U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Bedrock geology of the Moretown Formation, North River Igneous Suite and associated metasedimentary/metavolcanic rocks of the Connecticut Valley Belt, Brattleboro and Newfane quadrangles, Windham County, Vermont

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Open-File Report
OF 94-247

1994

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Introduction

This report will cover bedrock geologic mapping conducted at a scale of 1:25,000 within the western halves of the Brattleboro and Newfane 7.5 by 15 Minute quadrangles, in Windsor County, Vermont. Specifically, this includes rocks of the Ordovician (?) Moretown Formation, rocks previously mapped as the Ordovician (?) Barnard Gneiss or Barnard Member of the Missisquoi Formation (Hepburn and others 1984) and the Silurian-Devonian Northfield Formation. The geology of the northwestern part of the Newfane quadrangle also includes Middle Proterozoic rocks of the Mt. Holly Complex and overlying Late Proterozoic through Ordovician (?) metasedimentary and metavolcanic rocks of the Hoosac and Rowe Formations. These rocks comprise a Grenville basement-cored, Acadian domal structure, the Athens dome, mapped by N.M. Ratcliffe in 1989-1991. These rocks will not be discussed in this text, and the reader is referred to Ratcliffe and others (1992) for further treatment these rocks and the Athens dome structure.

The study area is bounded on the west side by the West Dover and Jacksonville 7.5 Minute quadrangles mapped by Ratcliffe and Armstrong (in review), to the north by the Townshend 7.5 by 15 Minute quadrangle, currently being mapped by N.M. Ratcliffe and T.R. Armstrong, and to the south by the Shelburne Falls quadrangle, of Massachusetts and Vermont. The eastern border of the study area occurs in the middle of both the Brattleboro and Newfane quadrangles and approximately lies immediately east of the Missisquoi - Northfield contact on the 1961 Vermont State Geologic map (Doll and others, 1961). The true eastern boundary of these two quadrangles generally lies along the Connecticut River, separating Vermont from New Hampshire. The city of Brattleboro lies within the southeast corner of the Brattleboro quadrangle.

Previous work in this area includes several mapping studies conducted by Hitchcock (1823) and Hitchcock and others (1874, 1877, 1878) whom conducted the southern part of the present Brattleboro quadrangle into their geologic maps of Massachusetts. More recently, work conducted in the Brattleboro quadrangle and the

adjacent Keene quadrangle in southwestern New Hampshire were mapped by Moore (1949). This study, along with reconnaissance mapping by J.B. Thompson and J.L. Rosenfeld, was integrated into the 1961 State Geologic map of Vermont (Doll and others, 1961). Trask (1964) and Hepburn (1972) mapped within the Brattleboro and Newfane areas as parts of their PhD dissertations, and discussed several nappe and subsequent dome structures within rocks of both the Vermont Silurian-Devonian sequence (the Connecticut Valley Belt) and the Ordovician-Devonian New Hampshire sequence (the Bronson Hill anticlinorium of Billings, 1937). Hepburn and others (1984) presented a 1:62,500 scale map and related text on the Brattleboro 15 Minute quadrangle (which is now the Newfane and Brattleboro 7.5 by 15 Minute 1:25,000 quadrangles) which focused on the stratigraphy and metamorphic and structural history of the Connecticut Valley Belt and rocks of the Moretown and Barnard, as well as younger (supposed Ordovician-Silurian), unnamed schists and interlayered mafic volcanics east of the Barnard (and supposedly stratigraphically above). Karabinos and Aleinikoff (1990), reported on U-Pb studies of zircons (both igneous and detrital) from the Barnard Gneiss and Moretown Formation. Igneous ages on zircons from supposed felsic volcanics yielded an upper intercept age of 525 ± 25 Ma. Detrital zircons from the Moretown yielded an age range of 1.1 to 1.6 Ga.

This report will focus on the rock-types, distributions of rocks, and contact relationships between rocks of the Moretown, Barnard and Northfield Formations. Mapping during this study has shown that rocks previously mapped as undifferentiated Barnard volcanics (bimodal, felsic and mafic volcanics), actually consist of many different intrusive rocks (herein referred to as the North River Igneous Suite) which cross-cut older interlayered volcanic and sedimentary rocks, producing complex along-strike and across-strike changes in the distribution of rock-types.

Description of Lithologies

Metasedimentary Rocks

Moretown Formation

Quartz-plagioclase granofels, laminated quartzite, schist, meta-diorite, and amphibolite of the Moretown Formation belong to the Moretown-Rowe lithotectonic unit and structurally overlie the Rowe Formation along the Brookside Thrust Zone (Ratcliffe and Armstrong, in review). Dark- and light-gray granofels, interbedded, well laminated quartzite (Omfp) and quartz-plagioclase-garnet schist (Omb and Omfs) occur within the lower part and middle parts of the of the formation, respectively. A dark green, well laminated, mylonitic schist unit occurs along the lower contact of the Moretown Formation, with rocks of the Rowe Formation. This unit (Oms) was mapped by N.M. Ratcliffe (1990 and 1991) andis restricted to the immediate west flank of the Athens dome in the Newfane quadrangle. It is likely that this unit represents highly tectoniaed Omfp granofels. The upper part of the Moretown in this area consists primarily of plagioclase and hornblende-rich granofels (Omfg) of presumed volcanic and volcaniclastic origin.

All of the granofels in the Moretown typically contain a "pinstripe" texture expressed by 3 mm to 1 cm laminations of quartz-plagioclase granofels separated by 1 mm thick planar horizons of muscovite-biotite-chlorite. This pinstriping has the appearance of rythmic bedding but in many places it is recognizably axial planar to F2 and later folds and thus is probably entirely tectonic in origin. Bedding and sedimentary features such as graded beds are common in the lower and upper parts of the Moretown (Omfp and Omfg), and possibly represent a turbidite, deep water origin.

