U.S. DEPARTMENT OF THE INTERIOR
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Preliminary Bedrock Geologic Map of the Vermont Part of the 7.5 x 15 Minute Bellows Falls Quadrangle, Windham and Windsor Counties, Vermont

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INTRODUCTION

Bedrock in the Vermont part of the Bellows Falls quadrangle consists of Silurian and Devonian metasedimentary and metavolcanic rocks of the Connecticut Valley sequence (or trough, after Hatch, 1988b), and Ordovician to Silurian and Devonian metasedimentary and Metaigneous rocks informally referred to as the New Hampshire sequence (Billings, 1937, 1956; White and Jahns, 1950). In addition, the rocks are intruded by granitic dikes of the Devonian New Hampshire Plutonic Suite and lamprophyric to intermediate dikes related to the Cretaceous White Mountain Plutonic Suite.

Previous work in this area includes the 1:62,500 published map and text of Kruger (1946), unpublished mapping by John L. Rosenfeld and James B. Thompson, Jr., that has been compiled and published in several guidebook articles (Thompson and Rosenfeld, 1979; Thompson and others, 1993b), and the 1961 State Geologic Map of Vermont (Doll and others, 1961).

Previous models regarding the stratigraphic framework in this area (Doll and others, 1961) maintain that the section of rocks from the western quadrangle boundary to the New Hampshire sequence is a non-faulted stratigraphic succession marked by an unconformity, separating the Connecticut Valley sequence from New Hampshire sequence, along a contact between what has typically been mapped as Putney Volcanics or Gile Mountain Formation of the Vermont sequence, and Littleton Formation of the New Hampshire sequence. This boundary has subsequently been interpreted as an unconformity (called the Chicken Yard Line; Hepburn and others, 1984; Trzcienski and others, 1992; Thompson and others, 1993a and 1993b) and a premetamorphic thrust fault (the Whately thrust; Robinson and others, 1988; the Monroe Line; Hatch, 1988a) that brings New Hampshire sequence rocks westward over the Connecticut Valley Sequence.

Kruger (1946) provided a different interpretation of the boundary between the Connecticut Valley and New Hampshire sequences. He included gray and black carbonaceous phyllite and interbedded conglomeratic quartzite that were typically mapped as Littleton Formation within the Ordovician Orfordville Formation. Because of lithic similarity and an apparent interlayered contact with rocks of the Waits River Formation, Kruger included the Orfordville within the upper part of the Vermont sequence. The boundary with New Hampshire sequence rocks (now placed further east by Kruger) was interpreted as a syn- to post-metamorphic thrust fault, called the Northey Hill thrust. Kruger interpreted the Vermont sequence to be transported eastward along the Northey Hill thrust over the New Hampshire sequence.

Recent work to the north, in the Springfield area (Walsh and others, 1996a, 1996b; Armstrong, 1997) and to the west in the Saxtons River quadrangle (Ratcliffe and Armstrong, 1995, 1996) has shown that lithologies within the Connecticut Valley Sequence are complexly interlayered and do not provide easy separation into two distinct formations, the Waits River and Gile Mountain, as previously reported by Doll and others (1961) and Thompson and others (1993b). In fact, this new work essentially agrees with Kruger (1946) in that similar gray and black carbonaceous rocks on both sides of the Connecticut River may be lithologically related and not separated by any fault or unconformity. Thus, all mapped metasedimentary and metavolcanic units within the Connecticut Valley Sequence in the Bellows Falls quadrangle are given informal member status within the Waits River (Armstrong, 1997).

Other studies in this area include detailed metamorphic petrologic studies by Boxwell and Laird (1987) on the prograde and retrograde reaction histories of assemblages within amphibolites and mafic schist of the Standing Pond Volcanics (now included as separate lithologies within the Waits River Formation), and metamorphic pressure-temperature-time (P-T-t) studies on pelitic schists within the Bellows Falls area (Spear and Chamberlain, 1986; Spear and others, 1990; Spear, 1992).

STRATIGRAPHY

Rocks of the Connecticut Valley Sequence, Metasedimentary Rocks

This study places rocks of the Connecticut Valley Sequence, previously mapped as at least three, into one formation (Waits River). This grouping is the result of the observation that several distinct lithologic units are present, west to east, across the entire belt. This distribution is consistent in areas that had been mapped as separate formations and even, in one case, across different lithostratigraphic sequences. These formations include the Waits River and Gile Mountain Formations, and the Putney Volcanics, all part of the Connecticut Valley Sequence, as well as the Littleton Formation, part of the New Hampshire sequence.

The major metasedimentary units mapped as Waits River Formation include the carbonate- and non-carbonate-bearing gray schists and phyllites (DSwl and DSw, respectively). Previous interpretations by Doll and others (1961) separated what is now mapped as one formation (Waits River) into three formations (Waits River, Gile Mountain, and Littleton). The assignment of rocks to the Gile Mountain Formation was based on the assumption that rocks mapped as the Standing Pond volcanic member of Doll and others (1961) occur as a time-stratigraphic unit that separates older rocks with abundant limestone (Waits River) from younger rocks with little or no limestone (Gile Mountain). Limestone occurs in roughly equal abundance on either side of the westernmost belt of Standing Pond metavolcanic rocks in the

Bellows Falls quadrangle. Thus, it is not possible to separate two distinct formations based on the abundance of limestone. In addition, rhythmically-bedded and graded sequences of gray phyllite and micaceous quartzite assigned to the Gile Mountain Formation, and reported by Fisher and Karabinos (1980) and Hatch (1988b, 1991) from areas north of this study, are absent here. For these reasons the name Gile Mountain is not used in this report, although rocks that are stratigraphically above the volcanics may still be time equivalents of the Gile Mountain rocks to the north.

Metasedimentary rock-types mapped within the Waits River Formation include limestone (DSwl) and non-limestone-bearing (DSw) carbonaceous schist and phyllite. These rocks are predominantly found in the western part of the Connecticut Valley Sequence where they are interlayered with the major metavolcanic and metavolcaniclastic units, described below. In the central part of the sequence, DSw and DSwl are in depositional contact with distinct belts of well-laminated quartzose schist and phyllite (DSwqp). This unit is also interlayered with the metavolcanic and metavolcaniclastic units. The eastern part of the sequence, up to the contact with rocks of the New Hampshire sequence, consists predominantly of DSwqp, with at least three discontinuous horizons of polymict quartz-pebble conglomerate (DSwqc). The conglomerate is strikingly similar in appearance to the lower member of the Clough Formation of the New Hampshire sequence. This unit (DSwqc) was mapped by Kruger as the Hardy Hill quartzite Member of the Orfordville Formation (Kruger, 1946), and subsequently labeled as thin, discontinuous layers of Silurian Clough Quartzite (Sc) on subsequent compilations (Doll and others, 1961). Totally enveloped within very similar gray carbonaceous schists (mapped as Littleton), these horizons were interpreted to represent a single stratigraphic horizon of Clough that was believed to represent the antiformal closure of the Cornish nappe (Thompson and Rosenfeld, 1979), and subsequently, the antiformal closure of the Bernardston nappe (Robinson and others, 1991). Mapping during this study shows that these quartz-pebble conglomerates occur along several different stratigraphic positions within several thin belts of DSw and one belt of DSwl, in the northeastern part of the quadrangle, and within the main belt of DSwqp. In addition, at least one horizon of DSwqc (Interstate 91 roadcut, east-side of northbound lane, 0.4 miles south of Williams River bridge) contains topping criteria that uniformly top east and suggest that it is not folded. Therefore, there is no evidence to suggest that DSwqc is either in the stratigraphic position of the main body of Clough Quartzite, or part of an antiformal or nappe structure.

