4). The amphibolites are low in TiO_2 (2–0.7 weight percent), range from 41.7 to 51.6 weight percent SiO_2 and 6.2 to 11.7 weight percent MgO, and are basaltic in composition. Little difference exists between amphibolites from the Rowe(?) Schist and the Rowe Schist, except that some samples higher in the Rowe are lower in TiO_2 and very high in MgO. Most samples exhibit flat chondrite-normalized patterns of REE at about 10 to 15 times chondrite abundances; six samples have La and cerium (Ce) depletion which ranges from 8 to 6 times chondrite abundances (fig. 5). In tectonic discrimination diagrams (fig. 3), the plots of Ti to Zr and Zr/Y to Zr illustrate that the metabasalts of the Rowe(?) Schist and Rowe Schist proper have compositions predominantly similar to MORB. Two samples of amphibolite (Єrba samples D32–9 and D32–8) more closely resemble within-plate alkalic basalts, and have light-REE enrichment, with La amounts that are 35 times chondrite abundances.

Whereas the chemistry of the amphibolites of the Hoosac Formation have a stratigraphic variation from alkalic basalt to MORB, the chemistry of the Rowe(?) and Rowe Schist amphibolites show no stratigraphic variation. However, they are indistinguishable from some basalts from the Turkey Mountain Member of the Hoosac Formation (ЄZhtm$_3$ and ЄZhtm$_4$), and patterns are similar in the tectonic discrimination diagrams (figs. 3, 4) and the chondrite-normalized REE patterns (figs. 2, 5). However, as a rule the Rowe basalts seem best interpreted as ocean floor and MORB-like, whereas basalts of the Turkey Mountain have a stronger affinity to within-plate basalts. Whether the basalts in

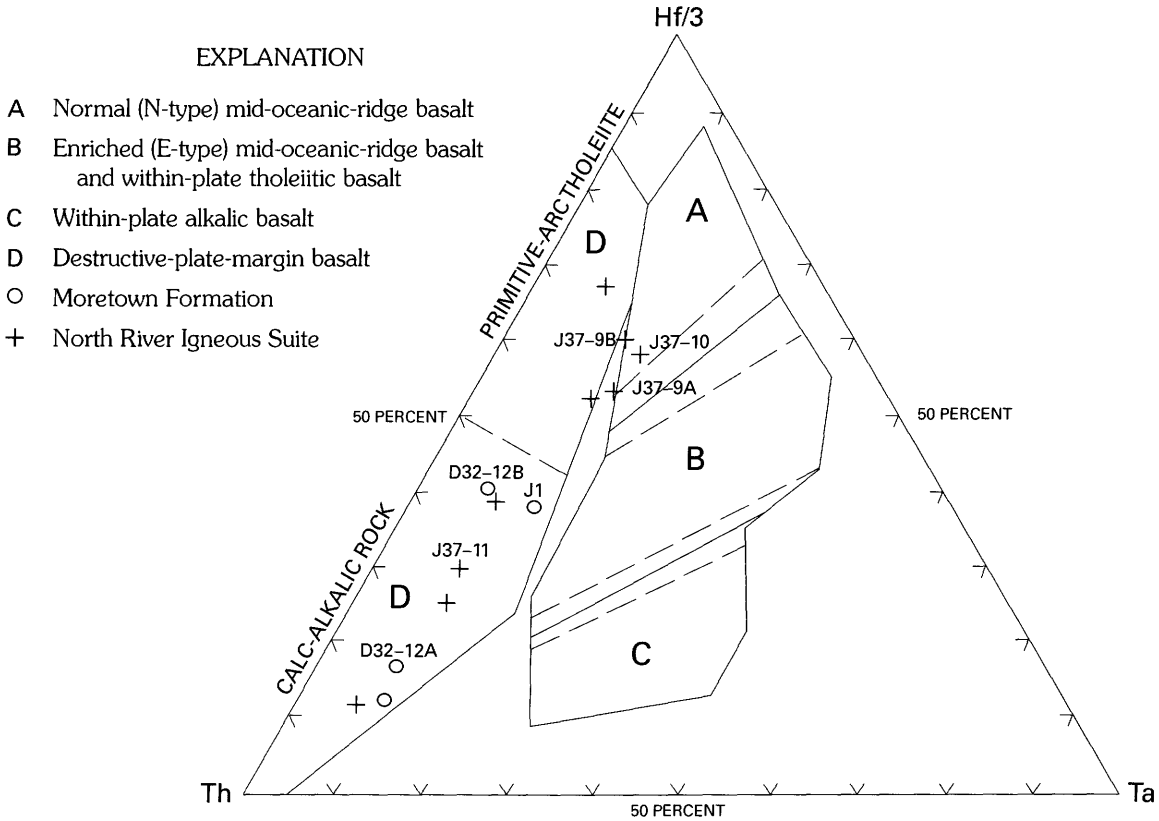

Figure 7.—Triangular tectonic discrimination diagram (from Wood, 1980) of hafnium (Hf), thorium (Th), and tantalum (Ta) comparing mafic rocks from the Moretown Formation and the North River Igneous Suite. Sample numbers identified in tables 5 and 6; other samples are from outside the area (T.R. Armstrong and N.M. Ratcliffe, unpub. data, 1990–93).

the Rowe truly represent ocean-floor basalts formed at a mid-ocean ridge or are end-stage rift basalts produced at or near the development of eventual oceanic growth is an important question. If the latter were true, the Rowe(?) and Rowe Schist sediments and basalts would be older than the carbonate platform of Early Cambrian to Early Ordovician age. This would affect the location of the source zones of the Taconian allochthons, because then the Early Cambrian to Early Ordovician rocks of the Taconian allochthons would be younger than any rocks in the Hoosac Formation, Rowe(?) Schist, and Rowe Schist proper exposed in this map area (Ratcliffe, 1993b).

Moretown Formation

Quartz-plagioclase granofels, quartzite, schist, metadiorite, and amphibolite of the Moretown Formation belong to the Moretown and Rowe Lithotectonic Unit (fig. 1) and structurally overlie the Rowe Formation along the Taconian East Dover and Brookside thrust zone. Nine lithostratigraphic units are mapped here. Pinstriped granofels (Omfp and Omqf) and quartz-plagioclase-garnet schist (Omfs and Omgs) dominate the lower and upper parts of the formation. The middle part consists primarily of plagioclase-hornblende-rich schist (Omfs and Omf) of presumed volcanic and volcaniclastic origin. Granofels typically has a pinstripe structure caused by 3-mm- to 1-cm-thick laminations of quartz-plagioclase granofels separated by 1-mm-thick planar horizons of muscovite, biotite, and chlorite. Although this pinstriping resembles rhythmic bedding, in many places it is recognizably axial planar to F_2 and later folds and, thus, is probably entirely tectonic in origin. Bedding and other sedimentary features, such as graded beds, are common in the lower parts of the Moretown, particularly in units Omfp and Omfg, which probably originated as deep-water turbidites. The upper section contains abundant quartzite, schist, and, less commonly, plagioclase granofels (Omgs) that all suggest a sedimentary origin lacking volcanic detritus. The metadiorites (Omd) appear to have a relict ophitic texture now replaced by intergrowths of metamorphic hornblende and plagioclase. Contacts with surrounding schist, quartzite, and granofels are typically concordant, and the metadiorites have finer grained margins of hornblende and plagioclase that suggest chilled margins. The hornblende-chlorite amphibolites (Oma and Omd) have no recognizable igneous texture and have sharp contacts with the surrounding schist and quartzite. Because the amphibolites do not truncate layering in the surrounding metasedimentary units, they must be either basaltic volcaniclastic sediments (water-laid tuffs) or sills. The Moretown units terminate against thrust fault contacts with the underlying Rowe and the overlying North River Igneous Suite. Within the formation, units pinch out along strike. Correlation of units along strike is difficult because of the discontinuous nature, but similar units have been mapped to the south in the Heath quadrangle (Hatch and Hartshorn, 1968) and to the north in the Townshend quadrangle (Ratcliffe, 1997).

Chemistry of the Moretown Formation

Two samples of hornblende metadiorite and one sample of hornblende-plagioclase felsic granofels gneiss (volcanic rock?) were analyzed for major, trace, and rare-earth elements (tables 5, 6). Sample J1 is a moderately low TiO_2 (1.6 weight percent) and high MgO (7.9 weight percent) basaltic rock that exhibits slight light-REE La enrichment 30 times chondrite (fig. 6). Sample D32–12B is more andesitic in composition and has much lower total REE, having La values of 7 times chondrite and a minor positive europium (Eu) anomaly. It is unlikely these two samples were cogenetic. Felsic layers, such as sample D32–12A, are interlayered with these andesitic basalts; they are strongly enriched in light-REE, where La is 70 times chondrite and Eu exhibits a moderate negative anomaly. It is plausible that samples D32–12A and B are cogenetic. All three samples were plotted in the calc-alkalic destructive-plate-margin field on the Th–Hf/3–Ta triangular diagram of Wood (1980) (fig. 7). They contrast markedly with the within-plate, enriched (E-type) and normal (N-type) MORB types of amphibolites of the Hoosac Formation, Rowe(?) Schist, and Rowe Schist proper. From these limited chemical data, the igneous rocks of the Moretown are interpreted as volcanic rocks, either tuffaceous rock derived from a volcanic arc source or possibly as intrusive dioritic sills.

Ultramafic rocks

Numerous small, discontinuous ultramafic bodies exist in the West Dover and Jacksonville quadrangles. These bodies are highly foliated, lens shaped, and composed of talc, serpentine, and minor magnesite or of serpentinized dunite containing large (1 cm) magnetite porphyroblasts. The serpentinized dunite has a talc and serpentine border. These ultramafics (OZu) are typically 10 to 100 m long but may be too small to show at this map scale. They are commonly found in amphibolite (Ꞓra?) just below the Cooper Hill Member (Ꞓrch?) of the Rowe(?) Schist and in various units of the Rowe Schist proper, especially near or along the fault contact with the Moretown Formation.

The largest mapped ultramafic body, a serpentinized dunite, is 6 km long and almost 1.5 km wide. Skehan (1961) called it the East Dover ultramafic. Petrologic observations by us and by Hoffman and Walker (1978) reveal abundant relict olivine having strong optical zonation, which is interpreted as a series of metamorphic overgrowths. Toward the margins and in the center of the northern part of the body, the olivine has been progressively resorbed, and the primary assemblages of olivine, chromium spinel, and clinopyroxene have been replaced by serpentine, and lesser amounts of secondary olivine (isochemical with olivine rims on primary grains), magnetite, and chromite. This primary assemblage also is replaced by talc and magnesite in S_2 high-strain zones. Both types of replacement were due to hydration reactions that were localized within S_2 shear zones and fault zones surrounding and within the OZd body. Such reactions could produce strain softening allowing for development of the high-strain zones and faults. These crystalloblastic and structural observations suggest that zoning of olivine preceded Taconian deformation.

The origin of the ultramafic bodies is not known. They could be fault slivers from oceanic crust or ophiolites (Stanley and Ratcliffe, 1985), or they could be olistoliths derived from oceanic material shed from an exposed accretionary wedge (Bothner and Laird, 1985). The large metadunite of East Dover could be a fault-emplaced sliver of depleted mantle from beneath oceanic or highly distended continental crust. Because of the lack of metalherzolites, metagabbros, and other plagioclase-rich mafic igneous rocks, the ultramafic rocks are probably not cumulates of dismembered intrusive plutonic complexes.

Cram Hill Formation

The Cram Hill Formation (Och) was named by Currier and Jahns (1941) for exposures of sulfidic schist, chlorite schist, quartzite, and metarhyolitic agglomerate from Cram Hill in central Vermont. In this area the Cram Hill Formation is restricted to the southeast part of the Jacksonville quadrangle in the South Newfane Lithotectonic Unit. Skehan (1961) had mapped the Cram Hill Formation as a black to dark-gray, fine-grained sulfidic schist containing thin beds of blue-black and white vitreous quartzite. A felsic layer from the Cram Hill Formation east of the Chester dome yielded zircon dated at 484±4 Ma by the ion-microprobe SHRIMP method suggesting a Middle Ordovician age for the Cram Hill (Ratcliffe and others, 1997). The Cram Hill correlates with carbonaceous schist of the Hawley Formation of Massachusetts (Hatch and Hartshorn, 1968), which also includes massive, fine-grained to porphyritic amphibolite interpreted as interlayered volcanic rock. Volcanic rocks in the type Cram Hill section are agglomeratic soda rhyolite (Currier and Jahns, 1941). In addition, the type Cram Hill Formation contains abundant mafic dikes that cut all the Cram Hill and older adjacent units (Currier and Jahns, 1941, p. 1494). Amphibolites intrude the Cram Hill in the Jacksonville area, but they have been included in the North River Igneous Suite. The sulfidic schist locally contains zones 1 to 10 cm thick of sandy schist and gray to black quartzite that have sharp planar contacts with the surrounding schist. Graded beds and crossbeds are common in these zones. Near the upper contact with the Northfield Formation, the sulfidic schist of the Cram Hill Formation becomes more carbonaceous and contains small garnets 2 to 6 mm in diameter that are not found elsewhere within the formation, but are nearly indistinguishable from garnet phyllite of the Northfield Formation. Garnet schists of the Northfield that are in contact with those of the Cram Hill are distinguished by the fissile, almost slaty parting of the latter, although the two units are interlayered on a meter scale. Locally, the upper part of the Cram Hill also contains centimeter- to 1-m-thick, discontinuous lenses of well-bedded, vitreous white quartzite in which 0.5- to 1-mm detrital grains of blue, rutilated quartz are preserved that are similar to those found within the Northfield.

