Bedrock Geology of the Middlesex Fells Reservation and Adjoining Parks and Preserves in Malden, Medford, Melrose, Stoneham, and Winchester in Middlesex County, Massachusetts (see also http://sites.tufts.edu/fellsgeology)

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Base Map Information

Geology mapped and compiled in GIS format since 2012 with continuing updates. Field data recorded in UTM coordinates (zone 19T) using 1927 North American Datum. Base map is a hill-shaded relief map from 2015 MassGIS LiDAR raster data with 1-meter resolution produced with ESRI's Multi-Directional Hillshade Raster Function in ARCMAP 10.4 and then projected to 1927 NAD UTM zone 19T. Field mapping was done at greater than 1:500 scale. Transportation infrastructure outside the Middlesex Fells is from the MassGIS MassDOT shape file with roads and rail lines (1983 NAD; last updated 2013). Trails and roads in the Middlesex Fells are from the MassGIS DCR Roads and Trails shape file (1983 NAD; last updated 2014). Small corrections were made to roads and trails to better correspond to the hillshade base where there was a clear mismatch. Water bodies and wetlands were traced as geologic units using the LiDAR generated hill shaded base map as a guide and 1927 NAD UTM zone 19T GPS coordinates measured in the field. The map sometimes shows LiDAR topography in areas mapped as water because LiDAR data were obtained when reservoirs had very low levels, while mapping was done during higher water levels. The map area is contained in the 1956, 1971, and 2015 editions of the 7.5-minute Boston North, MA Quadrangle (1:24,000), 1985 Boston North, MA 7.5 x 15-minute Quadrangle (1:25,000 metric), and the 1909 Boston, MA 15-minute Quadrangle. The western edge of the map area includes a small portion of the 1956, 1971, and 2015 editions of the Lexington, MA 7.5-minute Quadrangle (1:24,000).

DESCRIPTION OF MAP UNITS

Nomenclature for color of rock units is according to the Geological Society of America's Munsell Rock Color Chart as revised in 2009 and the Munsell Soil Color Chart, 1975 edition. Color is given only for fine-grained rocks or for individual mineral types. Rock terminology follows the IUGS classification of igneous rocks (Le Bas and Streckeisen, 1991). A separate document at http://sites.tufts.edu/fellsgeology gives a picture catalogue of volcanic rock features and textures in the Middlesex Fells, both in thin sections and hand samples, as well as definitions to show how the volcanic rocks were interpreted. The word "hornfels" is used in this document as a term for hard, brittle, generally fine-grained rock that breaks irregularly or with conchoidal fractures and is produced by contact metamorphism, loosely following the definition of Winter (2010). Here, hornfels includes fine-grained rocks produced by the contact metamorphism of mudstone or argillite and fine-grained basalt, which are often difficult to discern in the field. New formal rock names are used on this map to allow a subdivision of previously named units and to reinterpret correlations. This description is intended for poster display with the map. More detailed descriptions with hand sample and thin section images are given at the web address mentioned above.

Quaternary and Artificial Deposits and Water Bodies

af — **Artificial fill -** Land formed as a result of artificial filling or construction by humans. Only shown where it prevents interpretation of the bedrock geology.

w — **Water bodies –** ponds, lakes, and rivers. Water bodies were traced as geologic units using the LiDAR generated hill shaded base map as a guide and 1927 NAD UTM zone 19T GPS coordinates measured in the field. In some places the map shows shoreline topography in areas mapped as open water because the LiDAR data were obtained when reservoirs had very low levels. Mapping was done while water was higher.

sw — **Swamps and other wetlands** – areas covered by wetlands including permanent swamps and large vernal pools.

q — **Quaternary deposits** – glacial, stream, mass movement, and other surficial deposits, where they are thick enough to prevent interpretation of the bedrock geology. Includes areas covered by till and end moraines near South Reservoir, at Wrights Pond and south of Ravine Road.

Intrusive Igneous Rock Units Occurring as Dikes or Unnamed Units

d — **Dolerite and basalt dikes (Ediacaran through Mesozoic?)** – Grayish black to dark gray (N 2-3) and greenish-black to greenish-gray (5G 2-6/1) aphanitic to fine-grained phaneritic mafic dikes weathering to a rusty brown to gray color. Unit includes lamprophyric dikes. Some dikes have vesicles or amygdules with epidote, calcite, quartz, and prehnite mineralization. Dikes that could not be fully traced have terminations marked with (**?**). Rare dikes known to terminate with blunt ends are marked with (e). Chemistry, field relationships, and ages of the dikes are discussed by Ross (1981, 1984, 1990, 1992, 2010, 2020). Dolerite dikes are often cut by major faults. Mapped only where dikes exceed a width of 1.0 m. Thinner dikes that are not as traceable are shown with a separate line symbol. Radiometric ages for dolerite dikes: 573 ± 5 Ma ($^{40}Ar/^{39}Ar$, whole rock), 353 ± 4 Ma ($^{40}Ar/^{39}Ar$, whole rock), 290 ± 15 Ma (K/Ar whole rock), 226 ± 3 Ma ($^{40}Ar/^{39}Ar$, whole rock) from Ross (2001) and Zartman et al. (1970).

dp — **Porphyritic dolerite and basalt dikes (Ediacaran through Mesozoic?) –** Grayish-black to dark gray (N 2-3) and greenish-black (5G 2/1), aphanitic to fine-grained phaneritic, porphyritic dolerite and basalt dikes with plagioclase phenocrysts. Plagioclase phenocrysts are as long as 10 cm and can occur as single tabular crystals or cumulophyric clusters. Includes occasional lamprophyric dikes with altered mafic phenocrysts. The ground mass appears darker and less altered than in plain dolerite dikes (d), but they are likely related to the dolerite dikes and have similar ages. Weather to a rusty brown or gray color. Some porphyritic dolerite dikes on the west shore of Middle Reservoir also have large black xenoliths with densely packed coarse plagioclase phenocrysts. Mapped only where dikes exceed a width of 1.0 m. Thinner dikes that are not as traceable are shown with a separate line symbol. Likely the same ages as dolerite dikes (d).

gb — **Gabbro dikes (Ediacaran through Paleozoic?)** – Dark greenish gray (5G 4/1) medium to coarse-grained phaneritic equigranular gabbro dikes. Composition like dolerite dikes (d) but coarser. Crosscut by dikes trending NW-SE that pre-date the Medford Dike (Pm). Usually heavily altered with plagioclase replaced by sericite and pyroxene (augite) altered to amphibole (actinolite) and chlorite. A whole rock $^{40}Ar/^{39}Ar$ age determination by Ross (2001) is 403 ± 3 Ma.

ad — **Highly altered gabbro, dolerite and basalt dikes (Ediacaran through early Paleozoic?)** – Green (5G 4-2/4-6) heavily veined dikes of altered gabbro, dolerite and basalt. Included in this unit are highly altered (oxidized), dark reddish gray (5R 2/2 to 4-2/1), hematite-rich dolerite dikes. All dolerite dikes are altered to some degree, but this unit identifies extreme cases. Alteration includes almost complete replacement of feldspar by very fine sericite and epidote and replacement of pyroxene by amphibole (actinolite) and chlorite. Older than dolerite dikes (d) in the same area because they are crosscut by the less altered dikes, they may show the same deformation (fractures and foliation) as intruded rock units, and they may have a highly irregular trace.

