Bedrock Geology of the Hanover, NH, 7 ½′ Quadrangle

By Peter J. Thompson

Introduction

The bedrock geology of the New Hampshire portion of the Hanover 7 1/2′ Quadrangle is dominated by the Lebanon Dome. A core of Ordovician, meta-igneous granite is surrounded by quartz diorite, overlain in turn by Ordovician schist and metavolcanic rocks. Several lines of evidence indicate that the quartz diorite intruded the metamorphic rocks. The "dome" is actually a zeppelin-shaped body, elongated along a NNE-SSW axis with both north and south ends plunging northerly. Regionally, the mapped area lies between the Mesozoic Ammonoosuc Fault (up on the east side) and the Northey Hill Fault Zone (also up on the east side according to Thompson, 2014).

Previous Work

The area was mapped by Lyons (1955; 1958) as the northeast quadrant of the Hanover 15′ Quadrangle. He differentiated between the granite and quartz diorite in the dome, and mapped out three small amphibolite bodies (metagabbro) along the contact with the schist. Lyons also identified a small pluton near the mouth of the Mascoma River in West Lebanon as part of the Lebanon granite. Following Hadley (1938) and Chapman (1939) in quadrangles to the north and east, Lyons (1955) assigned the schist to the Orfordville Formation and the mafic volcanics to the Post Pond Member of that formation. In the later compilation for the state map (Lyons et al., 1997) these rocks were correlated with Partridge Formation (Ops) and Ammonoosuc Volcanics (Oa), respectively. Lyons et al. (1997) also reassigned what Lyons (1955) had interpreted as a metasomatic gneiss zone of the Orfordville (Oog), nearest the dome rocks, to metavolcanics in the Partridge (Opf in the present study). Lyons (1955) noted staurolite in schists west of the dome and attributed its presence to proximity with the intrusive rocks. The present study shows that grade actually increases west away from the dome, the implications of which are discussed in the summary section. Quaternary deposits cover much of the lower lying areas in the quadrangle, including extensive glacial Lake Hitchcock deposits (Hildreth, 2004).

Structural Geology

Compositional layering S_0, bedding S_0, dominant foliation S_1 in the schists and metavolcanics and weak foliation in the quartz diorite S_1 are all subparallel throughout the quadrangle. These planar features dip moderately northwest on Oak Hill, Balch Hill and Observatory Hill in Hanover, away from the dome, and swing around to dip more steeply west in the area of Wilder Dam and Boston Lot Lake. At the south end of the dome, in Lebanon, planar features dip moderately north and northwest, toward the dome. The dominant foliation is interpreted as a D_1 fabric associated with a huge west-directed nappe called the Cornish Nappe by Thompson et al. (1968). The rocks are apparently on the inverted limb of a nappe-stage anticline, with Ammonoosuc Volcanics overlying the presumably younger Partridge Formation around the west, north and (in the Enfield quadrangle) east sides of the dome. Where both S_0 and S_1 are exposed in the same outcrop, S_0 is less steep, consistent with an overturned limb position. Only one D_1 fold was found, at the very south edge of the quadrangle. Because the south end of the zeppelin-shaped dome is in turn inverted, the stratigraphy in the southeast corner of the map is in the upright order; Ammonoosuc crops out within 1000 meters of the southeast quadrangle corner (see cross section A′-A″).

Mineral lineations and S_1XS_2 intersection lineations plunge northwest throughout, parallel to rare, minor D_2 dome-stage fold axes.

In the North Hartland Quadrangle to the south, the Ammonoosuc Volcanics occupy a large area above an overturned classic “Bronson Hill sequence” of Partridge, Clough, Fitch, and Littleton, which are all folded by a large D2 syncline-anticline pair (Lyons et al., 1997; Walsh, in press). The syncline’s axial trace lines up with that of the Lebanon “zeppelin”, and one wonders how much farther south the dome rocks, now eroded away, formerly extended above the syncline. Was their presence in fact somehow related to the development of the folds? The D2 Meriden Anticline brings the Monroe Thrust to the surface, with various units of the Bronson Hill sequence in contact with Gile Mountain Formation of the “Vermont sequence” (Lyons et al., 1997; Walsh, in press). The D2 folds plunge north-northwest toward the Hanover Quadrangle, which begs the following questions: Does the Monroe Thrust extend beneath the Lebanon Dome? And is the Lebanon Dome therefore also allochthonous? This interpretation is portrayed schematically in cross section A-A′ of this report. Such an interpretation may help explain why the Lebanon Dome lies off to the west of the main Bronson Hill axis of Oliverian Domes. The question of where these rocks were rooted is an important one that is beyond the scope of this report.

