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The Bedrock Geology of the Middlesex Fells Reservation and Adjoining Northern Boston North 7.5-minute Quadrangle in Middlesex County, Massachusetts, USA

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Reading this publication

The extensive rock exposures in the Middlesex Fells and in many other parks and conservation lands in this area are an opportunity for detailed study of the geology where the land surface has not been obscured by development. The geologic map and explanation provided here are technical documents intended to further a detailed understanding of the geology of the Middlesex Fells Reservation and other parts of the northern Boston North, Mass. 7.5-minute Quadrangle.

For those familiar with the geology of the area from other publications it would be beneficial to review the introductory sections of this explanation on pages 4-19. These pages introduce new techniques and conventions used during mapping and give a summary of revisions from previous maps. The stratigraphy has changed from earlier maps in some fundamental ways – some units have been subdivided, some unit names have been changed, and new units have been introduced.

You should also be aware that this is unlikely the final word on the geology of the area since mapping is currently expanding in the Boston North and Lynn, Mass. Quadrangles. Mapping continues to accumulate information, and future updates should be expected.

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Methods and Conventions

1. Map Area and Base Map

The bedrock geology was mapped and compiled in GIS format (currently ArcMap 10.8.1) since 2012 with continuing updates and expansion of mapping outside the Middlesex Fells. Field data was recorded in UTM coordinates (zone 19T, 1927 North American Datum). The base map is a hill-shaded relief map based on 2015 MassGIS LiDAR raster data with 1-meter resolution and was produced with the Multi-Directional Hillshade Raster Function in ESRI’s ArcMap 10.4 and then projected to UTM coordinates (1927 NAD). Geologic map layers use UTM coordinates in zone 19T with either the 1927 or 1983 North American Datum.

The transportation infrastructure outside DCR lands is from the MassGIS MassDOT shape file with roads and rail lines (1983 NAD; last updated 2013). Trails and roads in DCR lands are from the MassGIS DCR Roads and Trails shape file (1983 NAD; last updated 2014). Small corrections were made in the Middlesex Fells to make roads and trails better align to the LiDAR hillshade base map when they clearly showed a mismatch verified by field observations. Water bodies and wetlands were traced as geologic units using the LiDAR generated hill-shade base map as a guide and in the field using UTM (1927 NAD, zone 19T) GPS coordinates. In some places the map shows the land surface and shoreline topography in areas mapped as water in the field because the LiDAR data were obtained when reservoirs had low levels. Mapping around North Reservoir in the Middlesex Fells was partly done while that reservoir was drained for maintenance.

The map area is 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 (1:62,500). 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).

2. Field Mapping and Data Collection

High-resolution (1.0 m) field mapping used GPS and LiDAR technology, which was not available to previous investigators. Many bedrock geologic maps show outcrop occurrences, but this was not unnecessary in the Fells where outcrop density is very high, and an enormous number of GPS coordinates were recorded to accurately display the detail and complexity of the map. Where bedrock units are concealed and cannot be interpreted because of surficial cover or artificial fill these units are mapped instead of a bedrock unit. While mapping outside the Fells, where exposures are not as dense, a red screen pattern was used to indicate outcrop areas.

Many samples were collected for slicing on a rock saw to refine initial identification of rocks in the field and to make thin sections. Digital images of sliced, wet surfaces of rock samples gave a clearer view of minerals and textures than outcrop surfaces and these images are shown throughout the explanation. Over 900 thin sections were also prepared and are critical to more accurate rock identification and compositional analysis.

3. <u>Rock Nomenclature</u>

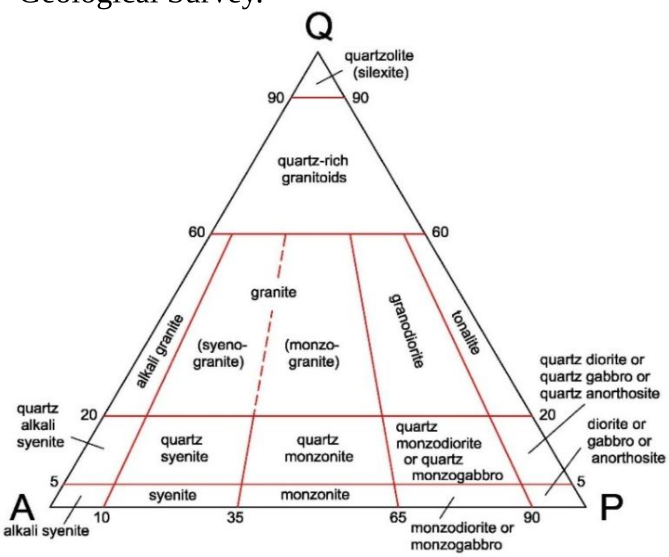
Igneous rock terminology follows the IUGS classification (Le Bas and Streckeisen, 1991). Below are the rock nomenclature triangles for the felsic (light-colored) components (quartz - alkali feldspar – plagioclase or QAP) of both coarse- and fine-grained igneous rocks. Mafic (dark-colored) igneous rocks were classified as basalt, dolerite, or gabbro based on their grain size and not classified further. The term “dolerite” is used instead of diabase for mafic dikes following the usage of recent studies of dikes in the Boston area (see references by Ross). Classification of felsic volcanic rocks in the field is often difficult and requires thin section or geochemical analysis. A special document “Textural and Petrographic Features of the Felsic Volcanic Rocks of the Middlesex Fells Reservation, eastern Massachusetts” at: http://sites.tufts.edu/fellsgeology gives a catalogue of felsic volcanic rock types, features, and textures in the area, both in thin sections and hand samples, as well as definitions of terms to show how the volcanic rocks were interpreted and classified in this study.

The word “hornfels” is used in this document as a term for hard, brittle, fine-grained rock that breaks irregularly or with conchoidal fractures due to contact metamorphism, following the definition of Winter (2010). Here, *hornfels* includes fine-grained rocks produced by the contact metamorphism of fine quartzite, metasiltstone, mudstone, argillite and fine basalt. Baked argillite and fine basalt without phenocrysts can be difficult to distinguish in the field without thin section analysis.

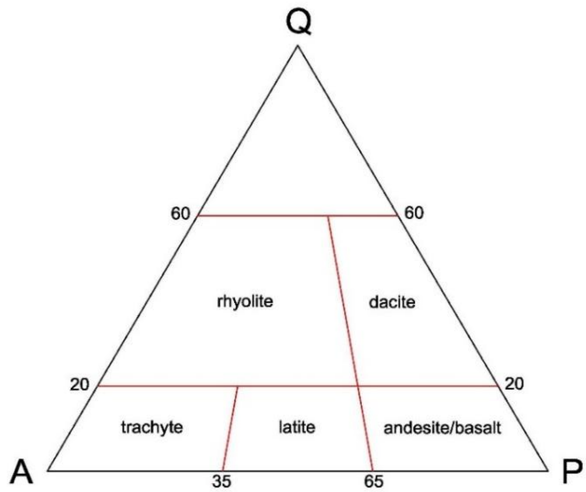
Nomenclature for rock color follows the Geological Society of America’s Munsell Rock Color Chart as revised in 2009 and the Munsell Soil Color Chart, 1975 edition. Color is given for only fine-grained rocks or for individual mineral types when relevant.

Descriptions of rock units are given with images of outcrops, thin sections, and cut rock slabs photographed under water which gives them a polished appearance. Thin sections were made by Burnham Petrographics in Rathdrum, Idaho and Spectrum Petrographics in Vancouver, Washington. Thin section images were captured using a Leica DMS 1000 petrographic microsystem.

Unit symbols for Late Proterozoic rocks use the “Z” designation adopted by the U.S. Geological Survey.



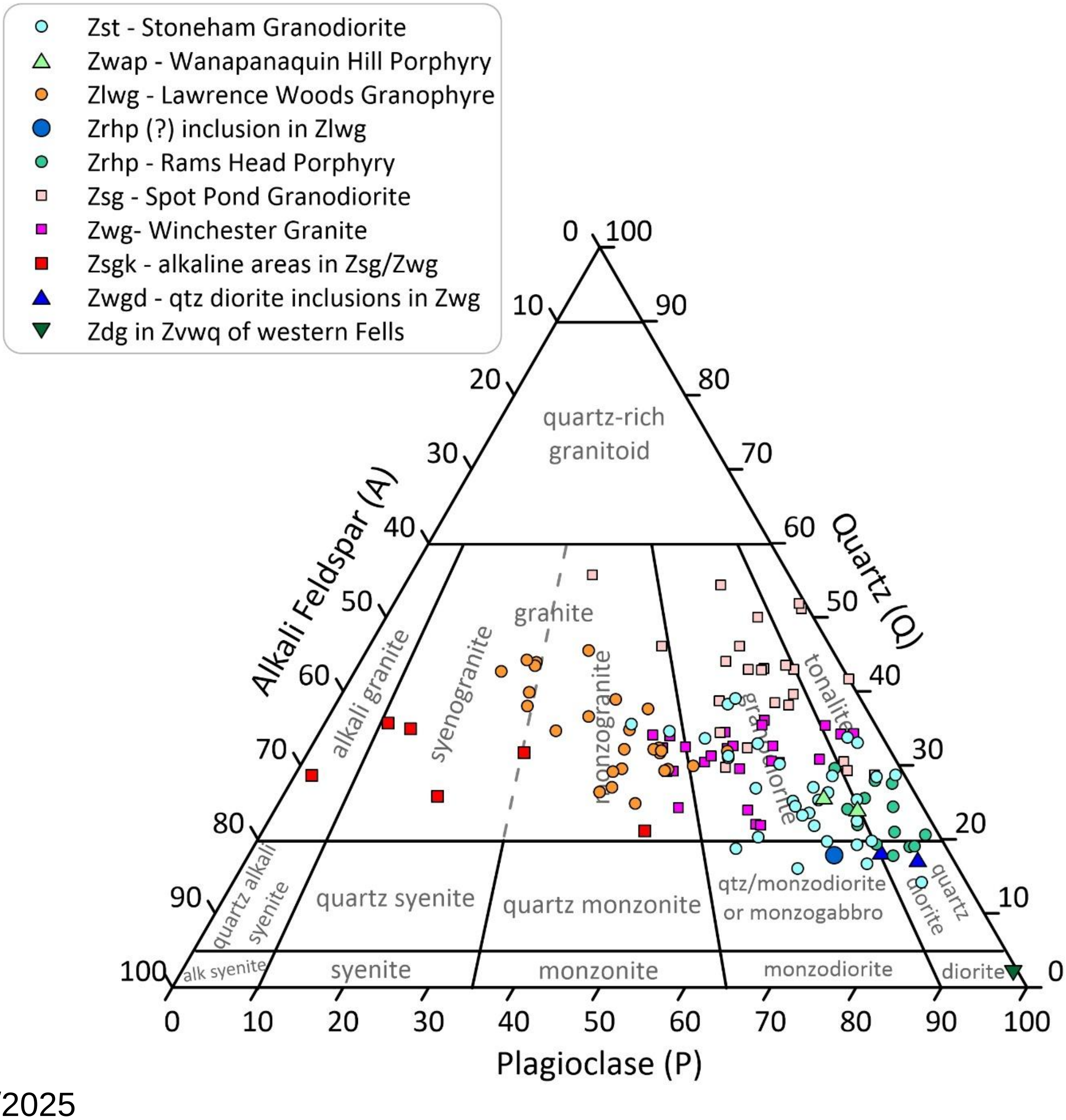
Coarse-grained igneous rocks



Fine-grained igneous rocks

4. <u>Point Count Data – Felsic Plutonic Igneous Rock Units</u>

Point count data was collected from all the felsic plutonic igneous rock units. This data is plotted below and is given for individual rock units in their descriptions, using normalized QAP ternary plots with IUGS nomenclature (Le Bas and Streckeisen, 1991; see previous page). The plots were used to investigate mineralogical differences or similarities between units that were distinguished by their field characteristics and radiometric ages. Each point count is at least 300 points. Thin sections were often stained for potassium, making identification of alkali feldspar and granophyric grains easier and more accurate. To include **granophyric grains** in the tabulation of values for QAP plots, and to get a more representative overall compositions, they were tabulated as ½ quartz and ½ alkali feldspar. Granophyric grains with coarse quartz and alkali feldspar bands were simply counted as either a quartz or alkali feldspar grain at the point of a crosshair. In addition to QAP differences, the units also have different mafic mineral abundances, which aids in their distinction in the field. Tables of point count data for felsic plutonic igneous rocks are given in Appendix 1.



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5. Point Count Data – Felsic Pyroclastic Rock Units (Tuffs)

Thin section counts were done on felsic pyroclastic volcanic units (tuffs) as a means of comparing different volcanic units and for determining possible regional trends. Pyroclastic units vary in terms of their three major components: crystals - abundance and type, lithic fragments - abundance and types, and matrices – abundance and types. Normalized ternary plots of the three main components and normalized ternary plots of crystal types show fundamental differences between some tuff units. Point count data for pyroclastic rocks is given in Appendix 2.

Below is a listing of the categories that were used in the point counts. A complete catalog of felsic pyroclastic rock types as well as lava flows and their attributes are given in a special document, "Textural and Petrographic Features of the Felsic Volcanic Rocks of the Middlesex Fells Reservation, eastern Massachusetts", at: http://sites.tufts.edu/fellsgeology. Some thin sections were not counted because they would not yield results reflecting an accurate assessment of a rock. The chief reason for this is geochemical alteration and devitrification or recrystallization when rocks are reheated. Some samples were also heavily sheared, cataclastic, or anomalously heterogeneous.

Crystal categories:
Quartz(Q), Plagioclase (P), Alkali feldspar (A), Hornblende and biotite, and Opaque minerals.
Note: Hornblende and biotite were not separated because they were sometimes identified where alteration products (epidote, chlorite and opaque oxides) indicated their original presence in the rock. Pseudomorphic crystal shapes preserved as chlorite and epidote and relict cleavage were often used for their identification, especially the diamond-shaped outlines of hornblende and micaceous cleavage of partly altered biotite. Opaque mineral grains were either titanomagnetite or ilmenite or less commonly pyrite. These types were not distinguished.

Lithic Fragments (separated into categories):
Felsic Volcanic Fragments – banded, porphyritic, fine-grained (granular, patchy, splotchy and micropoikilitic), microspherulitic, eutaxitic and perlitic fragments, and flattened and pinched glass and pumice.
Accidental Fragments – quartzite and argillite, basalt, coarse igneous multi-grain fragments

Matrix Types (see document mentioned above):
Fine granular to patchy, splotchy to micropoikilitic, poikilomosaic, microspherulitic

Mineral Growths and Veins:
Classified by dominant mineral - Chlorite, epidote, quartz and oxide

Others:
Notes were collected on any points not in the above categories and then added to the total count. The most common 'other' point was calcite either as an alteration product or in a vein.

6. Radiometric Ages

A complete listing of radiometric ages from the Fells and surrounding area is given in Appendix 3. Radiometric ages are reported in Ma (mega-annum or millions of years before present). In addition to radiometric ages collected as far back as 1970, new ages have been obtained during the last 10 years. K/Ar and Ar^{40}/Ar^{39} ages collected on mafic dikes have limited accuracy because of uncertainties in assumptions related to argon values in an area with several episodes of reheating and hydrothermal activity that caused mineral alteration.

Recently obtained ages are mostly on felsic rocks using U-Pb analyses of separated zircon crystals. These ages include both LA-ICPMS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) and CA-ID-TIMS (Chemical Abrasion - Isotope Dilution - Thermal Ionization Mass Spectrometry) analyses. The CA-ID-TIMS method is a more recently developed technique that substantially removes some uncertainties related to the loss of lead from zircon crystals. This method requires fewer zircon crystals, is more accurate, and generally delivers 2-sigma and 95% confidence intervals that are an order of magnitude smaller than with the LA-ICPMS method. For example, typical uncertainties (2σ or 95% confidence intervals) on felsic rocks in the Middlesex Fells using the LA-ICPMS method are $\pm$ 3.3 to 5.6 Ma while they are $\pm$ 0.17 to 0.54 Ma on 3-5 zircon crystals for the CA-ID-TIMS method. In this study an attempt was made to systematically replace LA-ICPMS ages with new CA-ID-TIMS ages and both ages were obtained for recent samples in tandem for comparison. In one case an Ar^{40}/Ar^{39} age on biotite in a mafic igneous rock has been replaced by an CA-ID-TIMS age on zircon. This situation (see the Medford Dike) is unusual because zircon crystals can be absent or difficult to find and separate from mafic igneous rocks. This was a rare opportunity to improve age control. In general, LA-ICPMS ages tend to be a small bit older than CA-ID-TIMS ages from the same sample. CA-ID-TIMS ages are reported as a weighted average of 3-6 zircon grains. New ages obtained for this project are reported with 95% confidence intervals, which are more conservative than 2σ. For other CA-ID-TIMS ages a 95% confidence interval is reported unless otherwise noted as 2σ.

Although the extreme precision of CA-ID-TIMS age measurements is a major improvement, interpretation of these results has certain limitations (Klein and Eddy, 2023). In some cases, there may be inherited crystals from earlier rocks and prolonged crystallization can yield crystals with cores that are older than the final crystallization of the rock. Zircon crystals can also be stored in subsurface magma chambers prior to magma reactivation and final intrusion of the magma into shallower crust. Crystallization of the remaining magma after zircons have formed leads to a zircon age that is older than the final intrusion or crystallization event. Early zircon crystals can also become armored by later crystals such as quartz or feldspar, which terminates their growth before the whole rock is completely crystallized. It is necessary to be aware of these potential scenarios when different age populations or a spread of ages is recorded in a single sample and when trying to explore the associations between plutonic and volcanic units. Magma and zircon crystallization can have a duration that when recorded with a high precision CA-ID-TIMS age should not be viewed as an instantaneous event. Therefore, it is important to not over interpret ages of intrusive rocks with small precision values. In this project subvolcanic plutonic bodies seem to be most susceptible to inheritance and differences between individual zircon crystal ages.

Detrital zircon grains in sedimentary and metasedimentary rocks of low metamorphic grade in the Westboro Formation have also been studied in the Middlesex Fells area. For studying these rocks LA-ICPMS ages are obtained on a large population of zircon crystals. Since sedimentary zircon grains are from the erosion of older igneous rock formations, ages for the zircon grains give the ages of the source rocks. The distribution of ages for these grains act as a fingerprint for a sedimentary rock formation and tell us characteristics of the eroded sources of the original sediment. The youngest zircon grain in the distribution serves as the oldest possible maximum age for a sedimentary or metasedimentary rock formation. CA-ID-TIMS dating of the youngest grain studied can give a more accurate and precise maximum age for the rock formation when this is necessary.

7. Paleomagnetic Analysis

Paleomagnetic investigations have been employed to further understand the relationships of magnetic fabrics (anisotropy of low field magnetic susceptibility or AMS) to metamorphic fabrics in quartzite/argillite units and foliated granodiorite, and to study sedimentary and post-depositional fabrics in laminated fine sandstones and mudstones. Further work has been initiated to measure remanent magnetization in dolerite dikes, in the wall rocks adjacent to dolerite and gabbro dikes, and in well bedded sedimentary units. This work has just started and may reveal ancient virtual pole positions from the times at which rock units were formed or when their magnetism was overprinted. A goal is to eventually use this data to constrain ages and formulate tectonic reconstructions. A major challenge to this effort is that rocks in the Middlesex Fells area (Avalon Terrane) went through several reheating and tectonic events that could alter paleomagnetic signals. The rocks are often thermally and hydrothermally altered with recrystallization as well as the formation of chlorite, epidote/zoisite, tremolite/actinolite, and oxides. The rocks also may have been tectonically rotated about horizontal and vertical axes.

Changes from Previous Maps - Reformulating the Stratigraphy

The new map employs several new methods and conventions and is different from previous smaller scale maps (LaForge, 1932; Kaye, 1980) and regional scale interpretations in numerous field trip guidebooks. The differences are discussed below, and details are given in individual rock unit descriptions. In general, the current map tries to show lithologic differences between or within previously defined geologic units and avoids lumping lithologically distinct units. This created disagreements with previous interpretations and nomenclature. New formal rock names are used on this map to indicate subdivisions of previously named units and to reinterpret rock units and their correlations. Listed below are the major changes that are incorporated into the map.

On the next page is a reformulation of the bedrock stratigraphy in chart form followed by <u>diagrammatic</u> cross sections for the Middlesex Fells. The chart lists all the bedrock units from the Middlesex Fells area and further north and east in the Boston North Quadrangle south of the Walden pond fault of Kaye (1980) and their relative and radiometric ages.

1. <u>Mapping of Dikes</u>

All dikes have been mapped with detailed GPS coordinate control and as far as they can be traced. This allows an exploration of their age relationships with plutonic bodies and faults, and the distinction of different ages of dikes.

2. <u>Mapping of Faults</u>

Considerable time was spent tracing faults, not only large faults and shear zones with conspicuous topographic expression, but also minor faults sometimes associated with the major faults. Faults are mapped only when they displace rock formation contacts or dikes. They should also have a clear land surface expression related to greater erosion where fracturing is associated with the fault. Some faults have significant metamorphism with ductile deformation and mineralogical changes associated with high temperature fault displacement. The best description of the area is that it has been shattered by several ages of faults. Some faults may have been reactivated but this has been difficult to demonstrate.

3. <u>Distinguishing Volcanic from Subvolcanic Plutonic Units</u>

On previous maps (LaForge, 1932; Kaye, 1980), there was mixing of volcanic and subvolcanic (fine-grained porphyritic, often granophyric) plutonic bodies that are sometimes difficult to separate in the field without supporting thin section analysis. In the past, crystal tuff units were sometimes lumped with porphyritic subvolcanic units. Thin section analysis and detailed mapping of subtle contacts between volcanic and subvolcanic units has allowed a separation of these bodies, particularly in the southern Fells near Boojum Rock and Pine Hill. A key observation is the occurrence of many broken crystals in tuff units and cumulophyric plagioclase in subvolcanic and flow units.

