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OMSG Geologic Map No. 06-01
Bedrock Geology
Marlborough Quadrangle
2006
Map last modified 3/13/08

Bedrock Geologic Map of the Marlborough Quadrangle, Massachusetts

by: Joseph P. Kopera[1], J. Christopher Hepburn[2], and Richard G. DiNitto[3]

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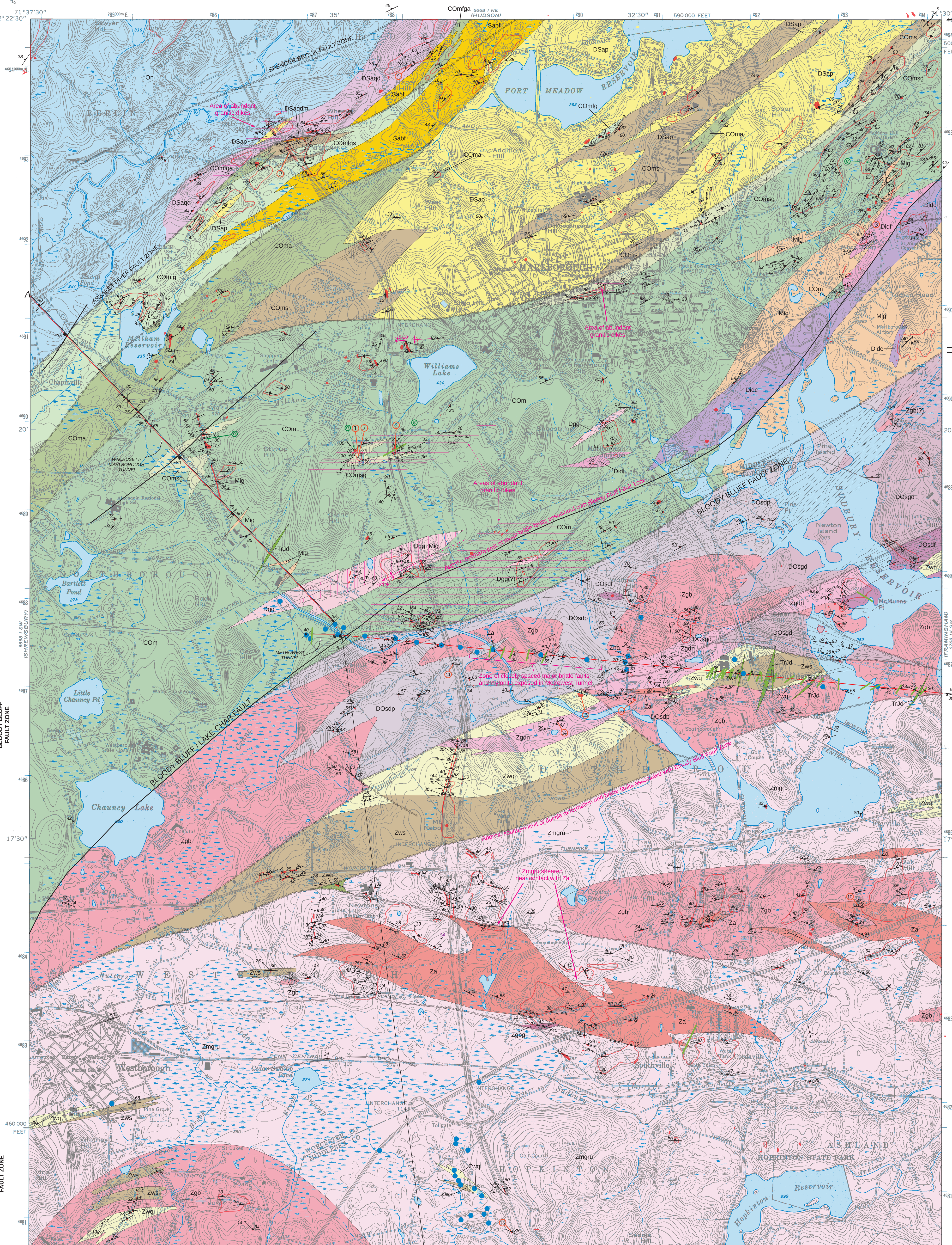
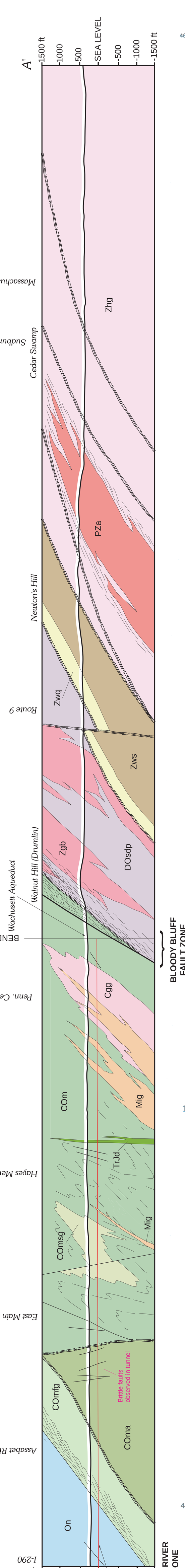