Meta-diorites (Omd) are abundant in all of the Moretown units and appear to contain subophitic texture preserved between metamorphic hornblende and plagioclase. Contacts with surrounding schist, quartzite, and granofels are typically concordant and meta-diorites have apparent chilled margins represented by much finer-grained hornblende

and plagioclase.

The along-strike termination of Moretown lithologies, both internally and along the tectonic contacts with the underlying Rowe and the overlying North River Igneous Suite make lithologic correlations with areas to the north and south extremely difficult. Some similar units, however, have been recognized in the Heath quadrangle of Massachusetts (Oml and Oms units of Hatch and Hartshorn, 1967 are correlative with Omfp and Omfs), immediately southwest of the Brattleboro quadrangle, and in the Jamaica-Townshend and Ludlow areas of south-central Vermont by Ratcliffe (in press) and Ratcliffe and Walsh (in review).

Cram Hill Formation

This unit was named for exposures of sulfidic schist and quartzite from Cram Hill in central Vermont by Currier and Jahns (1941). In this area, rocks of the Cram Hill Formation are restricted to the South Newfane Lithotectonic Belt, east of the Acadian fault contact with the Moretown Formation (figure 1). This unit was mapped as "the unnamed schist and amphibolite unit" (OSsa) by Hepburn and others (1984), as the Cram Hill Formation (Och) in the Jacksonville Quadrangle by Skehan (1961), and as Hawley Formation black schist (Ohb) in the Heath Quadrangle of Massachusetts by Hatch and Hartshorn (1968). The name Cram Hill Formation is retained in this report. In the Newfane and Brattleboro 7.5-15 Minute quadrangles, the Cram Hill Formation consists of dark gray to black, rusty-weathering sulfidic schist with occassional layers of up to 1 meter thick dark-gray quartzite. Fine-grained, tan, granulose, 10 to 100 meter thick zones of felsic granofels (Ochv) appear to be volcanic in origin and are interlayered with Och in several locations in the Brattleboro and southern part of the Newfane quadrangle. Several of these horizons also contain 3 to 10 mm clear quartz grains that appear to be phenocrysts. Skehan (1961) and Hepburn and others (1984) included massive fine-grained to porphyritic amphibolites within the Cram Hill and interpreted them as volcanics

interlayered with the sulfidic schist. Similar rocks were recognized by Currier and Jahns (1941) as dikes and sills, intruding Moretown-like rocks, within the type Cram Hill section. Field observations made during this study indicate that the amphibolites in the Newfane and Brattleboro quadrangles are intrusives within the Cram Hill and should therefore be separated from this unit. Dikes of the Whitneyville Facies of the North River Igneous Suite (SOnbw; see section below) are abundant within the Cram Hill Formation in this region and contain fine-grained chilled margins and small to very large (1 to 100 m long) xenoliths or screens of the sulfidic schist. In many areas, S1 compositional layering within the Cram Hill is truncated by the dikes, but in many instances igneous contacts with the schist are concordant suggesting that the intrusives may be sills. The sulfidic schist in the Cram Hill of southern Vermont locally contains 1 to 10 cm thick layers of sandy schist and gray to black quartzite with sharp planar contacts to the surrounding schist. Graded beds and cross beds are common in these zones.

The Cram Hill also contains a single horizon of quartz pebble conglomerate (Ochc) along the lower contact with granofels of the Cram Hill (Marlboro member of the Cram Hill) within the northeastern part of the Brattleboro quadrangle. Pebbles are blue to white in color and are typically rounded and range in size from 1 mm to 1.5 cm. The fine-grained, schistose matrix is a tan to brown weathering, gray, and consists of quartz-plagioclase-muscovite-chlorite, with small amounts of opaques (mostly ilmenite). This unit is lens-like and only 20 to 30 meters wide, and only 300 to 400 meters long. It is also interlayered with non-conglomeratic, Cram Hill sulfidic schist.

Within the north-central part of the South Newfane Lithotectonic Belt, in the Brattleboro quadrangle, 5 to 50 meter thick, fine-grained, massive, plagioclase felsite horizons appear as screens within Whitneyville Facies porphyritic amphibolites (SOnbw). The felsite (Neringa volcanics; Onn) is locally interlayered with porphyroblastic, fuchsite-bearing felsic schist horizons of probable volcanic origin. Some parts of these volcanic rocks contain massive, rusty-weathering plagioclase granofels, with abundant granular

quartz. These rocks are identical to fine-grained felsic volcanics (Ochv) mapped within the Cram Hill Formation in this belt, and previously referred to in this area as "meta-tuff" by Hepburn and others (1984). Because the Cram Hill lithologies are found both above and below rocks of the Neringa Facies, these different units must interfinger.

Marlboro member of the Cram Hill Formation

Informally named for exposures in the town of Marlboro, Vermont, within the northwest part of the Brattleboro quadrangle, this unit (Ocm) consists of tan- to rusty-weathered, dark to light gray, well bedded, hornblende-garnet-chlorite-muscovite-plagioclase-quartz schist, muscovite-chlorite-plagioclase-quartz granofels and hornblende-plagioclase gneiss. The latter two units occur as 1 to 25 meter thick, discontinuous horizons. Schist and granofels are similar to units Omgs and Omfq, and hornblende-plagioclase gneiss is similar to Omfs, of the Moretown Formation. All units are intruded by 1 to 10 meter thick intermediate and mafic dikes and sills of the Branch Brook Complex (South Pond Facies, SOnsp and Williamsville Facies, SOnbm). The Marlboro member also appears to be interlayered with metavolcanic and metasedimentary rocks of the South Pond and Cram Hill Formations in the lower and middle parts of the South Newfane Lithotectonic Belt. Although the Marlboro member is lithologically very similar to Omfp and Omfs units within the Moretown Formation, it completely lacks Taconian S1/S2, and Acadian S3 and S4, which are very common in the Moretown Formation. Therefore, the Marlboro member (and all other metasedimentary and metavolcanic rocks within the Cram Hill Formation) may be a tectonically transported eastern facies of rocks mapped as Moretown Formation which originated in a tectonic setting that did not accrue Taconian (and early Acadian) deformations.

