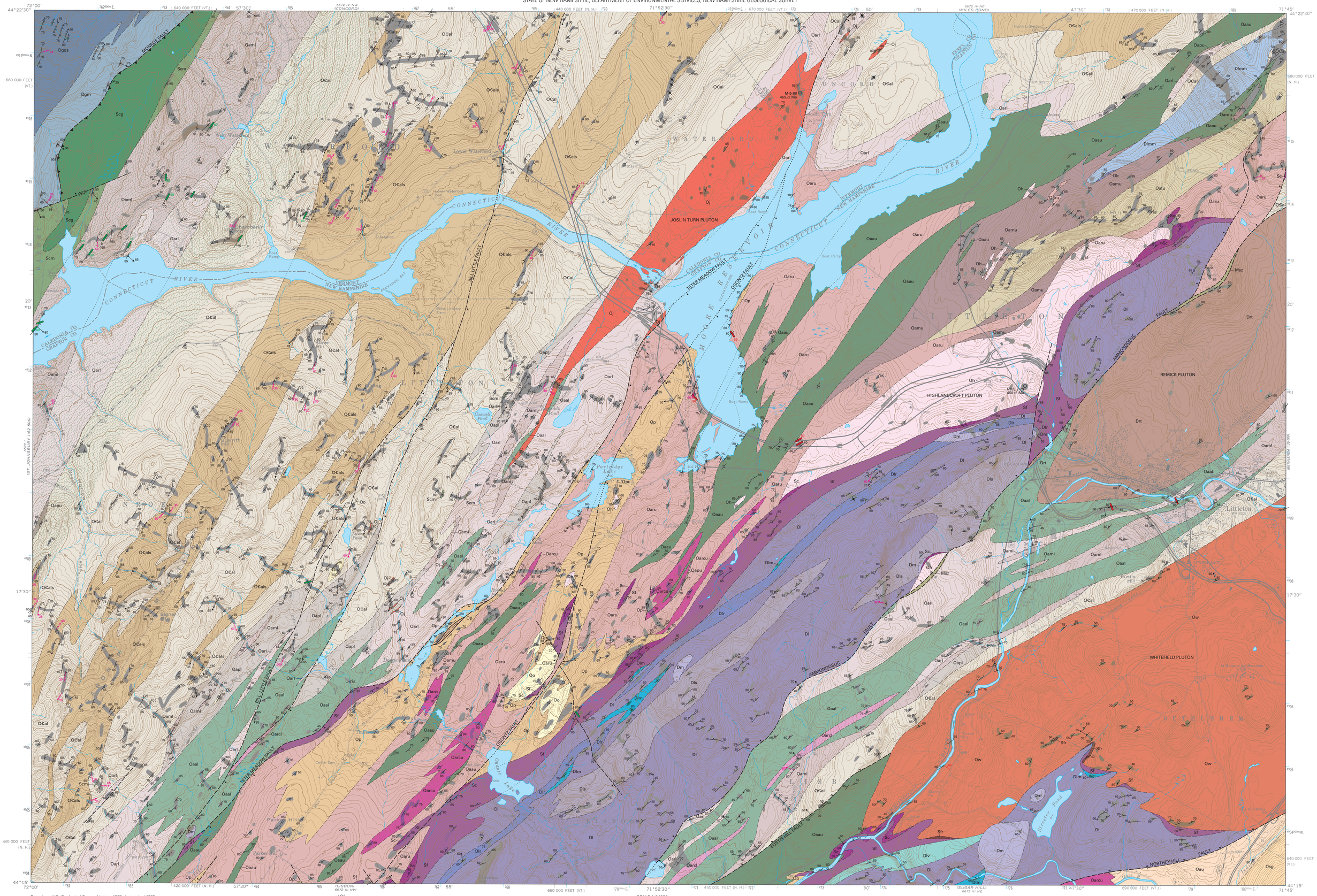
U.S. Department of the Interior
U.S. Geological Survey

Prepared in cooperation with
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

