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Preliminary Bedrock Geologic Map of the Vermont Part of the 7.5 x 15 Minute Mount Ascutney and Springfield Quadrangles, Windsor County, Vermont

by

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INTRODUCTION

Bedrock in the Vermont part of the Mount Ascutney and Springfield quadrangles consists largely of, from west to east, Middle Proterozoic gneisses in the core of the Chester Dome, pre-Silurian metasedimentary, metavolcanic, and meta-igneous rocks as a cover sequence immediately above the dome, Silurian and Devonian metasedimentary and metavolcanic rocks of the Connecticut Valley sequence (or trough, after Hatch, 1988), and Ordovician to Silurian and Devonian metasedimentary 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, at Mount Ascutney, the Cretaceous White Mountain Plutonic - Volcanic Suite. According to Doll and others (1961) the section includes: i) basement rocks -- Middle Proterozoic Mount Holly Complex; ii) eastern cover sequence -- Cambrian Cavendish and Hoosac Formations, undifferentiated Cambrian and Ordovician Pinney Hollow, Ottauquechee, and Stowe Formations, and Ordovician Mississquoi Formation; iii) Connecticut Valley sequence -- Silurian Shaw Mountain Formation, Devonian and Silurian Northfield Formation, Devonian Waits River and Gile Mountain Formations; and iv) New Hampshire sequence -- Ordovician Ammonoosuc Volcanics and Partridge Formation, Silurian Clough and Fitch Formations, and Devonian Littleton Formation. The previous interpretation (Doll and others, 1961) maintains that the section of rocks from the Middle Proterozoic basement to the New Hampshire sequence is a non-faulted stratigraphic succession marked by three unconformities separating: 1) the basement from the pre-Silurian cover sequence, 2) the pre-Silurian cover sequence from the Connecticut Valley sequence and 3) the Connecticut Valley sequence from New Hampshire sequence.

Recent work to the west and southwest in the Cavendish, Chester, and Saxtons River quadrangles has redefined the relationships within the Middle Proterozoic rocks of the Chester and Athens Dome, the basement-cover relationships, and the internal structure and stratigraphy in the pre-Silurian sequence (Ratcliffe, 1995a, b, c, in press, and Ratcliffe and Armstrong, 1995b, 1996). The primary purpose of this report is to present preliminary results on the stratigraphic and structural relationships in the Connecticut Valley and New Hampshire sequence rocks.

The information shown on the State map by Doll and others (1961) represents the most complete work on the bedrock geology of the Vermont part of the Mount Ascutney and Springfield quadrangles prior to this report. Previous work on the intrusive complex at Mount Ascutney began with the classic work by Daly (1903). Later workers studied divitrification structures in dikes related to the complex (Balk and Krieger, 1936), identified volcanic units as screens within the complex (Chapman and Chapman, 1940; Schneiderman, 1989), studied the contact metamorphic aureole (Nielson, 1973), and dated the intrusive complex at 121.4 to 125.5 Ma (Foland and Faul, 1977; Foland and others, 1985). These studies, however, did not greatly modify Daly's original mapping. Because the focus of this study is on the Paleozoic rocks into which the complex intrudes, detailed mapping of the interior of the complex was not completed. It should be noted, however, that the granite-syenite contact as mapped by Chapman and Chapman (1940) and incorporated onto the Vermont State map (Doll and others, 1961) appears to be overly simplified based on observations during this study of intricately commingled granite and syenite in the southeastern part of the complex. Aside from the studies at Mount Ascutney, several sketch maps, simplified maps, and field trip guidebook maps have been published of the area (Richardson, 1931; Thompson, 1954; Rosenfeld, 1968; Thompson and others, 1968; Boxwell and Laird, 1987; Thompson and others, 1990; Trzcienski and others, 1992; Thompson and others, 1993a and 1993b). The earliest work by Richardson is the first published map of the town of Springfield, and the later maps differ only slightly from the published State map of Doll and others (1961).

STRATIGRAPHY

Core Rocks of the Chester Dome

Metasedimentary, metavolcanic, and meta-intrusive rocks of the Middle Proterozoic Mount Holly Complex crop out in the western part of the Mount Ascutney and Springfield quadrangles along the northeastern flank of the Chester dome. Tonalitic gneiss and augen gneiss of Baileys Mills (Yt and Yta) intrude metasedimentary and metavolcanic rocks within the dome and are correlated with similar rocks in the adjacent Chester and Cavendish quadrangles (Ratcliffe, 1995a, 1995b, 1995c, in press). Both phases of the gneiss are well exposed under a transmission line 0.4 km south of Nelsons Corner in the Mount Ascutney quadrangle; outcrops of Yt are located west of Plains Road and outcrops of Yta are located on the slope east of the road. The biotite gneiss (Ybg) and amphibolite (Ya) are the major metasedimentary and metavolcanic units in the Mount Holly Complex. The biotite gneiss crops out in a fairly continuous belt along the outer limit of the dome and is well exposed at outcrops on both sides of Gulf Road 0.6 km west of the junction with Gravelin Road in the Mount Ascutney quadrangle. Outcrops of typical amphibolite (Ya) are exposed on the east side of a small hill 0.3 km southwest of Springfield Reservoir in the Springfield quadrangle. Just west of the summit of the same hill, outcrops of rusty gneiss (Yrg) are well exposed. Ratcliffe and others (1996) and Ratcliffe (1995a and in press) indicate that rocks mapped as Cambrian(?) Cavendish Formation by Doll and others (1961) are intruded by 1.4 Ga trondhjemite in the core of the Chester dome, suggesting a Middle Proterozoic age, or older, for the Cavendish. Although there are no exposures of the Cavendish Formation shown on this map, contacts have been extrapolated from exposures in the adjacent Cavendish quadrangle (Ratcliffe, 1995a and in press).

Rocks of the Pre-Silurian Sequence

Metasedimentary and metavolcanic rocks of the Moretown and Cram Hill Formations and metaintrusive rocks of the North River Igneous Suite of Armstrong (1994) comprise the pre-Silurian sequence in this area. Recent reports to the west and southwest (Ratcliffe, 1995a, 1995b, 1995c, in press; Ratcliffe and Armstrong, 1995b, 1996; Walsh and others, 1994) indicate that the sequence from the basement to the Silurian and Devonian rocks is not a continuous stratigraphic package bounded by unconformities as shown on the State map (Doll and others, 1961). Instead, the sequence is fault-bounded on the west side, and rocks of the Hoosac Formation, Rowe Schist, and Moretown Formation are thrust over rocks of the Mount Holly Complex. In the Mount Ascutney and Springfield quadrangles rocks of the Moretown Formation are at the base of the sequence and are in fault contact with Mount Holly Complex rocks. Rocks mapped as Hoosac Formation and undifferentiated Cambrian and Ordovician Pinney Hollow, Ottauquechee, and Stowe Formations by Doll and others (1961) and as Hoosac, Pinney Hollow and Ottauquechee Formations by Thompson and others (1993b) are here assigned to the Moretown Formation based on similarities with other Moretown lithologies to the west and southwest (Ratcliffe, 1995a, 1995b, 1995c, in press; Ratcliffe and Armstrong, 1995b and 1996; Walsh and others, 1994). This mapping has shown that map units of the Moretown Formation truncate against a fault along its base and that this fault progressively cuts out rocks of the underlying sequence northward from the southern end of the Athens dome to the Mount Ascutney quadrangle. This truncation results in the eventual elimination of all the rocks previously mapped as Hoosac through Pinney Hollow in the

Cavendish quadrangle by Thomspon and others (1993b).

In this area a green schist and granofels unit (Omg) with interbedded coticule ("c" on map) and amphibolite (Oma) is the lower-most unit in the Moretown with the exception of a thin, discontinuous belt of hornblende fascicle schist (Omhfs) in the northwestern part of the Mount Ascutney quadrangle. Both the large belt of Omg and small belt of Omhfs crop out discontinuously along a fault contact with the basement rocks. The fault is characterized by a very planar mylonitic foliation with a consistent steeply-plunging, down-dip lineation. Rusty carbonaceous schist (Omrs and Omb) with interbedded feldspathic quartzite (Omrq) overlies the Omg unit, and is overlain by hornblende fascicle schist (Omhfs) with interbedded rusty amphibolite (Omra). In the southern part of the Springfield quadrangle the Omhfs unit is overlain by Moretown laminated, or pinstriped, schist and granofels (Oml). Both the Oml and Omhfs units terminate northward beneath volcanic rocks of the Cram Hill Formation (Ochv) and a trondhjemitic gneiss (Ontr) assigned to the North River Igneous Suite of Armstrong (1994). The trondhjemite is interpreted as a hypabyssal sill. The northward termination of Oml, Omhfs, and Ontr units suggests the possibility of a disconformity beneath the Cram Hill volcanic unit, Ochv. A disconformity is favored over a fault because no fault fabrics or upper plate truncations are present along the contact.

Rocks above the Cram Hill volcanic unit (Ochv) consist of papery thin schists and phyllites with coticule (Ochs), hornblende-bearing granofels (Ochhg), greenstone (Ochg), and black schist and ironstone with coticule (Ochb). All Cram Hill units except the volcanic unit (Ochv) are interpreted to terminate along an unconformity in the northern part of the Springfield quadrangle beneath the Silurian and Devonian rocks. A minor fault cuts the upper part of the Cram Hill Formation in the southern part of the map, but is not responsible for the northern termination of most of the Cram Hill units.

