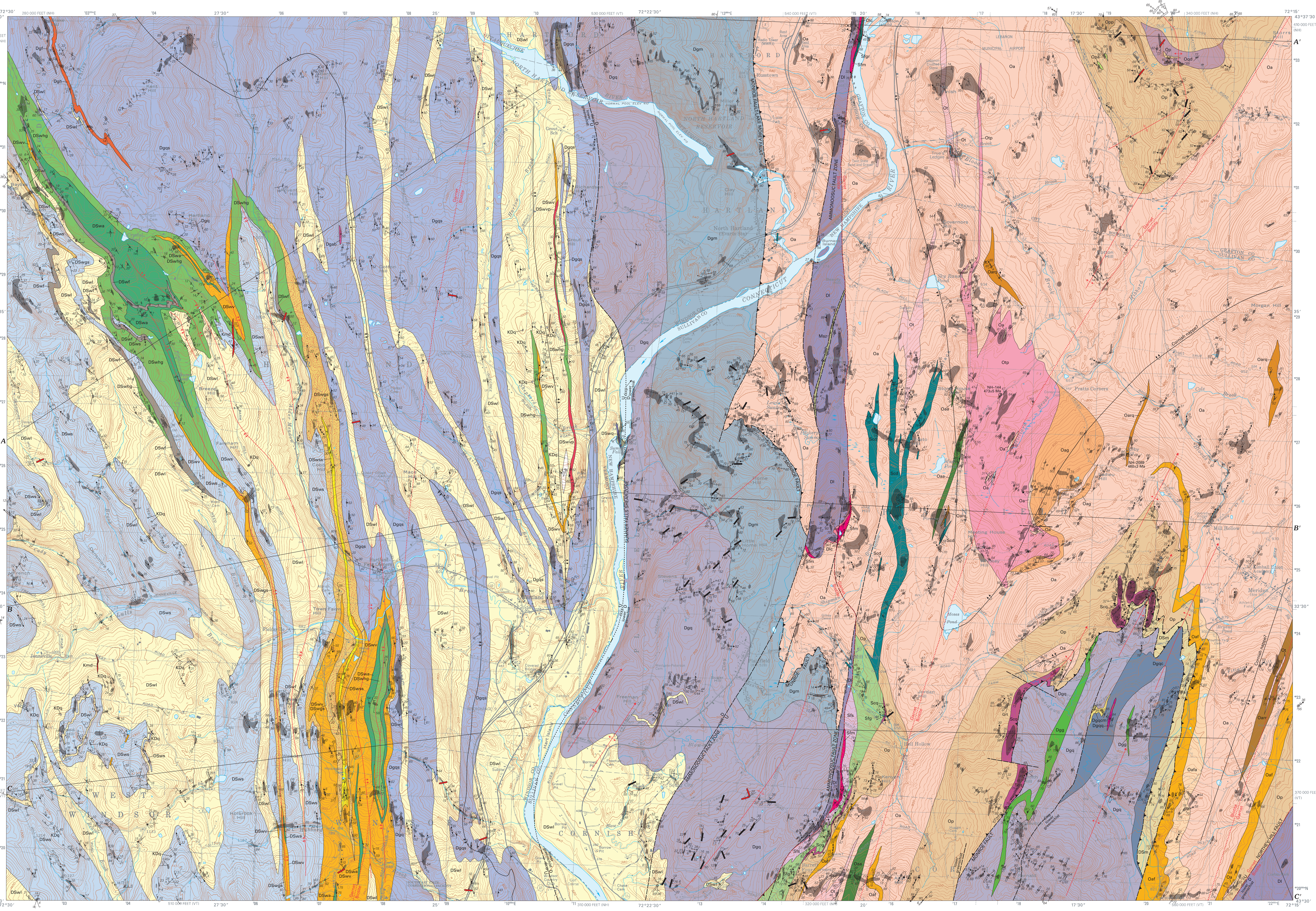
Prepared in cooperation with the
STATE OF VERMONT, VERMONT AGENCY OF NATURAL RESOURCES, VERMONT GEOLOGICAL SURVEY;
STATE OF NEW HAMPSHIRE, DEPARTMENT OF ENVIRONMENTAL SERVICES, NEW HAMPSHIRE GEOLOGICAL SURVEY;
and the
NATIONAL PARK SERVICE

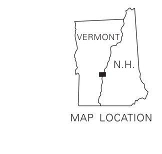


Base from U.S. Geological Survey
Hartland, 1998; North Hartland, 1998
North American Datum of 1927
Hartland projection based on Vermont coordinate system (Transverse Mercator)
North Hartland projection based on New Hampshire coordinate system (Transverse Mercator)
10,000-foot grid ticks based on Vermont and New Hampshire coordinate systems
1,000-meter Universal Transverse Mercator grid ticks, zone 18

APPROXIMATE MEAN DECLINATION, 2016

SCALE 1:24 000

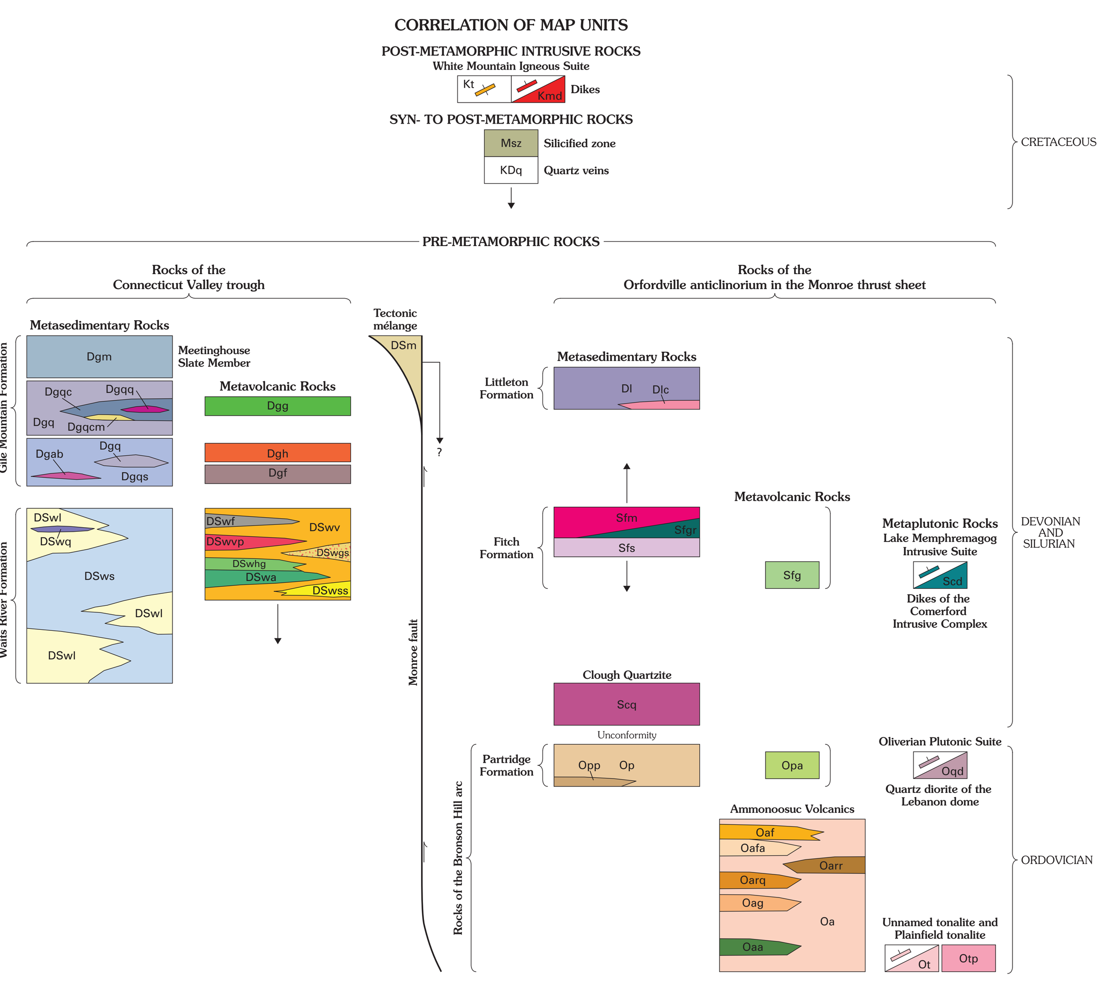
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



