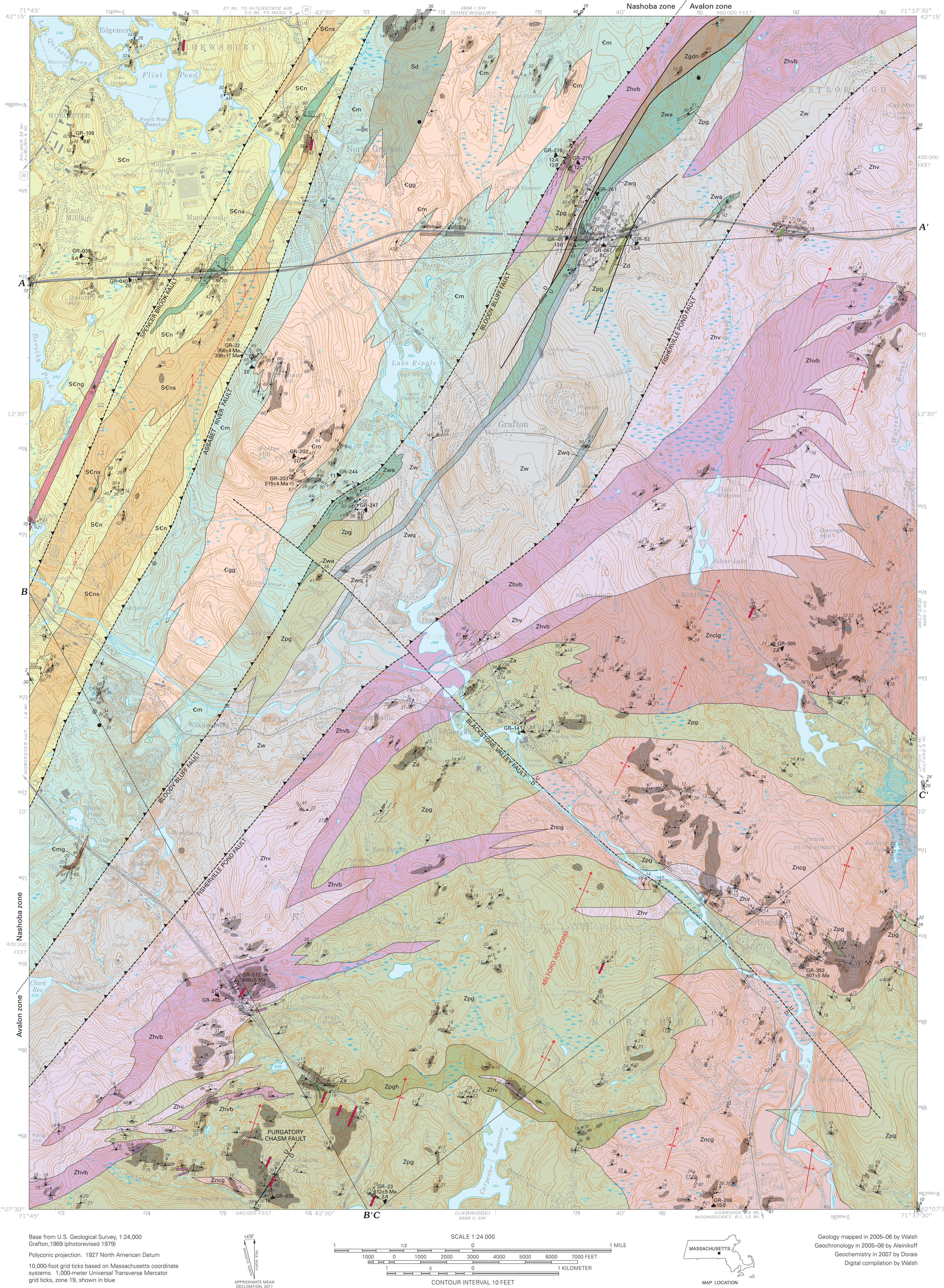
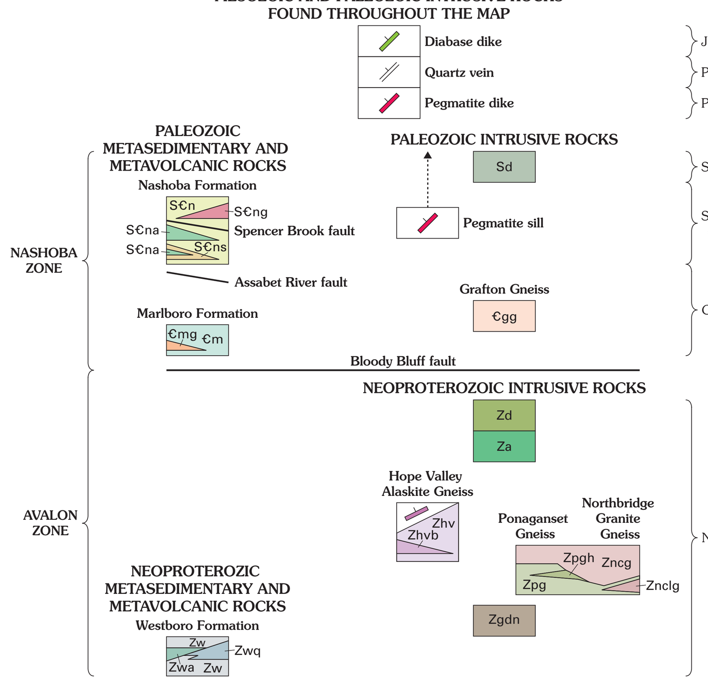
Prepared in cooperation with the
COMMONWEALTH OF MASSACHUSETTS
MASSACHUSETTS GEOLOGICAL SURVEY



CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

[Stations labeled on the photographs in the Description of Map Units correspond to locations shown in the GIS database. Major minerals listed in order of increasing abundance]

MESOZOIC INTRUSIVE ROCK

Diabase dike (Jurassic)—Black, fine-grained to aphanitic, diabase dike with plagioclase phenocrysts as much as 1 cm long and red-weathering biotite phenocrysts as much as 5 cm across. Occurs as a 2-m-thick dike in the Hope Valley Alaskite (Zhv) unit. Contains flattened amygdules elongated parallel to the contact of the dike. Observed at a single roadcut on the southern side of the Massachusetts Turnpike in Westborough. Location and orientation shown on the map with a green strike and dip symbol. The age of the dike is probably Jurassic on the basis of a correlation with the dated Medford diabase shown on the State map (Zen, 1983), which yielded a K-Ar biotite age of 194±6 Ma (Zartman and Marvin, 1991; Wones and Goldsmith, 1991)

GR–057

ROCKS OF THE NASHOBA ZONE

Paleozoic Intrusive Rocks

Quartz vein (Permian?)—Quartz veins locally contain variable amounts of graphite, muscovite, magnetite, epidote, hematite, biotite, chlorite, carbonate minerals, and K-feldspar. Milky to smoky quartz veins are generally tabular and locally irregularly shaped, show sharp boundaries with the host rock, and locally contain blocky to elongate quartz crystals with euhedral terminations in vugs as much as several centimeters across along the median line. Strike and dips symbols show the location and orientation of 55 veins. Measured veins are as much as 0.6 m thick, dip steeply, and show variable strikes

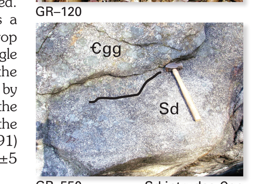
GR–061

Pegmatite dike (Permian) or sill (Ordovician to Mississippian)—Pink and white, white-weathering, coarse-grained, unfoliated, steeply dipping, tabular, muscovite granitic pegmatite dikes in the Avalon zone and foliated to weakly foliated syntectonic granitic pegmatite sills in the Nashoba zone. Red strike and dip symbols show the location and orientation of 10 pegmatite dikes in the Avalon zone and 2 pegmatite sills in the Nashoba zone. Pegmatites are as much as 3 m thick. Tabular dikes postdate the foliation and show a consistent strike to the northeast with a principal trend of 23°. Eight out of ten of the Avalon zone dikes were found in the southwestern part of the map. The two pegmatite sills in the Nashoba Formation occur in the plane of the foliation. Other smaller syntectonic pegmatite sills occur through the Nashoba Formation but were not mapped separately. A Permian age for the pegmatite dikes is inferred from regional correlations with similar dikes in Connecticut and Rhode Island (Zartman and Hermes, 1987; Wintsch and Aleinikoff, 1987; Zartman and others, 1988; Walsh and others, 2007). An Ordovician to Mississippian age range exists for the granite pegmatites in the Nashoba Formation (Zartman and Naylor, 1984; Hepburn and others, 1995, 1998; Acaster and Bickford, 1999)

GR–023

Sd **Metadiorite (Silurian?)**—Dark-gray, equigranular, fine- to coarse-grained, weakly to moderately foliated, biotite-hornblende diorite gneiss. Composition varies from quartz-biotite-hornblende-plagioclase to hornblende-quartz-biotite-plagioclase. The rock contains 7 to 13 percent quartz, 3 to 38 percent hornblende, 15 to 22 percent biotite, and 38 to 49 percent plagioclase. Accessory minerals include K-feldspar, epidote-clinozoisite, chlorite, apatite, sphene, and magnetite. Outcrops show slabby weathering where the foliation is developed or blocky weathering where the foliation is poorly developed. Contains layers and xenoliths of Marlboro Formation. Occurs as a single map unit along the northern border of the map. An outcrop located along the power line in the adjacent Shrewsbury quadrangle (277885 E., 4681175 N.), approximately 300 m north of the quadrangle boundary, shows that the Marlboro Formation is intruded by the Grafton Gneiss, and the Grafton Gneiss is, in turn, intruded by the metadiorite. May be correlative along strike to the northeast with the Sharpners Pond Diorite (Zen, 1983; Wones and Goldsmith, 1991) dated as Silurian based on a conventional U-Pb zircon age of 430±5 Ma (Zartman and Naylor, 1984; Wones and Goldsmith, 1991)

GR–120



GR–550 Sd intrudes €gg

Paleozoic Metasedimentary and Metavolcanic Rocks

Nashoba Formation (Cambrian to Silurian)

S€n Gray schist—Gray, medium- to coarse-grained, well-foliated, K-feldspar-sillimanite-biotite-plagioclase-quartz-muscovite schist to gneiss to muscovite-K-feldspar-plagioclase-quartz-biotite schist. Contains accessory chlorite, monazite, epidote, clinozoisite, apatite, hematite, and opaques including magnetite. Locally contains garnet. Sericite and larger flakes of muscovite occur around K-feldspar. The dominant foliation is locally mylonitic and characterized by extensive quartz ribbons, sericite-biotite-sillimanite±magnetite layers, and quartz-feldspar leucosomes. Sillimanite-K-feldspar assemblages show retrogression as sericite alteration of K-feldspar and minor alteration of sillimanite in sillimanite-magnetite bands surrounded by sericite. K-feldspar occurs as pre- to syntectonic porphyroblasts, as much as several cm across, that show retrogression to sericite. Unit is exposed in the northwestern part of the map, above the Assabet River fault. Contacts with the amphibolite unit (S€na) are sharp, but gradational with the sulfidic schist (S€ns) by intercalation over a few meters. The best exposures occur along the Massachusetts Turnpike. The age of the Nashoba Formation is interpreted as Cambrian to Silurian (Hepburn and others, 1995, 2004; Wintsch and others, 2007; Loan and others, 2011)