Rocks of the Connecticut Valley Sequence

The Connecticut Valley sequence consists of metasedimentary rocks of the Northfield and Waits River Formations, and metavolcanic rocks of the Waits River Formation. Also included in this sequence is a thin (0- to 10-m-thick) unnamed unit that is discontinuously exposed along the western side of the Northfield Formation, consisting of amphibolites (DSa), quartzites, and feldspathic granofels and schists (DScv). These rocks are very similar to rocks mapped in the Cavendish quadrangle (Ratcliffe, 1995a and in press) and are interpreted as a section of reworked volcaniclastic and metasedimentary rocks nonconformably overlying the Cram Hill Formation. In the Cavendish quadrangle this unit is interbedded at its top with limey schists of the Waits River Formation (Ratcliffe, in press).

Metasedimentary Rocks

The majority of the metasedimentary rocks in the Connecticut Valley sequence are included within two lithologic groups: 1) gray carbonaceous schist and phyllite (DSn, DSw, and DSwb), and 2) gray carbonaceous schist and phyllite with interbedded impure siliceous limestone (DSwl). A significant result of this study is the separation of the carbonate-bearing from non-carbonate-bearing rocks in the Connecticut Valley sequence. The major criterion by which the rocks were separated is the presence or absence of the brown-weathering impure limestone beds, locally referred to as "punky" limestones. In addition to limestone beds, these rocks locally contain rusty-weathering, calcite-bearing schists. This study groups rocks previously mapped as four formations (Northfield, Waits River, Gile Mountain, and Littleton of Doll and others, 1961) into two formations (Northfield and Waits River) based largely on the distribution of the limestone-bearing rocks.

On the State map (Doll and others, 1961) the Northfield Formation is shown as a continuous unit at the base of the Connecticut Valley sequence. Our mapping indicates the presence of a discontinuous belt of gray carbonaceous schist and phyllite without limestone that varies from 0 to 260 m thick along the western side of the Connecticut Valley sequence; the name Northfield Formation is applied to these rocks. The base of the Northfield is interpreted as an unconformity based on the presence of quartzites and quartz-conglomerates (DSnc) and grits (DSng) along the contact with the underlying Cram Hill Formation; this appears to indicate that the Northfield is right-side-up and tops to the east. The quartzites and quartz-conglomerates (DSnc) and grits (DSng) crop out in three small, separate bodies in the west-central part of the Springfield quadrangle. The units correlate in part with rocks mapped previously as Shaw Mountain Formation of Doll and others (1961), but we hesitate to use the name Shaw Mountain because of the discontinuous distribution of the units and their uncertain correlation with similar rocks at the type locality in Northfield (Currier and Jahns, 1941). Evidence for the existence of a major fault at the base of the Northfield was not observed. A minor fault cuts rocks of the Cram Hill and Northfield Formations in the soutwestern part of the Springfield quadrangle, and in places is parallel to the formational contact. The fault does not continue north of Pudding Hill, however, and does not represent a major tectonic boundary. The presence of an unconformity, and not a major fault, agrees with interpretations by Doll and others (1961) and Ratcliffe (in press), but disagrees with recent findings by Hatch (1988, 1991) and Westerman (1987) who place a major fault at the Northfield -- Cram Hill contact north of the Chester Dome.

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 we map 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). Our mapping indicates that limestones occur in roughly equal abundance on either side of the metavolcanic rocks and that it is not possible to separate two distinct formations based on the abundance of limestone-bearing rocks. In the Hanover 15 minute quadrangle, immediately north of the Mount Ascutney quadrangle, Lyons (1955) also noted that the Waits River and Gile Mountain Formations could not be separated on a lithologic basis because the Gile Mountain became more calcareous and the Waits River became more arenaceous from north to south. 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) from areas north of this study, are absent in the Mount Ascutney and Springfield quadrangles. For these reasons the name Gile Mountain is not used in this report.

Doll and others (1961) show the gray schists and phyllites 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). Recent field trip articles (Boxwell and Laird, 1987; Trzcienski and others, 1992) refer to the location of the chicken yard line (CYL) unconformity at a roadcut 0.5 km west of the junction of I-91 and route 11. At this CYL contact, a conglomeratic quartzite and gray phyllite unit (DSwc) is exposed east of a greenstone (DSwag). Other conglomeratic quartzite and gray phyllite (DSwc) and polymict conglomerate (DSwqc) units, however, crop out both east and west of the CYL of Trzcienski and others (1992) at different places in the section. The gray phyllite and schist unit (DSw) is also lithologically similar on both sides of the contact. Our 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 either there is no unconformity or that there may be several local disconformities. Primary sedimentary tops defined by cross beds in this area, especially within the DSwqc unit, indicate that the entire section youngs to the east, in agreement with observations made by earlier workers to the south (Rosenfeld, 1954; Hepburn and others, 1984). Generally, there is a decrease in the amount of volcanic and limestone-bearing rock and a corresponding increase in the amount of quartzite 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, we interpret the rocks as 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, the Clough Quartzite and the Partridge Formation, from immediately below the Littleton. We have, therefore, excluded the usage of Littleton Formation for the easternmost carbonaceous schists in this area.

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 rocks were previously mapped as Standing Pond volcanic member of the Waits River Formation (Doll and others, 1961), Putney Volcanics (Thompson and others, 1993b), and Ammonoosuc Volcanics (Doll and others, 1961). Our results indicate that all of the metavolcanic and metavolcaniclastic rocks are interbedded with the same pelitic metasedimentary rocks of the Waits River Formation, suggesting that they can not be assigned to separate formations. For this reason, the metavolcanic and metavolcaniclastic rocks are mapped as unnamed units 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, we prefer not to use the name Standing Pond and instead refer to the rocks 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. Our mapping shows that the felsic volcanic rocks (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. For these reasons the name Putney Volcanics is not used in this area.

On the State map, Doll and others (1961) show a small area of Ammonoosuc Volcanics northwest of Weathersfield Bow in the Springfield quadrangle. Our results show that the rocks in that area belong to the felsic volcanic unit (DSwvf) of the Waits River Formation and are not part of the New Hampshire sequence. Recent work by Thompson and others (1993b) also concluded that these rocks were not part of the Ammonoosuc Volcanics and called them Putney Volcanics instead.

Our mapping indicates that the volcanic rocks in the Connecticut Valley sequence can be subdivided into at least seven different units: laminated schist and granofels (DSwv), large garnet and hornblende garbenschiefer schist (DSwg), amphibolite (DSwa), greenstone (DSwag), 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. Mapping north of Mount Ascutney provides an explanation for the eastern distribution of the unit. East of the garnet isograd the unit maps as a single entity but contains many rock types that are impossible to map separately at 1:24,000. In this area, porphyroblasts of biotite and ilmenite are the most conspicuous secondary minerals. 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. Exposures typical of the low-grade DSwv unit crop out on the south side of Hunt Road 0.5 km west of the junction of Hunt Road and Marton Road at the 300 m elevation in Windsor, and under the transmission lines 0.6 km southwest of the junction of I-91 and route 131 on the south side of Mill Brook in Weathersfield. A large exposure of the DSwg unit crops out on a ridge 250 m west of the Weathersfield Center Road and north of the Old Crown Point Road near the municipal golf course in Weathersfield. The DSwv unit is interpreted as a heterogeneous assemblage of volcaniclastic and volcanic rocks.

The amphibolite (DSwa) and greenstone (DSwag) units also appear to be lithologically equivalent rocks. Both rocks are fine-grained mafic rocks that occur as both laminated and massive varieties. The more massive varieties may be mafic flows, and the laminated varieties either mafic tuffs or volcaniclastic sediments. Good exposures of the greenstone crop out 0.7 km west of the junction of Hunt Road and Marton Road on steep slopes on the north side of Hunt Road in Windsor. The amphibolite is well exposed just west of the DSwg outcrops mentioned above, near the municipal golf coarse.

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 amphibolite gneiss occur in the area but are not distinguished on the map due to difficulties in separating the two at 1:24,000 scale. The two units in the vicinity of Hunt Road in the Mount Ascutney quadrangle generally consist of the well-layered variety. The interlayering of the DSwhg and DSwv units in this area suggests that low-grade equivalents to the layered hornblende-plagioclase gneiss probably exist to the east within DSwv, but the differences in bulk composition make it possible to separate the unit west of the garnet isograd, similar to the relationships between DSwv and DSwg. In the massive variety, intergrowths of hornblende with matrix plagioclase may indicate replacement of relict ophitic texture; if true the massive variety may be, in part, intrusive. Good exposures of the massive variety crop out on the south side of Goulden Ridge Road 0.55 km east of Weathersfield Center Road and on the east slope of an unnamed ridge 200 m northwest of the junction of Weathersfield Center Road and Little Canada Road in Weathersfield.

The felsic volcanic unit (DSwvf) crops out in two belts in the central and southern parts of the map. The eastern belt has gradational and sharp contacts with gray phyllite and schist (DSw). Several road cuts on the west side of Route 5 north of Weathersfield Bow expose the rocks of the eastern belt. The western belt has gradational and sharp contacts with the limestone-bearing gray phyllite and schist (DSwl), laminated schist and granofels (DSwv), and gray phyllite and schist (DSw). Primary topping criteria in the vicinity of the western DSwvf belt suggest that the felsic volcanic unit is at the base of the thickest section of volcanic rock in the map area. Aleinikoff and Karabinos (1990) and Hueber and others (1990) report a U-Pb zircon age of 423 $\pm$ 4 Ma from a sample collected at a Route 11 roadcut just west of Goulds Mill in Springfield. The sample (VT/Sp 1-85) is from a 50-cm-thick, light-gray, fine-grained epidote-chlorite-albite-quartz granofels layer within a coarser grained sequence of feldspathic schist and granofels. Aleinikoff and Karabinos (1990) interpreted the layer as a dike but left open the possibility that it was a volcanic layer. We interpret the layer as a bed because of the lack of unequivocal cross-cutting relationships and the presence of many similar, yet thinner, layers within the feldspathic schist and granofels. We therefore interpret the U-Pb data as the Silurian age for the deposition of the felsic volcanic unit at this locality.

