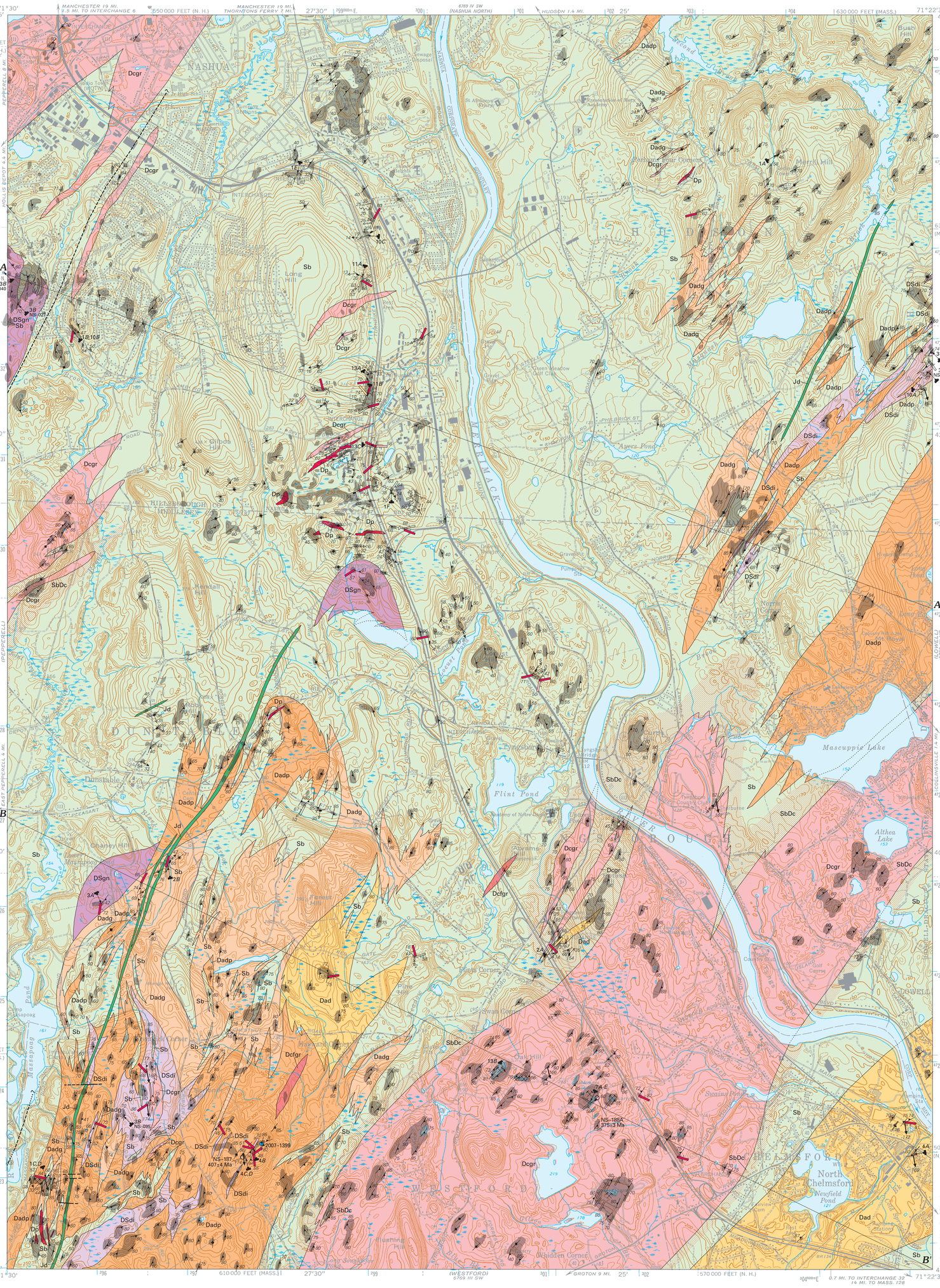
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
COMMONWEALTH OF MASSACHUSETTS, Massachusetts Geological Survey and the
STATE OF NEW HAMPSHIRE, New Hampshire Geological Survey