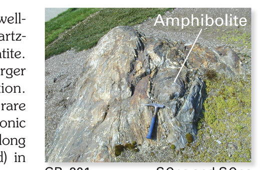
GR–040

S€na Amphibolite—Dark-green to black, rusty-weathering, well-foliated, fine- to medium-grained, plagioclase-hornblende amphibolite gneiss and lesser banded dark-gray and light-gray well-layered calc-silicate gneiss. Amphibolite contains accessory sphene and quartz, and trace pyrite, chalcopyrite, magnetite, epidote, and apatite. Calc-silicate gneiss is gray to light-gray, well-foliated, locally sulfidic, fine- to medium-grained, sphene-biotite-chlorite-actinolite-quartz-hornblende-plagioclase rock. The best exposures occur in roadcuts along the Massachusetts Turnpike

S€ng Garnetiferous schist—Dark-gray, medium- to coarse-grained, rusty-weathering, moderately foliated, kyanite-garnet-quartz-sillimanite-biotite schist to granofels. Contains trace plagioclase, K-feldspar, magnetite, monazite, sericite, and zircon. Biotite defines the foliation and occurs as post-tectonic porphyroblasts across the foliation. Sillimanite occurs as fibrolite, needles, and prisms in the plane of the foliation, and as porphyroblastic prisms and needles across the foliation. Microscopic kyanite (<1 mm) and megascopic garnet (<1 cm) occur as post-tectonic porphyroblasts. Garnet contains fibrolite inclusion trails that define the overgrown dominant foliation, especially along the rims of the porphyroblasts. The foliation is defined largely by biotite, quartz, and sillimanite. Contacts with the surrounding map unit are not exposed. Exposed at two outcrops in Millbury, west of the Assabet River fault

GR–190

S€ns Sulfidic schist—Dark-gray, medium-grained, rusty-weathering, well-foliated, sulfidic, K-feldspar-plagioclase-sillimanite-biotite-quartz-muscovite schist. Contains accessory graphite, sulfides, and hematite. Sericite and larger flakes of muscovite occur around K-feldspar. Larger flakes of muscovite occur both along and across the foliation. Sillimanite and K-feldspar show retrogression to sericite. Contains rare amphibolite mapped as S€na. K-feldspar occurs as pre- to syntectonic porphyroblasts as much as 1 cm across. Typical exposures occur along Rose Lane, west of Lordvale Avenue (actually Brigham Hill Road) in western Grafton

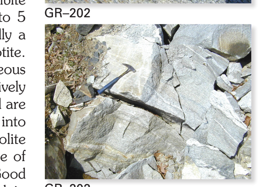


GR–201 S€ns and S€na

Lower Paleozoic Intrusive Rocks

€gg **Grafton Gneiss (Cambrian)**—Biotite granite gneiss. Light-gray to light-pink, medium-grained, well-foliated, chlorite-biotite-quartz-plagioclase-K-feldspar granite gneiss. Contains secondary accessory sericite, epidote-clinozoisite, sphene, apatite, and magnetite. Relict allotriomorphic texture of intergrown quartz and 1 to 5 mm long feldspar grains shows grain-size reduction along crystal boundaries. The foliation is defined by recrystallized quartz and feldspar and aligned biotite. Plagioclase shows relict polysynthetic twinning, local myrmikitic texture, and significant saussuritization and sericitization in a microcrystalline sieve texture. K-feldspar shows relict braided albite lamellae and mesoperthitic texture, and sericitization. Biotite, 2 to 5 percent of the rock, shows static retrogression to chlorite. Locally a dark- to medium-gray variety of gneiss contains 5 to 10 percent biotite. The interior of the map unit contains a somewhat heterogeneous distribution of biotite-rich and K-feldspar-rich layers but is relatively more homogeneous than the margins, which appear migmatitic and are characterized by abundant foliation-parallel granitic layers injected into the Marlboro Formation. Locally contains xenoliths of amphibolite derived from the Marlboro Formation. A SHRIMP U-Pb zircon age of 515±4 Ma (sample GR–203) indicates a Cambrian age. Good exposures occur in Grafton on Brigham Hill, on Potter Hill, and in roadcuts along the Massachusetts Turnpike

GR–202

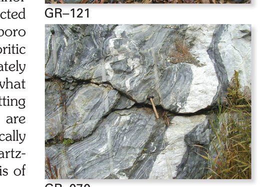

GR–202

Lower Paleozoic Metasedimentary and Metavolcanic Rocks

Marlboro Formation (Cambrian)

€m Amphibolite gneiss and layered gneiss—Dark-green to black, rusty-weathering, well-foliated, fine- to medium-grained, plagioclase-hornblende amphibolite gneiss containing banded dark-gray and light-gray well-layered felsic gneiss and calc-silicate gneiss. Amphibolite gneiss contains accessory sphene and quartz and trace pyrite, chalcopyrite, magnetite, epidote, and apatite. Layered gneiss consists of alternating bands of dark amphibolite gneiss and biotite amphibolite gneiss with lighter biotite granite gneiss, foliated pegmatite, and minor dioritic gneiss and calc-silicate gneiss. Banded gneiss with injected granitic material is migmatitic in the eastern part of the Marlboro Formation and along the contact with the Grafton Gneiss. Dioritic gneiss is dark-gray, medium- to coarse-grained, weakly to moderately foliated quartz-biotite-hornblende-plagioclase gneiss that somewhat resembles deformed Silurian(?) diorite (Sd), but unequivocal crosscutting relations were not observed, and it is unclear if the dioritic layers are intrusive. Calc-silicate gneiss is gray to light-gray, well-foliated, locally sulfidic, fine- to medium-grained biotite-chlorite-actinolite-quartz-hornblende-plagioclase rock. Age is Cambrian or older on the basis of the age of the Grafton Gneiss, which intrudes it