Topographic base modified from U.S. Geological Survey, 1969
Polyconic projection. Reprojected to 1983 North American Datum.

10,000 foot grid ticks based on Massachusetts state plane coordinate system, mainland zone, 1927 North American Datum

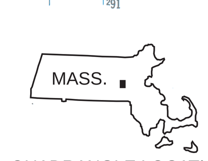
1000-meter Universal Transverse Mercator grid ticks from 1927 North American Datum, zone 19

Hydrography from MassGIS (http://www.mass.gov/mgis)

APPROXIMATE MEAN DECLINATION, 1969

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



QUADRANGLE LOCATION

Data Sources:
- Fieldwork by J. P. Kopera (2003-2006), assisted by A. Koenigsberg (2005)
- Hepburn and DiNitto, 1978 (USGS Open File Report 78-222)
- DiNitto, 1983 (M.S. Thesis, Boston College)
- Unpublished data by D. Ashenden (written commun., 2004)
- Skehan and Abu-Moustafa, 1976 (Wachusett-Marlborough Tunnel)
- Unpublished data by Hager Geoscience (written commun., 2006; Metrowest Tunnel)
- Duncan and Mabee, 2004 (borehole data)
- GZA GeoEnvironmental, Inc., et al., 2005 (Metrowest Tunnel)
- Digital cartography and editing by J.P. Kopera (2006, 2008)

EXPLANATION OF SYMBOLS

Location of cited photo shown below

Exposure

Bedrock outcrop examined in field

Area of abundant outcrop or shallow bedrock (within 10 feet of surface)

Well or geotechnical boring used to constrain bedrock lithology in areas of poor bedrock exposure. Data obtained from Duncan and Mabee (2004), and unpublished data by D. Ashenden (written commun., 2004)

Alignment of subsurface tunnel data used in construction of map

Planar Features *(placed over location measured. Where many symbols present placed as close to outcrop as possible)*

Strike and dip of foliaton and vertical foliation in all rocks, composite S_1 foliation in the Marlborough formation, composite S_1 or later foliation in the Nashoba formation, and foliation of undetermined age in plutonic rocks. In all layered rocks foliation is dominantly parallel to bedding and/or compositional layering.

Approximate strike and dip of heavily contorted foliation

Strike and dip of secondary foliation and crenulation cleavage (S_2) in Marlboro Formation. This foliation generally parallels the axial surfaces of F_2 folds and cuts the S_1 foliation.

Strike and dip of axial surface of secondary fold (F_2) of S_1 foliation in the Nashoba terrane (Photo 1), or fold of undetermined age in Avalon Terrane.

Mylonitic fabric and/or shear fabric of undetermined age

Fracture cleavage of undetermined age

Brittle fault observed in outcrop or tunnel interpreted to be significant at map scale. For additional outcrop-scale brittle structure information, see Mabee and Salamoff (2006).

Linear Features

Trend and plunge of mineral lineation of undetermined age

Trend and plunge of axis of secondary fold (F_2) of S_1 foliation in the Nashoba terrane, or fold of undetermined age in the Avalon terrane

EXPLANATION OF LINES

Contact-- Accuracy of location indicated by proximity to bedrock exposures. Contacts between units within the Marlboro Formation and Neo-Proterozoic plutonic rocks are generally gradational.

Trace of discrete shear zone or sheared contact. Queried in Nashoba terrane where relations to Andover granite are unknown.