The distribution of Waits River metasedimentary units described above, suggest that the DSwqp rocks are an eastern stratigraphic facies of the DSw and DSwl units. Doll and others (1961) portrayed the gray schists and phyllites (DSw, DSwl and DSwqp units of this study) east of the easternmost belt of volcanic rocks as Littleton Formation or undifferentiated New Hampshire sequence rocks. The contact between the volcanic rocks and the gray schists and phyllites to the east has been interpreted as an unconformity that separates the Connecticut Valley or

Vermont sequence from the New Hampshire sequence (Doll and others, 1961; Thompson and others, 1990; Thompson and others, 1993b), and is informally referred to as the "Chicken Yard Line" (Hepburn and others, 1984). The laminated, gray quartzose phyllite and schist member (DSwqp) is also present on both sides of the purported contact. This mapping shows that volcanic rocks, limestone-bearing schist and phyllite, and conglomeratic quartzite are present in a wide zone on both sides of the contact, suggesting that there is no demonstrable evidence for an unconformity. Generally, there is a decrease in the amount of volcanic and limestone-bearing rock and a corresponding increase in the amount of quartz-laminated schist and conglomerate east of where the CYL contact was previously defined but the transition cannot be assigned to a single horizon; this makes it difficult to assign regional significance to any particular contact. For these reasons, the metasedimentary rocks are interpreted to form a continuous sequence devoid of any recognizable unconformities or evidence of hiatus in the depositional record. Thus, all of the units are included in the Waits River Formation. The use of the name Littleton for any part of this sequence would imply a coherent a stratigraphic column that would join the Vermont sequence Waits River Formation with the New Hampshire sequence Littleton Formation, and exclude the traditional New Hampshire sequence units, including the Clough Quartzite and the Partridge Formation, from being immediately below the Littleton. This excludes usage of Littleton Formation for the easternmost carbonaceous schists in the Bellows Falls quadrangle.

Metavolcanic Rocks

The metavolcanic rocks in the Connecticut Valley sequence consist of a heterogeneous assemblage of mafic and felsic volcanic rocks interbedded with volcaniclastic sedimentary rocks. The seven different volcanic and volcaniclastic units, described below, are heterogeneously distributed within five general belts; the western belt, comprised of DSwv, DSwg, and Dswa has been mapped to the south within the Townshend quadrangle, where it is continuous with another belt in a large, north-plunging F1 synformal closure (Armstrong, 1995). This other belt (the eastern limb of the synform), consists of units Dswa, DSwv, DSwvf, and DSwsv, and is the third belt, going west to east. The second belt, comprised of DSwf, occurs in the core of the synform at a higher stratigraphic position. The fourth belt is present east of the third belt, and based upon its position with regard to the axial trace of the F1 synform, and local topping criteria, is stratigraphically beneath the first/third belts. The fourth belt is almost 1.5 kilometers wide and consists of numerous horizons of Dswa, Dswv, DSwvq, and single horizons of DSwsv and DSwf. The fifth, and easternmost volcanic belt is immediately east of the western limit of the Westminster West fault zone, and consists of DSwv and DSwvq rocks that mantle a single horizon of DSwvf that interfingers with Dswa to the south, near the Williams River. Based upon structural arguments and stratigraphic symmetry, this belt appears to be distributed within an F1 synform that is complexly refolded by subsequent S2 and S3 deformations. There exists the possibility that this belt may be the transported part of either the first and third belts, or even the lower part of the fourth belt.

The rocks were previously mapped as Standing Pond volcanic member of the Waits River Formation (Doll and others, 1961), Putney Volcanics (Thompson and others, 1993b). Results from this report indicate that all of the metavolcanic and metavolcaniclastic rocks are interbedded with the same types of pelitic metasedimentary rocks of the Waits River Formation (regardless of across-strike position), suggesting that they can not be assigned to separate formations or a single stratigraphic position, without complications due to stratigraphic repeat through faulting or folding. Therefore, the metavolcanic and metavolcaniclastic rocks are mapped as unnamed members of the Waits River Formation.

The name Standing Pond amphibolite was originally applied by Doll (1944) to dark-green, fine- to medium-grained needle amphibolite at Standing Pond in the Strafford 15 minute quadrangle. Later, Doll and others (1961) used the Standing Pond volcanic member of the Waits River Formation to refer to all the volcanic and volcaniclastic rocks deposited, in their interpretation, between the Waits River and Gile Mountain Formations. In accordance with Hatch (1991), however, the name Standing Pond is omitted and the rocks are referred to as unnamed volcanic rocks until a more thorough evaluation can be made of the correlation with the rocks at the type locality of the Standing Pond (Doll, 1944).

The name Putney Volcanics (Hepburn, 1972; Trask, 1980) was introduced to separate the easternmost belt of Standing Pond volcanics as mapped by Doll and others (1961) in southeastern Vermont from other Standing Pond volcanic rocks to the west because it was considered, "less mafic than the typical Standing Pond" (Trask, 1980, p. 133), and it could not be traced to the Standing Pond type locality. The felsic volcanic rocks mapped during this study (DSwvf), some of which would correspond to the Putney Volcanics as shown by Thompson and others (1993b), do not occupy a unique stratigraphic position. In addition, they are gradational with other metavolcanic rocks (DSwv) and metasedimentary rocks (DSwl and DSw), and can not be traced continuously to either of the type localities of the Standing Pond or the Putney. The name Putney Volcanics is therefore not used in this area.

The volcanic rocks in the Connecticut Valley sequence can be subdivided into at least six different units: laminated schist and granofels (DSwv), large garnet and hornblende garbenschiefer schist (DSwg), amphibolite (DSwa), hornblende-plagioclase gneiss (DSwhg), felsic volcanic rocks (DSwvf), and felsic gneiss and quartzose granofels (DSwf). The considerable across strike and along strike variation in the units is consistent with a volcanic and volcaniclastic origin for these rocks.

The laminated schist and granofels (DSwv) is the most heterogeneous and widely distributed volcanic unit in the Waits River but its distribution is largely in the eastern part of the map.

West of the garnet isograd, hornblende fascicle schist and layers with conspicuously large porphyroblasts of garnet and hornblende are mappable. Differences in bulk composition, not readily separable at lower grades, are accentuated by the growth of large porphyroblasts immediately west of the garnet isograd. This permits more detailed mapping of the subunits of the metavolcanic rocks at garnet grade. In the west, where the rocks are well within the garnet zone, only small amounts of the DSwv unit are mappable within the large-garnet hornblende garbenschiefer schist (DSwg) providing evidence that the two units are lithologic equivalents.

Two metavolcaniclastic units (DSwvq and DSwsv), are interbedded with all of the volcanic units, except DSwhg. DSwvq is composed of mm- to cm-scale laminations of limey- to non-limey carbonaceous schist and biotite-chlorite-muscovite-plagioclase-quartz granofels that may represent water-lain intermediate to felsic volcanics. DSwsv consists of very well-bedded limey, carbonaceous schist, calcitic-quartzite, and well-laminated (mm-scale) quartz-plagioclase and schistose horizons, occurs along the margins of DSwv and Dswa in the northern part of the quadrangle, along the western boundary of a central belt of volcanics (DSwvf, Dswa, DSwv, and DSwvq) and the middle of an eastern volcanic belt (Dswa, DSwv, DSwf, DSwvq), where both belts are in contact with either DSwl or DSw. This unit (DSwsv) appears to be an admixture of pelitic and volcanic water-lain sediments.