SCIENTIFIC INVESTIGATIONS MAP 3200
Explanatory pamphlet accompanies map



Base from U.S. Geological Survey, 1965
Photorevision as of 1979
Polyconic projection. 1927 North American Datum
10,000-foot grid ticks based on Massachusetts coordinate system, mainland zone, and New Hampshire coordinate system
1,000-meter Universal Transverse Mercator grid ticks, zone 19, shown in blue

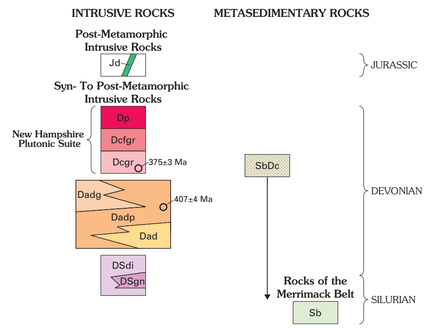
APPROXIMATE MEAN DECLINATION, 2012

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 10 FEET

MAP LOCATION

Geology mapped by G.J. Walsh, 2006, and compiled from unpublished mapping by R.H. Jahns, 1939–40 (Mass.) and 1951 (N.H.)
Geochronology by J.N. Aleinikoff, 2007–08
Digital compilation by G.J. Walsh

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

[Minerals listed in order of increasing abundance]

POST-METAMORPHIC INTRUSIVE ROCKS

Jd **Diabase dikes (Jurassic)**—Black to dark-gray and greenish-black, brown-weathering, fine- to medium-grained, subophitic to porphyritic diabase dikes. Dikes range in thickness from several meters (m) to approximately 20 m. Locally contains phenocrysts of pyroxene and plagioclase; may contain accessory serpentine, chlorite, and magnetite. Dikes locally contain amygdules filled with calcite or dolomite. Where carbonate minerals are relatively abundant, the dikes weather to an earthy black residuum. Good exposures occur in the town of Dunstable along Lowell Street and at the junction of Main Street and Forest Street about 1 kilometer (km) east of the village center. Dikes are probably part of the Eastern North American dolerite province of McHone and Sundeen (1995) and represent a continuation of the Higganum-Holden-Onway dike

SYN- TO POST-METAMORPHIC INTRUSIVE ROCKS

Rocks of the New Hampshire Plutonic Suite

Dp **Pegmatite (Permian(?) to Devonian)**—Light-gray to white, very coarse grained +/-muscovite-biotite-quartz-plagioclase-microcline pegmatite and coarse- grained granitic pegmatite. Contains accessory tourmaline, apatite, and zircon. Locally contains garnet (almandine). Dikes vary from folded and weakly foliated irregular masses to tabular, unfoliated bodies. Occurs as outcrop- and map-scale dikes that range from several centimeters thick to kilometer-scale intrusions. Larger mapped units generally represent sills that are roughly concordant to the dominant foliation. Red strike and dip symbols show the location and orientation of tabular outcrop-scale dikes that crosscut the foliation or sills that are generally concordant with the foliation. Good exposures crop out in the town of Nashua at roadcuts near Interchange 1 on U.S. Route 3 and at outcrops west of the interchange in an apartment complex south of Spit Brook Road

Chelmsford Granite (Late Devonian)