GR–121


GR–070

€mg Granofels—Gray, fine- to medium-grained, massive and blocky weathering biotite-quartz-feldspar granofels. May occur as a banded gneiss with as much as 50 percent of light-colored granitic and pegmatitic leucocratic layers. Contains thin layers of amphibolite that resemble rocks elsewhere in the Marlboro Formation. Unit is approximately 3 to 5 m thick, so its size is exaggerated on the map. Individual granofels layers, interpreted as beds, are 10 to 20 cm thick. Granofels consists of approximately 40 to 50 percent feldspar, most of which is plagioclase, 40 to 45 percent quartz, 3 to 10 percent biotite, 1 to 3 percent epidote-clinozoisite, and trace to 1 percent magnetite, sphene, hematite, apatite, and tourmaline. Microscopically the rock contains an inequigranular granofelsic texture with weakly developed foliation defined by aligned biotite. Subangular to subrounded clasts, interpreted as detrital grains, of quartz and feldspar range in size from approximately 1.0 to 2.0 mm and occur in a matrix of quartz and feldspar that ranges in size from approximately 0.08 to 0.1 mm. Feldspar grains consist mostly of recrystallized, partly zoned plagioclase with relict polysynthetic twins and lesser microcline K-feldspar indicated by cross-hatched twinning. Contains rare detrital grains of quartz-feldspar rock fragments with hypidiomorphic texture, suggesting a possible granitoid source. The rock is interpreted as a metawacke. Contacts with the enclosing map unit are not well exposed, but adjacent rocks include banded amphibolite gneiss of the Marlboro Formation. Occurs as a single map unit exposed on the hilltop between Marble Avenue and Sibley Road, west of State Route 146, in the southeastern part of the Marlboro Formation

GR–098

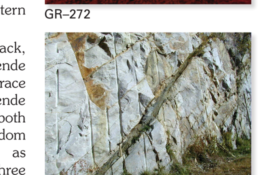
ROCKS OF THE AVALON ZONE

Intrusive Rocks

Zd **Metadiorite (Neoproterozoic)**—Dark-gray to grayish-greenish-black, medium- to coarse-grained, weakly foliated quartz-plagioclase-hornblende metadiorite to amphibolite. The rock contains approximately 3 percent K-feldspar, 5 percent epidote, 10 percent quartz, 35 percent plagioclase, 40 percent hornblende, and minor to trace amounts of biotite, apatite, and opaque minerals. Observed at one location between Estabrook Avenue and the Massachusetts Turnpike where it is in contact with megacrystic biotite granite gneiss (Zpg); a thin zone of unmapped gray biotite granodioritic gneiss was observed between the diorite and granite gneiss along the eastern contact of the metadiorite. Interpreted as a dike or sill

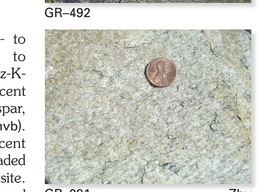
GR–272

Za **Amphibolite gneiss (Neoproterozoic)**—Dark-green to black, well-foliated, fine- to medium-grained, plagioclase-hornblende amphibolite gneiss. Contains accessory sphene and quartz, and trace chlorite, pyrite, chalcopyrite, epidote, and apatite. Hornblende porphyroblasts are as much as 4 cm long. Hornblende forms both syntectonic aligned mineral grain lineations and post-tectonic random crystals oriented in the plane of the foliation. Occurs as foliation-parallel layers as much as 2 m thick. Observed at three locations and are shown as small units within the granitic gneisses northwest of Farnumsville, southwest of Fisherville, and along State Route 146 in Sutton. Contacts with the adjacent rocks are sharp. May be deformed dikes or sills, or restitic material


GR–063

GR–492

Zhv, Zhvb **Hope Valley Alaskite Gneiss (Neoproterozoic)**—Light-pink, tan- to rusty-weathering or light-gray- to white-weathering, fine- to medium-grained, equigranular, well-foliated, plagioclase-quartz-K-feldspar alkali granite gneiss. Contains approximately 25 percent plagioclase, 30 to 40 percent quartz, and 30 to 40 percent K-feldspar, and trace to no biotite (Zhv) and trace to 3 percent biotite (Zhvb). Contains less than 2 percent muscovite and less than 1 percent magnetite. Zhvb contains up to 3 percent chlorite from retrograded biotite. Contains accessory garnet, apatite, and epidote-clinozoisite. Recrystallized quartz and feldspar define a faintly visible mineral aggregate lineation. Contacts are sharp where observed. The alaskite intrudes the Ponaganset Gneiss and the Northbridge Granite Gneiss. Four locations show strike and dip symbols for sill-like bodies that are subparallel to the foliation and as much as 3 m thick. Other thinner aplitic alaskite dikes or sills occur within the Ponaganset Gneiss and the Northbridge Granite Gneiss, but they were not mapped separately. A SHRIMP U-Pb zircon age of 606±5 Ma (Zhvb, sample GR–512) indicates a Neoproterozoic age. Good exposures occur along State Route 146, along the Massachusetts Turnpike, and on the cliffs east of Rockdale Pond just north of downtown Northbridge


GR–091 Zhv

GR–466 Zhvb

Northbridge Granite Gneiss (Neoproterozoic)