The hornblende-plagioclase gneiss (DSwhg) is a medium- to very coarse-grained rock consisting of roughly equal percentages of hornblende and plagioclase. Both massive and well-layered varieties of the gneiss occur in the area but are not distinguished on the map due to difficulties in separating the two at 1:24,000 scale. It is exclusively found within DSwqp east of the fifth volcanic belt. Thus, it may be the stratigraphically lowest volcanic horizon in the Bellows Falls quadrangle. Sharp contacts with the surrounding pelite, along with the coarse texture, suggest that an intrusive origin cannot be ruled out, although well defined compositional layering parallel to the contacts with the schist do suggest that it is bedded.

The felsic volcanic member (DSwvf) crops out in the third and fifth volcanic belts, in the northern and central parts of the quadrangle, respectively. The third belt DSwvf has gradational contacts with volcaniclastics of unit DSwsv. The fifth belt DSwvf has gradational and sharp contacts with the volcanic unit DSwv, and south of Coburn Hill, gradational, interfingering contacts with massive amphibolite (Dswa).

Rocks of the New Hampshire sequence

A sequence of rocks, herein referred to informally as the New Hampshire sequence, originally defined by Billings (1937) in the Littleton, New Hampshire area to the north and subsequently modified in the Fall Mountain area by Kruger (1946), consists of several formations, including the Ordovician Ammonoosuc Volcanics and the Partridge Formation, the Silurian Clough

Quartzite, the Silurian and Devonian Fitch Formation and the Devonian Littleton Formation. Results of mapping in the Bellows Falls quadrangle show that the New Hampshire sequence in Vermont is restricted to the southern part of the mapped part of the quadrangle, in Vermont. In addition, the Ammonoosuc Volcanics and Fitch Formation are not present within the Vermont of the quadrangle.

The Partridge Formation (Op) consists of rusty-weathering sulfidic schists that are typically well laminated parallel to the dominant S1 foliation. Several 1- to 2-m-thick, coarse-grained amphibolites (Opa) are present within the schist and have contacts parallel to the S1 foliation; these may be dikes or sills. The sulfidic schist of the Partridge Formation is readily distinguished from the voluminous gray schists and phyllite of the Waits River Formation by its rusty orange weathering. Good exposures of Partridge schist and amphibolite are present on the immediate west-side of the southern summit of Oak Hill, immediately west of the Connecticut River and approximately 1.0 km west of the village of Bellows Falls. One of the layers of amphibolite (Opa) cuts across the contact between sulfidic schist (Op) and massive to bedded, carbonate-rich granofels of the Partridge Formation (Opgc). This unit is immediately west of, and based on topping criteria in overlying units, stratigraphically below the sulfidic schist previously mentioned. West of, and below, Opgc is a bluish-gray phyllite (Opgs) and schist with distinctive small garnets that decorate foliation surfaces, producing a distinctive "bumple" texture. The contact with the overlying Opgc is sharp, and parallel to internal compositional layering within both units. Another layer of Opa is found within this belt of Opgs. This unit is extremely similar to the small garnet schist member of the Cram Hill Formation, and the Whetstone Member of the Moretown Formation, as mapped to the west in the Saxtons River quadrangle (Ratcliffe and Armstrong, 1995b, 1996). Both of these units are part of the Vermont pre-Silurian Taconide sequence. More sulfidic schist (Op) is found to the west of Opgs, and is in contact with the underlying DSwqp unit of the Waits River Formation along the Minards Pond thrust; the tectonic contact between the Vermont and New Hampshire sequence as interpreted in this study.

Along the northern part of Oak Hill, the Partridge Formation is in sharp contact with poorly bedded, massive white to light-gray quartz-pebble to boulder conglomerate which was mapped as the lower member of the Silurian Clough Quartzite (Scl) in the Springfield quadrangle, immediately north (Walsh and others, 1996a, 1996b; Armstrong, 1997). In the Springfield quadrangle, rare layers of deeply weathered, brown, quartz-calcite and calc-silicate rock, 0.5- to 3-m-thick, contain fossils. Tetracoral, brachiopods, pelycypods and a possible trilobite, described by Boucot and others (1958) and Boucot and Thompson (1963), support a Llhandovery (Early Silurian) age.

The contact between Partridge and Clough has classically been interpreted as a significant erosional unconformity (Thompson, 1954; Doll and others, 1961; Thompson and others, 1968, 1993b). The lower member of the Clough Quartzite is dominated by the poorly bedded conglomerate, having rounded clasts of vitreous, white vein quartz and rare clear clasts of quartzite. Local discontinuous lenses, 1- to 3-m-thick, of chlorite-biotite-muscovite-garnet-quartz schist and chlorite-muscovite-plagioclase-quartz granofels are found within the upper part of the lower member. Good exposures of this member can be found on the top part of the eastern slope of Oak Hill, 1.5 kilometers west of Bellows Falls village.

On the southern part of Oak Hill, the polymict conglomerate thins and is interbedded on a 1- to 5 meter scale with a very well-bedded sequence of gray quartzite and carbonate-bearing graywacke (Scbg) with distinct 1- to 10 mm diameter detrital blue-quartz grains, and thin (1 to 15 cm thick) lenses of polymict pebble conglomerate. Sedimentary tops from normal and reverse-graded beds, and occasional cross-beds indicate that the Clough tops to the east, and is stratigraphically above the Partridge Formation. These tops are further used to constrain the stratigraphic arrangement of the Partridge lithologies previously mentioned.

As the contact between the Scl and Scbg is traced southward from the interlayered zone, the Scbg unit is in direct contact with Partridge sulfidic schist (Op), and then carbonate-bearing granofels (Opgc). This suggests that Scbg is a facies of Scl and that the Clough unconformably overlies the Partridge, in agreement with Thompson (1954), Thompson and Rosenfeld (1979) and Thompson and others (1968, 1993a, 1993b).

Immediately south of Oak Hill, in the northern part of the Walpole quadrangle, Scbg is exposed in the bed of the Saxtons River. Topping criteria show that it tops east into excellent exposures of polymict conglomerate of unit Scl. Previous studies considered this section of Scbg to be part of the Fitch Formation, structurally underneath the Clough along the overturned limb of the Skitchewaug nappe (Thompson and Rosenfeld, 1979; Robinson and others, 1991). The topping criteria and stratigraphic relationships found in the Saxtons River and at Oak Hill, described above, argue against this interpretation, and help to constrain these rocks to the bottom of the Clough.

STRUCTURE

The oldest foliation in the Silurian and Devonian rocks is a bed-parallel schistosity (Acadian S1). Although not observed within the Bellows Falls area, rarely observed isoclinal folds with generally north or south gently plunging fold hinges (Acadian F1) have been found to the north in the Springfield area (Walsh and others, 1996a, 1996b). Only in the hinge regions of these early F1 folds is it possible to see bedding that is not parallel to a foliation. Both the Connecticut Valley and New Hampshire sequence rocks possess a first generation (Acadian S1) schistosity, but they do not appear to have developed under the same metamorphic conditions.

The S1 foliation in the New Hampshire sequence appears to have developed during an earlier metamorphic event that appears not to have occurred within rocks of the Vermont sequence (Armstrong, 1997; Walsh and others, 1996a, 1996b; Spear, 1992). S1 foliation in the Connecticut Valley sequence developed prior to the peak of greenschist facies metamorphism which, based upon porphyroblast-fabric relative-age relationships, occurred syn- to post-S2 development.