Northfield Formation

Small garnet-bearing (3 to 6 mm), carbonaceous phyllite within the eastern parts of the mapped portions of the Newfane and Brattleboro quadrangles have previously been mapped as Silurian-Devonian Northfield Formation (DSn; Doll and others, 1961; Skehan, 1961; Hepburn and others, 1984). These rocks lie structurally above rocks within the North River Igneous Suite and Cram Hill Formation, as mapped during this study. Bedding, defined by homogeneous gray to black carbonaceous phyllite and thin (mm to cm-scale) sandy, sulfidic layering, was recognized during this study. Well preserved graded beds consistently top eastward. Near the contact with the Northfield Formation, sulfidic schist of the Cram Hill becomes more carbonaceous, and contains small (2 to 6 mm) garnets that are not found within most of the formation. This garnetiferous schist is nearly identical to rocks within the Northfield. Several small, 1 to 2 m thick and discontinuous lenses of vitreous white quartzite and quartzitic, quartz pebble conglomerate are present within the Northfield and are identical to those found within the Cram Hill Formation. All discontinuous horizons are interpreted as submarine channel deposits.

The contact between the Northfield and underlying rocks is sharp where in contact with Whitneyville Facies amphibolites, or gradational over 1 to 200 m where in contact with Cram Hill sulfidic schist. Locally the upper part of the Cram Hill also contains cm to 1 m thick, discontinuous lenses of well bedded, vitreous white quartzite with preserved 0.5 to 1 mm detrital grains of blue (rutilated) quartz. This quartzite is similar to those found within the Northfield, and the surrounding garnetiferous schist is nearly indistinguishable from Northfield garnet phyllite. Garnet schists within the Northfield and the Cram Hill are *sometimes* distinguished by the fissile, almost slaty parting of the latter of these two units interlayered on a meter-scale.

The sharp contact between the Whitneyville Facies amphibolites and the overlying Northfield Formation, coupled with the *occasional* presence of discontinuous quartzite horizons, led previous workers to interpret it as a Silurian regional unconformity, with

rocks west and stratigraphically below having been previously deformed during the Ordovician Taconian orogeny (Doll and others, 1961; Skehan, 1961; Hepburn and others, 1984). The recognition of the amphibolites as intrusives, and recent discoveries within the Brattleboro quadrangle of Whitneyville Facies rocks intruding the Northfield Formation (figure 1), provide enough evidence to warrant reevaluation of the unconformable nature of this contact as well as the ages of the intruded metasedimentary rocks of both the Cram Hill and Northfield Formations. In addition, the wide spread distribution of quartzite and quartz-pebble conglomerate within both the Northfield and Cram Hill Formations argues against the quartzite near or along the Northfield-Cram Hill contact being a basal facies.

Metaigneous Rocks

Granite dikes

Non foliated, light gray to white, 1 to 2 meter thick, biotite-muscovite-K-feldspar-quartz-plagioclase±garnet, peraluminous, granite dikes (Dgr) are present within the Late-Proterozoic-Cambrian cover and Middle Proterozoic basment rocks within the Athens dome (Ratcliffe, in press; Ratcliffe and others, 1992). One 1.5 meter thick dike was mapped within the Omfp Moretown unit on the north side of Oregon Mountain in the Newfane quadrangle. Although unfoliated, these dikes display regional changes in trend that suggest late-stage arching of the dikes over the Athens dome structure. A nearly concordant U-Pb age on zircon of 373 (± 4 Ma) was obtained on the compositionally similar Black Mountain Granite, at Black Mountain, in the eastern part of the Brattleboro quadrangle (J.N. Aleinikoff, personal communication, 1992; reported in Ratcliffe and others, 1992). This age is completely consistent with the unfoliated nature of the dikes, suggestive of post-Acadian dome stage deformation , but possibly during late-stage domeal arching in this area.

North River Igneous Suite

This name is herein given to a suite of igneous, intrusive rocks recognized during mapping within the Newfane and Brattleboro quadrangles and during mapping in the Jacksonville quadrangle, immediately west of the Brattleboro quadrangle (Ratcliffe and Armstrong, in review). These rocks were previously mapped as undifferentiated metavolcanics of the Barnard Formation by Skehan (1961) in the southeastern part of the present Jacksonville quadrangle and as the Barnard Member of the Missisquoi Formation by Hepburn and others (1984). Intrusive rocks recognized during this study include the West Halifax trondhjemite (SOnwt) and Newfane Tonalite (SOnt), which cross-cut fine-grained and porphyritic amphibolite containing plagioclase phenocrysts (South Pond Facies; SOnsp). All of these units are intruded by the Branch Brook dike and sill complex, consisting of black to gray-green porphyritic amphibolite with zoned igneous plagioclase phenocrysts (the Williamsville and Whitneyville Facies, SOnbm and SOnbw, respectively). The porphyritic nature of the Branch Brook rocks, fine-grained matrix with 2 mm to 1 cm rectangular plagioclase phenocrysts, some with preserved igneous zoning, indicate a probable hypabyssal origin.

