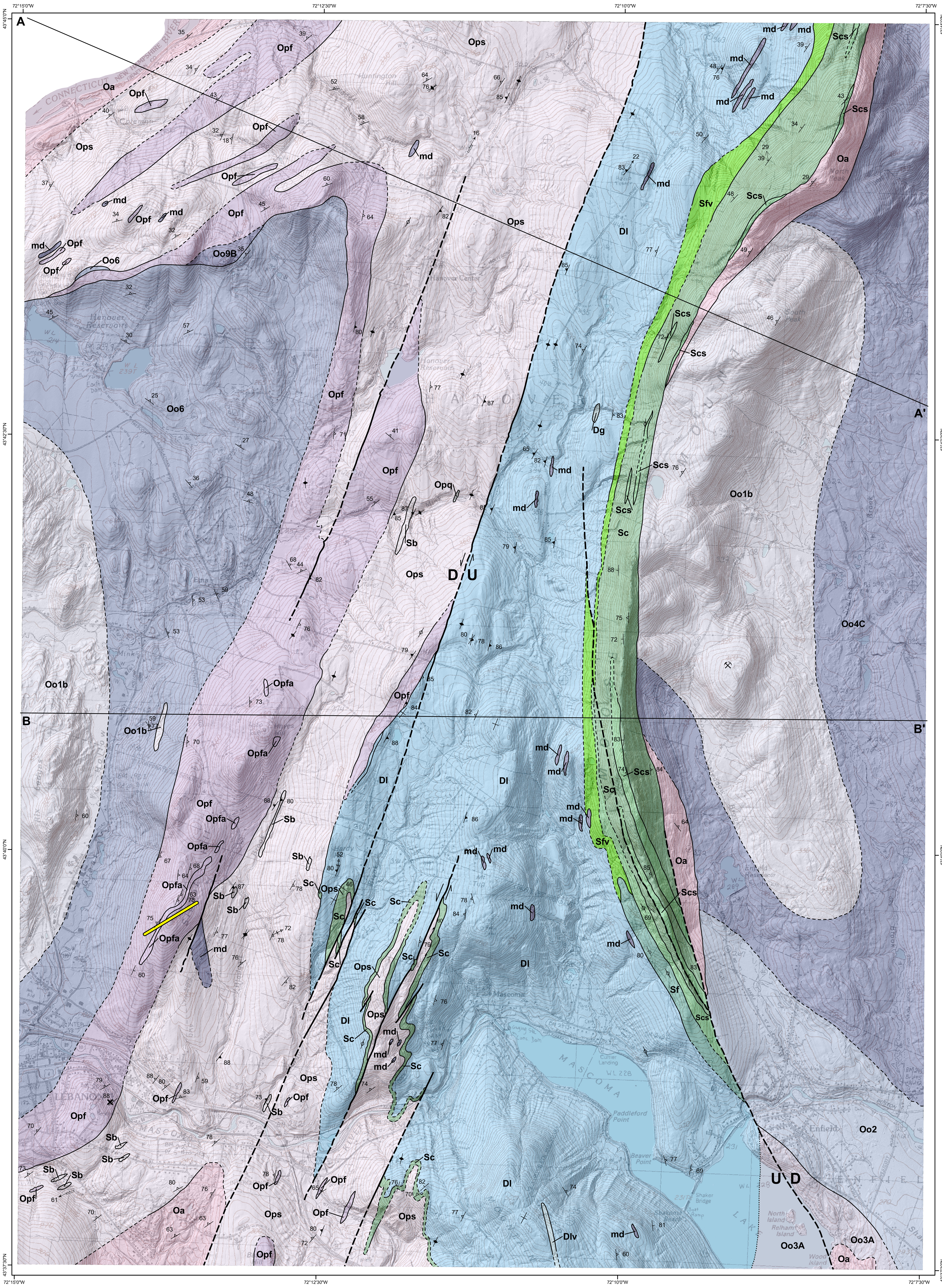
Bedrock Geologic Map of the Enfield 7.5' Quadrangle, New Hampshire, 2016