ap — **Gray Porphyritic andesite to dacite dikes (Ediacaran?) –** Greenish gray (5GY 5/1) to light to medium gray (N 5-7/0) weathering and dark to medium gray (N 2-3/0) when not weathered, porphyritic, sometimes cumulophyric, aphanitic andesite to dacite dikes. Phenocrysts are plagioclase and hornblende. Dikes can have abundant quartzite, argillite, and volcanic xenoliths from local quartzite and volcanic units. Possibly more than one age. Dikes on the east side of Spot Pond near the Stone Zoo are thought to be associated with the Stoneham Tonalite (Zst) that likely underlies the northern end of the pond. Mapped only where dikes exceed a width of 1.0 m. Thinner porphyritic gray andesite to dacite dikes that are not as traceable are shown with a separate line symbol.

fp — **Pink porphyritic dacite to rhyolite dikes (Ediacaran?) –** Reddish gray to orangish gray (5R 3/2 to 2.5YR 4/2) weathering and pinkish to tannish gray and light gray (7.5YR 7/2 to 5Y 7/1) non-weathered, porphyritic dacite and rhyolite dikes that are generally heavily fractured. Phenocrysts are plagioclase that are sometimes cumulophyric. Possibly more than one age but they occur west of Rt. 93 where a red variety crosscuts the Spot Pond Granodiorite (Zsg) and is truncated by the Rams Head Porphyry (Zrhp) in the Wenepoykin Hill area. Mostly north-south trending lenticular reddish gray rhyolitic dikes also occur in the Winchester Granite. Mapped with this unit are elongate lenticular rhyolite dikes in the Nanepashemet Formation that may be associated with the Winchester Granite (Zwg). Mapped only where dikes exceed a width of 1.0 m. Thinner dikes are shown with a separate symbol.

fq — **Dacite to rhyolite dikes with quartz and feldspar xenocrysts (Ediacaran to early Paleozoic?)** – White (10YR 8/1) weathering light gray (10YR 7/1) rhyolite to dacite dikes with medium (up to 1.5 cm) rounded and embayed feldspar and quartz xenocrysts. Based on grain size the xenocrysts appear to be derived from coarse granitic units. Color can vary from dark to light gray or tan (N 2-3/0 and 7.5YR 7/2 to 5Y 8/1) within one dike due to differences in grain size and assimilation of host units, which may also trigger variations in composition. Unit can weather to a chalky surface with protruding xenocrysts. Only found on Whip Hill, in the MWRA excavation south of Ravine Road, and on the east shore of the peninsula in the Fells Reservoir extending to east of the Fellsway East. On Whip Hill, contains cubic fluorite phenocrysts coated by dark red hematite.

dr — **Diorite (Ediacaran?)** – A previously unrecognized greenish-gray (5G 4/1) diorite. About 40-50% zoned euhedral plagioclase with the remainder of the rock hornblende that is partly altered to chlorite and opaque mineral grains. Plagioclase is partly altered to sericite. Ilmenite and sparse titanite occur as accessory minerals. Has a single occurrence in the Fells as a small lenticular outcrop (70 x 15 m) intruding the Westboro Formation (Zvwq) and bounded on its south side by an east-west trending fault west of South Reservoir. Fractures and abundant veins in the diorite suggest that it is cut but the fault. It remains uncertain as to whether the north side contact is also a fault. Except for rare isolated grains, quartz and alkali feldspar are absent, making it difficult to associate with most Ediacaran intrusive bodies in the Fells. This unit is likely an isolated outcrop of the Rams Head Porphyry (Zrhp), but with a higher than typical mafic content.

Named Rock Units

Pm — **Medford Dike (late Pennsylvanian) –** Brownish to olive black (5YR-Y 2/1), medium to coarse-grained gabbronorite. The Medford Diabase or Medford Dike of Wilson (1901) and LaForge (1932). Mostly composed of plagioclase, altered augite (actinolite), biotite, and accessory magnetite and possibly ilmenite. Margins have olivine and west margin has kaersutite (Ross, 2020). Unit contains abundant fine apatite needles and sparse interstitial calcite. Deeply weathered along fractures to depths in excess of 10 m in quarry walls and reduced to grus and corestones that show spheroidal weathering in surface exposures. The dike extends north-northeast across Rt. 93 where it pinches out just west of Wrights Pond with a smaller branch of the dike further north along the east side of Rt. 93 and on the east side of Lawrence Memorial Hospital. The unit crosscuts all known adjacent dolerite dikes except a north-south trending dike reported by LaForge (1932) in Medford (see detailed explanation document for more on this at: *http://sites.tufts.edu/fellsgeology*). Chemistry and field relationships to other dikes are discussed by Ross (1990, 1992, 2020). The unit has a K-Ar (biotite) age of 190 Ma (Ross, 1981, 1990, 2001) and a likely more accurate $^{40}Ar/^{39}Ar$ biotite age of 304.4 ± 0.6 Ma (Ross, 2020).

Zst — **Stoneham Tonalite (Ediacaran)** – Greenish gray (5B-GB 5-6/1) tonalite. Has appearance in the field of quartz diorite to diorite because quartz may be fine-grained and inconspicuous, and the rock can have a high mafic content. Usually porphyritic in chill zones, but not away from these zones, and has tabular euhedral plagioclase throughout with varying alteration of interiors to sericite and epidote. Plagioclase is sometimes enclosed in fresher more alkaline rims forming zonation. Typically, at least 15% quartz grains, which are smaller than plagioclase and interstitial, and less than 10% alkali feldspar that may be heavily altered and difficult to distinguish from altered plagioclase without potassium staining. Mafic mineral content of 15-50% that includes biotite and hornblende, which are mostly to partly altered to chlorite, epidote, and opaque oxides. Abundant inclusions of quartzite and argillite from the Westboro Formation (Zvwq) and metabasalt from the Nanepashemet Formation (Znpm), and to the north, basalt and argillite from the Straw Point Volcanic Complex (Zspb). A chill zone contact with the rhyolite facies of the Straw Point Volcanic Complex (Zspr) occurs on the western of two small peninsulas at the north end of Spot Pond. The Wanapanaquin Porphyry (Zwap) may be an extension of the tonalite into the Nanepashemet Formation (Znpm). Interpreted by Kaye (1980) and LaForge (1932) to be correlative to the Newburyport Quartz Diorite of Emerson (1917). Bell (1948) classified this unit as the "Newburyport Quartz Diorite" phase of the Dedham Granodiorite. Recently this unit was also lumped with the Dedham Granodiorite (mostly Spot Pond Granodiorite of this map) as a dioritic phase (Smith and Hon, 1984; Hepburn and others, 1993) but it is texturally distinct from the Spot Pond, does not contact it or the Rams Head Porphyry (Zrhp) to the south, and it intrudes the Straw Point Volcanic Complex (Zspr) indicating that it is separated from the Spot Pond in time by at least 14 Myr.

Zwap — **Wanapanaquin Hill Porphyry (Ediacaran)** – Pinkish tan to gray aphanitic porphyry at the south end of Wanapanaquin Hill along the east shore of Middle Reservoir in Winchester. Phenocrysts of well-formed tabular plagioclase in a much finer matrix of quartz, altered mafic minerals, and very minor alkali feldspar. Red matrix color due to hematite staining. The unit is no more than 100 m across and occurs entirely within the Nanepashemet Formation (Znpm). The relationship of this unit to surrounding plutonic bodies remains uncertain, however, it is like the porphyritic chill zone of the Stoneham Tonalite (Zst) and it may be a branch of this unit.