In a separate document is a catalog of volcanic rock features and textures, both in thin sections and hand samples, as well as examples of how volcanic rocks were characterized. See Special Document, "Textural and Petrographic Features of the Felsic Volcanic Rocks of the Middlesex Fells Reservation, eastern Massachusetts", ***with the Bedrock Map at:*** *http://sites.tufts.edu/fellsgeology*.

4. Summary of Bedrock Stratigraphy

Last update: May 27, 2025

238 Ma **TRm** **Medford Dike** – NNE-SSW trending gabbro dike. **Age (Ma): 238.07 ± 0.09 (U-Pb zircon CA-TIMS)**

---- Time gap, Medford Dike crosscuts all dikes below, except possible rare Mesozoic dikes ----

d **dp** **Dolerite and basalt dikes (d), porphyritic dolerite and basalt dikes (dp)** – numerous ages from Neoproterozoic to possibly Mesozoic, offset by faults and crosscut each other, youngest set is relatively large dikes that are E-W trending. Crosscut by the Medford Dike.

gb **Gabbro dikes** – altered, crosscuts some dolerite dikes, west side of Middle Hill and northern Pine Hill. Not related to Medford Dike. Neoproterozoic to Paleozoic (?).

ad **Highly altered dolerite and basalt dikes** – chloritic with epidote and porphyroblasts of amphibole and chlorite. Often have diffuse contacts. Possibly several ages, Neoproterozoic to Paleozoic. In Nanepashemet Fm. may have fed basalt flows in hydrothermal environments.

Dike ages (Ma)*: d 226 ± 3 ($^{40}Ar/^{39}Ar$ whole rock)
d 290 ± 15, (K/Ar whole rock)
d 353 ± 4, ($^{40}Ar/^{39}Ar$ whole rock)
gb 402.5 ± 3 ($^{40}Ar/^{39}Ar$ whole rock)
d 573 ± 4 ($^{40}Ar/^{39}Ar$ whole rock)
*K/Ar and Ar/Ar ages not accurate due to later thermal events

---- Large time gap in major map units. Dikes above are Neoproterozoic to possibly Mesozoic ----

Boston Bay Group *(~590-565 Ma)*

Zca **Cambridge Argillite** – argillite south of Northern Border Fault

Zrx **Roxbury Conglomerate** – conglomerate and sandstone north of Northern Border Fault

fq **Felsic dikes with medium to coarse embayed quartz and feldspar xenocrysts** – intrudes Zwp on Whip Hill, Zsg at MWRA facility, and Zbrc near Black Rock. Xenocrysts from coarse granite, has fluorite crystals. Neoproterozoic.

ap **Gray porphyritic andesite to dacite dikes** – east side of Spot Pond, probably offshoot of Zst. Xenoliths and xenocrysts including embayed quartz. Hornblende phenocrysts. Neoproterozoic.

Subvolcanic rocks related to Lynn Volcanic Complex ~597-595 Ma

Zst **Stoneham Granodiorite** – granodiorite to tonalite, high mafic content, porphyritic at contacts. **Age (Ma): 595.14 ± 0.17 (U-Pb CA-TIMS)**

Zwap **Wanapanaquin Porphyry** – granodiorite porphyry. Branch of Stoneham Granodiorite. Neoproterozoic.

Zlwg **Lawrence Woods Granophyre** – porphyritic granophyre with needle-like hornblende. **Age (Ma) - 2 zircon populations : inherited 598.13 ± 0.27 (U-Pb CA-TIMS); 596.77 ± 0.25 (U-Pb CA-TIMS)** - at Wrights Pond; **596.50 + 0.53 (U-Pb CA-TIMS)** - at Pine Hill.

Zdg **Unnamed gabbro-diorite porphyry** - intrudes Zvwq, may be related to Zrhp. **Age (Ma): 596.02 + 0.32 (U-Pb CA-TIMS)**

Zrhp **Rams Head Porphyry** – tonalite porphyry with minor quartz and alkali feldspar, intrudes Spot Pond Granodiorite. **Age (Ma): 596.24 ± 0.16 (U-Pb CA-TIMS)**

---- Stoneham Granodiorite intrudes Zlvf, Zlbf and Zlvx at Straw Point on Spot Pond and in Melrose, Stoneham and Wakefield ----
---- Lawrence Woods Granophyre intrudes base of Zlvc at Pine Hill and Boojum Rock, and Zlvx and Zlvv at Wrights Pond ----

Lynn Volcanic Complex (Neoproterozoic).

Lynn Volcanic Complex (597-594 Ma)

596-594 Ma

Zlbf **Zlbc** **Zlvc** **Zlvp** **Wakefield Formation** – interlayered volcanic facies (bimodal):
(Zlbf) – basaltic flows and associated breccia and tuff
(Zlbc) – basaltic volcaniclastic units, polymictic breccia and conglomerate
(Zlvc) – felsic volcaniclastic units, polymictic breccia and conglomerate
(Zlvp) – rhyolite porphyry, fissure intrusion

Zlvv **Zlvx** **Zlvl** **Zlvf**
(Zlvv) – felsic vitric tuff
(Zlvx) – felsic crystal tuff
(Zlvl) – felsic lithic tuff
(Zlvf) – rhyolitic flows

Ages (Ma): 594.70 ± 0.32 (U-Pb CA-TIMS) Zlvf at Middle Res.; **595.27 + 0.34 (U-Pb CA-TIMS)** Zlvf at Spot Pd.; **595.82 ± 0.23 (U-Pb CA-TIMS)** Zlvf at Wamoset Hill

---- Zlvc rests unconformably on Boojum Rock Tuff and Zsg ----

---- Unconformity, start of abundant embayed quartz and coarse feldspar xenocrysts in Lynn and felsic dikes ---

597-596 Ma

Zbrv **Zbrl** **Zbrc** **Zbrr** **Boojum Rock Tuff** – dacitic tuff facies with rare quartz (xenocrysts derived from broken quartzite in Westboro Fm.)

Zbrv - vitric tuff
(- - - - -) fiammé zone, top of Zbrl, Melrose to Pinnacle Rocks, dips steeply east
Zbrl - lithic crystal tuff facies
Zbrc – dominant crystal tuff facies, coarsens to east in Malden and Melrose
Zbrr – red crystal tuff in Malden and Melrose

Age (Ma): 596.35 ± 0.21 (U-Pb CA-TIMS), high in Zbrc east of Boojum Rock

---- Zbrc rests unconformably on Zsg north of Boojum Rock and Zvwq at Pine Banks Park ----

fp **Dark red to tan porphyritic rhyolite dikes west of Spot Pond** – in Zsg, Zwg and Znpm, several Neoproterozoic ages possible. At Wenepoykin Hill red dikes crosscut Zsg and are crosscut by Zrhp.

Dedham Complex (Neoproterozoic).

Dedham Complex (609-610 Ma)

Zsg **Spot Pond Granodiorite** – coarse granodiorite to granite with abundant Zvwq xenoliths. **Ages (Ma): 609.46 ± 0.18 (U-Pb CA-TIMS)** - Red Cross Path; **609.11 + 0.22 (U-Pb CA-TIMS)** - South of Spot Pond; **609.08 + 0.24 (U-Pb CA-TIMS)** - Doleful Pond

Zwg **Winchester Granite** – equigranular medium granite with relatively high mafic content. Plagioclase subordinate or equal to alkali feldspar. **Age (Ma): 609.72 ± 0.24 (U-Pb CA-TIMS)**

Zwgd **Quartz Diorite Xenoliths in Zwg** – medium-grained quartz diorite xenoliths (uncertain source and age).

Zsgk **Alkali granite** - alkali granite zones/xenoliths in the Dedham Complex (in both Zsg and Zwg). Uncertain origin and age.

▲ **Zfi** – felsite xenoliths in Zsg, unknown source and age.

---- Units below intruded by Zsg and Zwg ----

Znpm **Nanepashemet Formation** – mostly hydrothermally altered (baked) basalt and basaltic tuff with basaltic breccias and conglomerates. Basal red conglomerate and sandstone and dark argillite with Westboro Fm. clasts.

---- Angular Unconformity overlain by basal breccia/conglomerate of the Nanepashemet Formation along Molly's Spring Rd.) ----

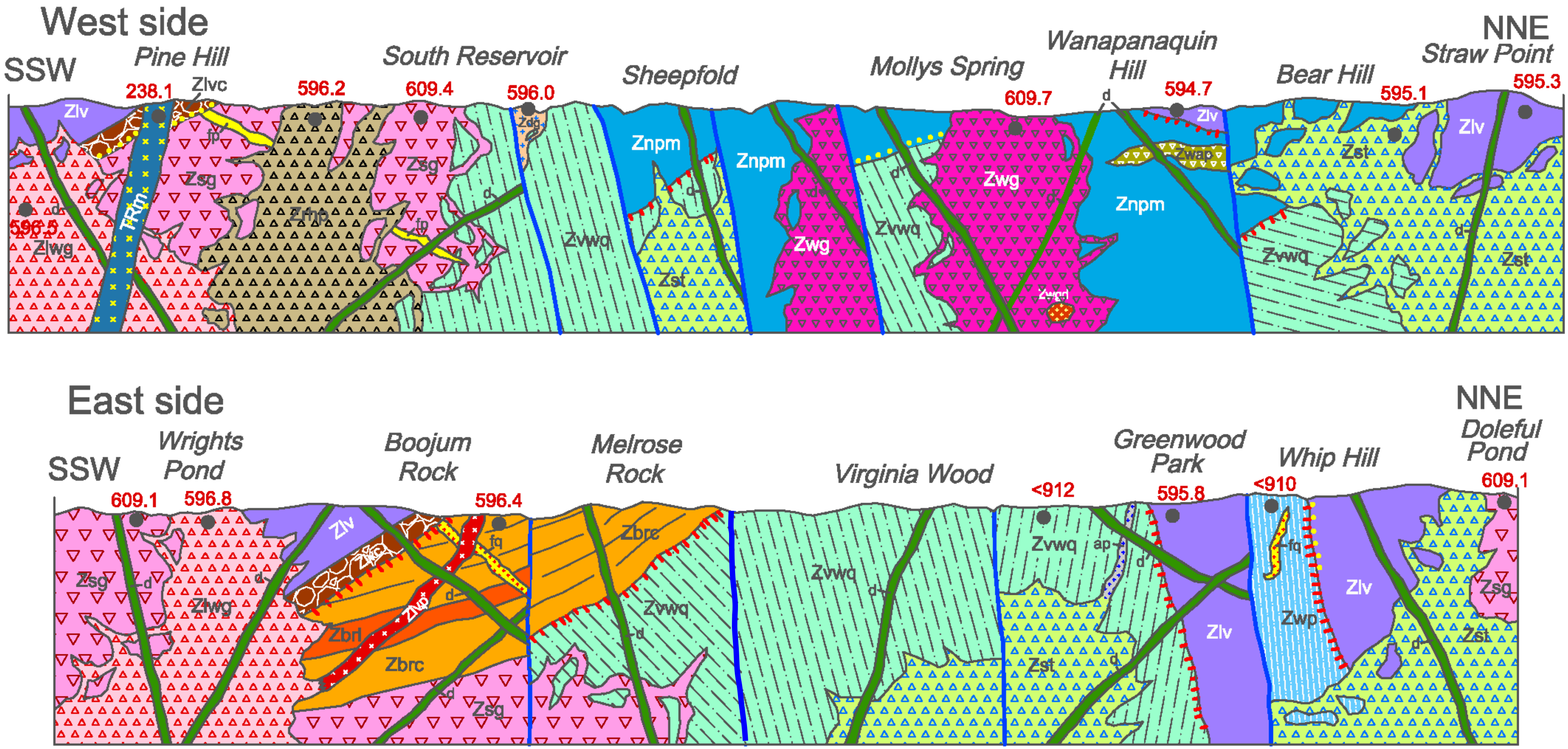
------ period of low-grade regional metamorphism ------

Westboro Fm. < 912 Ma

Zwp **Westboro Formation in Whip Hill area** – non-metamorphosed laminated mudstone, fine sandstone, and mass flow units with quartz sandstone olistoliths. Not regionally metamorphosed. Isolated in a separate fault block. Intruded by ap and fq dikes. Neoproterozoic. **Max. Age: < 910 Ma (LA-ICPMS, 210 detrital zircon grains, quartz sandstone olistolith)**

Zvwq **Westboro Formation in Virginia Wood and west of Spot Pond** – metamorphosed at a low grade and sheared, quartzite and argillite with calcium/magnesium silicate intervals. **Max. Age: < 912 ± 0.6 Ma (U-Pb CA-TIMS youngest detrital zircon)**

Diagrammatic cross sections of bedrock in the Middlesex Fells Reservation



5. Diagrammatic cross sections of the eastern and western sides of the Middlesex Fells Reservation intended to show the field and age relationships of the bedrock units. Geologic symbols are the same as those used on the bedrock map and in the explanation. Separate facies in the Wakefield Formation (Zlv) are not shown here except for the felsic clastic units (Zlvc). Black dots with red numbers are radiometric ages. Except for the limiting zircon ages in the Westboro Formation, all ages are CA-ID-TIMS U-Pb zircon ages. Unconformities are shown as surfaces beneath areas where either a unit above the unconformity contains fragments of the unit below that document erosion of the lower unit (yellow dots above unconformity surface) or erosion is documented beneath the unconformity as crosscutting of foliation or layering below (red tic marks beneath the unconformity).

6. Reformulating Plutonic Rock Stratigraphy

Plutonic rock units with different lithologies recognized in the field are here mapped separately and are now known to be plutons of separate ages and in some cases parts of "composite plutons" (Wones and Goldsmith, 1991) within magma complexes. Relative ages are revealed by field relationships such as 1) contacts between the plutonic bodies that are sharp with a well-defined chill zone in the younger unit, and 2) xenoliths of older volcanic and plutonic rock units in younger plutonic units. Age relationships are now confirmed by U-Pb CA-ID-TIMS zircon ages for each plutonic unit (see p.8 and Appendix 3).

In previous compilations of the geology of the Middlesex Fells area (Boston North and Lynn Quadrangles) most plutonic igneous bodies with different lithologies were lumped as the Dedham Granodiorite. Although the separate lithologies were recognized they were thought to represent different phases of the Dedham (Emerson, 1917; LaForge, 1932; Bell, 1948; Bell and Alvord, 1976). In particular, the PhD thesis of Bell (1948) accurately described separate plutonic lithologies in great petrologic detail but interpreted them as different Dedham phases. Some plutonic rocks in the northern Fells and Stoneham were also correlated to the Newburyport Quartz Diorite (Emerson, 1917; Clapp, 1921; LaForge, 1932; Kaye, 1980). During current mapping, it became clear that the plutonic units could and should be subdivided so the map would provide a better depiction of the distribution and geometry of different rock types. The units have not only distinct lithologies, but sharp contacts and younger units have chill zones against older units and inclusions of older units. Five new units are now recognized within what was the Dedham Granodiorite and Newburyport Quartz Diorite of older maps: the Spot Pond Granodiorite (Zsg), Winchester Granite (Zwg), Rams Head Porphyry (Zrhp), Lawrence Woods Granophyre (Zlwg), and Stoneham Granodiorite (Zst).

New CA-ID-TIMS U-Pb zircon ages confirm the subdivisions described above and reveal that the plutonic units fall into two major groups that are separated in age by 12-14 Myr. The CA-ID-TIMS technique allowed age determinations with much greater precision than in the past so that age differences could be tested. An older group of units, the Spot Pond Granodiorite and Winchester Granite, have ages of 610-609 Ma and include lithologies previously considered the "normal" Dedham (Bell, 1948). Three new U-Pb CA-ID-TIMS zircon ages for the Spot Pond Granodiorite across the Fells (609.1 to 609.4 Ma) are statistically indistinguishable while an age for the Winchester Granite is a small bit older (609.7 Ma). These units are given formation status in a group designated as the Dedham Complex. Further mapping to the east indicates that the Spot Pond Granodiorite is the same as a unit previously designated as the Dedham North Granodiorite (Smith and Hon, 1984 and Smith, 1985). So far, no volcanic equivalents of these units have been found in the Fells or other areas.

A younger group of plutonic units in the Fells and extending east and north of the Fells are the Rams Head Porphyry, Lawrence Woods Granophyre, and Stoneham Granodiorite.

As mentioned above, these units were recognized petrographically by Bell (1948), but he considered them phases of the Dedham. The Rams Head, Lawrence Woods, and Stoneham units are given formation status on the map since they are lithologically distinct and have new U-Pb CA-ID-TIMS ages (597-595 Ma) that are distinct from the age of the Dedham Complex. These units are porphyritic and sometimes granophyric and are interpreted to be subvolcanic units associated with the Lynn Volcanic Complex. The new radiometric ages eliminate correlations to Paleozoic plutonic rocks further east, especially the Newburyport Complex (Newburyport Quartz Diorite of older maps; Zen and others, 1983; Wones and Goldsmith, 1991).

7. Reformulating the “Middlesex Fells Volcanic Complex”

Emerson (1917) and LaForge (1932) mapped bimodal, mostly basaltic, volcanic rocks in the northern to northwest Fells and extending northeast to Stoneham and Melrose as part of the Marlborough Formation based on their mafic composition. This correlation was later dropped (Bell and Alvord, 1976) given the lack of regional metamorphism in the units in the Fells area and the Marlborough correlation was prior to the recognition of major fault boundaries in eastern Massachusetts. Later mapping and compilations of the stratigraphy in the northern Fells and Stoneham reformulated the mostly basaltic volcanic units into the Middlesex Fells Volcanic Complex (Bell and Alvord, 1976; Kaye, 1980; Naylor, 1981; Cardoza. 1987; Cardoza and others, 1990). This included bimodal units on the current map here assigned to the Lynn Volcanic Complex at Straw Point, Middle Reservoir and further north in Stoneham. A new U-Pb CA-ID-TIMS zircon age for a felsic flow unit in the bimodal units at Straw Point is 595.3 Ma. This new age along with a new U-Pb CA-ID-TIMS age of 594.7 Ma for a flow unit at Middle Reservoir MacDonald, pers. comm.) makes these felsic rocks the same age as the Lynn Volcanic Complex.

The Middlesex Fells Volcanic Complex was defined as including the large area of hydrothermally altered basalt in the northwest Fells (Bell and Alvord, 1976), here mapped as the Nanepashemet Formation. The Nanepashemet is not bimodal and is intruded by the Winchester Granite of the Dedham Complex. The Dedham units have new U-Pb CA-ID-TIMS zircon ages of 609-610 Ma, making the Nanepashemet significantly older than the new ages for the Lynn-age rocks in the northern Fells and Stoneham by at least 14 Myr. The “Middlesex Fells Volcanic Complex” therefore includes rocks of two separate ages and this name has been abandoned. The unit is now split into two separate units. The younger rocks are now part of the Lynn Volcanic Complex, and the older rocks, as mentioned above, are given a separate name, the Nanepashemet Formation. An important implication here is that a significant area of basaltic rocks across much of Stoneham were not previously recognized as part of the Lynn Volcanic Complex. Unfortunately, the direct dating of basaltic units in both the Lynn and Nanepashemet has not been possible due to contact metamorphism and hydrothermal alteration of these units by later intrusions making argon methods untenable and a scarcity of zircon crystals for U-Pb radiometric dating.

The basaltic rocks in the Nanepashemet Formation and Lynn Volcanic Complex also have geochemical differences that are distinguishable in geochemical data sets from two student theses (Cardoza, 1987; Hampton, 2017). Trace element concentrations in the two basaltic units show that they have different affinities. Basalt from the Nanepashemet Formation (Znpm) shows lower trace element abundances and a mid-ocean ridge (NMORB) affinity (blue lines on upper plot on Figure 1.5) while basalt from the units now mapped as part of the Lynn Volcanic Complex (Zlbf) has an ocean island (OIB) to inter-arc (IAB) basalt affinity (purple lines on upper plot on Fig. 1.5). For comparison, dolerite dikes (d) in the Fells that are younger than both basaltic units also have an OIB to IAB affinity (lower plot on Fig. 1.5). Although the two basaltic units seem to separate geochemically this distinction should be viewed with caution since both units, especially the Nanepashemet Formation, have been hydrothermally altered and reheated by younger plutonic intrusions. More work needs to be done to further investigate the geochemical separation of these units.