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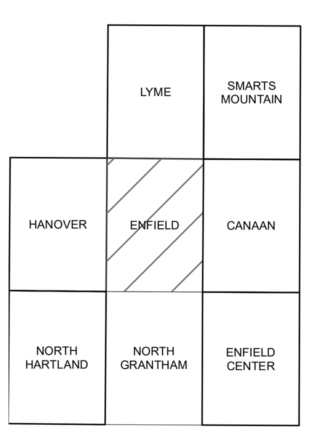
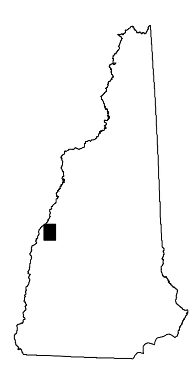
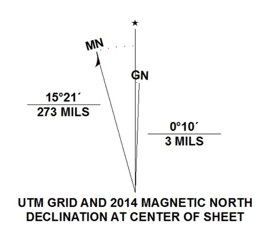


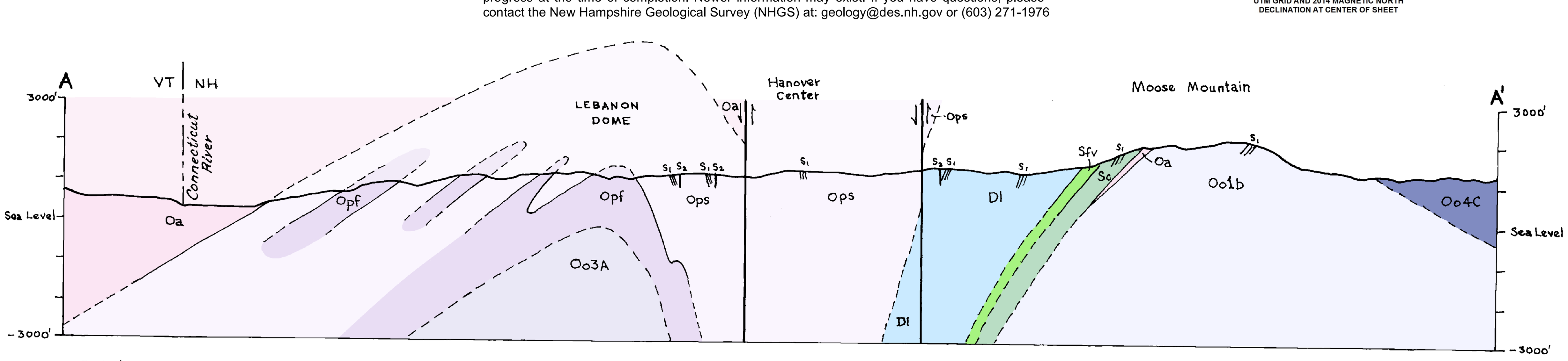


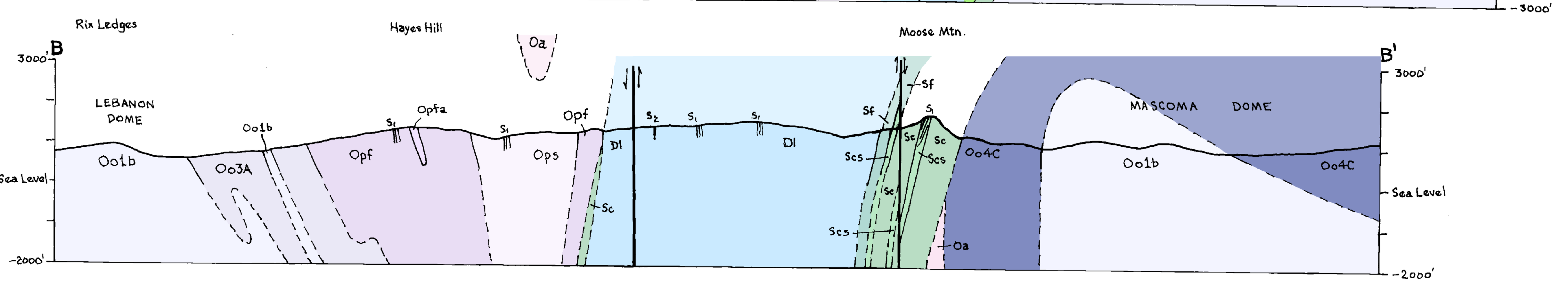
0 1,450 2,900 5,800
Feet
0 0.5 1 2
Miles
0 1 2 4
Kilometers