Dcgr Medium-grained two-mica granite—Light-gray to white, tan- to white-weathering, medium- to coarse-grained, foliated muscovite-biotite-quartz-plagioclase-microcline monzogranite to syenogranite and granitic pegmatite. Locally contains small (≤5 millimeter, mm) anhedral, zoned megacrysts of white feldspar, with myrmekitic rims. Feldspar megacrysts are interpreted as porphyroblasts of albite-oligoclase or microcline and orthoclase (Currier, 1937). Contains trace amounts of chlorite, opaques, apatite, titanite, epidote, clinozoisite, saussurite, and zircon. Locally contains trace amounts of garnet (almandine). Contains folded flow banding consisting of alternating dark-gray syenogranite and light-gray monzogranite layers, the latter of which contain relatively less biotite and muscovite. Dikes vary from folded, foliated irregular masses to tabular, weakly foliated bodies. Occurs as outcrop- and map-scale dikes that range from several centimeters thick to kilometer-scale intrusions. Light-red strike and dip symbols show the location and orientation of tabular outcrop-scale granite dikes or sills. A SHRIMP U-Pb zircon age of 375±3 Ma (sample NS–188A) indicates a Late Devonian age. Good exposures crop out in the town of Westford at the abandoned quarry at Oak Hill and the active quarries along Ledge Road and Groton Road

Dcfgr Fine-grained two-mica granite—Light-gray, tan- to white-weathering, fine-grained, weakly foliated muscovite-biotite-quartz-plagioclase-microcline monzogranite. Contains trace amounts of opaques, apatite, and clinozoisite. Exposed at two places in the town of Tyngsborough: on the southwestern side of Abrams Hill along U.S. Route 3 and 1 km southwest of Hayward Corner

SbDc Migmatitic Berwick Formation (Devonian and Silurian)—A zone of rock around the Chelmsford pluton, as much as 1 km wide, consisting of metasedimentary rocks of the Berwick Formation with abundant injected foliation-parallel granite and pegmatite sills. The unit consists of 50 to 75 percent granitic rock

Ayer Granodiorite (Early Devonian)

Devens-Long Pond facies

Dadg Biotite granodiorite—Medium-grained, light-gray to gray, generally equigranular, microcline-quartz-biotite-plagioclase granodiorite to quartz monzodiorite. Locally the rock is inequigranular where the rock contains trace amounts of deformed microcline megacrysts as much as 1 cm long; in these places the rock resembles the **Dadp** unit. Similar to the **Dad** unit but contains no hornblende. Plagioclase is altered to saussurite, K-feldspar is altered to sericite, and biotite is altered to chlorite. Contains as much as 3 percent muscovite. Contains trace amounts of chlorite, titanite, zircon, and apatite. A typical exposure crops out in the town of Tyngsborough at a roadcut on Patriot Drive (road is not on the base map), 0.4 km southeast of Scribner Hill

Dadp Porphyroblastic biotite granodiorite—Light-gray- to gray-weathering, black and white, inequigranular, medium- to coarse-grained, well-foliated biotite-microcline-quartz-plagioclase granodiorite to quartz monzodiorite with white feldspar megacrysts. Feldspar megacrysts are porphyroblasts of microcline and minor plagioclase (Gore, 1976). Discontinuous segregations of biotite define a gneissosity that wraps around and cuts through granular aggregates of quartz and feldspar. The aggregates are locally cored by anhedral to subhedral megacrysts of microcline that locally display Carlsbad twinning but lack well-formed crystal faces. Megacrysts of white to gray feldspar (mostly microcline) are as much as 3 cm long, but are more typically 1 to 2 cm long. Where strongly foliated, megacrysts are aligned in the plane of the gneissosity, and the rock is an augen gneiss. Contains 1 to 5 percent muscovite. Plagioclase is altered to saussurite, K-feldspar is altered to sericite, and biotite is altered to chlorite. Contains trace amounts of chlorite, opaques, clinozoisite, titanite, hematite, and apatite. A SHRIMP U-Pb zircon age of 407±4 Ma (sample NS–187) indicates an Early Devonian age. Good exposures occur in the town of Tyngsborough at roadcuts on Alpine Way (road is not on the base map), 0.8 km southeast of Scribner Hill