Zncg Coarse-grained biotite granite gneiss—Light-gray to light-pink, very light gray to tan-weathering, coarse-grained and, locally, medium- to coarse-grained, equigranular, weakly to moderately well-foliated biotite-plagioclase-quartz-K-feldspar granite gneiss. Contains approximately 25 percent plagioclase, 35 percent quartz, 35 percent K-feldspar, and 3 percent biotite. Contains less than 1 percent muscovite and magnetite. Contains accessory chlorite, apatite, allanite, zircon, and sphene. Distinguished from the Ponaganset Gneiss by the equigranularity due to the lack of alkali feldspar megacrysts. Recrystallized quartz and feldspar, and aligned biotite flakes define the foliation and mineral aggregate lineations. A SHRIMP U-Pb zircon age of 607±5 Ma (Zncg, sample GR–352) indicates a Neoproterozoic age. Good exposures occur in Northbridge along School Street and at Shining Rock in Northbridge, and in Grafton along Milford Road, especially at the junction with Bay Farm Lane (street name not on base map)

GR–305

Znclg Lineated coarse-grained biotite granite gneiss—Light-gray to light-pink, very light gray to tan-weathering, coarse-grained and, locally, medium- to coarse-grained, equigranular, weakly to moderately well-foliated and well-lineated biotite-plagioclase-quartz-K-feldspar granite gneiss. Recrystallized quartz and feldspar, and aligned biotite flakes define the foliation. Similar to Zncg, except for a distinctive mineral lineation on foliation surfaces defined by elongate spots and streaks of aggregated flakes of biotite as much as 2 cm wide and 7 cm long that locally form distinct mineral lineations, along with recrystallized quartz and feldspar. Good exposures occur under the power lines near Keith Hill Road, Salisbury Street, and at the southern end of George Hill in Grafton and Upton

GR–366

Ponaganset Gneiss (Neoproterozoic)

Zpg Megacrystic biotite granite gneiss—Light-gray to light-pinkish-gray, very light gray weathering, medium- to coarse-grained, inequigranular, moderately to well-foliated biotite-K-feldspar-plagioclase-quartz granite gneiss with distinct white-weathering, light-pink perthitic microcline megacrysts or augen. Megacrysts are anhedral to subhedral semi-rectangular grains as much as 5 cm long, and their presence is a diagnostic mapping tool. Rock is similar in composition, age, and chemistry to the Northbridge Granite Gneiss (Zncg), and the contact with it is based on the presence of megacrysts in Zpg. Contains approximately 33 percent quartz, 33 percent plagioclase, 25 percent K-feldspar, 5 percent biotite, and minor to trace amounts of magnetite, muscovite, chlorite, epidote, and apatite. Recrystallized quartz and feldspar and aligned biotite flakes define the foliation and mineral aggregate lineations. A SHRIMP U-Pb zircon age of 612±5 Ma (sample GR–23) indicates a Neoproterozoic age. Good exposures occur at Purgatory Chasm and along State Route 146 in Sutton

GR–354

Zpgh Megacrystic biotite-hornblende granite gneiss—Medium-gray to pinkish-gray, light-gray-weathering, medium- to coarse-grained, inequigranular, well-foliated biotite-hornblende-plagioclase-quartz-K-feldspar granite gneiss with distinct white-weathering, light-pink perthitic microcline megacrysts or augen. Megacrysts are anhedral to subhedral semi-rectangular grains as much as 5 cm long, and their presence along with hornblende are diagnostic features for mapping this rock. Contains approximately 30 percent plagioclase, 30 percent quartz, 25 percent K-feldspar, 10 percent hornblende, 2 percent biotite, and minor to trace amounts of epidote, magnetite, titanite, clinozoisite, chlorite, and apatite. Recrystallized quartz and feldspar, and aligned biotite flakes define the foliation, and mineral aggregate lineations. Hornblende forms both aligned syntectonic mineral grain lineations, and post-tectonic random crystals oriented in the plane of the foliation. The unit is exposed along State Route 146 in Sutton, on unnamed hills north of Carpenter Reservoir, and in Northbridge Center

GR–014

Zgdn **Granodiorite gneiss at Nourse Farm (Neoproterozoic)**— Medium-gray, weakly to strongly foliated, medium- to coarse-grained, equigranular K-feldspar-biotite-epidote-quartz-plagioclase granodiorite gneiss with distinctive green spots, laminations, and pods of epidote as much as 40 cm across. Non-mylonitic samples contain approximately 30 to 50 percent plagioclase, 10 to 30 percent quartz, 10 to 15 percent epidote, 5 to 20 percent biotite, and 1 to 8 percent K-feldspar. Contains accessory muscovite, chlorite, clinozoisite, and sphene, and trace amounts of magnetite, apatite, zoisite, and hematite. Plagioclase shows greater saussuritization in the cores indicating chemical zoning from calcic cores to sodic rims. Secondary muscovite defines the foliation and is a replacement product of K-feldspar and plagioclase alteration. Named informally for exposures at the Nourse Farm located along the Grafton-Shrewsbury quadrangle border (Markwort, 2007). Unit extends into the Marlborough quadrangle to the north (Kopera and others, 2006). Varies from medium to coarse grained where weakly foliated, to mylonitic and fine to medium grained at southernmost exposures on the Massachusetts Turnpike. Unit is exposed on the Massachusetts Turnpike, on the western side of the pond at the Nourse Farm off Jasper Street, and on the unnamed hill between Glenn Street and Jasper Street

GR–548

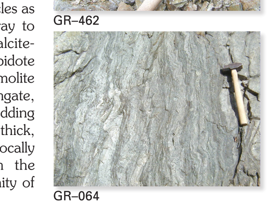
GR–299

Metasedimentary and Metavolcanic Rocks

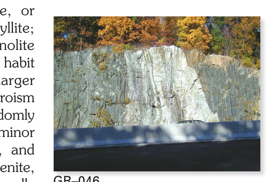
Westboro Formation (Neoproterozoic)