Zone of sheared and cataclastic rocks (e.g. Photo 16)

~60 Trace of brittle fault. Approximate dip shown where exposed in subsurface tunnel and/or outcrop. Only the traces of faults that can be supported by unequivocal field evidence are shown.

~10-20 Trace of axial surface of map-scale F_2 or later antiform showing plunge of axis, where estimated. Dashed where existence inferred.

EXPLANATION OF UNITS

TrJd DIABASE- Dark gray fine- to medium-grained, locally porphyritic diabase, occuring as north to northeast trending 10 cm- to 3 meter-thick dikes and dike swarms (Photo 2).

NASHOBA TERRANE

Intrusive Rocks

INDIAN HEAD HILL PLUTON

Mig GRANITE (MISSISSIPIAN)- Chiefly light-gray- to buff-weathering, light-gray to gray, fine- to medium-grained massive biotite-quarts-microcline-plagioclase granite, locally varying from granodiorite to quartz monzonite (Photo 3). Locally exhibits weak foliation.
Age: 349±4 Ma (U-Pb/zircon, titanite; Hepburn et al., 1995).

Didc Didf DIORITE (DEVONIAN?)- Chiefly medium-gray weathering, mottled dark-gray, coarse-grained biotite-hornblende-plagioclase ±quartz ±orthoclase diorite and granodiorite (Didc; Photo 3) locally grading into dark-gray, fine- to medium-grained diorite (Didf).
Age: 402±5 Ma for Didc (Rb-Sr/whole-rock; Hill et al., 1984)

Dgg GRANITE-GNEISS (DEVONIAN OR OLDER?)- Buff- to pink-weathering, fine-to-medium grained, moderately to well-foliated biotite-quartz-feldspar granite gneiss with locally distinct schlieren-like compositional segregations (Photo 7). Interfolded with Marlboro Formation. Overhatching indicates areas where extensively intruded by Mig. In part equivalent to Grafton granite in Grafton quadrangle (518 ± 5 Ma; SHRIMP/zircon; G. Walsh, written commun., 2006).

DSaqd DSaqdm ASSABET QUARTZ DIORITE (SILURIAN TO DEVONIAN?)- Medium- to dark-gray weathering, dark-gray, medium- to coarse-grained, quartz-biotite-plagioclase-hornblende±magnetite±garnet±pyrite diorite. Locally contains thin layers of rusty-weathering, silliminite-biotite-muscovite±garnet schist. Locally sheared to a biotite-pyrite schist (Photo 4), mylonite (DSaqdm), and/or faulted to a carbonate-sulfide breccia. Formerly mapped as the Straw Hollow diorite by Hepburn and DiNitto (1978), and DiNitto (1983). Possibly correlative with Sharpner's Pond pluton to northeast.
Age: 430±5 (U-Pb/zircon from Sharpner's Pond diorite; Zartman and Naylor, 1984); 385± 10 Ma (U-Pb and Pb-Pb/zircon; Acaster and Bickford, 1999)

ANDOVER GRANITE

DSap PEGMATITIC GRANITE (DEVONIAN TO SILURIAN?)- Buff- to pinkish-weathering, light- to medium-gray, coarse-grained to pegmatitic muscovite-biotite-placgioclase-microcline-quartz±garnet granite, granodiorite, and quartz monzonite (Photo 5). Generally displays a coarse gneissic foliation. *Age: 412±2 Ma (U-Pb/zircon; Hepburn et al., 1995); 408±22 Ma (Rb-Sr/whole rock; Zartman and Naylor, 1984), 415 Ma (Rb-Sr/whole rock; Hill et al., 1984).*

Sabf FOLIATED BINARY GRANITE (SILURIAN TO ORDOVICIAN?)- Buff-weathering, light- to medium-gray, well to moderately foliated, medium- to coarse-grained quartz-microcline-plagioclase-biotite-muscovite granite to quartz-monzonite gneiss (Photo 6). Locally fine- to medium-grained. Locally contains xenoliths of amphibolite. Correlation with Andover granite in type locality uncertain
Age: 446±32 (Rb-Sr/whole rock; Zartman and Naylor, 1984); 450±23 (Rb-Sr/whole rock; Handford et al., 1965).

Areas of abundant granitic dikes and sills of undetermined age and affinity. Includes probable dikes and sills of Mig and Dgg.