Topographic basemap from the USGS 1998 Enfield 7.5' quadrangle
Projection: North American Datum 1983 New Hampshire State Plane Feet.
1000 meter grid in UTM zone 19 North, Contour Interval 6 m

Hillshade produced from high resolution (1 meter) LiDAR data







DESCRIPTION OF MAP UNITS

INTRUSIVE AND FAULT ROCKS

Dg — **Granite sill (Devonian?)**

Sb — **Shear breccia (unknown age)**

md — **Metadiabase sills and dikes (unknown age)** — fine- to medium-grained hornblende gneiss, commonly less well foliated than similar metavolcanics in the Ammonoosuc. Their extent is limited to one or a few outcrops in most cases, except for one larger area along Alden Road on the east slope of Signal Hill. The latter is cut by a fault, along which it is a fine-grained, strongly foliated chlorite schist.

OLIVERIAN PLUTONIC SUITE ROCKS

Oo1b — **Granite (Ordovician)** — Granite 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. The granite (Oo1b) of the Mascoma Dome is a brownish-gray, medium-grained, biotite granite that has a somewhat porphyritic texture. K-feldspars are whiter than those in the Lebanon granite. The Shakers quarried this granite at two locations in the quadrangle and used it to construct foundations in Shaker Village. The reader is referred to Chapman (1939) for a thorough description of other rock types in the Mascoma Dome: quartz monzonite, granodiorite and quartz diorite.

Oo2 — **Granodiorite (Ordovician)**

Oo3A — **Tonalite/quartz diorite (Ordovician)** — mantles the granite (Oo1b), dark to medium gray, medium-grained biotite tonalite, more strongly foliated along the northwestern margin, where foliation parallels S1 in the adjacent Partridge. One sill of tonalite was found within the Partridge north of the Hanover Reservoirs, suggesting an intrusive relationship.

Oo4C — **Quartz monzonite (Ordovician)**

Oo6 — **Quartz diorite (Ordovician)**

Oo9B — **Hornblende gabbro (Ordovician)** — East of Pinneo Hill a body of hornblende gneiss (Oo9B) may represent a gabbroic phase of the dome (Chapman, 1939) or it may represent a gabbro dike along the tonalite/Partridge contact.

METASEDIMENTARY AND METAVOLCANIC ROCKS

Dl — **Littleton Formation (Devonian)** — Silvery-gray fine-grained schist, commonly with tiny biotite and/or garnet porphyroblasts. Clean exposures often show compositional layering a few centimeters thick in which darker gray layers alternate with lighter gray layers presumably containing more silt or fine sand. Foliation surfaces in many outcrops weather somewhat rusty, which can make distinguishing Littleton from Partridge a real challenge, especially where the Clough is not present. The schist was quarried by the Shakers on the hillside above Shakoma Beach and used for roofing slate.

Sf — **Fitch Formation (Silurian)** — A variety of calc-silicate granofels. Some outcrops are brown-weathering, dark grayish purple fine-grained biotitic granofels. Some of these granofels have carbonate lenses a few centimeters in length, which may weather out to form pits. Others are mottled by dark green amphibole, epidote, or carbonates. At the northwest base of Moose Mountain the Fitch is a white-spotted, dark green, medium-grained hornblende-rich rock that greatly resembles mafic metavolcanics of the Ammonoosuc.

Sfv — **Mafic volcanics of the Silurian Fitch Formation**

Sc — **Clough Quartzite** — White to gray fine-grained quartzite, quartz pebble conglomerate, schistose quartzite, and white to pale gray medium-grained muscovite-rich schist, with or without garnet. Thicker schist layers have been mapped out separately (Scs), especially toward the south end of Moose Mountain, where they lie oblique to the eastern contact with older rocks. Great care was taken to distinguish these layers from nearby Littleton schist, to rule out the possibility that isoclinal folds involving Clough Quartzite and Littleton Formation might explain the map pattern. Conglomerate layers range from stringers a few centimeters thick to massive beds up to several meters thick. Pebbles in the conglomerate layers are almost exclusively vein quartz or quartzite. A few beds were found with weathered-out pits that may have been fossils, both in the Clough proper and the former Hardy Hill Quartzite. One such calcareous quartzite layer east of the Fitch toward the south end of Moose Mountain is several meters thick and contains visible crinoid stems and a horn coral.