North River Igneous Suite

The North River Igneous Suite is here named for a suite of metamorphosed volcanic and intrusive igneous rocks exposed for almost 2 km north and south of the East Branch North River in the southeastern part of the Jacksonville quadrangle, south-southwest of West Halifax. Most of the North River Igneous Suite is intrusive. It was previously mapped as undifferentiated volcanic rocks of the Barnard Gneiss by Skehan (1961) and as the Barnard Volcanic Member of the Missisquoi Formation interlayered with the Cram Hill Formation by Hepburn and others (1984). Several intrusive rock types are mapped and named here. The West Halifax Trondhjemite (Onwt) is a fine-grained, porphyritic amphibolite containing plagioclase phenocrysts; the Blue Mountain facies (SOnbm) and Whitneyville facies (SOnbw) of the North River Igneous Suite comprise a dike and sill complex exposed near Branch Brook. Within the dike and sill complex are large screens (tabular inclusions) of fine-grained, well-layered plagioclase gneisses (Onmf and Onmg), which are thought to be of volcanic or volcaniclastic origin. These gneisses could be comagmatic volcanics and part of the North River Igneous Suite, or they could be inclusions of older volcanic rocks of the Cram Hill Formation. However, they are tentatively assigned to the North River Igneous Suite here. The newly named West Halifax Trondhjemite (Onwt) is well exposed in a bench-like outcrop 200

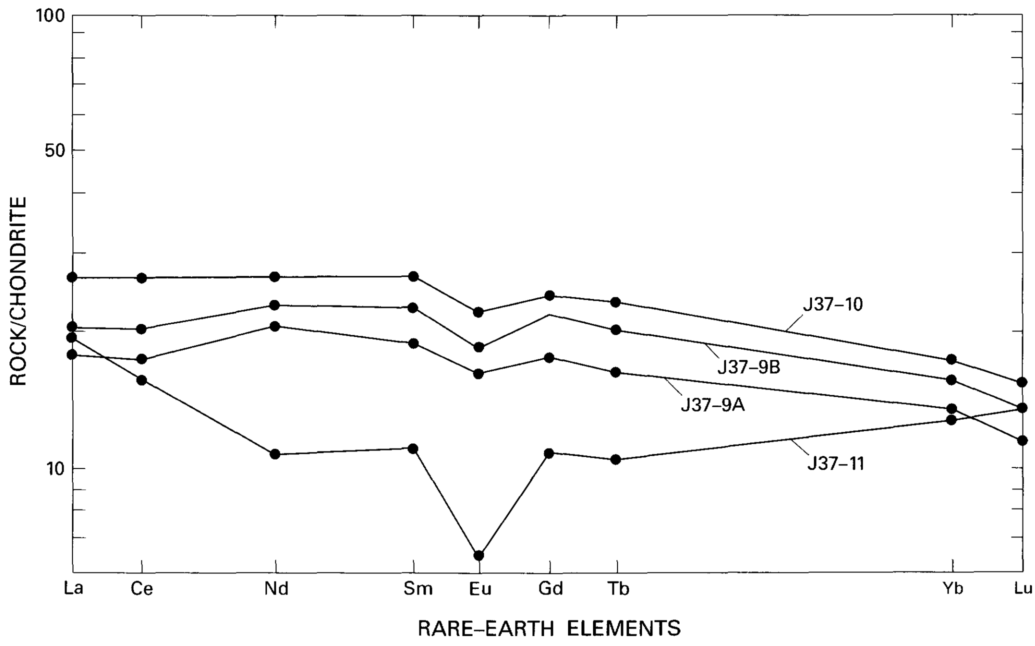

Figure 8.—Chondrite-normalized to rare-earth-element (REE) abundance diagram of mafic rocks from the North River Igneous Suite in the Jacksonville quadrangle. Samples identified in tables 5 and 6. Data normalized to CI chondrite of Anders and Ebihara (1982). Gadolinium (Gd) estimated by extrapolation.

m long and 25 m wide that extends along the west slope approximately 50 m from the crest of a northeast-trending ridge, 0.75 km east of the center of the village of West Halifax. The type section of the West Halifax Trondhjemite is a 0.85-km-long east-west section passing through West Halifax. Within the type section, the West Halifax Trondhjemite contains fine-grained mafic inclusions that are 0.1 to 20 m in diameter. Many of these inclusions contain fine-grained pyrite, and although not separable as map units, they are compositionally similar to rocks mapped by Armstrong (1994) as the South Pond volcanics of the Cram Hill Formation, immediately to the east within the Brattleboro quadrangle. Thin (1 cm to 1 m), fine-grained dikes of trondhjemite are present within the mafic inclusions and are sometimes continuous with the main body of West Halifax Trondhjemite.

The West Halifax Trondhjemite is intruded by the Blue Mountain facies of the dike and sill complex (SOnbm), located at Branch Brook that is also part of the North River Igneous Suite. The intrusive Whitneyville facies of the dike and sill complex at Branch Brook (SOnbw) forms the upper contact with the West Halifax Trondhjemite along the crest of the hill east of West Halifax. The presence of fine-grained chilled margins and 1- to 20-cm-thick dikes of plagioclase phenocryst-bearing mafic rock within the main body of the West Halifax Trondhjemite that extend back into the larger dikes and sills of the Branch Brook complex indicate that both the Blue Mountain facies and the Whitneyville facies intrude the West Halifax Trondhjemite. Mafic dikes and sills within the complex at Branch Brook therefore appear to be the youngest rocks within the North River Igneous Suite. Dikes of the Whitneyville facies (SOnbw) are abundant within the Cram Hill Formation. These dikes have fine-grained chilled margins and contain small to very large (1- to 100-m-long) xenoliths or screens of the sulfidic schist of the Cram Hill. Compositional layering within the Cram Hill Formation may be truncated by the dikes (SOnbw) or may be parallel to intrusive contacts suggesting that the Whitneyville occurs as both sills and dikes. Dikes of the Blue Mountain and Whitneyville facies are porphyritic with 2-mm- to 1-cm-long rectangular euhedral plagioclase phenocrysts set in a fine-grained matrix. Igneous zoning is preserved in some plagioclase phenocrysts. The combination of chilled margins, porphyritic texture, and sill-like habit suggest a hypabyssal origin.

The overlying Northfield Formation is in sharp contact with the Cram Hill Formation. Previous workers concluded that this contact was a regional unconformity. However, amphibolites similar to those in the dike and sill complex (SOnbw) along Branch Brook intrude the Northfield Formation to the east in the Brattleboro quadrangle (Armstrong, 1993a). This means that the North River Igneous Suite may extend into the Silurian, but only if the amphibolites do correlate with those here and if, in fact, the Northfield Formation is Silurian.

U-Pb ages determined from zircon in felsic volcanic rocks of the Barnard Volcanic Member of the Missisquoi Formation of Doll and others (1961) range from Cambrian to Silurian (Aleinikoff and Karabinos, 1990). A highly discordant array yielded an upper intercept age of 524±90 Ma from a felsic volcanic(?) rock from the east side of the Chester dome in Rockingham. Refinement of the U-Pb data from other localities in the North River Igneous Suite and from the Barnard Gneiss near Ludlow suggest that the intrusive members cluster in the age between 496±8 and 462±6 Ma based on both conventional U-Pb and Pb/Pb ion microprobe data (J.N. Aleinikoff, written commun., 1997; Ratcliffe and others, 1997). A nearly concordant upper intercept age of 418±1 Ma was obtained from felsic gneisses west of the Chester dome near Bridgewater. In the Ludlow area near Bridgewater so-called Barnard volcanics intrude the Moretown and Cram Hill Formations (N.M. Ratcliffe and G.J. Walsh, unpub. mapping, 1992–93). Tonalite of the North River Igneous Suite at South Newfane yielded an ion-microprobe SHRIMP age of 462±6 Ma (J.N. Aleinikoff, written commun., 1997). If indeed mafic rocks of the dike and sill complex at Branch Brook intrude rocks as young as the Northfield Formation, the age of the entire suite ranges from Ordovician to Silurian. This assumes that the Northfield here correlates with the type Northfield in central Vermont that is underlain by the fossiliferous Silurian to Lower Devonian Shaw Mountain Formation (Boucot and Thompson, 1963). It also assumes that all rocks mapped as Barnard are essentially the same age. We adopt a Late Ordovician to possibly Silurian age for the North River Igneous Suite, because although rocks previously mapped as the Barnard Volcanic Member of the Missisquoi Formation throughout southern Vermont (Doll and others, 1961) may appear to be similar to those of the North River Igneous Suite, in fact, they may be of a greatly different age.

Chemistry of the North River Igneous Suite

Preliminary geochemical data for the North River Igneous Suite appear in tables 5 and 6. One sample (J37–11) of the West Halifax Trondhjemite and three samples from two amphibolite dikes of the Whitneyville facies (an interior (J37–9A) and a chilled-margin (J37–9B) sample and a second dike sample (J37–10)) were analyzed for major, rare-earth, and trace elements. The amphibolites are of basaltic composition; they are low in TiO_2 (1.29–1.89 weight percent) and range from 47.2 to 49.3 weight percent SiO_2 and 6.4 to 7.5 weight percent MgO. In contrast, the trondhjemite sample contains 0.2 weight percent TiO_2, 74.2 weight percent SiO_2, and 1.4 weight percent MgO. The amphibolite dikes of the Whitneyville have flat chondrite-normalized patterns (fig. 8) and have chondrite-normalized lanthanum to lutecium (La/Lu) ratios of 1.6 (interior) and 1.52 (chilled margin) for dike 1 and 1.78 for dike 2. The trondhjemite sample shows moderate La and Ce enrichment (19.67 and 16.85 times chondrite values), an overall "saddle-shaped" REE pattern, La/Eu of 3.16 (chondrite normalized), and Eu/Lu of 0.46. Such patterns may be due to sequestering of REE within minor phases, such as titanite, zircon, and monazite. The lower total REE content and the strong negative Eu anomaly suggest that felsic rock was not differentiated from a mafic parent, such as from these amphibolite dikes. The amphibolite dikes plot within the normal MORB to enriched MORB, within-plate tholeiitic fields, whereas the trondhjemite plots in the calc-alkalic destructive-plate margin field on the Th–Hf/3–Ta triangular diagram of Wood (1980) (fig. 7).

Northfield Formation

Exposures of small (3 to 6 mm) garnet-bearing, carbonaceous phyllite (DSn) in the southeastern corner of the Jacksonville quadrangle were mapped as the Northfield Formation and interpreted as unconformably above the Barnard Volcanic Member of the Missisquoi Formation (Skehan, 1961). Compositional layers of homogeneous, gray to black, carbonaceous phyllite and thin (millimeter- to centimeter-scale), sandy sulfidic layers both contain well-preserved graded beds that consistently top to the east. Several small, 1- to 2-m-thick and discontinuous, vitreous white quartzite lenses are present within the Northfield that are identical to those in the Cram Hill Formation. The Northfield Formation is interbedded with and overlies the Cram Hill Formation, and, therefore, the Northfield appears to be younger than the Cram Hill, but the age of both is uncertain.

The Northfield Formation was interpreted by Doll and others (1961) to be between the Middle Ordovician Cram Hill Formation of the Missisquoi Group and the fossiliferous Silurian and Devonian Waits River Formation. Basal quartz-pebble conglomerate along the lower contact with the Cram Hill Formation seemed to confirm that the Northfield was post-Taconian and, presumably because of its stratigraphic position, was the oldest unit in the Silurian and Devonian Connecticut Valley synclinorium of eastern Vermont.

From limited sedimentary topping criteria near the contact of the Waits River and Northfield Formations in south-central Vermont, Hatch (1991) determined that the Northfield was stratigraphically above the Waits River, reassigned the Northfield as a member of the Gile Mountain Formation, and interpreted the lower contact between the Northfield and the Ordovician Missisquoi Group as an Acadian fault zone. In this interpretation, Hatch transformed the Connecticut Valley synclinorium into a fault-bounded anticlinorium, in which younger rocks (Northfield and Meetinghouse Slate Members of the Gile Mountain Formation, respectively) were on the west and east flanks and older rocks (Waits River Formation) were in the core.

Our mapping in the Jacksonville quadrangle and to the east and northeast in the Brattleboro and Newfane quadrangles (N.M. Ratcliffe and T.R. Armstrong, unpub. mapping, 1993) indicates that the contact between the Northfield and underlying rocks to the west (former Missisquoi Group, referred to here as the Cram Hill Formation and North River Igneous Suite) is neither a fault nor an unconformity. We have observed that the Cram Hill Formation is interlayered on a meter scale with the Northfield Formation in a 10- to 200-m-wide zone, and sedimentary tops in both units consistently face to the east. Dikes of the Whitneyville facies of the North River Igneous Suite are 5 to 25 m thick, and they locally crosscut the Cram Hill Formation and the contact between the Cram Hill and Northfield Formations. Thus, the dikes are younger than the sedimentary contact. Furthermore, no fault-zone fabrics were found in any of these rocks. Therefore, we conclude that what we have mapped as Northfield is older than the structurally overlying Waits River Formation and do not accept Hatch's (1991) usage of the Northfield as a member of the Gile Mountain Formation. Hence, we designate the Northfield as a discrete formation and the oldest part of the Connecticut Valley synclinorium as used by Doll and others (1961).

STRUCTURAL GEOLOGY

Explanation of structural terminology

In addition to poorly preserved folds from the Middle Proterozoic, the area has been subjected to as many as five folding events in the Taconian and Acadian orogenies. Structure symbols are shown in various colors on the map to facilitate recognition.

In order to simplify the discussion of these multiple structures, the following terms are used. F refers to the folds as well as the folding event itself. S refers to axial-planar surfaces (schistosity and crenulation cleavage) formed in the corresponding folding events. In general, the events and surfaces formed sequentially with the oldest nonidentified folds being Proterozoic; subscripts 1 and 2 represent Late Ordovician (Taconian); and subscripts 3, 4, 4.5, and 5 represent Devonian (Acadian). The terminology refers to an areally composite system of folds and related S surfaces that became progressively more intense eastward; structures shown resulted from a single, but protracted, multiple and coaxial folding event. In rocks east of the South Newfane thrust, metasedimentary and metavolcanic rocks contain an Acadian bedding-parallel foliation termed the Acadian S_0/S_1 fabric. This foliation is older than $S_{4.5}$ and S_5, but it is not associated or correlated with any known folding event.