Stratified Rocks
Stratified rocks in the Nashoba terrane have been metamorphosed under conditions of the mid- to upper amphibolite facies.

On NASHOBA FORMATION (ORDOVICIAN OR OLDER?)- Chiefly medium- to dark-gray, fine- to coarse-grained, quartz-plagioclase biotite±microcline±silliminite ±garnet gneiss (Photo 8), with subsidiary interlayers of amphibolite, calc-silicate, marble, quartzite, granulite, and biotite-muscovite-silliminite±garnet schist. Locally migmatitic. Contains abundant dioritic to granitic dikes and sills. The Nashoba Formation is poorly exposed in the Marlborough quadrangle.

MARLBORO FORMATION (CAMBRIAN TO ORDOVICIAN OR OLDER?)-

COmfg COmfgs COmfga FELSIC GRANULITE AT MILLHAM RESERVOIR- Light-gray- to tan-weathering, medium- to dark-gray, massive to moderately foliated, homogeneous, fine- to medium-grained, muscovite-biotite-plagioclase-quartz granulite (Photo 9). Gray-white feldspar porphyroclasts locally give rock charcteristic "mottled" appearance. Also included are lenses of rusty-weathering, fine-grained silliminite-biotite-muscovite schist (COmfgs), a light-gray weathering lineated coarse-grained biotite-plagioclase-hornblende amphibolite with distinctive pods of granite and granodiorite (COmfga).

COma COms AMPHIBOLITE AND SCHIST- Interlayered rusty-weathering, black to dark-gray, fine-to coarse-grained quartz-plagioclase-muscovite-biotite±silliminite±garnet schist (COms) and light- to medium-gray weathering, black to dark-gray hornblende-plagioclase-biotite-quartz amphibolite (COma). Garnet and silliminite occur locally as thin layers within the schist. Thin layers of light-gray- to buff- to rusty-weathering, dark gray biotite-muscovite-plagioclase-quartz granulite and calc-silicate also occur locally.

COmsg SCHIST AND GRANULITE- Light-gray-weathering, fine- to medium-grained biotite-muscovite-quartz-plagioclase±hornblende±garnet granulite interlayered with rusty- to silvery-white-weathering, silvery to dark brown to dark-gray, fine-grained quartz-plagioclase-muscovite-biotite±garnet schist (Photo 1, Photo 7), with local interlayers of amphibolite. Garnet coticule and calc-silicate layers locally present.

COm UNIDFFERIENTIATED AMPHIBOLITE AND OTHER ROCKS- Chiefly dark to light gray-weathering, locally rusty weathering, black, fine- to medium-grained epidote-quartz-biotite-plagioclase-hornblende amphibolite. Locally interlayered with dark-gray to black, fine-grained quartz-muscovite-plagioclase-biotite ±hornblende±garnet schists; light gray to beige granulites, fine-grained, granulitic quartz-muscovite-biotite-plagioclase±hornblende calc-silicates; and dark-gray, medium- to coarse-grained biotite-plagioclase-quartz gneisses and schists. Epidote and calc-silicate occurs locally as thin layers, boudins, and knots ranging from 5 cm to 1 m in length (Photo 2, Photo 7). Two- to five cm-thick stringers of plagioclase and quartz commonly occur parallel to foliation. Locally migmatitic along the Bloody Bluff Fault and near mappable bodies of Cgg. Mostly equivalent to the Sandy Pond Amphibolite of Hepburn and DiNitto (1978) and DiNitto (1983).

e Outcrop where layers of epidote are abundant in Marlboro Formation

AVALON TERRANE

Paleozoic (?) Intrusive Rocks

SUDBURY VALLEY INTRUSIVE COMPLEX (DEVONIAN TO ORDOVICIAN?)
Locally sheared to biotite gneiss and chlorite schist within Bloody Bluff Fault Zone. Equivalent in part to Zv and Zdigb as mapped by Zen et al. (1983). Age inferred based on correlations with similar rocks to the northeast (Hon et al., 1993).

DOsdp DOsdf DIORITE- Chiefly gray-weathering, mottled dark-gray to dark-greenish-gray, fine- to coarse-grained porphyritic quartz-microcline-biotite-hornblende-plagioclase±chlorite±epidote diorite to granodiorite (DOsdp; Photo 11). Characteristic plagioclase porphyroblasts up to 1 cm in diameter are abundant. Locally gneissic near margins with other units. A fine grained phase is present along the Sudbury Resevoir (DOsdf).