Open-File Report 2018–1087



Base from U.S. Geological Survey, Littleton, 1967, photorevised 1988;
Lower Waterford, 1967, photoinspected, 1983
Additional revisions performed in 2016 for the addition of Interstate 83
North American Datum of 1927
10,000-foot grid ticks based on New Hampshire State plane coordinate system and Vermont State plane coordinate system
1,000-meter Universal Transverse Mercator grid ticks, zone 19

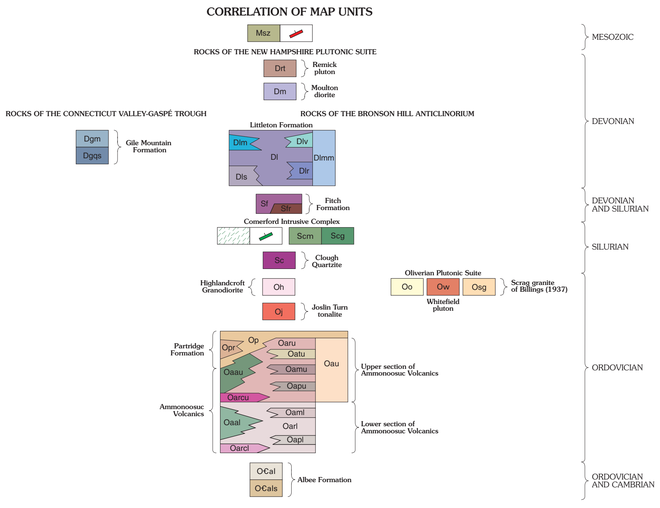
APPROXIMATE MEAN DECLINATION, 2018

SCALE 1:24000
1 MILE
1 KILOMETER
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAP LOCATION

Geology mapped by Douglas W. Rankin (1992–2014)
assisted by Mary B. Rankin
Declination when mapped approximately 16.3° (1992) to 15.1° (2014)
GIS database and cartography by E. Allen Crider (2010–2018)
Edited by David A. Shields

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Msz — **Silicified fault zone (Mesozoic)**—Very dark to white brecciated and (or) recrystallized vein quartz. Areas on map are enlarged to show locations

ROCKS OF THE NEW HAMPSHIRE PLUTONIC SUITE

Drt — **Remick pluton (Devonian)**—Gray, fine- to medium-grained biotite tonalite and biotite-hornblende tonalite composed of quartz, oligoclase, biotite, and local hornblende; contains swarms of small euhedral epidote crystals (Moench and others, 1995)

Dm — **Moulton diorite (Early Devonian)**—Dark-gray, medium-grained metadiorite and metagabbro composed mainly of secondary minerals including sausseritized plagioclase, amphibole, epidote, chlorite, and calcite. Interpreted as the intrusive equivalent of the mafic extrusive rocks found in the Littleton Formation (**Dlm**) (Rankin and Tucker, 2009). Occurs as dikes, sills, and small plugs. The unit is informally named for exposures northwest of Pethyboro on Moulton Hill (Billings, 1937)

ROCKS OF THE CONNECTICUT VALLEY-GASPÉ TROUGH

Gile Mountain Formation (Lower Devonian)

Dgm — **Meetinghouse Slate member**—Medium-dark-gray to grayish-black slate containing sparse to moderately abundant 1-millimeter (mm)- to 1-centimeter (cm)-thick beds of light-gray, fine-grained metasandstone and metasiltstone, commonly sulfidic and calcareous. Some graded bedding is locally present (Rankin and Rankin, 2014)

Dgqs — **Quartzite and metapelite member**—Gray to tan, fine to very fine grained quartzite with interlaminations and beds of dark-gray metapelite and dark-gray (dark-brownish-gray weathering) calcareous metasiltstone. Graded bedding is conspicuous. Bedding thickness overall is irregular, but locally, regular sets of graded beds are common. Beds in some regular sets are as much as 2 to 3 meters (m) thick (Rankin, 1994)