Locally, the trondhjemite and tonalite cross-cutthe South Pond Facies, but are consistently cross-cut by the Williamsville and Whitneyville Facies of the Branch Brook complex. These Branch Brook units either cross-cut South Pond *or* show gradational contacts, with progressive increases in plagioclase content and phenocryst abundance into rocks mapped as the latter two facies. Some of these gradational zones, as well as internal parts of the South Pond Facies, contain 1 to 100 meter thick, discontinuous trondhjemitic / tonalitic segregations that are indistinguishable from the main body of West Halifax Trondhjemite or Newfane Tonalite. These relationships suggest that the Branch Brook Complex and the West Halifax Trondhjemite and Newfane Tonalite are either roughly coeval (and possibly comagmatic) or that there were multiple pulses of felsic (trondjemitic and tonalitic) magmas.

Within the lowermost (western) and middle parts of the North River Igneous Suite in the Brattleboro and Newfane quadrangles is a well layered chlorite-biotite-muscovite-garnet-quartz-plagioclase gneisses (SOnb; informally named volcanics at Baker Brook) of probable volcanic or volcaniclastic origin, which are intruded by Williamsville Facies dikes (SOnbm), immediately west of the large body of Williamsville Facies in the town of Williamsville (Newfane quadrangle). These dikes cross-cut compositional layering within the felsic volcanics. To the west, the felsic volcanics are also intruded by Newfane Tonalite which appears to be chemically similar to the overlying SOnb which *may* have been the volcanic edifice of the underlying tonalitic intrusives.

Structural Geology

Moretown Formation

The Moretown Formation contains essentially the same fabrics as found in the Rowe Belt: The dominant schistosity, S2, is believed to be Late Ordovician in age (Taconian; Ratcliffe and others, 1992) and contains a generally consistently oriented mineral lineation (S65E). S2 is axial planar to F2 folds that are reclined and isoclinal (sheath folds) near the D2 Brookside fault zone, and open, west-verging to upright folds east of the Brookside Fault Zone where D2 strain abruptly decreases in intensity. No Taconian S1 foliation, correlative with S1 in the rocks immediately west within the West Dover and Jacksonville Quadrangles (Ratcliffe and Armstrong, in review), was recognized within the Moretown in the study area. S2 fabric is locally warped to highly folded by at least four phases of fold-related fabrics all of which are believed to be Acadian in age; syn-metamorphic S3 crenulate to spaced cleavage is axial planar to a set of folds whose axial surfaces appear to have had an original northwest trend with unknown original dip direction. Original S3 orientation is difficult to recognize due to the deformed nature of this fabric in most areas where it is found. Folds are typically characterized by "Z", or "S"

shaped chevron geometry, with large amplitudes relative to wavelengths. There does not appear to be a related mineral lineation although hornblende growth within S2/S3 intersections is widely found. F3 folding effects on the map-pattern geometry range from substantial to insignificant.

S3 fabric and related F3 folds are locally deformed by a second syn-metamorphic deformation event, D4, which includes upright to east-verging open to tight folds, F4, either with a moderately to weakly developed, closely to widely spaced (1 to 5mm) cleavage or crenulate cleavage, S4, typically northeast-trending and northwest dipping, where not deformed by subsequent deformation. F4 hingelines tend to have shallow (0 to 15°) to moderate (16 to 40°) plunges down S4 axial planes or related axial planar cleavage. Petrographic observations show that amphibole needles, typically fine-grained (1 to 3mm) hornblende, frequently grow within the S4/S2 intersection. Interference of F3 and F4 folds is responsible for the large-scale, map-pattern dome structures found within the northern part of the Newfane quadrangle (southern closure of the Athens dome) and the extreme northwestern part of the Brattleboro quadrangle (northeastern closure of the Sadawga antiform). Garnet porphyroblasts commonly contain mineral inclusion trails that define planar S2 fabric within garnet cores and progressively crenulated, or modulated, by F3 and F4 deformation toward garnet rims. These folds defined by the inclusion trails are coplanar with tight matrix crenulate folds defined by S2 mineral fabric that is continuous into S2 included within the garnet porphyroblasts. These relationships indicate that onset of garnet growth (part of the Acadian metamorphic event) occurred prior to F3 and F4 deformation with peak-thermal garnet growth (garnet rims) occurring during F3 and F4 fabric development.

Both S3 and S4 fabric are deformed by at least threet younger Acadian deformations; northeast-trending and southeast dipping schistosity (S4.5) is well developed almost exclusively on the southeast flank of the Sadawga dome in the Jacksonville quadrangle (Ratcliffe and Armstrong, in review) and is present in the

Moretown Formation and all rocks to the east. S4.5 foliation appears to be related to metamorphic retrogression of Acadian garnet-grade mineral assemblages within the Moretown Formation and thus postdates the local Acadian peak-T metamorphic conditions. Since S4.5 is collinear with the trend of undeformed S4 fabric, and appears to show progressive change in orientation from west to east dipping across the strike of the Sadawga dome structure, it is interpreted to be late D4 deformation, and is labeled S4.5. This fabric tends to form a composite fabric with the Taconian S2 in the Moretown rocks, with collinear strikes and small differences in magnitude of dip, with S4.5 commonly being somewhat shallower than S2. Locally high strain S4.5 shear zones are present within the Moretown rocks and are usually defined by a closely spaced foliation in rocks that show either a cataclastic "shredded" texture or phyllonitized, mylonite zones with abundant retrograde sericite and chlorite. These zones are typically no wider than 10 to 25 m and no longer than 100 to 500 m. F4.5 folds are common in the Moretown and are defined by west-verging, open to tight structures that locally warp the trend of the regional S2 fabrics and lithologic contacts. Locally, F4.5 folds are pervasive and tightly fold S2 fabric and F3 and F4 axial surfaces in tight, almost isoclinal geometries. In these pervasive zones, S4.5 can be distinguished from S2 by its northeast-trending chlorite mineral lineation (opposed to the southeast-trending S2 lineation). Since S2 and S4.5 are nearly coplanar, this distinguishing feature is extremely critical in separating Taconian and Acadian deformations.

