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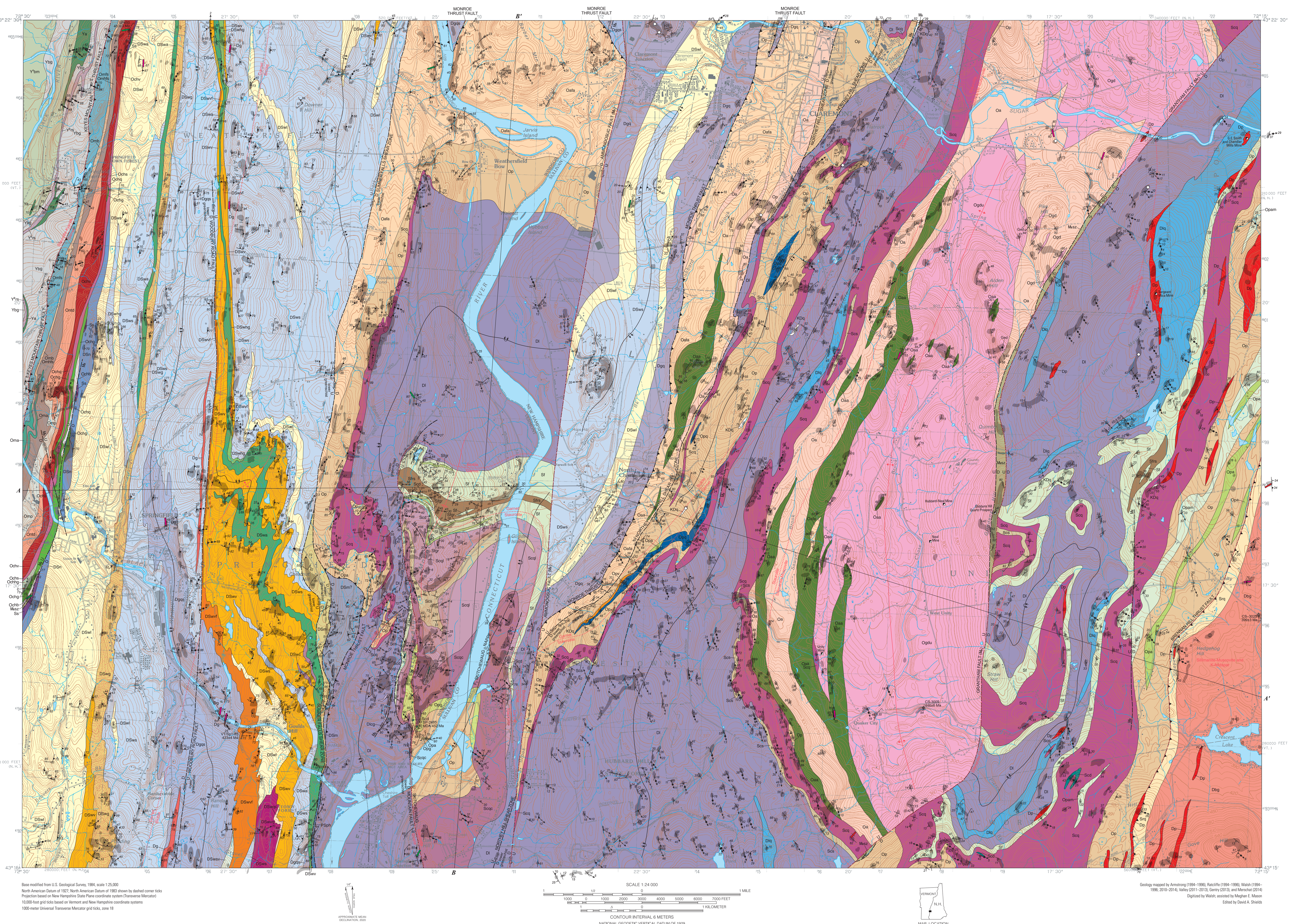
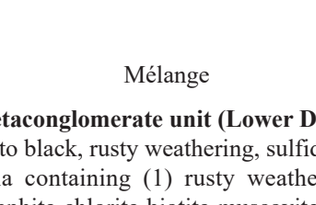
U.S. Geological Survey

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

Scientific Investigations Map 3462
Sheet 1 of 2



Base modified from U.S. Geological Survey, 1984, scale 1:25,000
North American Datum of 1927; North American Datum of 1983 shown by dashed corner ticks
Projection based on New Hampshire State Plane coordinate system (Transverse Mercator)
10,000-foot grid ticks based on Vermont and New Hampshire coordinate systems
1000-meter Universal Transverse Mercator grid ticks, zone 18



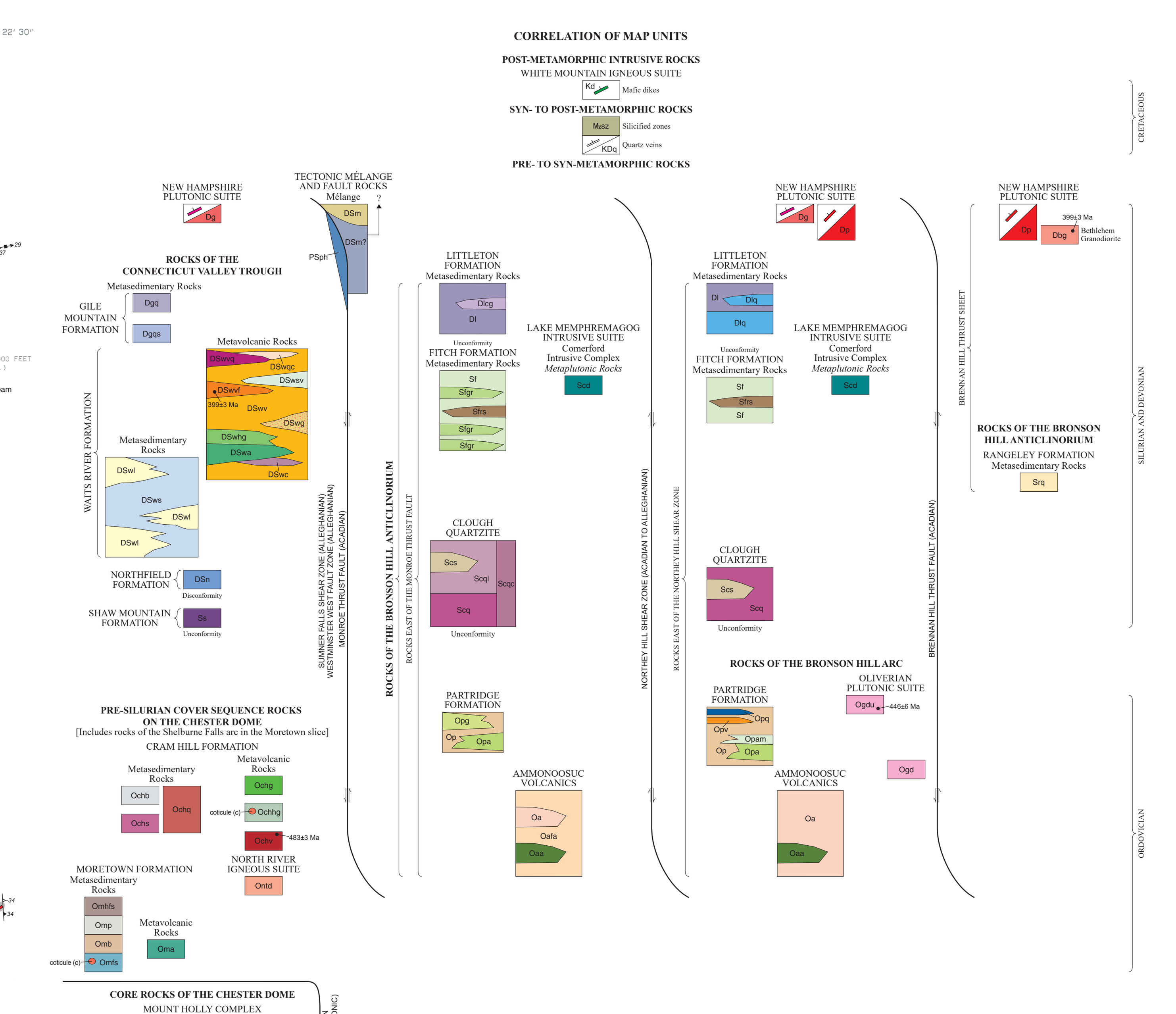
APPROXIMATE MEAN DECLINATION, 2020

SCALE 1:24 000
1 1/2 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 6 METERS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAP LOCATION