ROCKS OF THE BRONSON HILL ANTICLINORIUM

Littleton Formation (Lower Devonian)

Dl — **Gray slate member**—Medium-dark-gray to dark-gray slate and schist interlayered with light-gray, fine-grained, micaceous metasandstone with sparse grit. Locally, the unit exhibits rusty weathering and is highly pyritic (pyrite crystals are as large as 2 cm)

Dlmm — **Grit member at Mount Misery**—Massive, poorly sorted, coarse-grained feldspathic grit; thickly bedded metasandstone; granule conglomerate; and rhyolite grit containing angular to subrounded clasts of plagioclase, potassium feldspar, and quartz in a matrix of fine-grained quartz and micas (Moench and others, 1995; Rankin and others, 2013)

Dlv — **Mixed metavolcanic rock member**—Interbedded, gray pelitic schist; felsic, crystal and lithic metatuff; metatuff breccia; greenstone basalt or amphibolite (locally pillowed); and volcaniclastic metagraywacke (Moench and others, 1995)

Dlm — **Metabasalt and meta-andesite member**—Metamorphosed basalt and andesite (some pillowed), volcanic breccia, and tuff. Commonly porphyritic with stubby, relict plagioclase phenocrysts as large as 1 cm

Dlr — **Metarhyolite member**—Metamorphosed, very fine grained to aphanitic rhyolitic tuff, welded tuff, lithic tuff (commonly with a few percent quartz and alkali feldspar phenocrysts), and volcanic conglomerate (Rankin and others, 2013)

Dls — **Metasandstone member**—Fine-grained feldspathic metasandstone with dark slate partings. Pyrite is abundant in cubes as large as 0.5 cm and commonly contains quartz fibers growing in pressure shadows (Rankin and Rankin, 2014)

Sf — **Fitch Formation (Lower Devonian and upper Silurian)**—Metamorphosed limestone, calcareous sandstone, siltstone, and pelite. The unit contains some limestone conglomerate and polymict conglomerate with a calcareous matrix (Rankin and Tucker, 2009; Rankin and others, 2013)

Str — **Fitch Formation (regolith) (Lower Devonian and upper Silurian)**—Metamorphosed grus and bedded granitic detritus exposed along contacts with the Whitefield pluton and and Highlandcroft Granodiorite

Comerford Intrusive Complex (late Silurian)

Scm — Foliated to nonfoliated, pegmatitic metatonalite to metagabbro—Composed mostly of plagioclase and hornblende with prominent apatite and some biotite. Hornblende may contain cores of clinopyroxene. Grain size is generally measured in centimeters. Local concentrations of hornblende contain crystals as long as 15 cm. The pegmatitic metagabbro contains as much as 15 percent magnetite. Plagioclase-rich pegmatite veins are as much as 85 percent plagioclase, are 15 to 30 cm thick, and crosscut the pegmatitic metagabbro. In one of these veins, hornblende crystals as long as 8 cm extend from the pegmatite walls toward the center of the vein (Rankin, 1994)

Scg — Foliated to nonfoliated, fine-grained to pegmatitic metamorphosed gabbro, diorite, tonalite, aplitic tonalite, and crosscutting diabase dikes—Twenty fractions of zircon and baddeleyite from three sample locations (outside of the map area) of pegmatitic phases have a weighted mean $^{207}Pb/^{206}Pb$ age of 419±1 mega-annum (Ma, or million years before present) (Rankin and Tucker, 2007; Rankin and others, 2007)

Sc — **Clough Quartzite (lower Silurian)**—Metamorphosed quartz-cobble conglomerate, quartzite, and micaceous sandstone (Rankin and Tucker, 2009)