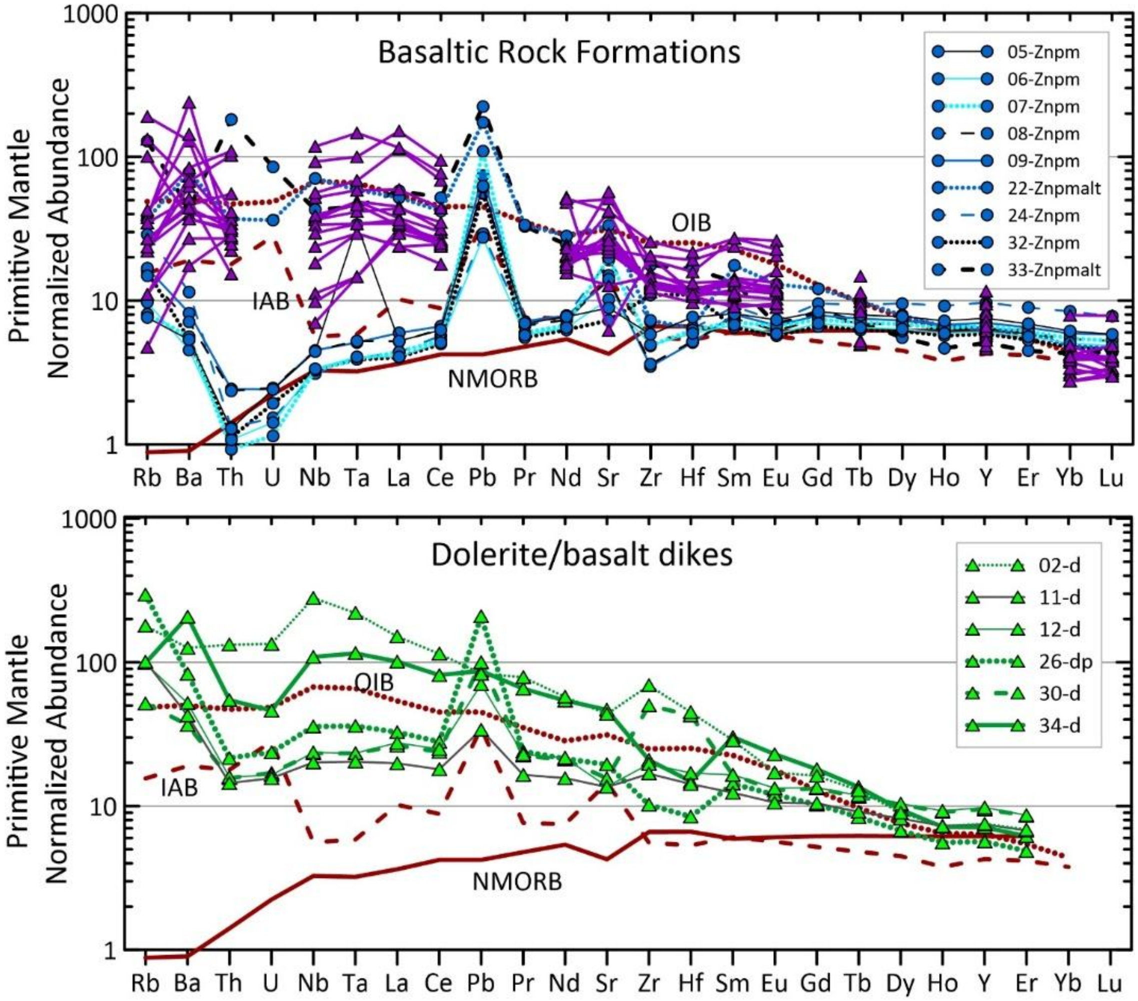


Figure 1.5. Spider diagram trace element plots. Above are XRF analyses of basalt in the Lynn Volcanic Complex (Zlbf) of the current map (purple, from Cardoza, 1987) and LA-ICPMS analyses of basalt from the Nanepashemet Formation (Znpm) of the current map (blue, Hampton, 2017). The two units labeled as “Znpmalt” experienced extreme alteration. At the time the analyses were collected they were both considered part of the Middlesex Fells Volcanic Complex. On the lower graph for comparison are LA-ICPMS trace element plots from mafic dikes with a variety of ages in the Fells (from Hampton, 2017), all younger than the two formations plotted in the upper graph.

8. Reformulating the Lynn Volcanic Complex

Volcanic rock units in the Lynn Volcanic Complex are dominantly rhyolitic to andesitic lavas and felsic pyroclastic rocks (flows and tuffs) and associated volcaniclastic breccias and conglomerates. The Lynn in the northern Fells and extending into Stoneham and Wakefield also has basaltic lava and pyroclastic rocks (flows and tuffs) as well as mafic volcaniclastic breccias and conglomerates formerly classified as part of the Middlesex Fells Volcanic Complex (see section above). Separating different units within the Lynn into a time stratigraphic system is challenging because although sequences of facies can be repeated, they may not be continuous over long distances, being interrupted by faults or large plutonic bodies that break their continuity. Therefore, the strategy chosen for mapping the Lynn is to map facies. Facies patterns along with radiometric ages may eventually help identify the continuity of formal lithostratigraphic units. The new map shows the Lynn Volcanic Complex, which is given group status, divided into two major formations, the Wakefield Formation (separated into 8 different facies), which unconformably overlies the Boojum Rock Tuff (separated into 4 facies).

The composition of the Boojum Rock Tuff (dacitic to andesitic; Fig. 1-6A) is distinct from the rest of the Lynn. It is entirely tuff with common hornblende crystals and only very rare small quartz crystals that are accidental fragments derived from quartzite in the Westboro Formation. The Boojum Rock Tuff covers a large area of the southeastern Fells and extends eastward into Malden and Melrose. A new radiometric (U-Pb CA-ID-TIMS zircon) age from the middle of the Boojum Rock Tuff in the southeastern Fells in Malden is 596.3 Ma. The Boojum Rock is intruded by the Lawrence Woods Granophyre south and east of the southeastern Fells in North Medford and in Malden.

The Wakefield Formation has many rhyolitic flows and felsic tuff units, is bimodal in the northern Fells and Stoneham with basaltic units and has common large quartz crystals in its felsic tuff units. This unit extends northward and eastward into Stoneham, Melrose, Wakefield, and Saugus where the bulk of the Wakefield Formation occurs. Three new radiometric (U-Pb CA-ID-TIMS zircon) ages in the northern Fells for rhyolitic flows in the Wakefield are 595.8-594.7 Ma. The new ages for the Wakefield Formation in the northern Fells indicate that the Wakefield is younger than the Boojum Rock Tuff in the southeastern Fells. In the northern Fells and extending to Wakefield, parts of the Wakefield are intruded by the Stoneham Granodiorite at 595.1 Ma. South of the southeastern Fells in North Medford and in the Pine Hill area the Wakefield Formation is intruded by the Lawrence Woods Granophyre and in the Boojum Rock area the Wakefield has basal conglomerates and breccias that lie unconformably on the Boojum Rock Tuff.

In addition to the characteristics of the Boojum Rock Tuff and Wakefield Formation outlined above, separation of the two units is supported by whole rock compositions and point count data. The Boojum Rock Tuff has a more andesitic composition while the Wakefield units are dacitic to rhyolitic (Fig. 1-6A). Normalized whole rock point count data shows that tuffs in the Boojum Rock Tuff generally have a higher crystal concentration than crystal tuffs in the Wakefield Formation (Fig. 1-6B). Normalized point counts of crystal types reveal that the Boojum Rock Tuff tends to have a higher mafic mineral abundance (dominantly hornblende) while having fewer quartz and alkali feldspar crystals (Fig. 1-6C). The Wakefield has a much higher abundance of alkali feldspar crystals and quartz crystals, which are often coarse and embayed, and a mostly lower mafic mineral abundance that is dominated by biotite.

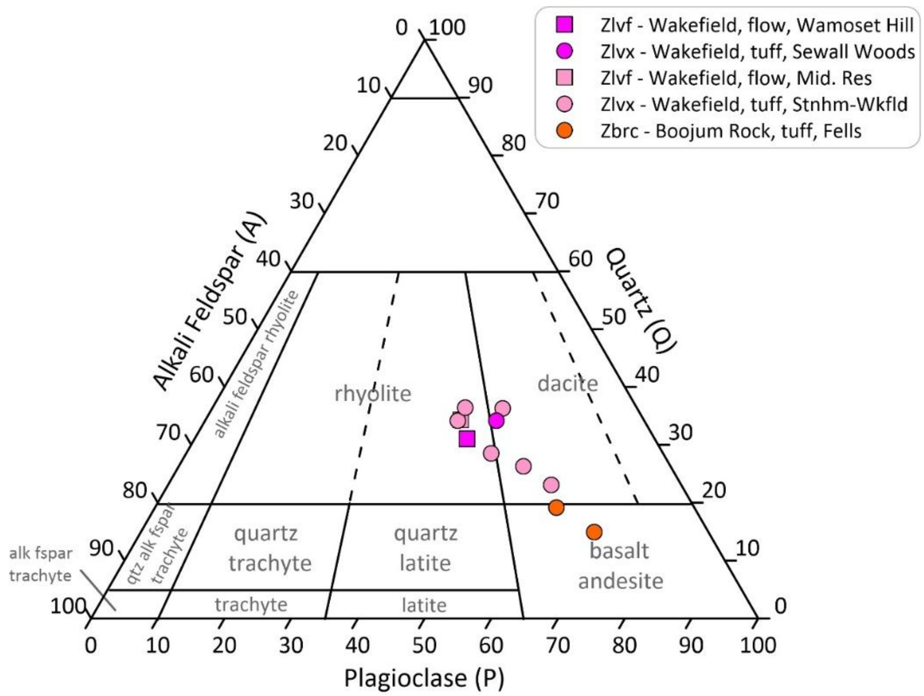


Figure 1-6A. Normalized Quartz-Alkali Feldspar-Plagioclase (QAP) plot of felsic volcanic units in the Lynn Volcanic Complex. Data is CIDW Norm% calculations from XRF data from tuff units (Smith, 1985) and LA-ICPMS data from the flow units (Hampton, 2017). Note that units in the Lynn have a range of compositions that are andesitic (exclusively in the Boojum Rock Tuff) to rhyolitic. Data in Appendices 1-C and 1-F.

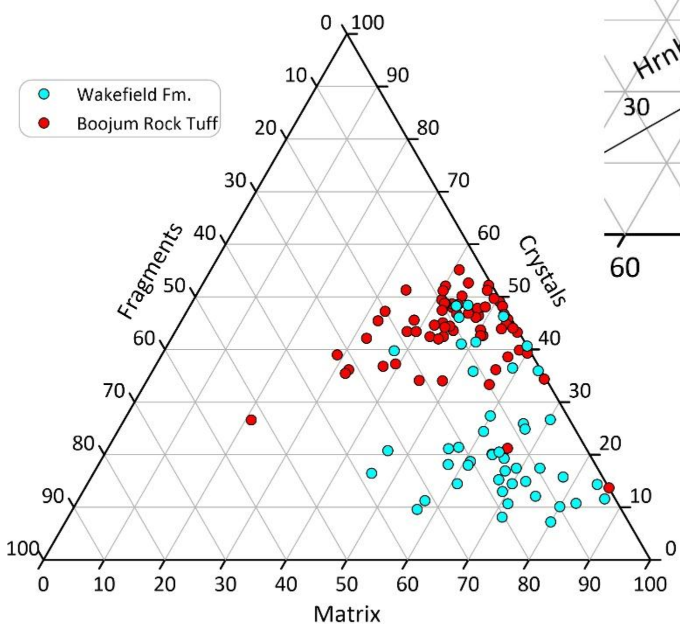


Figure 1-6B. Whole rock point count data of normalized Crystals-Lithic Fragments-Matrix percentages for the Wakefield Formation (crystal tuff units only) and the Boojum Rock Tuff. Data is in Appendix 2A and 2B.

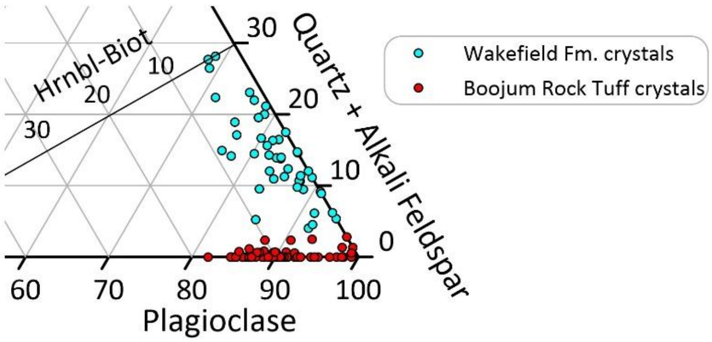


Figure 1-6C. Ternary plot of major crystal types (Quartz plus Alkali Feldspar-Mafic minerals (Hornblende plus Biotite)-Plagioclase) as normalized percentages for the Wakefield Formation (crystal tuff units only) and Boojum Rock Tuff. Data is in Appendix 2A and 2B.

In the past there were two situations that confused age relationships of some parts of the Lynn Volcanic Complex:

A) As discussed in Section 7 above, bimodal parts of the Lynn in the northern Fells were included in the "Middlesex Volcanic Complex" with what is here mapped as the Nanepashemet Formation. The new ages for the bimodal parts of the Lynn of 596-594 Ma conflict with the minimum age of the Nanepashemet that is intruded by the Winchester Granite in the Dedham Complex (see Section 6 above) at 609-610 Ma.

B) In the past the age of the Wakefield in the southern Fells was inferred to be older than the Dedham Complex because of the lumping of plutonic units of different ages in the southern Fells. In earlier studies of the Pine Hill area (Zarrow, 1978; Kaye, 1980; Naylor, 1981, Smith and Hon, 1984; Smith, 1985) the Lynn Volcanic Complex was thought to be intruded by the "Dedham Granodiorite" and therefore older than the Dedham leading to its correlation with the "Middlesex Fells Volcanic Complex" (Smith and Hon, 1984; Smith, 1985). Current mapping has revealed that the plutonic unit that intrudes the Lynn Volcanic Complex on Middle, Little Pine, and Pine Hills and in the Wrights Pond and Boojum Rock areas is the subvolcanic Lawrence Woods Granophyre of this map, which is not part of the Dedham Complex and has an age of 596-597 Ma. It was also known from field work by Bert Reuss at Tufts University in the 1980s, and confirmed in this study, that the basal volcaniclastic facies of the Lynn at Pine, Little Pine, and Middle Hills has clasts of the Spot Pond Granodiorite of the Dedham Complex, also making it younger than the Dedham.

9. <u>Recognition of Unconformities</u>

Major unconformities have been documented at the base of units where there are xenoliths or clasts from units below in units above and sudden changes in lithology and metamorphic grade along irregular surfaces that are not fault boundaries. Cross cutting of foliation/layers beneath these boundaries has also been recognized in some places. Unconformities are now recognized in the following situations:

A) Hydrothermally altered basalt and basal sedimentary units of the Nanepashemet Formation, which are not regionally metamorphosed, rest on an unconformity that truncates foliation in regionally metamorphosed quartzite and slaty argillite in the Westboro Formation at Sheepfold (lower parking lot) and on the north side of Molly's Spring Road.

B) The Boojum Rock Tuff unconformably overlies the Westboro Formation in eastern Pine Banks Park in Malden and Melrose. This may also be true in southern Virginia Wood (south of Ravine Road), but this contact is buried beneath glacial sediment.

C) Volcanic rocks in the Wakefield Formation at Wamoset Hill unconformably overlie the Westboro Fm. of the Virginia Wood area and truncate its foliation.

D) Volcanic rocks in the Wakefield Formation on Whip Hill and along Spot Pond at the Stone Zoo unconformably overlie the Westboro Formation and have lithic fragments from the Westboro. There are also both east-west and north-south trending fault contacts in this area separating these two units.

E) Based on radiometric ages, the Boojum Rock Tuff unconformably overlies the Spot Pond Granodiorite (Dedham Complex) east of Woodland Road and south of Ravine Road.

F) Volcaniclastic rocks at the base of the Wakefield Formation near Boojum Rock and at Fellsmere Pond in Malden unconformably overlie the Boojum Rock Tuff.

G) Rhyolitic flow units in the Wakefield Formation unconformably overlie the Winchester Granite of the Dedham Complex and Nanepashemet Formation at the northeast corner of Middle Reservoir.

H) In the southern Fells at Pine, Little Pine and Middle Hills and near Boojum Rock volcaniclastic rocks forming the base of the Wakefield Formation unconformably overlie the Spot Pond Granodiorite.

10. <u>Subdivision of the Westboro Formation</u>

Based on lithologic and metamorphic grade differences the map has a subdivision of metasedimentary vs. purely sedimentary parts of the Westboro Formation (Bell and Alvord, 1976; Kaye, 1980; Bailey, 1984; Bailey and others, 1989). A key discovery not shown on previous maps is the separation of the metasedimentary part of the Westboro Formation in Virginia Wood and west of Rt. 93 from a purely sedimentary part of the Westboro at Whip Hill that exhibits no regional metamorphism.

At Whip Hill the Westboro is a sandstone to laminated mudstone olistostrome with quartz sandstone olistoliths (Bailey and others, 1989) and well-preserved bedding and sedimentary structures including ripple crossbeds and small diastems. Although these units can be baked next to igneous bodies they have no regional metamorphism. The Westboro at Whip Hill is separated from the Westboro in Virginia Wood by large east-west trending faults and volcanic rocks of the Wakefield Formation on Wamoset Hill that extend further east into Stoneham and Melrose. The Whip Hill part of the Westboro has a U-Pb detrital zircon age profile like that of the Virginia Wood units and the Westboro Formation further east in Saugus (Thompson and others, 2012; Francis MacDonald, pers. comm.; see Appendix 3).

The Westboro Formation in Virginia Wood exhibits low grade regional metamorphism in the form of flattened and sutured, polycrystalline quartz grains, boudins, and slaty cleavage in argillaceous units. It also has calcium-magnesium silicate units with tremolite, diopside, zoisite, and calcite that have minor drag folds. The Ca/Mg-silicate units are absent from the non-metamorphosed Whip Hill part of the Westboro which generally has a finer grain size.

It appears that major east-west oriented faults have broken the area into juxtaposed fault-bounded slices with metamorphosed and non-metamorphosed sections of the Westboro Formation, each with overlying sections of the Wakefield Formation at unconformities. A tentative interpretation is that the metamorphosed part of the Westboro in Virginia Wood represents a sandy continental shelf deposit with carbonate (dolomitic) lithologies. The Westboro on Whip Hill is interpreted to be a muddy continental slope deposit with no carbonate component and abundant debris flows with sandstone olistoliths as recognized by Bailey and others (1989).

DESCRIPTION OF MAP UNITS

Figure numbers are abbreviated with unit symbols to allow easy revision.
All scale bars on sample images are in centimeters.

Quaternary and Artificial Deposits and Water Bodies

af

Artificial fill - Land formed by artificial filling or construction by humans. Only shown where it covers a large enough area to prevent interpretation of the bedrock geology.

w

Water bodies – ponds, lakes, and rivers. Water bodies were traced as units using the LiDAR generated hill-shaded base map as a guide and UTM (1927 NAD zone 19T) GPS coordinates measured in the field. In some places the map shows shoreline topography on the LiDAR image in areas mapped as open water because the LiDAR data was obtained when reservoirs had low levels. Mapping around North Reservoir was partly accomplished when the reservoir was drained for maintenance and geologic units are shown extending into the water body.

sw

Swamps and other wetlands – areas covered by wetlands including permanent swamps, marshes, 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 of till cover that are end moraines near South Reservoir, at Wrights Pond, and south of Ravine Road that may form an ice recessional position.

Areas of bedrock exposure – Screen overlay pattern shown only outside the Middlesex Fells.

Intrusive Igneous Rock Units Occurring as Dikes (Unnamed)

On most large-scale geologic maps (e.g., 1:24,000) thin dikes are generally not mapped in detail. For this project mapping was done at 1-meter resolution and all dike contacts were traced as much as possible given their exposure. Within each dike type are different compositions and ages, especially in the most abundant category of dolerite/basalt. Dikes are important because they are critical to framing the relative ages of major rock units they intrude, and the existence, displacement, and ages of faults.

d

Dolerite and basalt dikes (Neoproterozoic 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, non-porphyritic mafic dikes including lamprophyric dikes. These dikes weather to rusty brown (Fig. d1) to light gray (Fig. d2) with either distinct chill zones (usually as in Fig. d3) or diffuse contacts where the country rock is altered by local melting, assimilation, and contact metamorphism. Wilson (1901), Emerson (1917), LaForge (1932), and Kaye (1980) refer to these rocks as diabase, which is taken to be synonymous with dolerite. Most dolerite dikes are steeply inclined (>60°; Fig. d4). When measurable, the strike and dip of dikes is shown with a special symbol (see symbol descriptions). Most dikes are coarse enough to be classified as dolerite but range from very fine basalt to fine gabbro (Figs. d5-13). Many dikes have vesicles (Fig. d5) or amygdules with epidote, calcite, quartz, and prehnite mineralization (Figs. d12-13). The dikes have varying amounts of plagioclase vs. mafic mineral percentages with mafic minerals usually higher. Plagioclase may be lightly to almost completely altered to sericite. The main mafic mineral is clinopyroxene (augite), and occasionally biotite or hornblende. Pyroxene has varying degrees of alteration from none to complete replacement by amphibole (actinolite) and chlorite. Altered dikes with excessive growth of new minerals are mapped as separate units (ad) and are thought to be older. Opaque minerals include titanomagnetite, pyrite (Fig. d6), and possibly ilmenite. Dikes are mapped where they exceed a width of 1.0 m. Thinner dikes, which are not as traceable, are shown with a separate line symbol (see symbol descriptions). Dikes that could not be fully traced due to limited exposure have terminations marked with (?). Rare dikes terminating at blunt, non-tapered ends are marked with (e). Dikes were variably resistant to glacial erosion than host rocks depending on their fractures and orientation.

A range of ages is suggested by dolerite dike sets with different orientation, composition, alteration, and fault displacement, as well as crosscutting field relationships between dike sets. The Medford Dike was not found to be crosscut by any significant dolerite dike. One N-S trending dolerite dike cutting across the Medford Dike was reported by Wilson (1901) in Medford and a very thin (7 cm) dike has been found just north of 34 Governors Avenue ("House on Rock"). Dolerite dikes are crosscut by both E-W and N-S trending major faults, which are all cut by the Medford Dike. There may be a few younger dikes for which a relative age could not be determined. Significant is the fact that prominent E-W dolerite dikes, which appear to be the youngest set in the field area, are crosscut by major N-S faults and have an apparent left-lateral displacement. These dikes also appear to sometimes follow E-W faults because of large displacements of rock units on opposite sides. LaForge (1932) identified two major sets of dolerite dikes, an older N-S trending set and a younger E-W trending set. This has been confirmed at a few dike intersections, but it has not been possible because of exposure limitations to confirm this age relationship at all intersections. There are dikes with intermediate trends and many thin dikes with highly irregular traces that do not fit into well-oriented dike sets. The consistency of dike trends is highly dependent on the continuity of fractures in the host rock. Dolerite dikes are sometimes attributed to Mesozoic intrusion but almost all dolerite dikes in the Fells appear to be Paleozoic or Neoproterozoic (Ross, 1981, 1990, 2001, 2010). Whole rock $^{40}Ar/^{39}Ar$ ages for dolerite dikes in the Fells at Pine Hill by Ross (2001, 2021) are: 226 $\pm$ 3, 353 $\pm$ 4, and 573 $\pm$ 5 Ma (see gabbro dikes below); and by Zartman and others (1970) are a K-Ar whole rock age of 290 + 15 along Rt. 93 in Stoneham. However, these dike ages were likely reset by later thermal events. A comprehensive chronology of dolerite dikes, their chemistry, magmatic history, and field relationships are discussed at length by Ross (1981, 1984, 1990, 1992, 2001, 2010, 2020, 2021).