Geology mapped by Armstrong (1994–1996), Ratcliffe (1994–1996), Walsh (1994–1996; 2010–2014), Valley (2011–2013), Gentry (2013), and Merschat (2014)
Digitized by 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 based on (1) the 122.2±2 Ma (mega-annum) average age of the entire Ascutney Mountain igneous complex (Foland and others, 1985; Walsh and others, 2020), (2) an age of 133±6 Ma from a dike in the North Hartland Dam spillway (McHone and McHone, 2012; Walsh, 2016), and (3) on a regional summary by McHone (1984) for similar dikes throughout New England and Québec]

Kd **Mafic dikes (Cretaceous)**—Aphanitic, dark-gray to black, locally rusty weathering, lamprophyre, camptonite, or diabasic dikes. Six dikes are shown by point symbols on the map, and range from centimeters (cm) up to 2.0 meters (m) thick. The dikes may contain phenocrysts of biotite, amphibole, pyroxene, and olivine, and may contain amygdules filled with dolomite or calcite. Generally, the dikes intrude parallel to steeply dipping joint sets and show variable orientations. The dikes are unfoliated, but may be blocky jointed. Many similar dikes cut the syenite at Mount Ascutney in the adjacent quadrangle to the north (Walsh and others, 2020), so these undated dikes are younger than about 122 Ma

SYN- TO POST-METAMORPHIC ROCKS

Mzsz **Silicified zones (Mesozoic)**—Very dark gray to white, brecciated and recrystallized vein quartz and silicified and brecciated country rock. Vein quartz contains accessory calcite, opaques, chlorite, and muscovite. The unit occurs as approximately 5- to 150-m-thick zones along major Mesozoic faults like the Ammonoosuc and Grantham faults, and along smaller, unnamed faults. The unit is well exposed along the Grantham fault on Gliddens Hill and Quimby Hill, and in the small unnamed stream between the two hills

KDq **Quartz veins (Cretaceous to Devonian)**—White- to gray-weathering quartz veins. Veins range in size from 0.1 to 5 m thick, and may locally contain small amounts of muscovite, chlorite, graphite, sulfides, and carbonate minerals. A muscovite-kyanite-quartz vein occurs on the east side of Skitchewaug Mountain along U.S. Route 5, 2 kilometers (km) north of the Cheshire toll bridge, where it is shown with a strike-and-dip symbol and labelled as "Ky" on the map. The veins are shown as polygonal map bodies where veins are large enough to map; thickness of the map bodies is locally exaggerated to show location. Outcrop-scale veins may be shown by strike-and-dip symbols or triangles where orientation could not be determined. Large mapped veins are locally associated with Mesozoic brittle faults and mapped separately as silicified zones (Mzsz). The veins are generally steeply dipping and show a preferred north-northeast strike (fig. 3)

PRE- TO SYN-METAMORPHIC ROCKS

TECTONIC MÉLANGE AND FAULT ROCKS

PSph **Phyllonite (Permian, Carboniferous, Lower Devonian, and Silurian)**—Gray, mylonitic to phyllonitic chlorite-muscovite-quartz rock mapped along the Monroe thrust fault and the Westminster West fault zone in the southern part of the map area where the unit extends into the adjacent Bellows Falls quadrangle. $^{40}Ar/^{39}Ar$ data from this chlorite-zone phyllonite in the adjacent Bellows Falls quadrangle, yielded a white-mica age of ~300 Ma (McWilliams and others, 2013), interpreted to reflect the time of phyllonite formation. White-mica analyses west of the fault, in the biotite zone, yielded cooling ages of ~365 Ma, and analyses east of the fault, in the staurolite zone, yielded cooling ages of ~320 Ma (McWilliams and others, 2013). The unit is well-exposed along Route 5 and Interstate 91 (I–91)

Mélange

DSm **Polymict metaconglomerate unit (Lower Devonian and Silurian?)**—Dark-gray to black, rusty weathering, sulfidic, polymict conglomerate and breccia containing (1) rusty weathering, dark-gray to black, sulfidic graphite-chlorite-biotite-muscovite-quartz schist matrix; and (2) gray, plagioclase-biotite-chlorite-muscovite-quartz schist and phyllite matrix. The unit contains rounded to angular pebble- to boulder-size clasts of gray, black, and tan quartzite, pebbly quartzite, conglomerate, vein quartz, black schist, metavolcanic rocks, gray calcareous granofels with small vugs, calc-silicate rock, gray-green foliated phyllite, and rare granitoid suggesting the rock is derived from the pre-Silurian rocks in the Bronson Hill arc, including the Albee Formation (not exposed in the map area), Ammonoosuc Volcanics, and Partridge Formation. The mélange contains angular clasts and boulders that resemble the Clough Quartzite and Fitch Formation, indicating that the unit also postdates deposition and lithification of the Silurian units. At Chestnut Hill, the mélange contains angular boulders (up to 0.5 m across) of the Clough Quartzite indicating that its formation postdates deposition of the Clough Quartzite (Thompson and others, 2012). Some clasts have a metamorphic fabric that indicates the source rocks experienced an earlier period of deformation. The matrix may be reworked Partridge Formation or Silurian to Devonian gray phyllite and schist. The belt of rocks is in the stratigraphic position of the Partridge Formation or Clough Quartzite on the east side of the Connecticut Valley trough. The mélange is spatially related to the Monroe thrust fault, supporting a tectonic origin for this belt of rock (Thompson and others, 2012; Walsh, 2016). Typical exposures occur at Chestnut Hill in Springfield (Walsh and others, 1996a, b; Armstrong and others, 1997; Thompson and others, 2012). Similar rocks occur in the North Hartland quadrangle (Walsh, 2016) at the same structural position, but on the north and east side of the Meridan antiform (fig. 1)

DSm? **Pebbly phyllite unit (Lower Devonian and Silurian?)**—Gray, plagioclase-biotite-chlorite-muscovite-quartz schist to phyllite matrix with small angular to rounded polymict pebbles (<1 cm diameter) and rare cobbles (<15 cm diameter). The unit is distinctly gray with non-rusty weathering, which is similar to most of the Littleton Formation, but it also resembles a fine-grained equivalent of unit DSm. The map unit occurs between unit DSm to the west and the Partridge and Littleton Formations to the east and is interpreted as an older, more distal phase of the mélange that was subsequently overridden by unit DSm and the Monroe thrust fault. The unit is exposed near the junction of Crown Point Road and Spencer Hollow Road. The map-unit label is queried "?" because the fine-grained nature of the rock and its similarity to other gray phyllite units make it problematic and difficult to distinguish and map separately; the polymict clasts are characteristic but not readily visible at all outcrops

NEW HAMPSHIRE PLUTONIC SUITE

Dg **Granite (Devonian)**—Massive to moderately well foliated, ±garnet±microcline-muscovite-biotite-quartz-plagioclase granite to trondhjemite dikes and sills. The dikes crosscut foliated country rock and crosscut an early bed-parallel S_1 foliation in the Silurian-Devonian rocks, and either pre-date or are synchronous with the development of the S_2 foliation. Well exposed dikes cut the Gile Mountain Formation on the north bank of the Black River, 1 km west of Goulds Mill. On the map, the unit may be shown by a strike-and-dip symbol only, where rock exposure is very small

Dp **Pegmatite (Devonian)**—White- to pink-weathering, massive, ±garnet-tourmaline-biotite-muscovite-quartz-K-feldspar pegmatite. Pegmatite layers are largely concordant with the dominant foliation and layering, but they locally crosscut the rocks they intrude. Mapped pegmatite is restricted to the eastern part of the map in the sillimanite-muscovite zone where the dikes are deformed by the D2 deformation fabrics in these rocks. On the map, the unit may be shown by a strike-and-dip symbol only, where rock exposure is very small. Pegmatite ages may range from Late Devonian to Permian (Bradley and others, 2016)