Scs — **Schist within the Silurian Clough Quartzite**

Partridge Formation (Ordovician) — consists of schist (Ops) with felsic metavolcanic lenses and layers (Opf). Some rocks in the Partridge are rusty-weathering, black to dark gray, graphitic and sulfidic phyllite or very fine-grained schist. A distinctive dark gray quartzite (Opq) is exposed in Mink Brook east of Ruddsboro. Other rocks in the formation are dark gray, fine to medium-grained schist with biotite and/or garnet porphyroblasts across the foliation. In the very northwest corner of the quadrangle the schist is very coarse grained and contains clumps of biotite, possibly pseudomorphs after staurolite. Still other outcrops show lighter gray silty layers much like the Littleton. Chapman (1939) discussed the difficulty in distinguishing Partridge from Littleton, and pointed out that the Littleton schists are commonly more lustrous due to somewhat coarser or at least more abundant muscovite. The Littleton can be graphitic, but rarely contains pyrite. Strongly sheared breccia (“sb” on the map) is exposed at several places in the Partridge. In gross aspect the rock looks like a diamict, with a variety of clasts set in a black graphitic matrix. The clasts consist of vein quartz, felsite and schist intraclasts. Foliation wraps around the clasts and is deformed by F2 folds. This texture may have developed at the same time as the isoclinal folds, or independently.

Felsic volcanics of the Partridge are of two types: yellow-brown weathering, light gray fine-grained sulfidic felsite and rusty-weathering, gray to gray-green, medium-grained biotite granofels or gneiss. The latter is especially common from Etna south across Signal Hill, where a prospect pit is located in pyrite-rich rock cut by numerous quartz veins on the east slope of the hill.

Ops — **Sulfidic schist of the Ordovician Partridge Formation**

Opf — **Felsic volcanics of the Ordovician Partridge Formation**

Opfa — **Altered volcanics of the Ordovician Partridge Formation**

Opq — **Black quartzite of the Ordovician Partridge Formation**

Oa — **Ammonoosuc Volcanics (Ordovician)** — Undifferentiated, not widespread in the Enfield Quadrangle, being limited to several outcrops in the northwestern corner of the quadrangle and discontinuously along the west side of the Mascoma Dome. Rock types include dark green hornblende gneiss, intermediate black-and-white gneiss, and felsic gneisses much like those in the Partridge. No attempt was made to map out these different rock types separately.

EXPLANATION OF MAP SYMBOLS

Kjd — Mesozoic mafic dikes, also limited in exposure, are brown-weathering black rocks. Many are porphyritic, with feldspar phenocrysts up to a few cm across.

Contact
Dashed where approximate
Dotted where concealed

Fault
Dashed where approximate

Strike and dip of S_0 bedding
- Overturned
- Inclined
- Vertical

Strike and dip of nappe stage (S_1) foliation features
- Inclined
- Vertical

Strike and dip of dome (S_2) foliation features
- Inclined
- Vertical
- Spaced cleavage

Open fold features (F_2)
- Fold axial plane
- Fold axis

Trend and plunge of linear features
- Crenulation lineation (L_2)
- Mineral lineation

Other Features
- Quarry
- Metals prospect

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

Geology by Peter J. Thompson, 2014
Digital Compilation by Sarah W. Baker and Gregory A. Barker, 2016
Field assistants: Natalie Collins, Cody Whelan, and Taylor Hodgdon
New Hampshire State Geologist: Frederick H. Chormann

Bedrock Geologic Map Open-File Series GEO-092-024000-BMOF
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Bedrock Geology of the Enfield, NH, 7 ½′ Quadrangle

By Peter J. Thompson

Introduction

The Enfield Quadrangle is situated between two Ordovician Oliverian domes, the Lebanon Dome to the west and the Mascoma Dome to the east. These domes are composed of meta-igneous rocks and are foliated to varying degrees. The surrounding metamorphic rocks belong to the classic sequence of rock units known as the Bronson Hill sequence (Billings, 1935), consisting of Ordovician metavolcanic units that formed in a volcanic arc setting, and their Silurian and Devonian cover. These rocks range in metamorphic grade from biotite to staurolite grade and most are strongly foliated. A younger, steep to vertical foliation is well developed in the axial region between the two domes. Metadiabase dikes and sills of unknown age cut the metamorphic units. Mesozoic mafic dikes, mostly striking northeast, are also common.