The felsic gneiss and quartzose granofels (DSwf) is a minor unit that crops out within the hornblende-plagioclase gneiss (DSwhg) in the northwestern part of the Mount Ascutney quadrangle. The unit is interpreted as a volcaniclastic sediment interbedded with DSwhg. Although the unit has limited exposure in this map area and the adjacent Cavendish quadrangle (Ratcliffe, 1995a and in press), similar felsic gneiss and quartzose granofels are reported to the south in the Saxtons River quadrangle (Ratcliffe and Armstrong, 1995b and 1996).

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. Our results show that the New Hampshire sequence in Vermont is restricted to the southern part of the Springfield quadrangle and is not present in Vermont in the Mount Ascutney quadrangle. In addition, the Ammonoosuc Volcanics are not present within the Vermont parts of the Springfield or Mount Ascutney quadrangles.

Within the Springfield 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 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 at a roadcut along the west side of Route 5, immediately west of the Connecticut River and approximately 1.5 km north of the Route 10 junction near the Cheshire Toll Bridge.

The Partridge Formation is in sharp contact with poorly bedded, massive white to light-gray quartz-pebble to boulder conglomerate which we map as the lower member of the Silurian Clough Quartzite (Scl). This contact has classically been interpreted as a significant erosional unconformity (Thompson, 1954; Doll and others, 1961; Thompson and others, 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 locally within the upper part of the lower member. Good exposures of the lower member can be found at roadcuts along the west side of Route 5, 2.4 km north of the Cheshire Toll Bridge.

The contact between the lower member and the upper member (Scu) of the Clough Quartzite is defined by the first bed of vitreous white quartzite. Above the contact the upper member consists of a 25- to 100-m-thick section of well bedded, vitreous, white and gray quartzites with only minor discontinuous lenses of conglomerate. At several localities, the lenses of conglomerate form channels that indicate tops are toward the upper member. The upper part of the upper member is bluish gray quartzite and granofels interlayered with staurolite-garnet-biotite-chlorite-muscovite-plagioclase-quartz schist. 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. These horizons may represent limey horizons and relict coquina beds (Thompson and others, 1993b). A good exposure of the upper unit and the fossil horizons is at a roadcut on the west side of Route 5 northwest of Glidden Island. Good exposures of the schists in the Scu unit are present in the summit area of Skitchewaug Mountain at the approximate latitude of Glidden Island.

The quartzite and schist of the upper member of the Clough are in sharp contact with black to dark-gray biotite porphyroblastic, carbonaceous calcite schists and brownish gray weathering, well-bedded calc-silicates, granofels and marbles of the Fitch Formation (DSf). The Fitch Formation is limited to the northern summit and north slopes of Skitchewaug Mountain. Excellent exposures occur in roadcuts along I-91 immediately south of the Route 143 overpass, and within an abandoned quarry immediately east of the roadcuts. Well preserved bedding is typically parallel to S1 foliation within the Fitch Formation.

The contact of the Fitch Formation with gray phyllite and schist of the Waits River Formation is interpreted as a fault and is nowhere thought to be depositional. Thus rocks previously mapped (Doll and others, 1961) as overlying the Fitch (the Devonian Littleton Formation) are now mapped entirely as the Waits River Formation of the Connecticut Valley sequence, and are interpreted to underlie rocks of the New Hampshire sequence on Skitchewaug Mountain. A thin and discontinuous body of phyrrotite-bearing, carbonaceous, black schist (DSb) occurs within the fault, on the west side of Skitchewaug Mountain. Although this unit is highly tectonized it is lithologically similar to carbonaceous sulfidic schist of the Partridge Formation (Op), schists within the Fitch Formation (DSf), and the black schist unit within the Waits River Formation (DSwb). It is not clear whether this unit is a lens within the Waits River or a fault sliver of either DSf or Op.

STRUCTURE

The oldest structure is a relict gneissosity in the Middle Proterozoic Mount Holly Complex. This foliation is expressed by coarse-grained compositional layering, 1 cm to 1 m thick, consisting of alternating more mafic biotite-hornblende-rich layers and more felsic quartz-plagioclase- or microcline-rich layers. The gneissosity is parallel to migmatitic layers and compositional layers expressed by marble, calc-silicate rock, and thin layers of quartzite. The gneissosity and the coarser layering are Middle Proterozoic and predate the contact between the cover rocks and the core gneisses. At or near the contact with the cover rocks, the gneissosity is dragged into parallelism with a penetrative foliation that is a second generation foliation in the pre-Silurian cover rocks. This second generation foliation is axial planar to abundant isoclinal and reclined folds, both of the gneissosity in the Mount Holly Complex and the schistosity in the overlying pre-Silurian rocks. Hinge lines of these folds plunge down the dip of the axial surface, and coarse-grained plagioclase and quartz knots in rocks of the Mount Holly Complex are elongated parallel to the hinge lines of the folds. The lineation plunges to the east-southeast where the foliation strikes northeasterly and plunges more easterly or northeasterly where the foliation strikes to the northwest.

This second generation penetrative foliation and well developed grain-shape (elongation) lineation is folded over the Chester dome and the lineation plunges to the northwest on the west flank of the dome. This type of structure is absent from the Devonian and Silurian rocks. In the core of the Proctorsville syncline, west of the dome, this foliation and lineation is older than any foliation or lineation in the overlying Silurian and Devonian rocks (Ratcliffe, 1996). Hinge lines of the first generation folds in the Silurian and Devonian rocks of the Proctorsville syncline plunge gently to the north approximately perpendicular to the general east-west trending hinge lines in the underlying pre-Silurian rocks.

Despite the nearly coplanar orientation of the S1 foliation in the Silurian and Devonian rocks and the dominant foliation in the pre-Silurian rocks, we interpret the pre-Silurian here to contain pre-Acadian folds and foliations. We interpret the schistosity, reclined folds and southeast to northeast trending elongation lineation in the pre-Silurian rocks as a fold-thrust fabric inherited from Taconian imbricate thrusting of basement and cover rocks. Almost certainly Acadian foliation is developed in the pre-Silurian rocks but we think that it is sub-parallel to the older Taconian schistosity.

The oldest foliation in the Silurian and Devonian rocks is a bed-parallel schistosity (Acadian S1) containing rarely observed isoclinal folds with generally north or south gently plunging fold hinges (Acadian F1). 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 staurolite grade metamorphism, but the 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 all of the Silurian and Devonian rocks (Acadian S2) varies from a non-penetrative cleavage to a penetrative schistosity. 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. In the central part of the map S2 strikes north and dips steeply to the east and, in places, to the west. In the northwestern corner and easternmost part of the map the strike of S2 is deformed into more westerly and easterly orientations. 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. In such places where only a single penetrative schistosity is observed, and no cross-cutting relative age relationships can be discerned, a dominant foliation symbol is used on the map. S1 and S2 are deformed by a minimum of two younger cleavages.

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. These structures are, in part, related to the formation of the Chester dome, and the older Acadian S1 and S2 planar fabrics are deformed by them. It is not certain whether these younger "dome-related" structures are coeval or not. The S1, S2, and "dome-related" structures in the Silurian and Devonian units are Acadian.

The youngest generation 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 britttle faults in the area, may be related to Mesozoic extension (Hatch, 1988a).

METAMORPHISM

Rocks of the Mount Holly Complex in the core of the Chester dome probably reached hornblende-granulite facies metamorphism during the Middle Proterozoic Grenvillian orogeny, and experienced remetamorphism at lower grades during the Taconian and Acadian metamorphic events. Paleozoic metamorphism was regionally upper greenschist facies, but locally attained amphibolite facies conditions in the basement rocks, the pre-Silurian sequence, the New Hampshire sequence, and the western part of the Connecticut Valley sequence, but only greenschist facies metamorphism in the eastern part of the Connecticut Valley sequence during the Acadian orogeny. We recognize no relict Taconian metamorphic mineral assemblages in the pre-Silurian rocks in this area due to the thoroughness of recrystallization associated with the Acadian metamorphic overprint.

Paleozoic metamorphic grade within the Vermont parts of the Springfield and Mount Ascutney quadrangles ranges from the chlorite and biotite zone to the garnet zone, although a small area of staurolite zone rocks are exposed within the Clough Quartzite on Skitchewaug Mountain. Rocks in the western part of the map area are at garnet grade and higher as evidenced by abundant garnet porphyroblasts in pelitic and semi-pelitic rock types and hornblende-garnet amphibolite within the pre-Silurian cover sequence and abundant garnet in the Northfield Formation. 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 two belts of volcanic lithologies in the Waits River Formation. The eastern part of the Waits River Formation is devoid of garnets, and only the black schist unit (DSwb) and specific parts of the laminated schist and granofels unit (DSwv) contain biotite. The easternmost belt of felsic volcanics (DSwvf) contains no biotite but does contain actinolite as pseudomorphs after pyroxene. In the southern part of the Springfield quadrangle, the garnet isograd (garnet-in to the west) appears to be sharp and is approximately located along the syn-Acadian S2 shear zone near Hartness Park, east of the town of Springfield. In the Mount Ascutney quadrangle, the garnet isograd trends roughly north-northeast and cuts across several lithologies whose contacts are parallel to either S1 or S2; therefore, the isograd is not compositionally controlled and indicates increased pressure-temperature conditions to the west. Garnet porphyroblasts in this area grew syn- to post-S2 development.