The second generation planar fabric in the Silurian and Devonian rocks of the Vermont sequence and Ordovician to Devonian rocks of the New Hampshire sequence (Acadian S2) varies from a non-penetrative cleavage in some rocks in the southwestern part of the quadrangle, to a penetrative schistosity everywhere else. Folds associated with the second generation planar fabric (Acadian F2) vary from open to isoclinal with generally consistent shallow plunges to both the north and south, but locally the plunges are quite steep. S1 and S2 are the most dominant, or visibly conspicuous, planar fabrics in the Silurian and Devonian rocks. Locally, these two planar fabrics are parallel and it is difficult to discern one from the other.

The next youngest generation(s) of planar fabrics are broad to open folds with both shallow and steep fold hinges and associated mm to cm spaced cleavage. These structures have many different orientations, although they most commonly strike northeast and dip vertically to steeply northwest and southeast. To the west, in the Saxtons Rive quadrangle, these folds are related to development of both the Chester and Athens domes (Ratcliffe and Armstrong, 1995b, 1996). Within the central part of the Bellows Falls quadrangle, northeast-trending, steep northwest and southeast dipping folds appear to be genetically related to the development of a pervasive mylonitic foliation with associated shear-bands. This asymmetric fabric produces a C-S relationships, that along with other asymmetric fabric features and measurable offset markers that indicate sinistral, or left-lateral, fault motion. Elongation lineations and fabric intersections trend northeast and have a moderate plunge, indicating that (at least some) motion was also east-over-west, and thus oblique-slip in nature. There are two discreet zones shown on the map, and are labeled as the Westminster West fault zone. These zones can now be traced continuously into the Walpole and Townshend quadrangles to the south and southeast, respectively, where they were first mapped in the village of Westminster West, Vermont (Armstrong, 1995). The faults also appear to be traceable into the Springfield quadrangle to the north, although they are not portrayed on any maps of this area (Walsh and others, 1996a, 1996b). At present, it is believed that the two faults merge into one somewhere underneath the Connecticut River floodplain in either the northern part of the Bellows Falls quadrangle or the southern part of the Springfield quadrangle. The single zone appears to continue north along a contact that was previously mapped as the "Chicken Yard Line" (Trzcienski and others, 1993), and which is now mapped as a contact between volcanics and gray schist of the Waits River Formation (Walsh and others, 1996a, 1996b).

In the southern part of the Bellows Falls quadrangle, the eastern splay of the Westminster West fault zone seems to be the boundary between either staurolite- or garnet-grade rocks to the east and sub-garnet-grade rocks to the west. Thus it would be post-peak metamorphic with respect to the higher-grade rocks in the eastern part of the quadrangle. Parts of the fault, however, display intensely developed S2 mylonitic fabric, that is commonly deformed by both the C-S, S3 penetrative fabric and related F3 crenulate folds. This would suggest that the Westminster West fault zone, at least in the Bellows Falls area, is of composite age and may span S2 and S3 deformational events. Alternatively, S2 and S3 might have been parts of a single, continuous deformational event.

The youngest generation of cleavage in the area is a cm to 30 cm spaced cleavage that locally occurs as parallel kink bands or low-amplitude, high-wavelength folds with variable fold hinge orientations. Secondary minerals, largely quartz, calcite, and dolomite, occur as vein-filling material in the cleavage planes. This latest generation of cleavage generally strikes east-west and dips sub-vertically, and is largely restricted to the eastern and southern parts of the map area. This cleavage, and the outcrop-scale and map-scale brittle faults in the area, may be related to Mesozoic extension (Hatch, 1988a).

The Minards Pond thrust

Located west of Minards Pond, and well exposed along east-side roadcuts of northbound Interstate-91, the Minards Pond thrust is a post-metamorphic contact between staurolite- to sillimanite-grade sulfidic schist, calc-silicate and amphibolite rocks that structurally overlie sub-garnet to staurolite-grade rocks that are part of the Waits River Formation (DSwqp and DSwqc). In this area, the fault is folded by F2 and younger folds into a relatively tight synform. Compositional layering in the overlying rocks (labeled as Partridge Formation, Op) is defined by bed-parallel foliation, S1. S1 is truncated along the fault contact, which is generally concordant with the regional S2, that affects rocks of both Vermont and New Hampshire sequences. S1 in the Vermont rocks in this area, where recognizable, is also discordant with the fault contact. Based upon mineral textures and deformational fabric features, sillimanite-grade rocks within the upper plate of the fault appear to have experienced a metamorphism prior to the regional garnet-to staurolite-grade metamorphism that affected Vermont rocks as well. The chronology of events would thus be as follows; sillimanite-grade metamorphism within the sulfidic, calc-silicate rocks, prior to thrust transport. This metamorphism would have probably occurred somewhere to the east, since no sillimanite-grade rocks are found anywhere to the west, in Vermont. Sillimanite-grade rocks are present east of and immediately within Bellows Falls, and are associated with a contact metamorphic event and subsequent crustal loading related to the intrusion of the Bellows Falls pluton and thrust-nappe development (Spear and others, 1990; Spear, 1992). Preliminary work in the Fall Mountain (New Hampshire) area indicates that the rocks immediately underneath the Bellows Falls Pluton are probably part of the Silurian Rangeley Formation (see description of Rangeley in Spear, 1992). Since rocks of the Partridge Formation, immediately east of Minards Pond do not contain sillimanite, which would be likely if the rocks of the Minards Pond thrust slice were just part of an outlier of that section, it may be that these rocks are actually part of the Rangeley Formation. According to Spear (1992) and Allen (1985), the Rangeley Formation and the Bellows Falls Pluton were transported, east to west, within the Fall Mountain Nappe. Although considered to be a fold nappe, it may very well be that the Minards Pond thrust is a western extension of the Fall Mountain structure; which may actually be a thrust fault.

Rocks within the Minards Pond thrust slice have previously been interpreted as the northern closure of the Wellington Hill anticline (Thompson and Rosenfeld, 1979), located within the Walpole quadrangle, immediately south. Rocks within the anticline were interpreted as either autochthonous New Hampshire sequence (informally referred to as the Bronson Hill sequence) or the upright limb of another Acadian fold-nappe, structurally beneath the rocks at Oak Hill and Bellows Falls (the "Skitchewaug nappe"; Thompson and Rosenfeld, 1979). Reinterpretation of the structure within the Bellows Falls quadrangle as a synformal thrust slice implies that the Wellington Hill structure to the south may be synformal, allochthonous, and part of the Rangeley Formation rather than the Partridge Formation.

METAMORPHISM

Paleozoic metamorphic grade within the Vermont part of the Bellows Falls quadrangle ranges from the chlorite- through the staurolite-zone, with rocks of the Minards Pond thrust slice reaching into the sillimanite-zone Rocks in the western part of the map area are at garnet-grade as evidenced by abundant garnet porphyroblasts in pelitic and semi-pelitic rock types and hornblende-garnet amphibolite within the garbenschiefer unit of the Waits River (DSwg). Large garnets are found sporadically within the gray schists in the western part of the Waits River Formation (DSw and DSwl). Large garnet and hornblende porphyroblasts are common within the western three belts of volcanic lithologies in the Waits River Formation. The central part of the Waits River Formation is devoid of garnets, and only the specific units contain biotite.

The western garnet isograd (garnet-in to the west) appears to be sharp and is approximately located along the western splay of the Westminster West fault zone, although several areas east of the fault do contain garnets (DSw, and DSwqp), but these may be Mn-rich. Based upon mineral-fabric textural relationships, garnet porphyroblasts generally appear to have grown synchronous with , or after, S2 development.