Zwp — **Whip Hill Formation (Ediacaran)** – Dark gray (7.5YR 3/0), well cemented, laminated or thinly bedded to massive (when in mass flow units) sandy mudstone, which weathers to a rusty yellowish brown (10YR 5/6), enclosing fine to medium-grained quartz sandstone olistoliths. Has flat, laminated and graded bedding with crosscutting in mudstone and ripple crossbeds are preserved that dip very steeply to the north to northwest (see Bailey, 1984 and Bailey and others, 1989) in sandy units. Throughout unit and dominating in most places are dark gray rusty weathering mudstone debris flow layers (olistostromes) ranging from 10 cm to at least 20 m in thickness with mudstone breccias that have contorted and dismembered quartz sandstone beds. Unconformably rests on the Wamoset Hill Felsite at southern end of Whip Hill and along the west side of the swamp east of the DCR Yard.

Volcanic Units in the Northern Fells –*Two volcanic units of similar age but different compositions: Straw Point Volcanic Complex and the Wamoset Hill Felsite. These units are mapped separately until more definitive ages are determined for rhyolitic flows at the north end of Spot Pond.*

Straw Point Volcanic Complex (Ediacaran) –Three distinct facies of bimodal volcanic flows (basalt and rhyolite), sialic pyroclastic rocks, and dark bluish and greenish gray argillite associated with basalt at the northeast corner of Middle Reservoir and the northwest corner of Spot Pond. Mapped by Emerson (1917) and LaForge (1932) as the upper bimodal volcanic part of the Marlboro Formation. Bell and Alvord (1976) defined these units and dark units beneath them (mapped here as the Nanepashemet Formation) lying on the quartzite-rich Westboro Formation as the Middlesex Fells Volcanic Complex. Mapping in the Fells by Kaye (1980) misidentified large areas of chloritic and epidote-rich metabasalt hornfels and dark argillite as "quartz vitrophyre" that he included with the Middlesex Fells Volcanics following the stratigraphy of Bell and Alvord (1976). The Nanepashemet Formation (Znpm) is interpreted here to have pervasive contact metamorphism, hydrothermal alteration, and an unconformable relationship with the overlying Straw Point Volcanic Complex at the north end of Middle Reservoir. The Straw Point is not in contact with the Nanepashemet Fm. in exposures at the northwest corner of Spot Pond due to faults and intrusion of the Stoneham Tonalite but contact of the Straw Point and Nanepashemet may occur beneath Spot Pond.

Zspb — **Basalt/argillite facies** –Dark greenish gray (5BG-5G 3-4/1) to dark reddish gray (10R 3/1) altered aphanitic to very fine phaneritic and occasionally amygdaloidal basalt interlayered with laminated to thin bedded dark bluish to greenish gray (5BG-5G 3-4/1) argillite to fine sandstone, that has minor amounts of volcaniclastic or pyroclastic rock, both basaltic and sialic. Occurs as the top unit in the Straw Point Volcanic Complex at Straw Point. Basalt and argillite are mapped as a single facies because they are interlayered, and it has not been possible because of alteration and very fine grain sizes to consistently separate them in the field. Bedding in the argillite is often contorted. Basalt and sedimentary units are both heavily altered with abundant chlorite, and quartz, calcite, epidote, and iron oxide mineral precipitates in amygdules and veins. At least one argillaceous unit at the base of a basalt flow is partly calcareous and displays alveolar weathering that mimics vesicles. This unit represents the top of the Straw Point Volcanic Complex at Straw Point but exposures north and east of the Fells may have multiple basalt/felsite cycles.

Zspc — **Pyroclastic/volcaniclastic facies –** Light gray to gray (10YR 5-7/1) crystal tuff and volcaniclastic sandstone to conglomerate with abundant lithic fragments and abundant broken plagioclase crystals. Deeply embayed quartz xenocrysts found in the Wamoset Hill and Pine Hill Felsites have not been found. Some areas are non-welded. Also contains lithic volcanic clasts and basalt and quartzite lithic fragments. Unit overlies the rhyolite facies and is beneath and interbedded with the basalt/argillite facies (Zspb) at Straw Point. It is dominantly sialic pyroclastic and volcaniclastic rock. Not recognized by Kaye (1980).

Zspr — **Rhyolite flow facies** – Lower part of Straw Point Volcanic Complex that is light gray (10YR 7/1) to gray (10YR 6/1) banded recrystallized rhyolite with scattered lithic fragments and very dark grayish brown to reddish brown (10YR 3/2 to 5YR 4/4) banded rhyolite both interpreted to be flows with sparse euhedral cumulophyric plagioclase crystal clusters. Units on the east side of Straw Point display faint flow banding that dips gently and parallel to overlying basaltic units and indicates the unit's orientation. At Straw Point and on north shore of Spot Pond the unit displays a micropoikilitic texture due to devitrification and possibly recrystallization by contact metamorphism adjacent to the Stoneham Tonalite (Zst), which gives hand samples and weathered surfaces a faint spotted appearance. At Middle Reservoir there is a U-Pb zircon age of 594.7 ± 0.3 Ma (ID-TIMS, F. MacDonald, pers. com.).

Zwh — **Wamoset Hill Felsite (Ediacaran)** – East-west striking sialic volcanic units that include dark gray (7.5YR 4/0) welded vitric tuff with oriented fine plagioclase crystals; very dark gray (7.5R 3/0) flow banded rhyolitic lava with cumulophyric feldspar clusters, pinkish gray (7.5YR 6/2) to gray (7.5YR 6/0) mildly to non-welded crystal to lithic tuff and breccia with broken plagioclase and quartz crystals, abundant volcanic lithic fragments, and coarse granitic debris. Displays macro-spheroidal texture (relict lythophysae?) and relict perlitic texture in Whip Hill Park at the top of a flow unit. The basal contact nonconformably truncates metamorphic foliation in the Westboro Formation (Zvwq) and it displays none of the Westboro's deformation or metamorphism. Although often in fault contact above with the Whip Hill Formation an erosional unconformity is exposed west of Whip Hill and in Whip Hill Park with an abrupt change from volcanic to quartz-rich sedimentary units above that cuts across the general east-west trend of the volcanic units south of Whip Hill. Mapped as quartzite on Wamoset Hill by LaForge (1932) and Kaye (1980). Kaye overextends the unit along Pond Street in Stoneham to Greenwood Park. East of the Fells the unit has a large outcrop area, where LaForge and Kaye map the unit as part of the Lynn Volcanic Complex of Clapp (1921). The Wamoset Hill is mapped separately from the Straw Point Volcanic Complex because it has different lithologies and no basaltic component, but these two units are close in age. The Wamoset Hill is tentatively thought to be a Pine Hill Felsite equivalent but this has yet to be confirmed. The Wamoset Hill appears to be correlative to the Lynn Volcanic Complex further east but its exact member in the Lynn (Smith and Hon, 1984; Smith, 1985) is not known. The unit has a U-Pb zircon age of 595.8 ± 0.22 Ma (ID-TIMS; F. MacDonald, pers. com.).