In the Skitchewaug Mountain area, staurolite-grade rocks occur within pelitic schists in the upper Clough Quartzite unit (Scu). No other rocks within the New Hampshire sequence here contain staurolite. The Partridge Formation contains only garnet, although some chlorite clots in the Partridge may be pseudomorphs after staurolite. The appearance of key metamorphic minerals in the New Hampshire sequence is strongly controlled by bulk compositional variation and, therefore, variation in metamorphic intensity (pressure, temperature) may not be a factor within these structurally isolated rocks. Metamorphism within the New Hampshire sequence rocks appears to postdate S1 but predate S2, and is likely related to a metamorphic event which occurred prior to transport of the New Hampshire sequence rocks onto the Connecticut Valley sequence. The fault contact between the New Hampshire and Vermont sequences separates rocks of staurolite (New Hampshire sequence, above) and biotite (Vermont sequence, below) grades.

DISCUSSION

The results of this mapping show details not previously reported for the rocks in the Connecticut Valley sequence. The widespread distribution of similar metasedimentary and metavolcanic rocks throughout the sequence suggests a fairly uniform supply of pelitic, semi-pelitic, and volcaniclastic sediment and volcanic rock during the time of deposition. The distribution of interlayered limestone-bearing and non-limestone-bearing rocks across the Waits River belt is consistent with the distribution seen at the outcrop-scale. This suggests periodic influxes of carbonate sands into a dominantly pelagic sequence rather than transgressive and regressive cycles. The idea that rocks mapped earlier as Waits River and Gile Mountain Formations could represent lateral facies equivalents has been postulated by earlier workers (Thompson and others, 1993b). The State map by Doll and others (1961) shows the formations as laterally equivalent in the correlation of map units but shows the Gile Mountain as younger than the Waits River in the cross sections.

Previous workers interpreted key belts of volcanic rocks as time-stratigraphic units between different formations (Lyons, 1955; Doll and others, 1961). The Putney Volcanics (Hepburn, 1972; Trask, 1980) are shown in most places between the Gile Mountain and Littleton Formations and the Standing Pond separates the Waits River and Gile Mountain Formations. The map distribution we find indicates that volcanism occurred throughout fluctuations in carbonate sand deposition because the volcanic rocks do not separate carbonate-bearing from non-carbonate-bearing sequences. The map pattern suggests that the volcanic rocks transgress unit boundaries within the sequence; an observation also noted by Lyons (1955) immediately north of the map area, in the 15 minute Hanover quadrangle. The presence of limestones on both sides of volcanic units throughout the sequence and the probability of multiple volcanic horizons complicate criteria for separating the Waits River Formation from the Gile Mountain Formation on a stratigraphic basis. The use of the name Gile Mountain Formation is further complicated because non-limestone-bearing lithologies including gray slate to phyllite and quartzite, feldspathic quartzite and mica schist, and rhythmically graded schist and micaceous quartzite typical of the Gile Mountain Formation from east-central Vermont (Hatch, 1988b) are absent in this area. The mapping illustrates the need to re-evaluate the regional distribution of limestone-bearing and volcanic rocks within the Connecticut Valley sequence to assess the validity of previously mapped belts of the Gile Mountain Formation.

Outcrop-scale refolded F1 folds in the area are not useful for determination of major regional folds because the folds are commonly rootless, show no asymmetry, and are too widely distributed. Recent analyses of sedimentary topping criteria to the north (Fisher and Karabinos, 1980; Hatch, 1988b) provides evidence for the existence of map-scale F1 folds such as the Townshend-Brownington syncline. The lack of unequivocal fold and topping criteria means that interpretations as to the location of such folds in this area are conjectural. Several possibilities exist, however, that could explain the overall distribution of units.

According to the State map (Doll and others, 1961) major, regional-scale nappes are responsible for the distribution of all map units in the area. The distribution of the Standing Pond volcanic member is shown as a marker horizon that defines the shape of the nappes. Or mapping shows that the distribution of metavolcanic units is not as continuous as previously shown and the belts do not unequivocally define large scale folds. Based on the available data, an alternate and very simple interpretation could be that the entire sequence is a homoclinal eastward-younging and eastward-dipping sequence. This interpretation does not explain the potential significance of small-scale F1 folds in the area and regional F1 folds reported outside the area. The interpretation is consistent with topping criteria presented here, albeit in a restricted area. Some folds are present, however, within what may be an over all homoclinal sequence. Immediately northwest of Mount Ascutney we map only one belt of large-garnet garbenschiefer schist (DSwg) extending to the south rather than two as shown on the state map. We interpret this belt to bifurcate to the northwest with the volcanic rocks (DSwhg) in the core of a doubly plunging synform rather than a north plunging antiform. The southern closure of such a fold is not exposed because it may be truncated by the Mount Ascutney pluton. Southwest of Mount Ascutney, the western two belts of volcanic rock are continuous to a point in the Saxtons River quadrangle where they close in a north plunging synform (Ratcliffe and Armstrong, 1995b and 1996). The eastern limb extends northward to connect with the large mass of volcanic rock near Goulds Mill in the Springfield quadrangle. This wide belt is largely contained within limey schist of the Waits River (DSwl). Northerly plunges for F2 folds along the northeastern contacts of this belt indicate a generally antiformal F2 structure for the large area of volcanic rocks in the central part of the Springfield quadrangle. The internal structures and distribution of units suggest that the volcanic units may be repeated within the belt, and the map relations suggest the possibility of an older (F1) anticlinal structure. The continuity of the felsic volcanic unit (DSwvf) west of Goulds Mill and the lack of repetition of this unit, however, make it difficult to confirm the presence of early folds. Our data, therefore, can not confirm the doubly plunging inverted canoe structure for the western belts of the Standing Pond of Doll and others (1961).

The classic works by Rosenfeld (1968, 1970) present the apparent rotation of inclusion trails in large garnets from the volcanic rocks as evidence for changes in vergence across the limbs of the nappes. Recent work by Thompson and others (1993b) use this evidence to support the nappe model. Our mapping shows that the garnet isograd cuts across the distribution of the units and that garnet growth is syn- to post S2 development, making it difficult to correlate garnet growth with early F1 nappe-stage folds. The current controversy over whether garnets actually rotate (Bell and Johnson, 1989; Ratcliffe and others, 1992; Ratcliffe and Armstrong, 1995a) also raises considerable questions regarding the facing direction of major fold limbs in the area.

The possibility that the Connecticut Valley sequence is a grossly homoclinal east-facing sequence here has been noted above. Two alternative hypotheses include either the possibility of a major regional syncline or anticline. Hatch (1988b, 1991) proposed that rocks of the Connecticut Valley - Gaspé synclinorium are part of a fault-bounded anticlinorial sequence that he renamed the Connecticut Valley trough. This interpretation requires that the rocks in the Northfield Formation are overturned towards the west and that the contact between pre-Silurian and Silurian-Devonian rocks is a major fault. We have no data that can support or refute the topping direction of the Northfield Formation, but we also have no evidence of a major fault along the pre-Silurian and Silurian-Devonian contact. Part of Hatch's (1988b) argument asserts that fine-grained rocks such as the Northfield should not form the base of the sequence. Hatch's interpretation, however, does not account for the coarse-grained quartzites and conglomerates found along the contact. We prefer the interpretation that the quartzites and conglomerates are basal to the Silurian-Devonian section and that the Connecticut Valley sequence is a syncline. The lack of topping criteria and preservation of early fold closures, however, permit other interpretations. Layers of limestone-bearing (DSwl) and non-limestone-bearing (DSw) rocks in the central part of the Mount Ascutney quadrangle show an intriguing map pattern, but we are uncertain as to whether it is due to facies changes or early F1 fold closures. The asymmetric and discontinuous distribution of rock types in the sequence makes it difficult to place axial surfaces of such folds, if they exist, and would require significant lateral and vertical facies changes if certain volcanic horizons could be connected by such folds. We can not rule out the possibility of early folds, but might suggest that if such folds account for the map pattern the distribution of the units could be the result of a series of upward facing early (F1) folds in the synclinorium. This interpretation is simpler, and provides an alternative to the downward facing folds presented on the State map by Doll and others (1961).

Reinterpretation of the Skitchewaug Nappe

Based upon mapping in the Skitchewaug Mountain area, Thompson (1954) interprets a regional structure as a refolded east-trending recumbent anticline, or nappe. This structure, referred to as the Skitchewaug nappe, is defined by the map pattern of contacts between rocks of the Fitch, Clough, and Partridge Formations. The map pattern depicts a heart-shaped structure, or an arrowhead, the core of which contains the stratigraphically lowest Partridge Formation. The Clough lies outside of the Partridge and varies in thickness from only tens of meters thick on the southwestern limb to hundreds of meters thick on the southeastern limb. Structural measurements in Thompson (1954) show overturned beds on the north side of the structure and upright beds on the south side. According to Thompson (1954) and Thompson and others (1968) the axial surface of the nappe lies within the Clough, is parallel to the outer edges of the heart pattern, and contains a hinge line generally oriented east-west. Both the hinge line and the nappe itself are refolded into a synformal geometry by subsequent north-south oriented dome-stage folds. The orientation of the structural data shown in Thompson (1954) and a subsequent sketch map of the structure by D.U. Wise (published in Robinson and others, 1991; figure 6, p. 693) show the refolded nappe hinge line as east-west trending. East-west cross-sections of the Skitchewaug nappe, however, show a projected hinge line and nappe fold closure that is oriented more towards north-south (Thompson, 1954; Doll and others section E-E', 1961).