Previous Work

The topography of the quadrangle is dominated by Moose Mountain, a prominent north-south ridge held up by Clough Quartzite. It was here that in 1912 Charles Hitchcock observed, "I saw the quartzite of Moose Mountain; and said to my companion, 'There is the key to the geology of this region'". The Clough Quartzite and the Hardy Hill Quartzite, a thinner quartzite with a discontinuous and folded pattern in the south-central part of the quadrangle, serve as marker beds in the stratigraphy. The area was mapped as the northwest quarter of the 15′ Mascoma Quadrangle by Chapman (1939). Chapman designated the rocks in the domes as granite, quartz monzonite, granodiorite and quartz diorite, based on petrographic work. He assigned the rocks mantling the Lebanon Dome to members of the Orfordville Formation following Hadley (1938), and separated them from the Bronson Hill sequence above the Mascoma Dome by the Northey Hill fault. Lyons et al. (1997) reassigned units from the Orfordville to correlate with the Bronson Hill sequence: the Hardy Hill Quartzite correlates with the Clough, rocks west of that marker are Partridge Formation or Ammonoosuc Volcanics, and rocks east of the marker are Littleton Formation. In their interpretation, the Northey Hill fault was abandoned. Furthermore, metavolcanic rocks immediately above the Lebanon Dome were assigned to a volcanic member of the Partridge rather than to the Ammonoosuc. Pertinent work by geologists in adjacent quadrangles are cited in later sections.

Although outcrops are abundant in the quadrangle, thick glacial till obscures the bedrock on many slopes and alluvium covers valley bottoms. Some of the brooks that drain larger watersheds have cut deeply enough into the till to expose bedrock, but many of the smaller streams are disappointingly bouldery. Steep slopes on Lords Hill and Moose Mountain are commonly covered by talus. A major esker parallels the Connecticut River. For further details on the Quaternary geology of the Enfield Quadrangle, see Hildreth (2009).

Soils that would support "Rich Northern Hardwood Forest" communities (Thompson and Sorenson, 2000) are more limited than in the Lyme Quadrangle to the north, where mafic rocks of the Ammonoosuc are more common. However, calcareous soils are expected in association with the Fitch Formation, where indicator species such as hepatica, green spleenwort and blue cohosh were observed.

Present Study

The map produced as a result of this study, being at a larger scale than Chapman's 1939 map, shows more detail. Chapman's igneous subdivisions of the dome rocks are retained, since no thin sections were made during this study. The present mapping confirms Lyons et al.'s (1997) re-interpretation of the stratigraphy. In addition to the Partridge felsic metavolcanics along the east margin of the Lebanon Dome, smaller layers and lenses also occur within schists of the Partridge. It should be noted that the Partridge is entirely lacking above the Mascoma Dome, where Clough Quartzite rests unconformably either on Ammonoosuc Volcanics or directly on the dome rocks, whereas the Partridge is unusually thick above the Lebanon Dome. Another change from previous mapping is that discontinuous Fitch Formation was found along the west side of Moose Mountain, west of the Clough. (One patch of these rocks near the north edge of the quadrangle was mistakenly interpreted by Chapman (1939) as a small anticline of Ammonoosuc.)

The present mapping suggests that the Northey Hill fault may be a valid interpretation, although perhaps more complicated than previously conceived. North of the Enfield Quadrangle the Partridge-Littleton contact is marked by discontinuous lenses of Clough Quartzite and Fitch Formation (Hadley, 1938). Foliation and bedding are very steep along its length. In the Enfield Quadrangle, however, the fault continues in a south-southwest direction, leaving the Partridge/Littleton contact and truncating previously folded rock units. Parallel faults also offset early isoclines and other contacts in a sinistral sense. Many outcrops show sinistral minor offsets along the late foliation. The Northey Hill fault may be a composite structure, involving early shearing associated with isoclinal folds, an intermediate, wide zone of ductile shear parallel to the late foliation, and a later, brittle component. Slickenlines on a fault surface in Hardy Hill Brook suggest sinistral, down to the west, oblique displacement. The shear sense observed in the Enfield Quadrangle is consistent with work in the Mt. Cube 15' Quadrangle, where Rumble (1969) recorded rotated garnets and Thompson (2008) noted quartz shadows on pyrite, also indicating down to the west sense. Orange (1985) found a discrepancy in P-T conditions across the fault zone and concluded that the zone may have experienced "intense ductile deformation with a large normal component".