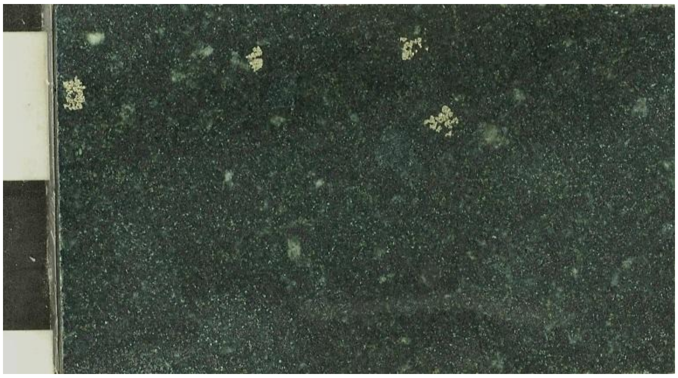
d1: Rusty weathered surface of dolerite dike with glacial grooving (parallel to hammer handle) southeast of Fells Reservoir in Melrose (site 413BN). Hammer for scale.

d2: Gray weathered surface of dolerite dike at Pinnacle Rock in Malden (site 10059). Penny for scale.

d3: Chill zone contact (arrow) of rusty weathering dolerite dike with altered granite (beneath hammer) north of Nanepashemet Hill in Winchester (site 11117).

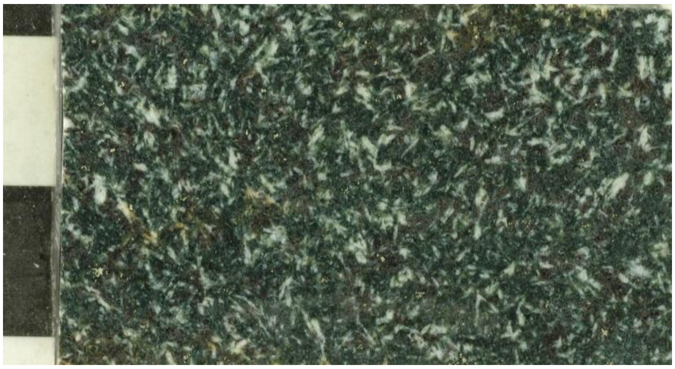
d4: Cross section view of nearly vertical dolerite dike in granodiorite at 2013 MWRA excavation east of Woodland Road in Stoneham (site 10286). Arrows at contacts. Site is now covered. Hammer below for scale.

d5: Vesicles (below hammer) along an epidote vein in dolerite dike on Boojum Rock in Malden (site 10018).

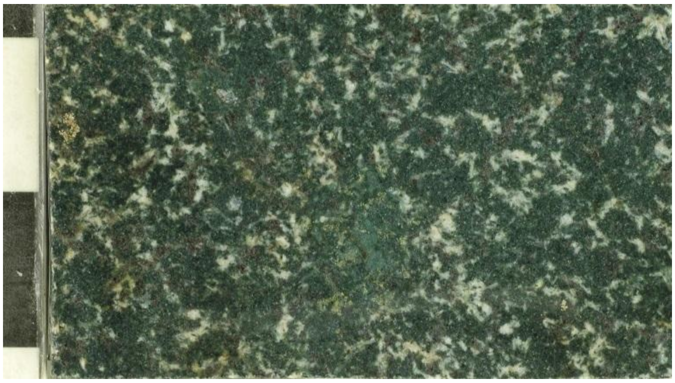


d6: Basalt dike with pyrite clusters east of Boojum Rock in Melrose (site 10031).

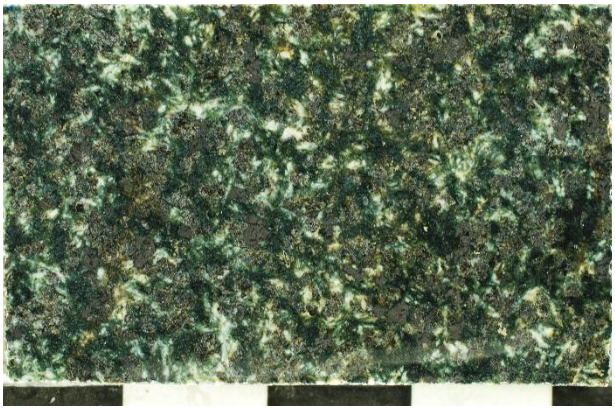
d7: Dolerite dike that is rich in mafic minerals (pyroxene, amphibole, and magnetite) west of Boojum Rock in Malden (site10001).



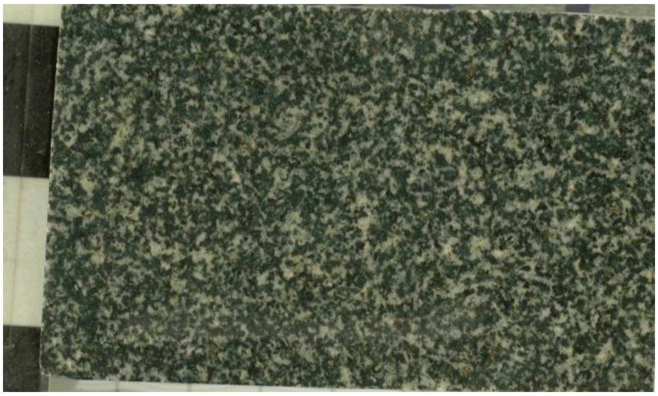
d8: Dolerite dike with moderate mafic mineral content, homogeneous mineral distribution, and relatively little alteration northwest of Wrights Pond in Medford (site 10471).



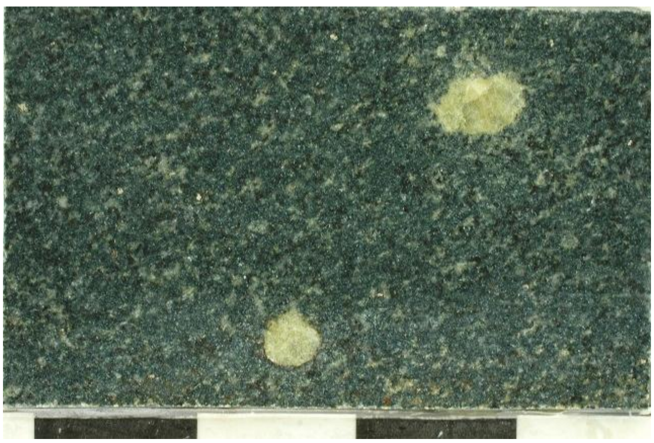
d9: Relatively coarse dolerite dike with heterogeneous (splotchy) distribution of plagioclase and mafic minerals and moderate alteration on Boojum Rock in Malden (site 10014). This rock has a subophitic texture.



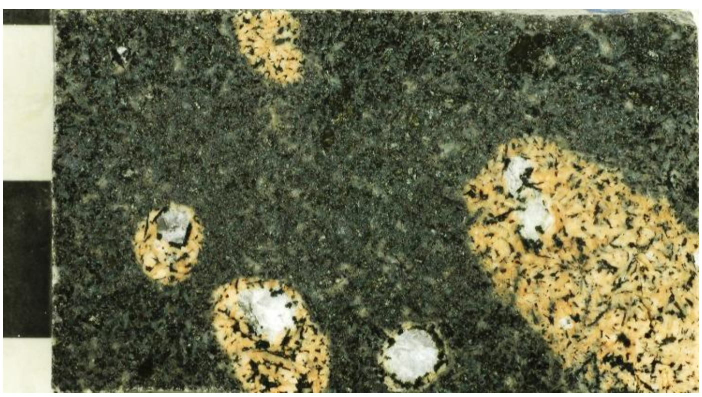
d10: Relatively coarse dolerite dike south of Greenwood Park in Stoneham (site 10578). Brownish areas are clinopyroxene (augite).



d11: Dolerite dike with relatively high plagioclase content on north end of Pine Hill in Medford. Dikes of this type often have a light greenish-gray weathered surface (site 10509). Mafic minerals in this rock are chlorite and biotite likely formed by alteration of clinopyroxene.



d12: Somewhat altered dolerite dike with amygdules filled with prehnite (see thin section analysis below) on Little Pine Hill in Medford (site 10661).

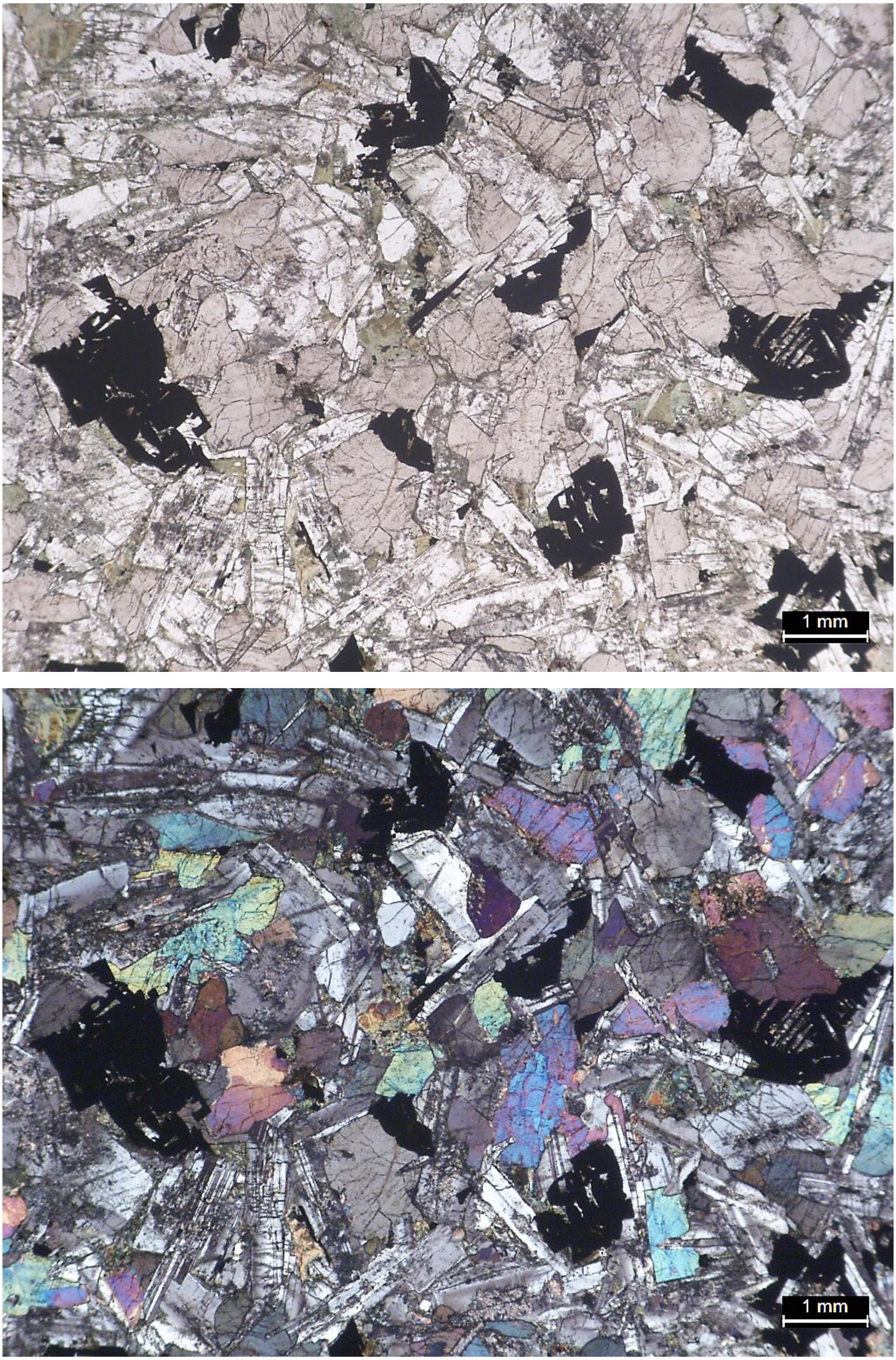


d13: Dolerite dike with crystallized melt inclusions from host rocks (granodiorite and andesitic tuff) filled with a mixture of iron-rich altered plagioclase (orange) with biotite and hornblende and a white calcite core in the 2013 MWRA excavation east of Woodland Road in Stoneham (site 10278, site now covered).

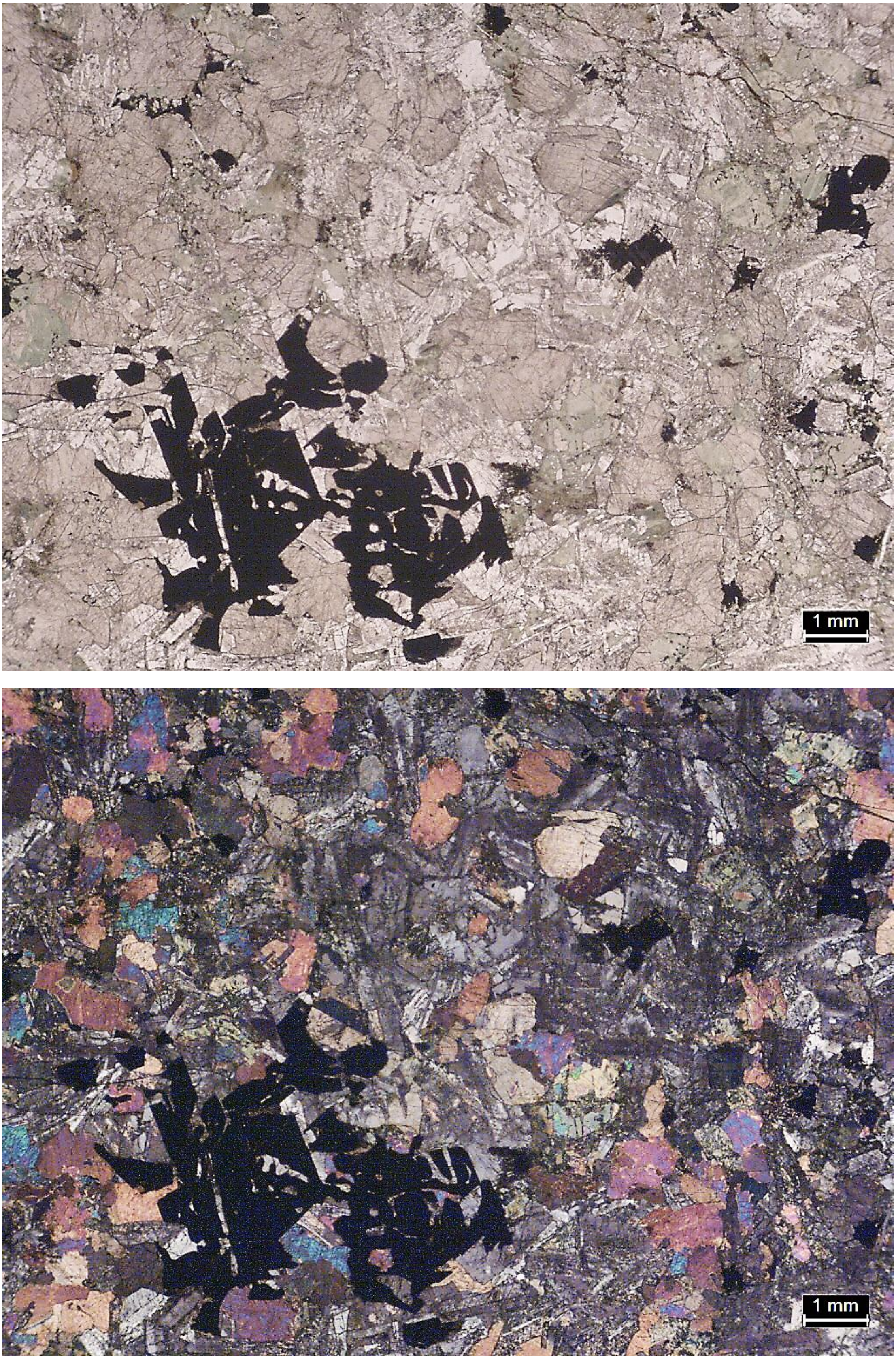
Dolerite and basalt dikes (cont.)

Thin section description – Almost all non-porphyritic dolerite and basalt dikes have a similar mineralogy with two fundamental components: plagioclase and original clinopyroxene (augite). Plagioclase is tabular with almost no alteration (Figs. d14-15) to heavy alteration to sericite (Figs. d16-17) and in some cases minor epidote. Usually, mafic minerals are or were originally pale pink to pale pinkish-gray clinopyroxene (augite; Figs. d14-15). Clinopyroxene has usually undergone at least minor alteration to actinolite (uralization) and/or chlorite (Figs. d16-17). Heavy alteration can remove clinopyroxene completely leaving just actinolite and chlorite (Fig. d18). Occasionally, dolerite dikes have hornblende or biotite, either being original or a product of pyroxene alteration (Figs. d19-20). Most dolerite dikes are intergranular (Figs. d14-15) with a few being subophitic with clinopyroxene surrounding plagioclase blades (Fig. d21). Opaque minerals can be titanomagnetite, pyrite, or ilmenite with skeletal titanomagnetite (Figs. d14-15) being the most common opaque mineral in augite-bearing dolerite along with some equant magnetite (Fig. d21) and occasional acicular magnetite (Figs. d16). Occasionally dolerite and basalt dikes have clusters of pyrite (Fig. d22, see also Fig. d6). Some dolerite has conspicuous apatite needles (Figs. d20, 23). About 15% of the dikes sampled have vesicles or amygdules filled by some combination of chlorite and actinolite with calcite cores (Fig. 22). Vesicles can also be filled with epidote and prehnite (Figs. d24-25). One dike had large crystallized melt inclusions filled with altered plagioclase, euhedral biotite and hornblende, auxiliary euhedral quartz, and a small calcite core. The melt inclusions are from intruded granodiorite or andesitic tuff (Fig. d26; see Fig. d13). Although dolerite is generally undersaturated with quartz, a few samples have small interstitial quartz pockets (Figs. d14, 19, 23), possibly related to assimilation or inclusions from quartzite or felsic igneous rocks.

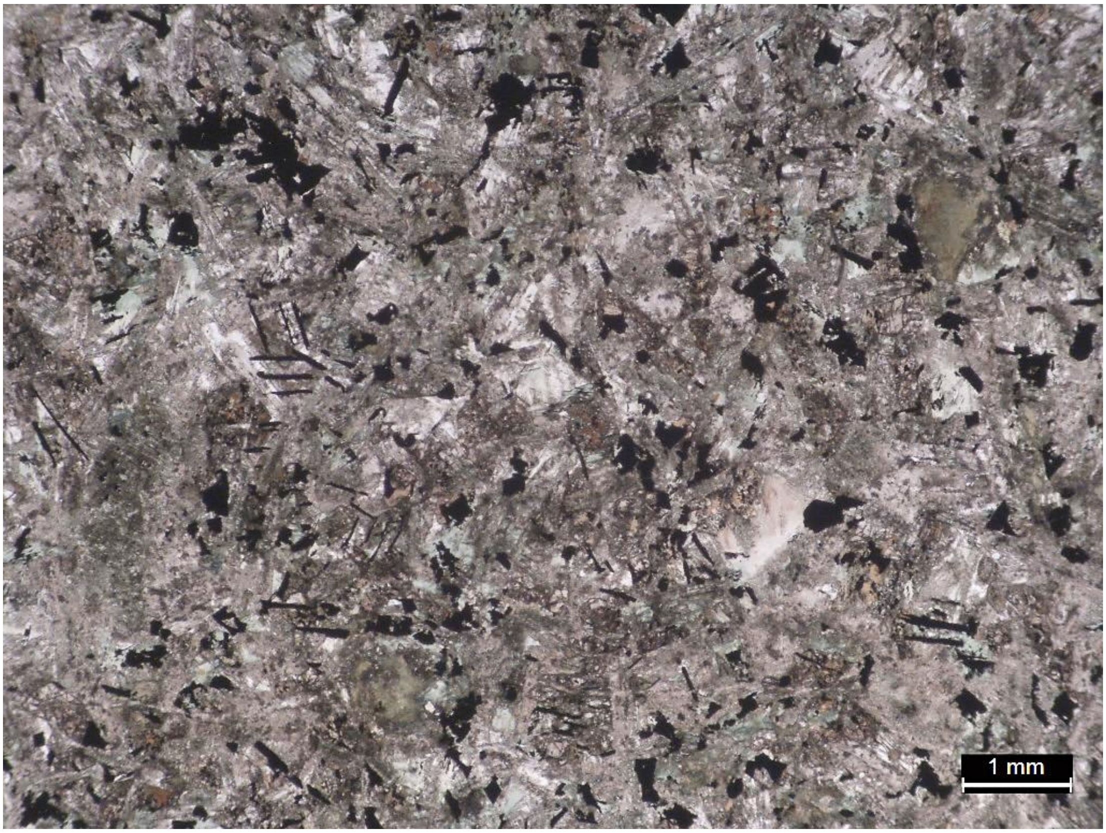
As compared to dolerite dikes, basalt dikes are usually pilotaxitic (Figs. d27-29). Basalt dikes generally appear to have the same composition as dolerite dikes with partially altered plagioclase and mafic minerals that are very fine interstitial clinopyroxene partly to entirely altered to actinolite and chlorite (Fig. d29). The fine grain size of basalt dikes makes an exact assessment of matrix minerals and alteration difficult using a petrographic microscope. Basalt has very fine equant (Fig. d28) and skeletal opaque grains (Fig. d27) that are probably titanomagnetite. Vesicle fillings or amygdules in basalt are filled by chlorite and actinolite with small calcite cores (Figs. d27-28).