The results of our mapping indicate that the New Hampshire sequence in this area is a klippe, or outlier, of previously deformed and metamorphosed rocks that was transported to a position structurally above lower grade rocks of the Connecticut Valley sequence -- an idea first postulated by Richardson (1931). The oldest foliation in the New Hampshire sequence, S1, is primarily bed-parallel and is generally sub-horizontal in the core of the structure with a sharp change in orientation on the extreme flanks. This change in orientation is produced by subsequent D2 and D3 deformation which transposes and folds S1 and bedding into a domal structure. The transposition of S1 along the contact between the New Hampshire sequence rocks and the surrounding carbonaceous schist of the Connecticut Valley sequence is related to a S2 mylonitic fault herein referred to as the Skitchewaug Mountain thrust. The thrust is characterized by outcrop- and map-scale lithologic truncations and the transposition of the S1 foliation within the New Hampshire sequence rocks. The thrust also represents a surface of metamorphic contrast between garnet- to staurolite-grade New Hampshire sequence rocks and the sub-garnet-grade rocks of the Connecticut Valley sequence. The Clough is completely truncated along the thrust fault in an area of nearly continuous exposure on the south summit and slopes of Skitchewaug Mountain approximately 1.3 km north-northeast of the Cheshire Toll Bridge. In this area, highly mylonitized and discontinuous tectonic slivers of Clough appear in several locations, but are absent in the fault zone for approximately 350 meters southward where the sulfidic schist of the Partridge is in direct contact with gray, non-sulfidic phyllite and schist of the Waits River Formation. This area coincides with the thin southwestern limb of Thompson's Skitchewaug nappe.

The results of our mapping do not conflict substantially with the interpretations from the previous studies. Both models agree that rocks included within the Fitch, Clough, and Partridge Formations are structurally above carbonaceous schist. We differ in the interpretation that the two sequences are coherent; we interpret the structurally lower carbonaceous schists as part of the Connecticut Valley sequence and not the New Hampshire sequence. Our mapping indicates that the Partridge is structurally beneath the Clough and that the Clough is structurally beneath the Fitch everywhere within the klippe. We can not confirm sedimentary topping criteria in the areas where Thompson (1954) reported overturned beds in the carbonaceous rocks, and find no evidence that these rocks are overturned. In our interpretation, the presence of upper and lower plate truncations, a sharp metamorphic contrast, and coherent stratigraphy within, but not between, the two sequences favors a thrust fault model for the Skitchewaug Mountain area.

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DESCRIPTION OF MAP UNITS

(Major minerals listed in order of increasing abundance)

POST-METAMORPHIC INTRUSIVE ROCKS

Dikes (Cretaceous)

Kd Mafic dikes -- 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.

Kt Trachyte dikes -- Aphanitic, gray to light-gray, tan-weathering, trachyte dikes. Dikes range in thickness from 0.7 to 1.5 m. Dikes are unfoliated but may be blocky jointed.

Kfd Spherulitic felsic dike -- Tan to light-gray, dark-gray to rusty-weathering, very fine-grained, discontinuously laminated, spherulitic felsic dike. Flow laminations are 1 to 2 mm thick and parallel to the walls of the dike. Spherulites are 1 to 2 mm in diameter and are composed of radial microlitic feldspathic material. The rock consists of 80 to 90 percent spherulites, 10 to 15 percent quartz, and accessory carbonate and sulfides. The rock crops out in an approximately 10 m wide zone as several en echelon dikes, 20 to 40 cm thick, at an exposure in Mill Brook 1.1 km west of the junction of I-91 and Route 131 in the Mount Ascutney quadrangle. The dikes are parallel to an east-west striking and steeply north dipping joint set. Balk and Krieger (1936) describe other felsic dikes with similar divitrification features in the vicinity of Mount Ascutney.

Intrusive Rocks at Mount Ascutney (Cretaceous)

Ks Syenite and granite-- Undifferentiated, medium-grained, light-gray, white- to very light-gray- to rusty-weathering, hornblende-biotite syenite and lesser granite. Occurs as the main stock of Mount Ascutney and as dikes, generally less than 1 m thick, in the country rock surrounding the pluton. Foland and Faul (1977) date the syenite-granite complex at 123.2 - 121.4 Ma.

Kgd Gabbro and diorite -- Undifferentiated, coarse-grained, dark-green hornblende-biotite gabbro and lighter colored cross-cutting medium- to coarse-grained, in places porphyritic, biotite-hornblende diorite. Foland and Faul (1977) and Foland and others (1985) date the gabbro-diorite complex at 125.5 - 122.2 Ma.

Volcanic Rocks at Mount Ascutney (Cretaceous)

Kv Trachyte and volcanic breccia -- Undifferentiated, fine-grained, gray trachyte and volcanic breccia. Unit not mapped extensively, but shown in stream above Cascade Falls on the soutwest side of Mount Ascutney where it occurs as a screen within the syenite (Ks). Breccia crops out on the upstream side of the unit.

Schneiderman (1989) and Chapman and Chapman (1940) describe the volcanic units at Mount Ascutney in greater detail.

CONTACT METAMORPHIC ROCKS AROUND MOUNT ASCUTNEY

Kch
Kh

Hornfels (Cretaceous) -- Layered, dark and light colored, foliated, hornfels. The hornfels is subdivided into outer (Kh) and inner (Kch) zones based on a textural change from black to dark-gray, laminated, flinty hornfels ±biotite (Kh) to a more indurated, variably light and dark colored layered black to dark-gray or purple to purplish gray and light-gray to pale bluish-green and light-pink cordierite hornfels (Kch). The outer contact between the hornfels (Kh) and the rocks of the Waits River Formation is transitional; the dotted contact is drawn on a textural basis and is located approximately where the phyllitic and schistose character of the country rock loses its fissility and becomes flinty, but the protolith is still recognizable. The hornfels becomes progressively indurated towards the intrusion. The major contact metamorphic phases in the inner zone (Kch) are cordierite, spinel (pleonaste), biotite, garnet, corundum, and epidote (Daly, 1903). The Paleozoic foliation is generally preserved in the hornfels up to approximately 30 m from the intrusion, within which is a zone where the hornfels is locally brecciated and cut by syenitic and aplitic dikes. The main contact with the syenite is sharp and sub-vertical. Daly (1903), Nielson (1973), and Schneiderman (1989) describe the hornfels in detail.

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. The 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 in the bed of the Black River 0.4 km west of a bridge that is due west of Goulds Mill in the Springfield quadrangle. May be shown by symbol only.

ROCKS OF THE NEW HAMPSHIRE SEQUENCE
(Springfield quadrangle only)

Metasedimentary Rocks

DSf

Fitch Formation (Silurian and Devonian) -- Dark- to steel-gray, tan weathering, rusty, sulfidic, pyrrhotite-biotite-chlorite-muscovite-plagioclase-quartz granofels and schist, interlayered with massive steel- and light-gray epidote-quartz-calcite-dolomite marble. Schist contains distinctive 0.5- to 1.5-mm-diameter biotite porphyroblasts. Marble contains distinctive 1- to 3-cm-diameter tan-weathering pods of calcite that define bedding.

Clough Formation (Silurian)

Scu

Upper member -- Dark- to light-gray, well bedded, vitreous quartzite with beds 1 to 25 cm thick. Upper part of unit contains biotite-spotted, chlorite-muscovite-plagioclase-quartz schist, similar to biotite porphyroblastic unit in DSf. Middle part of unit contains distinctive bluish-gray, plagioclase-muscovite-garnet-quartz-chlorite schist with 5- to 15-mm-diameter garnet porphyroblasts and approximately 10-mm-diameter staurolite porphyroblasts. Lower part of unit contains 1 to 10 m thick, discontinuous horizons of muscovite-plagioclase-quartz, polymictic conglomerate with elongated to rounded quartz vein and quartzite clasts ranging from 1 to 35 cm in diameter. Conglomerate horizons become more abundant toward lower contact with Scl unit. Fossiliferous horizons described by Boucot and others (1958) and Boucot and Thompson (1963) occur in the lower part of the unit and contain tetracoral, brachiopods, pelycypods and a possible trilobite and support a Llhandovery (Early Silurian) age.

Scl

Lower member -- 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 Scu. Clasts consist of vitreous quartzite, vein quartz, and rare quartzose schist. The proportion of matrix to clasts varies but the majority of the unit is clast-supported. Lower part of unit contains distinct layers of gray, carbonaceous, sulfidic schist similar to Op unit.

Unnamed schist unit (Silurian and Devonian?)

DSb

Black schist unit -- Dark-gray to blackish-gray weathering, finely laminated, carbonaceous, phyrrotite-plagioclase-chlorite-quartz-muscovite schist and phyllite with 1.5 mm thick, discontinous seams of chlorite and muscovite coated with carbonaceous matter. Unit occurs within an early fault zone and in juxtaposition with Op, Scl, Scu and DSf units of the New Hampshire sequence rocks along the west side of Skitchewaug Mountain and may be entirely tectonic. Unit is lithically similar to schist lithology within DSwb.

Op

Partridge Formation (Ordovician) -- Heterogeneous, rusty and tan weathering, dark- to light-gray, pyritiferous ilmenite-muscovite-chlorite-plagioclase-quartz$\pm$garnet schist with several 1- to 3-m-thick, dark-green, epidote-chlorite-hornblende-plagioclase amphibolite dikes or metavolcanic layers.

ROCKS OF THE CONNECTICUT VALLEY SEQUENCE

Metasedimentary Rocks

Waits River Formation (Silurian and Early Devonian)

DSwl — Limestone and schist -- Dark- to light-gray, in places 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. The schist contains biotite and garnet in the western part of the map. Distinguished from the underlying Northfield (DSn), and the interlayered gray phyllite and schist unit (DSw) by the abundance of brown-weathered limestone and rusty calcite-bearing schist. Beds of limestone range in thickness from 1 cm to 1.5 m and may constitute anywhere from 10 to 90 percent of an exposure. Contacts with DSw are gradational to sharp as limestone beds either decrease in abundance and thickness gradually or abruptly. 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. Two 1- to 2-m-thick quartzites are shown on the map with a line and a "Q"; one east of Gird Lot Road in the southern part of the Mount Ascutney quadrangle, the other west of Camp Hill in the Springfield quadrangle. Locally contains trace amounts of very thin (1-2 cm) brown-weathering limestone beds. The schist contains biotite and garnet in the western part of the map.