Dbg **Bethlehem Granodiorite (Devonian)**—Light- to medium-gray, moderately to strongly foliated, locally massive, porphyritic to porphyroclastic, garnet- and muscovite-bearing, biotite granodiorite gneiss to granite gneiss; locally a hornblende diorite. Also, locally, the unit contains outcrop- to map-scale xenoliths of granofels and biotite schist of the Rangeley Formation (Srq). The rock contains garnet, muscovite, biotite, K-feldspar, quartz, and plagioclase with accessory to trace amounts of garnet, myrmekite, monazite, and zircon; plagioclase and K-feldspar porphyroclasts are commonly 1 to 3 cm across but decrease to millimeter (mm)-size porphyroclasts near the Brennan Hill thrust and in internal shear zones; unit Dbg was intruded by felsic aplite and pegmatite dikes. The unit occurs only in the Brennan Hill thrust sheet. Sensitive high-resolution ion microprobe (SHRIMP) analyses yielded U-Pb zircon ages of 401±3 Ma from Bellows Falls on the Connecticut River in the adjacent Bellows Falls quadrangle (Fall Mountain pluton), and 399±3 Ma (sample CS–3025, this report) from a roadcut that is 1 km southeast of Unity (Mount Clough pluton) (Merschat and others, 2015)

ROCKS OF THE CONNECTICUT VALLEY TROUGH

GILE MOUNTAIN FORMATION
[Age from McWilliams and others, 2010]

Metasedimentary Rocks

Dgq **Feldspathic quartzite, granofels, and metapelite member (Lower Devonian)**—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, slightly calcareous rock 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. Layering becomes "pinstriped" near the Monroe thrust fault. The lower contact is gradational with the Waits River Formation and the upper contact is either, (1) a facies change, where it is in contact with upper members of the Gile Mountain Formation, or (2) tectonic, where it is in contact with the Ammonoosuc Volcanics and Partridge Formation. The unit is well-exposed on the south side of the Little Sugar River in North Charlestown

Dgqs **Gray quartzite and metapelite member (Lower Devonian)**—Dark- to light-gray, lustrous, locally sulfidic, carbonaceous chlorite±garnet±biotite-plagioclase-quartz-muscovite schist and phyllite, interbedded with thin gray quartzite, tan to gray feldspathic quartzite, and gritty micaceous plagioclase-quartz granofels. Quartzite is generally less than 50 percent of the unit. The unit is similar to the phyllite and schist member (DSws) of the Waits River Formation, but has more quartzite beds; it is also similar to member Dgq, but it has fewer quartzite beds. Typical exposures occur in the Black River east of Springfield and on the south end of Calavant Mountain in Charlestown

WAITS RIVER FORMATION
[Age from McWilliams and others, 2010]

Metasedimentary Rocks

DSwl **Limestone and schist member (Lower Devonian and upper Silurian)**—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, punky-dark-brown 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, 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. The unit is distinguished from the adjacent metasedimentary units by the abundance of brown-weathered limestone and rusty weathering calcite-bearing schist. Beds of limestone range in thickness from 1 cm to 1.5 m and may constitute as much as 10 to 90 percent of an exposure; bedding in the metapelite is generally not visible. Contacts with adjacent units are gradational to sharp as the limestone beds decrease in abundance and thickness, either gradually or abruptly. Contacts with unit DSws are interpreted as facies changes and may not necessarily imply stratigraphic order. The unit is well-exposed along the Black River near downtown Springfield

DSws **Gray phyllite and schist member (Lower Devonian and upper Silurian)**—Dark- to light-gray, fine-grained, lustrous, carbonaceous chlorite-muscovite-plagioclase-quartz schist and phyllite. In places, the unit is interbedded with thin gray quartzite, tan to gray feldspathic quartzite, and gritty plagioclase-quartz granofels. Beds range in thickness from 3 to 10 cm. Locally, the unit contains trace amounts of very thin (1- to 2-cm thick) brown-weathering limestone beds. The schist contains biotite and garnet in the western part of the map. The unit is similar to the gray quartzite and metapelite member (Dgqs) of the Gile Mountain Formation, but generally has fewer quartzite layers. Typical exposures occur along Weathersfield Center Road near the junction with Town Farm Road

Metavolcanic Rocks

DSwv **Laminated schist and granofels member (Lower Devonian and upper Silurian)**—(1) Heterogeneous, laminated (mm-scale) to layered (cm-scale), green and white, in places rusty weathering, fine- to medium-grained, muscovite±biotite-chlorite-quartz-plagioclase schist; (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) gray to light gray, ±carbonate±garnet-biotite-chlorite-muscovite-quartz-plagioclase granofels in 5-cm- to 2-m-thick beds with coarse (1- to 8-mm-diameter) plagioclase and quartz porphyroclasts; (5) green, fine-grained, quartz-epidote-chlorite-plagioclase schist or greenstone; and (6) silvery-gray, rusty weathering, calcite-muscovite-chlorite-quartz-plagioclase schist. In places, the unit is pitted where it contains accessory carbonate; it also contains accessory ilmenite porphyroblasts and porphyroclasts 1 to 5 mm in diameter. The unit is interpreted as a heterogenous assemblage of metamorphosed volcaniclastic and primary volcanic rocks. Typical exposures occur along Spencer Hollow Road north of Goulds Mill

DSwqc **Polymict conglomerate member (Lower Devonian and upper Silurian)**—Creamy-white- to light-gray-weathering, massive to weakly layered, typically clast-supported, quartz-pebble and cobble conglomerate. Where present, the matrix around clasts consists of ilmenite, chlorite, muscovite, and quartz and is usually 1 to 5 mm thick and discontinuous. Pebbles consist of angular to rounded, 1-mm- to 10-cm-diameter clasts of (1) light- to bluish-gray, vitreous quartzite, or (2) white to buff-gray quartz derived from veins. The unit is mapped in one place on an unnamed hill in the Springfield Town Forest area between unit members DSwvq and DSwv in the southern part of the map. The unit is lithologically similar to the lower unit of the Clough Quartzite (Scqc)

DSwvq, DSwsv **Metavolcaniclastic members (Lower Devonian and upper Silurian)**—DSwvq consists of mm- to cm-scale laminations of limey- to non-limey carbonaceous schist and biotite-chlorite-muscovite-plagioclase-quartz granofels that may represent water-lain intermediate to felsic volcanics. DSwsv consists of very well bedded, limey, carbonaceous schist; calcareous quartzite; and well-laminated (mm-scale) quartz-plagioclase schist horizons. The units appear to be an admixture of pelitic and volcanic water-lain sediments, and are located in the southern part of the map where they are extrapolated from the Bellows Falls quadrangle (Armstrong, 1997)

DSwvf **Felsic volcanic member (Lower Devonian and upper Silurian)**—Heterogeneous unit consisting of (1) silvery-green to green ±calcite±epidote-muscovite-quartz-chlorite-plagioclase phyllite or schist; (2) light-gray to whitish-pale-green, fine-grained, layered (3- to 50-cm-thick), epidote-muscovite-chlorite-quartz-plagioclase-feldspathic quartz granofels, locally with 1- to 3-mm-diameter quartz and plagioclase porphyroclasts interpreted as phenocrysts; (3) gray-green, massive, fine- to medium-grained, muscovite-chlorite-quartz-plagioclase feldspathic granofels with 1- to 3-mm diameter quartz and saussuritized plagioclase porphyroclasts that are interpreted as phenocrysts of epidote and actinolite pseudomorphs after pyroxene; and (4) green to dark-green, fine-grained, quartz-plagioclase-epidote-chlorite schist or greenstone (less than 10 percent of exposures). The unit contains accessory sulfides and is interpreted as metamorphosed volcaniclastic sedimentary rocks, crystal tuffs, dacitic to andesitic flows, and mafic volcaniclastic sedimentary rocks. A sample of a metafelsite (VT/Sp1-85) that was collected from a roadcut on the south side of Route 11 near Goulds Mill yielded a thermal ionization mass spectrometry (TIMS) U-Pb zircon age of 423±4 Ma (Aleinikoff and Karabinos, 1990; Hueber and others, 1990). The dated metafelsite is interpreted as a dike (Aleinikoff and Karabinos, 1990) or alternatively a volcanic horizon (Walsh and others, 1996a, b)

DSwg **Large-garnet and hornblende-garbenschiefer schist member (Lower Devonian and upper Silurian)**—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 5-cm-diameter garnet porphyroblasts. The unit is interpreted as metamorphosed pelitic sedimentary rock with a volcaniclastic component of intermediate to mafic composition and is interlayered with units DSws and DSwl, and all metavolcanic units on the map. The unit is well exposed on Pudding Hill in the southwest corner of the map