Zw Interlayered schist, phyllite, quartzite, amphibolite, and greenstone—A heterogeneous unit, variably interlayered or bedded, consisting of the following rocks: Silvery-gray to pale-green or gray, locally rusty-weathering quartz-rich chlorite-muscovite-quartz phyllite and schist and calc-silicate phyllite and schist; pale-green to very light gray or white, tan- to rusty-weathering quartzite; dark-gray to pale-green calc-silicate granofels; dark-green to black amphibolite and greenstone; green chlorite-rich phyllite or schist; dark-green to black chlorite-biotite schist. Locally contains randomly oriented post-tectonic hornblende fascicles as much as 5 cm long. Calc-silicate phyllite to schist is a light-gray to gray-green, rusty- or tan-weathering, fine-grained, chlorite-calcite-biotite-plagioclase-quartz-tremolite rock that contains accessory epidote and sphene and trace apatite, hematite, pyrite, and zircon. Tremolite occurs as colorless to very pale green, very fine grained, elongate, parallel prisms aligned parallel to the foliation. Rarely observed bedding is generally less than 30 cm thick, but locally as much a 1 m thick, especially in quartzite. Mafic rocks (Zwa) and quartzite (Zwq) locally mapped separately. Unit is poorly exposed, especially in the southwestern part of the map. Best exposures occur in the vicinity of the Massachusetts Turnpike and Old Westboro Road

GR–462


GR–064

Zwa Interlayered amphibolite, greenstone, quartzite, and calc-silicate rock—A heterogeneous unit consisting of the following mafic metavolcanic, metavolcaniclastic, or calcareous metasedimentary rocks: Dark-grayish-green to black or green, fine-grained magnetite-actinolite-quartz-epidote-hornblende-plagioclase-chlorite amphibolite, greenstone, or schist; calcite-quartz-epidote-biotite plagioclase schist to phyllite; sphene-epidote-clinozoisite-biotite schist; and quartzite. Actinolite shows pale-yellow to pale-green pleochroism and fine acicular habit generally parallel to the foliation. Hornblende occurs as larger post-tectonic porphyroblasts with green to bluish-green pleochroism and forms stubby to elongate fascicles as much as 5 cm long randomly oriented across the foliation. Rocks contain variable amounts of minor or accessory chlorite, muscovite, quartz, plagioclase, sphene, and apatite where they are not major minerals. Contains trace ilmenite, calcite, dolomite, and hematite. Epidote-clinozoisite and apatite locally occur as abundant post-tectonic porphyroblasts as much as 0.25 mm across. Locally contains secondary dolomite in vugs as much as several centimeters across. Best exposed along the Massachusetts Turnpike and along Brendan Drive (name not on base map) south of Millbury Street in Grafton


GR–046

Zwq Quartzite—Pale-green to very light gray or white, gray- or tan- to rusty-weathering massive quartzite, laminated quartzite, muscovite-quartz schist, and minor calc-silicate rock. Contacts are sharp or gradational by intercalation. Best exposed at a roadcut on the northern side of the Massachusetts Turnpike, just west of the Old Westboro Road overpass

GR–274

EXPLANATION OF MAP SYMBOLS

Contact—Approximately located; dotted where concealed by water

Outcrops—Areas of exposed bedrock or closely spaced contiguous bedrock exposures examined in this study; dashed outcrops consist ofclosely spaced loose blocks where rock type was identified, but nostructural measurements were made

FAULTS

Inferred mylonitic thrust fault—Parallel to metamorphic foliation; sawteeth on upper plate show dip direction; locally reactivated as a normal brittle fault along the Bloody Bluff fault. Dotted where concealed

Mylonitic fault in the Burlington mylonite zone—May be parallel to, or postdate, metamorphic foliation; relative motion indicated where known; U, upthrown side; D, downthrown side

Brittle fault—Dashed where inferred; U, upthrown side; D, downthrown side

FOLDS

[Showing trace of axial surface, direction of dip of limbs, and direction of plunge where known or inferred]

Inferred trace of F_1 fold in the Nashoba Formation (Salinic orogeny?)—Box shows dip direction of axial surface; arrow shows plunge direction

Upright folds of the Milford antiform in the Avalon zone (Alleghanian orogeny)—Arrow shows plunge direction

Antiform

Synform

PLANAR FEATURES

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

68 **Strike and dip of diabase dike (Jurassic)**

Strike and dip of pegmatite dike (Permian)

42 Inclined

Vertical

Strike and dip of quartz vein (Permian)

64 Inclined

Vertical

19 **Strike and dip of alaskite sill (Neoproterozoic)**

45 **Strike and dip of deformed relict foliation (S_1)**—Parallel to bedding in the Westboro Formation or compositional layering in the Nashoba and Marlboro Formations

56 **Strike and dip of compositional banding in intrusive rocks**—Observed at the contact between Zncg and Zpg in the Avalon zone, where it predates the dominant foliation; also observed in intrusive rocks within the Marlboro Formation

Strike and dip of dominant foliation (S_2)—In the Avalon zone, a schistosity in the Westboro Formation and a gneissosity in the intrusive rocks; in the Nashoba zone, a schistosity to gneissosity in the metasedimentary and metavolcanic rocks and a gneissosity in the intrusive rocks

20 Inclined

Vertical

16 **Strike and dip of mylonitic or phyllonitic S_2 foliation**—Observed especially along the Bloody Bluff fault and in the Burlington mylonite zone

Strike and dip of axial surface of F_2 minor fold parallel to S_2 foliation—Tight to isoclinal, locally rootless folds in the Avalon zone, especially in the Westboro Formation and rootless isoclinal folds in the Nashoba Formation