Pine Hill Felsite (Ediacaran) – ***Volcanic rock units unconformably overlying the Spot Pond Granodiorite (Zsg) in the Pine Hill and Wrights Pond areas and the Black Rock Tuff in the Boojum Rock area. Present mapping of these units does not match the volcanic units mapped by Kaye (1980) who correlated this unit to the Lynn Volcanic Complex of Clapp (1921) and LaForge (1932) and lumped it with what is here interpreted as a separate older, more massive, and quartz deficient Black Rock Tuff (Zbrc). Previous maps also lumped this unit with finer parts of the subvolcanic Lawrence Woods Granophyre (Zlwg). In the Pine Hill area the unit is split into two members: lower lithic tuff and volcaniclastic sediment of the Middle Hill Member (Zpmh) and upper lithic crystal tuff of the Wrights Tower Tuff Member (Zpt). In the Boojum Rock area the unit is divided into four facies because units are intensely faulted and not traceable as members.***

Zpt — **Wrights Tower Tuff Member ("Tower Member" of Zarrow, 1976)** – Dark bluish gray (5B 4/1) to gray (N4/1) welded crystal tuff with varying sizes and abundances of crystals and lithic fragments. Unit well exposed at Wright's Tower on Pine Hill and on the southern end of Middle Hill where it is intruded by the Lawrence Woods Granophyre (Zlwg). At Wrights Tower the unit contains irregular and pinched masses of vitric tuff . Crystals are both euhedral and broken and are primarily plagioclase but also include rare rounded and embayed quartz crystals, which appear to be xenocrysts from the Spot Pond Granodiorite and include rounded quartz dipyramids, and minor alkali feldspar. Lithic fragments include a wide variety of sialic volcanic rocks and quartzite that sometimes has heavily sutured, stretched, and recrystallized quartz grains indicating a likely Westboro Formation (Zvwq) source. Thin sections display layering and crystal fabrics that are deformed around lithic fragments but are difficult to recognize in the field.

Zpmh — **Middle Hill Member** –Dark bluish gray (5BG 3-4/1) to gray (N4/1) fine-grained volcaniclastic sandy mudstone (Fig. Zpmh1) to greenish gray (5GY-G 5/1 matrix) polymictic conglomerate (diamictite) with a variety of lithic grains (Fig. Zpmh2-3) including pebbles to boulders of the Spot Pond Granodiorite (Zsg). Large Spot Pond Granodiorite (Zsg) clasts on Middle Hill were first recognized by Robert Reuss of Tufts University (samples and unpublished field notes, 1982-1985). On Pine and Middle Hills unit includes deformed and pinched masses of light gray weathering, gray (N 5-6) vitric tuff that are sometimes banded and enclosed in a rusty weathering volcaniclastic sandstone to conglomerate containing abundant rounded and broken plagioclase and quartz grains, sparse alkali feldspar, and granodiorite, volcanic, and quartzite sand to cobble size clasts. West of Bellevue Pond the base of the unit contains brecciated granophyre clasts from the subvolcanic Lawrence Woods Granophyre, while in other places the granophyre appears to intrude this unit suggesting the granophyre and volcanics are coeval. This unit is thought to be equivalent to the breccia/volcaniclastic conglomerate facies in the Boojum Rock area.

Facies in the Boojum Rock area

Zbjb — **Banded and flattened pumice-bearing welded crystal tuff facies** – Dusky blue to grayish purple (5PB 4/2 to 5P 2-4/2) welded, lithic, and crystal tuff with well preserved volcanic structures including banding, flattened pumice fragments, and (auto-?) brecciated reddish to purple crystal and banded tuff. Surface of unit weathers to a pale grayish blue (5PB 5-6/2). On the northeast shore of Wrights Pond part of the unit is reddish black (5R 2/1) welded and banded vitric tuff with minor crystals and lithic fragments.

Zbjv — **Vitric tuff facies** - Light bluish to pinkish gray (5B 7/11 to5 YR 8/1) fine vitric tuff with occasional faint layering, and a chert-like appearance in outcrop. This unit grades between almost pure fine ash tuff and fine ash tuff with sparse fine crystals and lithic fragments. A unit of this type has not been found in the Pine Hill area.

Zbjc — **Granule to boulder volcanic breccia and volcaniclastic conglomerate facies** – Medium light to dark gray (N3-6) to greenish gray (5GY-G 5/1, matrix) volcanic breccia to volcaniclastic clast-supported, round pebble conglomerate similar to the Middle Hill Member of the Pine Hill area but with different clasts, especially dark red volcanics and alkali granite. Lithologies are interbedded but generally grade upward from volcanic breccia with only volcanic clasts and very poorly sorted matrix to better sorted, polymictic volcaniclastic conglomerate with round pebbles. In addition to volcanic lithologies pebbles are also composed of white and gray to red sandstone, quartzite, laminated fine sandstone and siltstone, and granitic rocks. This facies forms the base of the Pine Hill Felsite at Boojum Rock and rests on an angular unconformity cutting across the regional trend of layering in the Black Rock Tuff. It may be the same as the Vinegar Hill member of the Lynn Volcanics described by Smith and Hon (1984) and Smith (1985).

Zbjp — **Red rhyolite porphyry facies** – Rhyolite porphyry, up to 100 m wide and trending north-northeast to south-southwest, that cuts across the crystal tuff facies of the Black Rock Tuff (Zbrc). Traced from Boojum Rock area northward to the northeast peninsula of Fells Reservoir where it terminates at a fault. Unit has a distinct reddish to pinkish gray color (2.5YR6/6 to 5YR 7/2) when weathered and is medium to dark reddish gray (2.5YR 4-5/2) when non-weathered. It has euhedral plagioclase phenocrysts and rounded and embayed quartz crystals. Unit is distinct from tuff of the Black Rock Tuff in that it has: 1) large almost completely euhedral plagioclase phenocrysts and cumulophyric plagioclase clusters that appear to be fresher and larger than in the Black Rock, where crystals are mostly broken and never cumulophyric; 2) areas of flow layering along its contact with the same color characteristics and plagioclase crystals as in the dominant more massive porphyry at the core of the unit; and 3) abundant rounded and embayed quartz crystals that do not occur in the Black Rock. Along the unit's contact is occasional pinkish gray to light gray (7.5YR 7/0-8/2) weathering and gray to faintly greenish gray (7.5YR 5/0 to 5BG 6/1) volcaniclastic sandstone or lithic tuff that has red to pink and gray rounded volcanic lithic fragments. Based on its map geometry and composition this unit is tentatively interpreted to be a large fissure invaded by the porphyry and associated with the Pine Hill Felsite. Similarities with the Lawrence Woods Granophyre (Zlwg) suggest that it is a near surface offshoot of the granophyre but no physical connection has been found.

Zlwg — **Lawrence Woods Granophyre (Ediacaran)** – Porphyritic granophyre in southern Fells of Medford. Pale red to pale reddish purple (5R 6/2 – 5RP 6/2) and pale brown (10YR 6/3) to faintly brownish to reddish gray (5-10YR 4-6/1) granite to quartz monzonite granophyre with phenocrysts of plagioclase and needle-like hornblende. Rock has a granophyric and micrographic alkali matrix that gives the unit its reddish to pinkish color and heavily stains for potassium. Very fine-grained, porphyritic, and distinctly reddish orange to pink in chill zones along its northern contact with rocks of the Pine Hill Felsite at Pine Hill, Wrights Pond and East Border Road) and Spot Pond Granodiorite (Lawrence Woods). Rock gets progressively coarser to the south away from contacts with other units. Contains xenoliths from the Pine Hill Felsite (Zpt) on west side of Middle Hill, and what is interpreted to be a xenolith of the Rams Head Porphyry in northeast Lawrence Woods. Unit is clearly intrusive in thin section and is thought to be a subvolcanic body related to the Pine Hill Felsite. Mapped as part of the Dedham Granodiorite by LaForge (1932) and Kaye (1980) with the finer chilled margin of the unit lumped by Kaye (1980) with the Lynn Volcanics. Bell (1948) classified this unit as the "porphyritic micrographic granodiorite" and "micrographic granodiorite" phases of the Dedham Granodiorite. This unit was also lumped with the Dedham Granodiorite (Spot Pond Granodiorite of this study) as a granophyric marginal phase (Smith and Hon, 1984; Hepburn and others, 1993). However, the gradational chilled margin is sharp and coarsens away from the Spot Pond Granodiorite and volcanic rock formations of the southern Fells. U-Pb zircon ages (ID-TIMS) reveal two separate populations (3 crystals each). The older population (598.13 ± 0.27 Ma) and possibly the younger (596.77 ± 0.25 Ma) are inherited.