In the eastern part of the study area, garnet- and staurolite-grade rocks occur within pelitic schists of the Waits River Formation (especially DSwqp). Garnet appears to the east, along Interstate-91, although subsequent syn-S3 (Westminster West fault zone) deformation appears to be related to locally intense retrogression of garnet assemblages. Pristine staurolite occurs in rocks just east of the interstate, and is well exposed in outcrops along highway U.S. 5, immediately south of the intersection with state route 131. The steep metamorphic field gradient (with increasing grade from west to east) may be largely telescoped by the subsequent S3 deformation, specifically, by truncation of garnet- and sub-garnet-grade sections along the eastern splay of the Westminster West fault zone.

In the New Hampshire sequence, only the sulfidic schist and gray schist units of the Partridge Formation contain either garnet or staurolite. The lack of appearance of key metamorphic minerals in the other New Hampshire sequence rocks may be strongly controlled by bulk compositional variation. Therefore, variation in metamorphic intensity (pressure, temperature) may not be a factor within these rocks. Metamorphism within the New Hampshire sequence rocks appears to postdate S1 but may be synchronous with S2, and is likely related to the same metamorphic event which caused the garnet to staurolite-grade metamorphism within the eastern part of the Connecticut Valley sequence. This eastward increase in metamorphic grade may be related to eastward thickening tectonic load during S2, westward transport of the New Hampshire sequence over the Vermont sequence. Thus rocks were buried progressively deeper during this event, from west to east. The westward increase, from chlorite-biotite to garnet-grade, in the western part of the Connecticut Valley sequence, is most likely related to an increase in burial from east to west across this area; the opposite direction for increasing intensity for rocks in the eastern part of the sequence. It is not known whether the western and eastern metamorphic sequences are of the same age. Regardless, the explanation for the change in direction of increasing metamorphic grade, and thus opposing directions of progressive crustal burial during regional metamorphism must somehow be related to the post-peak metamorphic Westminster West fault zone. The exact role of this tectonic event in the distribution of metamorphic regimes, however, is not known at this time.

REFERENCES CITED

Allen, T., 1985, A reinterpretation of the Fall Mountain nappe, as seen from Fall Mountain, North Walpole, New Hampshire. Geological Society of America Abstracts with Programs.

Armstrong, T.R., 1995, The Westminster West Fault Zone: A late Acadian-Alleghenian contact between the Vermont and New Hampshire Sequences in southern Vermont. Geological Society of America Abstracts with Programs.

Armstrong, Thomas R., 1997, The boundary between the Connecticut Valley trough and Bronson Hill anticlinorium in southeastern Vermont and adjacent New Hampshire: Geological Society of America Abstracts with Programs.

Billings, M.P., 1937, Regional metamorphism in the Littleton - Moosilauke area, New Hampshire: Geological Society of America Bulletin, v. 48, p. 463-566.

Billings, M.P., 1956, The geology of New Hampshire, Part II, bedrock geology: Concord, N.H., New Hampshire State Planning and Development Commission, 203 p., scale 1:250,000.

Boucot, A.J., MacDonald, G.J.F., Milton, C., and Thompson, J.B., Jr., 1958, Metamorphosed Middle Paleozoic fossils from central Massachusetts, eastern Vermont, and western New Hampshire: Geological Society of America Bulletin, v. 69, p. 855-870.

Boucot, A.J., and Thompson, J.B., Jr., 1963, Metamorphosed Silurian brachiopods from New Hampshire: Geological Society of America Bulletin, v. 74, p. 1313-1334.

Boxwell, M. and Laird, J., 1987, Metamorphic and deformational history of the Standing Pond and Putney Volcanics in southeastern Vermont, *in* Westerman, D.S., editor, *New England Intercollegiate Geological Conference: Guidebook for Field Trips in Vermont*, v. 2, 79th Meeting, Montpelier, Vermont, p. 1-20.

Doll, C.G., 1944, A preliminary report on the geology of the Strafford quadrangle, Vermont: Vermont State Geologist Report 24, p. 14-28, scale 1:62,500.

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

Fisher, G.W., and Karabinos, P. 1980, Stratigraphic sequence of the Gile Mountain and Waits River Formations near Royalton, Vermont: Geological Society of America Bulletin, Part I, v. 91, p. 282-286.

Hatch, N.L., Jr., 1988a, New evidence for faulting along the "Monroe Line", eastern Vermont and westernmost New Hampshire: American Journal of Science, v. 288, no. 1, p. 1-18.

Hatch, N.L., Jr., 1988b, Some revisions to the stratigraphy and structure of the Connecticut Valley trough, eastern Vermont: American Journal of Science, v. 288, no. 10, p. 1041-1059.

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

Hepburn, J.C., 1972, Geology of the metamorphosed Paleozoic rocks in the Brattleboro area, Vermont: Cambridge, Massachusetts, Harvard University, unpublished Ph.D. thesis, 342 p.

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 No. 32, 162 p., scale 1:62,500.

Kruger, F.C, 1946, Structure and metamorphism of the Bellows Falls quadrangle of New Hampshire and Vermont: Geological Society of America Bulletin, v. 57, p. 161-206.

Ratcliffe, N.M. and Armstrong, T.R., 1995, Preliminary bedrock geologic map of the Saxtons River 7.5 x 15 minute quadrangle, Windham and Windsor counties, Vermont: U.S. Geological Survey Open-File Report 95-482, scale 1:24,000.

Ratcliffe, N.M., and Armstrong, T.R., 1996, Digital bedrock geologic map of the Saxtons River 7.5 x 15 minute quadrangle, Vermont: U.S. Geological Survey Open-File Report 96-52, scale 1:24000.

Robinson, Peter, Hatch, N. L. and Stanely, R. S., 1984, The Whately thrust: A proposed structural solution to the stratigraphic dilemma of the Erving Formation and associated Devonian strata, western Massachusetts and adjacent Vermont. Geological Society of America Abstracts with Programs.

Robinson, Peter, Thompson, P. J., and Elbert, D. C., 1991, The nappe theory in the Connecticut Valley region: Thirty-five years since Jim Thompson's first proposal. American Mineralogist, v. 76, p. 689-712.

Spear, F. S., and Chamberlain, C. P., 1986, Metamorphic and tectonic evolution of the Fall Mountain nappe complex and adjacent Merrimack synclinorium. *In* Peter Robinson and D. C. Elbert, Eds., *Field trip guidebook: Regional metamorphism and metamorphic phase relations in northwestern and central New England*, p. 121-144. Field Trip B-5, International Mineralogical Association, 14th General Meeting at Stanford University, Contribution no. 59, Department of Geology and Geography, University of Massachusetts, Amherst, Massachusetts.

Spear, F. S., Hickmott, D. D., and Selverstone, J., 1990, Metamorphic consequences of thrust emplacement, Fall Mountain, New Hampshire. Geological Society of America Bulletin, v. 102, p. 1344-1360.

Spear, F. S., 1992, Inverted metamorphism, P-T paths and cooling history of west-central New Hampshire: Implications for the tectonic evolution of central New England, *in* Robinson, P., and Brady, J.B., editors, *Guidebook for Field Trips in the Connecticut Valley Region of Massachusetts and Adjacent States*, v. 2, New England Intercollegiate Geological Conference, 84th Annual Meeting, Amherst, Massachusetts, p. 446-466.

Thompson, J.B., Jr., 1954, Structural geology of the Skitchewaug Mountain area, Claremont quadrangle, Vermont - New Hampshire, *in* New England Intercollegiate Geological Conference, 46th meeting, Hanover, New Hampshire, p. 36-41.