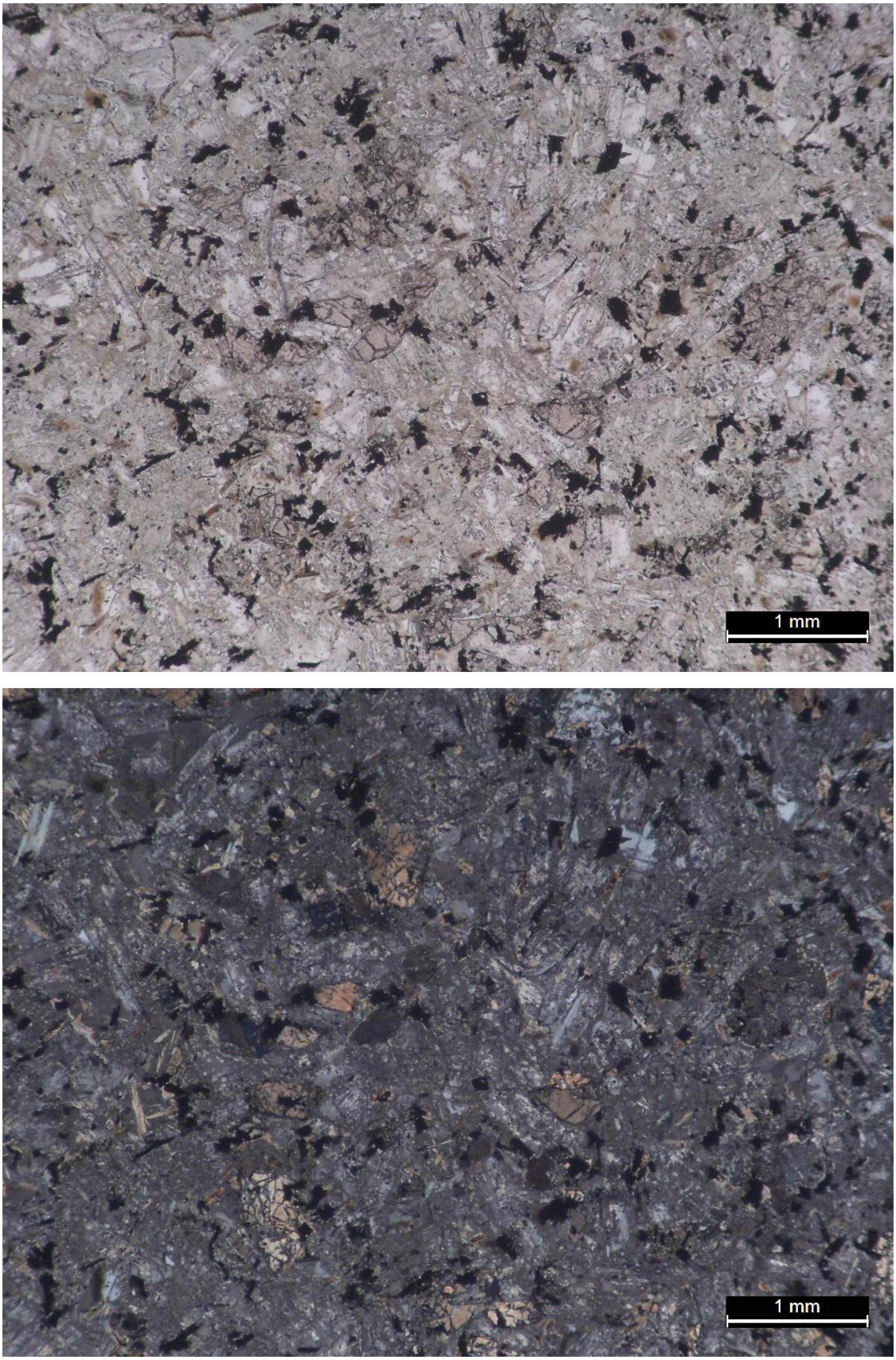
d14: Thin section in plane polarized light (above) and crossed polarizers (below). Dolerite dike with intergranular texture, and minor alteration of plagioclase to sericite. Clinopyroxene (colorful grains below) is lightly altered to actinolite and chlorite (green areas above). Opaque grains are skeletal titanomagnetite. Near center of images is interstitial quartz (very clear grain, likely a xenocryst). West of Boojum Rock in Malden (site 10001). See also Fig. d7.



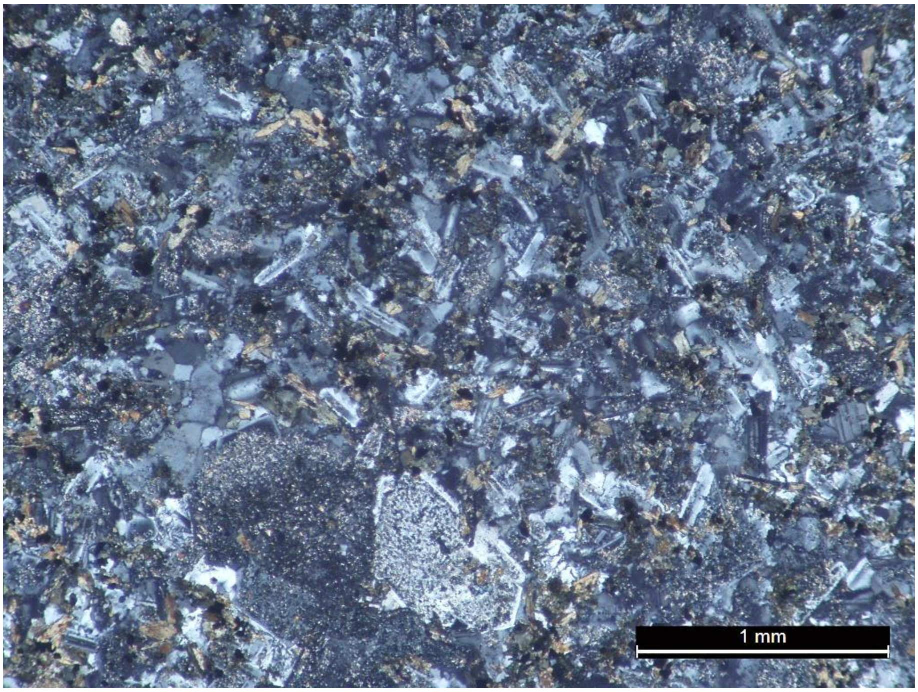
d15: Thin section in plane polarized light (above) and with crossed polarizers (below). Dolerite dike with intergranular texture, partial alteration of plagioclase to sericite, and clinopyroxene (colorful grains below) altered to actinolite and chlorite (green areas above). Opaque grains are skeletal titanomagnetite. West of Sheepfold in Stoneham (site 10820).



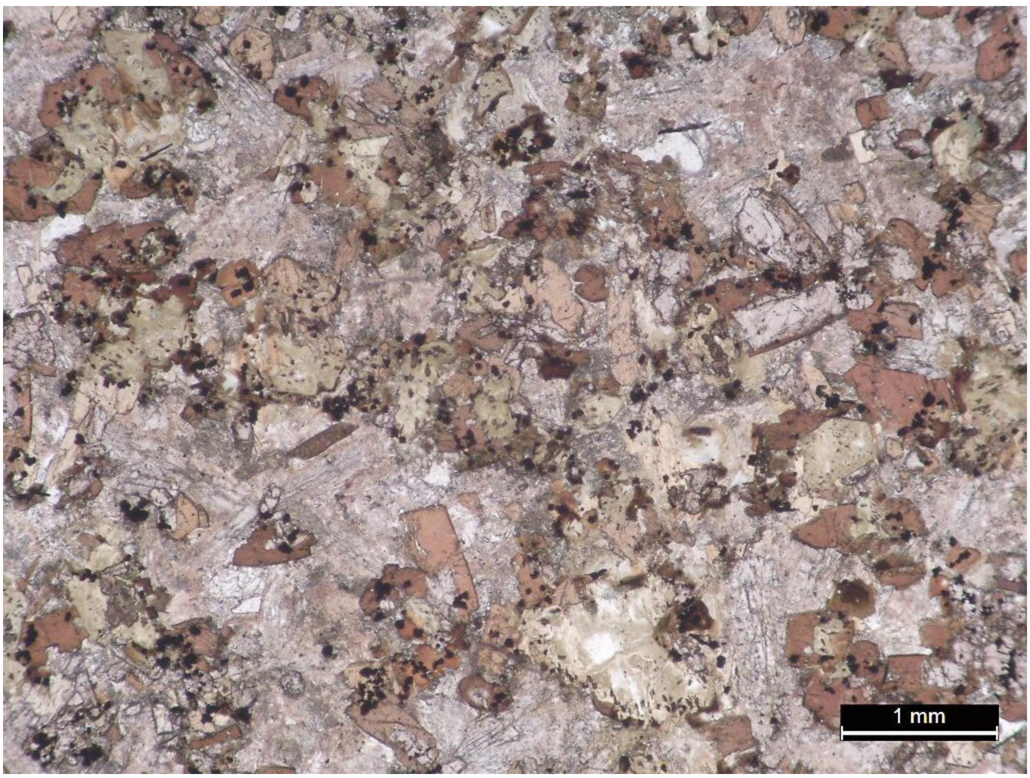
d16: Thin section in plane polarized light (above) and with crossed polarizers (below). Dolerite dike with heavy alteration of plagioclase to sericite and sparse remnant clinopyroxene that is heavily altered to intergrown actinolite and chlorite (green and tan areas above). Opaque grains are skeletal and acicular titanomagnetite. North end of Pine Hill in Medford (site 10508).



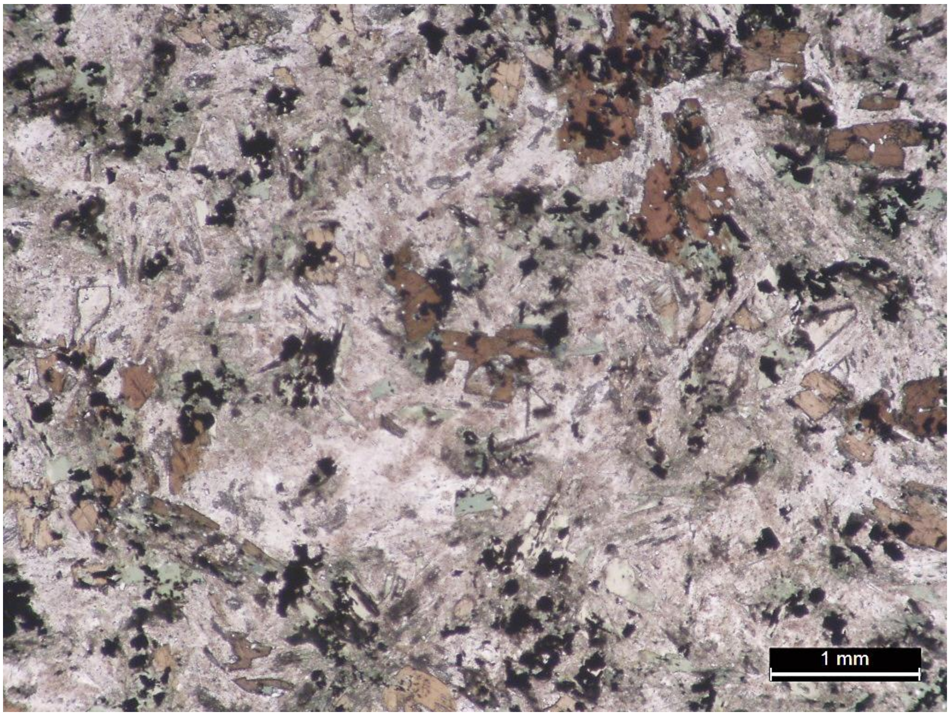
d17: Thin section in plane polarized light (above) and with crossed polarizers (below). Dolerite dike with almost complete alteration of plagioclase to sericite and mostly altered remnant clinopyroxene (colorful grains below) that is now chlorite (pale green above) with minor actinolite. Opaque grains are altered skeletal magnetite. East of Greenwood Park in Stoneham (site 10568).



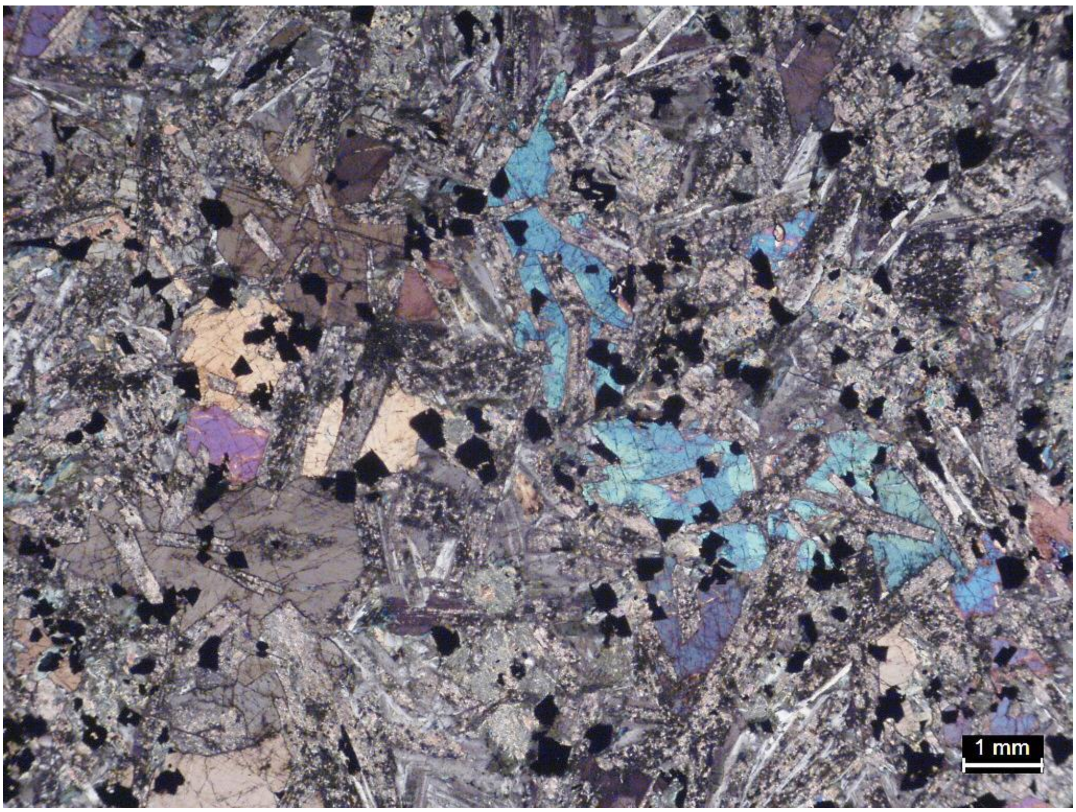
d18: Dolerite dike (d) cutting across Winchester Granite (Zwg). Thin section in crossed polarizers. Clinopyroxene completely altered to actinolite and chlorite. Plagioclase is partly altered to sericite. At bottom of image is altered xenolith from adjacent granite with plagioclase with fresh rim. Near Hillcrest Parkway west of Middle Reservoir in Winchester (site 11127).



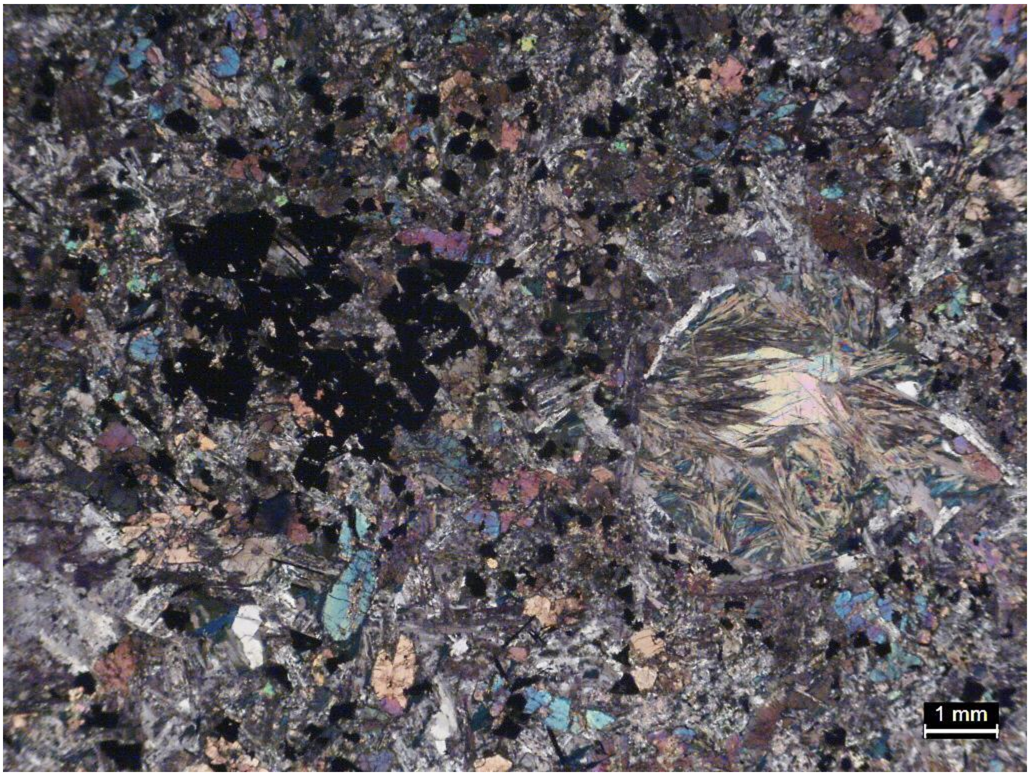
d19: Dolerite dike (d) that cuts through shattered Spot Pond Granodiorite (Zsg) in the MWRA excavation along Woodland Road in Stoneham (site 10282). Thin section in plane polarized light. Altered plagioclase, very sparse clinopyroxene (augite) remnants altered to chlorite with actinolite (green and tan), brown to tan hornblende, and very minor quartz (white grains - right of upper center and upper left side). Opaque minerals are fine, equant, and recrystallized titanomagnetite.



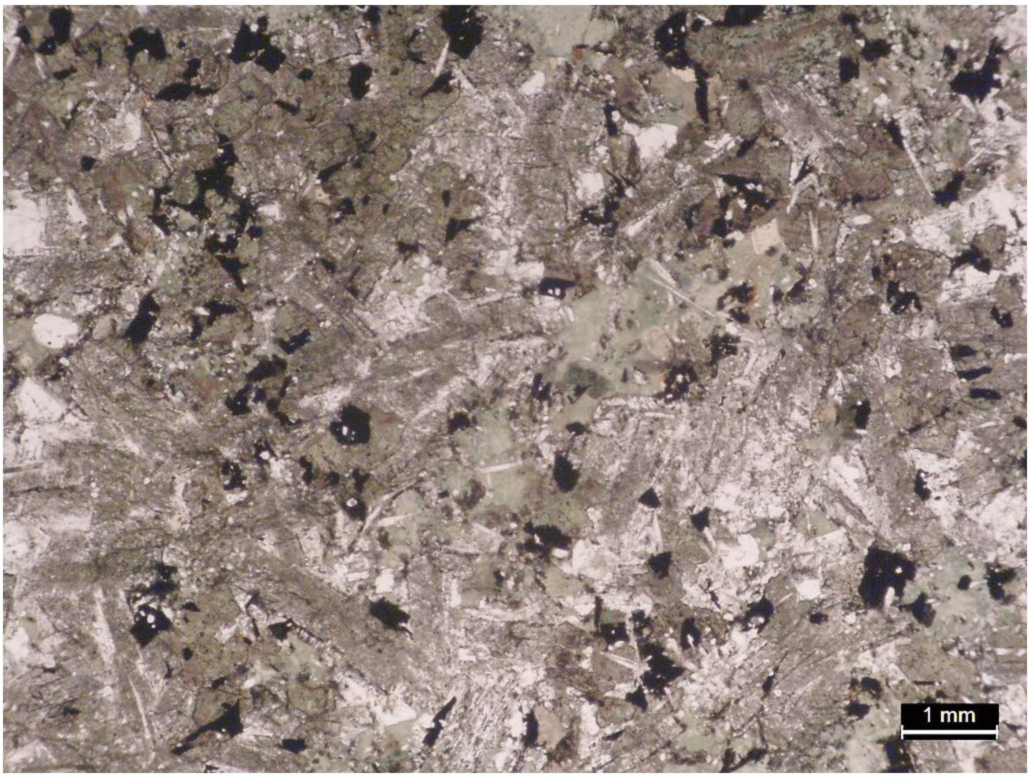
d20 (see also Fig. d11): Dolerite dike (d) cutting across crystal tuff in Lynn Volcanic Complex (Zlvx) on north end of Pine Hill in Medford (site 10509). Thin section in plane polarized light. Altered plagioclase and no remnant clinopyroxene (augite) altered to chlorite, and brown hornblende. Small white crystals in hornblende are apatite.