DSwqs — Quartzose schist and gray phyllite -- Light-steel-gray to light-gray weathering, dark-gray, muscovite-chlorite-plagioclase-quartz schist. Occurs within schist unit (DSw) as 10- to 250-m-thick zones of 0.5- to 3-m-thick quartzite beds with thin (1 mm to 1 cm) carbonaceous schist laminations. May contain detrital blue quartz grains. Unit occurs in the middle of the large western belt of DSw in the Springfield quadrangle and in a fault slice along the contact with the New Hamsphire sequence rocks east of the Cheshire toll bridge.

DSwb — Dark-gray schist and metawacke -- Distinctive, dark-gray to coaly black, fine-grained, carbonaceous, biotite-plagioclase-chlorite-muscovite-quartz schist with 1- to 2-mm-diameter bronze-colored muscovite porphyroblasts. Lower part of unit consists of well bedded to massive, light gray to tan, medium-grained chlorite-muscovite-plagioclase-quartz metagraywacke, characterized by distinctive graded beds.

DSwqc — Polymict conglomerate -- Creamy-white to light-gray weathering, massive to weakly layered, typically clast-supported, quartz-pebble and cobble conglomerate.

Where present, matrix around clasts consists of ilmenite, chlorite, muscovite, and quartz and is usually 1 to 5 mm thick and discontinous. 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 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 DSw unit are typically gradational over a distance of 1 to 10 meters. Unit occurs within two separate bodies; a large 10- to 200-m-thick horizon above (east of) the Waits River volcanic units, and a smaller, discontinuous body in the southern part of the Springfield quadrangle, within the gray schist of the Waits River and between several of the volcanic units. Unit is lithically similar to the lower unit of the Clough Formation (Scl) of the New Hampshire sequence.

DSwc

Conglomeratic quartzite and gray phyllite -- Dark-gray, plagioclase-biotite-chlorite-muscovite-quartz schist and phyllite with zones of matrix-supported, angular to rounded 1-mm- to 3-cm-diameter pebbles of clear to yellowish gray, highly recrystallized, coarse-grained quartzite and possible vein quartz, and rounded, deformed, pebbles to 25-cm-diameter cobbles of bluish gray quartzite, light-gray quartzite, quartz pebble conglomerate, and rare greenish gray metasiltstone. Clasts are only rarely size-sorted, and graded beds are rare although some graded conglomeratic beds are found. Matrix material also found as disarticulated, 1- to 25-cm-long by 2- to 5-cm-thick clasts within well- to poorly sorted and graded conglomeratic layers which appear to be early stage autoclastic conglomerates.

Metavolcanic Rocks

DSwvf

Felsic volcanic rocks -- Silvery-green to green ±calcite±epidote-muscovite-quartz-chlorite-plagioclase phyllite to schist; light-gray to whitish pale-green, fine-grained, layered (3 to 50 cm thick), epidote-muscovite-chlorite-quartz-plagioclase-feldspathic schist and granofels, locally with 1- to 3-mm-diameter quartz and plagioclase porphyroclasts (phenocrysts?); gray-green, massive, fine- to medium-grained, muscovite-chlorite-quartz-plagioclase feldspathic granofels with 1- to 3-mm-diameter 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 sedimentary rocks, crystal tuffs, dacitic to andesitic flows, and mafic volcaniclastic sedimentary rocks. Unit formerly mapped as Ammonoosuc or Standing Pond Volcanics (Doll and others, 1961), or Putney Volcanics (Thompson and others, 1993b). Sample VT/Sp 1-85 (in Springfield quadrangle) of Aleinikoff and Karabinos (1990) and Hueber and others (1990) yields a zircon age of 423± 4 Ma. The eastern belt of DSwvf exposed west of Weathersfield Bow is not clearly the same unit as the dated volcanic rocks designated by the same symbol. At present we prefer to regard this as a separate and higher collection of felsic rocks.

DSwv

Laminated schist and granofels -- Heterogenous, 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-diameter) 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 heterogenous assemblage of metamorphosed volcaniclastic and primary volcanic rocks.

DSwa
DSwag

Amphibolite and greenstone -- Dark-green to green, fine-grained, massive epidote-chlorite-hornblende-plagioclase gneiss (amphibolite) with 1- to 3-mm-diameter, white, sausseritized plagioclase porphyroclasts (DSwa) and laminated to massive, epidote carbonate-actinolite-chlorite-plagioclase greenstone (DSwag). Generally, the laminated greenstone (DSwag) is intercalated with DSwv, and the massive greenstone and amphibolite have sharp contacts with adjacent units. In the north-central part of the Mount Ascutney quadrangle the greenstone (DSwag) is interlayered with DSwv on a 1 to 3 cm scale over a distance of several meters along the contact. The amphibolite crops out in the west where the rocks are at higher metamorphic grade, and there it contains layers of greenstone similar to DSwag to the east.

DSwg

Large-garnet and hornblende garbenschiefer schist -- Silvery-gray to light-gray, in places rusty weathering, epidote-biotite-chlorite-muscovite-garnet-hornblende-quartz-plagioclase schist with distinctive 1- to 5-cm-long sprays of hornblende and 1- to 7-cm-diameter garnet porphyroblasts. Unit is interpreted as metamorphosed pelitic sedimentary rock with a volcaniclastic component of intermediate to mafic composition. Unit is interlayered with DSw and DSwl, and all volcanic units except DSwvf.

DSwhg

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

DSwf

Felsic gneiss and quartzose granofels -- Light-gray, tan-weathering, biotite-quartz-plagioclase gneiss, and medium-gray, feldspathic biotite quartzite and granofels, and volcaniclastic rock interbedded with DSwhg. Exposures limited to the northwest part of the Mount Ascutney quadrangle.

Northfield Formation (Lower Devonian and Silurian)

DSn — Schist -- Dark-gray to silvery gray, carbonaceous, fine-grained, muscovite-biotite-plagioclase-quartz schist or phyllite marked by conspicuous small garnets 1 to 2 mm in diameter that form small bumps on the foliation surfaces. Garnets are commonly partially to completed replaced by white plagioclase, or by chlorite.

DSng — Grit -- Medium- to dark-gray to steel-gray-weathering, biotite-plagioclase-quartz granofels, impure quartzite and minor quartz-pebble conglomerate, occurs near base of unit interbedded with layers of schist or phyllite; thickness variable from 0 to 10 m.

DSnc — Calc-silicate rock -- Light-gray-green to gray-weathering, medium-grained zoisite-magnetite-phlogopite calc-silicate granofels, locally occurs associated with DSng near base of unit.

Unnamed ampibolite, quartzite, and volcaniclastic rocks (Silurian and Devonian)

DScv DSa — Heterogeneous unit of interbedded, rusty, slabby quartz-amphibolite (DSa), gray quartzite, feldspathic granofels and biotite schist less than 10 m thick near base of the Waits River Formation and underlying Ochv. Interpreted as a discontinuous section of volcaniclastic and metasedimentary rocks nonconformably overlying the Cram Hill Formation.

PRE-SILURIAN COVER SEQUENCE ROCKS

Cram Hill Formation (Ordovician)

Ochb — Black quartz phyllite and ironstone -- Dark-gray- to dull-black-weathering, very fine-grained, siliceous phyllite and phyllitic metasiltstone(?). Forms thin beds of splintery, highly fractured rock; contains beds of pale gray-green- to steel-gray-weathering, sulfidic, cummingtonite-magnetite-plagioclase-quartz amphibolite as much as 3 m thick, and discontinuous very rusty, manganiferous garnet quartzite and pinkish layers of coticule 1 to 2 cm thick.

Ochg — Greenstone -- Medium-green to gray-green, highly foliated, hornblende-plagioclase greenstone, marked by distinctive irregular, clots, or indistinct patches of more plagioclase-rich inclusions as much as 3 cm in length set in a more uniform amphibolite matrix. Unit interpreted as basaltic to andesitic tuff breccia and volcaniclastic rock.

Ochhg — Hornblende-plagioclase-quartz granofels -- Light-gray-weathering, medium- to coarse-grained, garnet-biotite-hornblende-plagioclase-quartz granofels, marked by abundant sprays of large hornblende as much as 5 cm in length, interbedded with layers of biotitic amphibolite and hornblende-garnet amphibolite. The coarseness of the hornblende and grain size of plagioclase in the granofels distinguishes this unit from similar hornblende fasicle granofels and schist in the Moretown Formation; unit is lithologically identical to and correlated with the Marlboro member of the Cram Hill Formation of Armstrong (1994).

Ochs c Papery thin schist and phyllite -- Pale gray-brown- to whitish tan-weathering, fine-grained, biotite-garnet-muscovite schist and carbonaceous phyllite. Unit contains beds rich in tiny 1- to 2-mm-diameter garnets that are similar to garnet-rich phyllites of the Northfield Formation. Passes laterally into a darker gray- to slightly rusty-weathering siliceous phyllite or schist that contains discontinuous layers of steel-gray quartzite. Locally contains thin garnet quartzite or coticule beds 1 to 2 cm thick (denoted by a leader and a lower case "c"). Locally unit contains a distinctive, steel-gray- to yellow-tan-weathering quartzite and quartz-pebble conglomerate as much as 2 m thick (Ochq). Unit Ochs closely resembles phyllite and schist in the Whetstone Hill Member of the Mississquoi Formation of Doll and others (1961). Unit is transitional downwards into Ochv.

Ochq Quartzite -- Steel-gray- to yellow-tan-weathering quartzite and quartz-pebble conglomerate as much as 2-m-thick. Occurs as beds within Ochs, and along contact with Ochb and Ochg.