Lithotectonic Units and major faults

The first letters of Lithotectonic Units are capitalized to distinguish them from lithostratigraphic units. Five Lithotectonic Units are shown in figure 1, and of these, the Green Mountain, Mount Snow, and Wilmington Lithotectonic Units were named and defined in the adjacent Mount Snow and Readsboro quadrangles (Ratcliffe, 1993a). In the West Dover and Jacksonville quadrangles from the base up are (1) the Mount Snow Lithotectonic Unit, which consists of Middle Proterozoic gneiss and the Hoosac Formation to the west of and beneath the Wilmington fault; (2) the Wilmington Lithotectonic Unit, which also consists of Middle Proterozoic gneiss and the Hoosac Formation, but between the Wilmington and Whitcomb Summit thrust faults; (3) the Moretown-Rowe Lithotectonic Unit, which consists of Rowe-Moretown rocks between the Whitcomb Summit and South Newfane thrusts; and (4) the South Newfane Lithotectonic Unit, which consists of the North River Igneous Suite and the Cram Hill and Northfield Formations above and east of the South Newfane thrust.

The major faults that bound each Unit, except for the South Newfane thrust, are all interpreted as Taconian synmetamorphic faults and are expressed by the strong development of an S_2 mylonitic fabric. They may have experienced some reactivation in the Acadian as indicated by superposed, slickensided brittle fractures in some fault zones exposed to the west (Ratcliffe, 1993a). The South Newfane thrust and structures within the South Newfane Lithotectonic Unit are entirely Acadian, and rocks of this unit lack the older Taconic folds and deformation (F_1 and F_2) found in lithotectonic units to the west. Rocks of the South Newfane Lithotectonic Unit appear to have escaped Acadian F_3 deformation as well. The most intense deformation in the South Newfane Lithotectonic Unit coincided with peak metamorphic conditions in the $F_{4\text{-}4.5}$ folding event. This composite structural event resulted from an earlier F_4 shortening and S_4 cleavage development west of the South Newfane thrust and a later $F_{4.5}$ refolding and $S_{4.5}$ mylonitization produced during final positioning of the South Newfane Lithotectonic Unit against the Moretown-Rowe Lithotectonic Unit. Farther to the west in the Rayponda and Sadawga domes, peak Acadian metamorphism accompanied the development of F_3 and F_4 structures. Armstrong (1992) proposed that structures and peak metamorphic conditions became younger to the east and that structures in the South Newfane Lithotectonic Unit postdated those to the west.

Middle Proterozoic structures

Although rocks of the Mount Holly Complex were subjected to deformation during Middle Proterozoic high-grade dynamothermal events related to the Grenville orogeny, the resulting structures were not recognized here because of intense Paleozoic deformation. The Cardinal Brook Intrusive Suite is younger than Grenvillian and only contains post-Grenville foliations. Middle Proterozoic structures in the area are described elsewhere (Ratcliffe and others, 1992; Ratcliffe, 1993a, 1997).

Taconian structures

The oldest well-preserved folds and foliation belong to the F_1 and F_2 folding events, which formed under metamorphic conditions during the Taconian orogeny and affected all rocks west of the South Newfane Lithotectonic Unit. Taconian S_1 schistosity is axial planar to a set of isoclinal, generally upright folds present in all rocks beneath the Moretown Formation. The absence of S_1 schistosity in the Moretown is probably due to extensive S_2 transposition that makes recognition of the older surface difficult. F_1 folds are present and are indicated by their axial traces on the map. They are preserved only in less deformed areas between F_2 thrust faults. Near the Wilmington and Whitcomb Summit thrusts, a strong, second-generation S_2 foliation and mylonitic fabric is pervasive. The S_2 foliation transects F_1 folds and S_1 schistosity. The S_1 schistosity is folded into tight folds having fold axes that plunge, in reclined fashion, down the dip of the F_2 axial surfaces. The hinge lines of these F_2 folds are curvilinear and approximate sheath folds. In F_2 fault zones, intense plications of S_1 schistosity form stacked isoclinal folds. Many important fold closures in the Hoosac Formation, Rowe(?) Schist, Rowe Schist proper, and Moretown Formation are F_2 folds that plunge generally to the southeast, except where arched or folded by younger folds. Axial traces of F_2 folds frame the domal structures at Lake Rayponda and northeast of Sadawga Lake. F_2 closures are particularly apparent in the longitudinal cross section, *E–E′*, rather than in the cross-strike sections *A–A′*, *B–B′*, *C–C′*, and *D–D′* because of the downdip plunges of the F_2 folds.

S_2 foliation is parallel to most of the faults in the area, and F_2 folds are synchronous with the faulting. Intense F_2 folding within the thrust slices is expressed by a nearly ubiquitous S_2 foliation. A well-developed elongation shape fabric is interpreted as the direction of tectonic transport of the F_2-generation faults. This elongation lineation is expressed primarily by ellipsoidal clots and rods of quartz, spears of chlorite, and long axes of porphyroclasts, such as microcline augen, in Middle Proterozoic gneisses.

The age of the regional Taconian S_2 foliation, F_2 folds, and associated thrusts has been determined from $^{40}Ar/^{39}Ar$ ages on muscovite and biotite from mylonitic zones containing a similar southeast-plunging mineral elongation and lineation. For example, biotite ages of 446±4 and 436±4 Ma from the Mount Snow area (Sutter and others, 1985; Ratcliffe, 1993a) and muscovite cooling ages of about 400 Ma from S_2 shear zones in the Green Mountain massif (Burton and others, 1990, 1991) indicate a Late Ordovician (Taconian) age for the development of the S_2 foliation and F_2 folds. Muscovite samples came from coarse-grained, garnet-grade rocks that probably experienced temperatures in excess of 450°C; therefore, it is unlikely that the 400-Ma cooling ages are Acadian.

Because all rocks from this area were heated above the closure temperatures for biotite and muscovite in the Acadian orogeny, these minerals yield Acadian cooling ages of approximately 350 to 340 Ma (Sutter and others, 1985; Ratcliffe and others, 1988). Metamorphic minerals indicative of the peak Acadian metamorphism (garnet, biotite, and hornblende) overgrow S_1 and S_2 foliation throughout this area (Ratcliffe, 1993a). $^{40}Ar/^{39}Ar$ cooling ages of 387 to 355 Ma were determined from biotite and hornblende grains (Sutter and others, 1985; Sutter and Hatch, 1985). Microprobe analyses clearly indicate both biotite and hornblende grew during Acadian peak metamorphic conditions. Garnet porphyroblasts include microfolds of S_1 and S_2 foliations, and the garnets grow across and include the quartz-feldspar fabric, as well as fold hinges of F_2 folds. These relations suggest that present garnets did not grow syntectonically in the S_2 event, but, instead, grew after the formation of the Taconian structures. Aligned fine-grained muscovite, some biotite and ilmenite, and clots of matrix chlorite are still preserved in the S_2 orientation; they may represent textural relicts, but probably not chemical compositions, of Taconian minerals. Some elongated spears of chlorite, aligned along the S_2 foliation may have formed after Taconian garnets.

Major thrust faults, such as the Wilmington fault system, Whitcomb Summit thrust, Ellis Brook, Dover, Goose City, Rock River, East Dover, and possibly the Brookside fault zones, are all regarded as Taconian faults that are spatially and temporally linked to F_2 and S_2 features. These faults caused imbrication of basement and cover rocks late in the Taconian orogeny. The deformed S_1 foliation within the thrust slices indicates that the faults juxtaposed already metamorphosed and foliated rocks. The magnitude of this faulting and pervasiveness of F_2 and S_2 events destroyed or altered the stratigraphic succession, distribution, and original contacts of rocks from the Hoosac Formation through Rowe Schist proper. Judging from the uniform structural habit of S_2 and its associated lineation, the S_2 foliation probably was a regionally pervasive structure that developed subparallel to the major Taconian faults. Faults and foliations having the style and expression of the F_2–S_2 folding and thrusting in these quadrangles are continuous with faults that extend from the Taconian zone of the Berkshire massif to the south. There $^{40}Ar/^{39}Ar$ hornblende ages establish the Taconian age of the faults and S_2 fabric (Sutter and others, 1985). The extent and intensity of subsequent Acadian deformation can be evaluated by structural analysis of the folded Taconic S_2 foliation.

Acadian structures

Three, possibly four, deformational events in the Acadian orogeny have affected the area. They have been superposed on Taconian S_1 and S_2 features in rocks older than the Cram Hill Formation. Interference among these differently oriented folds resulted in domal and basinal warps in the Taconian foliations and contacts that give rise to the irregular, generally antiformal areas such as the Rayponda and Sadawga domes and broad basins. The effects are uneven across the map area. F_3 and F_4 folds predominate in the west, whereas composite F_4 and $F_{4.5}$ folds predominate in the east, and $F_{4.5}$ folds are dominant east of the South Newfane thrust. Silurian(?) and Devonian rocks of the Northfield Formation and North River Igneous Suite contain a well-developed composite schistosity consisting of bedding-parallel schistosity (Acadian S_0/S_1) and nearly coplanar $S_{4.5}$ crenulation cleavage.

S_3 crenulation cleavage is axial planar to open to tight overturned folds in all rocks west of the South Newfane thrust. This cleavage is folded into the domal structures, but generally trends northwest and dips to the northeast near the eastern part of the map and the Mount Olga area of the Jacksonville quadrangle. This crenulation cleavage is upright to vertical in the western part of the map and in the adjacent Mount Snow and Readsboro quadrangles (Ratcliffe, 1993a). Folds of the F_3 generation are restricted largely to outcrop scale and only a few examples of map-scale F_3 folds are recognized. Garnet, hornblende, and biotite are overgrown on the S_3 crenulation cleavage, thus indicating that peak metamorphic conditions probably outlasted development of the S_3 cleavage.

A well-developed S_4 crenulation cleavage is axial planar to upright to southeast-verging folds of the S_2 and S_3 reference surfaces. Over much of the West Dover quadrangle, F_4 folds and S_4 cleavage are upright, moderately weakly developed, and northeast trending. However, in the Sadawga Lake antiform and eastward, S_4 is represented by a locally well-developed, west-dipping schistosity having well-aligned muscovite and biotite parallel to the axial surface of tight asymmetric folds. Large garnets include F_4 microfolds of the older schistosity near their rims, but the schistosity in their cores is unfolded, indicating that garnet grew during the F_4 event. Crosscutting biotite and coarse sprays of hornblende are overgrown on the S_4 crenulation cleavage, especially in the eastern third of the West Dover quadrangle and east of a line extending from Mount Olga southwest to the southwest corner of the Jacksonville quadrangle.

Along the east flank of the Sadawga Lake antiform southwest from the Green River to the southern border of the map, rocks of the Moretown-Rowe Lithotectonic Unit contain a set of northeast-trending, northwest-verging minor folds that fold the west-dipping F_4 minor folds. This set of folds (termed $F_{4.5}$ folds) are coaxial with F_4 folds and appear to be associated either with late-stage tightening of the Sadawga Lake antiform or with shear zones and thrust faults within the Rowe and Moretown rocks. Axial surfaces of the $F_{4.5}$ folds are expressed by a strong $S_{4.5}$ crenulation cleavage and abundant folding of the relict S_2 schistosity. Because S_2 and $S_{4.5}$ features are subparallel on the limbs of $F_{4.5}$ folds and in shear zones, S_2 schistosity and $S_{4.5}$ cleavage form a composite east-dipping cleavage in many areas.

The intensity of the $F_{4.5}$ folds and $S_{4.5}$ cleavage increases eastward toward the South Newfane thrust and they become the dominant structures in rocks east of the thrust. $S_{4.5}$ features are coplanar with the S_0/S_1 composite foliation and crenulation cleavage displayed in the North River Igneous Suite and the Cram Hill and Northfield Formations. This prominent, composite, east-dipping foliation and cleavage are interpreted as the same general age as the thrust faulting and late $F_{4.5}$ deformation of the east limb of the Sadawga Lake antiform.

Regionally developed north- to north-northeast-trending upright F_5 folds affect all rocks. F_5 folds are characterized by a very weakly developed, spaced crenulation cleavage or by broad, open warps with no cleavage. These late-stage folds are late to postmetamorphic. Mineral alteration in the crests of minor folds may have caused widespread retrogression of biotite and garnet to chlorite in rocks along the east limb of the Sadawga Lake antiform. Although some of this retrogression may date back to the $F_{4.5}$ folding event, this retrogression is absent from rocks in the South Newfane Lithotectonic Unit.

Structures in the Moretown Formation

The Moretown Formation contains essentially the same fabrics as found in the underlying Rowe Schist proper beneath. A dominant Taconian S_2 schistosity has a consistently oriented mineral lineation of S. 65° E. The S_2 fabric is axial planar to F_2 reclined and isoclinal sheath folds near the Brookside-East Dover fault zone and axial planar to open, west-verging to upright folds farther east where the intensity of F_2 strain abruptly decreases. The S_1 Taconian foliation seen in the rocks farther west was not evident within the Moretown unit here. S_2 fabrics may have formed as a late synmetamorphic schistosity in the Moretown. S_2 fabric locally was warped or highly folded during at least four deformation phases of the Acadian orogeny. Acadian synmetamorphic S_3 crenulation cleavage or spaced cleavage is axial planar to a set of folds with axial surfaces that originally trended northwest with an unknown dip direction. The original orientation of the S_3 cleavage is unknown because of later deformation. The F_3 folds are characterized by an S- or Z-shaped chevron geometry and have large amplitudes relative to wavelengths. Extension-related mineral lineation appears to be absent, although hornblende commonly grows within the S_2 and S_3 intersections. F_3-folding effects on the map-pattern geometry are substantial to insignificant.