DOsgd GABBRODIORITE- Dark-gray-green to black, fine- to medium-grained plagioclase-hornblende±biotite gabbro or diorite with characteristic pink-weathering microcline megacrysts (Photo 12). Megacrysts locally occur in swarms which grade into xenoliths of granitic rock.

Neo-Proterozoic Plutonic rocks
Note: The Neo-Proterozoic plutonic rocks commonly contain small bodies of dark-greenish-gray, crumbly, fine-grained chloritized biotite amphibolite and biotite schist, up to 3 m in width intepreted to be altered mafic dikes or sills which are distinct from TrJd (Hepburn and DiNitto, 1978).

Za ALASKITE (NEO-PROTEROZOIC?)- Beige- to to pink-weathering, light gray to pinkish-gray, fine-grained quartz-microcline-feldspar-±magnetite alaskite to aplite (Photo 10). Magnetite typically occurs as small dipyramids. Equivalent to the Hope-Valley Alaskite Gneiss as mapped by Walsh and Aleinikoff (*in press*) and Proterozoic Alaskite as mapped by Kopera et al. (2007), in part to Zhv as mapped by Zen et al. (1983), and the mafic-poor foliated Milford granite as mapped by Hepburn and DiNitto (1978).
Age: 601 ± 7 Ma (SHRIMP/zircon; G. Walsh, written commun., 2006) for Zhg in the Grafton quadrangle.

Zgdn GRANODIORITE AT NOURSE FARM (NEO-PROTEROZOIC?) (*after Markwort, 2006, in the Shrewsbury quadrangle)*- Light- to medium-gray, medium- to coarse-grained plagioclase-feldspar hornblende±biotite±epidote granodiorite to diorite (Photo 14). Pods and masses of epidote are common.

Zgb Zgbg BIOTITE-GRANITE AND GRANITE-GNEISS (NEO-PROTEROZOIC?)- Light-pink-gray to light-pink, medium- to coarse-grained moderately to well-foliated - biotite-quartz-feldspar-microcline±magnetite granite to granodiorite (Photo 10). Rock typically contains 3-5% biotite, but locally 10% or more. Locally sheared to a biotite-magnetite gneiss (Zgbg). Partly equivalent to Zsg and Zpg as mapped by Walsh and Aleinikoff (*in press*) in the Grafton quadrangle, Zen et al., (1983), and the foliated Milford granite as mapped by Hepburn and DiNitto (1978).
Age: 604 ± 5 Ma and 607 ± 5 Ma (SHRIMP/zircon; G. Walsh, written commun., 2006) for Zpg in Grafton quadrangle.

Zmgru UNDIFFERENTIATED MILFORD GRANITE AND BIOTITE-POOR GRANITE (NEO-PROTEROZOIC)- Light-pink-gray to gray medium- to coarse grained weakly to well-foliated quartz-feldspar-microcline±biotite±hornblende±magnetite granite and alaskite (Photo 13). Mafic minerals are typically found in trace amounts up to 1-3%. Biotite where present, commonly occurs in distinctive 0.5- to 1 cm-diameter clots. Magnetite commonly occurs in granular masses with biotite and hornblende, and locally as small dipyramids. Equivalent in part to Zhg as mapped by Zen et al., (1983), the Milford granite as mapped by Kopera et al. (2007), and phases of the Milford granite as mapped by Hepburn and DiNitto (1978). Late, fine-grained aplitic dikes are common.
Age: 633 ± 9 Ma and 601 ± 7 Ma (SHRIMP/zircon; G. Walsh, written commun., 2006) for Zhg in the Grafton quadrangle. Approximately 606 Ma (206Pb/238U) for the Milford granite in the Holliston quadrangle (M. Thompson, written commun., 2007).