Two generations of folding have affected the area. Early isoclines are best preserved by the Clough Quartzite (formerly Hardy Hill) in the south central part of the quadrangle. These folds are interpreted as minor folds on huge, west-directed nappes (Baker, 1954; Thompson et al., 1968). Early foliation (S_1) is subparallel to bedding in most outcrops. Bedding and the early foliation are deformed by northeast plunging dome-stage folds, except at the south end of the Mascoma Dome, where they plunge southeast. A weak S_2 foliation lies parallel to D_2 axial planes in a few exposures. Regionally, peak metamorphic isograds appear to have been deformed by the domes.

Both domes are asymmetrical: at the north edge of the quad, the Clough dips moderately northwest above the Mascoma Dome, becomes vertical in the central part of the quad, and then is steeply overturned in the south. West of the Lebanon Dome the Partridge dips moderately northwest, but then turns to a steep orientation along the east side of the dome. A late dome-stage foliation (S_2) is most strongly developed in the axial region between the domes, parallel to the Northey Hill fault zone. Rumble (1969) referred to this foliation as the "Sunday Mountain cleavage belt". Many outcrops display only one dominant foliation, and it is often impossible to tell if it is S_1 or S_2, especially where S_1 is also steep. In many instances, where S_1 and S_2 are nearly parallel, the dominant foliation may actually be a composite S_{1-2} foliation. This might make it difficult to separate micas for $^{40}Ar/^{39}Ar$ dating of the foliations. It should be noted that the Northey Hill fault zone is on strike with the Westminster West fault system of southeastern Vermont (Armstrong, 1997), where micas have been dated at ~300 Ma (McWilliams, 2007).

Chapman (1939) proposed a northwest-striking, Mesozoic fault along the north shore of Mascoma Lake south of Enfield village, to explain the repetition of south-dipping Ammonoosuc Volcanics above dome rocks at the south end of the Mascoma Dome. He showed the fault as the northern terminus of the Mesozoic Grantham normal fault, with a west-side-up sense of displacement. Lyons et al. (1997) follow his interpretation, but show additional splays off to the north and northeast. I have no reason to doubt these interpretations, as Ammonoosuc Volcanics are only exposed along the lakeshore farther south in the next quadrangle. I have continued this fault north along the west margin of the dome and show the fault truncating the Fitch and Clough, and continuing north into the Littleton Formation along several exposures of kink folds, which are common near Mesozoic faults elsewhere (Walsh et al., 2012). Chapman (1939) shows a greatly thinned Clough crossing Mascoma Lake, but I think this is unlikely. A gap in the outcrop distribution of the Clough may in fact explain the location of the Mascoma Valley. Likewise, west of Mascoma village, the former Hardy Hill Quartzite may be cut out by faults where it would be expected in the Mascoma River.

Description of Map Units

The Littleton Formation (Dl) consists of silvery-gray fine-grained schist, commonly with tiny biotite and/or garnet porphyroblasts. Clean exposures often show compositional layering a few centimeters thick in which darker gray layers alternate with lighter gray layers presumably containing more silt or fine sand. Foliation surfaces in many outcrops weather somewhat rusty, which can make distinguishing Littleton from Partridge a real challenge, especially where the Clough is not present. The schist was quarried by the Shakers on the hillside above Shakoma Beach and used for roofing slate.

The Fitch Formation (Sf) is made up of a variety of calc-silicate granofels. Some outcrops are brown-weathering, dark grayish purple fine-grained biotitic granofels. Some of these granofels have carbonate lenses a few centimeters in length, which may weather out to form pits. Others are mottled by dark green amphibole, epidote, or carbonates. At the northwest base of Moose Mountain the Fitch is a white-spotted, dark green, medium-grained hornblende-rich rock that greatly resembles mafic metavolcanics of the Ammonoosuc.