Zrhp — **Rams Head Porphyry (Ediacaran)** – Greenish-gray to gray (5G 4-5/1) porphyritic tonalite to quartz diorite. Has the appearance in the field of diorite because: 1) quartz and alkali feldspar form fine interstitial pockets lying inconspicuously between much larger euhedral zoned plagioclase phenocrysts, which dominate the rock; and 2) mafic mineral content is relatively high. Typically about 10-25% quartz and always <10% alkali feldspar in the non-mafic component. Mafic mineral content is usually about 15% but can be higher and is mostly hornblende with lesser biotite that are often altered to chlorite, calcite, epidote and opaque oxide minerals. Also in the rock is primary interstitial titanite and occasional rutile. Southeast of South Reservoir and near Medford High School are dismembered rafts of the Spot Pond Granodiorite (Zsg) that may form a roof pendant. In contact with the Spot Pond Granodiorite the porphyry has well displayed chilled margins and contacts that show assimilation of granodiorite. Unit has intrusive contact with the Westboro Formation (Zvwq) near Rams Head Hill in northern Lawrence Woods and on Silver Mine Hill. The Lawrence Woods Granophyre (Zlwg) has a chill zone along its contact with the porphyry at the entrance to Medford High School. Relative age with the Stoneham Tonalite (Zst) has not been determined but the Stoneham is thought to be younger because it intrudes younger volcanic units. The Rams Head crosscuts and terminates reddish colored rhyolite dikes (fp) that pass through the Spot Pond Granodiorite at Wenepoykin Hill. Southeast of South Reservoir LaForge (1932) did not distinguish the porphyry from the much coarser and quartz-rich Spot Pond Granodiorite of this study. Kaye's (1980) map distinguishes the porphyry from the Dedham Granodiorite (Spot Pond of this map) and classifies the unit as "tonalite-granodiorite", but the unit has too little alkali feldspar to be granodiorite. Kaye includes the unit with the Stoneham Tonalite of this map in the northern Middlesex Fells and correlates it with the Newburyport Quartz Diorite of Emerson (1917) and LaForge (1932). The Stoneham and Rams Head are not physically connected at the surface and the Stoneham is not porphyritic except in its contact areas. A U-Pb zircon age for the Rams Head (6 crystals, ID-TIMS): 596.24 ± 0.16 Ma.

Black Rock Tuff (Ediacaran) – ***Massive dacitic very crystal-rich pyroclastic volcanic rocks in the southeastern Fells. Three different facies of the Black Rock Tuff are recognized that form an eastward-dipping regional structure with younger parts of the unit to the east. The unit contains many volcanic lithic fragments as well as quartzite and argillite lithic fragments likely from the Westboro Formation (Zvwq). This unit, unlike all younger volcanic units in the area, only has rare small broken quartz fragments. These rare quartz grains appear to be xenocrysts from the Westboro Formation. They are not first generation crystals or the embayed and rounded quartz xenocrysts found in all younger volcanic units that are derived from coarse granitic rocks. The Black Rock may be co-magmatic, or nearly so, with the Spot Pond Granodiorite, which appears to have intruded its own volcanic pile. The contact of these two units occurs north of Hemlock Pond where the units seem to intermingle and the tuff has a lower crystal density along the contact. The Black Rock is heavily fractured and in some places has a closely-spaced cleavage set with slickensides that are mineralized by hematite, which does not appear in the nearby Pine Hill Felsite. Correlated by Kaye (1980) to the Lynn Volcanic Complex of Clapp (1921) and LaForge (1932).***

Zbrv — **Vitric (fine-crystal) tuff facies –** Light bluish to pinkish gray (5B 7/11 to5 YR 8/1) vitreous to very fine crystal tuff. Weathers to light colors (very pale orange to very light gray: 10 YR 8/2 – N8) and in places has faint steeply eastward-dipping layers that define bedding. Can have a chert-like appearance and crystals greater than 1 mm are sparse. This unit also has more fine broken quartz fragments than the other facies. Unit occurs at the southeastern border of the Fells in Malden and is not exposed over a wide area.

Zbrl — **Lithic crystal tuff facies** – A traceable N-S striking and east dipping layer within the crystal tuff facies (Zbrc) in the southeastern Fells similar to the crystal tuff facies but with the addition of up to 20% mostly volcanic lithic fragments more than 0.5 cm in diameter. Rounded to angular lithic fragments range up to 8 cm and include abundant reddish-brown and medium to dark gray crystal tuff with white plagioclase crystals, medium to dark gray aphanitic devitrified volcanic rock, sparse amygdaloidal rocks, highly foliated very fine-grained banded felsite, lithics with flattened glass or pumice, devitrified flattened porphyritic sialic lava fragments (originally glass), and occasional quartzite and argillite. This layer has a sharp western contact and grades to the east to crystal tuff with smaller and sparser lithic fragments that occur in discontinuous patches where the rock transitions to the crystal tuff facies. This suggests that the unit is upright and younger to the east. Layering defined by the unit matches the trend of layering occasionally seen in the adjacent crystal tuff facies and internal to the unit (see next unit below). LaForge (1932) recognized this unit as a breccia with dacitic matrix in the Melrose Highlands and Oak Grove area of Malden (near Black and Melrose Rocks). While the Oak Grove deposit is the one identified here the Melrose deposit may be in a younger volcanic unit further north.

Zone with flattened and stretched glass (pumice?) fragments – At the top (east side) of the lithic crystal tuff facies (Zbrl), recrystallized flattened pockets interpreted to be flattened and stretched glass/pumice fragments. Pockets are up to 10 cm long, but usually 2-4 cm, weather to a dark color, and are recessed from the rock surface due to weathering. The mineralized pockets parallel the overall layering depicted by the lithic tuff unit and banding measured within the Black Rock Tuff. Measurements of the strike and dip of the foliation defined by the pockets are indicated with a separate symbol.

Zbrc — **Crystal tuff facies –** The dominant facies of the Black Rock Tuff. Light to dark gray (N3-6 with occasional slight greenish or reddish tones) welded crystal tuff that weathers by flaking. Surface of unit weathers to a very pale orange (10YR 8/2) to yellowish gray (5Y 8/1). Up to 50% of the rock is crystals of white plagioclase sitting in a very hard, dark, aphanitic ground mass of finely intergrown quartz and feldspar formed from devitrified glass. Matrix areas do not stain strongly for potassium indicating a dacitic composition. Crystals are 0.5-3 mm, tabular to blocky, and euhedral to broken plagioclase with less abundant broken and euhedral amphibole (hornblende) crystals that are usually altered to chlorite and epidote. The matrix occasionally shows bands, faint microscopic layering around crystals and lithic fragments, and faint layering defined by flattened and pinched black to reddish black porphyritic lenses that stain heavily for potassium, especially at Black Rock. These elongate masses are rarely observable in outcrop and have a spherulitic and axiolitic microscopic texture indicating devitrified flattened glass or pumice fragments. Scattered lithic fragments of volcanic lithologies and argillaceous quartzite are generally 0.2-1.0 cm. The unit has a very high crystal density throughout except in a narrow band along the contact with the Spot Pond Granodiorite north of Hemlock Glen. The massive homogeneous character of the unit across its entire outcrop area supports well-organized joint patterns. It also has mineralized (specular hematite) closely-spaced slickensided surfaces not related to the joints that appear to be a cleavage, possibly formed early in the rock's history. A radiometric age near Hemlock Pond is 602.1 ± 3.9 Ma (LA-ICPMS, 42 zircons; Hamilton, 2017).