Dad Hornblende-biotite granite to tonalite—Medium-grained, locally coarse-grained, gray to black and white, largely equigranular hornblende-biotite granite to hornblende-biotite tonalite. Locally the rock is inequigranular where the rock contains trace amounts of deformed microcline megacrysts as much as 1.2 cm long; in these places the rock resembles the **Dadp** unit. The granite is a hornblende-quartz-plagioclase-biotite-microcline rock, and the tonalite is a hornblende-quartz-biotite-plagioclase rock with trace amounts of K-feldspar. Plagioclase is altered to saussurite, K-feldspar is altered to sericite, and biotite is altered to chlorite. Hornblende shows blue-green to light-brown pleochroism. A heterogeneous unit locally containing well-layered leucocratic layers alternating with darker more mafic layers containing more hornblende and biotite; layering is approximately 10 to 20 cm thick. Garnet as much as 1 cm in diameter occurs in a dike exposed on U.S. Route 3; the dike is shown by a yellow strike and dip symbol. Contains trace amounts of titanite, zircon, apatite, epidote, clinozoisite, and opaques. Unit is well exposed in the town of Tyngsborough along Appaloosa Circle (road is not on the base map), 0.75 km northwest of Hayward Corner, and in downtown Chelmsford in cuts along the Boston and Maine Railroad

Diorite–gabbro suite (Early Devonian to Late Silurian)

DSdi Fine-grained diorite-gabbro—Equigranular, fine- to medium-grained, weakly foliated, very dark green to black or gray and white, salt and pepper textured biotite-hornblende-plagioclase (oligoclase-andesine) metadiorite. Contains relict subhedral granular texture. Contains a few percent to trace amounts of quartz (as much as 6 percent), sulfides, magnetite, epidote, allanite, titanite, apatite, and hematite. Plagioclase is saussuritized. Similar to **DSgn** unit but fine grained. Good exposures crop out in a residential neighborhood north of Groton Road and west of Scribner Road. Good exposures also crop out in the town of Pelham, along the jeep trail section of Spaulding Road

DSgn Medium- to coarse-grained diorite-gabbro—Equigranular, medium- to coarse-grained, weakly foliated, very dark green to black or gray biotite-plagioclase-hornblende metadiorite to metagabbro. Contains relict subhedral granular texture. Contains a few percent to trace amounts of quartz (as much as 9 percent). Hornblende has largely pale-green to bluish-green and light-brown pleochroism, and actinolite is pale green. Uralite occurs locally as very fine grained alteration of relict pyroxene. Biotite occurs as reaction rims in and around amphibole. Biotite is locally chloritized. Contains trace amounts of opaques, titanite, epidote, clinozoiste, apatite, and serpentine. Opaques (sulfides-magnetite-ilmenite) occur as lamellae within biotite and amphibole, and as anhedral masses. Plagioclase is saussuritized. Similar to **DSdi** unit but coarser grained. Good exposures crop out in the town of Tyngsborough at Fox Ledge, in the town of Dunstable under the power lines west of Pond Street and southeast of Lower Massapoag Pond, and in Nashua, west of Conant Road

METASEDIMENTARY ROCKS OF THE MERRIMACK BELT

Berwick Formation (Late Silurian)