MAP LOCATION

Geology mapped by Walsh (1995–96) and (2010–12); assisted by Bart T. Cubrich (2011)
Declination when mapped: 15.5° (1995–96) and 15° (2010–12)
The Northey Hill fault and the geology in Corbin Park in the southeastern corner of the map were extrapolated from Lyons (1955)
Digitized by Gregory J. Walsh; assisted by Meghan E. Mason
Edited by David A. Shields

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

[Major minerals are listed in order of increasing abundance]

POST-METAMORPHIC INTRUSIVE ROCKS

White Mountain Igneous Suite

[Dikes are assigned a Cretaceous age on the basis of the 122.2±2-Ma (mega-annum) age of the Ascutney Mountain Igneous Complex (Foland and others, 1985), a 133±6-Ma age from a dike in the North Hartland Dam spillway (McHone and McHone, 2012), and a regional summary by McHone (1984) for similar dikes throughout New England and Québec]

Kmd — **Mafic dikes (Cretaceous)**—Aphanitic, dark-gray to black, undifferentiated lamprophyre, camptonite, or diabase dikes. Dikes range in thickness from 0.1 to 2.5 meters (m) and may contain phenocrysts of biotite, amphibole, pyroxene, and olivine. May also contain amygdules filled with dolomite or calcite. The dike in the North Hartland Dam spillway contains mantle xenoliths of lherzolite, dunite, harzburgite, and clinopyroxenite (McHone and McHone, 2012). Generally, the dikes intrude parallel to joint sets and are unfoliated, but may be blocky jointed. Shown as polygonal map units or with strike and dip symbols; the thickness on the map is exaggerated to show location

Kt — **Trachyte dikes (Cretaceous)**—Aphanitic, gray to light-gray, tan-weathering trachyte dikes. Dikes are approximately 1 to 1.5 m thick and may contain quartz and feldspar phenocrysts. Two north-northeast trending dikes occur in West Windsor on the eastern ridge of Blood Hill. The dikes intrude parallel to vertical joint sets and are unfoliated, but may be blocky jointed. Shown with strike and dip symbols only

SYN- TO POST-METAMORPHIC ROCKS

Msz — **Silicified zone (Mesozoic)**—Very dark gray to white, brecciated and recrystallized, vein quartz and brecciated quartz-laminated phyllite of the Littleton Formation (Dl). Contains accessory calcite, opaques, chlorite, and muscovite. Occurs as an approximately 5- to 15-m-thick, sub-vertical zone in Plainfield west of Willard Ledge, between the two splays of the Ammonoosuc fault. The orientation of the silicified zone is consistent with development in the R-shear plane during right-lateral (dextral) displacement of the fault. Thickness of the zone is exaggerated to show its location

KDq — **Quartz veins (Cretaceous and Devonian)**—White quartz veins; may locally contain small amounts of muscovite, chlorite, graphite, sulfides, and carbonate minerals. Shown as polygonal map units or with strike and dip symbols

PRE-METAMORPHIC ROCKS

Mélange (Lower Devonian and Silurian?)

DSm — Polymict metaconglomerate member—Dark-gray to black, rusty weathering, sulfidic, polymict conglomerate to breccia with a rusty weathering, dark-gray to black, sulfidic graphite-chlorite-biotite-muscovite-quartz schist matrix. The unit contains clasts of gray, black, and tan quartzite, pebbly quartzite, vein quartz, black schist, metavolcanic rocks, and rare granitoid suggesting the rock is derived from the pre-Silurian rocks in the Bronson Hill arc. Some clasts have a metamorphic fabric which implies a pre-deformed source. The unit also contains gray, calcareous graphite-chlorite-calcite-muscovite-biotite-quartz granofels with small vugs at one place at French's Ledges (labeled "cal" on map); this rock resembles the Fitch Formation unit Sfgr. The matrix may be reworked Partridge Formation. The belt of rocks is in the stratigraphic position of the Partridge Formation or Clough Quartzite on the east side of the Meriden antiform, between the metafelsite of the Ammonoosuc Volcanics (Oaf) to the east and the Gile Mountain Formation occurring to the west. We interpret this rock as a mélange, either tectonic or sedimentary (Raymond, 1984), and suggest that it may possibly be correlative with polymict conglomerate seen at Chestnut Hill in the Springfield quadrangle (Walsh and others, 1996a,b; Armstrong and others, 1997; Thompson and others, 2012). At Chestnut Hill, the mélange contains clasts of the Clough Quartzite indicating that its formation postdates deposition of the Clough (Thompson and others, 2012). The mélange is spatially related to the Monroe thrust, supporting a tectonic origin for this belt of rock (Thompson and others, 2012). The mélange is exposed on either side of Route 120 near the junction of Whitaker Road and south of the junction with Underhill Road

Rocks of the Connecticut Valley trough

Gile Mountain Formation (Lower Devonian)

Dgm — Meetinghouse Slate Member—Dark-gray and silvery gray, lustrous, carbonaceous, plagioclase-quartz-chlorite-muscovite slate and phyllite rhythmically interbedded with lesser micaceous plagioclase-quartz granofels and micaceous quartzite similar to Dgf. Quartzite and granofels beds generally range in thickness from 1 to 5 centimeters (cm), and rarely exceed 10 cm thick. A 10-cm-thick bed of small-pebble quartz-rich conglomerate was observed at one place in Plainfield on Short Knoll (labeled "cgl" on map). The unit is well exposed at the North Hartland Dam spillway