DSwhg **Hornblende-plagioclase gneiss member (Lower Devonian and upper Silurian)**—Dark-green, medium- to coarse-grained, ±garnet-epidote-chlorite-hornblende-plagioclase gneiss with roughly equal percentages of hornblende and plagioclase. The unit varies from a massive, weakly foliated, and very coarse-grained gneiss to a well-layered gneiss. The massive variety may be partly intrusive where intergrowths of hornblende with matrix plagioclase are ubiquitous, and these intergrowths reflect replacement of a primary ophitic texture. Contacts with surrounding units are sharp. Unit exposures north of Hunt Road in Windsor are of the well-layered variety

DSwa **Amphibolite and greenstone member (Lower Devonian and upper Silurian)**—(1) Dark-green to green, fine-grained, massive epidote-chlorite-hornblende-plagioclase amphibolite gneiss with 1- to 3-mm-diameter, white, saussuritized, plagioclase porphyroclasts; and (2) laminated to massive, epidote-carbonate-actinolite-chlorite-plagioclase greenstone. Generally, the laminated greenstone is intercalated with unit DSwv, and the massive greenstone and amphibolite have sharp contacts with adjacent units. In the northwestern part of the map, the greenstone is interlayered with unit DSwv on a 1- to 3-cm-scale over a distance of several meters along the contact. The amphibolite crops out in the western part of the map where the rocks are at a higher metamorphic grade, and there it contains layers of greenstone similar to those found to the eastern part of the map. The unit is well exposed at roadcuts on the north side of Route 11 just west of I–91

DSwc **Conglomeratic quartzite and gray phyllite member (Lower Devonian and upper Silurian)**—Dark-gray, plagioclase-biotite-chlorite-muscovite-quartz schist and phyllite with zones of (1) 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 (2) rounded deformed pebbles to cobbles (25-cm-diameter) of bluish-gray quartzite, light-gray quartzite, quartz pebble conglomerate, and rare greenish-gray metasiltstone. Clasts are only rarely sorted by size, and graded beds are rare, although some graded conglomerate beds occur. Matrix material is also found as disarticulated, 1- to 25-cm-long by 2- to 5-cm-thick clasts within well- to poorly-sorted and graded conglomerate layers, which appear to be early-stage autoclastic conglomerates. The unit occurs in two places along Spencer Hollow Road where it is in contact with metavolcanic rocks of members DSwv and DSwa

NORTHFIELD FORMATION

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

SHAW MOUNTAIN FORMATION

Ss **Shaw Mountain Formation (Silurian)**—Heterogeneous unit of (1) interbedded rusty, slabby quartz-amphibolite, gray quartzite, quartz-pebble conglomerate, feldspathic granofels, biotite schist; and (2) punky weathering, massive to pinstriped, calcareous granofels, locally with small (<1-cm-wide) weathering calcite pits. The unit is exposed discontinuously along the unconformity at the base of the Connecticut Valley trough

ROCKS OF THE BRONSON HILL ANTICLINORIUM

LITTLETON FORMATION

Metasedimentary Rocks

Dl **Schist member (Lower Devonian)**—Silvery gray to dark-gray, fine- to medium-grained, biotite-chlorite-muscovite-quartz schist, minor carbonaceous muscovite-quartz schist, and interbedded muscovite schist and micaceous quartzite (metaturbidite). Locally, rusty weathering is present, and in such places, it is extremely difficult to distinguish this unit from the Partridge Formation. The unit contains characteristic garnet and large (cm-scale) staurolite at higher metamorphic grade. Locally, the garnet is completely pseudomorphed by chlorite. Staurolite typically has retrograde muscovite±chlorite rims and locally exhibits complete replacement by muscovite±chlorite especially near lower-greenschist facies faults; partial to complete replacement of staurolite by muscovite and sillimanite occurs at higher metamorphic grade. The unit is in fault-contact with the Clough Quartzite or the Partridge Formation along much of the Northey Hill shear zone and unconformably overlies the Clough Quartzite and Fitch Formation. The unit is in gradational contact with unit Dlq and is locally conformable with the Fitch Formation in the eastern part of the map. Typical exposures occur along I–91 (biotite-grade), in Hubbard Hill State Forest (staurolite-grade), and on Unity Mountain (muscovite-sillimanite grade)

Dlcg **Metaconglomerate member (Lower Devonian)**—Gray to dark-gray, fine-grained, matrix-supported, quartz-pebble conglomerate and polymict conglomerate with gray phyllite matrix. The unit may locally contain felsic volcanic clasts or volcaniclastic rock. The unit occurs within the Dl member of the Littleton Formation located 300 m east of the Crown Point Cemetery in Springfield. Thickness of the unit is as much as 10 m, but is exaggerated on the map to show its location

Dlq **Interbedded quartzite and schist member (Lower Devonian)**—(1) Silvery gray to dark-gray, micaceous quartzite; (2) micaceous quartzite interbedded with biotite-muscovite-quartz schist; and (3) carbonaceous schist. Quartzite layers are distinctly "sandy" or rough to the touch. The unit contains characteristic garnet and large (cm-scale) staurolite or quartz-muscovite-fibrolite knots at higher metamorphic grade; garnet is locally pseudomorphed by chlorite. Staurolite typically has retrograde muscovite±chlorite rims and locally exhibits complete replacement by muscovite±chlorite at lower metamorphic grades and partial replacement by muscovite±sillimanite at higher metamorphic grade. Locally, the unit is magnetite-rich near the contact with the Fitch Formation; the contact with the Fitch Formation is locally conformable but largely unconformable, and the lower contact is unconformable with the Clough Quartzite. The contact between units Dl and Dlq is gradational and interpreted as a facies change; Dlq is typically the lowest unit in the Littleton Formation in the eastern part of the map, but in places, it is interfingered with unit Dl. Typical unit exposures occur on Unity Mountain near Marshall Pond (muscovite-sillimanite metamorphic grade)

LAKE MEMPHREMAGOG INTRUSIVE SUITE

Comerford Intrusive Complex

Metaplutonic Rocks

Scd **Metadiabase dike (Silurian)**—Massive, medium-grained, very dark-green to black and white, ±garnet-calcite-epidote-chlorite-biotite-hornblende-plagioclase metadiabase. The unit is shown on the map as several small bodies within the Clough Quartzite or Fitch Formation on Skitchewaug Mountain, Rattlesnake Hill, and Breed Hill; rarely observed unit contacts with the surrounding host rocks are sharp. It is unclear if the rock bodies are unequivocally dikes in all cases because the contacts are largely obscured. Thirteen observed dikes are correlated with the Comerford Intrusive Complex that has been dated at 419±1 Ma from samples collected in the Connecticut River Valley about 80 to 120 km up river (Rankin and others, 2007)

FITCH FORMATION

Metasedimentary Rocks

Sf **Gray granofels and schist member (Lower Devonian and upper Silurian)**—Gray to dark-greenish-gray, medium-grained, ±magnetite±actinolite/tremolite-carbonate-muscovite-biotite-plagioclase-quartz granofels and schist. Locally, the unit contains distinctive calcareous pods that are 1 to 3 cm across and irregular dissolution cracks and pits that are locally aligned along bedding. Locally, the unit also contains (1) calc-silicate pods consisting of garnet, quartz, actinolite, and diopside at higher metamorphic grade east of the Grantham fault; (2) variably rusty to bronze-weathering, medium-grained carbonate-biotite-quartz schist with carbonate pods and layers 2 cm to 10 cm thick; and (3) gray to light-gray, medium-grained, biotite-chlorite-garnet-muscovite-quartz schist and micaceous quartzite with distinctive high-relief weathering, white quartz-rich knots, pods, layers or pebbles. Pods are composed predominantly of quartz and muscovite, but may contain chlorite, garnet, magnetite, and biotite; the pods may represent pseudomorphs after earlier staurolite or andalusite. Disseminated magnetite is common in all rock types. Millimeter- to cm-scale magnetite layers locally occur near the contact with the Littleton Formation and Clough Quartzite. The unit is well exposed at an active quarry on the northwest side of Skitchewaug Mountain in Springfield, just east of I–91