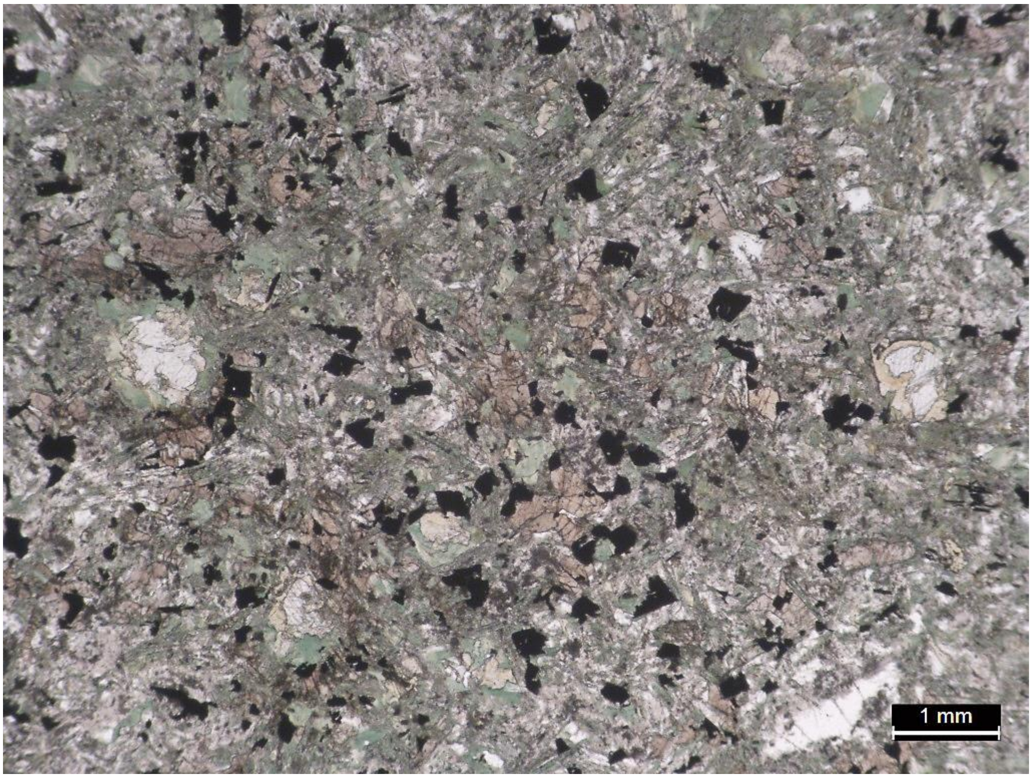
d21 (see also Fig. d8): Dolerite dike (d) cutting across crystal tuff of the Lynn Volcanic Complex (Zlvx) northwest of Wrights Pond in Medford (site 10471). Thin section in crossed polarizers. Subophitic texture with clinopyroxene (augite) housing altered plagioclase and equant opaque grains, likely titanomagnetite. Clinopyroxene is lightly altered to actinolite and fine chlorite.



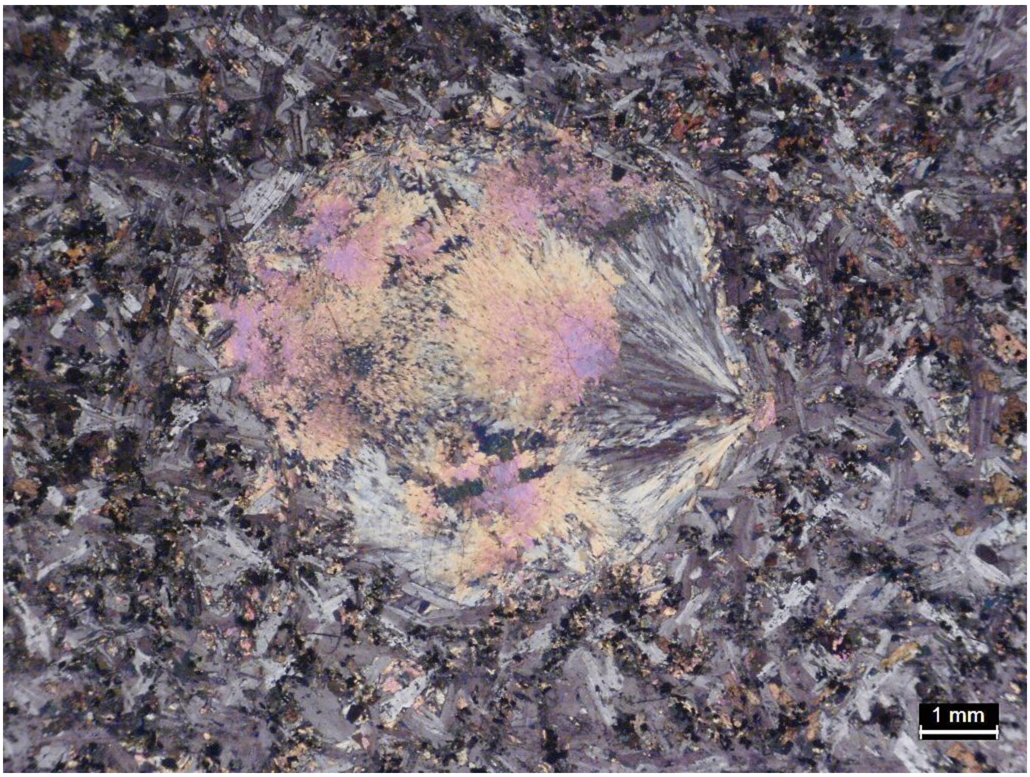
d22 (see also Fig. d6): Dolerite dike (d) east of Boojum Rock in Melrose that cuts through crystal tuff of the Boojum Rock Tuff (Zbrc; site 10031). View with crossed polarizers. The opaque cluster is pyrite. The amygdule on the right is filled by splintery actinolite and chlorite with a core of calcite.



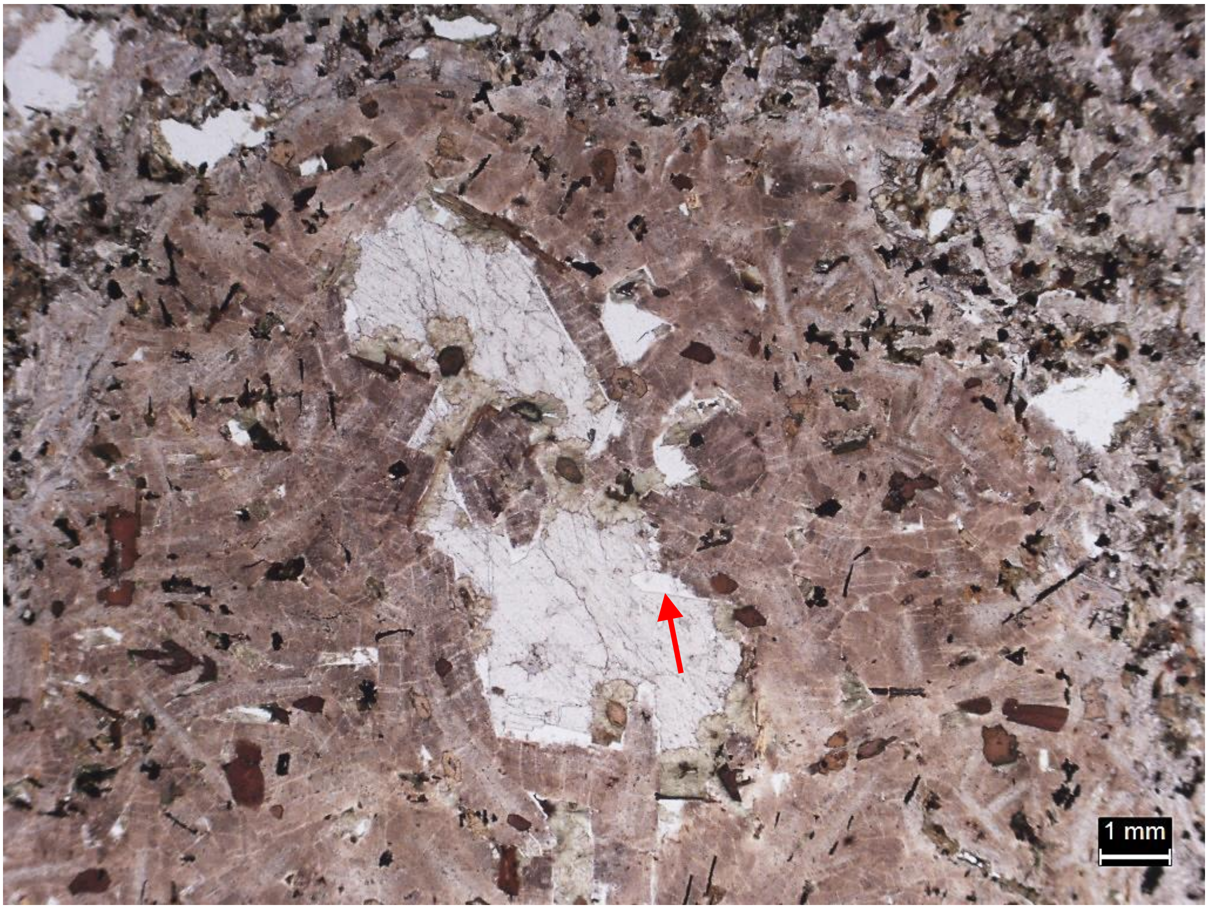
d23: Large E-W trending dolerite dike (d) south of Sheepfold in Medford (site 10858). Thin section in plane polarized light. Altered plagioclase, very sparse remnant clinopyroxene (augite) altered to intergrown chlorite and actinolite, and skeletal magnetite. On left side and in upper center is quartz (bright grains), likely xenocrysts from adjacent quartzite. Slender white crystals and small circular spots in opaque grains and chlorite are needle-like apatite crystals.



d24: NW-SE trending dolerite dike (d) on east flank of Boojum Rock in Malden that cuts through crystal tuff of the Boojum Rock Tuff (Zbrc; site 10018). View in plane polarized light. Plagioclase is altered and fractured with orangish-pink clinopyroxene (augite) mostly altered to chlorite. Vesicles are filled with rims of chlorite and epidote and cores of calcite.

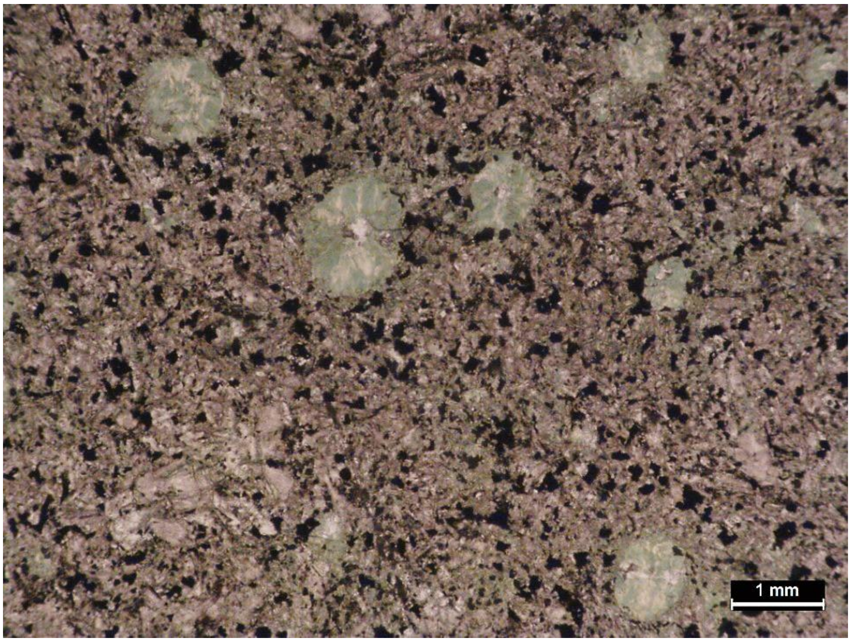


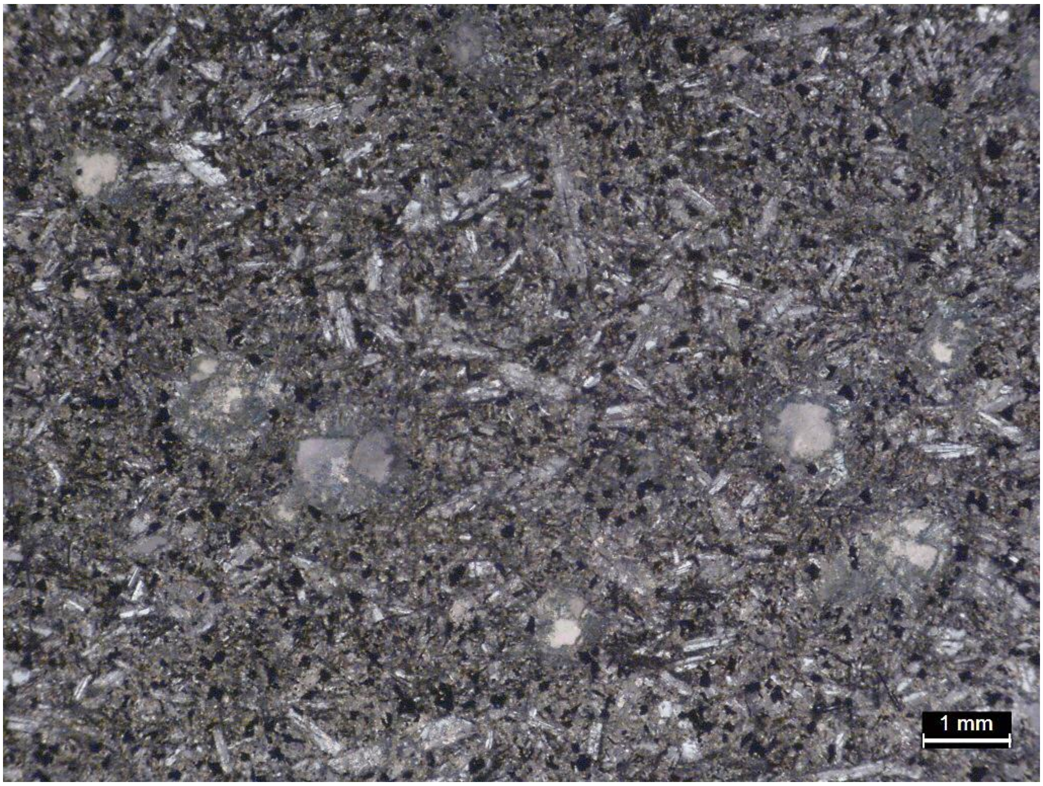
d25 (see also Fig. d12): Dolerite dike (d) in Lawrence Woods Granophyre (Zlwg) on Middle Hill in Medford (site 10661). Thin section with crossed polarizers. Dike has plagioclase and biotite (orange to brown) and chlorite formed by alteration of clinopyroxene. Vesicle filling is radiating prehnite.



d26 (see also Fig. d13): Melt inclusion in dolerite dike (d) that cuts across cataclastic Spot Pond Granodiorite (Zsg) in 2013 excavation for MWRA water storage facility along Woodland Road (site 10278, now covered) in Stoneham. Thin section in plane polarized light. In upper right and top is intergranular texture of dolerite with altered plagioclase and sparse clinopyroxene (augite) remnants altered to biotite and minor chlorite with actinolite. Most of image is an amygdule with altered (iron-stained) plagioclase, minor quartz with euhedral growth (arrow), biotite (dark brown) and minor hornblende (tan) with a calcite core.

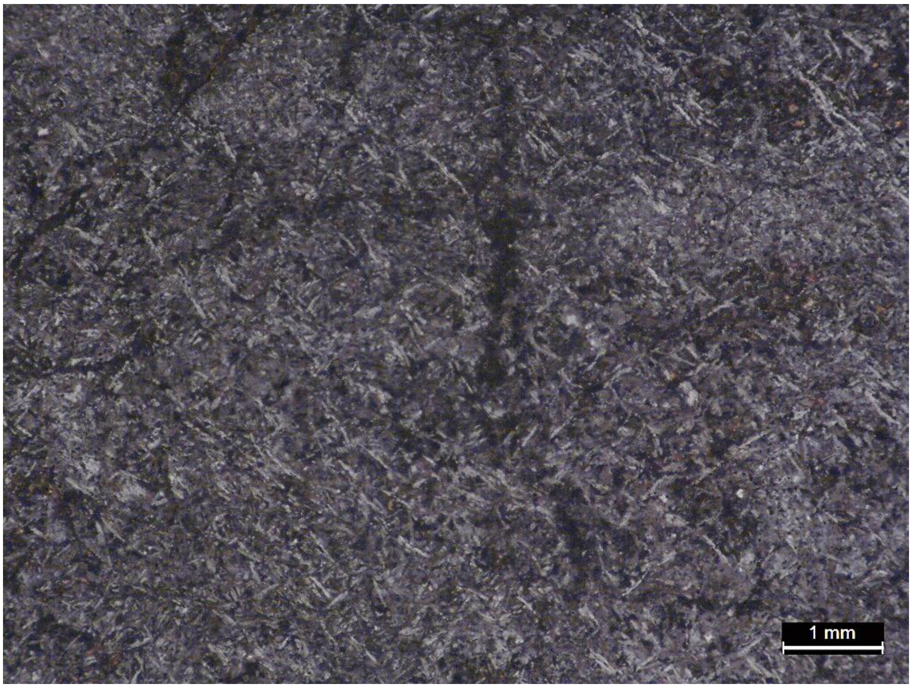
d27: Basalt dike (b) in crystal tuff of the Boojum Rock Tuff (Zbrc) west of Fells Reservoir in Stoneham (site 10194). Thin section in plane polarized light. Pilotaxitic texture with a matrix of fine plagioclase microlites partly altered to sericite, and fine chlorite and actinolite derived from clinopyroxene alteration. Opaque grains are skeletal magnetite. Vesicles are chlorite with calcite cores.





d28: Small basaltic dike (d) in Westboro Formation (Zvwq) south of Wamoset Hill in Stoneham (site 10330). Thin section in crossed polarizers. Pilotaxitic texture with a matrix of fine plagioclase blades lightly altered to sericite and fine chlorite and actinolite derived from alteration of clinopyroxene. Opaque grains are equant and skeletal magnetite. Vesicles are filled with chlorite and actinolite with calcite cores.

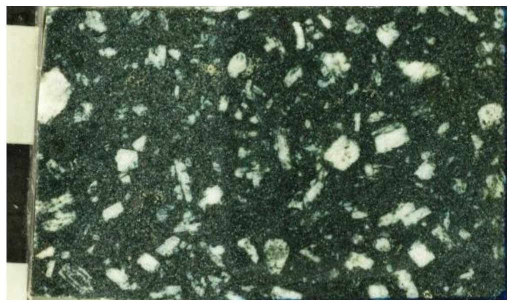
d29: Basalt dike (d) in Spot Pond Granodiorite (Zsg) east of South Border Road in Medford (site 10975). Thin section in crossed polarizers. Pilotaxitic texture with plagioclase microlites separated by mafic minerals altered to chlorite and actinolite as well as opaque minerals.



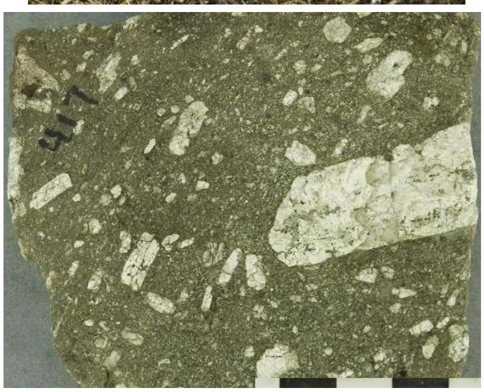
dp **Porphyritic dolerite and basalt dikes (Neoproterozoic through Paleozoic?)** – Grayish-black to dark gray (N 2-3) and greenish-black (5G 2/1), aphanitic to fine-grained phaneritic, porphyritic dolerite and basalt dikes (Figs. dp1-11). Plagioclase phenocrysts are up to 10 cm (Fig. d6-7) and can occur as single tabular crystals (Figs. dp1-5, 10) or cumulophyric clusters (Figs. dp6-9). Includes occasional lamprophyric dikes with altered amphibole or biotite phenocrysts (Figs. dp12-13). The ground mass often appears darker and finer than in non-porphyritic dolerite/basalt dikes (d), possibly because more plagioclase crystallizes as phenocrysts instead of in the matrix. Some porphyritic dolerite dikes on the west shore of Middle Reservoir have large basalt xenoliths with densely packed coarse plagioclase phenocrysts, coarse pyroxene, and a black very fine matrix (Fig. dp11). Porphyritic dikes may be related to or are porphyritic portions of non-porphyritic dikes (d). Porphyritic dolerite dikes tend to have heavily altered plagioclase. The dikes weather to a rusty-brown or gray color. Age information is lacking but the age range may be like the range of non-porphyritic dikes (d), although Mesozoic seems unlikely. Mapped only where dikes exceed a width of 1.0 m. Thinner dikes are shown with a separate line symbol (see symbols below).

dp1 (left): Typical porphyritic dolerite dike with large single plagioclase phenocrysts along west shore of Fells Reservoir in Stoneham (site 10217).

dp2 (below): Dolerite porphyry with high density of altered single crystal plagioclase phenocrysts north of Crystal Spring in Stoneham (site 10343).
dp3 (below right): Cut rock surface of rock in Fig. dp2.

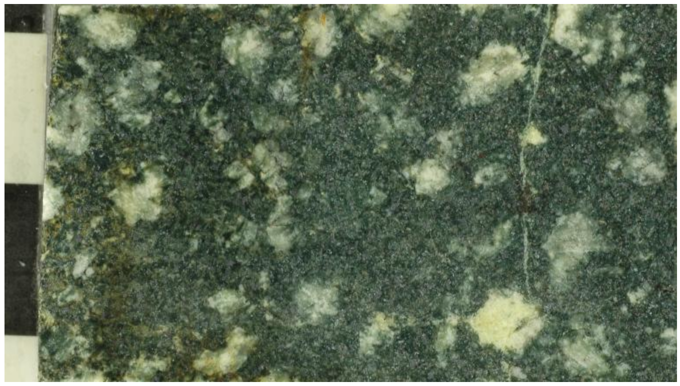


dp4: Basalt porphyry with high density of coarse flow-aligned (trachytic), tabular plagioclase phenocrysts near Crystal Spring in Stoneham (site 10417).
dp5 (far right): Cut surface of sample in Fig. dp4.