The Lebanon Dome has long puzzled regional geologists; Peter Robinson (pers. comm., 2014) recalls making a special trip to Hanover from Harvard in the 1950’s to talk with John Lyons about it. Robinson had the idea that the dome must have moved in somehow from above rather than from below like the other Oliverian domes. Lyons et al. (1996) concluded from gravimetry studies that the Lebanon granite might have a thickness on the order of 8.5 kilometers. This depth is compatible with a projection of the Monroe Thrust in the Plainfield Syncline plunging northerly at about 50º beneath the core of the dome. All these structures are truncated along the west by the Ammonoosuc Fault. West of that fault, in Vermont, is another steep Mesozoic fault, which on some older maps is labeled “Monroe Fault” or “Monroe Line”. However, Hatch (1988) demonstrated that at this latitude an early ductile fault was reactivated during the Mesozoic, and to avoid confusion, I propose that the Mesozoic portion of the Monroe Line be called the Lake Morey Fault. The thrust fault of Acadian age, best called the Monroe Thrust, would dip much more gently (see cross-section A-A′). The ductile portion diverges from the Lake Morey Fault north of Lake Morey, and follows an arcuate path through the type locality of Monroe, New Hampshire (Ratcliffe et al., 2011).

Description of Map Units

The Ammonoosuc Volcanics (Oa) in the Hanover Quadrangle range from dark green-black fine- to medium-grained hornblende gneisses to black and white metavolcanics with distinct alternating hornblende-rich and feldspathic layers. The unit is well exposed on the Dartmouth College campus, where a sill of white-weathering feldspar-garnet gneiss with hornblende fascicles lies parallel to more typical mafic rocks. Some layers contain epidote-rich lenses up to 30 centimeters long, some of which have pillow-like shapes. The Ammonoosuc is also exposed in a small quarry east of Route 10 near Camp Brook, on Chambers Road just south of the Hanover line, and from Wilder Dam south along a ridge east of Route 10 to the outskirts of West Lebanon, where it disappears beneath Quaternary cover. The only exposures south of there are at the I-89/Route 12A intersection (discussed further below) and on Poverty Lane at the south border of the quadrangle, where it is a well foliated, coarse-grained amphibole-epidote-chlorite gneiss.

The Partridge Formation in this quadrangle consists of schist (Ops) with felsic metavolcanic lenses and layers (Opf). Schists in the Partridge are rusty-weathering, black to dark gray, graphitic and sulfidic fine- to coarse-grained schist. They are coarser away from the Lebanon Dome, for example on the west slopes of Oak Hill, where clumps of biotite (pseudomorphs after staurolite?) and locally staurolite itself join tiny garnets as porphyroblasts. Closer to the dome the Partridge is overall finer-grained biotite schist, locally with garnet. The staurolite isograd trends northeast toward a well defined continuation in the Lyme Quadrangle (Thompson, 2008). (A study of feldspar compositions in the mafic rocks would contribute to locating the comparable amphibolite facies limits.)

Felsic metavolcanics of the Partridge range from rusty weathering, light gray fine-grained sulfidic felsite to rusty, medium-grained biotite feldspar-studded gneiss. Sulfide prospects are common in this unit, especially near Farnum Hill in the North Hartland Quadrangle, where a series of trenches and pits were dug in the 1880's (Lyons, 1958) in metavolcanic rocks and what appears to be a quartz diorite sill. Material in spoils piles consists of vein quartz and gossan-like material. About 1500 meters north, in the Hanover Quadrangle north of the Old Kings Highway, another trench was found during this study, where the rocks are so rich in pyrrhotite that compass bearings were disturbed. Amphibolite, likely metagabbro, crops out as sills within the metavolcanics west of Bald Hill and in a larger body along the crest of Crafts Hill. The massive, blocky- and brown-weathering rock seems to be intercalated with quartz diorite along the east side of Crafts Hill. This body continues south all the way to a near-outcrop at an old dam site on the Mascoma River upstream from the Route 4 bridge north of the airport. Rumble (pers. comm., 2015) reported that Lyons had suggested to a contractor that the amphibolite might serve as road metal, but the rock was so tough that it apparently broke the testing equipment.