S4.5 fabric increases in intensity to the east, into the South Newfane Thrust where it transposes preexisting Taconian and Acadian fold structures. The South Newfane Thrust is the tectonic contact between the Moretown Formation and rocks of the North River Igneous Suite and associated metasedimentary/metavolcanic rocks of the Connecticut Valley Belt (CVB). Within this fault zone, rocks of the Moretown Formation contain abundant euhedral chlorite pseudomorphs after garnet which show progressive flattening and streaking of chlorite grains up to the contact with the North River Igneous Suite.

Above the North River Igneous Suite, pristine garnet-bearing assemblages show no evidence of retrogression to chlorite and thus demonstrate a metamorphic discordance associated with the South Newfane Thrust Zone. Argon Single crystal, total fusion agesa from 10 different neoblatic hornblende crystals from the fault zone all yield ages of 356 Ma (± 1 Ma; Armstrong and Hames, 1993). P-T conditions are 475°C at 6.7kbars; thus, the hornblende ages appear to record the time of metamorphism since peak T never reached effective the upper threshold of Ar solid-state volume diffusion (500°C). Transposition of S2, F3 and F4 fabric is extremely strong within Moretown rocks immediately below (west of) the South Newfane Thrust, such that S4.5 is the dominant fabric and distinguishing of earlier fabrics, especially F3 and F4, is nearly impossible.

North River Igneous Suite

Ordovician to Silurian (?) meta-igneous of the North River Igneous Suite and the meta-sedimentary and meta-volcanic rocks which they intrude are situated above the South Newfane Thrust and contain a maximum of three discrete deformational fabrics: the meta-volcanic and meta-sedimentary rocks locally contain weakly developed compositional layering, strongly developed transposed bedding, or a weak to moderately developed bed-parallel cleavage believed to be Acadian (Acadian S1). This fabric is not associated with any observed folding event in this area, nor is there any evidence of an S1 mineral lineation. S1 foliation spacing ranges from 1 mm to 10 cm in thickly bedded volcanic units. S1 is not present in any of the North River Igneous Suite rocks; both mafic and felsic intrusive rock-types truncate S1 layering along contacts with the meta-sedimentary and meta-volcanic rocks.

All of the igneous and older meta-sedimentary and meta-volcanic host rocks contain the regionally dominant foliation, S4.5 and related northeast-trending mineral lineation. Many, if not all, of the lithologic and lithodemic contacts are parallel to either S4.5 or a composite S1/S4.5 fabric. F4.5 isoclinal folds appear to be small-scale, rootless

folds of either S1 or S4.5 layering exclusively found within the South Newfane Thrust. No other F4.5 folds, or large isoclinal structures, were observed in this study area. F4.5, are therefore not common and if present, have little affect on the map pattern distribution of the major rock units in this belt.

S4.5 fabric and the parallel lithologic contacts are locally folded by syn- to post-peak metamorphic west-verging to upright open folds (F5) which may or may not contain an axial planar, 2 to 5 mm spaced, crenulation cleavage (F5). These folds are demonstrably correlative with F5 in the Rowe and Moretown belts since these consistently north-trending, sub-vertically dipping folds affect all the rocks on both sides of, and the South Newfane Thrust itself. This relationship provides an important upper end age constraint on the regional fabric age relationships. No younger fabrics were found within the North River Igneous Suite in this area. In addition, no mylonitic fabric, related isoclinal folds, or southeast-trending mineral lineation typical of Taconian S2 were found in any of these rocks. F3 and F4 axial surfaces, cleavages, and related map-scale axial traces, all of which are effectively transposed into the S4.5 orientation within Moretown rocks west of the South Newfane Thrust, *are not* present within rocks east of the South Newfane Thrust. Since most rocks of the North River Igneous Suite and associated host rocks contain only weakly developed S4.5 fabric, it does not seem likely that S4.5 is a composite of S2, S3 and S4 as seen in the highly strained Moretown rocks. Also, none of the rocks east of the South Newfane Thrust show any substantial evidence of either polymetamorphic garnet-grade growth or retrogression of garnet-grade rocks as is typical for Moretown and Rowe rocks on the southeast flank of the Sadawga dome. These structural relationships suggest that the rocks east of the South Newfane Thrust either were not in an environment that was exposed to D2, D3 or D4 strain prior to D4.5 juxtaposition with the Moretown along the South Newfane Thrust, *or*, all of the rocks east of the South Newfane Thrust are post-Taconian and possibly post-D4 in age or a combination of both possibilities.

F5 folds tend to be most pervasive in Cram Hill schist horizons but do occur as

large open to tight upright folds within North River rocks as well. F5 folds must be younger than Acadian F3 and F4 in the Moretown since F5 locally warps S4.5 fabric (including the South Newfane Thrust fault surface) and lithologic contacts parallel to S4.5. Although no F5 folds have been recognized within rocks west of the South Newfane Thrust, they may be broadly correlative with what has been mapped as F4.5 folds in these rocks, and thus may represent late-stage 4.5 deformation within rocks east of the thrust.