S_3 fabrics and F_3 folds are deformed locally by later synmetamorphic Acadian events including upright to east-verging, open to tight F_4 folds. They have either moderately to weakly developed, closely to widely spaced (1–5 mm) S_4 cleavage or a crenulation cleavage that typically trends northeast and dips to the northwest unless deformed later. F_4 hinge lines tend to have shallow (0°–15°) to moderate (16°–40°) plunges. Typically fine-grained (1- to 3-mm-long) needles of hornblende grow within the S_4 and S_2 intersection. F_4 folds are represented by large-scale map-pattern structures in the northeastern part of the Jacksonville quadrangle and the southeastern part of the West Dover quadrangle. Garnet porphyroblasts commonly contain mineral inclusion trails that define a planar (nonfolded) S_2 fabric within the core. The inclusion trails become more crenulated toward the rim. The folds defined by the inclusion trails are coplanar with crenulate folds in the matrix. Thus, garnet cores originated prior to F_3 deformation, and peak-thermal garnet growth (garnet rims) occurred during F_3 and F_4 deformation and the development of crenulation cleavages.

Both Rowe and Moretown rocks have a strongly developed $S_{4.5}$ foliation that forms a composite foliation with the Taconian S_2 foliation. Both foliations have the same strike, but $S_{4.5}$ commonly dips more gently to the southeast than S_2. Locally, high-strain $S_{4.5}$ shear zones are present within the Moretown rocks. These shear zones appear as closely spaced, cataclastic phyllonitized zones as wide as 25 m that contain shredded micas, abundant retrograde sericite, and chlorite. $F_{4.5}$ folds in the Moretown are west verging, open to tight, and locally warp the trend of the regional S_2 fabric and lithologic contacts. Locally, $F_{4.5}$ folds are pervasive and fold the S_2 fabric and F_3 and F_4 axial surfaces tightly, almost isoclinally. In these pervasive zones, $S_{4.5}$ fabrics are distinguished from S_2 fabrics by ubiquitous, northeast-trending chlorite mineral lineation in the $S_{4.5}$ versus southeast-trending lineation in S_2.

$S_{4.5}$ fabric increases in intensity to the east toward the South Newfane thrust. Near the fault, rocks of the Moretown Formation in the footwall contain abundant euhedral pseudomorphs of chlorite after garnet that show increasing flattening and streaking closer to the fault. In contrast, garnet-bearing assemblages in the hanging wall show no evidence of retrogression to chlorite. Therefore, peak synmetamorphic rocks must have been thrust over rocks that already had attained peak metamorphism. Hence, the South Newfane thrust may mark an important zone of tectonic shortening of the metamorphic zones. Transposition of S_2, S_3, and S_4 fabrics is so pronounced within the Moretown rocks immediately below (west of) the South Newfane thrust that the $S_{4.5}$ fabric dominates and nearly obliterates earlier fabrics, especially of the F_3 and F_4 folding events.

The last folding event (F_5) occurred after peak metamorphism and is recognized by a widely spaced (3–5 mm), weakly to strongly developed, axial-plane slip or pressure-solution cleavage (S_5) that trends almost due north and dips nearly vertically. F_5 folds tend to be open and west verging and have gentle north- or south-plunging hinge lines and small amplitude to wavelength ratios. F_5 folds are more evident beyond the flanks of F_3 and F_4 dome and basin structures. F_5 folds seem to accommodate late-stage shortening within areas not previously greatly shortened by older Acadian deformation. F_5 folds also locally warp $S_{4.5}$ fabric, the South Newfane fault, and lithologic contacts that are parallel to S_2 and $S_{4.5}$ intersections.

Structures in the North River Igneous Suite and the Cram Hill Formation

The Cram Hill Formation and North River Igneous Suite contain three discrete deformational fabrics. The oldest occurs locally in metavolcaniclastic rocks of the Cram Hill Formation as a weak to moderately developed bedding and parallel foliation (S_0/S_1). This bedding-plane foliation is not associated with a folding event, mineral lineation is absent, and it may have developed from metamorphism due to burial early in the Acadian orogeny. The bedding-parallel foliation ranges in thickness from 1 mm to 10 cm. It is not present in the North River Igneous Suite, even though both mafic and felsic intrusives truncate the metasedimentary and metavolcanic rocks of the Cram Hill Formation.

The dominant foliation in the North River Igneous Suite and Cram Hill Formation is the regionally dominant Acadian $S_{4.5}$ foliation, which contains a prominent northeast-trending mineral lineation. These rocks, as well as older rocks to the west, also contain west-verging to upright, open to isoclinal $F_{4.5}$ folds that commonly have shallow-plunging (5°–25°) hinge lines. $F_{4.5}$ folds occur as open folds in the more competent, massive West Halifax Trondhjemite and massive gneiss (Onwt, Onmg). $S_{4.5}$ fabric development in these massive rocks is typically very weak, in contrast to the strong $S_{4.5}$ fabric development in the less competent, well-layered metasedimentary and metavolcanic units. Most lithologic contacts are concordant with $S_{4.5}$ or a composite S_0/S_1 and $S_{4.5}$ composite foliation. $F_{4.5}$ folds, therefore, have little affect on the map patterns of the major rock units.

Locally, syn- to peak-metamorphic, minor, west-verging to upright, open F_5 folds deform the $S_{4.5}$ foliation and may or may not contain an axial planar, 2- to 5-mm-spaced S_5 crenulation cleavage. These youngest folds also affect the rocks in the Moretown-Rowe Lithotectonic Unit and within the South Newfane thrust zone. All F_5 folds are consistently north trending and almost vertically dipping.

Because the North River Igneous Suite may range in age from Ordovician to Silurian, parts of it could have been subjected to Taconian deformation. However, no typically S_2 fabrics, such as S_2 mylonitic fabric, no F_2-related isoclinal folds, and no southeast-trending mineral lineations were found. F_3 and F_4 axial surfaces, cleavages, and related map-scale axial traces, all of which are effectively transposed into the $S_{4.5}$ orientation within Moretown rocks west of the South Newfane thrust, are not present in rocks east of the thrust. All rocks of the North River Igneous Suite and associated host rocks contain a weakly developed $S_{4.5}$ fabric, but lack the intensely developed S_2, S_3, and S_4 fabrics of the highly strained Moretown rocks. Moreover, the rocks east of the South Newfane thrust also lack the polymetamorphic textures and retrogression of garnet-grade rocks typical of the Rowe and Moretown rocks on the southeast flank of the Sadawga dome. These structural and textural relationships suggest that the rocks of the North River Igneous Suite are younger than the Taconian orogeny, or they were not properly situated in the Taconian orogen to develop F_2. The lack of F_3 or F_4 folds in these rocks suggests that these fold phases were restricted by fault and fold dynamics only to the footwall of the South Newfane fault.

Structures in the Northfield Formation

The weakly developed, bedding-parallel Acadian foliation (S_0/S_1) present in the Cram Hill Formation is also present in the Northfield Formation. Again, it may have developed from static metamorphism due to burial early in the Acadian orogeny.

The Northfield Formation and dikes from the Whitneyville facies of the North River Igneous Suite within the Northfield contain $F_{4.5}$ and F_5 folds identical in magnitude and style as in the North River Igneous Suite and Cram Hill Formation adjacent to the west. The carbonaceous schist locally contains millimeter- to centimeter-scale sandy beds that have a weak foliation, which parallels the bedding. This bedding-parallel fabric is the same as the S_0/S_1 fabric in the Cram Hill Formation. Thus, deformation in the Northfield Formation and in the crosscutting dikes of the North River Igneous Suite must be Acadian, because the Shaw Mountain Formation, equivalent to the stratigraphic base of the Northfield Formation in central Vermont, contains Middle Silurian fossils (Boucot and Thompson, 1963). Mafic intrusive rocks identical to the Whitneyville facies crosscut interbedded sulfidic schists of the Cram Hill and Northfield Formations. Therefore, the North River Igneous Suite is entirely or partly post-Taconian. We found no evidence of a structural or unconformable break between the Cram Hill and Northfield Formations here. Also, F_5 and related S_5 features in the Northfield Formation have a similar style and pervasiveness as in the Moretown rocks to the west. We feel that the deformation in all rocks east of the South Newfane thrust is Acadian and that some of the North River Igneous Suite is younger than the Middle to Late Ordovician Taconian orogeny.

METAMORPHISM

Previous work

Skehan (1961) provided the first petrologic study involving the West Dover and Jacksonville areas. He recognized that garnet-grade assemblages and garnets from pelitic rocks showed a chemical variation that was a function of pressure and temperature conditions rather than changes in rock bulk composition. From petrographic and regional structural studies, Skehan suggested that only one metamorphic event during the Acadian orogeny affected the area.

Variation in amphibole chemistry within the amphibolites produced qualitative evidence for different pressure-facies series for the mafic rocks (Laird and others, 1984; Laird and Albee, 1981). These studies concluded that there was evidence for at least two periods of amphibole growth; the first was a medium to medium-high pressure-facies series of hornblende that was followed by a second growth phase of medium pressure-facies series of hornblende or actinolite growth. Laird and others (1984) suggested that these growth phases were related to a Taconian and then Acadian metamorphic event, or to two discrete phases of Acadian metamorphic growth.

Petrographic observations coupled with thermobarometry indicate that changes in preserved metamorphic mineral assemblages and associated compositions and intensive pressure and temperature conditions took place during Late Silurian to Early Devonian (Acadian) regional metamorphism (Laird and others, 1984; Sutter and others, 1985). Relict Taconian metamorphic mineral assemblages in Ordovician and older pelites were documented from the Jamaica quadrangle (Karabinos, 1984a, b), from the west side of the Athens dome (Rosenfeld and others, 1988), and from the northern part of the Chester dome near Cavendish (Thompson and others, 1977; Armstrong and Tracy, 1991).

Combined structural, metamorphic, and $^{40}Ar/^{39}Ar$ studies in Massachusetts (Sutter and others, 1985; Ratcliffe and others, 1988) and detailed mapping by Ratcliffe throughout western Massachusetts referenced in Zen and others (1983) have noted the existence of Taconian polymetamorphism and deformation in the Green Mountain and Berkshire massifs and their cover rocks. Therefore, the Ordovician and older rocks of the West Dover and Jacksonville quadrangles must have been subjected to Taconian metamorphism and deformation. However, before recent studies of Burton (1991), Karabinos (1984a, b), Ratcliffe and others (1992), Ratcliffe (1993a), and by us in this map, these Taconian structures were unrecognized. Essentially all Ordovician and older rocks within this belt contain structures and relict metamorphic mineral compositions inherited during the Taconian metamorphism. However, all workers agree that the dominant metamorphic effects preserved in these rocks are from the Acadian orogeny.

Recent work by Armstrong (1992, 1993b), Armstrong and Tracy (1991), and Ratcliffe and others (1992) has integrated petrologic, thermobarometric, and structural data to create regional Taconian and Acadian tectonic interpretations and models of Acadian dome evolution. Petrographic results suggest that Acadian metamorphic (pressure and temperature) conditions in this region appear to be uniform because rocks throughout the area are at garnet grade, even though not all rocks contain garnet due to original deficiencies in bulk chemical composition (for example, quartzite, albitic granofels, amphibolite, and ultramafic rocks). Thermobarometric results, however, confirm the conclusions of Skehan (1961) that pressure and temperature increased from west to east. These ranged from 465°C and 6.5 kilobars on the west side of the Sadawga dome in the Readsboro quadrangle to 545°C and 8.2 kilobars (see table 8) in the Rowe Schist proper on the east side of the Sadawga dome (Armstrong and Tracy, 1991; Ratcliffe and others, 1992).

Mineral assemblages

Metamorphosed sedimentary rock types within this region include quartzite (sandstone), quartz-plagioclase granofels (arenite), quartz-plagioclase-mica schist and gneiss (psammite, wacke), quartz-plagioclase-mica-garnet and aluminum-rich quartz-mica-garnet schist and phyllite (pelite), and garnet-hornblende schist (calcic pelite, calc-silicate rock). Metamorphosed igneous rock types include hornblende and (or) actinolite-bearing amphibolite (basalt), chlorite-epidote greenstone (basalt, volcaniclastic rocks), and quartz-plagioclase-mica±potassium-feldspar gneiss (felsic volcanic rock, trondhjemite).

Although all rocks have some compositional variation, the pelitic rocks have the greatest range of phase and compositional variation due to original bulk chemical composition and pressure and temperature conditions during metamorphism. Most pelitic rock types here contain garnet, biotite, chlorite, white mica, plagioclase, quartz, and minor amounts of ilmenite, rutile, and magnetite. Garnet is almandine rich, and plagioclase composition ranges from An_{20} to An_{27}; both are typical of garnet-grade metamorphic conditions. Other pelitic mineral assemblages exist in schist containing chloritoid, garnet, muscovite, paragonite, chlorite, quartz, and accessory amounts of ilmenite and, locally, rutile that occurs as thin layers within the large-garnet schist of the Rowe Schist proper (Ꞓrgs). Paragonite may be present instead of plagioclase in rocks of aluminous bulk composition where biotite is also absent. Another pelitic schist (Ꞓrs) in the Rowe belt contains magnetite, biotite, muscovite, chlorite, and quartz. Chlorite is anomalously rich in magnesium (sample M–3 in table 7) compared with other more typical pelite units (samples M–1 and M–2). This Mg-rich Ꞓrs unit occurs in close proximity to ultramafic dunite (OZd) and amphibolite (Ꞓrba) and, perhaps, originated in either an oceanic or rift setting.