The granite (Oo1b) in the center of the Lebanon Dome is a pinkish gray, medium-grained, weakly to non-foliated biotite granite, which has been quarried for dimension stone. Quartz diorite or tonalite (Oo3A) mantles the granite and is well exposed on Starr Hill in Lebanon and in the Mascoma River between old mills north and south of Route 4. The quartz diorite is a dark to medium gray, medium-grained biotite rock, more strongly foliated along its contacts with the Partridge Formation. Valley et al. (2015) reported a U/Pb age on zircons from the granite in the Enfield Quadrangle as 448+/-5 Ma, and from the quartz diorite near the Poverty Lane/Route 4 intersection in Hanover Quadrangle as 445+/-7 Ma. Field relations suggest that the granite is younger. The Route 4 road cut also contains a xenolith of Partridge felsic volcanics parallel to foliation within the quartz diorite. At the I-89/Route 12A intersection, north of the Verizon Wireless building, a white-weathering tonalite that intrudes the Ammonoosuc Volcanics was dated at 466+/-8 Ma (Valley et al., 2015). This is part of the small pluton shown by Lyons (1955) as a body of Lebanon granite, but it is clearly older than the dome rocks, and together with tonalite in Plainfield (U/Pb 475+/-5 Ma, Valley et al., 2015), provides some constraints on the minimum age of the Ammonoosuc.

A few metadiabase dikes of unknown age (md) consisting of fine- to medium-grained hornblende gneiss intrude the Partridge Formation. Their extent is limited to one or a few outcrops. No Mesozoic diabase dikes were found, although Lyons (1958) reported one on Crafts Hill and several intruding the Lebanon granite.

Summary

To summarize the geological history of rocks in the Hanover Quadrangle, we start with deposition of the Ordovician Ammonoosuc Volcanics and Partridge Formation. Igneous rocks of the Lebanon dome, also Ordovician but somewhat younger, then intruded. The whole package was folded by the Cornish Nappe (D_1) and carried westward on the Monroe Thrust, presumably during the Acadian Orogeny. The Ammonoosuc-Partridge sequence is inverted in the entire quadrangle. The stacking of hot rocks from above set up the conditions necessary to produce inverted metamorphic isograds (Spear and Rumble, 1986), which were then arched by the Meriden Anticline and the Lebanon Dome (D_2). Spear and Rumble (1986) and Lyons et al. (1997, Sheet 2) incorrectly show the staurolite isograd encircling the Lebanon Dome, when in fact the rocks closest to the dome are at garnet grade. The garnet isograd loops around the north end of the Meriden Anticline just south of the Hanover Quadrangle boundary (Walsh, in press) and the staurolite isograd lies both west of the dome, and far to the east, separated by a zone of garnet grade rocks parallel to the Salmon Hole Brook Syncline and the Northey Hill Fault (Thompson, 2008; 2014). The Lebanon Dome and the D_2 folds may be in part coeval, but the dome may have moved south and upwards during the time that sinistral shear was concentrated along the Northey Hill Fault (late D_2?). Finally, greenschist facies rocks of the upright Cornish Nappe limb were dropped down on the west side of the Ammonoosuc Fault during the Mesozoic.

References:

Chapman, C.A., 1939, Geology of the Mascoma Quadrangle, New Hampshire: Bulletin of the Geological Society of America, v. 50, p. 127-180, scale 1:62,500.

Hadley, J. B., 1938, Geology of the New Hampshire portion of the Mt. Cube quadrangle: Ph.D. thesis, Harvard University (published in 1942 as a Bulletin of the Geological Society of America, v. 53, p. 113-176).

Hatch, N.L., Jr., 1988, New evidence for faulting along the “Monroe Line”, eastern Vermont and westernmost New Hampshire: American Journal of Science, v.288, p.1-18.

Hildreth, C.T., 2004, Surficial geology of the Hanover quadrangle, New Hampshire and Vermont: New Hampshire Geological Survey Open-file report Geo-91 SMOF, scale 1:24,000.

Lyons, J.B., 1955, Geology of the Hanover Quadrangle, New Hampshire—Vermont: Geological Society of America Bulletin, v.66, p.106-146, scale 1:62,500.

Lyons, J.B., 1958, Geology of the Hanover Quadrangle, New Hampshire: New Hampshire State Planning and Development Commission, 43 p., scale 1:62,500.