Dgq — Feldspathic quartzite, granofels, and metapelite member—Light-gray, tan-weathering, massive, micaceous, feldspathic quartzite and micaceous plagioclase-quartz granofels interbedded with lesser dark-gray carbonaceous chlorite-biotite-muscovite-plagioclase-quartz slate, phyllite, or schist. Locally, the unit is a slightly calcareous rock that contains round-weathering pits as much as a few cm across. Quartzite and granofels comprise approximately 50 to 90 percent of the unit in beds that generally range in thickness from 2 to 100 cm. In the core of the Meriden antiform the unit consists largely of quartzite, locally with 10 percent or less of metapelite. The unit is well exposed in Cornish and Plainfield on Fernald Hill, Yetsevitch Hill, Stevens Hill, and on the lower western slopes of Home Hill

Dgqs — Gray quartzite and metapelite member—Dark- to light-gray, lustrous, carbonaceous chlorite±garnet±biotite-plagioclase-quartz-muscovite schist and phyllite, locally interbedded with thin gray quartzite, tan to gray feldspathic quartzite, and gritty micaceous plagioclase-quartz granofels. The unit is locally sulfidic and is similar to the phyllite and schist member (DSws) of the Waits River Formation, but generally has more quartzite beds. Typical exposures occur in Hartland on Kent Hill

Dgqc, **Dgqcm**, **Dgqq** — Quartzite, conglomerate, and metapelite member (Dgqc)—Interbedded, tan-weathering, gray micaceous quartzite; dark-gray, fine-grained, polymict conglomerate to breccia; and silvery gray to dark-gray, locally rusty weathering phyllite to schist. The conglomerate occurs in beds as much as 4 m thick. Clasts occur in a gray metapelite matrix and consist of quartz veins, chips of black metapelite, gray quartzite, sulfidic metapelite, and possible metafelsite and green schist. The conglomerate is present in the North Hartland quadrangle in the Meriden antiform, and is well exposed on Penniman Hill. East of Whitaker Road the rock contains clasts of white and gray calcite marble, and there it is mapped as unit Dgqcm. A white quartzite to quartz-pebble conglomerate mapped as Dgqq was observed at a single outcrop on the west side of Penniman Hill at an elevation of 1,040 feet. Dgqq resembles the Clough Quartzite (unit Scq). The conglomerate may represent Devonian flysch deposits in front of the advancing Acadian thrust sheets such as the Monroe thrust sheet

Dgab — Ankeritic biotite schist member—Dark-gray, rusty spotted, ankerite-quartz-biotite schist with accessory plagioclase, epidote, chlorite, and garnet. Observed within Dgqs at one place in the headwaters of Fulling Brook in Hartland at an approximate elevation of 1,100 feet

Dgg — Greenstone member—Layered to massive, dark-green to green, fine-grained, ±actinolite-epidote-chlorite-plagioclase greenstone; contains accessory biotite, opaques, and calcite; locally sulfidic. The western map unit on Fernald, Yatsevitch, and Smith Hills is generally fine-grained and layered, locally contains large (as much as 30 cm) epidote boudins, and is intercalated with silvery gray green chlorite-muscovite-quartz-plagioclase schist along the contacts with the adjacent feldspathic quartzite, granofels, and metapelite member (Dgq). This western belt is interpreted as a mafic volcanic to volcaniclastic rock. The eastern unit on Penniman Hill is massive and exhibits diabasic texture with amphibole-actinolite intergrowths; the contacts with Dgq are sharp. The unit may be a massive flow or a dike

Dgh — Hornblende fascicle schist member—Silvery gray, medium- to coarse-grained, calcite-hornblende-quartz-biotite schist with conspicuous hornblende fascicles; contains accessory muscovite and chlorite. Crops out on Blake Hill in the northwestern corner of the map. The unit is interpreted as a volcaniclastic rock

Dgf — Felsic gneiss and quartzose granofels member—Light-gray, biotite-quartz-plagioclase gneiss, and feldspathic biotite quartzite and granofels with accessory hornblende and garnet. The unit resembles DSwf and crops out on Blake Hill in the northwestern corner of the map. The unit is interpreted as a mixed volcaniclastic and sedimentary rock

Waits River Formation (Lower Devonian and upper Silurian)

DSwl — Limestone and schist member—Dark- to light-gray, locally sulfidic and rusty-weathering, lustrous, carbonaceous chlorite±garnet±biotite-plagioclase-quartz-muscovite schist and phyllite with characteristic interbedded dark-blue-gray, dark-brown punky weathering, impure siliceous limestone or marble, quartz-rich calcareous schist, and gray calcareous to non-calcareous quartzite. The phyllite contains less than 10 percent chlorite and plagioclase, and accessory biotite and garnet porphyroblasts in the garnet zone and rare biotite porphyroblasts in the biotite zone. The limestones contain trace to 5 percent muscovite, 20 to 40 percent quartz, and 60 to 80 percent calcite with accessory plagioclase, pyrite, opaques, graphite, tourmaline, and apatite. Limestone beds generally measure 0.1 to 3.0 m thick; bedding in the metapelite is generally not visible. The unit is well exposed on Interstate 91 and in Lulls Brook south of the village of Hartland

DSws — Gray phyllite and schist member—Dark- to light-gray, lustrous, carbonaceous chlorite±garnet±biotite-plagioclase-quartz-muscovite schist and phyllite, locally interbedded with thin gray quartzite, tan to gray feldspathic quartzite, and gritty micaceous plagioclase-quartz granofels. The unit contains trace limestone and is similar to the quartzite and metapelite member (Dgqs) of the Gile Mountain Formation, but generally has fewer quartzite beds. Typical exposures occur in Hartland in the valley of Densmore Brook

DSwq — Quartzite member—Gray micaceous quartzite, tan to gray feldspathic quartzite, and dark-gray to blue-gray, carbonaceous muscovite-chlorite-plagioclase quartz-rich schist and micaceous quartzite. The unit resembles quartzites of Dgq. The unit crops out in the Connecticut River at Sumner Falls

DSwv — Laminated schist and granofels member—(1) Heterogeneous, laminated to layered, green and white, in places rusty weathering, fine- to medium-grained, muscovite±biotite-chlorite-quartz-plagioclase schist; (2) silvery green, fine- to medium-grained muscovite±biotite-chlorite-quartz-plagioclase schist; (3) gray-green, medium-grained, muscovite±biotite-chlorite-quartz-plagioclase granofels; (4) greenstone; and (5) silvery gray, rusty weathering, carbonaceous calcite-plagioclase-quartz-chlorite-biotite-muscovite schist. The unit contains accessory calcite and ilmenite and is interpreted as a heterogeneous assemblage of volcaniclastic sediments and primary volcanic rocks

DSwvp — Porphyritic schist and granofels member—Gray-green to light-gray, medium-grained, actinolite-muscovite-quartz-plagioclase-chlorite- biotite schist with quartz and plagioclase phenocrysts up to 1 cm long; contains accessory calcite, ilmenite, apatite, and idocrase. The unit is interpreted as a primary volcanic rock