All of the rocks within the Brattleboro and Newfane quadrangles are deformed by the youngest recognized deformation (F6); upright to west-overturned open folds with either no axial plane cleavage (igneous rocks) or a 1 to 3mm spaced or pressure solution cleavage (schist and metavolcanics). In rocks west of the South Newfane Thrust, F6 folds deform S2, S3 and S4 fabrics into large-scale folds. On the east side of the thrust, F6 deforms both the dominant S4.5 fabric and locally pervasive F5/S5 structures. F6 trends are quite consistent in all rocks; approximately North-South strike with subvertical dips of axial surfaces. Hingleines plunges vary due to local variations in the oriewntations of the different folded planar elements (S2, S3/S4, S4.5, and S5). F6 deformation may represent the last stages of Acadian compressional history within this area. It is important to note that F6 may correlate with the Dome-stage cleavage recognized by Hepburn and others (1984) producing the Guilford dome, immediately east of the map area. If so, than the Argon ages from hornblende from the South Newfane Thrust fabric (S4.5; 356 Ma) require that the F5 and F6 deformations and related structures are Carboniferous in age (Armstrong and Hames, 1993).

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DESCRIPTION OF MAP UNITS

METAIGNEOUS ROCKS

Granite Dikes- (Devonian) Light gray to white, equigranular, nonfoliated, peraluminous, biotite-muscovite-k-feldspar-quartz-plagioclase±garnet granite dikes with well developed hypidiomorphic igneous texture. Dikes are compositionally identical to Black Mountain Granite, at Black Mountain, eastern part of Brattleboro quadrangle

Dgr

North River Igneous Suite

Branch Brook Sill and Dike Complex

Whitneyville Facies-(Silurian-Ordovician) Light to medium-green, massive, epidote-ilmenite-sphene-chlorite-hornblende-plagioclase-pyrite±calcite amphibolite. Commonly contains a porphyritic to glomeroporphyritic texture defined by fine-grained groundmass and 3 to 10mm euhedral, tabular, and anhedral plagioclase metacrysts (metamorphosed phenocrysts) which comprise 5 to 50 volume percent of the entire rock. Typically occurs as a series of anastomosing dikes or sills which show 1mm to 100cm thick, fine-grained, relict chilled margins, defined by progressive allotriomorphic texture and absence of plagioclase metacrysts toward border with host metasedimentary units. Also intrudes SOnsp and SOnwt. This unit may be comagmatic with similar SOnbm facies

SOnbw

Williamsville Facies-(Silurian-Ordovician) Dark gray-green to blackish-gray, poorly layered, porphyritic and nonporphyritic, ilmenite-epidote-chlorite-plagioclase-hornblende amphibolite with 1 to 10mm plagioclase metacrysts, similar to those in SOnbw. Metacrysts comprise 5 to 60 volume percent of individual layers within this unit. Layering appears to be related to multiple auto injections of dikes and sills which

SOnbm

produce an anastomosing geometry of cross-cutting layers with variable amounts of metacrysts. Main part of unit occurs as an auto injected sill/dike complex, over 2.5km thick and broadly concordant to compositional layering within host metasedimentary rocks. Several individual dikes contain variably sized xenoliths of tan to brown, fine-grained chlorite-biotite-quartz-plagioclase, felsic gneiss, similar to SOnb unit. Xenoliths occur in discreet groups and appear to be brecciated beds of metavolcanic horizons, presumably intruded by SOnbm. This unit intrudes SOnt, SOnwt, Och, Ochc, Ochv, Onn, Ocm, and SOnsp

West Halifax Trondhjemite- (Silurian-Ordovician) Cream, light-gray, to white, coarse-grained chlorite-biotite-muscovite-quartz-plagioclase ±garnet ±hornblende orthogneiss of

SOnwt

tondhjemitic to tonalitic composition. In low strain areas, plagioclase and quartz form relict hypidiomorphic texture with muscovite, biotite and chlorite aligned within weak foliation. 2 to 6mm idioblastic garnets occur sporadically with rare fascicles of hornblende on foliation surfaces. Also occurs as thin dikes (1 to 10m) within SOnsp, and may be broadly coeval with intrusive, metacrystic phases of that unit. Unit is cut by 1 to 20m thick dikes and sills of SOnbm . Unit intrudes fine-grained phases of SOnsp. Unit is physically continuous with Ohg (Hawley Fm.; Hatch and Hartshorn, 1968) in the Heath Quadrangle, Massachusetts. May be coeval with SOnt

Newfane Tonalite-(Silurian-Ordovician) Cream to light-gray, white-weathering, fine to coarse-grained epidote-chlorite-muscovite-quartz-plagioclase ±garnet ±hornblende

SOnt

orthogneiss of tonalitic composition. In low strain areas, plagioclase and quartz form relict hypidiomorphic texture with muscovite, biotite and chlorite aligned within weak foliation. Intrudes overlying layered volcanic facies (SOnb) which may be a volcanic edifice to SOnt. Locally found within the northeastern part of the

Brattleboro quadrangle as fault slivers within the South Newfane thrust, and as sills or dikes within Ocm. Includes a large screen of Och within the Newfane quadrangle. Unit may also intrude Fine-grained part of SOnsp, but is intruded by dikes of SOnbm in both quads

South Pond Facies- (Silurian-Ordovician) Light to dark gray and steel-blue and apple-green, fine-grained hornblende-chlorite-plagioclase ± ilmenite ± magnetite ± calcite ± pyrite

SOnsp

greenstone and porphyritic amphibolite with fine grained chlorite- plagioclase matrix, coarse 5 to 15mm hornblende porphyroblasts and rare to abundant relict zoned, 5 to 15mm plagioclase phenocrysts, similar to SOnbm and SOnbw facies. Locally includes rare to numerous 1 to 5 meter thick layers and/or sills of fine- to coarse-grained light gray to cream colored metamorphosed trondhjemite/tonalite similar to both SOnt and SOnwt. Contacts between homogeneous greenstones and porphyritic amphibolites tend to be either sharp, in which case amphibolites appear to be cross-cutting dikes or sills, or gradational, with progressive increases in plagioclase phenocrysts away from contact. Map pattern cross-cutting relationships and local contact relationships, including chilled margins and host rock xenoliths, indicate that the porphyritic parts of the unit are, at least in part, intrusive into Och, Ochv, Ochc , Onn, Ocm, and possibly SOnwt, although finer-grained phases may be metavolcanic and interbedded with surrounding metasedimentary units.