Sfgr **Gray to black granofels member (Lower Devonian and upper Silurian)**—Massive, gray, ±magnetite±actinolite/tremolite±chlorite±muscovite-garnet-biotite-plagioclase-quartz granofels to massive, black magnetite-garnet-biotite-quartz granofels. The unit contains distinct 1- to 5-mm-size garnet porphyroblasts and occurs as resistant horizons within unit Sf where it is mapped separately on Skitchewaug Mountain

Sfrs **Rusty schist member (Lower Devonian and upper Silurian)**—Very rusty weathering, gray to dark-gray or black, sulfidic, ±calcite-plagioclase-chlorite-biotite-muscovite-quartz schist and granofels with locally distinct biotite porphyroblasts. The unit contains rare calcareous lenses that are parallel to bedding and it also contains trace amounts of graphite and zircon. The unit is interbedded with metasedimentary rocks (Sf) and is exposed on Skitchewaug Mountain, especially south of the quarry and radio tower, where it is mapped separately. Similar rusty schist occurs throughout the Fitch Formation but was not mapped separately. The schist resembles the Partridge Formation (Op), but is locally calcareous

CLOUGH QUARTZITE

Scql **Layered quartzite member (Silurian)**—Dark- to light-gray, well-bedded, vitreous quartzite with beds 1 to 25 cm thick. The unit contains rare calcareous partings and poorly preserved fossils (Boucot and others, 1958) that possibly represent relict coquina beds (Thompson and others, 1993). The unit occurs as the upper part of the Clough Quartzite on Skitchewaug Mountain where it is mapped separately, and it locally contains thin, interbedded, biotite-spotted, chlorite-muscovite-plagioclase-quartz schist

Scq **Undifferentiated conglomerate and quartzite member (Silurian)**—Undifferentiated (1) massive, poorly bedded, weakly foliated, light-gray, orange-weathering quartzite with minor muscovite; (2) well-bedded, gray to orange, micaceous quartzite with beds from 1-cm- to 1-m-thick; and (3) white to gray, muscovite-bearing quartz-pebble to quartz-cobble metaconglomerate. Extremely rare, faintly visible cross-beds are locally preserved. Clasts are typically elongated with aspect ratios commonly exceeding 10:1; clasts consist dominantly of vein quartz and gray to white quartzite. Contacts are typically sharp, and the unit may contain magnetite and, at higher metamorphic grade, it may contain chloritoid, garnet, staurolite, and sillimanite. Locally, the unit is mylonitic along the Northey Hill shear zone. Fossils described by Boucot and others (1958) and Boucot and Thompson (1963) occur in the upper part of the Clough Quartzite (Scql, where mapped separately) and include tetracorals, brachiopods, pelycypods, and a possible trilobite; fossils support a Llhandovery (early Silurian) age. The unit is well exposed on Perry Mountain

Scs **Rusty muscovite schist member (Silurian)**—Rusty orange weathering, gray to silvery gray, medium- to coarse-grained, chlorite-biotite-plagioclase-muscovite-quartz schist characterized by garnet porphyroblasts, and less abundant staurolite porphyroblasts. The unit occurs within the upper part of the Clough Quartzite (Scql) on Skitchewaug Mountain, as mapped horizons within unit Scq, or elsewhere on the map at the top of the Clough Quartzite along the contact with the Littleton Formation

Scqc **Metaconglomerate member (Silurian)**—Light-gray to creamy-whitish-gray, massive, polymict conglomerate and lesser schistose to granulose, light-gray to buff-colored, chlorite-muscovite-plagioclase-quartz quartzite layers that are similar to vitreous quartzite beds in the overlying unit Scql. Pebble to cobble, and rare boulder-size clasts, consist of vitreous gray and white quartzite, vein quartz, and quartzose schist. The proportion of matrix to clasts varies, but the majority of the unit is clast-supported. The unit contains rare layers of gray, carbonaceous, sulfidic schist similar to the rusty schist units in the Partridge or Fitch Formations. Where mapped separately on Skitchewaug Mountain, the unit occurs at the base of the Clough Quartzite and is well exposed on Skitchewaug Mountain, along Route 5, and on the west slopes of Rattlesnake Hill. The contact with the underlying Partridge Formation is a sharp unconformity

RANGELEY FORMATION

Metasedimentary Rocks in the Brennan Hill Thrust Sheet

Srq **Quartzite, calc-silicate, and schist member (Silurian)**—Light-greenish-gray- to light-gray-weathering, light-greenish-gray to white, strongly foliated quartzite to granofels, calc-silicate, and muscovite schist that consists of quartz, clinopyroxene, biotite, plagioclase, zoisite, iron- and titanium-oxides, and trace amounts of calcite and zircon; the calc-silicate contains greenish-black clinopyroxene, zoisite, and biotite that define the dominant foliation (S_n). Quartz pebbles are 1 to 2 cm across and consist of undulose subgrains with serrated edges. The contact with the underlying Partridge Formation is not exposed; the contact with the Bethlehem Granodiorite (Dbg) is intrusive and locally mylonitic. Exposures in the map area are limited, and the unit is best exposed on the west side of Hedgehog Hill near Sleeper Brook in Unity

ROCKS OF THE BRONSON HILL ARC

OLIVERIAN PLUTONIC SUITE

Ogd, Ogdu **Granodiorite, trondhjemite, and tonalite of the Sugar River (Ogd) and Unity (Ogdu) plutons (Ordovician)**—Gray, gray- to orange-weathering, fine- to medium-grained, ±garnet±hornblende-chlorite-biotite-K-feldspar-plagioclase-quartz granodiorite, trondhjemite, and tonalite; accessory minerals include magnetite and apatite. Locally, the unit is enriched in magnetite near the contact with the Ammonoosuc Volcanics, which suggests contact metasomatism. Also locally, the unit contains xenoliths of coarse-grained garnet-cordierite-biotite-gedrite granofels that contain minor chlorite, magnetite, plagioclase, and apatite; the xenoliths were observed at the following two locations (labelled as "Ged" on the map; samples CS-3211 and CS-3454 in the database): (1) near the northeastern contact of the Unity pluton with the Ammonoosuc Volcanics (Oa) about 0.25 miles southwest of Pike Hill, and (2) approximately 0.75 miles south-southeast of Alden Hill. Enclaves and xenoliths of amphibolite are present locally within the plutons, and dikes cut the adjacent host rock that demonstrates that the rocks intruded the Ammonoosuc Volcanics. The unit is mapped as the Sugar River pluton (Ogd) in the northern part of the map, and mapped as the Unity pluton (Ogdu) in the east-central part of the map. The plutons yielded U-Pb SHRIMP zircon ages of 460±3 Ma (Sugar River pluton) (Valley and others, 2015; Walsh and others, 2020, in the adjacent Mount Ascutney quadrangle) and 446±6 Ma (Unity pluton; sample CS-3009) (Valley and others, 2020, in the Springfield quadrangle). The Sugar River pluton (Ogd) is well exposed in an unnamed stream located south of Newport Road, and the Unity pluton (Ogdu) is well exposed in the Little Sugar River near Quaker City

PARTRIDGE FORMATION

Op **Sulfidic schist member (Ordovician)**—Dark-gray to light-gray and grayish-black, rusty weathering, sulfidic graphite±sillimanite±staurolite±garnet-ilmenite-plagioclase-biotite-chlorite-quartz-muscovite phyllite and schist. Locally, the unit contains light- to dark-gray, micaceous quartzite in thinly laminated layers or boudins; and dark-gray to black, quartz beds that are mapped separately as unit Opq. The unit also contains rare 1- to 3-m-thick, dark-green, epidote-chlorite-hornblende-plagioclase amphibolite as dikes or metavolcanic layers that are mapped as unit Opa. Small quartzite (Opq) and amphibolite (Opa) bodies are exaggerated in size on the map to show their locations. Contacts with the Ammonoosuc Volcanics are generally sharp, but may be gradational within a few meters. Contacts with the Clough Quartzite are very sharp and rocks are phyllonitic to mylonitic along the Northey Hill shear zone