Zdpg — **Doleful Pond Granite (Ediacaran) –** Coarse-grained white to greenish gray or light pink equigranular granite to granodiorite with tannish white or light greenish gray (5GY 8/1), euhedral to subhedral plagioclase and pale red (10R 5-6/2), perthitic alkali feldspar (microcline). Feldspars have a pistachio greenish appearance when they are altered to epidote and sericite. Mafic minerals (always <10%), which were originally biotite, are largely altered to chlorite, epidote, and fine opaque minerals. Quartz is strained and shows undulatory extinction. Occurs in an area northeast of Doleful Pond in the northern Fells. This unit is similar to the Spot Pond Granodiorite in mineralogy and grain size but has more conspicuous alkali feldspar. It has no physical connection with the Spot Pond and is conservatively treated as a separate unit pending age control and further mapping outside the Fells. The Doleful Pond Granite was interpreted as part of the Dedham Granodiorite by Emerson (1917) and LaForge (1932). LaForge (1932) shows this unit as an isolated circular area of Newburyport Diorite that was lumped with Stoneham Tonalite of the current map. Kaye (1980) does not distinguish this unit from the tonalite, which is surprising given its conspicuous alkali feldspar grains and coarse grain size. Kaye mapped it as part of a large body of tonalite/granodiorite mapped here as the Stoneham Tonalite (Zst) and Winchester Granite (Zwg). The age of this unit remains uncertain.

Zsg — **Spot Pond Granodiorite (Ediacaran) –** Coarse-grained, mostly leucocratic, white to greenish gray or light pink equigranular granodiorite with some areas of granite. Plagioclase is creamy white or light greenish gray (5GY 8/1) euhedral to subhedral with greenish appearance when altered to epidote and sericite. Subordinate pale red (10R 5-6/2), perthitic, interstitial alkali feldspar (microcline; see Zsgk below) that is occasionally a poikilitic host to euhedral plagioclase. Feldspar colors determine overall color of rock. Quartz occurs as abundant (up to 50%), coarse strained grains with undulatory extinction. Mafic minerals (usually <10%), are chlorite, epidote and opaque minerals formed by alteration of biotite with a few scattered primary opaque grains that are titanomagnetite or ilmenite. Hornblende also occurs in the unit but is much less abundant than biotite and is usually completely altered to chlorite and epidote. Local variations occur with: 1) alkali feldspar concentration and minor grain size changes, and 2) mafic mineral concentration. Areas of higher alkali feldspar have fewer mafics. Accessory minerals are titanite, which occurs in almost every non-deformed sample, and apatite, which occurs as small cylindrical crystals in areas of biotite alteration. Occurs at southern end and southeastern corner of Spot Pond and extends west of Rt. 93 through the northern Pine Hill and Gerry Hill areas to Lawrence Woods as rounded glacially streamlined outcrops. Heavily baked quartzite and argillite xenoliths, sometimes partly assimilated, of all sizes (up to 150 m in length) from the Westboro Formation (Zvwq) are common throughout the granodiorite. Displays a strong foliation with mylonitic polycrystalline quartz and aligned plagioclase and mafic minerals within a kilometer of its contact with the Westboro Formation on Gerry Hill, possibly in association with an east-west trending fault. The margin of the unit in contact with quartzite and the Black Rock Tuff displays no chill zone but in places may have coarser alkali feldspar and a higher chlorite content. The Spot Pond is the ideal "Dedham" lithology of previous studies and Bell's (1948) "normal" variety of the Dedham Granodiorite. It is the main part of the Dedham Granodiorite of Emerson (1917) and LaForge (1932), who lumped several plutonic bodies with it. Mapped as trondhjemite by Kaye (1980) but it is too rich in potassium feldspar and has too much calcium in plagioclase for this to be the case. Kaye's map groups several plutonic bodies with the unit mapped here and because of this makes the claim that it intrudes surrounding volcanic rocks. No evidence for this intrusive relationship has been found for the Spot Pond with volcanic rocks of the Pine Hill, Straw Point, or Wamoset Hill units mapped here, which except for the Straw Point have embayed quartz grains (xenocrysts) thought to be derived from the Spot Pond. The Pine Hill and Wamoset Hill also contain coarse granitic debris likely from the Spot Pond. The Black Rock contact has been difficult to interpret being either co-magmatic or intruded by the Spot Pond ages. The Spot Pond has rare sialic volcanic xenoliths of unknown origin (see Zfi below). A radiometric zircon age near Red Cross Path is 609.5 ± 0.2 Ma (ID-TIMS; F. MacDonald, pers. com.). The Spot Pond appears to be an equivalent of the Dedham Granodiorite south of Boston.

Zsgk — **Spot Pond Granodiorite, leucocratic alkali feldspar granite zones (Neoproterozoic?) –** Leucocratic and alkali-rich areas within the Spot Pond Granodiorite that have alkali feldspar dominant over plagioclase, almost no mafic minerals, and generally a bright orange red color (2.5YR 6/6-5/8). Two types of areas have been mapped. One type is more abundant and is alkali granite as coarse as the host granodiorite with abundant light red (2.5YR 6/8) coarse alkali feldspar crystals (up to 50%) and less than 15% plagioclase. This may be a local variation of the granodiorite or large xenoliths of a unit not exposed at the surface in the Fells. These zones occur along the east side of Rt. 28 northwest of Wrights Pond, south of Gerry Hill, and in Lawrence Woods near Medford High School. An area of the first type has also been mapped in the Winchester Granite (Zwg, see description) west of Bear Hill and appears to be an area identical to what is described here. This lends support for these areas being xenoliths. A second type occurs at only one place on a hilltop northwest of Wrights Pond and is a distinctly finer-grained zone than the host granodiorite with a granular appearance. This may be a xenolith from a unit not exposed at the surface.

Zfi — **Baked xenoliths of Sialic Volcanic Rock in Spot Pond Granodiorite (Neoproterozoic?) –** Small (up to 10 m) dark gray (N 5/0), greenish gray (5G-5GB 5/1), and brown (10YR 5/1) very fine rhyolitic to dacitic volcanic xenoliths that are sparsely porphyritic. Except for minor color differences and alteration by contact metamorphism, all occurrences have the same overall appearance. Occur at three places: 1) east side of Woodland Avenue northwest of Hemlock Pond, 2) on the southwest side of the swamp along Rt. 28 west of Wrights Pond, and 3) west of Red Path and northern extension of Little Pine Hill (Figs. Zfi1-2). The source(s) of the sialic xenoliths is not known.