Oh — **Highlandcroft Granodiorite of the Highlandcroft Plutonic Suite (Late Ordovician)**—Foliated, medium-greenish-gray to dark-greenish-gray, medium-grained metamorphosed granite, granodiorite, and tonalite containing quartz, microcline, sausseritized plagioclase, hornblende, biotite (chlorite altered) and secondary calcite and sericite. Larger intrusions produced a contact metamorphic aureole in rhyolite (**Oarl**) of the Ammonoosuc Volcanics outside of the map area (Rankin and Tucker, 2009). Lyons and others (1986) report a U-Pb zircon age of 450±5 Ma from the Highlandcroft pluton at its type-locality shown on the map (sample NH/L 2–79) (Billings, 1935; Rankin and Rankin, 2014). The original "Highland Croft" farm and barn, from which the locality is named, is now gone (Rankin and Rankin, 2014)

Oliverian Plutonic Suite (Late Ordovician)

Oo — **Unnamed granodiorite (Ordovician?)**—Weakly to moderately foliated, medium-grained, commonly porphyritic biotite granodiorite; occurs as small plutons or dikes

Ow — **Whitefield pluton (Late Ordovician)**—Weakly to moderately foliated, medium-grained, commonly porphyritic, light-gray to flesh-colored biotite granodiorite (Rankin and Tucker, 2009). The unit is part of the Jefferson dome or Jefferson batholith, which yielded a U-Pb zircon age of 454±4 Ma (Lyons and others, 1997; Moench and Aleinikoff, 2003)

Osg — **Scrag granite of Billings (1937) (Late Ordovician)**—Typically pink to light-gray, weakly to strongly foliated, medium-grained, equigranular to subporphyritic granite; composed of quartz, microcline, oligoclase, biotite, minor muscovite, and accessory magnetite, sphene, pyrite, zircon, and apatite (Moench and others, 1995). The unit is not exposed in the map area, but shown in the southeast corner of the map from the extrapolation of adjacent quadrangles where it is part of the Jefferson dome or Jefferson batholith (Lyons and others, 1997; Moench and Aleinikoff, 2003). Moench and Aleinikoff (2003) report a U-Pb zircon age of 456±3 Ma from a location outside of the map area

Oj — **Joslin Turn tonalite (Middle Ordovician)**—Hypabyssal, weakly foliated, greenish-gray to light-brownish-gray, medium-grained metamorphosed tonalite. Primary minerals include quartz, plagioclase, biotite, magnetite, pyrite, and apatite; secondary minerals include chlorite, epidote, sericite, and calcite. Granophyric intergrowths of quartz and plagioclase are present (Ratcliffe and others, 2011). Moench and Aleinikoff (2003) report a U-Pb zircon age of 469±2 Ma from sample M–5–88 shown on the map

Partridge Formation (Ordovician)

Op — **Sulfidic slate member**—Dark-gray to grayish-black, rusty-weathering sulfidic slate; interlayered locally with metamorphosed rhyolite. Where the sulfide is pyrrhotite as opposed to pyrite, the rusty weathering is pronounced. The rock is informally referred to as "cruddy black slate"

Opr — **Metarhyolite member**—Metamorphosed rhyolite tuff, lapilli tuff, tuff breccia, and rhyolite. Generally porphyritic with 5 to 20 percent plagioclase phenocrysts and, in some places, quartz phenocrysts are present

Ammonoosuc Volcanics (Ordovician)

[Map units labelled with lowercase "u" or "l" as the last letter of the map symbol are interpreted as part of the "upper" and "lower" sections of the Ammonoosuc Volcanics, respectively. Lower Ammonoosuc Volcanics have an approximate age of magmatism of 480 to 462 Ma; upper Ammonoosuc Volcanics have an approximate age of 458 to 445 Ma (Aleinikoff and others, 2015)]

Oau — Undifferentiated, metamorphosed, felsic and mafic volcanic and volcaniclastic rocks, pelite, and ironstone