Opg **Gray granofels member (Ordovician)**—Undivided (1) dark-gray to gray, massive, staurolite-garnet-plagioclase-chlorite-muscovite-quartz granofels with quartz clasts; and (2) gray titanite-quartz-calcite-biotite-chlorite-plagioclase-amphibole calc-silicate rock; and (3) altered amphibolite. The unconformable contact with the overlying Clough Quartzite is sharp. Detrital zircons from a granofels sample (SP-2485) collected 1 m below the contact with the Clough Quartzite yielded a maximum depositional age (MDA) of 452 Ma (Walsh and others, 2017). The unit is interpreted as volcaniclastic rock and it occurs as 1- to 2-m-thick horizons in the sulfidic schist member (Op) along Route 5, 1 km northeast of the Cheshire Toll Bridge in Springfield; it also occurs as a massive granofels unit that is tens of meters thick at the top of the Partridge Formation at the south end of Skitchewaug Mountain

Opq **Quartzite member (Ordovician)**—Dark-gray to black quartzite interbedded with dark-gray sulfidic schist. The unit contains cm-scale, layered black and white, carbonaceous quartzite with biotite and garnet porphyroblasts and trace amounts of muscovite, chlorite, and tourmaline

Opv **Metafelsite volcanic member (Ordovician)**—Silvery, rusty tan weathering, plagioclase-quartz-biotite-muscovite schist with retrograded garnet porphyroblasts and trace amounts of ilmenite, opaques, graphite, and chlorite interlayered with dark-gray sulfidic schist. The unit contains sub-mm-size quartz fragments interpreted as phenocrysts. Light-colored layers, as much as 40 cm thick, occur within dark-gray schist (Op) along the contact with unit Opq on the northwest side of Hubbard Hill in Charlestown

Opam **Gray-green chlorite-amphibole schist and amphibole member (Ordovician)**—Interlayered amphibolite (Opa), minor sulfidic schist (Op), and very pale gray-green, silvery gray weathering, chlorite-amphibole schist characterized by very dark green amphibole/tremolite porphyroblasts that occur as dark-gray weathered spots. In thin section, the chlorite is almost colorless with very low birefringence and is probably magnesium-rich, possibly antigorite. The amphibole/tremolite is very pale green to very pale brown with little pleochroism. The rock contains trace amounts of opaques, sphene, apatite, quartz, plagioclase, talc, and serpentine (antigorite). Crosscutting carbonate veins contain minor amounts of talc, tremolite, and chlorite

Opa **Greenstone and amphibolite member (Ordovician)**—Dark-green to black, coarse-grained, actinolite-plagioclase greenstone or hornblende-plagioclase amphibolite

AMMONOOSUC VOLCANICS

Oa **Undifferentiated volcanic member (Ordovician)**—Heterogeneous assemblage of rock types consisting of (1) dark-greenish-gray, fine to medium-grained, plagioclase-biotite-chlorite-quartz schist to phyllite, (2) layered to massive greenstone and amphibolite (locally with garbenschiefer texture), (3) felsic quartz-plagioclase granofels (metafelsite), (4) limonite-muscovite quartzite, and (5) sulfidic quartz-plagioclase schist. Locally, the rocks contain minor carbonate, magnetite, and sulfides. All rocks are locally rusty to very rusty weathering. At sub-garnet metamorphic grade, the rocks are green, gray-green, bluish-green, silvery gray green, and green and white layered. In the garnet metamorphic zone or higher, the rocks are darker-green, gray-green to black, and black and white layered. Locally, the rocks contain pods and lenses of epidote, plagioclase and lesser quartz phenocrysts, deformed pillows, fiamme (eutaxitic texture), and volcanic breccia. The unit is interpreted as a heterogeneous, metamorphosed sequence of volcanic and volcaniclastic rocks, crystal tuffs, dacitic to andesitic flows, and mafic volcanic and volcaniclastic rocks. Internal contacts are variable and are either sharp or gradational by intercalation; contacts with the Partridge Formation are generally sharp, but are locally gradational

Oaa **Greenstone and amphibolite member (Ordovician)**—Dark-green to black, locally rusty weathering, massive to thickly layered, ±carbonate ±magnetite-chlorite-actinolite-epidote-plagioclase, schistose greenstone, or hornblende-plagioclase amphibolite. Epidote nodules and layers are common, and the unit rarely contains deformed pillows. Overall, the unit is interpreted to be submarine metabasalt, but it may in part consist of mafic sills. At higher metamorphic grade, the rock contains appreciable amphibole and locally it exhibits garbenschiefer texture. The unit is well exposed on Perry Hill

Oafa **Bimodal metavolcanic rock member (Ordovician)**—Interlayered greenstone, greenschist, green phyllite, and metamorphosed felsic volcanic and possible intrusive rocks. Typically, the unit consists of distinctly banded rocks of green and white (below garnet metamorphic grade) and dark-green to black and white (at and above garnet metamorphic grade). Locally, the unit is sulfidic and rusty weathering. Also locally, the felsic volcanic rocks contain quartz and (or) plagioclase phenocrysts. The unit is interpreted as a heterogeneous, metamorphosed sequence of volcanic and volcaniclastic rocks, crystal tuffs, dacitic to andesitic flows, and mafic volcanic and volcaniclastic rocks. Contacts are gradational with unit Oa of the Ammonoosuc Volcanics and is distinguished from Oa by the distinct alternating layering of felsic and mafic rocks. The unit is in tectonic contact with the rocks of the Connecticut Valley trough along the Monroe thrust fault. Generally, the unit is well exposed in areas of abundant outcrop, especially on Barber Mountain and along U.S. Route 5, north of Weathersfield Bow

PRE-SILURIAN COVER SEQUENCE ROCKS ON THE CHESTER DOME

[Includes rocks of the Shelburne Falls arc in the Moretown slice]

CRAM HILL FORMATION

Metasedimentary Rocks

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

Ochs **Papery thin schist and phyllite member (Ordovician)**—Pale-gray-brown- to whitish-tan weathering, fine-grained biotite-garnet-muscovite schist and carbonaceous phyllite. The unit contains beds that are rich in tiny 1- to 2-mm-diameter garnets that are similar to the garnet-rich phyllites of the Northfield Formation (DSn), and it also contains coticule (identified by a lower case "c" on the map). The unit grades laterally into a darker-gray to slightly rusty weathering siliceous phyllite or schist that contains discontinuous layers of steel-gray quartzite. The rock closely resembles phyllite and schist in the Whetstone Hill member of the Missisquoi Formation (Ratcliffe and others, 2011). Locally, the unit contains a distinctive steel-gray- to yellow-tan-weathering quartzite and quartz-pebble conglomerate (Ochq) as much as 2 m thick, and is transitional downwards into unit Ochv

Ochq **Quartzite member (Ordovician)**—Steel-gray- to yellow-tan-weathering quartzite and quartz-pebble conglomerate as much as 2 m thick. The unit occurs along the contacts with units Ochs, Ochb, Ochg, and Ochv

Metavolcanic Rocks

Ochg **Greenstone member (Ordovician)**—Medium-green to gray-green, highly foliated, hornblende-plagioclase greenstone that is 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. The unit is interpreted as basaltic- to andesitic-tuff breccia and volcaniclastic rock. The unit is mapped at five locations just below the unconformity at the base of the Connecticut Valley trough

Ochhg **Hornblende-plagioclase-quartz granofels member (Ordovician)**—Light-gray-weathering, medium- to coarse-grained garnet-biotite-hornblende-plagioclase-quartz granofels. The unit is (1) marked by abundant sprays of large hornblende as much as 5 cm in length; (2) is interbedded with layers of biotitic amphibolite and hornblende-garnet amphibolite; and (3) contains coticule (identified by a lower case "c" on the map). The contact with unit Ochg is gradational by intercalation. The unit is mapped on an unnamed hill southwest of downtown Springfield where it passes into the adjacent Chester quadrangle (Ratcliffe, 2000b)

Ochv **Felsic and mafic volcaniclastic rock member (Ordovician)**—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 that are present throughout the unit indicate a collection of volcanic, volcaniclastic, and interbedded metasedimentary rocks; for this reason, the unit is interpreted as a member of the Cram Hill Formation. The contact relations with the underlying units are uncertain, but it may disconformably overlie the Moretown Formation and trondhjemite (Ontd) of the North River Igneous Suite. The unit occurs below the unconformity at the base of the Connecticut Valley trough. A sample of a felsic volcanic rock (sample SP450, this report) that was collected about 2.8 km north-northeast of North Springfield Reservoir and about 1.2 km west of Weathersfield Center Road, yielded a U-Pb SHRIMP zircon age of 483±3 Ma (Aleinikoff and others, 2011)