DSwgs — Large garnet and hornblende garbenschiefer schist member—Silvery gray to light-gray, in places rusty weathering, calcite-epidote-chlorite-garnet-hornblende-plagioclase-quartz-biotite-muscovite schist with distinctive sprays of hornblende and large garnet porphyroblasts. The unit is interpreted as metamorphosed pelitic sediments with a volcaniclastic component

DSwa — Amphibolite and greenstone member—Massive, dark-green to green, fine-grained, calcite-epidote-chlorite-biotite±hornblende±actinolite-plagioclase amphibolite and greenstone. The unit is interpreted as mafic volcanic and volcaniclastic rock

DSwhg — Hornblende-plagioclase gneiss member—Medium-grained to very coarse grained, black and white to dark-green, calcite-epidote±garnet-chlorite-biotite-hornblende-plagioclase amphibolite gneiss with roughly equal percentages of hornblende and plagioclase; contains accessory calcite and ilmenite. The unit is interpreted as a mafic volcanic flow or composite flow

DSwf — Felsic gneiss and quartzose granofels member—Light-gray, biotite-quartz-plagioclase gneiss, and feldspathic biotite quartzite and granofels with accessory hornblende and garnet. The unit is interpreted as a volcaniclastic sedimentary and primary sedimentary rock

DSwss — Sulfidic schist member—Silvery, rusty yellow weathering, sulfidic quartz-muscovite schist. The unit is interpreted as a hydrothermally produced stratiform sulfide deposit

Rocks of the Orfordville anticlinorium in the Monroe thrust sheet

Littleton Formation (Lower Devonian)

Dl — Gray quartz-laminated phyllite member—Dark-gray to light silvery gray, lustrous, locally thinly laminated, carbonaceous chlorite±biotite-plagioclase-quartz-muscovite schist and phyllite with interbedded gray micaceous or feldspathic quartzite. Typical exposures occur at Willard Ledge and on Prospect Hill in the Prospect Hill belt. The unit of Dl shown in the southeastern corner of the map in Corbin Park, east of the Northey Hill fault, was extrapolated from Lyons (1955) and from ongoing mapping in the adjacent Claremont North quadrangle

Dlc — Coticule and ironstone member—Dark-gray to light silvery gray, lustrous, locally thinly laminated, carbonaceous chlorite±biotite-plagioclase-quartz-muscovite schist and phyllite, and thin quartzite with distinctive, thin (1- to 20-cm-thick) layers of pink to yellowish-pink coticule, garnetiferous quartzite, and dark-gray to black ironstone; contains chlorite pseudomorphs after retrograded biotite and garnet. The unit crops out at the base of the Littleton Formation in the Prospect Hill belt

Fitch Formation (Lower Devonian and upper Silurian)

Sfm — Marble member—Light-gray to white, gray to orange-tan weathering, opaque-quartz-muscovite-calcite marble and sphene-epidote-quartz-garnet-muscovite-biotite-calcite marble. Garnetiferous marble occurs in layers above the contact with the calc-silicate granofels member (Sfgr). Garnet porphyroblasts are poikilitic and up to 1 cm across. Contains interbedded layers of gray calc-silicate granofels at the contact with Sfgr at the railroad cut in Hartford, west of Johnston Island. The unit is exposed at the railroad cut on the east side of Prospect Hill in Hartford, Vt., and on the east side of Read Hill; crops out at the top of the Fitch Formation

Sfgr — Calc-silicate granofels member—Gray to bluish-gray or gray-green, dark-gray to light-gray weathering, massive, calcite-biotite-chlorite-muscovite-plagioclase-quartz granofels with distinctive small (as little as a few centimeters) calcite-filled vugs and weathered pits. Contains as much as a few percent sphene, apatite, epidote, and opaques

Sfs — Laminated schist member—Silvery gray green, banded to laminated, magnetite-chlorite-biotite-epidote-quartz-plagioclase-muscovite schist and garnet-biotite-quartz-muscovite schist. Contains thin (centimeter-scale) layers and boudins of magnetite-garnet-quartz coticule. The member is interlayered with the greenstone member (Sfg) along its lower contact. The unit crops out on the eastern side of Read Hill above the greenstone member (Sfg) and below the marble member (Sfm) or Littleton Formation (Dl)

Sfg — Greenstone member—Massive to layered, green to gray-green, fine-grained, ±ilmenite±apatite±calcite±actinolite±biotite-quartz-chlorite -epidote-hornblende-plagioclase amphibolite or greenstone. The unit is exposed in Plainfield from Mill Village to southwest of Bartlett Four Corners, and typical exposures occur in Blow-Me-Down Brook upstream of Mill Village where it contains deformed pillows. The unit occurs above the Clough Quartzite at the base of the Fitch Formation. The unit is interpreted as mafic volcanic and volcaniclastic rock; perhaps correlative to potential feeder dikes of the Comerford Intrusive Complex (Scd)

Lake Memphremagog Intrusive Suite

Scd — **Comerford Intrusive Complex (late Silurian)**
Metadiabase dikes—Massive, medium-grained, very dark green to black and white, calcite-epidote±garnet-chlorite-biotite-hornblende-plagioclase amphibolite to diorite granofels with white plagioclase phenocrysts up to 1 cm long. The dikes contain leucocratic black and white segregations of hornblende-plagioclase pegmatitic diorite with intergrown phenocrysts up to 2 cm across, postdate compositional layering within the Ammonoosuc Volcanics, and measure as much as several meters thick. Shown as map units or as strike and dip symbols. The map units consist of swarms of dikes in the host Ammonoosuc Volcanics. The unit is correlated with the Comerford Intrusive Complex dated at 419±1 Ma (Rankin and others, 2007). The unit is interpreted as feeder dikes to the Fitch Formation greenstone member (Sfg). Typical exposures occur on Black Hill, Potato Hill, and the west side of Pinnacle Hill

Scq — **Clough Quartzite (lower Silurian)**
Conglomerate member—White, locally rusty weathering, massive, quartz-cobble metaconglomerate and lesser white quartzite. Locally contains ankerite or magnetite. Contains thin seams of silvery white, chloritoid-quartz-muscovite schist at French's Ledges. Cobbles consist largely of vein quartz and white and gray quartzite. Contacts with adjacent units are sharp and not intercalated. Typcial exposures occur on French's Ledges and Smith Hill. Possibly occurs as olistoliths on the east side of French's Ledges where the Clough Quartzite is bounded on both sides by the mélange unit DSm

Rocks of the Bronson Hill arc

Oliverian Plutonic Suite (Late Ordovician)