Ochv Felsic and mafic volcaniclastic rocks -- A heterogeneous unit consisting of well-layered, light-gray-weathering, felsic biotite-hornblende-quartz plagioclase gneiss intimately interlayered with darker gray-green hornblende-biotite-plagioclase amphibolite and hornblende-plagioclase granofels and gneiss. The proportion of felsic to mafic layers varies greatly and the thickness of the mafic layers which are generally subordinate, ranges from one to several meters. The rusty-weathering-biotite-muscovite-quartz schist, feldspathic granofels and layers of coticule present throughout indicate a collection of volcaniclastic rocks and interbedded metasedimentary rocks, for this reason the unit is interpreted as a member of the Cram Hill Formation. Contact relations with underlying units uncertain, may disconformably overlie both the Moretown and metatrondhjemite (Ontr) of the North River Igneous Suite.

Intrusive rocks of the North River Igneous Suite of Armstrong (1994) (Ordovician)

Ontr Trondhjemite gneiss -- Principally, light-gray- to chalky-white-weathering, massive, medium-grained, biotite$\pm$garnet-quartz-plagioclase gneiss; lacks mafic layers present in Ochv unit of the Cram Hill Formation and is interpreted as intrusive into Omhfs and Oml units of the Moretown Formation. Alternatively it could be a metadacite.

Moretown Formation (Ordovician)

Oml	Pinstripe granofels -- Light-gray- to pinkish-gray-weathering, pinstriped, biotite-plagioclase-quartz granofels and quartzite. Granofels layers contain abundant fasicles of hornblende, or layers of hornblende-plagioclase granofels 1 to 5 cm thick, where these hornblende fasicles and granofels layers predominate, unit passes into Omhfs.
Omhfs	Hornblende fasicle schist -- Light-gray to gray-green, chlorite-muscovite-biotite-plagioclase-quartz schist and granofels marked by conspicuous sprays of hornblende and distinctive, large 5-mm- to 1-cm-diameter porphyroblasts of cross-foliation biotite, and abundant irregular layers of coticule 1 to 2 cm thick, and abundant layers of pinstriped light-gray biotite-quartz granofels like Oml.
Omrs	Rusty schist -- Dark-gray- to rusty-brown-weathering, sulfidic, muscovite-biotite-quartz-plagioclase schist; has gradational contacts with surrounding Omhfs and Omg, and with Omra in the southwestern part of the Springfield quadrangle.
Omb	Black schist -- Dark-gray to silvery-gray, garnet-biotite-muscovite carbonaceous schist, and associated rusty-weathering muscovite-biotite-quartz schist. Unit contains layers rich in small garnet 1-2 mm in diameter, like layers in Ochs which resemble phyllites of the Whetstone Hill Member of the Mississquoi Formation of Doll and others (1961).
Omrq	Quartzite -- Light-tan-weathering, thinly layered muscovite-biotite-plagioclase quartzite; occurs in contact with Omgg and as layers within Omb and Omrs.
Omgg	Garnet schist and granofels -- Light-gray- to gray-green-weathering, garnet-biotite-chlorite-muscovite-quartz schist and schistose biotite-garnet-plagioclase-quartz granofels; occurs in depositional contact with Omb.
Omg c	Green schist and granofels -- Principally light-green to pale-gray-green, lustrous, chlorite-biotite-muscovite-quartz schist and light-gray feldspathic granofels interbedded on a scale of 10 cm; locally contains coarse-grained garnet schist and widespread thin beds as much as 10 cm thick of pinstriped, chlorite-muscovite-plagioclase-quartz schist and granofels identical to Oml; beds of coticule 1 to 2 cm thick (denoted by a leader and a lower case "c") or layers of dark-green well-foliated amphibolite may be abundant. Distinctive porphyroblasts of cross-foliation biotite occur throughout; these porphyroblasts and the very feldspathic interbeds are regionally characteristic of the Moretown or Stowe Formations and are absent from the Pinney Hollow Formation at the type locality and regionally (Ratcliffe, 1992, 1995a, 1995b, 1995c, 1996, in press; Walsh and others 1994; Walsh and Ratcliffe, 1994a, 1994b; Walsh and Falta, 1996a, 1996b) with which these rocks have been

correlated by Thompson and others (1993b). Unit is in fault contact with Middle Proterozoic rocks at its base and is bedded with and gradational upwards into Omrs and Omb.

Oma

Amphibolite -- Dark-green, highly foliated epidote-biotite-hornblende and hornblende-plagioclase amphibolite, varies from highly foliated and epidote-podded to a more granular rock consisting of approximately 70 percent hornblende and 30 percent plagioclase.

CORE ROCKS OF THE CHESTER DOME

Bull Hill Gneiss Member of the Cardinal Brook Intrusive Suite (Middle Proterozoic)
There are no exposures of the Bull Hill Gneiss in the map area, but it is shown in the subsurface of cross-section B-B' and is extrapolated from Ratcliffe (1995a and b).

Ybh

Bull Hill Gneiss Member of the Cardinal Brook Intrusive Suite -- Light-pinkish gray to gray, coarse-grained to medium-grained, mylonitic, biotite-plagioclase-microcline augen gneiss, distinguished by distinctive partially recrystallized augen of microcline set in a much finer grained biotitic and epidotic mylonitic matrix. Where less deformed, contains rectangular to ovoidal relict phenocrysts of microcline that make up more than 50 percent of the rock.

Mount Holly Complex (Middle Proterozoic)

Intrusive and Migmatitic Rocks

Yt

Tonalite gneiss of Baileys Mills -- Coarse-biotite-flecked, light-gray to whitish-gray-weathering, medium-grained, biotite-quartz-plagioclase gneiss, having a distinctive non-gneissic, igneous appearing texture, in less sheared rocks. Rock closely resembles tonalitic and trondhjemitic gneisses within the core of the Green Mountain massif, dated at 1.3 Ga (Ratcliffe and others, 1991). Contains numerous inclusions of coarse biotite amphibolite mapped as Ya that may be, in part, comagmatic dikes of metagabbro. Passes into lighter gray, more leucocratic, biotite trondhjemite gneiss.

Yta

Augen gneiss facies of the tonalite gneiss of Baileys Mills -- Very-well foliated, mylonitic, biotite gneiss containing porphyroclastic eyes of plagioclase as much as 5 mm long set in a mylonitic matrix rich in biotite; rock gradually passes into a mylonite gneiss or schist that may be equivalent to much of the dark biotitic feldspathic schist in the feldspathic member of the Cavendish (Ycfs) on Hawks Mountain and on Pine Hill in the adjacent Chester quadrangle (Ratcliffe, 1995b and 1995c).

Ygg

Granitic and migmatitic gneiss -- Light-gray to pinkish-tan-weathering, fine-grained, ropy to well-foliated biotite-quartz-microcline-plagioclase granite gniess commonly having indistinct layers with augen of microcline and intergrown plagioclase as much as 2 cm in diameter. Contains accessory metamorphic muscovite and epidote, and lesser magnetite. Unit interpreted as a feldspathic volcanic rock that was migmatized in the Middle Proterozoic.

Metasedimentary and Metavolcanic Rocks

Cavendish Formation (Middle Proterozoic)

There are no exposures of the Cavendish Formation in this map area, however, contacts have been extrapolated from exposures in the adjacent Cavendish quadrangle (Ratcliffe, 1995a and in press).

Ycfs — Feldspathic schist or granofels -- Either a rusty-weathering, light- to medium-dark-gray, white-plagioclase-spotted, biotite-quartz granofels or a biotite-rich porphyroclastic schist having isolated augen of plagioclase, as much as 1 cm in diameter set in a phyllonitic matrix of biotite, muscovite, epidote, and quartz.

Ycm — Marble -- Consists of a variety marbles intimately associated with calc-silicate gneiss and or beds of actinolitic quartzite, including, whitish-gray weathering, medium- to coarse-grained, phlogopite-calcite-dolomite and quartz-knotted marble; greenish actinolite-rich dolomitic marble; fine-grained yellow-gray weathering, highly foliated phlogopite-talc(?)-tremolite-dolomite marble.

Other layered gneiss of the Mount Holly Complex

Ybg — Biotite-quartz-plagioclase gneiss -- A heterogeneous assemblage of dark- to medium-gray, nonrusty-weathering, quartz-rich biotitic gneisses, all characterized by having abundant plagioclase and epidote and little or no microcline. Distinctive other rock types include: light-gray-weathering, magnetite-muscovite-biotite-plagioclase-quartz gneiss containing thin layers of hornblende-spotted gneiss; a very dark-gray, biotite-rich plagioclase-quartz gneiss commonly associated with epidotic quartzite, and medium- to dark-gray, white-albite-spotted-biotite-quartz gneiss. Muscovite is a common accessory in most rocks and small garnet may be present as well. The biotite-quartz- plagioclase gneiss unit contains numerous layers of other distinctive rocks interlayered throughout; where thick enough to map, these units, listed below, are mapped separately.

Ya — Amphibolite -- Dark-green- to dull-gray-weathering, fine- to coarse-grained, biotite-hornblende and hornblende-garnet-plagioclase amphibolite, commonly associated with Yrs or Ycs.

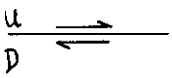
Yrg — Rusty muscovite-biotite-plagioclase-quartz gneiss -- Dark-brown to gray, rusty weathering, gneiss and schist containing abundant layers of schistose quartzite, biotite-garnet quartzite, and rusty sulfidic amphibolite. Locally passes into more muscovitic, lustrous, chlorite-garnet-schist mapped in the adjacent Chester and Cavendish quadrangles as unit Yrs, but here not distinguished separately (Ratcliffe, 1995a, 1995b, 1995c, and in press).