Garnet inclusion fabrics

Samples of garnet-bearing rocks from the West Dover and Jacksonville quadrangles were studied to determine the relationship of overgrowth structures to S_2 fabric, S_2 extension lineation, and, if possible, to F_3 and F_4 fold hinge lines and associated S_3 and S_4 axial surfaces and crenulation cleavages. Without exception, garnets were overgrown on S_2-related microfolds and extension lineations and showed no syntectonic rotation or growth in the S_2 fabrics. Hence, there was no evidence of syntectonic Taconian growth of garnet.

False-color X-ray emission images of garnet porphyroblasts surrounded by matrix (sample nos. 1 and 2, table 4) (Armstrong, 1993b) have revealed a dominant foliation, defined by ilmenite, muscovite, biotite, and chlorite matrix grains, that is continuous with inclusions in the garnet. The inclusion trails are planar within the garnet cores and moderately crenulated along their rims (Armstrong, 1993b). Axial surfaces of the crenulations included in the garnets are coplanar to S_4 crenulation surfaces within the matrix. Large chlorite spears 3 to 6 mm long parallel the S_2 extension lineation. Garnets typically overgrow these chlorite spears. The chlorite may have developed by retrogression of earlier Taconian garnets. These crystalloblastic textures indicate that garnet grew late in the structural evolution during formation of the S_4 crenulation event. Because the F_4 folds are responsible for much of the domal-stage folding, peak metamorphic conditions were coeval with dome formation.

Thermobarometry

Estimates of Acadian metamorphic temperatures and pressures during peak conditions were obtained using several exchange and net transfer geothermobarometers (table 8). Mineral compositions of porphyroblasts and matrix grains from several different pelitic rock types were obtained by quantitative and qualitative microprobe analyses at the Virginia Polytechnic Institute and State University. The rocks included quartz-muscovite-garnet-biotite-plagioclase-chlorite-ilmenite±rutile metapelite (sample number M–4), quartz-garnet-muscovite-calcic paragonite-chlorite-rutile-ilmenite metapelite (sample M–5), and garnet-chloritoid-chlorite-muscovite-calcic paragonite metapelite (sample M–6). Selection of points for analyses was strongly influenced by examination of false-color analog X-ray images of individual porphyroblasts, matrix grains, and selected regions of thin sections including both small porphyroblasts and surrounding matrix.

Individual pressure and temperature estimates were compared to those produced by applying mineral compositions from those specific assemblages using the Ge0calc phase equilibria program of Berman (1988). These three samples were chosen because they had a well-constrained intersection of several different equilibria in pressure and temperature space that agreed with pressure and temperature estimates determined from the thermobarometers. Exchange and net transfer thermobarometers yielded a temperature range from 500 to 545°C and a pressure range from 7.0 to 8.2 kilobars.

Pressure and temperature must have increased eastward and predated the development of regional domal structures because of differential crustal loading that caused Acadian metamorphism (Armstrong, 1992; Ratcliffe and others, 1992). Acadian garnet-grade mineral growth and concurrent domal development must have occurred at midcrustal depths of 25 to 29 km beneath an eastward-thickening tectonic wedge.

Metamorphic geochronology

$^{40}Ar/^{39}Ar$ mineral ages from the area between the Green Mountain massif and the Athens dome indicate that closure temperatures of 500°C for hornblende were exceeded in the Acadian orogeny. Temperature data (table 8) indicate values of 500 to 540°C. Two hornblende ages from this area are from the Rowe Schist amphibolite (Ꞓrba) exposed in roadcuts on Route 9 at the crest of the ridge northeast of Mount Olga in the Jacksonville quadrangle and from the Turkey Mountain Member at the school on Route 100, 1 mile north of the West Dover quadrangle border. At the former location Samuel Mukasa obtained a 355.2±4.8 Ma plateau age for hornblende (Sutter and others, 1985, sample GM–20). Textures in the rock sample actually dated indicate that hornblende grew late and across both the S_2 foliation and the F_4 crenulation cleavage. The age obtained suggests that maximum temperatures here may have occurred later than in the Townshend quadrangle where Laird (1991) reported a plateau age of 376 Ma on well-lineated hornblende lying in what we map as the regional S_4 crenulation cleavage. From the latter locality (GM–28H) in the Jamaica quadrangle, Mukasa obtained a hornblende plateau age of 376±5 Ma; here the hornblende lies in the dominant S_2 foliation.

SUMMARY OF TECTONIC EVENTS

Evolution of the Middle Proterozoic rocks is summarized in the Jamaica and Townshend quadrangles (Ratcliffe, 1997). Clastic deposition and the extrusion of alkalic basalt of the Hoosac Formation began in a subsiding probably marine rift environment. Rifting led to the eventual rupturing of the Laurentian continent to form the Iapetus Ocean, which existed from the Late Proterozoic to Ordovician(?). By the end of Hoosac deposition, basalt extrusions were like E-type MORB (fig. 4) suggesting that continental separation had begun. Feldspathic and aluminous rocks of the Rowe(?) Schist and Rowe Schist proper were deposited in a marine setting where basalts similar to N-type MORB were erupted. The presence of oceanic-like basalts derived from a depleted mantle source suggests that drift-stage subsidence occurred by the time of Rowe deposition.

At some time following deposition of the Rowe, coarse feldspathic and quartzose sediments of the Moretown Formation were deposited, perhaps in a fore arc, in front of an advancing accretionary prism. Sediments probably were recycled from rocks of the accretionary prism and were mixed with island-arc volcanics and volcaniclastic deposits. Inclusions of ultramafic rock within the Rowe(?) Schist, Rowe Schist proper, and Moretown Formation probably are tectonic inclusions derived from olistolithics or ophiolitic slabs derived from ocean floor mantle of the destructing Iapetus Ocean.

Final assembly of the Hoosac, Rowe, and Moretown packages of rocks accompanied the collision of an island-arc terrane with Laurentian in the Middle to Late Ordovician. As shortening continued during the Taconian orogeny, the continental margin and overlying tectonic cover were imbricated along synmetamorphic thrust faults of the F_2–S_2 generation in medium- to high-grade Barrovian metamorphic conditions. Accumulation of these imbricate thrust stacks completed assembly of the Mount Snow, Wilmington, and Moretown-Rowe Lithotectonic Units.

Conditions immediately following the Taconian orogeny and the nature of the transition into the Acadian orogeny are imperfectly known. Interpretations require more specific data than we have at present about the rocks of the South Newfane Lithotectonic Unit.

Several origins are possible for the rocks in the South Newfane Lithotectonic Unit. The Cram Hill Formation may represent euxinic deposits within a restricted fore-arc setting east of zones affected by Taconian deformation, or the Cram Hill may have been deposited entirely after the Taconian orogeny. Mafic rocks, including the dike and sill complex at Branch Brook and the West Halifax Trondhjemite, may have intruded either in an oceanic or a transitional continental arc setting. This igneous activity may have occurred late in the Taconian orogeny in a suprasubduction-zone setting and, hence, the rocks were protected from deformation. Alternately, the igneous activity may have resulted from partial mantle melts or assimilated continental crustal melts formed in a rift or relaxation stage following Taconian subduction. The similarity of rocks of the Cram Hill Formation, Moretown Formation, and North River Igneous Suite with metasedimentary and meta-igneous Ordovician rocks of the Bronson Hill belt of New Hampshire, generally interpreted as arc volcanic and plutonic rocks (Leo, 1991), suggests that an arc origin is likely. Intrusion of the North River Igneous Suite is, in part, coeval with deposition of the lower part of the Northfield Formation, and, therefore, it is linked to the paleotectonic setting of the Silurian and Devonian rocks of the Connecticut Valley belt to the east.

Acadian metamorphism in this region may have begun in response to loading by an eastward-thickening tectonic wedge of rocks. The bedding-parallel S_0/S_1 foliation in the Cram Hill and Northfield Formations may have formed by burial metamorphism at this time. The first recognized Acadian F_3 and F_4 deformations produced low-amplitude fold-interference dome structures, the Rayponda and Sadawga domes. Dome development corresponded with regional block uplift that brought the rocks to shallower crustal levels corresponding to depths of 25 to 29 km during attainment of peak-temperature conditions. Following initial development of the Rayponda and Sadawga domes and attainment of the Acadian peak-temperature assemblage at approximately 395 to 390 Ma, the rocks cooled through their hornblende-blocking temperatures of 500°C at around 385 Ma. All this preceded development of the South Newfane thrust, which bought the South Newfane Lithotectonic Unit into contact with the Moretown-Rowe Lithotectonic Unit at around 375 to 370 Ma, which was synchronous with the development of $F_{4\,5}$ folds. This loading event and consequent heating caused partial to full resetting of argon systematics in lower plate rocks near the fault. Lastly, regional, late-stage shortening (F_5) may have been partly responsible for the formation of domes farther east.

REFERENCES CITED

Aleinikoff, J.N., and Karabinos, P., 1990, Zircon U-Pb data for the Moretown and Barnard volcanic members of the Missisquoi Formation and a dike cutting the Standing Pond Volcanics, southeastern Vermont, *in* Slack, J.F., ed., Summary results of the Glens Falls CUSMAP project, New York, Vermont, and New Hampshire: U.S. Geological Survey Bulletin 1887, p. D1–D10.

Anders, Edward, and Ebihara, Mitsuru, 1982, Solar-system abundances of the elements: Geochemica et Cosmochimica Acta, v. 46, no. 11, p. 2262–2380.

Armstrong, T.R., 1992, Progressive evolution of Acadian dynamothermal events in southern Vermont; Evidence for time transgressive dome development: Geological Society of America Abstracts with Programs, v. 24, no. 3, p. 4.

——1993a, Intrusive relationships within the Barnard Gneiss of southern Vermont; Lithodemic constraints on Ordovician arc tectonics: Geological Society of America Abstracts with Programs, v. 25, no. 2, p. 3.

——1993b, Structural and petrologic evolution of Acadian dome structures in southern Vermont: Blacksburg, Virginia Polytechnic Institute and State University, Ph.D. thesis, 189 p.

——1994, Bedrock geology of the Moretown Formation, North River Igneous Suite and associated metasedimentary/metavolcanic rocks of the Connecticut Valley belt, Brattleboro and Newfane 7.5 x 15 minute quadrangles, Windham County, Vermont: U.S. Geological Survey Open-File Report 94–247, 27 p., 2 sheets.

Armstrong, T.R., and Tracy, R.J., 1991, Tectonometamorphic evolution of Acadian domes in southern Vermont: Geological Society of America Abstracts with Programs, v. 23, no. 1, p. 3.

Berman, R.G., 1988, Internally consistent thermodynamic data for minerals in the system Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-SiO_2-TiO_2-H_2O-CO_2: Journal of Petrology, v. 29, no. 22, p. 445–522.

——1990, Mixing properties of Ca-Mg-Fe-Mn garnets: American Mineralogist, v. 75, no. 3–4, p. 328–344.

Bohlen, S.R., and Liotta, J.J., 1986, A barometer for garnet amphibolites and garnet granulites: Journal of Petrology, v. 27, no. 5, p. 1025–1034.

Bothner, W.A., and Laird, Jo, 1985, Are glaucophane- and omphacite-bearing mafic rocks in north-central Vermont olistoliths in a mélange?: Geological Society of America Abstracts with Programs, v. 17, no. 1, p. 6.

Boucot, A.J., and Thompson, J.B., Jr., 1963, Metamorphosed Silurian brachipods from New Hampshire: Geological Society of America Bulletin, v. 74, no. 11, p. 1313–1333.

Burton, W.C., 1991, Bedrock geologic map of the Woodford quadrangle, Bennington and Windham Counties, Vermont: U.S. Geological Survey Geologic Quadrangle Map GQ–1687, scale 1:24,000.

Burton, W.C., Kunk, M.J., and Ratcliffe, N.M., 1990, Muscovite and microcline $^{40}Ar/^{39}Ar$ ages from the Taconian- and Acadian-overprinted central Green Mountain massif, Vermont: Geological Society of America Abstracts with Programs, v. 22, no. 2, p. 7.

——1991, Microcline and biotite $^{40}Ar/^{39}Ar$ ages and their bearing on the Taconian and Acadian thermal history of the central Green Mountain massif, Vermont: Geological Society of America Abstracts with Programs, v. 23, no. 1, p. 13.

Chang, P.H., Ern, E.H., Jr., and Thompson, J.B., Jr., 1965, Bedrock geology of the Woodstock quadrangle, Vermont: Vermont Geological Survey Bulletin 29, 65 p., scale 1:62,500.

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

Currier, L.W., and Jahns, R.H., 1941, Ordovician stratigraphy of central Vermont: Geological Society of America Bulletin, v. 52, no. 9, p. 1487–1512.

Doll, C.G., Cady, M.W., Thompson, J.B., Jr., and Billings, M.P., 1961, Centennial geologic map of Vermont: Montpelier, Vermont Geological Survey, scale 1:250,000.

Ferry, J.M., and Spear, F.S., 1978, Experimental calibration of the partitioning of Fe and Mg between biotite and garnet: Contributions to Mineralogy and Petrology, v. 66, no. 2, p. 113–117.

Ghent, E.D., and Stout, M.Z., 1981, Geobarometry and geothermometry of plagioclase-biotite-garnet-muscovite assemblages: Contributions to Mineralogy and Petrology, v. 76, no. 1, p. 92–97.

Hatch, N.L., Jr., 1991, Revisions to the stratigraphy of the Connecticut Valley trough, eastern Vermont, *in* Stratigraphic Notes, 1989–90: U.S. Geological Survey Bulletin 1935, p. 5–7.

Hatch, N.L., Jr., and Hartshorn, J.H., 1968, Geologic map of the Heath quadrangle, Massachusetts and Vermont: U.S.

Geological Survey Geologic Quadrangle Map GQ–735, scale 1:24,000.

Hatch, N.L., Jr., and Stanley, R.S., 1988, Post-Taconian structural geology of the Rowe-Hawley zone and the Connecticut Valley belt west of the Mesozoic basins, *in* Hatch, N.L., Jr., ed., The bedrock geology of Massachusetts: U.S. Geological Survey Professional Paper 1366, p. C1–C36.