Oqd — Quartz diorite of the Lebanon dome—Gray, weakly to moderately well foliated, blocky weathering, epidote-quartz-hornblende-biotite-plagioclase quartz diorite gneiss. The quartz diorite intrudes the Partridge Formation in the northeastern part of the map. The contact is sharp and roughly parallel to the dominant foliation. The quartz diorite is well exposed in Lebanon at an abandoned quarry about 450 m west of Slayton Road. This unit is the border-phase of the Lebanon pluton, and it surrounds a core of pink biotite granite, which is not exposed in the area of this map; the latter is exposed in the adjacent Hanover quadrangle to the north (Kaiser, 1938; Lyons, 1955). Valley and Walsh (2013) report a preliminary U-Pb SHRIMP zircon age of about 447 Ma for the quartz diorite. At the dated sample locality in the Hanover quadrangle (Stop 1 of Walsh and others, 2012), the intruded Partridge Formation consists of rusty sulfidic, psammitic quartz-muscovite schist, which was not mapped separately in the area of this report. The schist in the North Hartland quadrangle is generally more pelitic than the rock at Stop 1 of Walsh and others (2012)

Partridge Formation (Ordovician)

Opp — Plagioclase studded schist member—Gray to light-gray, moderately well foliated to poorly foliated, quartz-biotite-epidote-plagioclase schist to granofels with abundant white plagioclase porphyroblasts consisting of recrystallized aggregates of plagioclase and granular epidote-clinozoisite. The unit is interpreted as a metasomatized version of the Partridge Formation sulfidic schist member (Op). The rock occurs discontinuously near the contact with the Lebanon quartz diorite. The metasomatized zone extends into the adjacent Hanover quadrangle (Kaiser, 1938; Lyons 1955); it was noted by Lyons but mapped differently

Op, **Opa** — Sulfidic schist member (Op)—Dark-gray to grayish-black, rusty-weathering, sulfidic, graphite±garnet-plagioclase-biotite-quartz-muscovite phyllite and schist; locally contains light- to dark-gray micaceous quartzite in thinly laminated layers or boudins. In Plainfield, south of Town Farm Road, an anomalous micaceous quartzite contains accessory graphite, hematite, and garnet in the biotite zone (labeled "Grt" on map). Dark-gray quartzite beds as much as 30 cm thick occur locally. The unit contains lesser silvery gray garnet-muscovite-epidote-plagioclase-chlorite-biotite-quartz near the contact with the Ammonoosuc Volcanics. It also contains rare, light-gray and pale-yellow banded magnetite-muscovite-biotite-quartz-calcite-plagioclase-garnet coticule interlayered with magnetite-muscovite-quartz-plagioclase-biotite schist in the northeastern part of the map in Lebanon west of Storrs Hill (labeled "c" on map). Contacts with the Ammonoosuc Volcanics are generally sharp, but may be gradational over a few meters. Contacts with the Clough Quartzite are very sharp. The unit contains coarse-grained hornblende-plagioclase amphibolite lenses and boudins mapped as Opa at exposures under the power transmission lines on the west side of Farnum Hill. The amphibolites measure 0.2 to 1 m thick and their size is exaggerated on the map to show their locations

Otp — **Plainfield tonalite (Early Ordovician)**—Greenish-gray, light-gray weathering, moderately to weakly foliated, epidote±hornblende-biotite-chlorite-quartz-plagioclase tonalite to trondhjemite gneiss. Contains characteristic small augen of quartz and lesser feldspar, up to 0.5 cm across, and accessory calcite and muscovite. Chlorite is a product of retrograded biotite. Lyons (1955) first mapped this rock as the "gneiss east of Plainfield" and noted the similarity between this rock and the tonalitic "gneiss at White River Junction." Lyons considered the Plainfield tonalite to be conformable with the surrounding volcanic rocks, but new mapping shows that it is intrusive into the Ammonoosuc Volcanics, at least along the western side. The unit contains screens and xenoliths of the Ammonoosuc Volcanics. Good intrusive contacts are exposed along the power line on the southeast side of Stone House Hill (Walsh and others, 2012) and along Black Hill Road southeast of Sky Ranch Pond. Valley and Walsh (2013) report a preliminary U-Pb SHRIMP zircon age of 473±5 Ma for the tonalite

Ot — **Unnamed tonalite (Early Ordovician)**—Light-gray to gray, light-gray weathering, well foliated, ±garnet±hornblende-biotite tonalite to trondhjemite and lesser biotite granite gneiss. Occurs as abundant foliation-parallel lit-par-lit dikes or sills in the Ammonoosuc Volcanics. The map unit contains undifferentiated Ammonoosuc Volcanics, and is similar to and probably correlative with the Plainfied tonalite, but mapped bodies are not contiguous with the Plainfield pluton (Otp). The unit is well exposed in Lebanon at the Lebanon Crushed Stone quarry on Mount Finish and at True's Ledges Natural Area along True's Brook (shown as Bloods Brook on the base map). Shown as polygonal map units or with strike and dip symbols; thickness is exaggerated on the map to show the location of zones of abundant dikes or sills

Ammonoosuc Volcanics (Ordovician)

Oa — Undifferentiated volcanic member—Heterogeneous complex of rock types consisting of layered to massive, greenstone, amphibolite, biotite-muscovite-chlorite-quartz-plagioclase schist and phyllite, felsic quartz-plagioclase granofels (metafelsite), and sulfidic quartz-plagioclase schist. May contain accessory calcite, ankerite, magnetite, or pyrite. The unit is dominated by mafic rocks, either volcanic or volcaniclastic. Metamorphic index minerals include hornblende and garnet in the garnet zone, and biotite and actinolite in the biotite zone; contains anomalous garnet in the biotite zone in Hibbard Brook (labeled "Grt" on map). Locally, the unit contains fascicular hornblende garbenschiefer in the garnet zone. At sub-garnet grade, the rocks are green, gray green, bluish green, silvery gray green, and green and white layered. In the garnet zone, the rocks are darker green, gray green to black, and black and white layered. Locally, the unit also contains pods and lenses of epidote, plagioclase, and lesser quartz phenocrysts, deformed pillows, fiamme (eutaxitic texture), and volcanic breccia

Oaf, **Oafa** — Metafelsite member (Oaf)—Pale-green to silvery light gray or white, light-gray to white to rusty weathering, laminated and well-foliated, ±biotite-muscovite-chlorite-quartz-plagioclase schist to protomylonite or granofels. Contains accessory magnetite and sulfides, local epidote and amphibole, and millimeter-size quartz and feldspar phenocrysts. Contacts with the other units of the Ammonoosuc Volcanics are gradational. A belt of green and white banded rock on the west side of Fifield Hill is mapped separately as "Oafa," which contains metafelsite beds 5 to 30 cm thick interlayered with undifferentiated volcanic rocks. The contact along the Monroe fault is sharp and the metafelsite there is protomylonitic. Typical exposures of Oaf occur on the west side of Fifield Hill, about 100 m east of Route 120. The unit is interpreted as felsic volcanic and volcaniclastic rock

Oaa — Amphibolite member—Massive to layered, gray-green to dark-green or black, fine-grained, apatite±calcite±actinolite±chlorite±biotite-epidote-hornblende-plagioclase amphibolite. The unit is exposed from Pinnacle Hill to the ridge east of Mud Pond, west of Porter Road. The unit is interpreted as mafic volcanic and volcaniclastic rock