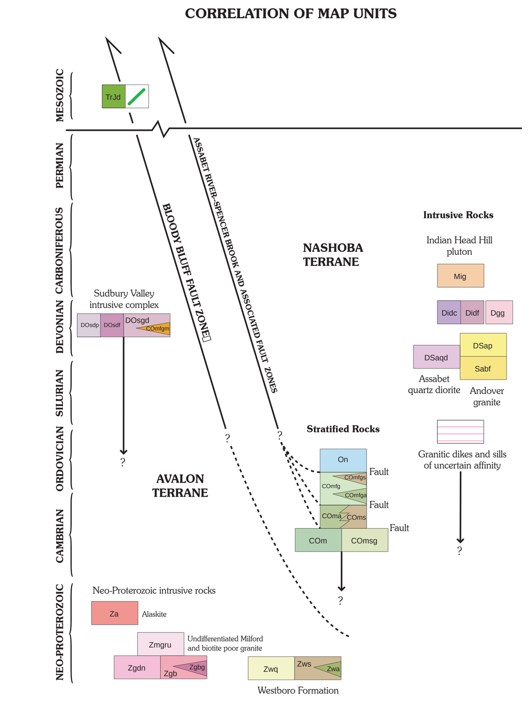
Stratified Rocks
Stratified rocks of the Avalon terrane have been metamorphosed under conditions of the greenschist and lower amphibolite facies.

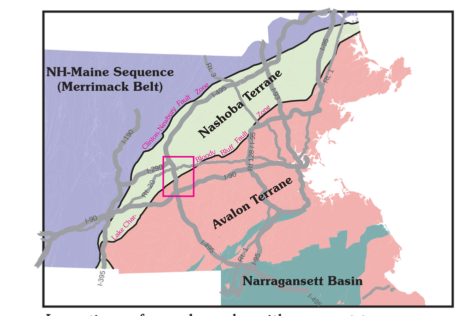
WESTBORO FORMATION (NEO-PROTEROZOIC OR YOUNGER?)

Zwq QUARTZITE- Chiefly light- to dark-gray, tan, or pink-gray, fine-grained, well-bedded to massive feldspathic to pure quartzite (Photo 15). Interbeds of micaceous quartzite and quartz-mica schist are common. Light-green, fine- to medium-grained actinolite-carbonate calc-silicate granulites, light-purplish-brown fine-grained biotite granulites, or calc-silicate-bearing quartzites are common as thin layers, pods, or lenses within the quartzite. Interbeds of Zws are common.

Zws Zwa SCHIST AND GREENSTONE- Rusty weathering, dark-gray, fine- to medium-grained biotite-quartz-feldspar schist and phyllite, light-gray fine- to medium-grained muscovite-quartz schist, dark-green fine- to medium-grained chlorite schist and phyllite, and dark-bluish-gray to dark-green fine-grained chlorite-epidote greenstone with isolated pods and lenses of quartzite. Interlayers of light- to medium-gray weathering, dark-gray to dark-gray-green hornblende-plagioclase±biotite±epidote amphibolite, amphibolite gneiss, or

CORRELATION OF MAP UNITS





Location of quadrangle with respect to major geologic terranes of eastern Massachusetts

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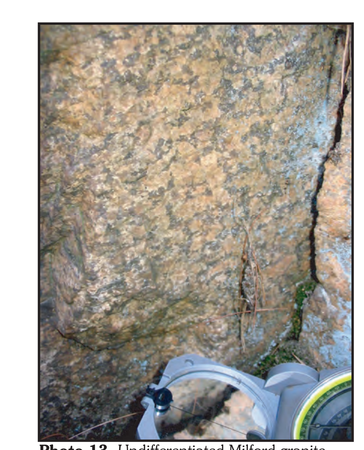

Photo 13. Undifferentiated Milford granite and biotite-poor granite (Zmgru) with trace mafic minerals.

Photo 15. Sheared quartzite (Zwq) of the Westborough formation. Shearing has obliterated bedding at this outcrop and has formed finely laminated foliation planes on which the pencil is resting.

Photo 9. Felsic granulite at Milham Resevoir (COmfg). Foliation is defined by layers of white-weathering felspar porhyroclasts. The entire unit is intensley sheared by the Assabet River fault zone.

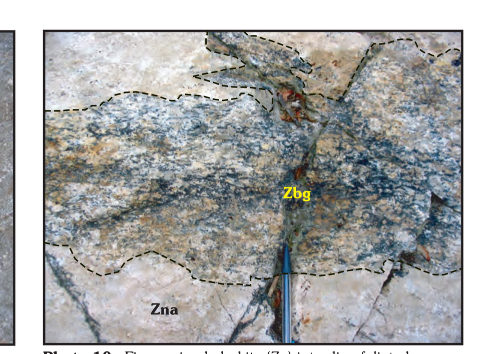

Photo 10. Fine-grained alaskite (Za) intruding foliated coarse-grained Neo-Proterozoic biotite-granite (Zbg).