Lyons, J.B., J.G. Campbell and J.P. Erikson, 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.

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

Ratcliffe, N.M., R.S. Stanley, M.H. Gale, P.J. Thompson and G.J. Walsh, 2011, Bedrock geologic map of Vermont: U.S. Geological Survey Scientific Investigations Map 3184, scale 1:100,000.

Spear, F.S. and D. Rumble III, 1986, Pressure, temperature, and structural evolution of the Orfordville Belt, west-central New Hampshire: Journal of Petrology, v.27, part 5, p.1071-1093.

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

Thompson, P.J., 2008, Bedrock geology of the Lyme 7.5 minute quadrangle, New Hampshire: Open-file report Geo-080 BMOF, scale 1:24,000.

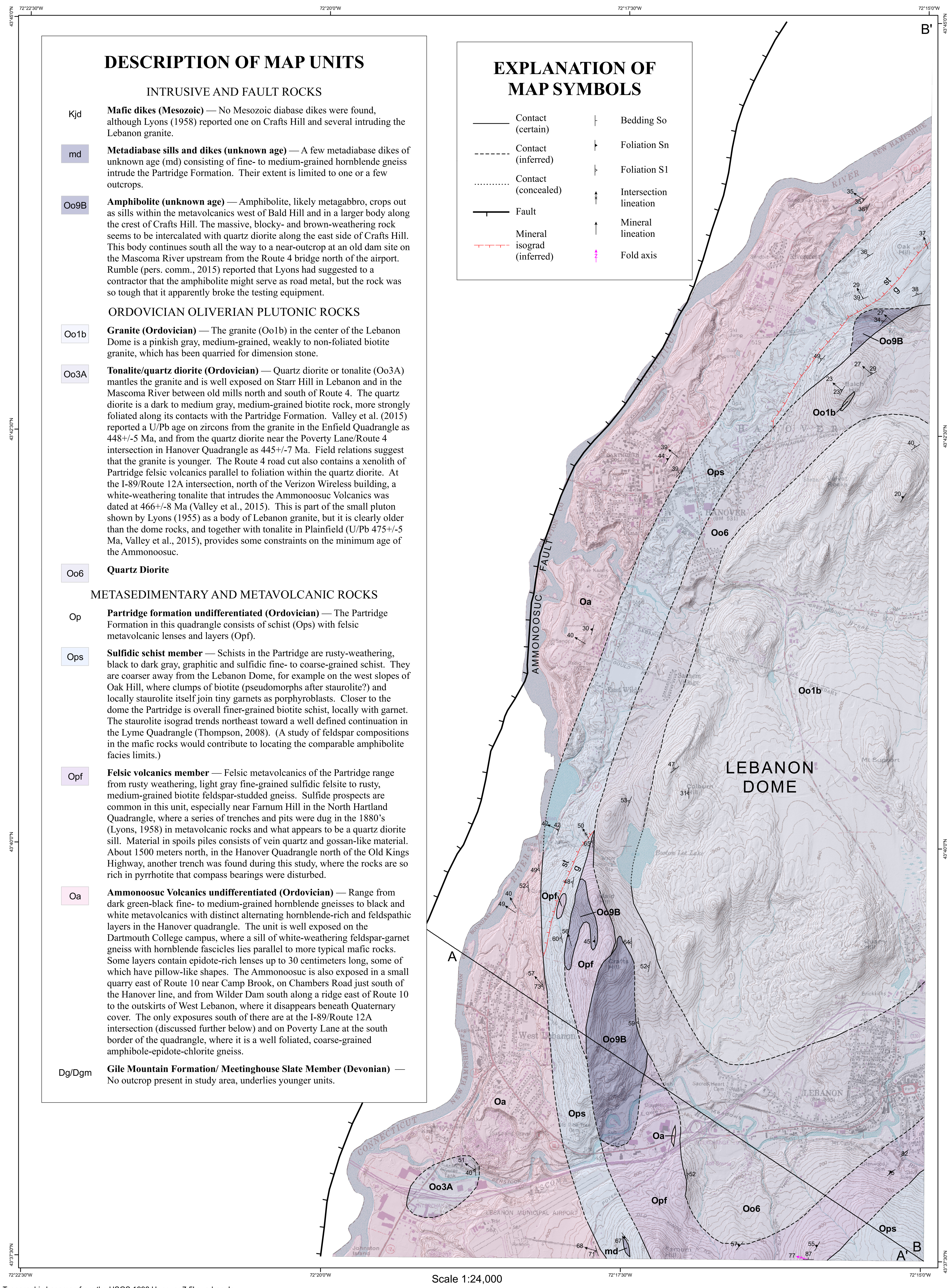
Thompson, P.J., 2014, Bedrock geology of the Enfield 7.5 minute quadrangle, New Hampshire: Open-file report Geo-092 BMOF, scale 1:24,000.