Thompson, J.B., Jr., Robinson, P., Clifford, T.N., and Trask, N.J.,Jr., 1968, Nappes and gneiss domes in west-central New England, *in* E-an Zen, W.S. White, J.B. Hadley, and J.B. Thompson, Jr., editors, *Studies of Appalachian Geology: Northern and Maritime*, Wiley-Interscience, New York, New York, p. 203-218.

Thompson, J.B., Jr., and Rosenfeld, J.L., 1979, Reinterpretation of nappes in the Bellows Falls - Brattleboro area, New Hampshire - Vermont, *in* J. W. Skehan and P. H. Osberg, Eds., *The Caledonides in the U. S. A.: Geological excursions in the northeast Appalachians*, p. 117 - 121. International Geological Correlation Program Project 27, Caledonide Orogen, Weston Observatory, Weston, Massachusetts.

Thompson, J.B., Jr., McLelland, J.M., and Rankin, D.W., 1990, Simplified geologic map of the Glens Falls 1° x 2° quadrangle, New York, Vermont, and New Hampshire: U.S. Geological Survey Miscellaneous Field Studies Map MF-2073, scale 1:250,000.

Thompson, J.B., Jr., Bothner, W.A., Robinson, Peter, Isachsen, Y.W., and Klitgord, K.D., 1993a, Geological Society of America, Centennial Continent-Ocean Transect, No. 17, E-1, Adirondacks to Georges Bank, 55 p., scale 1:500,000.

Thompson, J.B., Jr., Rosenfeld, J.L., and Chamberlain, C.P., 1993b, Sequence and correlation of tectonic and metamorphic events in southeastern Vermont, *in* Cheney, J.T. and Hepburn, J.C, editors, *Field Trip Guidebook for the Northeastern United States: 1993 Boston GSA*, v. 1, Contribution No. 67, Department of Geology and Geography, University of Massachusetts, Amherst, Massachusetts, p. B1-B26.

Trask, N.J., 1980, The Putney Volcanics in southeastern Vermont and north-central Massachusetts: in Changes in Stratigraphic Nomenclature: U.S Geological Survey Bulletin 1502-A, p. 133-134.

Trzcienski, W.E., Thompson, J.B., Jr., Rosenfeld, J.L., and Hepburn, J.C., 1992, The chicken yard line / Whately fault debate: From Springfield, Vermont to Whately, Massachusetts, *in* Robinson, P., and Brady, J.B., editors, *Guidebook for Field Trips in the Connecticut Valley Region of Massachusetts and Adjacent States*, v. 2, New England Intercollegiate Geological Conference, 84th Annual Meeting, Amherst, Massachusetts, p. 291-304.

Walsh, G.J., Armstrong, T. R., and Ratcliffe, 1996a, Digital bedrock geologic map of the Vermont part of the 7.5 x 15 Minute Mount Ascutney and Springfield quadrangles, Vermont: U.S. Geological Survey Open-File Report 96-733a, scale 1:24,000.

Walsh, G.J., Armstrong, T. R., and Ratcliffe, 1996b, Preliminary bedrock geologic map of the Vermont part of the 7.5 x 15 Minute Mount Ascutney and Springfield quadrangles, Vermont: U.S. Geological Survey Open-File Report 96-733b, scale 1:24,000.

White, W.S., and Jahns, R.H., 1950, Structure of central and east-central Vermont: Journal of Geology, v. 58, p. 179-220.

DESCRIPTION OF MAP UNITS

(Major minerals listed in order of increasing abundance)

POST-METAMORPHIC INTRUSIVE ROCKS

Kd

Mafic dikes (Cretaceous)--- Aphanitic, dark-gray to black, lamprophyre, camptonite, or diabasic dikes. Dikes range in thickness from 0.3 to 2.0 m and may contain phenocrysts of biotite, amphibole, pyroxene, and olivine. May contain amygdules filled with dolomite or calcite. Generally, dikes intrude parallel to joint sets. Dikes are unfoliated but may be blocky jointed. Shown by symbol only

LATE-METAMORPHIC INTRUSIVE ROCKS

Dg

Granite (Devonian) -- Massive to weakly foliated, muscovite-biotite-quartz-microcline-plagioclase granite to granodiorite dikes and sills, that cross cut foliated country rocks. Dikes cut an early bed-parallel foliation (S1) in the Silurian-Devonian rocks, but pre-date or are synchronous with the development of the S2 foliation. Well-exposed granite dikes exhibiting cross-cutting relationships are exposed at an outcrop on the west side of Interstate 91 (southbound) directly east of Coburn Hill and on top of Randall Hill in the northwestern part of the map area

ROCKS OF THE NEW HAMPSHIRE SEQUENCE

Metasedimentary Rocks

Clough Formation (Silurian)

Scbq

Upper, bedded-granofels unit -- dark- to light-gray to creamy-whitish gray, chlorite-muscovite-plagioclase-quartz schist and granofels, interbedded with 1- to 15-cm thick layers of light-gray to buff-colored quartzite, identical to vitreous quartzite beds in lower unit (Scl). Unit contains very distinctive normal- and reverse-graded beds

Scl

Lower, quartzite unit – Light- gray to creamy-whitish gray, massive, polymictic conglomerate with chlorite-muscovite-plagioclase-quartz schistose to granulose light- gray to buff-colored quartzite, identical to vitreous quartzite beds in overlying bedded granofels (Scbq). The proportion of matrix to clasts varies but the majority of the unit is clast-supported. Lower part of unit contains distinct horizons of gray carbonaceous sulfidic schist similar to sulfidic schist in Partridge Formation (Op)

Partridge Formation (Ordovician)

metasedimentary rocks

Op

Sulfidic schist -- Heterogeneous, rusty- and tan-weathering, dark- to light-gray, pyritiferous ilmenite-muscovite-chlorite-plagioclase-quartz±garnet±staurolite schist

Opgc

Carbonate-bearing granofels -- Massive, coarse-grained, granulose, tan-weathering, dark- to light-gray, ilmenite-chlorite-muscovite-biotite-calcite-quartz-plagioclase granofels

Opgs

Gray garnet schist -- Homogeneous, medium-grained, dark- to light-gray, pyritiferous, ilmenite-chlorite-biotite-muscovite-plagioclase-quartz±garnet±staurolite±magnetite schist with distinctive 1- to 5-mm garnet bumps on foliation surfaces

metaigneous rocks

Opt

Tonalite gneiss -- Heterogeneously layered, medium- to coarse-grained, creamy-gray-weathering, light-gray, ilmenite-chlorite-muscovite-plagioclase-quartz±garnet gneiss with frequent 1- to 10-cm, discontinuous, dark-gray, chlorite-muscovite-biotite layers that might represent relict restite or more mafic phases of melt

Opa

Amphibolite -- Dark-green to green, medium- to coarse-grained, massive, epidote-chlorite-hornblende-plagioclase gneiss (amphibolite) with 1 to 3 mm, white, plagioclase porphyroclasts and hornblende forming a relict ophitic texture. Generally, amphibolite has sharp contacts with adjacent units and may be intrusive

ROCKS OF THE CONNECTICUT VALLEY SEQUENCE

Waits River Formation (Silurian and Lower Devonian)

metasedimentary rocks

DSwl

Limestone and schist -- Dark- to light-gray, locally rusty-weathering, fine-grained, lustrous, carbonaceous chlorite-muscovite-plagioclase-quartz schist and phyllite with interbedded dark blue-gray, dark-brown weathering siliceous limestone, quartz-rich limey schist, and gray calcareous to non-calcareous quartzite. Schist contains biotite and garnet in the western part of the map area. Distinguished from the gray phyllite and schist unit (DSw) by the abundance of brown-weathering limestone and rusty calcite-bearing schist. Beds of limestone range in thickness from 1 cm to 1.5 m and may comprise anywhere from 10 to 90 percent of an exposure. Contacts with DSw are gradational to sharp as limestone beds either gradually or abruptly decrease in abundance and thickness. Contacts with DSw are interpreted as facies changes and may not necessarily imply stratigraphic order