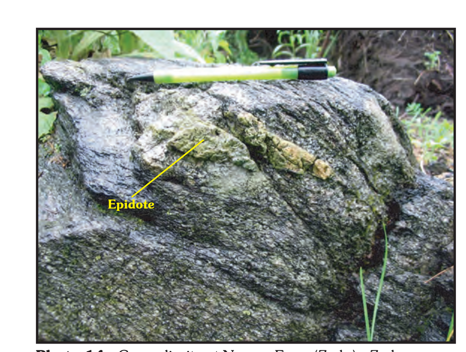

Photo 14. Granodiorite at Nourse Farm (Zgdn). Zgdn characteristially contains pods and masses of epidote, as shown in the above photograph.

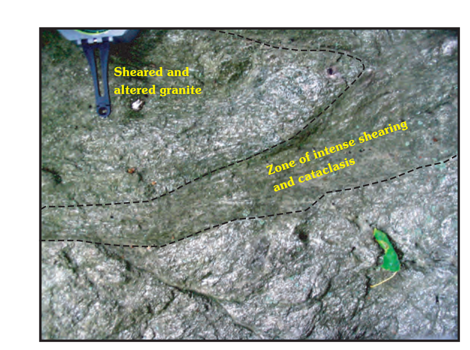

Photo 16. Sheared and altered granite within the Bloody Bluff fault zone.

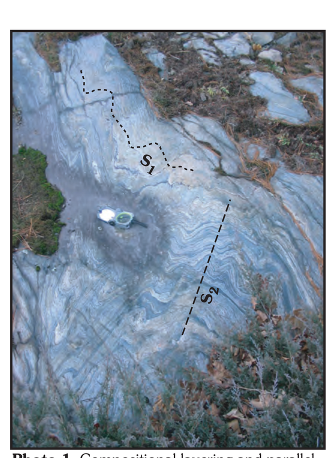

Photo 1. Compositional layering and parallel foliation (S_1) defining F_2 folds about S_2 in the schist and granulite member (COmsg) of the Marlboro Formation.

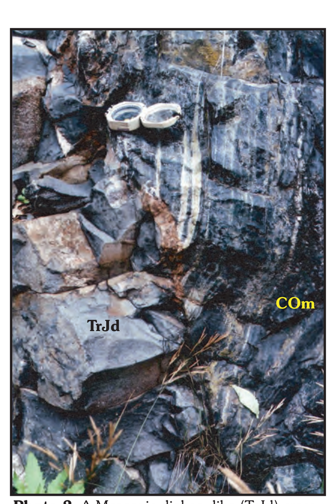

Photo 2. A Mesozoic diabse dike (TrJd) cross-cutting compositional layering in the Marlboro Formation (COm). The light green streaks are layers of epidote and are common in the Marlboro Formation.

Photo 3. Coarse-grained granite (Mig) intruding well-foliated, coarse-grained diorite (Didc) of the Indian Head Hill Pluton. The fine-grained black layers in the diorite are xenoliths of amphibolite of the Marlboro Formation (COm)

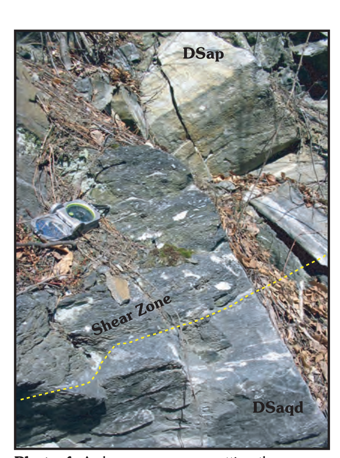

Photo 4. A shear zone cross-cutting the Assabet quartz diorite (DSaqd) near the Assabet River fault zone. Quartz veins that were stretched into boudins form the white blebs in the photograph. A dike of sheared Andover granite (DSap) is shown near the top of the photograph.

Photo 5. A pavement outcrop of the pegmatitic phase of the Andover granite (DSap). The granite is a heterogeneous mix of pegmatite and finer-grained granite, and exhibits a weak gneissic foliation parallel to regional foliation. Photograph taken in southeasternmost portion of the Hudson quadrangle, approximately .5 miles west of intersection of Hudson Rd. and Broad St., in the town of Marlborough.