Oaru — Dominantly metamorphosed rhyolite tuff, lapilli tuff, tuff breccia, and rhyolite. Generally porphyritic with 5 to 20 percent plagioclase phenocrysts and, in some locations, quartz phenocrysts are present. The unit is generally strongly foliated with waxy sheen on foliation surfaces. The unit includes unmapped coarsely porphyritic rhyolite tuff, lapilli tuff, and tuff breccia, in which quartz and plagioclase phenocrysts are commonly as large as 5 mm (Rankin and Rankin, 2014). A sample of felsic metatuff (**Oaru**)(Moench and Aleinikoff, 2003) outside of the map area yielded a thermal ionization mass spectrometry (TIMS) age of 461±8 Ma and a sensitive high-resolution ion microprobe (SHRIMP) age of 447±4 Ma (Aleinikoff and others, 2015)

Oatu — Metamorphosed, medium- to light-bluish-gray, aphyric rhyolite tuff and siltstone

Oaau / **Oaal** — Dominantly metamorphosed andesitic and basaltic tuff, crystal tuff, and tuff breccia; contains minor pillows. Commonly contains relict plagioclase and (or) mafic phenocrysts (Rankin and Rankin, 2014)

Oamu / **Oaml** — Metamorphosed, medium-light-bluish-gray, medium-bluish-gray, and medium-dark-gray to medium-dark-greenish-gray siltstone and phyllite; medium-gray feldspathic graywacke; and grit. Purple tinge is common; coticule and magnetite are locally abundant (Rankin and Rankin, 2014)

Oapu / **Oapl** — Dark-gray to grayish-black, rusty-weathering sulfidic slate and phyllite interlayered with metamorphosed ultra-fine-grained sulfidic ironstone, chert, felsic tuff, and minor sandstone. Much of the unit is indistinguishable from the Partridge Formation (**Op** and **Opr**). A sample of felsic metatuff (**Oapu**) collected outside of the map area by Moench and Aleinikoff (2003) yielded a TIMS age of 443±4 Ma and a SHRIMP age of 456±6 Ma (Aleinikoff and others, 2015)

Oarcu / **Oarcl** — Coarsely porphyritic metarhyolite tuff, lapilli tuff, and tuff breccia. Quartz and plagioclase phenocrysts are commonly as large as 5 mm

Albee Formation (Middle Ordovician and Upper Cambrian)

OCal — **Gray-green pinstriped member**—Interbedded light-gray to greenish-gray, white-weathering, feldspathic, fine-grained metamorphosed sandstone and siltstone; and light-gray to greenish-gray to dark-gray phyllite. Contains lesser amounts of quartzite and rare calc-silicate nodules. Phyllosilicates are commonly 10 to 25 percent of the matrix. Tourmaline and magnetite are sporadic accessory minerals. Locally, the unit may be sulfidic (with either pyrite of pyrrhotite) and exhibits rusty weathering. The unit is generally sharply bedded, but graded beds as well as slump structures are locally obvious. Bedding thickness varies from less than a cm to more than a meter. "Pinstriping" is common (quartzo-feldspathic laminae 1 mm to a few mm thick separated by paper-thin micaceous partings that are commonly magnetite-bearing) (Rankin and Rankin, 2014)

OCals — **Scarritt member**—Dark-gray slate interlayered with thin beds of light-gray, fine-grained, micaceous and feldspathic metamorphosed sandstone. Ribbed weathering is common, but in places where pelite dominates, bedding is difficult to identify. Abruptly graded beds (less than a cm to 30 cm thick) are locally common along with channeling and, in places, soft-sediment deformation is present. The unit is commonly sulfidic (with either pyrite or pyrrhotite) and exhibits rusty weathering (Rankin and Rankin, 2014)

EXPLANATION OF MAP SYMBOLS

Contact—Dashed where approximately located; dotted where concealed by water

FAULTS

Major faults include the following named faults from Rankin and others (2013):

Mesozoic faults—Bill Little fault, Ammonoosuc fault, Ogontz fault, Teter Meadow fault, and Eustis Hill fault

Paleozoic faults—Monroe fault and Northey Hill fault

Normal fault—Approximately located; dotted where concealed by water; ball and bar on downthrown side

Thrust fault—Dashed where approximately located; teeth on upper plate

Strike-slip fault—Dashed where approximately located; dotted where concealed by water; arrows show relative movement