Valley, P.M., G.J. Walsh and R.J. McAleer, 2015, New U-Pb zircon ages from the Bronson Hill Arc, west-central New Hampshire: Geological Society of America Abstracts with Programs, v.47, no.3, p.41.

Walsh, G.J., P.M. Valley and K.R. Sicard, 2012, A Transect through the base of the Bronson Hill Anticlinorium in western New Hampshire, *in* Thompson, P.J. and T.B. Thompson, eds., Guidebook to Field Trips in Western New Hampshire and Adjacent Vermont and Massachusetts: 104th New England Intercollegiate Geological Conference, Sunapee, N.H., Trip A4, p. 83-103.

Walsh, G.J., in press, 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, map scale 1:24,000.

Bedrock Geologic Map of the Hanover 7.5' Quadrangle, New Hampshire



DESCRIPTION OF MAP UNITS

INTRUSIVE AND FAULT ROCKS

Kjd — **Mafic dikes (Mesozoic)** — No Mesozoic diabase dikes were found, although Lyons (1958) reported one on Crafts Hill and several intruding the Lebanon granite.

md — **Metadiabase sills and dikes (unknown age)** — A few metadiabase dikes of unknown age (md) consisting of fine- to medium-grained hornblende gneiss intrude the Partridge Formation. Their extent is limited to one or a few outcrops.

Oo9B — **Amphibolite (unknown age)** — Amphibolite, likely metagabbro, crops out as sills within the metavolcanics west of Bald Hill and in a larger body along the crest of Crafts Hill. The massive, blocky- and brown-weathering rock seems to be intercalated with quartz diorite along the east side of Crafts Hill. This body continues south all the way to a near-outcrop at an old dam site on the Mascoma River upstream from the Route 4 bridge north of the airport. Rumble (pers. comm., 2015) reported that Lyons had suggested to a contractor that the amphibolite might serve as road metal, but the rock was so tough that it apparently broke the testing equipment.

ORDOVICIAN OLIVERIAN PLUTONIC ROCKS

Oo1b — **Granite (Ordovician)** — The granite (Oo1b) in the center of the Lebanon Dome is a pinkish gray, medium-grained, weakly to non-foliated biotite granite, which has been quarried for dimension stone.

Oo3A — **Tonalite/quartz diorite (Ordovician)** — Quartz diorite or tonalite (Oo3A) mantles the granite and is well exposed on Starr Hill in Lebanon and in the Mascoma River between old mills north and south of Route 4. The quartz diorite is a dark to medium gray, medium-grained biotite rock, more strongly foliated along its contacts with the Partridge Formation. Valley et al. (2015) reported a U/Pb age on zircons from the granite in the Enfield Quadrangle as 448+/-5 Ma, and from the quartz diorite near the Poverty Lane/Route 4 intersection in Hanover Quadrangle as 445+/-7 Ma. Field relations suggest that the granite is younger. The Route 4 road cut also contains a xenolith of Partridge felsic volcanics parallel to foliation within the quartz diorite. At the I-89/Route 12A intersection, north of the Verizon Wireless building, a white-weathering tonalite that intrudes the Ammonoosuc Volcanics was dated at 466+/-8 Ma (Valley et al., 2015). This is part of the small pluton shown by Lyons (1955) as a body of Lebanon granite, but it is clearly older than the dome rocks, and together with tonalite in Plainfield (U/Pb 475+/-5 Ma, Valley et al., 2015), provides some constraints on the minimum age of the Ammonoosuc.

Oo6 — **Quartz Diorite**

METASEDIMENTARY AND METAVOLCANIC ROCKS

Op — **Partridge formation undifferentiated (Ordovician)** — The Partridge Formation in this quadrangle consists of schist (Ops) with felsic metavolcanic lenses and layers (Opf).