Hatch, N.L., Jr., Chidester, A.H., Osberg, P.H., and Norton, S.A., 1966, Redefinition of the Rowe Schist in northwestern Massachusetts, *in* Cohee, G.V., and West, W.S., eds., Changes in stratigraphic nomenclature by the U.S. Geological Survey 1965: U.S. Geological Survey Bulletin 1244–A, p. A33–A35.

Hepburn, J.C., Trask, N.J., Rosenfeld, J.L., and Thompson, J.B., Jr., 1984, Bedrock geology of the Brattleboro quadrangle, Vermont-New Hampshire: Vermont Geological Survey Bulletin 32, 162 p., scale 1:62,500.

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

Hoffman, M.A., and Walker, David, 1978, Textural and chemical variation of olivine and chrome spinel in the East Dover ultramafic bodies, south-central Vermont: Geological Society of America Bulletin, v. 89, no. 5, p. 699–710.

Karabinos, Paul, 1984a, Deformation and metamorphism on the east side of the Green Mountain massif in southern Vermont: Geological Society of America Bulletin, v. 95, no. 5, p. 584–593.

——1984b, Polymetamorphic garnet zoning from southeastern Vermont: American Journal of Science, v. 284, no. 9, p. 1008–1025.

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

Laird, Jo, 1991, Acadian metamorphism about the Taconian line, southeastern Vermont: Geological Society of America Abstracts with Programs, v. 23, no. 1, p. 55.

Laird, Jo, and Albee, A.L., 1981, Pressure, temperature, and time indicators in mafic schist; Their application to reconstructing the polymetamorphic history of Vermont: American Journal of Science, v. 281, no. 2, p. 127–175.

Laird, Jo, Lanphere, M.A., and Albee, A.L., 1984, Distribution of Ordovician and Devonian metamorphism in mafic and pelitic schists from northern Vermont, *in* Misra, K.C., and others, eds., Mafic and ultramafic rocks of the Appalachian orogen: American Journal of Science, v. 284, no. 4–5, p. 376–413.

Leo, G.W., 1991, Oliverian domes, related plutonic rocks, and mantling Ammonoosuc Volcanics of the Bronson Hill anticlinorium, New England Appalachians: U.S. Geological Survey Professional Paper 1516, 92 p.

Pearce, J.A., 1982, Trace element characteristics of lavas from destructive plate boundaries, *in* Thorpe, R.S., ed., Andesites; Orogenic andesites and related rocks: New York, John Wiley and Sons, p. 525–548.

Pearce, J.A., and Cann, J.R., 1973, Tectonic setting of basic volcanic rocks determined using trace element analyses: Earth and Planetary Science Letters, v. 19, no. 2, p. 290–300.

Pearce, J.A., and Norry, M.J., 1979, Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks: Contributions to Mineralogy and Petrology, v. 69, no. 1, p. 33–47.

Ratcliffe, N.M., 1991a, Chemistry and tectonic setting of metabasalts of the Hoosac Formation, southern Vermont: Geological Society of America Abstracts with Programs, v. 23, no. 1, p. 122.

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

——1993a, Bedrock geologic map of the Mount Snow and Readsboro quadrangles, Bennington and Windham Counties, Vermont: U.S. Geological Survey Miscellaneous Investigations Series Map I–2307, scale 1:24,000.

——1993b, Searching for the root zone(s) of the Taconic allochthons; Leaving no stone unturned: Geological Society of America Abstracts with Programs, v. 25, no. 2, p. 72.

——1994, Changes in stratigraphic nomenclature in the eastern cover sequence in the Green Mountain, Vermont, from Ludlow to West Bridgewater, Vermont, *in* Stratigraphic Notes, 1992: U.S. Geological Survey Bulletin 2060, p. 1–10, scale 1:100,000.

——1997, Bedrock geologic map of the Jamaica and part of the Townshend quadrangles, Windham and Bennington Counties, Vermont: U.S. Geological Survey Miscellaneous Investigations Series Map I–2453, scale 1:24,000.

Ratcliffe, N.M., Burton, W.C., Sutter, J.F., and Mukasa, S.A., 1988, Stratigraphic, structural geology, and thermochronology of the northern Berkshire massif and southern Green Mountains, Trips A–1 and B–1, *in* Bothner, W.A., ed., Guidebook for field trips in southwestern New Hampshire, southeastern Vermont, and north-central Massachusetts: New England Intercollegiate Geological Conference, 80th Annual Meeting, Keene, N.H., Oct. 14–16, 1988, pt. 1, p. 1–31 and pt. 2, p. 126–135.

Ratcliffe, N.M., Aleinikoff, J.N., Burton, W.C., and Karabinos, P.A., 1991, Trondhjemitic 1.35–1.3 Ga gneisses from the Mount Holly Complex of Vermont; And evidence for an Elzevirian event in the Grenville province of the U.S. Appalachians: Canadian Journal of Earth Sciences, v. 28, no. 1, p. 77–93.

Ratcliffe, N.M., Armstrong, T.R., and Tracy, R.J., 1992, Tectonic-cover basement relations and metamorphic conditions of formation of the Sadawga, Rayponda, and Athens domes, southern Vermont, *in* Robinson, Peter, and Brady, J.B., eds., Guidebook for field trips in the Connecticut Valley region of Massachusetts and adjacent states: New England Intercollegiate Geological Conference, 84th Annual Meeting, Amherst, Mass., Oct. 9–11, 1992, v. 2, p. 257–290.

Ratcliffe, N.M., Potter, D.B., and Stanley, R.S., 1993, Bedrock geologic map of the Williamstown and North Adams quadrangles, Massachusetts and Vermont, and part of the Cheshire quadrangle, Massachusetts: U.S. Geological Survey Miscellaneous Investigations Series Map I–2369, scale 1:24,000.

Ratcliffe, N.M., Walsh, G.F., and Aleinikoff, J.N., 1997, Basement, metasedimentary, and tectonic cover of the Green Mountain massif and western flank of the Chester dome, Trip C6 *in* Grover, T.W., Mango, H.N., and Hasenohr, E.J., eds., Guidebook to field trips in Vermont and adjacent New Hampshire and New York: New England Intercollegiate Geological Conference, 89th Annual Meeting, Sept. 19–21, 1994, Killington-Pico region, Vermont, p. C6-1–C6-54.

Ratcliffe, N.M., Harris, A.G., and Walsh, G.J., in press, Tectonic and regional metamorphic implications of the discovery of Middle Ordovician conodonts in cover rocks east of the Green Mountain massif, Vermont: Canadian Journal of Earth Sciences.

Richardson, C.H., 1924, The terranes of Bethel, Vermont: Vermont State Geologist, 14th Annual Report, 1923–1924, p. 76–96.

Rosenfeld, J.L., Christensen, J.N., and DePaolo, D.J., 1988, Snowball garnets revisited, southeastern Vermont, *in* Bothner, W.A., ed., Guidebook for field trips in southwestern New Hampshire, southeastern Vermont and north-central Massachusetts: New England Intercollegiate Geological Conference, 80th Annual Meeting, Keene, N.H., Oct. 14–16, 1988, pt. 2, p. 223–240.

Skehan, J.W., 1961, The Green Mountain anticlinorium in the vicinity of Wilmington and Woodford, Vermont: Vermont Geological Survey Bulletin 17, 159 p., scale 1:62,500.

Stanley, R.S., and Hatch, N.L., Jr., 1988, The pre-Silurian geology of the Rowe-Hawley zone, *in* Hatch, N.L., Jr., ed., The bedrock geology of Massachusetts: U.S. Geological Survey Professional Paper 1366–A, p. A1–A39.

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

Sutter, J.F., and Hatch, N.L., Jr., 1985, Timing of metamorphism in the Rowe-Hawley zone, western Massachusetts: Geological Society of America Abstracts with Programs, v. 17, no. 1, p. 65.

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

Thompson, A.B., Tracy, R.J., Lyttle, P.T., and Thompson, J.B., Jr., 1977, Prograde reaction histories deduced from compositional zonation and mineral inclusions in garnet from the Gassetts Schist, Vermont: American Journal of Science, v. 277, no. 9, p. 1152–1167.

Walsh, G.J., and Aleinikoff, J.N., 1999, U-Pb zircon age of metafelsite from the Pinney Hollow Formation; Implications for development of the Vermont Appalachians: American Journal of Science, v. 299, no. 2.

Walsh, G.J., and Ratcliffe, N.M., 1993, Lithostratigraphy and internal structure of the Ottauquechee Formation, southern Vermont: Geological Society of America Abstracts with Programs, v. 25, no. 2, p. 87.

Wood, D.A., 1980, The application of a Th–Hf/3–Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province: Earth and Planetary Science Letters, v. 50, no. 1, p. 11–30.

Zen, E-an, ed., Goldsmith, Richard, Ratcliffe, N.M., Robinson, Peter, and Stanley, R.S., comp., 1983, Bedrock geologic map of Massachusetts: Reston, Va., U.S. Geological Survey Special Geologic Map, scale 1:250,000.

TABLES 1–8 FOLLOW

Table 1.—Major-oxide composition, in weight percent, of metabasalt from the Hoosac Formation

[Samples arranged in ascending stratigraphic position. Sample numbers correspond to those in figure 2. D or J field number prefix refers to West Dover or Jacksonville quadrangle. Determined by X-ray fluorescence (XRF) spectroscopy, supplemented by conventional analysis for H_2O, CO_2, and FeO. Hezekiah Smith, C.C. Prosser, J.E. Taggart, A. Bartel, and D.F. Siems, analysts]

Map unit	€Zhtm$_1$				€Zhtm$_2$			€Zhtm$_3$		
Sample no.	8	9	10	11	19	20	21	27	29	30
Field no.	D27–12	J2–20	J6–11	J13–6A,B	D8002	D7974A	D7974B	D4–55	J2–4	D8004
SiO_2	48.20	46.8	47.2	43.8	47.10	44.80	45.50	48.89	50.7	48.30
Al_2O_3	13.09	12.0	13.0	15.0	14.59	15.30	15.09	14.20	13.3	14.70
Fe_2O_3	4.63	6.0	6.1	6.8	5.52	6.17	6.23	4.83	4.4	5.13
FeO	9.60	10.5	9.5	8.2	7.90	7.40	6.90	7.79	9.0	7.79
MgO	6.03	5.64	6.21	3.64	6.91	6.88	7.19	7.34	6.71	7.02
CaO	9.42	9.74	7.97	12.56	10.59	13.77	13.20	10.50	9.77	10.59
Na_2O	2.70	1.82	3.99	2.77	2.60	1.67	2.14	3.02	2.37	2.84
K_2O	.90	.70	.22	.38	.18	.19	.17	.29	.29	.22
H_2O^+	.74	1.5	1.3	1.5	1.30	.61	.46	.60	1.7	.30
H_2O^-	.03	.05	.08	.09	.10	.10	.11	.06	.08	.09
TiO_2	2.95	4.23	3.99	4.73	2.16	2.16	2.08	1.35	1.37	1.84
P_2O_5	.79	.70	.65	.53	.19	.15	.16	.13	.09	.18
MnO	.24	.25	.20	.26	.22	.20	.20	.20	.23	.19
CO_2	.00	.01	.01	.02	.00	.03	.03	.10	.07	.00
Total	99.32	99.94	100.42	100.28	99.36	99.43	99.46	99.30	100.08	99.19

Description of Samples

8. D27–12; fine-grained metabasalt? sill or lava flow at base of Hoosac Formation; Mt. Snow airport.
9. J2–20; thin amphibolite in albitic granofels; 0.6 km southeast of Spruce Lake.
10. J6–11; massive amphibolite near base of Hoosac Formation; 2 km east of Wilmington.
11. J13–6; average of two samples near base of Hoosac Formation: A, massive, coarse hornblende-epidote amphibolite and B, fine-grained amphibolite; 2.6 km east of Sadawga Lake.
19. D8002; metabasalt from middle? of Hoosac Formation; 0.9 km southwest of Johnson Hill.
20, 21. D7974A and D7974B; metabasalt from middle of Hoosac Formation; stream exposure 1.4 km southeast of West Dover.
27. D4–55; amphibolite from upper part of Hoosac Formation; 0.6 km east of West Dover.
29. J2–4; thinly laminated amphibolite near top of Hoosac Formation; 1.4 km southwest slope of Mount Olga.
30. D8004; amphibolite from upper part of Hoosac Formation; 3.9 km southeast of West Dover.