Left lateral oblique-slip fault—Approximately located; arrows show relative movement; ball and bar on downthrown side

Fault—Approximately located; queried where movement direction is questionable or conjectural; dotted where concealed by water

PLANAR FEATURES

[May be combined with linear and (or) other planar features]

Strike and dip of bedding

30 — Inclined
— — Vertical
70 — Overturned

Strike and dip of bedding (younging direction indicated by channeling)

80 — Inclined
— — Vertical
65 — Overturned

Strike and dip of bedding (younging direction indicated by graded bedding)

45 — Inclined
— — Vertical
75 — Overturned

Inclined strike and dip of bedding (younging direction indicated by crossbedding)

36 — Inclined

Inclined plicated bedding

60 — Inclined

Strike and dip of bedding and subparallel S_2 foliation or composite S_1-S_2 foliation

50 — Inclined
— — Vertical

Strike and dip of S_2 foliation

85 — Inclined
— — Vertical

Strike and dip of inclined highly plicated or mylonitic S_2 foliation

55 — Inclined

Strike and dip of inclined igneous foliation

80 — Inclined

Strike and dip of S_3 crenulation cleavage or spaced cleavage

70 — Inclined
— — Vertical

Strike and dip of inclined ductile shear zone

45 — Inclined

Strike and dip of prominent inclined joint sets

60 — Inclined

DIKES

Strike and dip of Mesozoic diabase dikes

65 — Inclined
— — Vertical

Strike and dip of Silurian dikes of the Comerford Intrusive Complex

80 — Inclined
— — Vertical

LINEAR FEATURES

Bearing and plunge of mineral lineation, clast elongation, and (or) rodding

45 — 70 — 55 — 40 — 35 — 50

Bearing and plunge of slickensides

Bearing and plunge of the intersection of bedding and S_2 foliation

Bearing and plunge of the intersection of two foliations and (or) cleavages

Bearing and plunge of F_2 fold axis; some may include F_1 fold axis

Bearing and plunge of F_3 fold axis

25 — **Bearing and plunge of S-fold axis**
30 — **Bearing and plunge of Z-fold axis**
15 — **Minor anticline**—Showing bearing and plunge of axis
5 — **Minor syncline**—Showing bearing and plunge of axis
60 — **Minor syncline with overturned limb**—Showing bearing and plunge of axis

OTHER FEATURES

Outcrops—Areas of exposed bedrock or closely spaced continuous bedrock exposures examined in this study. Size of symbols are exaggerated to show location

M–5–88 469±2 Ma — **Geochronology sample location**—Showing sample number and age in mega-annum (Ma, or million years before present)

REFERENCES CITED

Aleinikoff, J.N., Rankin, D.W., Moench, R.H., and Walsh, G.J., 2015, New SHRIMP U-Pb zircon ages for felsic Ammonoosuc Volcanics, Northern NH-VT [abs.]: Geological Society of America Abstracts with Programs, v. 47, no. 3, p. 41. [Also available at https://gsa.confex.com/gsa/2015NE/webprogram/Paper252886.html.]

Billings, M.P., 1935, Geology of the Littleton and Moosilauke quadrangles, New Hampshire: New Hampshire State Planning and Development Commission, 51 p. text, 1 sheet, scale 1:62,500.

Billings, M.P., 1937, Regional metamorphism of the Littleton-Moosilauke area, New Hampshire: Geological Society of America Bulletin, v. 48, no. 4, p. 463–566, 1 sheet, scale 1:62,500. [Also available at https://doi.org/10.1130/GSAB-48-463.]

Lyons, J.B., Aleinikoff, J.N., and Zartman, R.E., 1986, Uranium–thorium–lead ages of the Highlandcroft Plutonic Suite, northern New England: American Journal of Science, v. 286, no. 6, p. 489–509. [Also available at https://doi.org/10.2475/ajs.286.6.489.]