Oag — Felsic granofels member—Massive, light-gray to very pale green, white- to tan-weathering, fine- to medium-grained, muscovite-chlorite-biotite-quartz-plagioclase granofels. Locally, contains millimeter- to centimeter-scale phenocrysts of quartz and feldspar and small centimeter-scale epidote pods. Contains accessory epidote, blue-green amphibole, and trace opaques. The unit is exposed in Plainfield on the west side of Ladieu Hill; typical exposures occur along Ladieu Road west of Colby Hill. The unit is interlayered with the Oa unit. The unit is interpreted as felsic volcanic and volcaniclastic rock

Oarq — Lapilli tuff member—Massive, pale-green to light-gray, gray weathering, muscovite-chlorite-biotite-quartz-plagioclase schist with white to light-gray felsic, flattened lapilli or lesser volcanic bombs as much as 10 cm long. May contain lesser, dark-gray-green mafic clasts. The matrix is aphanitic with millimeter-size quartz and feldspar phenocrysts. The unit occurs as layers within the undifferentiated Oa unit. Typical exposures occur under the power line at the summit of Pinnacle Hill and about 1 km east of Sky Ranch Pond, and just east of the summit of Colby Hill. The unit is interpreted as a pyroclastic volcanic rock. A SHRIMP U-Pb zircon age of 460±2 Ma from Colby Hill indicates that part of the Ammonoosuc Volcanics in this area is younger than the Plainfield tonalite (Valley and others, 2015)

Oarr — Rusty sulfidic granofels member—Very light gray to silvery white, very rusty yellow weathering, well-foliated, sulfidic pyrite-muscovite-quartz-plagioclase granofels to schist. The unit is interlayered with the undifferentiated Oa unit on the east side of Fifield Hill in Plainfield

EXPLANATION OF MAP SYMBOLS

Contact—Approximately located; dotted where concealed by water. In cross section, dotted where projected above the ground surface

Outcrops—Areas of exposed bedrock or closely spaced contiguous bedrock exposures examined in this study

FAULTS

[Approximately located; dotted where concealed by water. In cross section, dotted where projected above the ground surface]

Pre-peak metamorphic D_1 thrust fault (Acadian)—Parallel to the S_1 foliation; sawteeth on upper plate

Post-peak metamorphic, lower greenschist, D_2 or younger, strike-slip fault or shear zone (Acadian or Alleghanian)—Steeply dipping, parallel to the S_2 foliation; arrows indicate relative motion where known; U, upthrown side; D, downthrown side. In cross sections: T, toward observer; A, away from observer. Long arrow shows dominant lineation trend where known. Locally reactivated during brittle deformation

Brittle fault (Mesozoic)—Steeply dipping, arrows indicate relative motion where known; U, upthrown side; D, downthrown side. In cross sections: T, toward observer; A, away from observer

FOLDS

[Location is known or inferred; symbols show trace of axial surface and direction of dip of limbs]

Axial trace of inferred isoclinal F_1 fold (Acadian, nappe-stage)

Overturned anticline; locally inverted or recumbent; the conjectual Cornish nappe of Lyons and others (1996) is queried

Overturned syncline; locally inverted or recumbent

Axial trace of F_2 fold (Acadian?, early dome-stage)

Antiform; arrow shows plunge direction of Meriden antiform

Synform; arrow shows plunge direction

Overturned antiform

Overturned synform

Axial trace of F_3 or younger fold (Alleghanian?, late dome-stage or Mesozoic near the Ammonoosuc fault)

Antiform

Synform

MINOR FOLDS

Strike and dip of folded axial surface of F_1 fold parallel to S_1 foliation—Isoclinal, rootless folds; Acadian nappe-stage

Strike and dip of axial surface of F_2 fold parallel to S_2 foliation—Tight to isoclinal, locally rootless folds; Acadian early dome-stage

Inclined

Inclined, with horizontal fold axis

Vertical

Strike and dip of axial surface of F_3 or younger minor fold—Open folds; Alleghanian late dome-stage or younger related to Mesozoic faults

Inclined

Vertical

PLANAR FEATURES

[Symbols may be combined; point of intersection shows location of measurement]

Strike and dip of bedding parallel to S_1

Inclined

Inclined, showing tops from graded beds or pillows

Inclined, overturned showing tops

Strike and dip of quartz vein

Inclined

Vertical

Strike and dip of mafic dike (Kmd)

Inclined

Vertical

Strike and dip of trachyte dike (Kt)

Vertical

Strike and dip of metadiabase dike (Scd)

Inclined

Vertical

Strike and dip of dioritic dike or sill (Oqd? or Scd?)

Strike and dip of granitic to tonalitic dike or sill (Ot?)

FOLIATION

Strike and dip of layer-parallel schistosity (S_1) (Acadian)—Parallel to bedding or compositional layering

Inclined

Inclined, deformed

Vertical

Horizontal

Strike and dip of spaced foliation (S_2) (Acadian or younger)—Variable across the map, less penetrative to the west, zonal in the east

Cleavage

Inclined

Horizontal

Schistosity

Inclined

Vertical

Mylonitic or phyllonitic S_2 inclined foliation in local shear zones

Phyllonitic S_2 or younger inclined shear bands showing left-lateral (sinistral) relative motion

Strike and dip of dominant foliation (S_d)—Not age specific, but either S_1 or a composite S_1-S_2 foliation expressed as a schistosity where S_2 is penetrative

Inclined

Vertical

Strike and dip of crenulation cleavage (S_3) (Alleghanian)—Associated with open folds and a crenulation lineation that is most apparent in fine-grained metapelites

Inclined

Vertical

LINEAR FEATURES

[Symbols may be combined; point of intersection shows location of measurement]

Approximate bearing and plunge of folded F_1 minor fold axis

Bearing and plunge of L_2 intersection lineation—Intersection between the S_2 and S_1 foliations

Bearing and plunge of F_2 minor fold axis—Fold axis of tight, isoclinal, or rootless fold associated with S_2

Bearing and plunge of L_2 mineral lineation—Aggregate lineation or grain lineation associated with the S_2 foliation; consists of quartz, plagioclase, biotite, muscovite, chlorite, or amphibole

Bearing and plunge of L_2 rods or object lineations—Lineations composed of elongate objects such as pebbles and quartz or plagioclase phenocrysts; lineation generally associated with the S_2 foliation but may represent an older L_1 lineation

Bearing and plunge of F_3 minor fold axis—Fold axis of late, open fold or crenulation lineation

OTHER FEATURES

Garnet
Biotite

Isograd or tectonic metamorphic boundary—Approximate boundary between rocks with garnet and (or) hornblende in the garnet zone versus rocks with biotite and (or) actinolite, or locally chloritoid (in Scq), in the biotite zone. The boundary locally coincides with splays of the Ammonoosuc or Northey Hill faults