Table 2.—Concentrations of rare-earth elements and selected trace elements in metabasalt from the Hoosac Formation

[Samples arranged in ascending stratigraphic position. Sample numbers correspond to those in figures 2–4 and in table 1. D or J field number prefix refers to West Dover or Jacksonville quadrangle]

Map unit	€Zhtm$_1$					€Zhtm$_2$			€Zhtm$_3$	
Sample no.	8	9	10	11A	11B	19	20	21	29	30
Field no.	D27–12	J2–20	J6–11	J13–6A	J13–6B	D8002	D7974A	D7974B	J2–4	D8004
Replicates	1	1	1	1	1	1	1	1	1	1

Instrumental neutron activation analysis (INAA)
[Concentrations are given in the units shown in the first column; error limits are one standard deviation by counting statistics. Sample 27 not analyzed. G.A. Wandless and James Mee, analysts]

	8	9	10	11A	11B	19	20	21	29	30
Sc (ppm)	30.8±2%	39.0±2%	34.2±2%	29.6±2%	36.0±2%	42.0±2%	40.5±2%	39.4±2%	49.9±2%	41.6±2%
Cr (ppm)	126±3%	3.1±25%	21.9±5%	3.1±18%	5.5±24%	250±2%	280±2%	270±2%	65.9±3%	257±2%
Fe (%)	11.03±2%	12.51±2%	11.91±2%	10.67±2%	12.52±2%	10.48±2%	10.62±2%	10.13±2%	10.42±2%	9.98±2%
Co (ppm)	41.9±2%	43.4±2%	40.3±3%	19.3±2%	35.3±2%	49.7±2%	50.8±2%	52.7±2%	48.4±2%	49.3±2%
Zn (ppm)	105.0±3%	148±6%	147±3%	54.3±5%	128±5%	114±4%	100±4%	103±4%	118±6%	107±4%
La (ppm)	25.7±3%	25.1±6%	24.9±5%	16.5±5%	19.7±6%	7.64±4%	6.38±4%	6.87±4%	3.98±5%	8.0±6%
Ce (ppm)	57.8±3%	56.0±3%	53.7±5%	36.8±2%	42.8±2%	18.2±4%	16.2±4%	15.5±4%	9.5±6%	18.8±4%
Nd (ppm)	35.5±5%	33.1±9%	31.2±6%	23.3±5%	24.9±8%	14.0±8%	11.1±13%	11.0±14%	9.2±12%	12.2±8%
Sm (ppm)	9.65±3%	9.75±2%	9.05±2%	6.72±2%	7.43±2%	4.39±2%	4.13±2%	4.07±2%	2.94±2%	4.11±3%
Eu (ppm)	2.94±3%	3.01±3%	2.78±3%	2.54±3%	2.51±3%	1.51±3%	1.56±3%	1.40±3%	1.08±4%	1.38±3%
Tb (ppm)	1.44±3%	1.42±4%	1.44±3%	1.047±3%	1.16±3%	.91±4%	.88±7%	.83±4%	.786±4%	.84±4%
Yb (ppm)	3.67±5%	3.75±4%	4.24±4%	2.77±4%	3.00±5%	3.09±4%	2.72±6%	2.93±5%	3.56±4%	2.98±4%
Lu (ppm)	.521±3%	.491±4%	.544±4%	.392±4%	.413±5%	.431±4%	.370±4%	.380±4%	.519±4%	.421±4%
Hf (ppm)	6.73±3%	6.56±3%	6.61±3%	4.30±3%	5.11±3%	2.85±3%	2.52±3%	2.45±4%	1.91±4%	2.50±4%
Ta (ppm)	1.71±3%	1.72±3%	1.83±3%	1.29±3%	1.83±3%	.58±9%	.577±5%	.542±5%	.233±10%	.57±6%
Au (ppb)	<9	<13	<3	<7	<8	<1	<2	6.1±32%	<12	<1
Th (ppm)	2.33±4%	2.26±5%	2.42±4%	1.14±6%	1.21±7%	.58±11%	.34±17%	.36±16%	.30±32%	.51±18%
U (ppm)	.72±14%	.54±13%	.35±13%	.28±26%	.38±12%	<.2	<.2	<.2	<.4	.24±23%

Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, except as noted
[Concentrations are in parts per million. J.R. Evans, analyst]

Sample no.	8	9	10	11A	11B	19	20	21	27	29	30
Nb	24	18	22	16	24	13*	<10	4.6*	11	4.2*	18
Rb	22	23	8	14	9	5	<2	5	13	11	8
Sr	301	536	157	598	139	326	373	366	175	124	177
Zr	271	281	252	178	191	104	87	83	74	63	100
Y	41	41	45	33	35	34	21	23	33	30	36
Ba	288	165	42	39	39	12	17	17	77	42	55
Ce	82	63	55	40	52	24	19	23	9	22	14
Cu	28	36	22	16	5	43	111	111	43	154	23
Ni	63	31	34	10	7	91	125	113	82	57	79
Zn	86	130	127	50	104	90	82	76	96	98	84
Cr	139	<20	<20	<20	<20	271	313	299	161	55	293

*Determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES); M.W. Doughten, analyst.

Table 3.—Major-oxide composition, in weight percent, of metabasalt from the Rowe(?) Schist and Rowe Schist proper

[Samples correspond to those in figures 3–5 and in table 4. Determined by X-ray fluorescence (XRF) spectroscopy, supplemented by conventional analysis for H_2O, CO_2, and FeO. Hezekiah Smith, C.C. Prosser, J.E. Taggart, A. Bartel, and D.F. Siems, analysts]

Map unit	€ra?					€rg		€rba			
Field no.	D32–1	D32–5	D32–2A	D32–2B	D32–4	D32–7A	D32–7B	D32–8	D32–9	D32–10	D32–11
Sample no.	1	2	3	4	5	6	7	8	9	10	11
	West Dover quadrangle [Samples in ascending stratigraphic position]										
SiO_2	48.4	51.6	48.6	46.3	44.4	48.7	48.8	49.2	47.9	49.5	50.9
Al_2O_3	13.5	13.7	15.60	14.9	12.0	13.8	13.7	14.2	14.3	14.6	15.1
Fe_2O_3	8.29	4.23	3.87	4.81	4.24	8.15	8.07	3.90	4.72	4.88	2.44
FeO	6.4	7.8	5.7	6.2	11.3	6.7	6.6	9.0	7.9	7.4	7.7
MgO	7.28	7.61	8.37	7.61	11.7	6.57	6.23	7.25	8.46	7.42	8.24
CaO	10.70	9.22	12.60	14.20	9.43	9.06	9.44	10.50	10.30	10.50	9.25
Na_2O	2.03	1.97	2.35	1.97	1.66	3.85	3.56	1.97	1.86	2.93	3.59
K_2O	.13	.20	.18	.26	.84	.21	.23	.20	.33	.24	.19
H_2O^+	2.0	1.9	2.3	2.0	2.7	1.3	1.5	1.6	2.4	1.6	1.7
H_2O^-	.09	.08	.10	.10	.08	.10	.07	.08	.15	.06	.07
TiO_2	1.6	1.25	.71	.94	1.12	1.6	1.61	2.08	1.8	1.07	1.07
P_2O_5	.13	.23	.06	.08	<.05	.12	.12	.09	.19	.09	.11
MnO	.19	.19	.18	.19	.30	.19	.21	.23	.20	.25	.20
CO_2	<.01	<.01	.22	1.2	.57	.18	.47	.06	.09	.19	<.01
Total	100.74	99.98	100.84	100.76	100.34	100.53	100.61	100.36	100.60	100.73	100.56

Description of Samples

1. D32-1; fine-grained, needled garnet amphibolite interlayered with lustrous Rowe(?) Schist (€r?); 1.5 km north of West Dover quadrangle border and 1 km north of Podunk; Jamaica quadrangle.
2. D32-5; dark-green, fine-grained needle amphibolite; knob 1.2 km southwest of Dover.
3, 4. D32–2A and B; fine-grained, well-foliated amphibolite; fresh excavations 0.7 km northwest of top of Cooper Hill.
5. D32–4; coarse-grained hornblende-garnet-plagioclase metagabbro(?), possibly a cumulate; east base of Cooper Hill.
6, 7. D32–7A and B; fine-grained, well-foliated, greenish-gray chlorite amphibolite containing small disseminated grains of ankerite; road junction 1.5 km north of Goose City.
8. D32–8; dark-green, glistening, fine-grained needled-hornblende amphibolite interlayered with large-garnet schist (€rgs); 1.7 km northwest of Elwin Meadow.
9. D32–9; dark-green, glistening, fine-grained needled-hornblende amphibolite similar to D32–8; 1.3 km northwest of Elwin Meadow.
10. D32–10; dark-green to black, fine-grained needled-hornblende amphibolite; 0.5 km west of Stratton Hill.
11. D32–11; dark-green, fine-grained needled-hornblende similar to D32–10; 2.1 km southwest of Stratton Hill.

Table 3.—Major-oxide composition, in weight percent, of metabasalt from the Rowe(?) Schist and Rowe Schist proper—Continued

[Samples correspond to those in figures 3–5 and in table 4. Determined by X-ray fluorescence (XRF) spectroscopy, supplemented by conventional analysis for H_2O, CO_2, and FeO. Hezekiah Smith, C.C. Prosser, J.E. Taggart, A. Bartel, and D.F. Siems, analysts]

Jacksonville quadrangle
All samples from map unit Ꞓrba

	Southern traverse			Middle traverse				Northern traverse	
Field no.	J37–7A	J37–6	J37–8	J37–3	J37–4A	J37–4B	J37–5	J37–2	J37–1
Sample no.	12	13	14	15	16	17	18	19	20
SiO_2	50.4	47.4	47.0	50.4	46.0	50.9	49.7	41.7	48.1
Al_2O_3	13.8	13.6	15.2	13.0	15.0	13.3	15.0	17.2	16.4
Fe_2O_3	5.2	4.8	4.4	5.9	6.0	5.4	3.4	6.5	3.6
FeO	8.2	7.1	5.8	8.8	7.8	7.2	6.8	7.6	6.0
MgO	7.17	7.5	8.9	6.75	7.49	6.89	8.83	7.38	7.69
CaO	9.66	11.90	13.60	9.63	11.70	10.60	9.83	13.6	12.8
Na_2O	2.36	2.83	2.10	2.23	2.31	2.22	3.52	1.44	2.53
K_2O	.20	.29	.14	.19	.28	.21	.33	.82	.14
H_2O^+	1.6	1.5	2.0	1.6	1.8	1.8	1.8	2.1	1.6
H_2O^-	.06	.03	.12	.07	.07	.07	.09	.08	.06
TiO_2	1.26	1.47	.90	1.62	1.36	1.22	.97	1.31	1.09
P_2O_5	.01	.20	.07	.13	.10	.10	.10	.14	.09
MnO	.23	.21	.17	.25	.23	.22	.19	.21	.17
CO_2	.02	1.40	.01	.01	.13	.22	.01	.44	.01
Total	100.17	100.23	100.41	100.58	100.27	100.35	100.57	100.52	100.28

Description of Samples

12. J37–7A; mylonitic hornblende-epidote amphibolite at contact with Ꞓrfb; 2.6 km southwest of Stickney Hill.
13. J37–6; fine-grained, greenish, well-layered ankerite-chlorite-hornblende amphibolite; freshly blasted exposure; 2.5 km southwest of Stickney Hill.
14. J37–8; highly mylonitic epidote-hornblende amphibolite near contact with Moretown Formation (Omf); 2.7 km southwest of Stickney Hill.
15. J37–3; black, fine-grained needled-hornblende amphibolite; 2.1 km northeast of Hosley Hill.
16, 17. J37–4A and B; dark-green, finely laminated quartz-epidote amphibolite; freshly blasted excavation; 2 km northeast of Hosley Hill. Sample A is channel sample collected over a distance of 1.2 m; sample B is single sample 15 cm thick.
18. J37–5; greenish chlorite-epidote-hornblende amphibolite near contact with Moretown Formation; 3.2 km northeast of Hosley Hill.
19. J37–2; thinly laminated, greenish epidote-quartz-hornblende amphibolite; along Route 9; 1.7 km south of Hogback Mountain in channel sample of 15-cm-thick layer.
20. J37–1; amphibolite; roadcut along Route 9; 1.1 km southeast of Hogback Mountain.

Table 4.—Concentrations of rare-earth and selected trace elements in metabasalts from the Rowe(?) Schist and Rowe Schist proper

[Sample numbers correspond to those in figures 3–5 and in table 3. D or J field number prefix refers to West Dover or Jacksonville quadrangle]

Map unit	€ra?					€rg		€rba			
Sample no.	1	2	3	4	5	6	7	8	9	10	11
Field no.	D32–1	D32–5	D32–2A	D32–2B	D32–4	D32–7A	D32–7B	D32–8	D32–9	D32–10	D32–11
Replicates	2	1	1	1	1	1	1	1	1	1	1
Instrumental neutron activation analysis (INAA) [Concentrations are given in the units shown in the first column; error limits are one standard deviation by counting statistics. G.A. Wandless and James Mee, analysts. Samples arranged in ascending stratigraphic position]											
Sc ppm)	48.9±2%	44.1±2%	41.0±2%	43.0±2%	50.2±2%	50.1±2%	49.2±2%	33.8±2%	34.2±2%	44.9±2%	35.0±2%
Fe (%)	10.62±2%	9.00±2%	7.25±2%	8.21±2%	10.19±2%	10.91±2%	10.46±2%	9.53±2%	9.43±2%	9.18±2%	7.61±2%
La (ppm)	2.82±4%	3.73±4%	2.42±5%	2.87±4%	.90±7%	2.45±5%	2.29±5%	11.7±5%	10.2±4%	2.96±5%	1.78±6%
Ce (ppm)	8.4±4%	8.6±5%	6.8±7%	6.9±7%	3.4±11%	7.2±7%	6.6±9%	26.4±3%	22.6±3%	7.6±6%	6.2±15%
Nd (ppm)	7.4±9%	6.8±18%	4.5±19%	5.0±13%	4.3±17%	9.0±11%	9.0±19%	15.8±6%	14.6±7%	7.5±23%	8.0±17%
Sm (ppm)	3.35±5%	2.65±3%	1.58±4%	2.12±3%	2.02±2%	3.34±3%	3.21±3%	4.46±2%	3.90±2%	2.21±4%	2.29±3%
Eu (ppm)	1.19±3%	.93±4%	.619±5%	.764±4%	.635±4%	1.17±3%	1.16±3%	1.44±3%	1.27±3%	.85±4%	.84±4%
Tb (ppm)	.93±5%	.72±5%	.436±6%	.56±6%	.64±5%	.98±4%	.90±4%	.767±4%	.67±5%	.64±5%	.67±5%
Yb (ppm)	4.16±3%	3.32±6%	2.06±5%	2.67±4%	2.85±4%	4.28±4%	4.14±4%	2.15±5%	2.20±5%	2.98±5%	2.90±4%
Lu (ppm)	.584±4%	.469±5%	.280±5%	.395±4%	.399±4%	.588±5%	.593±4%	.338±4%	.300±8%	.420±5%	.403±4%
Hf (ppm)	2.21±4%	1.81±5%	.95±9%	1.32±5%	1.05±6%	2.37±4%	2.28±4%	2.96±3%	2.55±4%	1.50±5%	1.63±4%
Ta (ppm)	.208±13%	.19±28%	.20±27%	.184±16%	.39±9%	.26±21%	.22±31%	.83±5%	.68±6%	.29±13%	<.2
Au (ppb)	<3	<18	11.5±22%	<4	21.1±12%	<8	<5	<10	<4	<5	<10
Th (ppm)	.39±16%	.38±17%	.36±15%	.40±16%	<.2	<.2	<.2	1.11±6%	.89±7%	.33±18%	<.2
U (ppm)	.19±19%	<.4	<.3	<.4	<.3	<.4	<.4	.30±21%	<.3	<.3	<.4
Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, except as noted [Concentrations are in parts per million. J.R. Evans, analyst]											
Nb*	28	3.6	3.5	4.2	7.2	2.3	1.8	12	10	4.3	1.4
Rb	<5	6	<5	6	22	<5	<5	7	11	<5	<5
Sr	109	46	89	80	37	79	103	344	189	69	136
Zr	78	62	38	47	32	82	82	123	98	58	59
Y	37	27	16	18	21	31	33	25	21	24	23
Ba	23	41	36	37	68	26	37	28	76	39	36
Ce	14	21	18	11	<10	17	12	35	34	13	<10
Cu	96	115	45	57	348	24	36	44	64	43	30
Ni	73	66	125	133	83	62	65	79	124	78	95
Zn	118	87	83	83	176	124	118	104	122	99	85
Cr	95	129	404	441	117	95	99	140	215	108	275