25 Inclined

Vertical

Strike and dip of axial surface of F_3 minor fold—Open to tight, late fold observed in the Westboro, Marlboro, and Nashoba Formations; probably Alleghanian and correlative across structural domains

8 Inclined

Vertical

Strike and dip of F_3 minor kink bands—Late kink bands locally associated with extensional veins or pegmatites; probably Alleghanian and correlative across structural domains

80 Inclined

Vertical

LINEAR FEATURES

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

28 **Bearing and plunge of L_2 intersection lineation**—Intersection between the dominant foliation (S_2) and an older foliation that is parallel to compositional layering (S_1) in the Westboro Formation; and intersection lineation between the dominant foliation (S_2) and an older foliation that is parallel to compositional layering (S_1) in the Nashoba Formation

60 **Bearing and plunge of L_2 mineral lineation**—Aggregate lineation or grain lineation associated with the dominant foliation (S_2); consists of quartz, biotite, amphibole, or K-feldspar in the Avalon zone and quartz, biotite, amphibole, sillimanite, or K-feldspar in the Nashoba zone

60 **Bearing and plunge of L_3 mineral lineation**—Grain lineation of aligned hornblende that postdates the dominant lineation in the Avalon zone; observed in map units Zpgh and Za

25 **Bearing and plunge of F_2 minor fold axis**—Fold axis of tight, isoclinal, or rootless fold associated with the dominant foliation (S_2)

54 **Bearing and plunge of F_3 minor fold axis**—Fold axis of late open to tight fold; observed primarily in the Westboro Formation

OTHER FEATURES

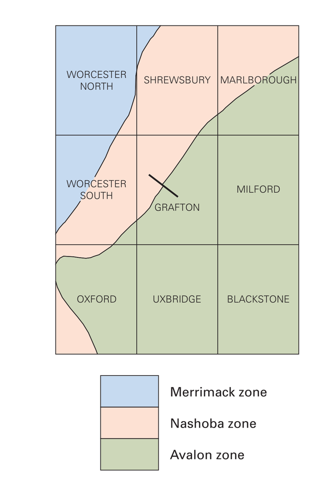
GR–352 607±5 Ma **Geochronology sample location showing age**

Quarry

Well—Cuttings used to identify rock type

Spring

GR–202 2D **Site of photograph**—Tip of arrow at point of observation; number keyed to station in GIS database and figure(s) in explanatory pamphlet