Ops — **Sulfidic schist member** — Schists in the Partridge are rusty-weathering, black to dark gray, graphitic and sulfidic fine- to coarse-grained schist. They are coarser away from the Lebanon Dome, for example on the west slopes of Oak Hill, where clumps of biotite (pseudomorphs after staurolite?) and locally staurolite itself join tiny garnets as porphyroblasts. Closer to the dome the Partridge is overall finer-grained biotite schist, locally with garnet. The staurolite isograd trends northeast toward a well defined continuation in the Lyme Quadrangle (Thompson, 2008). (A study of feldspar compositions in the mafic rocks would contribute to locating the comparable amphibolite facies limits.)

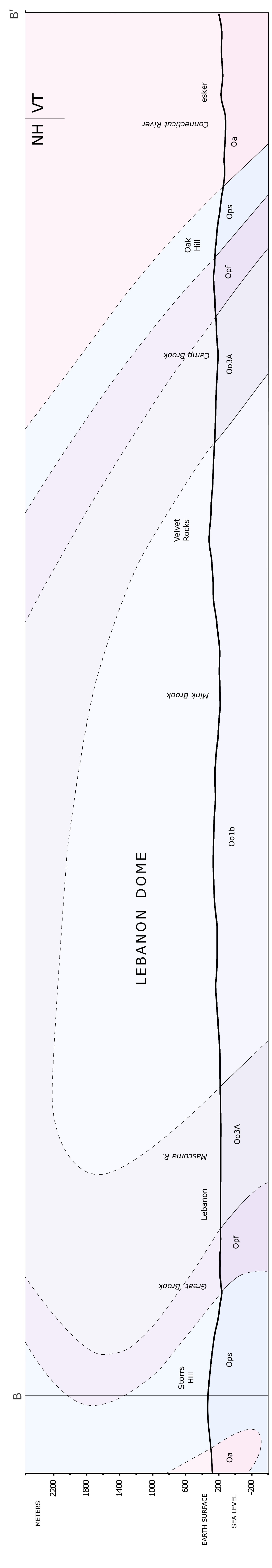
Opf — **Felsic volcanics member** — Felsic metavolcanics of the Partridge range from rusty weathering, light gray fine-grained sulfidic felsite to rusty, medium-grained biotite feldspar-studded gneiss. Sulfide prospects are common in this unit, especially near Farnum Hill in the North Hartland Quadrangle, where a series of trenches and pits were dug in the 1880's (Lyons, 1958) in metavolcanic rocks and what appears to be a quartz diorite sill. Material in spoils piles consists of vein quartz and gossan-like material. About 1500 meters north, in the Hanover Quadrangle north of the Old Kings Highway, another trench was found during this study, where the rocks are so rich in pyrrhotite that compass bearings were disturbed.

Oa — **Ammonoosuc Volcanics undifferentiated (Ordovician)** — Range from dark green-black fine- to medium-grained hornblende gneisses to black and white metavolcanics with distinct alternating hornblende-rich and feldspathic layers in the Hanover quadrangle. The unit is well exposed on the Dartmouth College campus, where a sill of white-weathering feldspar-garnet gneiss with hornblende fascicles lies parallel to more typical mafic rocks. Some layers contain epidote-rich lenses up to 30 centimeters long, some of which have pillow-like shapes. The Ammonoosuc is also exposed in a small quarry east of Route 10 near Camp Brook, on Chambers Road just south of the Hanover line, and from Wilder Dam south along a ridge east of Route 10 to the outskirts of West Lebanon, where it disappears beneath Quaternary cover. The only exposures south of there are at the I-89/Route 12A intersection (discussed further below) and on Poverty Lane at the south border of the quadrangle, where it is a well foliated, coarse-grained amphibole-epidote-chlorite gneiss.

Dg/Dgm — **Gile Mountain Formation/ Meetinghouse Slate Member (Devonian)** — No outcrop present in study area, underlies younger units.