Quarry

Active—Construction aggregate in the Ammonoosuc Volcanics

Abandoned

Spring

NH–144
475±5 Ma

Geochronology sample location—Showing sample number and preliminary uranium-lead (U-Pb) zircon age in millions of years before present (Ma, mega annum) by sensitive high resolution ion microprobe (SHRIMP) from Valley and Walsh (2013) and Valley and others (2015)

DISCUSSION

INTRODUCTION

The bedrock geology of the 7.5-minute Hartland and North Hartland quadrangles, Vermont-New Hampshire, consists of highly deformed and metamorphosed lower Paleozoic metasedimentary, metavolcanic, and metaplutonic rocks of the Bronson Hill anticlinorium (BHA) and the Connecticut Valley trough (CVT) (Lyons and others, 1997; Ratcliffe and others, 2011; Walsh and others, 2012, 2014). Rocks of the Orfordville anticlinorium on this map occupy the western part of the broader BHA. In the BHA, the Ordovician Ammonoosuc Volcanics and graphitic, sulfidic metapelite of the Partridge Formation are intruded by Ordovician plutonic rocks of the Oliverian Plutonic Suite. The Ordovician rocks are collectively referred to as the Bronson Hill arc. The Ordovician rocks are overlain by Silurian to Devonian Clough, Fitch, and Littleton Formations (Lyons and others, 1997). On this map, rocks of the CVT occupy the eastern part of the broader CVT. In the CVT in Vermont, the Silurian to Devonian Shaw Mountain, Waits River, and Gile Mountain Formations form an unconformable autochthonous to parautochthonous cover sequence on the pre-Silurian rocks of the Rowe-Hawley zone above Precambrian basement rocks of the Mount Holly Complex (Ratcliffe and others, 2011). On this map, however, only the Waits River and Gile Mountain Formations are exposed. Syn- to post-metamorphic rocks include quartz veins and Cretaceous dikes of the White Mountain Igneous Suite.

Rocks of the BHA occur in a thrust sheet floored by the Monroe fault, which carried a deformed section of plutonic rocks, Ammonoosuc Volcanics, Partridge Formation, Clough Quartzite, and the Fitch and Littleton Formations. The Monroe thrust sheet placed the BHA rocks over the CVT during an early Acadian F_1 nappe-stage event prior to peak metamorphism at lower amphibolite facies conditions. Upper and lower plate truncations, mylonite, and local mélange characterize the Monroe fault. F_2 doming deformed the Monroe thrust sheet, folded earlier isograds, and created the Meriden antiform and Lebanon dome. Lower greenschist facies (Acadian to Alleghanian) faults such as the Sumner Falls shear zone truncated peak-metamorphic assemblages, isograds, and older F_1 folds and faults. Late-stage F_3 folds show preferred left-lateral rotation sense (see Orientation Points in the database) and are probably related to late dome-stage Alleghanian deformation or motion along lower greenschist facies faults. The youngest deformation is characterized by Mesozoic brittle faulting and spatially associated kink bands along the Ammonoosuc fault zone, followed by subsequent jointing (see sheet 2).

Currently major economic natural resource activities are related to aggregate quarrying in the Ammonoosuc Volcanics at Twin State Sand and Gravel in Hartford, Vt., and Lebanon Crushed Stone in Lebanon, N.H.

This report consists of sheets 1 and 2 as well as an online geographic information system (GIS) database that includes contacts of bedrock geologic units, faults, outcrops, structural geologic information, and photographs. Sheet 2 of this report shows three cross sections, a tectonic map (fig. 1), and two brittle features maps (figs. 2A and 2B) that show measured outcrop-scale strike and dip results with summary stereonets and rose diagrams.

ACKNOWLEDGMENTS

Partial funding for this map came from the National Park Service. Helpful review comments were provided by P.M. Valley (U.S. Geological Survey), A.J. Merschat (U.S. Geological Survey), and P.J. Thompson (University of New Hampshire).

REFERENCES CITED

Armstrong, T.R., Walsh, G.J., and Spear, F.S., 1997, A transect across the Connecticut Valley sequence in east-central Vermont, Trip A6, *in* New England Intercollegiate Geological Conference, 89th Annual Meeting, Killington-Pico region, Vt., Sept. 19–21, 1997, Guidebook to field trips in Vermont and adjacent New Hampshire and New York: Castleton, Vt., Castleton State College, p. A6–1 to A6–56. (Edited by T.W. Grover, H.N. Mango, and E.J. Hasenohr.)

Foland, K.A., Henderson, C.M.B., and Gleason, Jim, 1985, Petrogenesis of the magmatic complex at Mount Ascutney, Vermont, USA; I. Assimilation of crust by mafic magmas based on Sr and O isotopic and major element relationships: Contributions to Mineralogy and Petrology, v. 90, no. 4, p. 331–345, http://link.springer.com/article/10.1007%2FBF00384712#.

Kaiser, E.P., 1938, Geology of the Lebanon Granite, Hanover, N.H.: American Journal of Science, v. 36, no. 212, p. 107–136, http://www.ajsonline.org/content/s5-36/212/107.full.pdf+html.

Lyons, J.B., 1955, Geology of the Hanover quadrangle, New Hampshire-Vermont: Geological Society of America Bulletin, v. 66, no. 1, p. 105–146, http://gsabulletin.gsapubs.org/content/66/1/105.full.pdf+html.

Lyons, J.B., Bothner, W.A., Moench, R.H., and Thompson, J.B., 1997, Bedrock geologic map of New Hampshire: U.S. Geological Survey State Geologic Map, 2 sheets, scale 1:250,000 and 1:500,000.

Lyons, J.B., Campbell, J.G., and Erikson, J.P., 1996, Gravity signatures and geometric configurations of some Oliverian plutons; Their relation to Acadian structures: Geological Society of America Bulletin, v. 108, no. 7, p. 872–882, http://gsabulletin.gsapubs.org/content/108/7/872.

McHone, J.G., 1984, Mesozoic igneous rocks of northern New England and adjacent Québec; Summary, description of map, and bibliography of data sources: Geological Society of America Map and Chart Series MC–49, scale 1:690,000.

McHone, J.G., and McHone, N.W., 2012, Mesozoic dikes and tectonic features in the central Connecticut River Valley, Vermont and New Hampshire, Trip C–2, *in* New England Intercollegiate Geological Conference, 104th Annual Meeting, Mount Sunapee Resort, Newbury, N.H., Oct. 12–14, 2012, Guidebook to field trips in western New Hampshire and adjacent Vermont and Massachusetts: Keene, N.H., Keene State College, p. C2–1 to C2–18. (Edited by P.J. Thompson and T.B. Thompson.)

Rankin, D.W., Coish, R.A., Tucker, R.D., Peng, Z.X., Wilson, S.A., and Rouff, A.A., 2007, Silurian extension in the upper Connecticut Valley, United States and the origin of middle Paleozoic basins in the Québec embayment: American Journal of Science, v. 307, no. 1, p. 216–264, http://www.ajsonline.org/content/307/1.toc.