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, scales 1:250,000 and 1:500,000. [Also available at http://libarchive.dartmouth.edu/cdm/ref/collection/gsmaps/id/2087.]

Moench, R.H., and Aleinikoff, J.N., 2003, Stratigraphy, geochronology, and accretionary terrane setting of two Bronson Hill arc sequences, northern New England: Physics and Chemistry of the Earth, v. 28, nos. 1–3, p. 47–95. [Also available at https://doi.org/10.1016/S1474-7065(01)00003-1.]

Moench, R.H., Boone, G.M., Bothner, W.A., Boudette, E.L., Hatch, N.L., Jr., Hussey, A.M., III, and Marvinney, R.G., 1995, Geologic map of the Shelburne-Lewiston area, Maine, New Hampshire, and Vermont, United States, and Quebec, Canada: U.S. Geological Survey Miscellaneous Investigations Series Map I–1898–D, 56 p. pamphlet, 2 sheets, scale 1:250,000. [Also available at https://pubs.er.usgs.gov/publication/i1898D.]

Rankin, D.W., 1994, Preliminary bedrock geologic map of parts of the Lower Waterford, Concord, Littleton, and Miles Pond 7 1/2-minute quadrangles, Vermont and New Hampshire: U.S. Geological Survey Open-File Report 94–410, 28 p. pamphlet, 3 sheets, scale 1:24,000. [Also available at https://pubs.er.usgs.gov/publication/ofr94410.]

Rankin, D.W., Coish, R.A., Tucker, R.D., Peng, Z.X., Wilson, S.A., and Rou, 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. [Also available at https://doi.org/10.2475/01.2007.07.]

Rankin, D.W., and Rankin, M.B., 2014, A field trip guidebook to the type localities of Marland Billings' 1935 Paleozoic bedrock stratigraphy near Littleton, New Hampshire: U.S. Geological Survey Open-File Report 2014–1026, 21 p. [Also available at https://doi.org/10.3133/ofr20141026.]

Rankin, D.W., and Tucker, R.D., 2007, The Piermont allochthon revisited and redefined at its type locality—Discussion: Geological Society of America Bulletin, v. 119, nos. 3–4, p. 500–502. [Also available at https://doi.org/10.1130/B26089.]

Rankin, D.W., and Tucker, R.D., 2009, A "homoclinal" stratigraphy across the Ammonoosuc Valley southwest of Littleton, New Hampshire, Trip B3, *in* Westerman, D.S., and Lathrop, A.S., eds.: New England Intercollegiate Geological Conference, 101st Annual Meeting, Lyndon State College, Lyndonville, Vt., Sept. 25–27, 2009, Guidebook to field trips in the Northeast Kingdom of Vermont and adjacent regions: Orono, Maine, University of Maine, p. 121–146.

Rankin, D.W., Tucker, R.D., and Amelin, Yuri, 2013, Reevaluation of the Piermont-Frontenac allochthon in the Upper Connecticut Valley—Restoration of a coherent Boundary Mountains-Bronson Hill stratigraphic sequence: Geological Society of America Bulletin, v. 125, nos. 5–6, p. 998–1,024. [Also available at https://doi.org/10.1130/B30590.1.]

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 https://pubs.er.usgs.gov/publication/sim3184.]

Bedrock Geologic Map of the Littleton and Lower Waterford Quadrangles, Essex and Caledonia Counties, Vermont, and Grafton County, New Hampshire

By
Douglas W. Rankin[1]

2018

[1]Deceased

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

For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225;
1–888–ASK–USGS (1–888–275–8747)

Suggested citation: Rankin, D.W., 2018, Bedrock geologic map of the Littleton and Lower Waterford quadrangles, Essex and Caledonia Counties, Vermont, and Grafton County, New Hampshire: U.S. Geological Survey Open-File Report 2018–1087, 1 sheet, scale 1:24,000, https://doi.org/10.3133/ofr20181087.

ISSN 2331–1258 (online)
https://doi.org/10.3133/ofr20181087