DSw

Gray phyllite and schist -- Dark- to light-gray, fine-grained, lustrous carbonaceous chlorite-muscovite-plagioclase-quartz schist and phyllite. In places interbedded with thin, gray quartzite, tan to gray feldspathic quartzite, and gritty plagioclase-quartz granofels. Beds range in thickness from 3 to 10 cm. Locally contains rare, very thin (1-2 cm) brown-weathering limestone beds. Schist contains biotite and garnet in the western part of the map area

DSwqp

Quartzose schist and gray phyllite -- Homogenous, well-layered, light-steel-gray-weathering, dark-gray, muscovite-chlorite-plagioclase-quartz schist with distinctive 1- to 4-cm ribbon-like layers of bluish gray, medium-grained quartzite that may contain detrital blue quartz grains. Unit occurs in the middle of the quadrangle and along the contact with the New Hampshire sequence rocks

DSwqc

Polymict conglomerate -- Creamy-white to light-gray weathering, massive to weakly layered, typically clast-supported, quartz-pebble and cobble conglomerate. Matrix around clasts consists of ilmenite-chlorite-muscovite-quartz and is usually 1- to 5-mm-thick and discontinuous. Pebbles consist of angular to rounded, 1 mm to 10 cm diameter clasts of light- to bluish gray, vitreous quartzite or white to buff gray, opaque quartz derived from veins. Along mutual, irregular contacts, many pebbles show signs of dissolution and accumulation of ilmenite. Pebbles are either undeformed or weakly flattened in the plane of weakly developed foliation (in areas of more abundant matrix). Contacts with quartzose schist and phyllite unit (DSwqp) are typically sharp. Unit is lithically similar to the lower unit of the Clough Formation (Scl) of the New Hampshire sequence metavolcanic rocks

DSwr

Rusty schist -- Heterogeneous, laminated (mm-scale) to layered (cm-scale), green and white, in places rusty-weathering, fine- to medium-grained muscovite±biotite-chlorite-quartz-plagioclase schist and silvery-green, fine- to medium-grained, muscovite±biotite-chlorite-quartz-plagioclase schist. Occurs as thin (10- to 30-m thick) discontinuous layer within the southwestern part of the map area

DSwv

Laminated schist and granofels -- Heterogeneous, laminated (mm-scale) to layered (cm-scale), green and white, in places rusty-weathering, fine- to medium-grained muscovite±biotite-chlorite-quartz-plagioclase schist; silvery-green, fine- to medium-grained, muscovite±biotite-chlorite-quartz-plagioclase schist; gray-green, medium-grained, muscovite±biotite-chlorite-quartz-plagioclase granofels; gray to light-gray, biotite-chlorite-muscovite-quartz-plagioclase± carbonate±garnet granofels in 5-cm- to 2-m-thick beds with coarse (1- to 8-mm) plagioclase and quartz porphyroclasts; green, fine-grained quartz-epidote-chlorite-plagioclase schist or greenstone; and silvery-gray, rusty- weathering calcite-muscovite-chlorite-quartz-plagioclase schist. In places, the unit is pitted where it contains accessory carbonate; contains accesory ilmenite porphyroblasts and porphyroclasts 1- to 5-mm in diameter. Unit is interpreted as a heterogeneous assemblage of volcaniclastic sediments and primary volcanics

DSwvf

Felsic volcanics -- Silvery-green to green calcite±epidote-muscovite-quartz-chlorite-plagioclase phyllite to schist; light-gray to whitish pale-green, fine-grained, bedded (3- to 50-cm-thick), epidote-muscovite-chlorite-quartz-plagioclase-feldspathic schist and granofels locally with 1 to 3 mm quartz and plagioclase porphyroclasts (phenocrysts ?); gray-green, massive, fine- to medium-grained, muscovite-chlorite-quartz-plagioclase feldspathic granofels with 1 to 3 mm quartz and sausseritized plagioclase porphyroclasts (phenocrysts?) and epidote and actinolite pseudomorphs after pyroxene; and green to dark-green, fine-grained, quartz-plagioclase-epidote-chlorite schist or greenstone (less than 10 percent of exposures). Contains accessory sulfides. Interpreted as a heterogeneous, metamorphosed sequence of volcaniclastic sediments, crystal tuffs, dacitic to andesitic flows, and mafic volcanics

DSwa

Amphibolite -- Dark-green to green, fine-grained, massive epidote-chlorite-hornblende-plagioclase gneiss (amphibolite) with 1 to 3 mm, white, sausseritized plagioclase porphyroclasts (DSwa) and laminated to massive, epidote carbonate-actinolite-chlorite-plagioclase greenstone

DSwg

Large-garnet and hornblende garbenschiefer schist -- Silvery-gray to light-gray, in places rusty-weathering, epidote-muscovite-biotite-chlorite-garnet-hornblende-quartz-plagioclase schist with distinctive 1 to 5 cm sprays of hornblende and 1 to 7 cm garnet porphyroblasts. Unit is interpreted as metamorphosed pelitic sediments with a volcaniclastic component. Unit is interlayered with metasedimentary (DSwl) and metavolcanic (DSwa and DSwvf) rocks

DSwhg

Hornblende-plagioclase gneiss -- Dark-green to purplish-gray, medium- to coarse-grained, epidote-chlorite±garnet-hornblende-plagioclase gneiss with roughly equal percentages of hornblende and plagioclase. Unit varies from massive, weakly foliated, and very coarse-grained gneiss to well layered gneiss. Where massive, intergrowths of hornblende with matrix plagioclase are ubiquitous, forming a possible replacement for relict ophitic texture. Contacts with surrounding units are sharp. Massive variety may, in part, be intrusive

DSwf

Felsic gneiss and quartzose granofels member -- Light-gray, tan-weathering, biotite-quartz-plagioclase gneiss, and medium-gray, feldspathic biotite quartzite and granofels, and volcaniclastic rock interbedded with hornblende-plagioclase gneiss (DSwhg)