NORTH RIVER IGNEOUS SUITE

Ontd **Trondhjemite gneiss (Ordovician)**—Principally, light-gray- to chalky-white-weathering, massive, medium-grained biotite±garnet-quartz-plagioclase trondhjemite gneiss. The unit lacks the mafic layers that are present in unit Ochv of the Cram Hill Formation and is interpreted as intrusive into unit Omhfs of the Moretown Formation along the contact with Ochv. Alternatively, the rock may be metadacite

MORETOWN FORMATION

Metasedimentary Rocks

Omhfs **Hornblende fascicle schist member (Ordovician to Cambrian)**—Light-gray to gray-green, chlorite-muscovite-biotite-plagioclase-quartz schist and granofels characterized by (1) conspicuous sprays of hornblende; (2) distinctive, large (5-mm- to 1-cm-diameter) porphyroblasts of cross-foliation biotite; (3) abundant irregular layers of coticule that are 1 to 2 cm thick; and (4) abundant layers of light-gray, pinstriped biotite-quartz granofels similar to the "pinstriped" granofels member (Omp) of Ratcliffe and others (2011)

Omp **Pinstriped granofels member (Ordovician to Cambrian)**—Light-gray to pale-green, whitish-gray weathering, chlorite-biotite-plagioclase-quartz granofels and tectonically pinstriped granofels and feldspathic biotite quartzite. Locally, the granofels layers contain abundant fascicles of hornblende, or hornblende-plagioclase layers that are 1 to 5 cm thick. The contact with the hornblende fascicle schist (Omhfs) is gradational

Omb **Black schist member (Ordovician to Cambrian)**—Dark-gray to silvery gray, garnet-biotite-muscovite carbonaceous schist, and associated rusty weathering muscovite-biotite-quartz schist. The unit contains layers that are rich in small garnets (1 to 2 mm in diameter), which resemble phyllites of the Whetstone Hill Member of the Moretown Formation (Ratcliffe and others, 2011)

Omfs **Green schist and granofels member (Ordovician to Cambrian)**—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, the unit 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 unit Omp. The unit also contains beds of coticule that are 1 to 2 cm thick (identified by a lower case "c" on the map) or layers of abundant dark-green well-foliated amphibolite. Distinctive porphyroblasts of cross-foliation biotite occur throughout the rock; these porphyroblasts and the very thin feldspathic layers are regionally characteristic of the Moretown or Stowe Formations and are absent from the Pinney Hollow Formation (Ratcliffe and others, 2011) with which these rocks have been incorrectly correlated by Thompson and others (1993). The unit is in fault contact with Mesoproterozoic rocks at its base and is in upwards-gradational contact with, and bedded with, the black schist unit (Omb). The unit is well exposed on the east side of the Springfield Reservoir

Metavolcanic Rocks

Oma **Amphibolite (Ordovician to Cambrian)**—Dark-green, highly foliated epidote-biotite-hornblende and hornblende-plagioclase amphibolite. The unit 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

MOUNT HOLLY COMPLEX

Intrusive and Migmatitic Rocks

Y^1bm **Baileys Mills tonalitic gneiss (Mesoproterozoic)**—Coarse-biotite-flecked, light-gray to whitish-gray-weathering, medium-grained biotite-quartz-plagioclase gneiss that has a distinctive non-gneissic igneous-appearing texture in less-sheared rocks. The rock contains numerous inclusions of coarse-biotite amphibolite that is mapped as unit Ya that may be, in part, comagmatic dikes of metagabbro. The unit passes into lighter-gray, more leucocratic, biotite trondhjemite gneiss. The unit yielded a U-Pb SHRIMP zircon age of 1,383±13 Ma (Ratcliffe and others, 1991; Aleinikoff and others, 2011) and is exposed along Reservoir Road in the northwest corner of the map

Metasedimentary and Metavolcanic Rocks

Ybg **Biotite-quartz-plagioclase gneiss (Mesoproterozoic)**—A heterogeneous assemblage of dark- to medium-gray, non-rusty weathering, quartz-rich biotitic gneisses, which are all characterized by having abundant plagioclase and epidote and little or no microcline. Other distinctive rock types include (1) light-gray-weathering magnetite-muscovite-biotite-plagioclase-quartz gneiss containing thin layers of hornblende-spotted gneiss; (2) a very dark-gray, biotite-rich plagioclase-quartz gneiss commonly associated with epidote quartzite; and (3) 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-plagioclase-quartz gneiss contains numerous layers of other distinctive rocks that are regionally interlayered throughout the Mount Holly Complex. Where the rock is thick enough to map, units Ya, Ybg, and Y^2rs, are mapped separately. The unit is best exposed on Butterfield Hill in the northwest part of the map and it is also exposed to the south and west of Springfield Reservoir

Ya **Amphibolite (Mesoproterozoic)**—Dark-green- to dull-gray-weathering, fine- to coarse-grained biotite-hornblende and hornblende-garnet-plagioclase amphibolite commonly associated with units Y^2rs or Ybg

Y^2rs **Quartz schist and gneiss (Mesoproterozoic)**—Dark-brown to gray, rusty weathering gneiss and schist containing abundant layers of schistose quartzite, biotite-garnet quartzite, and rusty sulfidic amphibolite. Locally, the unit passes into a muscovite-rich, lustrous, chlorite-garnet-schist that is mapped in the adjacent Chester and Cavendish quadrangles as unit Yrs (Ratcliffe, 1995a, b; 2000a, b). The unit is exposed on Butterfield Hill

EXPLANATION OF MAP SYMBOLS

[Taconic, Acadian, Neo-Acadian, and Alleghanian, refer to orogenic events and not to divisions of geologic time]

Contact—Approximately located; dotted where concealed by water. In cross section, dotted where projected above the ground surface; projections are based on structural measurements of surface exposures

Outcrops—Areas of exposed bedrock or closely spaced contiguous bedrock exposures examined in this study; some areas are enlarged to show location

FAULTS

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

Thrust fault—Includes ductile Acadian D_1 faults (Monroe and Brennan Hill thrust faults) and the Keyes Mountain thrust fault, which is likely a Taconic fault (possibly a reactivated Acadian D_1 fault). Parallel to the Acadian S_1 foliation. Sawteeth on upper plate

(U D, lower greenschist) **Post-peak metamorphic, strike-slip fault or shear zone (Alleghanian)**—Steeply dipping, lower-greenschist chlorite zone that is parallel to the S_2 or younger foliation; arrows indicate relative motion where known; U, upthrown side; D, downthrown side. Includes the Sumner Falls shear zone, the Northey Hill shear zone, and the Woodbury Road and Skitchewaug Mountain faults. Locally, brittlely re-activated

(U D) **Brittle fault (Mesozoic)**—Steeply dipping, arrows indicate relative motion where known. U, upthrown side; D, downthrown side, where known. Includes the Ammonoosuc fault zone and Grantham fault. Indicated as Mesozoic (Mz) on map

FOLDS

[Location is known or inferred; dotted where concealed by water. Symbols show trace of axial surface and direction of dip of limbs]

Axial trace of F_1 fold (Acadian, nappe-stage)
- Recumbent anticline
- Recumbent syncline

Axial trace of F_2 fold (Acadian or Alleghanian, early dome-stage)
- Antiform

Axial trace of F_3 or younger fold (Alleghanian to Mesozoic)
- Antiform (dome-stage or younger)
- Synform (dome-stage or younger)

MINOR FOLDS

Folds in pre-Silurian rocks of the Moretown slice and Chester dome

47 42 — Strike and dip of inclined axial surface of minor isoclinal fold of schistosity or gneissosity that is parallel to the composite first and second generation schistosity; probably Taconic; arrow shows bearing and plunge of hinge line of fold. Minor folds are concentrated near and parallel to the Keyes Mountain thrust fault between the core gneisses and pre-Silurian cover rocks of the Chester dome

41 15 — Strike and dip of inclined axial surface of minor fold that is parallel to non-penetrative cleavage; arrow shows bearing and plunge of hinge line of fold. May correlate with F_2 or F_3 folds in rocks that are east of the Moretown slice

Folds in rocks that are east of the Moretown slice

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

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

Strike and dip of kink bands (S_4)—Locally a crenulation cleavage. Associated with low-amplitude, long-wavelength folds with variable fold hinge orientations. Mesozoic age
- 86, 30 Inclined
- Vertical