EXPLANATION OF MAP SYMBOLS

- Contact (certain)
- Contact (inferred)
- Contact (concealed)
- Fault
- Mineral isograd (inferred)
- Bedding So
- Foliation Sn
- Foliation S1
- Intersection lineation
- Mineral lineation
- Fold axis



Interpretive Cross Section B - B' (No Vertical Exaggeration)

Topographic basemap from the USGS 1998 Hanover 7.5' quadrangle
Projection: North American Datum 1983 New Hampshire State Plane Feet.
1000 meter grid in UTM zone 18 North, Contour Interval 20 ft

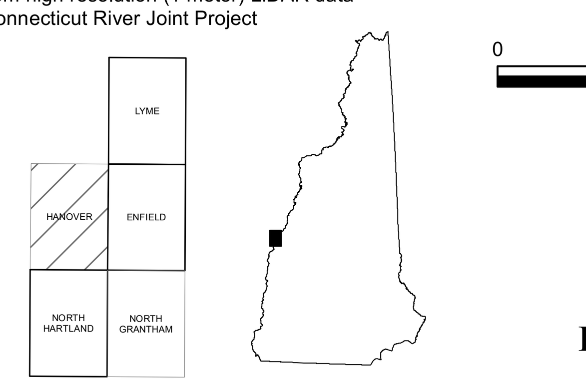
Hillshade produced from high resolution (1 meter) LiDAR data acquired from 2015 Connecticut River Joint Project

Scale 1:24,000

0 1,450 2,900 5,800 Feet

0 0.5 1 2 Miles

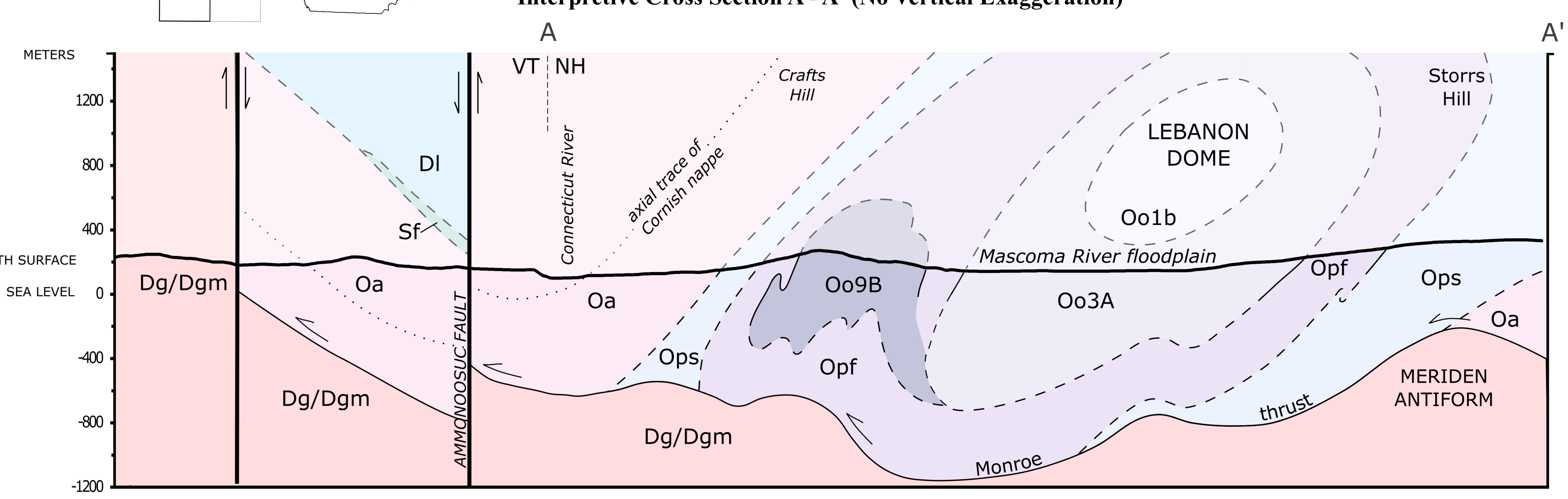
0 1 2 4 Kilometers



NHGS Open-File Disclaimer: This map and the accompanying legend(s) are understood to be open-file products. They are draft versions of an unpublished report and represent mapping progress at the time of completion. Newer information may exist. If you have questions, please contact the New Hampshire Geological Survey (NHGS) at: geology@des.nh.gov or (603) 271-1976

MN
GN
14°48´
263 MILS
0°21´
6 MILS
UTM GRID AND 2014 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

Interpretive Cross Section A - A' (No Vertical Exaggeration)



Bedrock Geologic Map of the Hanover 7.5' Quadrangle, New Hampshire

Geology by Peter J. Thompson, 2014
Digital Compilation by Sarah W. Baker and Gregory A. Barker, 2016
New Hampshire State Geologist: Frederick H. Chormann

Bedrock Geologic Map Open-File Series GEO-091-024000-BMOF

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