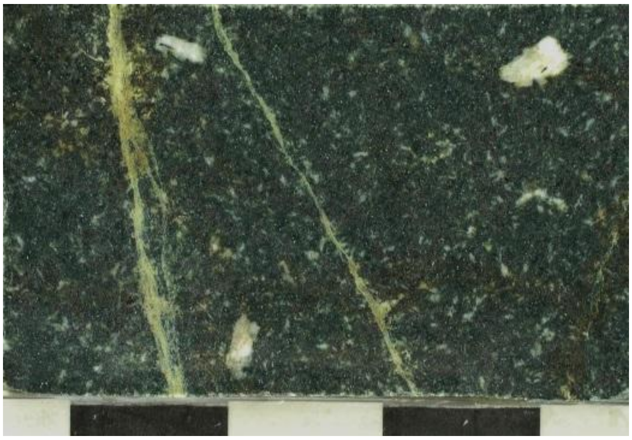


dp6: Basalt porphyry with very coarse (up to 10 cm) plagioclase phenocrysts on Nanepashemet Hill in Winchester (site 11084). Pencil for scale.
dp7 (far right): Cut surface of rock in Fig. dp6.

dp8: Weathered surface of porphyritic dolerite, so called “pimple texture”, with altered cumulophyric plagioclase east of Whip Hill in Stoneham (site 10360).

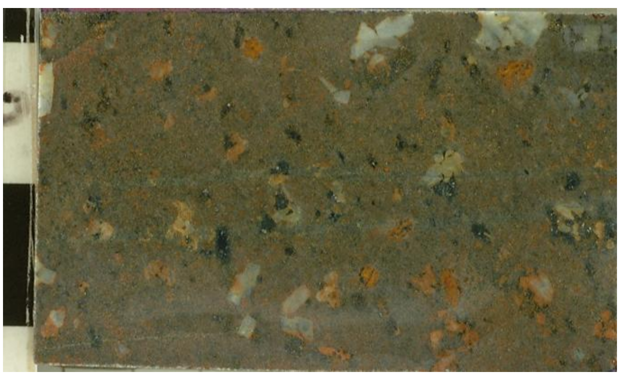


dp9: Cut surface of altered cumulophyric dolerite in Fig. dp8. Alteration of these dikes suggests they may be older than other porphyritic dikes.

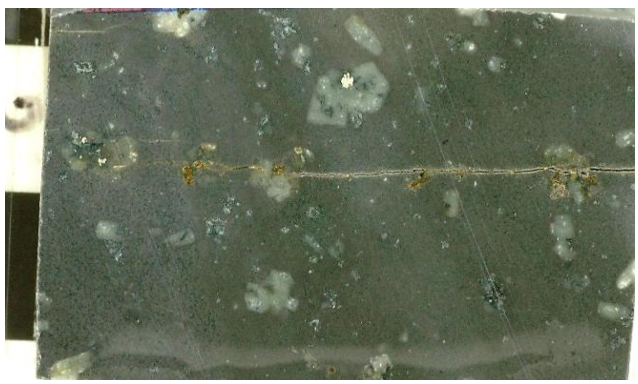


dp10 (left): Dolerite with sparse single-crystal plagioclase phenocrysts south of Sheepfold in Medford (site 10741). Note epidote veins.

dp11 (right): Porphyritic dolerite with coarse plagioclase phenocrysts, and densely and coarsely porphyritic basalt xenoliths on west shore of Middle Reservoir (site 11128).



dp12: Porphyritic basalt (lamprophyre) with cumulophyric plagioclase and hornblende or biotite phenocrysts altered to chlorite on the southwest side of Middle Hill in Medford (site 10526). Orange phenocrysts are heavily altered plagioclase.



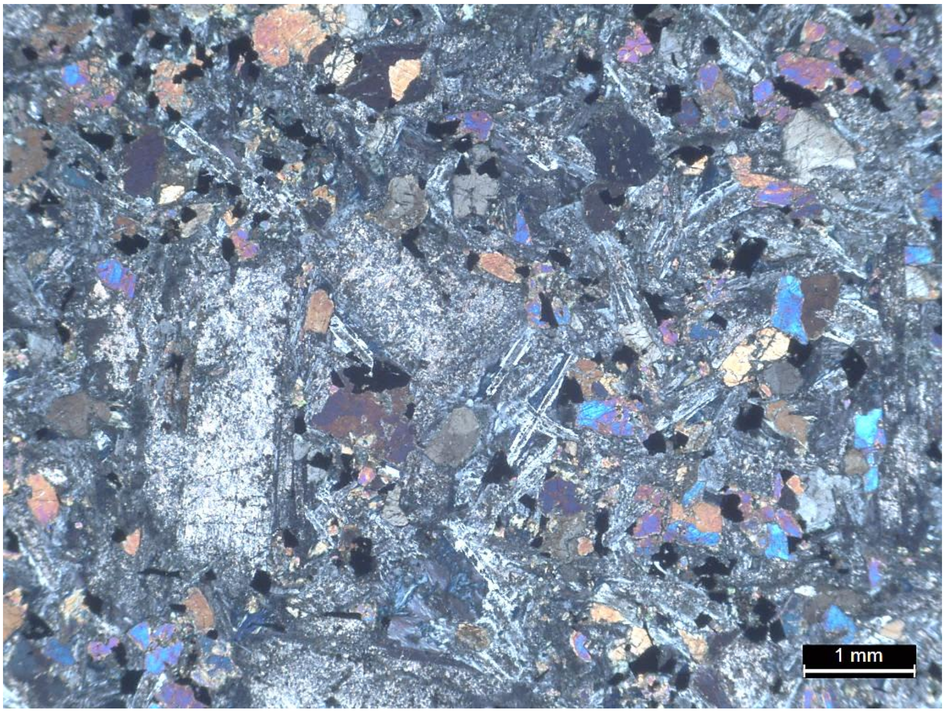
dp13: Porphyritic basalt (lamprophyre?) with cumulophyric plagioclase and altered hornblende or biotite phenocrysts on west side of Middle Hill in Medford (site 10528).

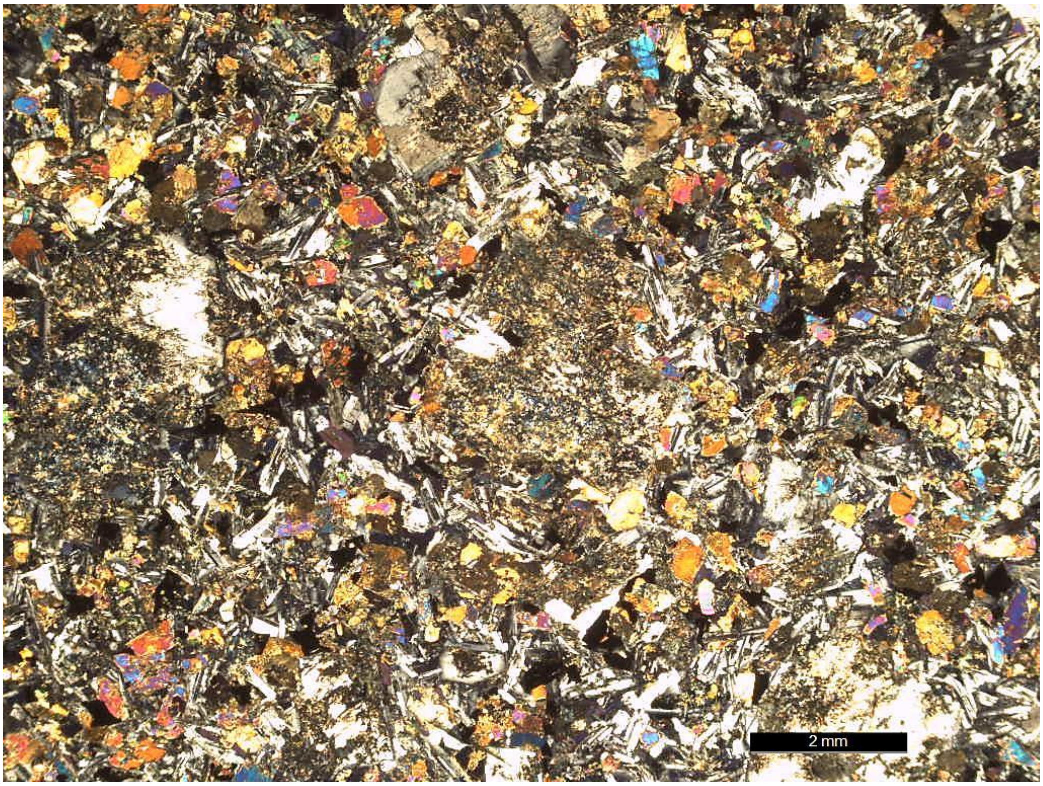
Porphyritic dolerite and basalt dikes (cont.)

Thin section description – Like dolerite dikes, **porphyritic dolerite dikes** have two fundamental components: plagioclase and original clinopyroxene, which are usually altered. Matrix plagioclase is tabular with partial (Figs. dp14-15) to heavy alteration to sericite (Figs. dp16-17), and in some cases minor epidote. Often mafic minerals are or were originally very fine clinopyroxene (augite; Fig. dp18). Matrix clinopyroxene has usually undergone at least minor alteration to actinolite (uralization) and/or chlorite (Figs. dp19-20). Matrices are most commonly intergranular (Figs. dp14-15) and opaque minerals can be magnetite (titanomagnetite), pyrite (Fig. dp18), and possibly ilmenite with skeletal titanomagnetite (Fig. dp16) being common. Subophitic textures have been found (Figs. dp19, 21). Phenocrysts in dolerite dikes are almost exclusively plagioclase that is commonly cumulophyric and more altered to sericite than matrix plagioclase (Fig. dp14), although, plagioclase phenocryst alteration can be irregular (Figs. dp20, 22). The phenocrysts and matrix can be pilotaxitic (Fig. dp23) or trachytic (Fig. dp4-5). Vesicles or amygdules are common and usually filled by some combination of chlorite and actinolite (Fig. dp18).

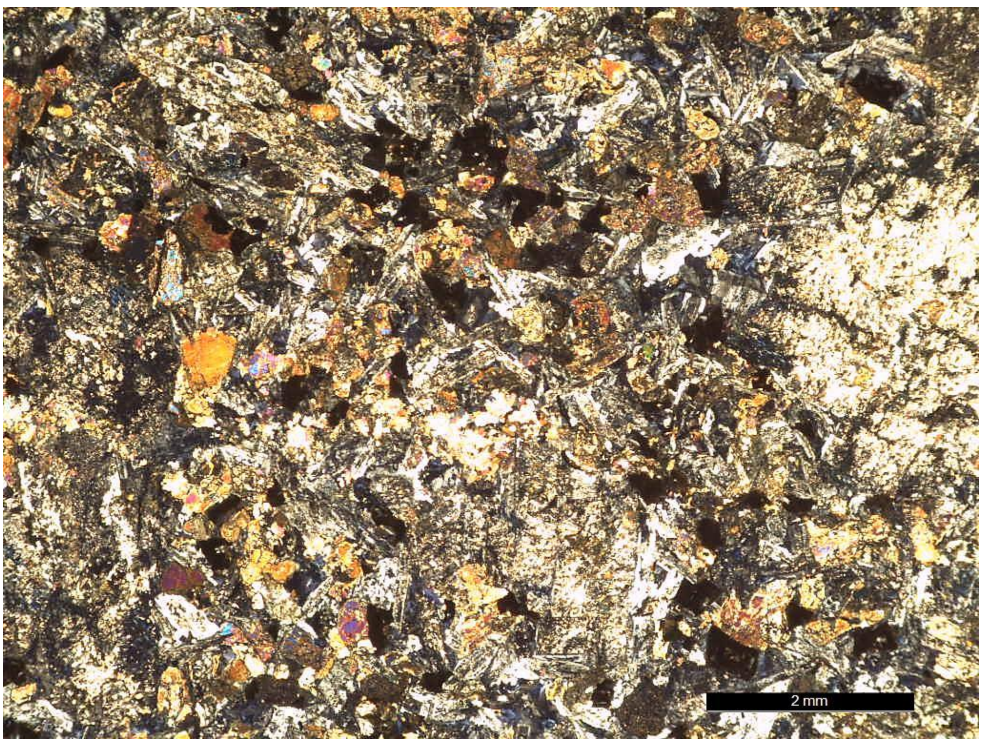
Petrographically, **porphyritic basalt dikes** are more interesting than porphyritic dolerite dikes because of their more varied mineralogy of phenocrysts and grain size. Fine grain size and alteration often makes an exact identification of matrix minerals difficult, but matrices have mostly pilotaxitic plagioclase partly altered to sericite (Figs. dp24-25), mafic minerals that are very fine interstitial clinopyroxene (augite) partly to entirely altered to actinolite and chlorite (Figs. dp24-25), and fine opaque grains thought to be mostly titanomagnetite. Phenocrysts are mostly plagioclase that is usually heavily altered (Figs. dp25-27), and rarely clinopyroxene (Figs. dp27-28) or altered olivine along with fresh clinopyroxene (Figs. dp29-30). Some plagioclase phenocrysts are very coarse and have been found up to 10 cm long (Fig. dp31, see also Fig. dp4-7). Many porphyritic basalts have cumulophyric plagioclase (Fig. dp24) occurring as radiating clusters along with clinopyroxene (Fig. dp28). A few dikes with original mafic minerals (hornblende or biotite) altered to chlorite, epidote, and opaque minerals appear to be lamprophyres (Figs. dp32-33). Porphyritic basalts may locally be pilotaxitic (Fig. 27) or trachytic (Figs. dp4-5) with alignment of matrix plagioclase around phenocrysts. Vesicle or amygdules fillings in porphyritic basalt are chlorite (Fig. dp24), chlorite and/or actinolite with calcite cores (Fig. dp29), chlorite and radiating prehnite with calcite cores (Fig. dp26), and chlorite and epidote with calcite cores (Fig. dp25). Occasionally, basalt dikes have pyrite growths (Figs. dp24, 27) that may be spherical and framboid-like (Fig. dp34).

dp14: Porphyritic dolerite dike (dp) at north end of Dark Hollow Pond in Stoneham (site 11203). Thin section in crossed polarizers. Intergranular texture with a matrix of plagioclase blades partly altered to sericite and clinopyroxene partly altered to actinolite and chlorite. Opaque grains are equant and skeletal magnetite. Plagioclase phenocrysts (left side) are highly altered to sericite with minor epidote.

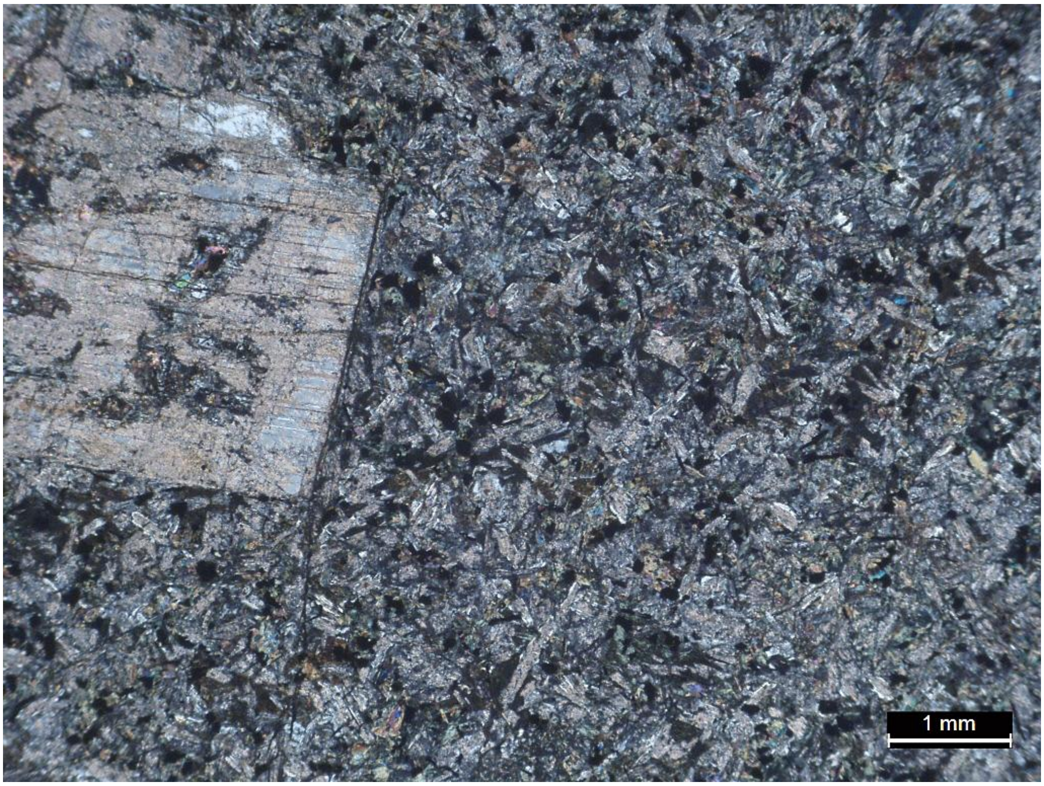




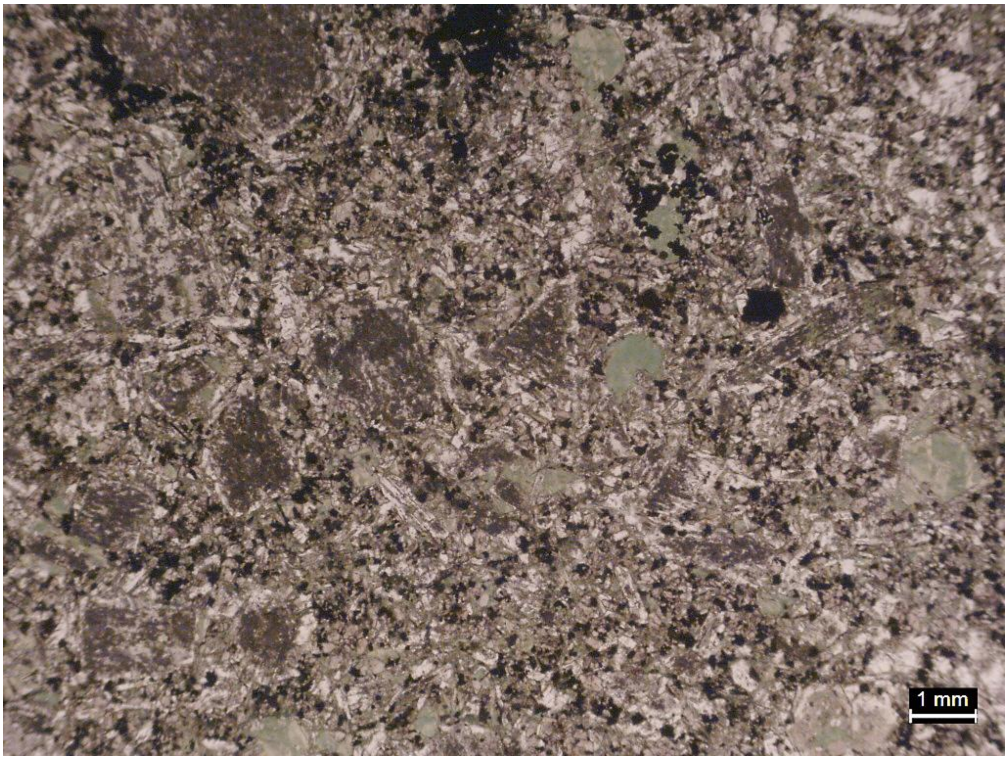
dp15: Float boulder of porphyritic dolerite from north of Crystal Spring in Stoneham (site 480BN). Thin section in crossed polarizers. Intergranular texture with a matrix of tabular plagioclase and clinopyroxene partly altered to fine chlorite and actinolite. Opaque grains are equant and skeletal titanomagnetite. Phenocrysts (center and left side) are plagioclase heavily altered to sericite.



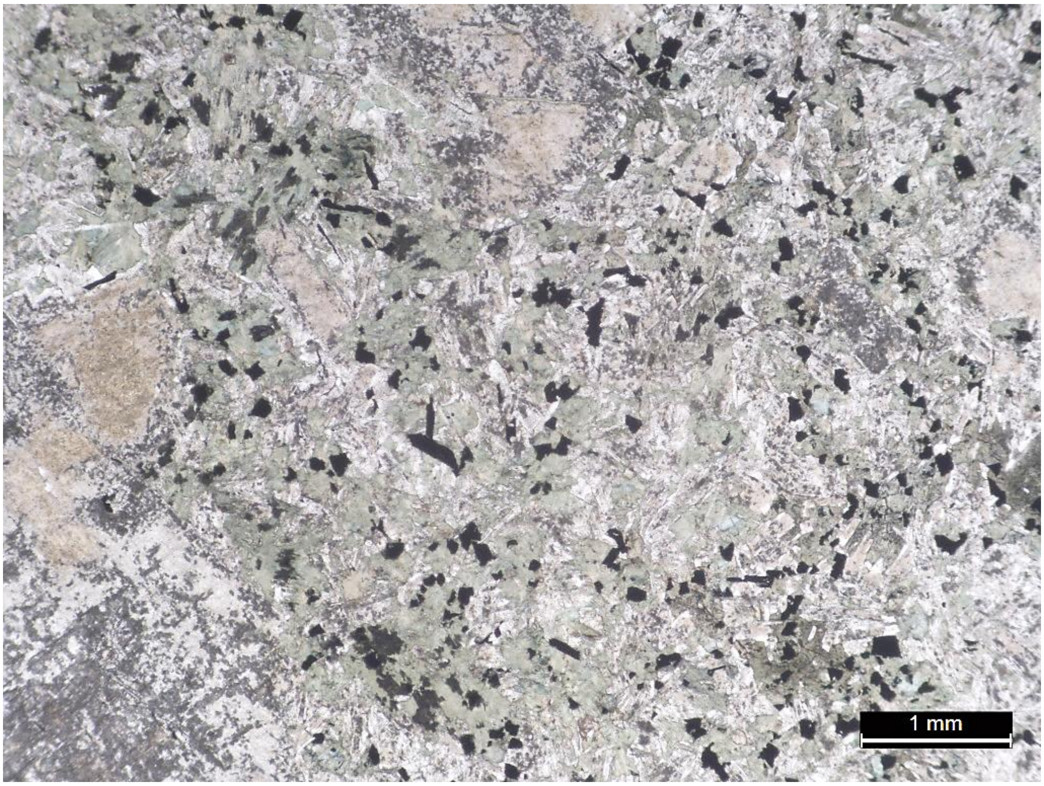
dp16 (see also Fig. dp8-9): Porphyritic dolerite dike (dp) in Westboro Formation (Zwp) east of Whip Hill in Stoneham (site 10360). Thin section in crossed polarizers. Intergranular texture with tabular plagioclase altered to sericite, clinopyroxene altered to chlorite and actinolite, and altered (slightly transparent) opaque minerals. Phenocrysts (right side) are plagioclase heavily altered to sericite.