Sb Biotite-plagioclase-quartz granofels with minor schist and calc-silicate rocks—Purplish-gray, grayish-green, and light-gray to dark-gray, locally sulfidic and rusty-weathering, fine- to medium-grained biotite-plagioclase-quartz granofels, muscovite-biotite-quartz schist, and intercalated purplish-gray to pale-green, white-weathering, dark-green-spotted±garnet(grossular)±calcite±dolomite-epidote-clinozoisite-quartz±diopside-actinolite±hornblende-plagioclase calc-silicate gneiss or granofels. The biotite-plagioclase-quartz granofels contains trace to accessory amounts of epidote, diopside, actinolite, and hornblende and accessory muscovite, chlorite, magnetite, titanite, apatite, and garnet (grossular). The percentage of calc-silicate rock varies within the unit from approximately 5 percent, or less, up to about 30 percent. Calcite and dolomite are present in trace amounts. Calc-silicate rock locally occurs as distinct layers up to 30 cm thick or as disarticulated, boudinaged lenses and pods within the psammitic granofels. Centimeter-scale quartz veins and white-weathering calc-silicate and quartz segregations, both syn- and post-deformational, cut the granofels. Locally, finely laminated (2–3 mm thick) plagioclase-quartz layers alternate with thin planes of biotite and (or) calc-silicate minerals to produce a pinstripe texture within **Sb**. Locally, light-gray granofels displays thicker (0.5–1.5 cm thick) biotite-plagioclase-quartz laminations separated by 0.5-mm-thick, biotite-rich or calc-silicate partings. Unit is well exposed in the town of Nashua at large roadcuts along U.S. Route 3 at Interchanges 1 and 3

EXPLANATION OF MAP SYMBOLS

Contact—Approximately located; dotted where concealed by water

Fault—Dashed where inferred; queried where conjectural

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

PLANAR FEATURES

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

Strike and dip of bedding

41 Inclined, deformed

82 Inclined, overturned

74 **Strike and dip of inclined granodiorite-tonalite dike or sill (Dad) (Devonian)**

Strike and dip of pegmatite dike (Dp) (Devonian)

57 Inclined

Vertical

Strike and dip of granitic dike (Dcgr) (Devonian)

50 Inclined

Vertical

Strike and dip of quartz vein

64 Inclined

Vertical

Strike and dip of layer-parallel foliation in the Berwick Formation—S_1 or composite S_1/S_2

60 Inclined

Vertical

86 Inclined, deformed

Strike and dip of dominant foliation of undetermined age in the Berwick Formation—S_2 or composite S_1/S_2

70 Inclined

Vertical

Strike and dip of compositional banding interpreted as flow banding in the Chelmsford Granite—Locally deformed by F_2 folds

56 Inclined

Vertical

Strike and dip of S_2 penetrative cleavage or schistosity in the Berwick Formation or gneissosity in the foliated intrusive rocks

20 Inclined

Vertical

Strike and dip of axial surface of minor fold

Deformed early F_1 fold parallel to layer-parallel foliation (S_1)

25 Inclined

Vertical

F_2 fold parallel to dominant foliation (S_2) or penetrative cleavage (S_2)