PLANAR FEATURES

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

Strike and dip of bedding
- 38 Inclined
- 51 Inclined, showing tops from graded beds or pillows
- 76 Inclined, overturned showing tops

Strike and dip of quartz vein (KDq)
- 50 Inclined
- Vertical
- Location only, no orientation measured

Strike and dip of mafic dike (Kd)
- 78 Inclined
- Vertical

68 **Strike and dip of granite dike (Dg)**

Strike and dip of pegmatite dike (Dp)
- 70 Inclined
- Vertical

FOLIATION

Planar features in pre-Silurian rocks of the Moretown slice or in the Chester dome in the northwestern part of the map
- Strike and dip of vertical Mesoproterozoic gneissosity
- 76 Strike and dip of inclined penetrative schistosity; either Taconic or a Taconic-Acadian composite foliation
- Strike and dip of inclined penetrative schistosity of undetermined age
  - 60 Inclined
  - Vertical
- Strike and dip of schistosity of undetermined age that is parallel to compositional layering
  - 46 Inclined
  - 60 Inclined, deformed
- 70, 75 Strike and dip of nonpenetrative spaced (zonal) cleavage or crenulation cleavage; may correlate with S_2 or S_3 in rocks east of Moretown slice

Planar features in rocks east of the Moretown slice
- Strike and dip of layer-parallel schistosity (S_1)—Parallel to bedding or compositional layering; Acadian
  - 46 Inclined
  - 60 Inclined, deformed
  - Vertical
- Strike and dip of foliation (S_2)—Variable across the map, less penetrative to the west, zonal in the east; Acadian to Alleghanian
  - Spaced cleavage
    - 70, 75 Inclined
    - Vertical
  - 32 Penetrative schistosity
  - Mylonitic or phyllonitic S_2 to S_3 foliation
    - 75 Inclined
    - Vertical

Strike and dip of dominant foliation (S_n)—Not age specific, but either S_1 or a composite S_1-S_2 foliation expressed as a schistosity where the S_2 strike and dip of foliation is penetrative
- 60 Inclined
- Vertical
- Horizontal

Strike and dip of late crenulation cleavage (S_3 or S_4)—Associated with open folds and a crenulation lineation which post-date the dominant schistosity; most apparent in fine-grained metapelites; Neo-Acadian, Alleghanian, or younger. Cleavage is either S_3 or S_4. Folds often display sinistral (counterclockwise) sense of rotation
- 82, 62 Inclined
- Vertical

LINEAR FEATURES

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

29 **Bearing and plunge of F_1 minor fold axis**

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

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

30 **Bearing and plunge of mineral lineation**—Aggregate lineation or grain lineation associated with the dominant foliation (S_n); consists of quartz, plagioclase, biotite, muscovite, chlorite, staurolite, or amphibole

40 **Bearing and plunge of object lineation**—Lineation composed of elongate objects such as pebbles and quartz or plagioclase phenocrysts; generally associated with the dominant foliation (S_n)

32 **Bearing and plunge of rods**—Lineation composed of elongate quartz rods associated with the dominant foliation (S_n). The symbol is used for the rocks in the Moretown slice and Chester dome where it may be Taconic; elsewhere it is Acadian or Alleghanian

16 **Bearing and plunge of F_3 or F_4 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 biotite and (or) actinolite or locally chloritoid (in Scq) in the biotite zone; garnet and (or) hornblende in the garnet zone; staurolite in the staurolite zone; sillimanite-muscovite assemblages in the sillimanite zone. Orthoclase locally occurs with migmatite and sillimanite-muscovite assemblages in the Brennan Hill thrust sheet. Rocks of the Mount Holly Complex in the Chester dome probably reached hornblende-granulite facies metamorphism during Mesoproterozoic events, but experienced re-metamorphism during the Paleozoic in the staurolite-kyanite assemblage zone. No boundary is shown between rocks in the biotite and chlorite zone. Locally, regional sub-biotite zone rocks are present in the Connecticut Valley trough. Additionally, local retrograde deformation and metamorphism has resulted in lower-greenschist facies assemblages within and adjacent to shear zones. These zones are marked "lower greenschist" on the geologic map

Mine, Prospect, or Quarry—Abandoned mine or prospect (see list of names below). The location listed as "uncertain" was located by GPS during mapping, but land-use changes made it difficult to confirm if the site was truly the location of the abandoned mine. Locations listed as "approximate" are from the Mineral Resource Data System (MRDS) database and were not confirmed during mapping. Locations listed as "confirmed" were located by GPS during mapping

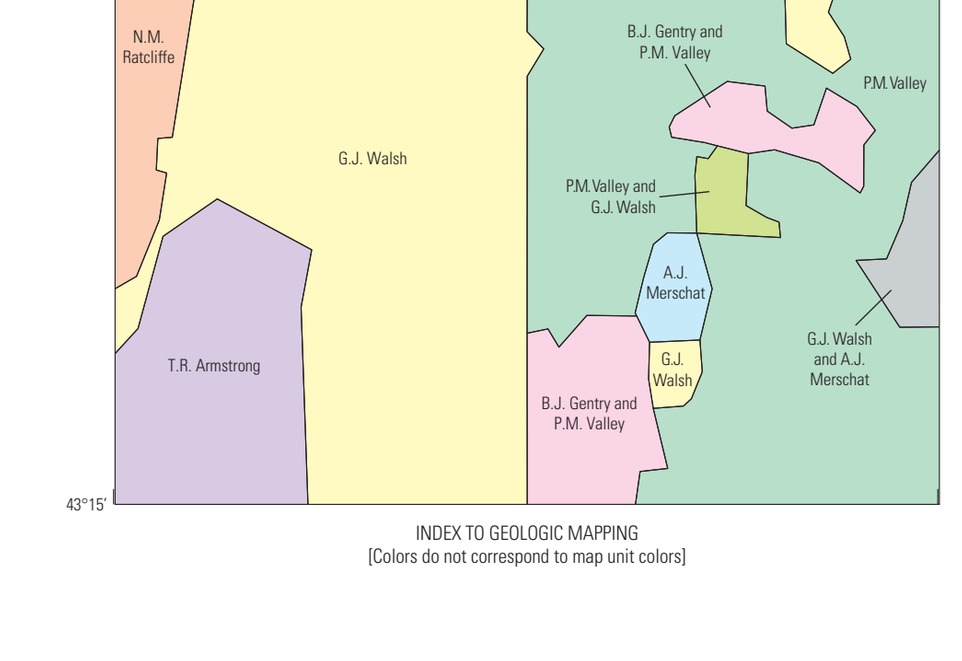
Name	Commodity	MRDS deposit identification number	Location
Unity Mine	Copper and sulfur	10081616	Uncertain
Hubbard-Neal Mine	Copper and sulfur	10088745	Approximate
Neal Mine	Copper and sulfur	10198562	Approximate
Gliddens Hill Quartz Prospect	Silica	10198286	Confirmed
Sargeant Mica Mine	Feldspar and mica	10150537	Confirmed
G.F. Smith and Chandler Mills Mine	Feldspar and mica	10125772	Confirmed

Active quarry (aggregate)

Inactive quarry (aggregate or slate)

Spring

CS–3025 399±3 Ma **Geochronology sample location**—Showing sample number and uranium-lead (U-Pb) zircon age (with uncertainty of 2 sigma) in millions of years before present (Ma, mega-annum) by sensitive high-resolution ion microprobe (SHRIMP) or thermal ionization mass spectrometry (TIMS) (table 1)



INDEX TO GEOLOGIC MAPPING
[Colors do not correspond to map unit colors]

Bedrock Geologic Map of the Springfield 7.5- x 15-Minute Quadrangle, Windsor County, Vermont, and Sullivan County, New Hampshire

By

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2020

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ISSN 2329-132X (online)
https://doi.org/10.3133/sim3462

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Suggested citation: Walsh, G.J., Valley, P.M., Armstrong, T.R., Ratcliffe, N.M., Merschat, A.J., and Gentry, B.J., 2020, Bedrock geologic map of the Springfield 7.5- x 15-minute quadrangle, Windsor County, Vermont, and Sullivan County, New Hampshire: U.S. Geological Survey Scientific Investigations Map 3462, 2 sheets, scale 1:24,000, https://doi.org/10.3133/sim3462.