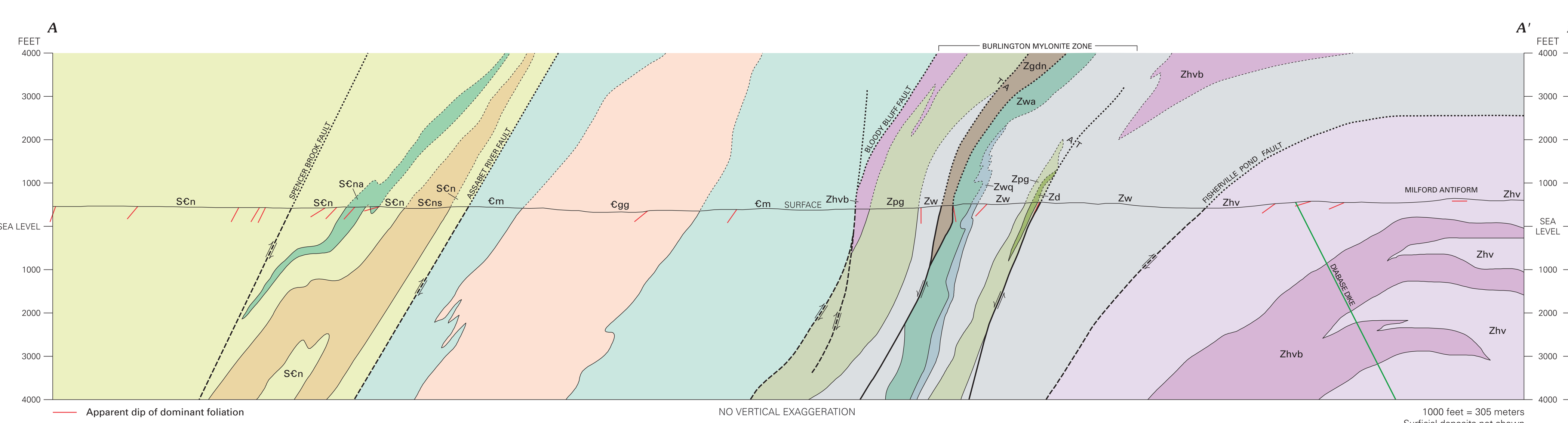


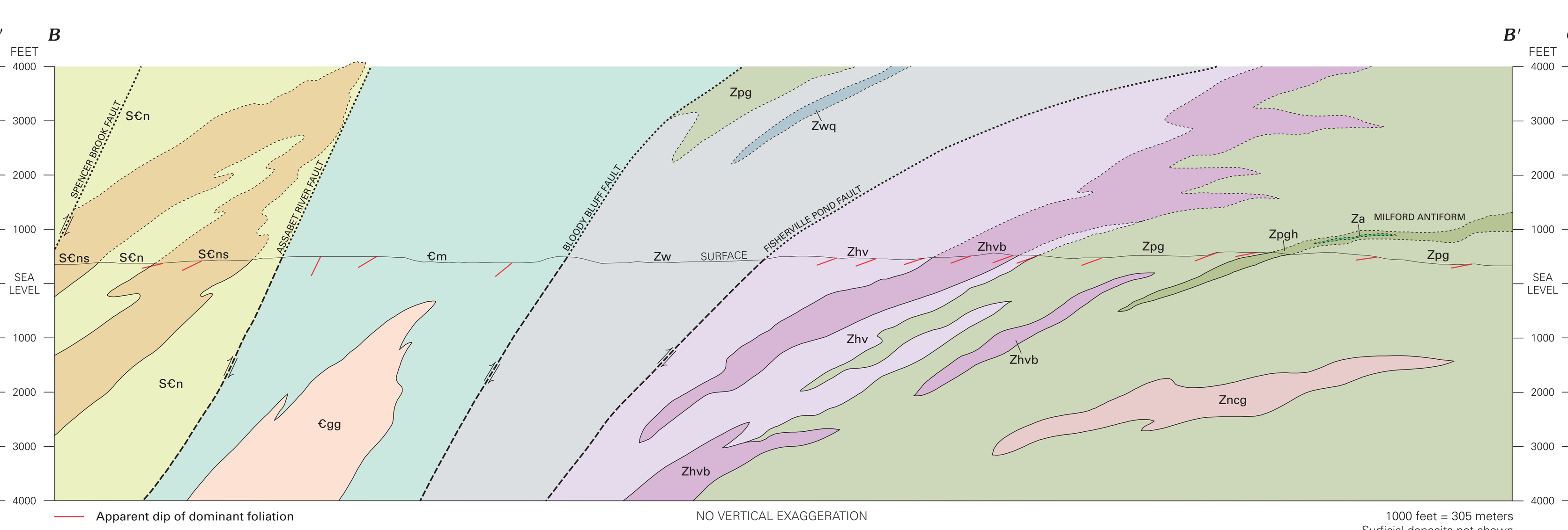
7.5-MINUTE QUADRANGLE LOCATIONS

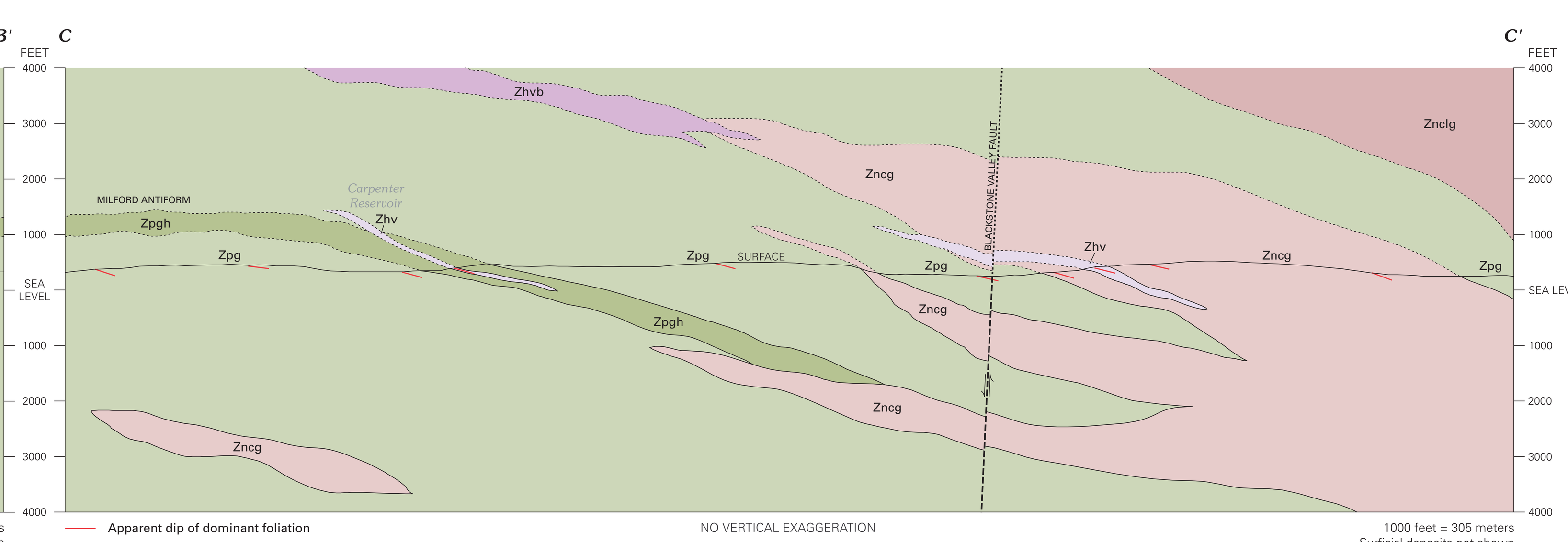
Summary of U-Pb zircon ages from the Grafton quadrangle

Sample no.	Map unit and rock type	Age[1] (Ma)
GR–32	Marlboro Formation—Amphibolite gneiss (€m)	
	Metamorphic zircon rims	339±17
	Metamorphic zircon cores	356±4
GR–203	Grafton Gneiss—Biotite granite gneiss (€gg)	515±4
GR–512	Hope Valley Alaskite Gneiss (Zhvb)	606±5
GR–352	Northbridge Granite Gneiss—Biotite granite gneiss (Zncg)	607±5
GR–23	Ponaganset Gneiss—Megacrystic biotite granite gneiss (Zpg)	612±5

[1]Ages are from igneous cores, except for sample no. GR–32.
Ages from the Grafton Gneiss and Marlboro Formation of the Nashoba zone obtained by sensitive high-resolution ion microprobe (SHRIMP) at Stanford University, Palo Alto, Calif. Ages from rocks in the Avalon zone obtained by SHRIMP II, Research School of Earth Sciences, Australian National University, Canberra, Australia.







BEDROCK GEOLOGIC MAP OF THE GRAFTON QUADRANGLE, WORCESTER COUNTY, MASSACHUSETTS

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