EXPLANATION OF MAP SYMBOLS

Contact -- Dashed where approximately located, dotted where concealed by water or as the maximum limit of hornfels around Mount Ascutney

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

Thrust fault or shear zone, teeth on upper plate

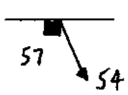


High angle, post-metamorphic fault characterized by brittle features and/or cataclasite fabrics; U = up and D = down, double arrows show lateral offset

Shear zone parallel to Acadian S2 foliation in Connecticut Valley sequence

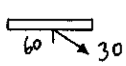
MINOR FOLDS

Folds in the pre-Silurian rocks

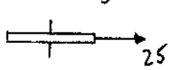


Strike and dip of inclined axial surface of minor isoclinal fold of schistosity or gneissosity parallel to composite first and second generation schistosity; probably Taconian; arrow shows bearing and plunge of hinge line of fold; minor folds concentrated near and parallel to fault between the core gneisses and pre-Silurian cover rocks of the Chester dome

Strike and dip of axial surface of minor fold parallel to non-penetrative cleavage, arrow shows bearing and plunge of hinge line of fold; may correlate with F2 and F3 folds in the Silurian and Devonian rocks

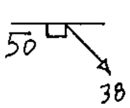


Inclined



Vertical

Folds in the Connecticut Valley and New Hampshire Sequences; interpreted as Acadian folds

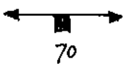


Generalized strike and dip of axial surface of inclined and refolded, isoclinal, intrafolial folds (F1) that are parallel to the first generation schistosity that deforms bedding; arrow shows generalized bearing and plunge of hinge line of fold

Strike and dip of axial surface of tight to isoclinal folds (F2) parallel to the second generation schistosity; arrow shows bearing and plunge of hinge line of fold

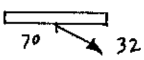
Inclined

Vertical

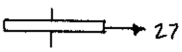


Inclined; double arrow indicates horizontal hinge line

Strike and dip of axial surface of open to tight folds (F2) parallel to the second generation cleavage; arrow shows bearing and plunge of hinge line of fold

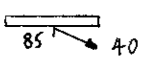


Inclined

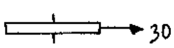


Vertical

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



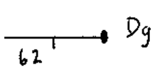
Inclined



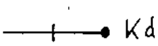
Vertical

PLANAR FEATURES

Strike and dip of dikes; shown with map unit designator

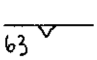


Inclined

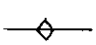


Vertical

Strike and dip of dominant schistosity of indeterminate age; may represent a composite foliation, or a single foliation where age relationships are uncertain



Inclined



Vertical

Planar Features in the pre-Silurian Rocks

Strike and dip of gneissic layering of Proterozoic age

Inclined

Vertical

Generalized strike and dip of highly-plicated inclined schistosity of indeterminate age

Strike and dip of inclined schistosity of indeterminate age parallel to compositional layering

Strike and dip of non-penetrative spaced cleavage or crenulation cleavage; may correlate with S2 or S3 in Silurian and Devonian rocks

Planar Features in the Silurian and Devonian Rocks

Strike and dip of bedding, 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

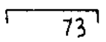
Vertical

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

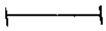
Inclined

Vertical

Strike and dip of second generation planar fabric expressed as a non-penetrative cleavage (Acadian, S2)

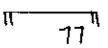


Inclined

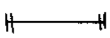


Vertical

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)

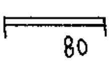


Inclined

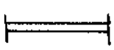


Vertical

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

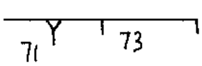


Inclined

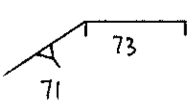


Vertical

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



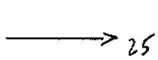
Example of combined S1 and S2 with same strike



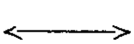
Example of combined S1 and S2 with different strike

LINEAR FEATURES

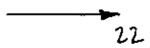
Bearing and plunge of lineations in Silurian and Devonian rocks of either 1) mineral lineations of hornblende (Hb) or chlorite (Ch); 2) quartz rods; 3) elongation lineations comprised of porphyroclastic plagioclase (Pl) or pebbles; or 4) intersection lineations of two planar fabrics (combined with schistosity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



Plunging



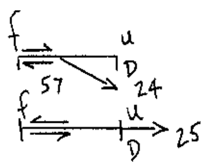
Horizontal



Bearing and plunge of elongated porphyroclasts and of hinge lines of micro folds in mylonite in pre-Silurian rocks; combined with foliation and axial surface symbols; interpreted as marking approximate bearing of thrust displacement in Taconian mylonite zone.

OTHER FEATURES

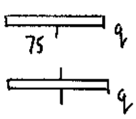
Strike and dip of late, outcrop-scale brittle fault characterized by pseudotachylyte, gouge, crush breccia, and/or cataclasite fabrics; U = up and D = down, double arrows show sense of strike-slip motion, single arrow shows bearing and plunge of slickenlines



Inclined

Vertical

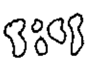
Approximate strike and dip of large (1- to 3-m-thick and 5- to 30-m-long) quartz vein



Inclined

Vertical

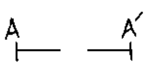
Location of abandoned quarry



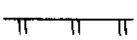
Area of exposed bedrock examined in this study

VT/Sp 1-85
U-Pb 423±4 Ma

Sample locality showing age from Aleinikoff and Karabinos (1990) and Hueber and others (1990)



Line of cross section



Metamorphic isograd-- ticks on higher intensity side; Gt = garnet, Sta = staurolite

Map units on structure sheet:

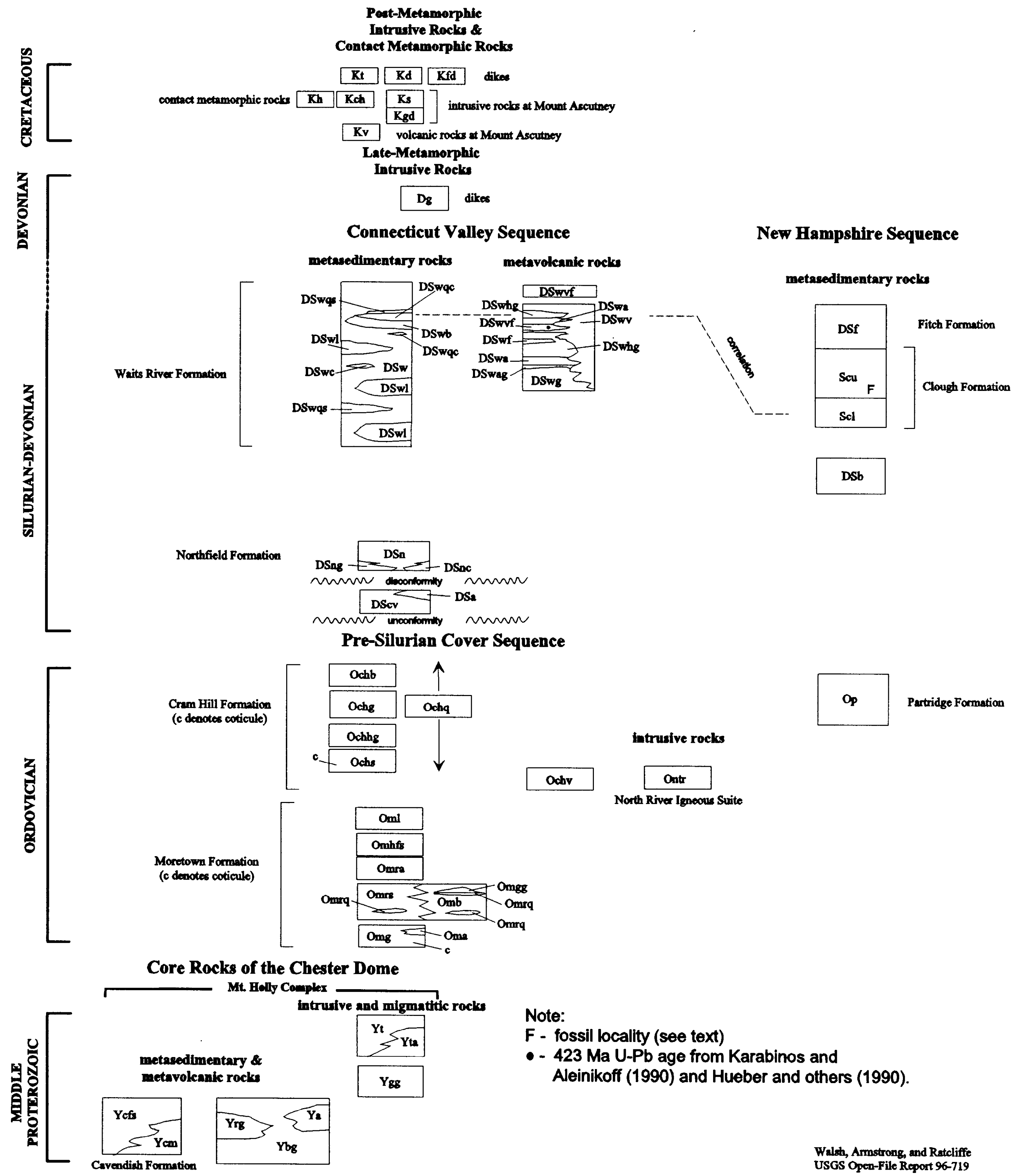
New Hampshire sequence — NH

Connecticut Valley sequence — DS

Ordovician rocks	O
Middle Proterozoic rocks	Y

LIST OF PLATES

CORRELATION OF MAP UNITS
MOUNT ASCUTNEY & SPRINGFIELD QUADRANGES
WINDSOR COUNTY, VERMONT



Note:
F - fossil locality (see text)
● - 423 Ma U-Pb age from Karabinos and Aleinikoff (1990) and Hueber and others (1990).

Walsh, Armstrong, and Ratcliffe
USGS Open-File Report 96-719