20 Inclined

Vertical

F_3 fold parallel to nonpenetrative S_3 cleavage

8 Inclined

Vertical

25 Inclined shear band associated with S_3

LINEAR FEATURES

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

Bearing and plunge of lineations and fold axes

Lineations

33 L_2 intersection lineation between dominant foliation and compositional layering (S_0 or S_1)

25 L_3 intersection lineation between dominant foliation and younger S_3 cleavage

60 L_2 mineral lineation; grain lineation of aligned amphibole

Minor Folds

23 Deformed F_1 fold axis

35 F_2 fold axis

54 F_3 fold axis

OTHER FEATURES

Quarry

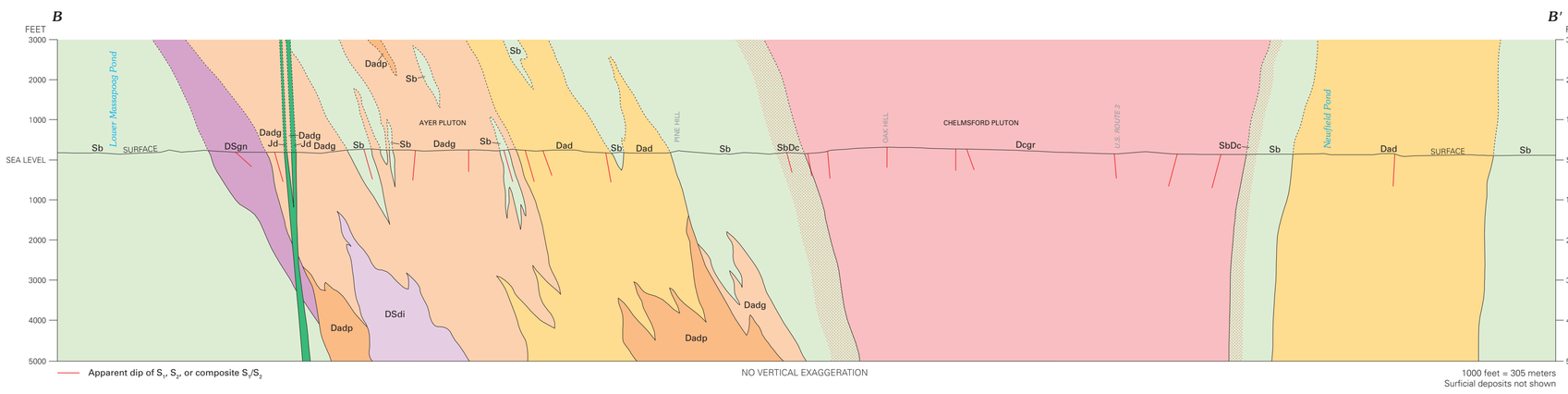
NS–187 407±4 Ma **Geochronology sample location showing SHRIMP U-Pb zircon age, in mega-annum (Ma)**

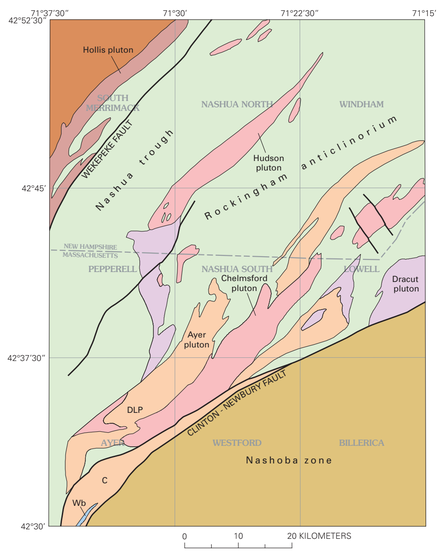
2007–1399 **Methane-yielding bedrock water well studied by Pierce and others (2007)**

1A **Site of photograph**—Tip of arrow at point of observation; arrow shows direction of view; number keyed to figure in explanatory pamphlet; for figure 3B, sample numbers are shown

166 **Trend of glacial striations or grooves**

Apparent dip of dominant foliation on cross sections





EXPLANATION

- Worcester basin (Pennsylvanian)
- Granite (Permian)
- Merrimack Belt
  - Chelmsford Granite (Devonian)
  - C DLP Ayer Granodiorite (Devonian)
  - Diorite to gabbro (Silurian-Devonian)
  - Metasedimentary rocks of the Merrimack trough (Silurian)
- Nashoba zone (lower Paleozoic)
- Massabesic Gneiss Complex (Neoproterozoic)
- Fault

Index to adjacent 7.5-minute quadrangles
South Merrimack (Sriramadas, 1966)
Nashua North (Sriramadas, 1966)
Windham (Walsh and Clark, 1999)
Pepperell (Robinson, 1978, 1981)
Lowell (Jahns and others, 1959)
Ayer (Kopera, 2006)
Westford (Kopera and others, 2008)
Billerica (Alvord, 1975)

Simplified tectonic map.—Modified after Lyons and others (1997) and Zen and others (1983). C, Clinton facies; DLP, Devens-Long Pond facies of the Ayer Granodiorite; Wb, Worcester basin.

BEDROCK GEOLOGIC MAP OF THE NASHUA SOUTH QUADRANGLE, HILLSBOROUGH COUNTY, NEW HAMPSHIRE AND MIDDLESEX COUNTY, MASSACHUSETTS

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