The Clough Quartzite (Sc) consists of white to gray fine-grained quartzite, quartz pebble conglomerate, schistose quartzite, and white to pale gray medium-grained muscovite-rich schist, with or without garnet. Thicker schist layers have been mapped out separately (Scs), especially toward the south end of Moose Mountain, where they lie oblique to the eastern contact with older rocks. Great care was taken to distinguish these layers from nearby Littleton schist, to rule out the possibility that isoclinal folds involving Clough Quartzite and Littleton Formation might explain the map pattern. Conglomerate layers range from stringers a few centimeters thick to massive beds up to several meters thick. Pebbles in the conglomerate layers are almost exclusively vein quartz or quartzite. A few beds were found with weathered-out pits that may have been fossils, both in the Clough proper and the former Hardy Hill Quartzite. One such calcareous quartzite layer east of the Fitch toward the south end of Moose Mountain is several meters thick and contains visible crinoid stems and a horn coral.

The Partridge Formation in this quadrangle consists of schist (Ops) with felsic metavolcanic lenses and layers (Opf). Some rocks in the Partridge are rusty-weathering, black to dark gray, graphitic and sulfidic phyllite or very fine-grained schist. A distinctive dark gray quartzite (Opq) is exposed in Mink Brook east of Ruddsboro. Other rocks in the formation are dark gray, fine to medium-grained schist with biotite and/or garnet porphyroblasts across the foliation. In the very northwest corner of the quadrangle the schist is very coarse grained and contains clumps of biotite, possibly pseudomorphs after staurolite. Still other outcrops show lighter gray silty layers much like the Littleton. Chapman (1939) discussed the difficulty in distinguishing Partridge from Littleton, and pointed out that the Littleton schists are commonly more lustrous due to somewhat coarser or at least more abundant muscovite. The Littleton can be graphitic, but rarely contains pyrite. Strongly sheared breccia ("sb" on the map) is exposed at several places in the Partridge. In gross aspect the rock looks like a diamict, with a variety of clasts set in a black graphitic matrix. The clasts consist of vein quartz, felsite and schist intraclasts. Foliation wraps around the clasts and is deformed by F2 folds. This texture may have developed at the same time as the isoclinal folds, or independently.

Felsic volcanics of the Partridge are of two types: yellow-brown weathering, light gray fine-grained sulfidic felsite and rusty-weathering, gray to gray-green, medium-grained biotite granofels or gneiss. The latter is especially common from Etna south across Signal Hill, where a prospect pit is located in pyrite-rich rock cut by numerous quartz veins on the east slope of the hill. Lyons et al. (1997) show a distinctive coarse quartz-kyanite rock within the metavolcanics (Opvi), originally mapped out by James Page (1941) and likely representing a hydrothermally altered horizon. A prospect sometimes referred to as the "Reservoir Hill gold mine" (Meyers, 1940) lies just south of Route 4 east of Lebanon. Lyons (1955) mentions only galena and sphalerite at that prospect.

The Ammonoosuc Volcanics (Oa) are not widespread in the Enfield Quadrangle, being limited to several outcrops in the northwestern corner of the quadrangle and discontinuously along the west side of the Mascoma Dome. Rock types include dark green hornblende gneiss, intermediate black-and-white gneiss, and felsic gneisses much like those in the Partridge. No attempt was made to map out these different rock types separately.

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. It is dark to medium gray, medium-grained biotite tonalite, more strongly foliated along the northwestern margin, where foliation parallels S_1 in the adjacent Partridge. One sill of tonalite was found within the Partridge north of the Hanover Reservoirs, suggesting an intrusive relationship. East of Pinneo Hill a body of hornblende gneiss (Oo9B) may represent a gabbroic phase of the dome (Chapman, 1939) or it may represent a gabbro dike along the tonalite/Partridge contact.

The granite (Oo1b) of the Mascoma Dome is a brownish-gray, medium-grained, biotite granite that has a somewhat porphyritic texture. K-feldspars are whiter than those in the Lebanon granite.   The Shakers quarried this granite at two locations in the quadrangle and used it to construct foundations in Shaker Village. The reader is referred to Chapman (1939) for a thorough description of other rock types in the Mascoma Dome: quartz monzonite, granodiorite and quartz diorite.

Metadiabase dikes of unknown age (md) are fine- to medium-grained hornblende gneiss, commonly less well foliated than similar metavolcanics in the Ammonoosuc. Their extent is limited to one or a few outcrops in most cases, except for one larger area along Alden Road on the east slope of Signal Hill. The latter is cut by a fault, along which it is a fine-grained, strongly foliated chlorite schist.

Mesozoic mafic dikes, also limited in exposure, are brown-weathering black rocks.   Many are porphyritic, with feldspar phenocrysts up to a few centimeters across.

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