The variably fine-grained and porphyritic nature of this unit, coupled with the internal cross-cutting relationships, suggest a sub volcanic or hypabyssal setting during crystallization

Igneous Rocks within the Moretown Formation

Metadiorite.- (Ordovician) Steel-gray to dark gray-green, coarse-grained quartz-chlorite-plagioclase-hornblende±garnet±epidote metadiorite with subophitic intergrowths of hornblende and plagioclase. Unit typically occurs as 1 to 15m thick dikes or sills which intrude host rocks either parallel or at low angles to compositional layering in metasediments. Fine-grained, sharp contacts with host rocks appear to be preserved igneous chilled margins. Omd occurs in all Om units

Omd

Volcanics within the North River Igneous Suite

Volcanics at Baker Brook- (Silurian-Ordovician) Well layered, cream to light tan and brown, granulose, equigranular, ilmenite-chlorite-garnet-hornblende-muscovite-quartz-plagioclase gneiss with 1 to 20cm thick compositional layering. Appears to be a series of metavolcanic screens intruded by SOnt and Sonbm units. SOnt is compositionally similar and may represent an intrusive, comagmatic phase. Locally mapped by Hepburn and others (1984) as a "metatuff" horizon, this unit is actually composed of many discreet screens within surrounding intrusive units. Lithostratigraphic position of this unit suggests that deposition may have been contemporaneous with Och metasedimentary unit

SOnb

Volcanics / volcaniclastics within the Cram Hill Formation

Neringa Volcanics-(Ordovician) Light gray to creamy-white and gray, massive, fine-grained epidote-chlorite-quartz-plagioclase felsite and felsic gneiss with several 1m thick layers of light to emerald green quartz-muscovite-chlorite schist with 3 to 6mm porphyroblasts of fuschite. The layering appears to be bedding. This unit typically occurs with fine-grained part of SOnsp, Och schist and Ochv quartz-phenocryst bearing volcanics. Unit is locally intruded by dikes of SOnbw and coarse-grained

Onn

part of SOnsp. Unit appears to be volcaniclastic in origin. May be broadly coeval with Och units and SOnb

Cram Hill Volcanics-(Ordovician) Tan to rusty weathering, light gray to cream colored, fine-grained, weakly foliated, granulose, chlorite-muscovite-plagioclase-quartz metavolcanics with relict 2mm to 2cm subhedral to angular quartz phenocrysts. Unit is interlayered with Och metasedimentary unit and locally is in sharp contact with Onn volcanics. Locally, unit does not contain quartz phenocrysts, and is well foliated and homogeneous quartz-muscovite-plagioclase granofels that appear to be relict tuffaceous metasediments, and has been included within the "metatuff" unit of Hepburn and others (1984). Unit also contains interlayered granofels similar to Ocm within the northwestern part of the Brattleboro quadrangle

Ochv

METASEDIMENTARY UNITS

Northfield Formation- (Silurian-Devonian) Gray to dark-gray, carbonaceous, plagioclase-garnet-chlorite-quartz-muscovite-quartz±carbonate±epidote schist and phyllite with 1 to 6mm garnet porphyroblasts that produce distinctive "bumps" on foliation surfaces. Locally includes thin, discontinuous, 10cm to 1m thick vitreous, white to light gray quartzite layers with abundant 0.5 to 1.5mm detrital blue quartz grains and rare, discontinuous beds of 1m thick quartz pebble conglomerate. Pebbles are typically flattened. Quartzite unit is identical to unit previously mapped as Shaw Mountain Fm. by Doll and others (1961) and as Russell Mountain Formation by Hepburn and others (1984) in this region. DSn is typically interlayered with garnet-bearing sulfidic schist (Cram Hill Fm.) near and along its western extent. And locally contains thin, 1mm to 5cm thick tan, sulfidic, plagioclase schist layers within this zone which display graded bedding characteristics. Western part of unit is locally intruded by 1 to 5m thick dikes of SOnbw

DSn

Northfield Formation,

Quartzite Member- (Silurian-Devonian) Thin, discontinuous, 10cm to 1m thick vitreous, white to light gray quartzite layers with abundant 0.5 to 1.5mm detrital blue quartz grains and rare, discontinuous beds of 1m thick quartz pebble conglomerate. Pebbles are typically flattened. Quartzite unit is identical to unit previously mapped as Shaw Mountain Fm. by Doll and others (1961) and as Russell Mountain Formation by Hepburn and others (1984) in this region

DSnq

Cram Hill Formation- (Ordovician) Homogeneous, rusty and tan weathering, dark to light gray, pyritiferous ilmenite-muscovite-chlorite-plagioclase-quartz±garnet±staurolite schist and granofels with occasional 1 to 35m thick bedded, dark gray to black quartzite horizons with thin 1mm thick schist laminae between quartzite beds. Unit is locally interlayered or in depositional contact with Ochv and Ochc units. Unit is intruded by SOnbm, SOnbw, Coarse-grained parts of SOnsp, and SOnt. Appears to be in depositional contact with fine-grained parts of SOnsp. Eastern (upper) contact with DSn is both gradational (becomes more garnetiferous and less sulfidic) and interlayered with no demonstrable evidence for a regional unconformity as proposed by Doll and others (1961) and Hepburn and others (1984)