Photo 6. Foliated binary Andover Granite (Sabf). Streaks of biotite and muscovite locally define the foliation. Photograph taken from the Hudson quadrangle at intersection of Marlboro St. and Reed Rd. in the town of Hudson.

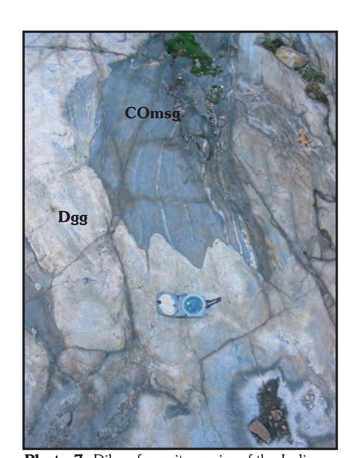

Photo 7. Dike of granite gneiss of the Indian Head Hill pluton(Dgg) cross-cutting foliation of the schist and granulite of the Marlboro Formation (COmsg). A phase of regional deformation post-dated the intrusion of the granite-gneiss, resulting in folded (F_2) intrusive contacts.

Photo 8. Sheared and folded migmatitic gneiss of the Nashoba formation (On). Photo taken in Hudson quadrangle, approximately 50 meters north of intersection of Crescent St. and Hartley Rd. in Stowe center.

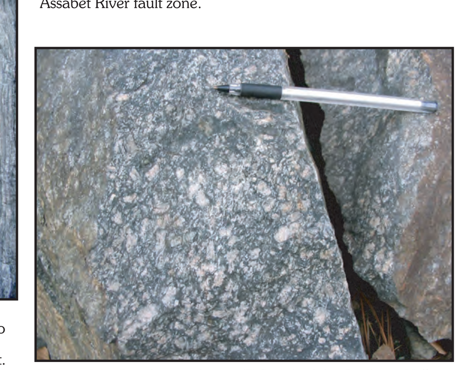

Photo 11. Porphyritic diorite (DOsdp) of the Sudbury Valley intrusive complex. The white-weathering plagioclase phenocrysts are characteristic of this unit.

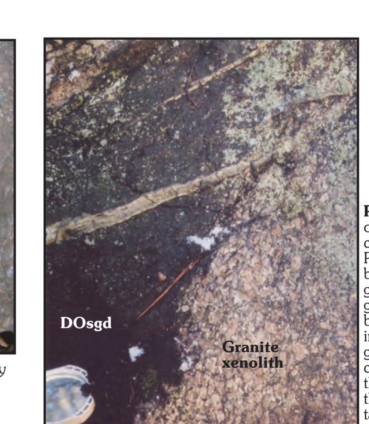

Photo 12. Gabbrodiorite (DOsgd) of the Sudbury Valley Intrusive complex with a xenolith of Neo-Proterozoic granite. The contacts between the xenoliths and gabbrodiorite are commonly gradational, and are characterized by bright pink-weathering feldspars in a gabbro-diorite matrix. The green epidote vein cross-cutting the contact is related to motion along the Bloody Bluff Fault zone just to the north of the outcrop. Photo taken in the Framingham quadrangle, approximately 0.25 miles east of the intersection of Broad Meadow St. with the boundary between the Marlborough and Framingham quadrangles.

Comments to the Map User

A geologic map displays information on the distribution, nature, orientation and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map are based on reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

We recommend reading Reading Maps with a Critical Eye: Becoming an Informed Map Reader by the Maine Geologic Survey (http://www.maine.gov/doc/nrimc/mgs/mapuse/informed/informed.htm), to make the best use of a geologic map.

Cross sections are constructed based upon the interpretations of the authors made from geologic mapping, and available geophysical and subsurface (drillhole) data. Cross sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.

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Kopera J., Hepburn J.C., and DiNitto R., 2006, Bedrock geologic map of the Marlborough quadrangle, Massachusetts: Office of the Massachusetts State Geologist Geologic Map 06-01. Scale 1:24,000. 1 sheet and digital product: Adobe PDF and ESRI ArcGIS database.

This map was produced on request directly from digital files (PDF format) on an electronic plotter.

A digital copy of this map (PDF format), including GIS datalayers, is available at http://www.geo.umass.edu/stategeologist