Zwg — **Winchester Granite (Ediacaran)** – Reddish to pinkish tan, medium-grained equigranular granite to granodiorite in northwestern Fells of Winchester west of South Reservoir and west and north of Middle and North Reservoirs. Reddish color derived from moderate reddish orange (10R 6/6) to moderate reddish brown (10R 4/6) alkali feldspar that is up to 40% of the rock. Reddish coloration can be misleading in some areas and resulting from hematite staining. Mafic minerals can be 15-50%, quartz 15-20%, and plagioclase up to 30% but usually subordinate or equal to alkali feldspar. The unit displays rapid changes in grain size and mafic mineral content suggesting local assimilation of mafic-rich quartz diorite, iron-rich metabasalt, and coarse alkali granite in some areas. Two of these areas have been mapped as xenoliths on Money Hill (Zwgd) and west of Bear Hill (Zsgk). The quartz diorite xenolith appears to have a source in a rock unit not exposed at the land surface in the Fells. The granite is heavily sheared in some places near faults. It is distinct from the Stoneham Tonalite (Zst) in being equigranular (non-porphyritic) and having larger quartz grains and more abundant alkali feldspar. In the northwest Fells along Wyman Path and along Middle Reservoir this unit has occasional metabasalt hornfels xenoliths from the Nanepashemet Formation. Bell (1948) classified this rock as the "Stoneham red granite stock" and identified it as different than the tonalitic rocks at Bear Hill and further east in Stoneham, although he included it as part of the "Dedham Granodiorite". Classified by Kaye (1980) as tonalite-granodiorite and lumped with the Stoneham Tonalite (Zst) of this study but the rock has too much alkali feldspar to be classified this way. Kaye, like Emerson (1917) and LaForge (1932) correlated it with the Newburyport Quartz Diorite. A radiometric zircon age near Long Pond is 609.7 ± 0.24 Ma (ID-TIMS; F. MacDonald, pers. com.) giving it an age indistinguishable from the Spot Pond Granodiorite. Like the Spot Pond, the Winchester Granite appears to be an equivalent of the Dedham Granodiorite south of Boston.

Zwgd — **Quartz Diorite Xenolith in Winchester Granite (Neoproterozoic?)** – Gray medium-grained equigranular to faintly porphyritic quartz diorite xenolith (?) on east side of Money Hill in northwestern Fells of Winchester north of North Reservoir. Xenolith has a higher mafic content than other sialic plutonic bodies. Pieces of this lithology may also be partly assimilated into the granite in several places, most notably in shore exposures at the north end of North Reservoir.

Znpm — **Nanepashemet Formation (Neoproterozoic)** – Dark gray to almost black (N 1-4) and dark olive to greenish and bluish gray (5Y-5G 3-4/1) metabasalt and argillite with occasional metabasalt breccias and conglomerates and basal red mudstone to sandstone and breccias. The breccia/conglomerate beds hydrothermally altered and may have had a matrix of palagonite. They are often difficult to recognize in the field and are likely more widespread than where identified so far. The overall dark greenish gray color of the formation, results from various combinations of chlorite, actinolite, hornblende, and epidote. This formation has mostly been altered to hornfels near its contacts with the Winchester Granite (Zwg) and Stoneham Tonalite (Zst) and in places appears to form a thin roof over these plutonic bodies. Later sialic intrusions have created plutonic breccias and numerous irregular sialic dikes in the formation and both the alteration of large phenocrysts/xenocrysts of pyroxene and contact metamorphism can cause the rock to weather with a honeycomb (alveolar) texture that mimics lava with coarse vesicles. The recrystallized dark hornfels makes mapping younger dolerite and basalt dikes challenging, especially where they have diffuse contacts due to melting of the hornfels along the edges of the dikes. Although the rock has metabasalt no lava flows or pillow structures, and only very infrequent relict amygdaloidal units have thus far been found (keratophyre and quartz keratophyre of Kaye, 1980). Recognition of primary structures is nearly impossible because: 1) the unit may be sheared along faults imparting a wavy chloritic and actinolite foliation with quartz and epidote veins, 2) original bedding may have been obscured by mass flow in volcaniclastic units, 3) the unit is hydrothermally altered by fluids that created epidote, oxide, quartz and opal veins, and 4) the unit occurs near plutons and dikes that have transformed the unit to actinolite-hornblende hornfels, especially in the Winthrop and Bear Hills and Taylor Mountain areas. In addition to metabasalt/argillite hornfels, the unit has three unique lithologies among rocks in the Fells including: 1) a basal matrix-supported breccia and conglomerate with quartzite clasts in a red mudstone to well-bedded reddish gray to light gray sandy matrix (see below); 2) scattered clast-supported conglomerate and breccia beds with volcanic to coarse mafic pebbles. A notable location is at the northeast corner of Middle Reservoir beneath an unconformity with younger volcanics where baked conglomerate beds contain pebbles of basalt, vesicular basalt, dolerite, gabbro and also sialic volcanic lithologies; and 3) marble (skarn) at the north end of Middle Reservoir that is interlayered with dark blackish green hornfels adjacent to a contact with the Winchester Granite (Zwg). Bounding time relationships with surrounding units have been difficult to discern because of east-west trending faults and large intrusions that bake and interrupt the formation. Outcrops west of South and Middle Reservoirs indicate that the formation rests on an unconformity on the Westboro Formation (Zvwq). On the north side of a fault along Molly's Spring Road the Westboro Formation is in contact with the Nanepashemet Formation. The Westboro Formation has a regional metamorphic foliation that does not pass into the base of the Nanepashemet. The base of the Nanepashemet has a sandy breccia/conglomerate with angular chunks of Westboro Formation in a sandy matrix. Nearby are also partly melted and recrystallized inclusions of quartzite with opal veins in metabasalt. Along Molly's Spring Road are well bedded red mudstone to reddish fine sandstone layers in float boulders associated with the quartzite-bearing breccia and conglomerate beds. Exposures of the top of the formation are equally elusive because the unit is mostly terminated at faults or interrupted by intrusions (Stoneham Tonalite and Winchester Granite). At the north end of Middle Reservoir, steeply foliated metabasalt and bedding in conglomerate beds in the Nanepashemet are truncated by gently dipping, banded rhyolite in the Straw Point Volcanic Complex, indicating an angular unconformity. Local float boulders of bedded siliceous mudstone hornfels are associated with the conglomerate. The Nanepashemet Formation was correlated to the Marlboro Formation of Emerson (1917) by LaForge (1932) based on its basaltic volcanic origin. Later the rocks were classified as part of the Middlesex Fells Volcanics (Bell and Alvord, 1976), which is here split into different formations (Straw Point and Nanepashemet) that have an unconformable contact. See Straw Point Volcanic Complex for more detailed discussion.