Och

Cram Hill Formation,

quartz pebble

conglomerate Member- (Ordovician) Homogeneous, rusty and tan weathering, dark to light gray, pyritiferous ilmenite-muscovite-chlorite-plagioclase-quartz granofels with 1mm to 3.5cm rounded blue quartz pebbles in weakly foliated matrix. Unit appears to contain 1 to 10cm thick, discontinuous horizons of Ochv-like fine-grained, metavolcanics without quartz phenocrysts. Unit maybe reworked Ochv material. Unit is found in depositional contact with Ocm along eastern side of Ocm horizon within northwestern part of Brattleboro quadrangle

Ochc

Marlboro member- (Ordovician) Tan- to Rusty-weathered, dark to light gray, well bedded, hornblende- garnet-chlorite-muscovite-plagioclase-quartz schist, muscovite-chlorite-plagioclase-quartz granofels and hornblende- plagioclase gneiss. The later two units occur as 1 to 25 meter thick, discontinuous horizons. Schist and granofels are similar to Omgs and Omfq, and hornblende-plagioclase gneiss is similar to Omfs, all of which are units in the Moretown Formation in the Jacksonville Quadrangle. All units are intruded by 1 to 10 meter thick intermediate and mafic dikes and sills of the Branch Brook Complex (South Pond Facies, SOnsp and Williamsville Facies, SOnbm). The Marlboro Formation may be either a transported, eastern facies of rocks mapped as Moretown Formation in southern Vermont (Ratcliffe and Armstrong, in press), and/or the southern continuation of the Moretown Formation mapped in the Ludlow area of Central Vermont (N.M. Ratcliffe, T.R. Armstrong and G.J. Walsh; unpublished maps)

Ocm

Moretown Formation

Feldspathic Gneiss Member- (Ordovician) White-weathered, light-gray to tan, well layered, ilmenite-biotite-garnet-hornblende-chlorite-muscovite-quartz-plagioclase gneiss. Compositional layering parallel to Taconian S2 fabric, and rarely parallel to relict beds with sedimentary graded characteristics. Rare 1 to 5mm garnets are a distinctive deep red color. Unit contains abundant 0.5 to 5m thick layers of Omd. Contact with lower Omfs unit is defined by 10 to 30m thick interbedded zone with 0.5 to 2.0m thick discreet beds. Unit is believed to be volcaniclastic in origin

Omfg

Feldspathic Schist Member- (Ordovician) Rusty-weathered to lustrous, silver-gray, granulose, pyrite-biotite-garnet-chlorite-quartz-muscovite-plagioclase schist and granofels with thin (0.5 to 2.0m) discontinuous horizons of hornblende-plagioclase gneiss. Garnets within this unit are typically deep red, and 2 to 5mm in diameter except for occasional lustrous schist horizons (1 to 10m thick) which contain abundant 0.7 to 3.0 cm garnets. Also contains numerous dikes of Omd. Contact with lower Omb unit is a 20 to 100m thick zone of 1 to 2m thick intercalated layers of both units

Omfs

Brookside Member- (Ordovician) Coaly black, carbonaceous to silver-gray and white, noncarbonaceous, fine-grained, garnet-biotite-chlorite-quartz-plagioclase-muscovite schist and phyllite with minor and unevenly distributed amounts of disseminated and porphyroblastic (1 to 3mm) pyrite. Garnets are typically 1mm to 4mm and lavender in color. Coaly-black rocks are commonly interlayered with noncarbonaceous rocks on meter-scale with bedding parallel to weak Taconian S2 foliation. Garnets form distinctive bumps on foliations surfaces and give coaly-black rocks similar appearance to DSn. Termination of this unit within the extreme NW part of the Newfane quadrangle appears to be controlled primarily by sedimentary facies change into Omfs; thus, both units may be broadly correlative. Contact with lower Omfp defined by 5 to 15m thick interbedded zone with individual beds 1 to 2m thick. May correlate with Whetstone Hill Member of the Missisquoi Group of central Vermont (Doll and others, 1961; Ratcliffe, in press; Walsh, in press)

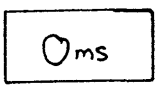
Omb

Pinstriped Granofels Member- (Ordovician) Tan to buff weathering, light to dark gray, well laminated and bedded, garnet-chlorite-muscovite-quartz-plagioclase granofels and interbedded chlorite-muscovite-plagioclase-bearing quartzite. Distinctive mm-scale laminations ("pinstripes") result from mm-scale segregation of quartz-plagioclase lithons from tectonically produced 0.1 to 0.5mm muscovite-chlorite folia, defining

Omfp

either Taconian S2 or Acadian S4.5 foliation. Scattered, 1 to 6mm red garnets are found throughout the granofels layers and frequently mark aluminous tops to graded beds. Quartzite beds appear to be most prevalent in upper part of unit. Also contains abundant Omd dikes. Omfp (and entire Moretown Formation) is separated from underlying Rowe Formation by a Taconian S2 mylonitic fault zone, the Brookside Thrust Zone

Moretown Formation; immediate west side of the Athens Dome (Description from Ratcliffe, 1993)



Lustrous Schist member- (Ordovician) Light gray to silvery-gray, lustrous, biotite-chlorite-quartz-muscovite schist and spangly muscovite schist; unit is highly mylonitic. Distribution and texture may be determined by tectonic position and mylonitization rather than by original sedimentary character