Ratcliffe, N.M., Stanley, R.S., Gale, M.H., Thompson, P.J., and Walsh, G.J., 2011, Bedrock geologic map of Vermont: U.S. Geological Survey Scientific Investigations Map 3184, 3 sheets, scale 1:100,000. [Also available at http://pubs.usgs.gov/sim/3184/.]

Raymond, L.A., 1984, Classification of mélanges, *in* Raymond, L.A., ed., Mélanges; Their nature, origin, and significance: Geological Society of America Special Paper 184, Boulder, Colo., p. 7–20, http://specialpapers.gsapubs.org/content/198/7.abstract.

Salvini, Francesco, 2013, DAISY 3; The Structural Data Integrated System Analyzer software (version 4.95.05): Rome, Italy, Roma Tre University, Department of Geological Sciences, software available at http://host.uniroma3.it/progetti/fralab/Downloads/Programs/.

Salvini, Francesco, Billi, Andrea, and Wise, D.U., 1999, Strike-slip fault-propagation cleavage in carbonate rocks; The Mattinata fault zone, Southern Apennines, Italy: Journal of Structural Geology, v. 21, no. 12, p. 1731–1749, http://www.sciencedirect.com/science/article/pii/S0191814199001200.

Thompson, P.J., Robinson, Peter, and Wise, D.U., 2012, Geology of Skitchewaug Mountain, Vermont and adjacent New Hampshire; A reprise of Jim Thompson's 1954 NEIGC trip and consequences for regional geology, Trip B–4, *in* New England Intercollegiate Geological Conference, 104th Annual Meeting, Mount Sunapee Resort, Newbury, N.H., Oct. 12–14, 2012, Guidebook to field trips in western New Hampshire and adjacent Vermont and Massachusetts: Keene, N.H., Keene State College, p. B4–1 to B4–11. (Edited by P.J. Thompson and T.B. Thompson.)

Valley, P.M., and Walsh, G.J., 2013, New U-Pb zircon ages from the Bronson Hill anticlinorium, west-central New Hampshire [abs.]: Geological Society of America Abstracts with Programs, v. 45, no. 1, p. 108, https://gsa.confex.com/gsa/2013NE/finalprogram/abstract_215331.htm.

Valley, P.M., Walsh, G.J., and McAleer, R.J., 2015, New U-Pb zircon ages from the Bronson Hill arc, west-central New Hampshire [abs.]: Geological Society of America Abstracts with Programs, v. 47, no. 3, p. 41, https://gsa.confex.com/gsa/2015NE/webprogram/Paper252722.html

Walsh, G.J., 1998, Digital bedrock geologic map of the Vermont part of the Hartland quadrangle, Windsor County, Vermont: U.S. Geological Survey Open-File Report 98–123–A, 17 p., scale 1:24,000. [Also available at http://pubs.er.usgs.gov/publication/ofr98123A.]

Walsh, G.J., Armstrong, T.R., and Ratcliffe, N.M., 1996a, Preliminary bedrock geologic map of the Vermont part of the 7.5 x 15 minute Mount Ascutney and Springfield quadrangles, Windsor County, Vermont: U.S. Geological Survey Open-File Report 96–719, 37 p., 4 pls., scale 1:24,000. [Map text also available at http://pubs.usgs.gov/of/1996/719/.]

Walsh, G.J., Armstrong, T.R., and Ratcliffe, N.M., 1996b, Digital bedrock geologic map of the Vermont part of the 7.5 x 15 minute Mount Ascutney and Springfield quadrangles, Vermont: U.S. Geological Survey Open-File Report 96–733, scale 1:24,000. [Also available at http://pubs.er.usgs.gov/publication/ofr96733A.]

Walsh, G.J., Merschat, Arthur, McAleer, R.J., Valley, P.M., Armstrong, T.R., Thompson, P.J., Roden-Tice, M.K., Iriondo, Alexander, and Kunk, M.J., 2014, Tectonic evolution and exhumation of the lower structural levels of the Bronson Hill anticlinorium in southwestern New Hampshire and adjacent Vermont [abs.]: Geological Society of America Abstracts with Programs, v. 46, no. 2, p. 96, https://gsa.confex.com/gsa/2014NE/webprogram/Paper236459.html.

Walsh, G.J., Valley, P.M., and Sicard, K.R., 2012, A transect through the base of the Bronson Hill anticlinorium in western New Hampshire, Trip A–4, *in* New England Intercollegiate Geological Conference, 104th Annual Meeting, Mount Sunapee Resort, Newbury, N.H., Oct. 12–14, 2012, Guidebook to field trips in western New Hampshire and adjacent Vermont and Massachusetts: Keene, N.H., Keene State College, p. A4–1 to A4–21. (Edited by P.J. Thompson and T.B. Thompson.)

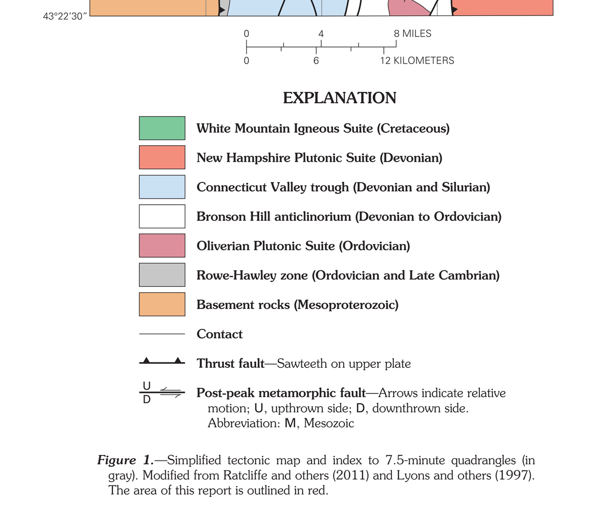


Figure 1.—Simplified tectonic map and index to 7.5-minute quadrangles (in gray). Modified from Ratcliffe and others (2011) and Lyons and others (1997). The area of this report is outlined in red.

BEDROCK GEOLOGIC MAP OF THE HARTLAND AND NORTH HARTLAND QUADRANGLES, WINDSOR COUNTY, VERMONT, AND SULLIVAN AND GRAFTON COUNTIES, NEW HAMPSHIRE

By

Gregory J. Walsh[1]

[1]U.S. Geological Survey, Montpelier, VT 05601.

2016

USGS
science for a changing world

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government

For sale by U.S. Geological Survey, Box 25286, Denver Federal Center, Denver, CO 80225; http://store.usgs.gov; 1–888–ASK–USGS (1–888–275–8747)

Suggested citation: Walsh, G.J., 2016, Bedrock geologic map of the Hartland and North Hartland quadrangles, Windsor County, Vermont, and Sullivan and Grafton Counties, New Hampshire: U.S. Geological Survey Scientific Investigations Map 3361, 2 sheets, scale 1:24,000, https://doi.org/10.3133/sim3361.

ISSN 2329-132X (online)
https://doi.org/10.3133/sim3361