Zvwq — **Westboro Formation (Neoproterozoic)** – Alternating layers of dark gray (7.5YR 4-5/0), rusty weathering, siliceous argillite, metasiltstone, and fine white to light gray (7.5 YR 8-7/0) layered to massive fine to medium quartzite. These units have a deformed zone with calcium/magnesium silicate minerals (tremolite, diopside, calcite, and zoisite) near along Pond Street, in Virginia Wood, and west of the southern end of South Reservoir. Quartzite seems to dominate outcrops, but argillaceous units are not as well exposed and make up a considerable part of the unit. The upper surface of the unit is a thick (2-3 m) quartzite layer truncated by an unconformity beneath the Nanepashemet Formation (Znpm), which is well exposed on the north side of the entrance to the southern parking lot at Sheepfold. East of Middle Reservoir and west of Sheepfold the unit is truncated along a fault bounded to the north by bluish-green (5G-BG 4/1-2) chloritic metabasalt of the Nanepashemet Formation (Znpm). West of South Reservoir the unit is unconformably truncated by basal sedimentary units of the Nanepashemet Formation (Nanepashemet description above). In other places the unit is truncated above by faults and intrusions. The lowest part of the Westboro in the Fells is in fault or unconformable contact with younger volcanic units (Black Rock Tuff) south of Ravine Road, but glacial sediment conceals this interval. The quartzite is truncated below by intrusive igneous rocks from Spot Pond to the area east of Medford High School. Slab-like quartzite/argillite hornfels xenoliths of the Westboro up to 150 m long are mapped in the Spot Pond Granodiorite. Argillite in the unit is baked to hornfels in inclusions or where it is intruded by the Spot Pond Granodiorite (Zsg), Rams Head Porphyry (Zrhp), Winchester Granite (Zwg), and Stoneham Tonalite (Zst). The hornfels generally has biotite or chlorite and/or hornblende crystals. The Stoneham Tonalite has abundant small xenoliths from the Westboro. The Westboro has significant regional metamorphism not seen in any other unit in the Fells. Deformation is generally parallel to original bedding, preserved to varying degrees depending on local shear. Usually, thick quartzite layers are massive and may be brittley dismembered or within argillaceous units are stretched and folded and form boudin-like lenses. Quartzite units have stretched and heavily sutured quartz grains with muscovite tails and shadows. The unit can be mylonitic in southern Virginia Wood and along near faults, which gives the rock a banded or streaked appearance. These units usually have abundant tremolite. There is a consistent E to NE striking foliation that dips to the NNW except where this trend is reoriented near faults. East of Spot Pond the unit has a well developed magnetic (AMS) foliation with a lineation indicating stretching in addition to flattening. Small drag folds occur west and south of South Reservoir, along Pond Street in Virginia Wood, and in large quartzite xenoliths, and are likely in other areas but are hard to see in the field. The sense of shear indicated by folds on the NW dipping plane of foliation at Pond Street is for SE translation of layers upward on the foliation plane over layers below. The Westboro was previously mapped with the Whip Hill Formation of this map as Westboro Quartzite by LaForge (1932) as originally defined by Emerson (1917) without recognition of the intervening Wamoset Hill Felsite. Kaye (1980) also did not recognize the separation of the quartzite units by the intervening volcanic rocks. The Westboro in the Fells cannot be physically connected to the type area of the Westboro Formation (Bell and Alvord, 1976) and in the Fells it has a somewhat different lithology with more abundant calcium-magnesium silicate zones and a lower metamorphic grade than the type area. Metamorphic grade is still above that of any other unit in the Fells. Earlier versions of this map recorded the Westboro Formation in the Fells as the Virginia Wood Quartzite but correlation to the Westboro Formation seems secure based on detrital zircon ages. Minimum zircon ages from Pond Street (909 ± 24 Ma; F. Macdonald, pers. com.) indicate the formation is younger than ~900 Ma and likely Tonian in age given its lithology and metamorphism. This matches the Westboro Formation further east (F. Macdonald, pers. com.; Thompson et al., 2012).

EXPLANATION OF MAP SYMBOLS

ORIENTATION DATA

Strike and dip of planar features in sedimentary and metasedimentary rocks

- 70 — Orientation of bedding for which top is known. At these locations bedding has not been significantly altered by structural deformation.
- 70 — Orientation of overturned bedding for which top is known. At these locations bedding has not been significantly altered by structural deformation.
- 70 — Orientation of bedding for which a top is not known from field information. At these locations bedding has not been significantly altered by structural deformation.
- 70 — Orientation of foliation. Also represents orientation of compositional layering and in most cases is a strong foliation parallel to significantly deformed bedding.
- 45 — Bearing and plunge of lineation on bedding or foliation plane.
- 65 / 58 — Anisotropy of magnetic susceptibility (AMS): strike and dip of magnetic foliation - plane of maximum (K1) and intermediate (K2) susceptibility axes (strike and dip symbol and large number) and plunge of lineation (K1) on foliation plane (arrow and small number).

Strike and dip of planar features in volcanic rocks

- 60 — Orientation of foliation represented by banding in felsite or flow structure in basalt.
- 60 — Foliation of flattened and stretched glass or pumice fragments (fiammé).

Strike and dip of planar foliation in deformed plutonic igneous rocks

- 75 — Gneissic or mylonitic banding in coarse-grained igneous rocks expressed as elongated quartz grains and the orientation of other minerals. Only found in the Spot Pond Granodiorite (Zsg) near its intrusive contact with quartzite west of Rt. 93.

Strike and dip of dikes

80 basalt — 80 dolerite — 80 porphyritic basalt/dolerite

Small dikes – dikes less than 1.0 m in width that are traceable over at least 2 m.

b basalt — d dolerite — p porphyritic basalt/dolerite — f andesite, dacite or rhyolite

65e — **Strike and dip of veins or mineralized minor fault surfaces sometimes with gouge -** labels indicate vein minerals and materials: q – quartz, e - epidote, g – fault gouge.

70 — **Strike and dip of continuous flat planar fractures and joints -** only shown where fractures are flat and continuous over a distance of at least 10 m. Associated with these prominent joints are many other local fractures not indicated on the map. Density of measurements is dependent on rock units, some of which have a massive character that allows the development of long flat fractures while other units have fractures with many directions that are not traceable over more than a few meters.

50 66 — **Slickensides** – strike and dip of surface on which slickensides occur (large number is dip of slickensided surface) with arrow indicating plunge direction and plunge (small number) of slickensides on the dipping slickensided surface.

50 / 63 — **Tension gashes along shear or joint surfaces** – strike and dip of shear or joint surface (black) and strike and dip of tension gash surfaces (red)

FAULTS

Minor faults and fracture zones (dashed where inferred) – prominent fractures and minor faults with minor displacement and lateral extent as determined by the offset of dikes, contacts between major rock units, and other continuous features in rock units. Usually expressed as low spots or slot-like valleys in rock where erosion has taken advantage of fractures. Minor fault zones have smaller displacement and less shearing of adjacent rock than major faults.

Major faults (dashed where inferred) - major faults with large displacement (>50 m) and lateral extent (over kilometers) as determined by the offset of dikes, contacts between major rock units, minor faults, and other continuous features such as other major faults. These faults are generally associated with highly sheared rock that forms larger valleys or ravines than along minor faults.

UNCONFORMITIES

Surfaces overlain by sedimentary, pyroclastic, or volcaniclastic units or lava flows that are interpreted to be unconformities, which either truncate bedding or layering in the unit below, represent erosion of the unit below, or represent an abrupt change in metamorphism that requires erosion in the absence of a fault.

OTHER DATA

10573 / 10226 — Bedrock sample site with sample number. Sample sites are numbered in two sequences. Sites with three digits, beginning with site 001, are from an earlier surficial mapping project. Five-digit numbers beginning with site 10001 are from bedrock mapping for this project. Samples marked Pf, DG, X, or MR are sites of Zarrow (1978).

Locations where bedrock displays noteworthy properties described in field notes.

Bedrock quarry, mine or excavation for fill. Dashed line only used in areas of large excavations. Letter abbreviations for rock types: f - felsite, g - granite, G – gabbro, m – metasedimentary rock, d - dolerite.

Abandoned bedrock quarry, mine or excavation for fill. Dashed line only used in areas of large excavations. Letter abbreviations for rock types: f - felsite, g - granite, G – gabbro, m – metasedimentary rock, d - dolerite.

Abandoned mine shaft on Silver Mine Hill in the Middlesex Fells Reservation east of South Reservoir.

Exposure of pre-glacially weathered rock or saprolite (up to 10 m exposed). The only unit of occurrence is the Medford Dike.

602 — Site of radiometric age with age listed in millions of years before present (Ma).

REFERENCES (see detailed map explanation with images at: http://sites.tufts.edu/fellsgeology)

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