Table 4.—Concentrations of rare-earth and selected trace elements in metabasalts from the Rowe(?) Schist and Rowe Schist proper—Continued

[Sample numbers correspond to those in figures 3–5 and in table 3. D or J field number prefix refers to West Dover or Jacksonville quadrangle]

€rba, Jacksonville quadrangle									
	Southern traverse			Middle traverse			Northern traverse		
Sample no.	12	13	14	15	16	17	18	19	20
Field no.	J37–7A	J37–6	J37–8	J37–3	J37–4A	J37–4B	J37–5	J37–2	J37–1
Replicates	1	1	1	1	1	1	1	1	1
Instrumental neutron activation analysis (INAA) [Concentrations are given in the units shown in the first column; error limits are one standard deviation by counting statistics. G.A. Wandless and James Mee, analysts]									
Sc (ppm)	50.0±2%	41.5±2%	41.5±2%	46.4±2%	54.9±2%	48.1±2%	42.7±2%	61.0±2%	40.6±2%
Fe (%)	10.50±2%	9.10±2%	7.66±2%	11.00±2%	10.52±2%	9.78±2%	7.71±2%	10.47±2%	7.40±2%
La (ppm)	2.74±5%	7.2±8%	1.31±7%	4.20±4%	2.16±6%	1.96±12%	4.7±8%	1.80±6%	3.31±9%
Ce (ppm)	6.9±12%	16.4±4%	4.7±13%	10.9±7%	6.4±8%	6.0±14%	10.3±10%	5.4±17%	8.5±9%
Nd (ppm)	7.2±12%	11.2±12%	5.4±11%	10.1±11%	7.2±13%	6.4±13%	7.4±10%	7.2±11%	7.1±9%
Sm (ppm)	2.85±2%	4.12±4%	2.10±3%	3.64±2%	3.12±2%	2.82±2%	2.38±4%	2.91±3%	2.62±2%
Eu (ppm)	.97±6%	1.28±5%	.766±4%	1.19±4%	1.05±4%	.98±4%	.790±4%	1.07±4%	.936±3%
Tb (ppm)	.80±6%	.93±4%	.610±5%	.97±4%	.82±9%	.74±7%	.597±4%	.81±7%	.72±6%
Yb (ppm)	3.79±5%	3.95±4%	2.70±5%	4.39±4%	3.96±7%	3.84±4%	2.61±4%	3.71±4%	2.94±4%
Lu (ppm)	.505±4%	.524±4%	.378±4%	.615±4%	.553±4%	.491±4%	.353±4%	.502±4%	.405±4%
Hf (ppm)	1.82±5%	2.70±4%	1.33±5%	2.41±4%	1.95±4%	1.79±5%	1.52±5%	1.73±5%	1.68±4%
Ta (ppm)	.170±14%	.502±6%	.087±28%	.297±9%	.13±30%	.130±17%	.499±6%	<.1	.263±7%
Au (ppb)	10.7±28%	<3	<4	<13	<11	<5	<4	<13	<3
Th (ppm)	.36±23%	.86±8%	<.1	.41±13%	<.2	<.2	.51±9%	<.4	.28±26%
U (ppm)	<.3	.21±18%	<.3	<.3	<.3	<.3	.12±28%	<.4	<.3
Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, except as noted [Concentrations are in parts per million. J.R. Evans, analyst]									
Nb*	2.5	7.1	<1.0	4.1	1.4	1.6	6.9	1.2	3.8
Rb	6	5	<5	7	5	7	10	31	8
Sr	69	132	93	45	70	68	82	78	116
Zr	55	89	40	78	60	51	49	52	55
Y	26	32	21	38	31	29	21	33	23
Ba	<21	22	23	34	23	<21	52	97	42
Ce	11	24	16	26	17	14	23	22	21
Cu	120	95	41	112	131	159	40	102	52
Ni	70	111	148	52	74	64	95	112	105
Zn	105	82	76	110	107	94	214	92	71
Cr	131	400	463	88	159	116	197	343	405

*Determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES); M.W. Doughten, analyst.

Table 5.—Major-oxide composition, in weight percent, of mafic igneous rocks from the Moretown Formation and the North River Igneous Suite

[Samples correspond to those in figures 6–8. D or J field number prefix refers to West Dover or Jacksonville quadrangle. Determined by X-ray fluorescence (XRF) spectroscopy, supplemented by conventional analysis for H_2O, CO_2, and FeO. Hezekiah Smith, J.M. Allingham, J.E. Taggart, A. Bartel, and D.F. Siems, analysts]

Map unit	Moretown Formation (Omd)			North River Igneous Suite			
Field no.	J1	D32–12B	D32–12A	J37–9A	J37–9B	J37–10	J37–11
SiO_2	48.8	52.9	70.0	47.2	49.3	48.7	74.2
TiO_2	1.6	.94	.91	1.29	1.77	1.89	.20
Al_2O_3	15.3	15.3	13.0	20.2	15.7	15.3	13.2
Fe_2O_3	4.47	4.04	2.22	.14	1.69	1.63	1.21
FeO	6.6	7.7	3.0	7.5	8.2	8.7	1.8
MnO	.19	.21	.12	.15	.21	.19	<.02
MgO	7.87	5.89	2.03	6.4	7.5	7.1	1.4
CaO	11.5	8.95	1.81	12.3	10.9	11.0	.4
Na_2O	1.64	2.47	3.29	2.63	2.31	3.01	5.03
K_2O	.25	.33	1.87	.14	.24	.47	.71
P_2O_5	.16	.11	.21	.15	.19	.22	<.05
CO_2	.05	—	—	—	—	—	—
H_2O^-	.05	.02	.05	.09	.04	.09	.02
H_2O^+	2.20	1.90	1.00	2.50	2.2	1.8	1.2
Total	100.68	100.76	99.51	100.69	100.25	100.1	99.44

Description of Samples

J1; coarse-grained hornblende-plagioclase amphibolite (diorite), which has relict subophitic (dioritic?) texture and occurs as 2.5-m-thick layer that roughly parallels compositional layering in surrounding metasediments (Omfp); along roadcut on south side of Route 9, 1.1 km west of eastern quadrangle boundary.

D32–12A; well-layered, hornblende-chlorite feldspathic granofels within (Omfg) unit, 1.25 km N. 40° W. of southeast corner of quadrangle.

D32–12B; medium-grained hornblende-plagioclase amphibolite (diorite) in layer 1 m thick that parallels layering in surrounding Omfg; within and 2.5 m south of sample D32–12A.

J37–9A; 2.2-m-thick porphyritic amphibolite of the Whitneyville facies (SOnbw) of the North River Igneous Suite, with fine-grained matrix of hornblende-chlorite and abundant 3 mm to 1 cm relict plagioclase phenocrysts. Located within North River approximately 3 km east of Jacksonville town center and immediately south of Route 112.

J37–9B; fine-grained amphibolite from chill margin of sill sampled in J37–9A; except lacks plagioclase phenocrysts.

J37–10; medium- to fine-grained epidote-chlorite-hornblende-plagioclase amphibolite; along Branch Brook 1.5 km south of West Halifax center.

J37–11; medium- to coarse-grained trondhjemite having relict hypidiomorphic texture; west side of main Onwt sill-like body, 0.6 km S. 70° E. of West Halifax center.

Table 6.—Concentrations of rare-earth elements and selected trace elements in mafic igneous rocks from the Moretown Formation and the North River Igneous Suite

[Samples correspond to those figures 6–8 and in table 5]

	Moretown Formation (Omd)			North River Igneous Suite			
Field no.	J1	D32–12B	D32–12A	J37–9A	J37–9B	J37–10	J37–11
Replicates	—	1	1	1	1	1	—
	Instrumental neutron activation analysis (INAA) [Concentrations are given in the units shown in the first column; error limits are one standard deviation by counting statistics. G.A. Wandless and James Mee, analysts]						
Sc (ppm)	39.1±2%	41.9±2%	14.04±2%	27.3±2%	36.0±2%	40.4±2%	12.33±2%
Fe (%)	8.34±2%	8.85±2%	3.89±2%	6.00±2%	7.62±2%	8.17±2%	2.27±2%
La (ppm)	7.4±7%	2.36±5%	22.5±3%	5.6±7%	6.4±8%	8.1±6%	24.9±5%
Ce (ppm)	17.1±4%	6.1±8%	53.0±3%	14.1±3%	16.7±3%	21.2±5%	53.7±5%
Nd (ppm)	12.3±8%	5.5±27%	18.6±6%	12.5±11%	13.2±7%	16.4±6%	31.2±6%
Sm (ppm)	3.80±2%	1.84±3%	4.37±2%	3.74±2%	4.52±2%	5.12±2%	9.05±2%
Eu (ppm)	1.30±3%	.760±4%	.90±4%	1.20±3%	1.39±3%	1.66±3%	2.78±3%
Tb (ppm)	.81±7%	.484±6%	.730±4%	.74±5%	.94±6%	1.02±4%	1.44±3%
Yb (ppm)	2.88±5%	2.48±4%	3.36±4%	2.71±5%	3.37±4%	3.61±6%	4.24±4%
Lu (ppm)	.420±5%	.376±4%	.498±4%	.366±4%	.438±4%	.474±3%	.54±4%
Hf (ppm)	2.63±4%	1.21±5%	6.81±2%	2.62±3%	3.27±3%	3.59±3%	6.61±3%
Ta (ppm)	.338±9%	<.1	1.13±4%	.229±8%	.257±8%	.365±7%	1.83±3%
Au (ppb)	<2	<6	<4	<2	<3	<3	<3
Th (ppm)	1.11±7%	.52±17%	9.63±2%	.53±8%	.48±10%	.51±9%	2.42±4%
U (ppm)	.33±18%	<.4	1.35±6%	.15±30%	.21±31%	<.3	.35±13%

Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, except as noted
[Concentrations are in parts per million. J.R. Evans, analyst]

Map unit	Moretown Formation (Omd)			North River Igneous Suite			
Field no.	J1	D32–12B	D32–12A	J37–9A	J37–9B	J37–10	J37–11
Nb	<5	<5	11	2.8*	4.0*	5.1*	3.2*
Rb	16	8	89	<5	6	16	10
Sr	171	271	87	286	154	254	52
Zr	95	45	238	103	126	147	80
Y	30	19	27	23	28	35	18
Ba	<21	110	580	26	<21	65	124
Cu	53	16	<5	<5	21	32	<5
Ni	100	14	43	78	68	55	5
Zn	88	92	81	101	95	101	21
Cr	391	<20	94	260	271	200	<20

*Determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES); M.W. Doughten, analyst.

Table 7.—Major-oxide composition, in weight percent, of chlorite from the Rowe(?) Schist and Rowe Schist proper in the West Dover quadrangle determined by microprobe analysis (T.R. Armstrong, analyst)

Map unit Sample no. Field no.	€r? M–1 367	€rg M–2 518	€rs M–3 448
SiO_2	25.07	24.77	24.80
Al_2O_3	21.37	21.84	21.95
FeO*	22.45	21.55	19.87
MgO	18.14	18.47	19.65
CaO	.00	.00	.00
Na_2O	.00	.00	.00
K_2O	.00	.00	.00
H_2O**	10.57	10.49	10.60
TiO_2	.03	.12	.10
MnO	.01	.01	.94
ZnO	.01	.01	.01
Total	97.65	97.26	97.92

*All Fe as FeO.

**Value obtained during reduction of microprobe data.

Table 8.—Peak temperature and pressure reached in the large-garnet schist unit (€rgs) of the Rowe Schist proper during Acadian metamorphism determined by exchange and net transfer geothermobarometers

Sample no., quadrangle	Method		
	Garnet-biotite thermometry[1]	Garnet-plagioclase-muscovite-biotite barometry[2]	Garnet-rutile-ilmenite-plagioclase-quartz barometry[3]
M–4, West Dover			
Temperature, in degrees Celsius	520–540		
Pressure, in kilobars		7.3–7.9	8.2
M–5, Jacksonville			
Temperature, in degrees Celsius	510–545		
Pressure, in kilobars		7.0–7.6	7.6–7.7
M–6, Jacksonville			
Temperature, in degrees Celsius	500–530		
Pressure, in kilobars		7.1–7.5	7.7

[1] From Ferry and Spear (1978) using Berman (1990) garnet-activity model.

[2] Ghent and Stout (1981).

[3] Bohlen and Liotta (1986).