metavolcaniclastic rocks

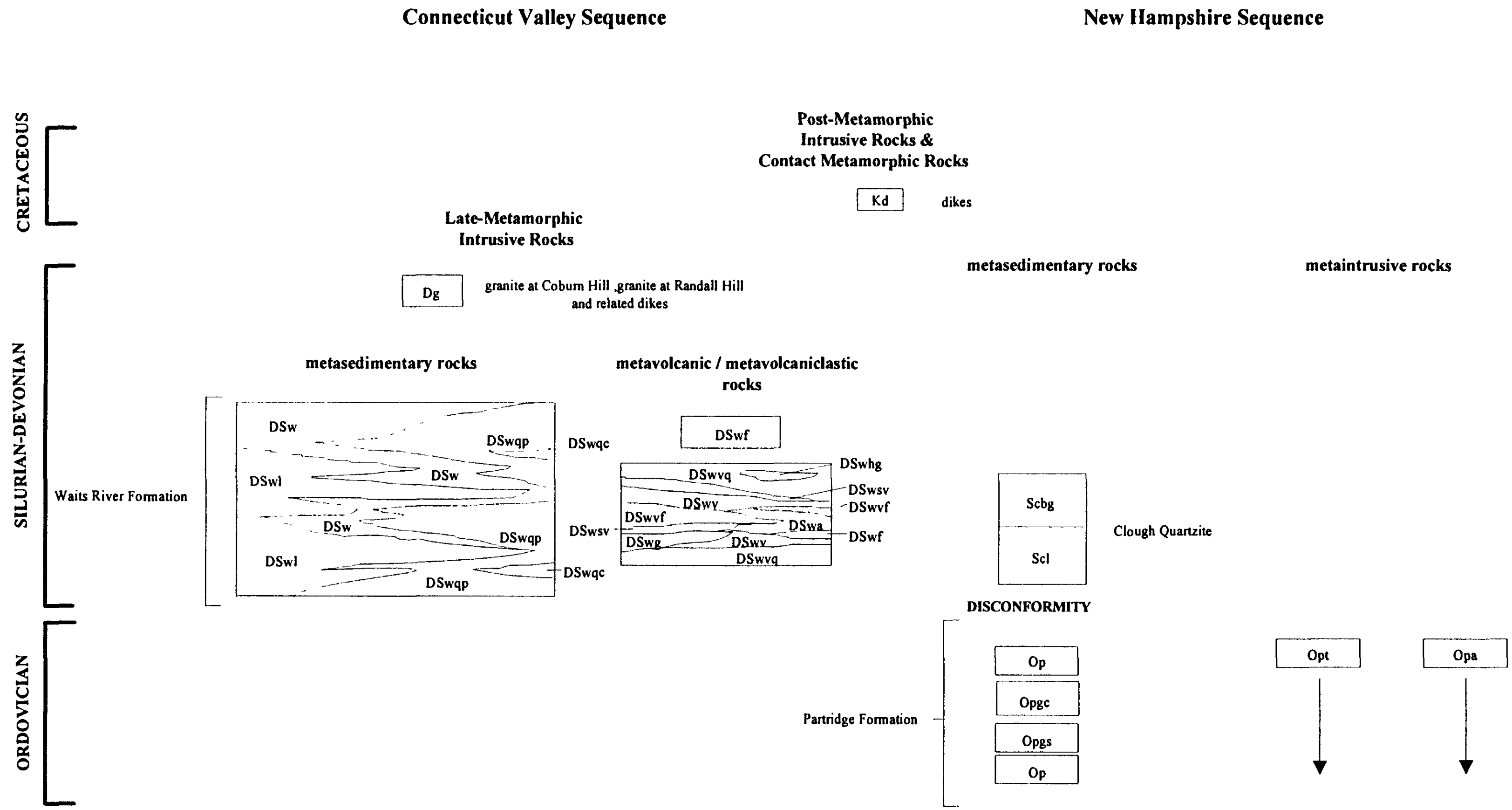
DSwv

Laminated quartzose schist -- Laminated (mm-scale) to layered (cm-scale), carbonate-bearing, and non-carbonate-bearing, grayish-green to purplish-gray, in places rusty-weathering, fine- to medium-grained, muscovite-chlorite-plagioclase -quartz±biotite schist. Unit occurs as 5 mm- to 2 cm-thick plagioclase-quartz±biotite laminations within a chlorite-muscovite-plagioclase-quartz matrix. Unit is interpreted as rythymically deposited felsic to intermediate volcanics and pelitic to psammitic sediments

DSws

Bedded volcaniclastics -- Very heterogeneous, tan- to gray-weathering, partly rusty-weathering, bluish-to dark-gray, carbonate- and non-carbonate-bearing layers of muscovite-chlorite-plagioclase-quartz±bioite±epidote±pyrite±pyrrhotite schist with numerous 1- to 20-cm thick, continuous, tan-weathering, light- to dark-gray beds of epidote-calcite-chlorite-plagioclase-quartz granulite that are similar to the punky-beds within DSwl. Unit is interpreted as rythymically intermediate volcanics and pelitic to psammitic sediments

CORRELATION OF MAP UNITS
BELLOWS FALLS QUADRANGLE
WINDHAM AND WINDSOR COUNTIES, VERMONT



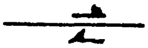
Thomas R. Armstrong
USGS Open-File Report 97-284

EXPLANATION OF MAP SYMBOLS

Contact -- Dashed where approximately located, dotted where concealed by water

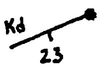
Major Faults -- Dashed where approximately located, dotted where concealed by water

Thrust fault or shear zone, teeth on upper plate

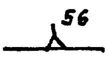


Shear zone parallel to Acadian S2 foliation in Connecticut Valley sequence

PLANAR FEATURES



Strike and dip of inclined Cretaceous lamprophyric dikes; shown with map unit designator



Strike and dip of bedding parallel to first generation Acadian foliation (S1), tops uncertain

Generalized strike and dip of highly-plicated inclined schistosity parallel to compositional layering (Acadian, S1)

Strike and dip of first generation schistosity parallel to compositional layering (Acadian, S1)

Inclined

Inclined; with upright tops determined from sedimentary features

Vertical

Strike and dip of second generation planar fabric expressed as a schistosity (Acadian, S2)

Inclined

Vertical

Strike and dip of second generation planar fabric expressed as a schistosity (Acadian, S2), and axial planar to mesoscopic folds (Acadian, F2) of earlier foliation (Acadian S1)

Inclined

Vertical

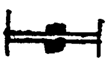
Strike and dip of second generation planar fabric expressed as a schistosity (Acadian, S2),with shear-band development and fabric asymmetry. Sense of shear along foliation shown by direction of arrows

Inclined

Vertical

Strike and dip of non-penetrative spaced cleavage, or crenulation cleavage in Late Proterozoic through Devonian rocks that cuts older foliations (Acadian S3 or younger)

Inclined



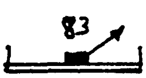
Vertical

Strike and dip of non-penetrative widely-spaced kink bands, locally parallel to broad low-amplitude and high-wavelength folds; locally vein-filling quartz and carbonate mineralization occurs within the kink surfaces; found in the eastern and southern parts of the map area and post-date all foliations

Inclined

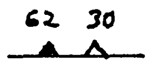
Vertical

Strike and dip of axial surface of Acadian F2 folds that are parallel to the second generation schistosity that deforms bedding and Acadian S1 foliation; arrow shows bearing and plunge of hinge line of fold

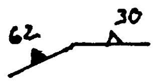


Strike and dip of axial surface of broad to open folds (F3 or younger) parallel to late generation cleavages; arrow shows bearing and plunge of hinge line of fold

Combined symbols: Planar symbols may be combined where multiple measurements are from the same outcrop; the measurement point is where the symbols are joined



Example of combined S1 and S2 with same strike



Example of combined S1 and S2 with different strike

LINEAR FEATURES

Bearing and plunge of lineations in Silurian and Devonian rocks of either 1) mineral lineations of hornblende (Hb) or chlorite (Ch); 2) quartz rods; 3) elongation lineations comprised of porphyroclastic plagioclase (Pl) or pebbles; or 4) intersection lineations of two planar fabrics (combined with schistosity and/or cleavage symbols)

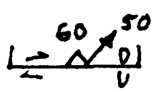
Plunging

Horizontal

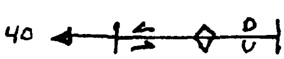
Generalized bearing of hinge line of Acadian third generation (or younger) open fold

OTHER FEATURES

Strike and dip of late, outcrop-scale brittle fault characterized by pseudotachylyte, gouge, crush breccia, and/or cataclasite fabrics; U = up and D = down, double arrows show sense of strike-slip motion, single arrow shows bearing and plunge of slickenlines



Inclined



Vertical

 Location of abandoned quarry

 Area of exposed bedrock examined in this study

A —— A′ Line of cross section