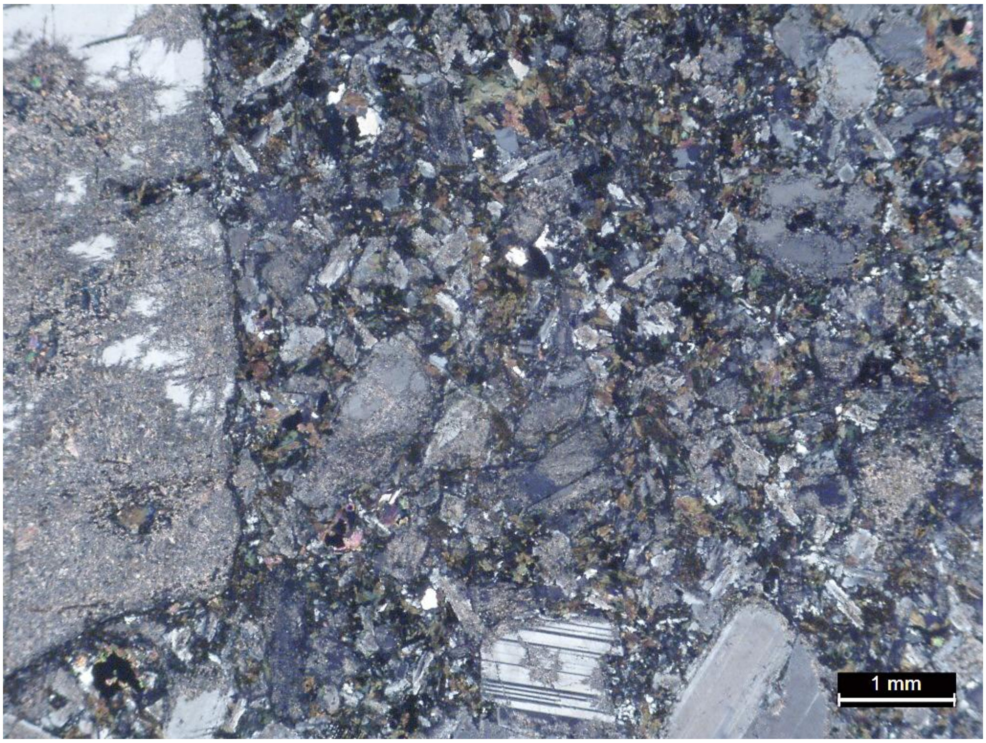
dp17: Porphyritic dolerite dike (dp) cutting through Nanepashemet Formation (Znpm) along west shore of Middle Reservoir in Stoneham (11268). Thin section with crossed polarizers. Fine intergranular texture with a matrix of tabular plagioclase highly altered to sericite and clinopyroxene completely altered to fine chlorite and actinolite. Phenocrysts are very coarse plagioclase heavily altered to sericite and epidote.



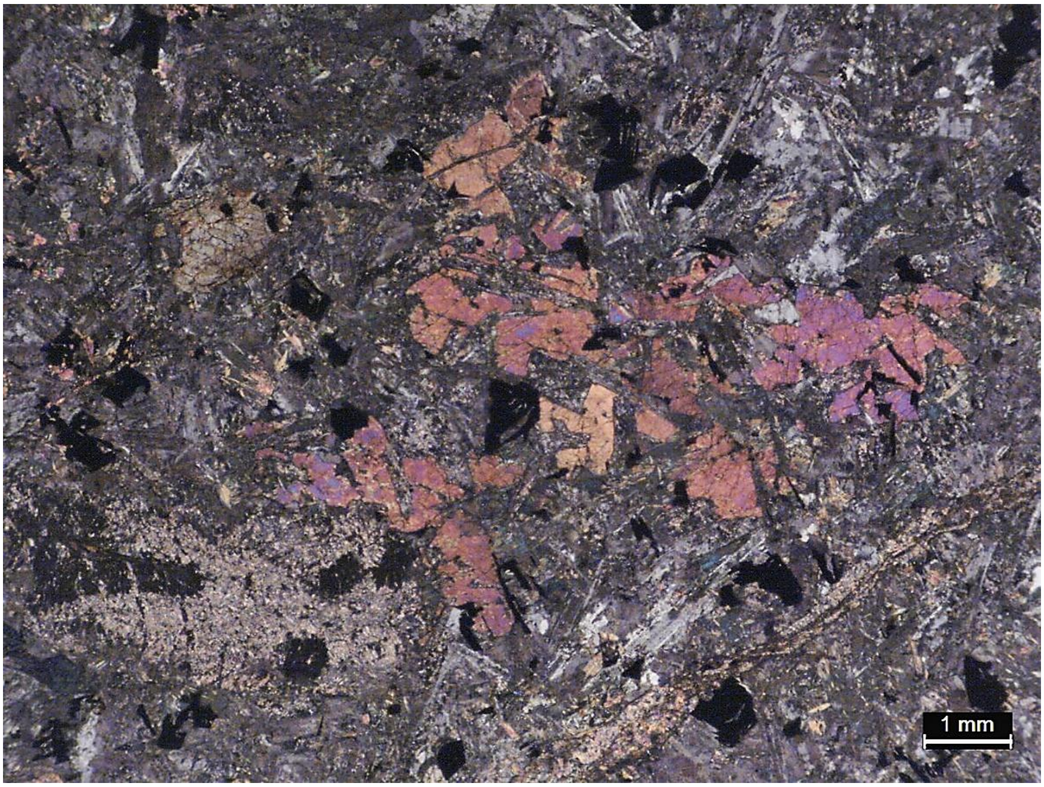
dp18 (see also Fig. dp2-3): Porphyritic dolerite dike (dp) in Westboro Formation (Zvwq) on Wamoset Hill in Stoneham (site 10343). Thin section in plane polarized light. Fine intergranular texture with tabular plagioclase partly altered to sericite, clinopyroxene partly altered to chlorite, and fine opaque minerals. Phenocrysts are plagioclase heavily altered to sericite. Amygdules are filled with chlorite and actinolite. At top of image are opaque pyrite clusters.



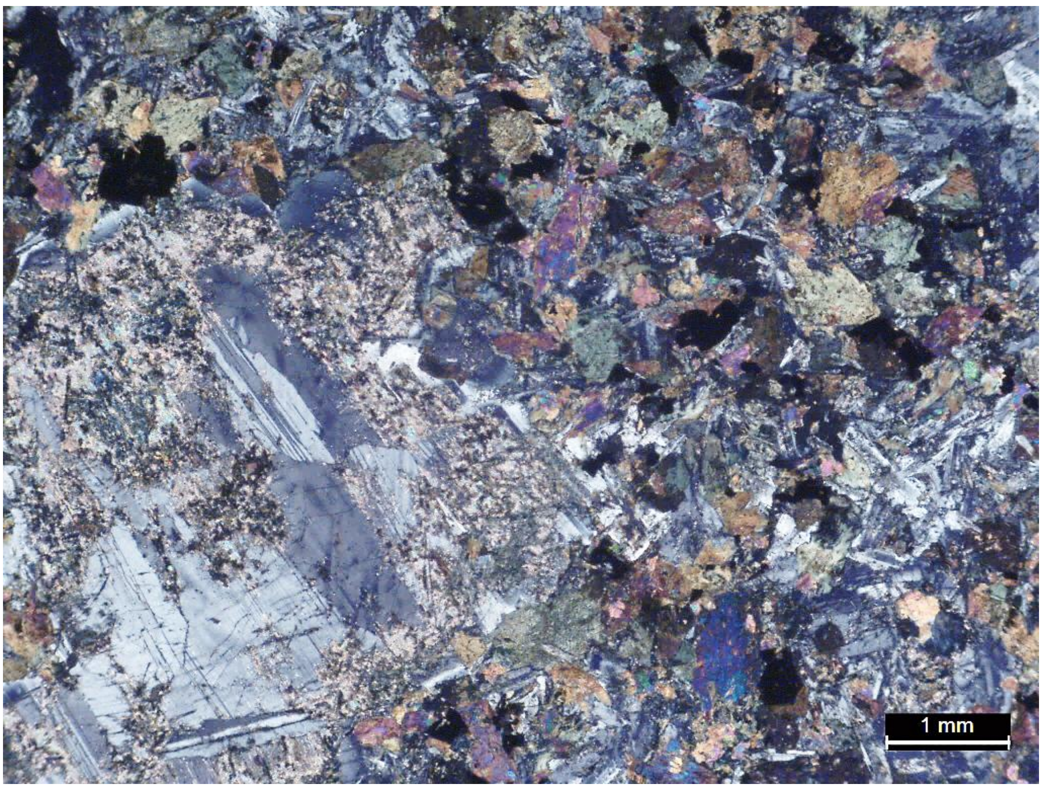
dp19: Porphyritic dolerite dike (dp) cutting through the Nanepashemet Formation (Znpm) west of Winthrop Hill in Stoneham (11188). Thin section in plane polarized light. Subophitic texture with tabular plagioclase highly altered to sericite enclosed by clinopyroxene completely altered to fine chlorite and actinolite. Phenocrysts (lower left and middle top) are plagioclase heavily altered to sericite.



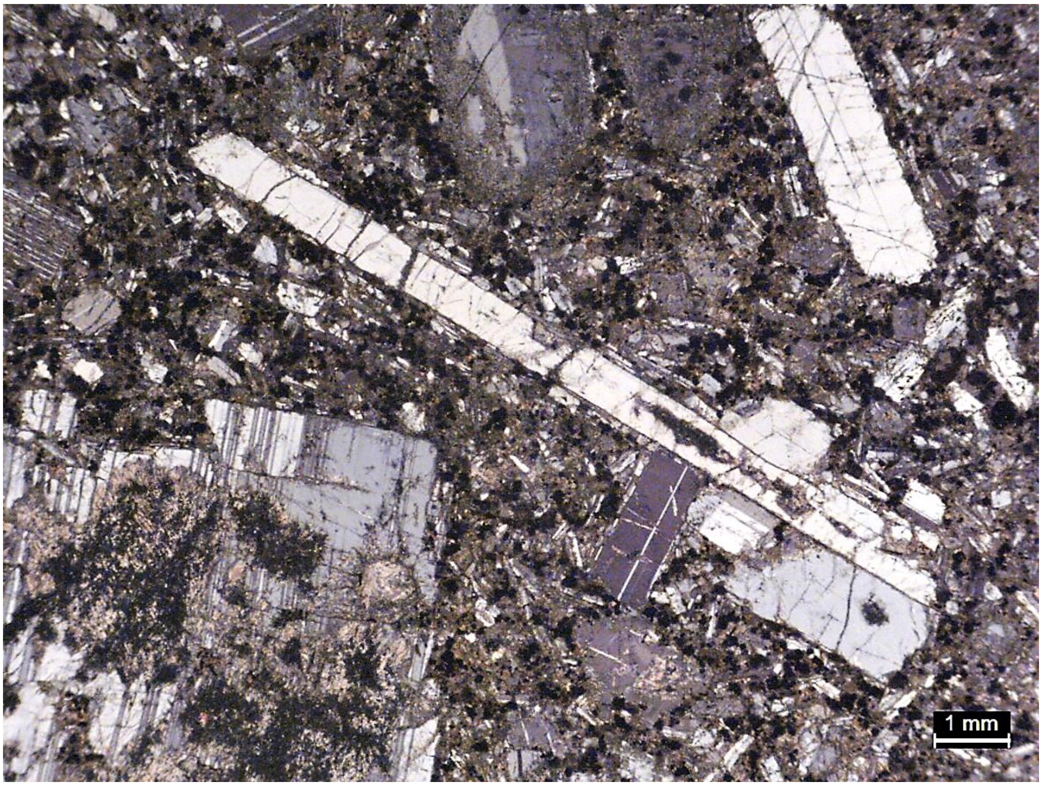
dp20: Porphyritic dolerite dike (dp) in Winchester Granite (Zwg) north of North Reservoir Dam in Winchester (site 11233). Thin section with crossed polarizers. Intergranular texture with tabular plagioclase partly altered to sericite and clinopyroxene altered to chlorite and actinolite. Phenocrysts are plagioclase (left side) irregularly altered to sericite with minor epidote.



dp21 (see also Fig. dp10): Porphyritic dolerite dike (dp) cutting through Spot Pond Granodiorite (Zsg) south of Gate no. 27 adjacent to Rt. 93 (site 10741) in Medford. Thin section with crossed polarizers. Subophitic texture with clinopyroxene housing altered plagioclase. Phenocrysts are plagioclase heavily altered to sericite and epidote.

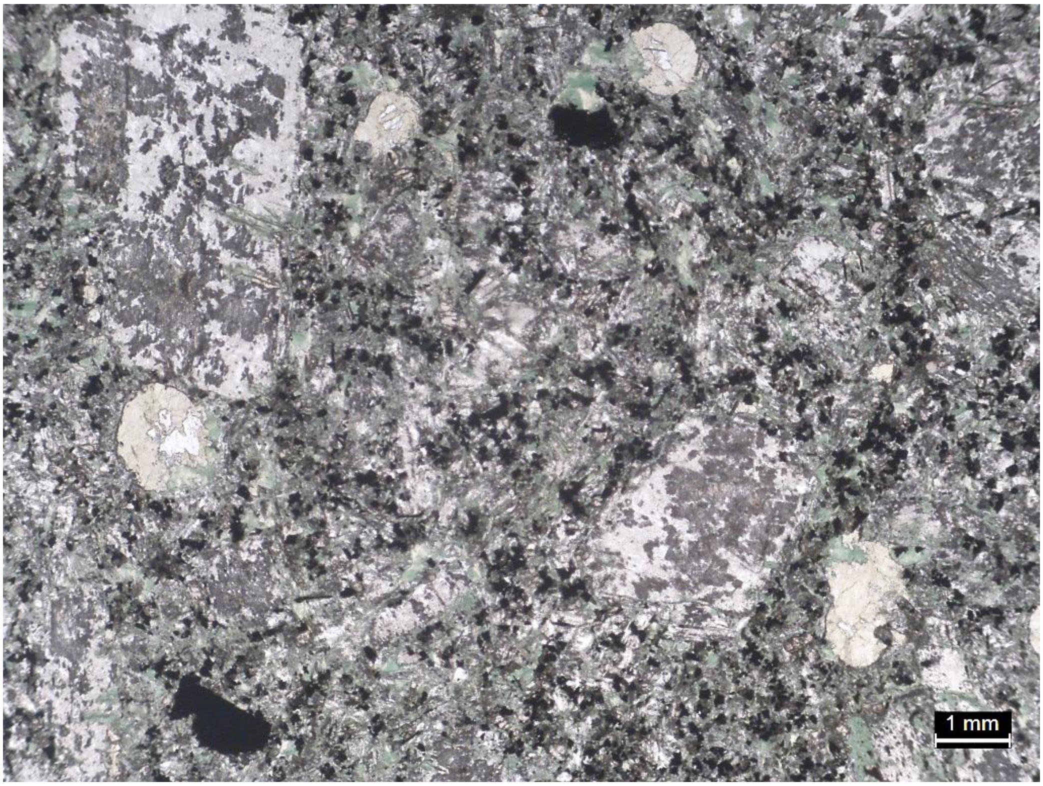


dp22: Porphyritic dolerite dike (dp) in Nanepashemet Formation (Znpm) northeast of North Reservoir in Winchester (site 11224). Thin section with crossed polarizers. Intergranular texture with tabular plagioclase lightly altered to sericite and clinopyroxene partly altered to chlorite and actinolite. Phenocrysts are plagioclase irregularly altered to sericite and epidote.

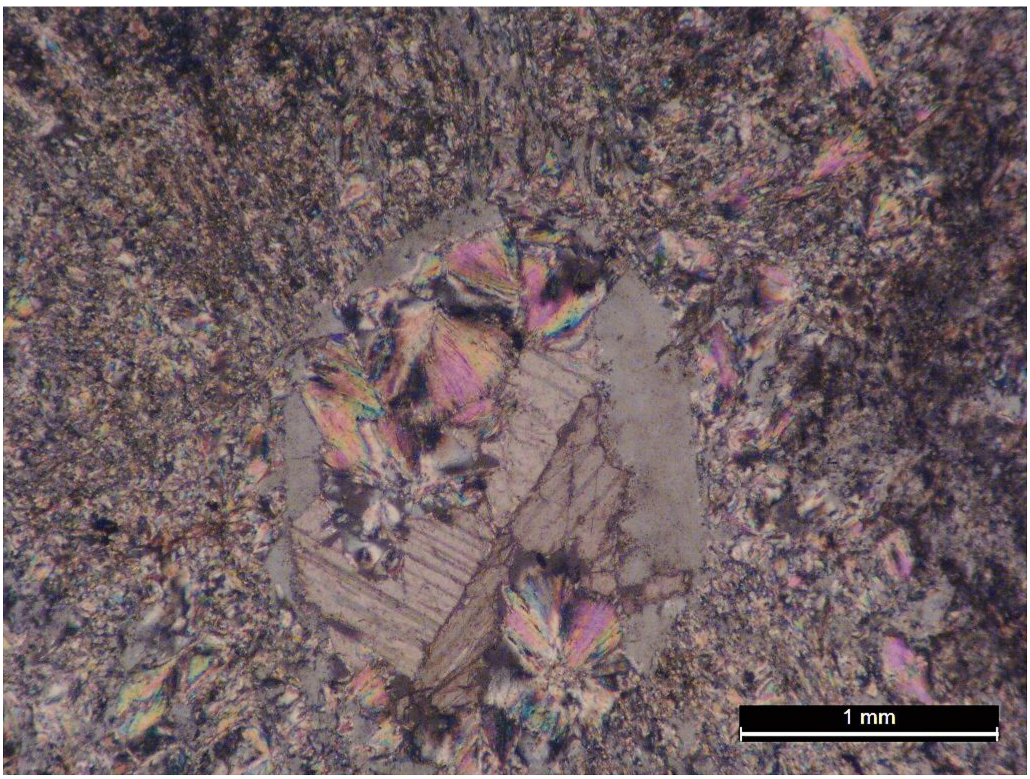


dp23 (see also Fig. dp4-5): Porphyritic basalt dike (dp) cutting through the Westboro Formation (Zvwq) near Crystal Spring in Stoneham (site 10417). Thin section with crossed polarizers. Fine plagioclase has a pilotaxitic texture and clinopyroxene is altered to chlorite and actinolite. Aligned plagioclase phenocrysts are coarse, cumulophyric, and partly altered to sericite and epidote.

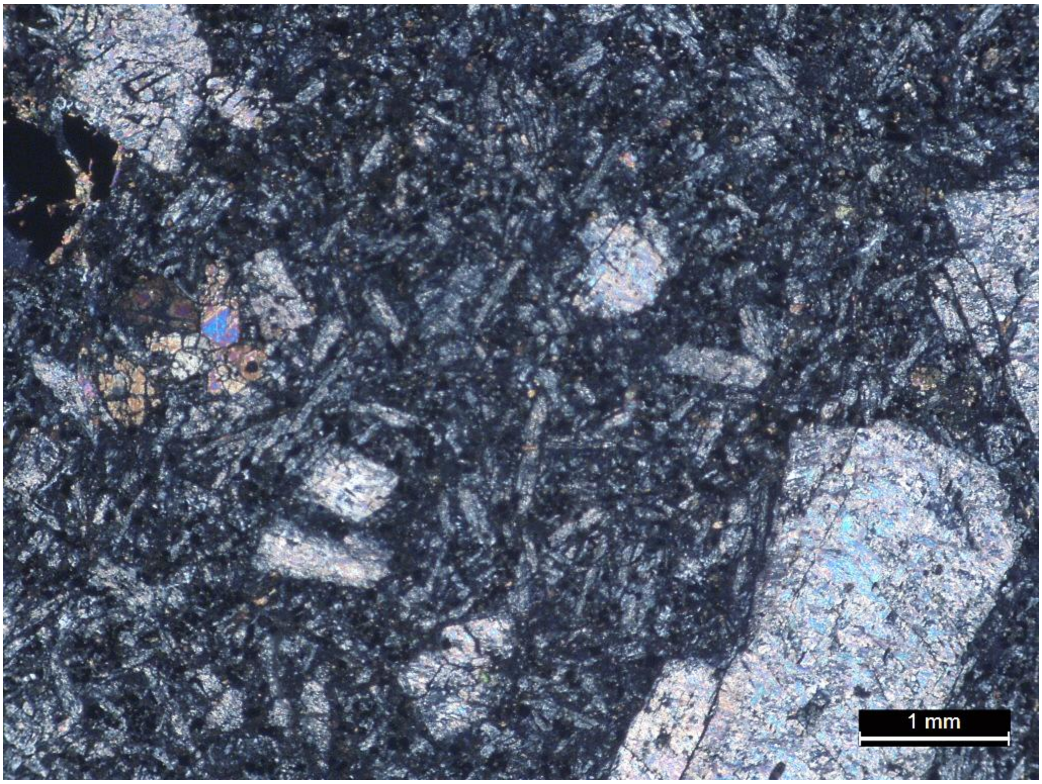
dp24: Porphyritic basalt dike (dp) in Boojum Rock Tuff (Zbrc) south of Fells Reservoir in Malden (site 10176). Thin section in plane polarized light. Pilotaxitic matrix of tabular radiating cumulophyric plagioclase and clinopyroxene altered to chlorite and actinolite. Phenocrysts are plagioclase altered to sericite. Large opaque grain on left is pyrite. Sub-millimeter, circular, green amygdules are filled with chlorite with calcite cores.



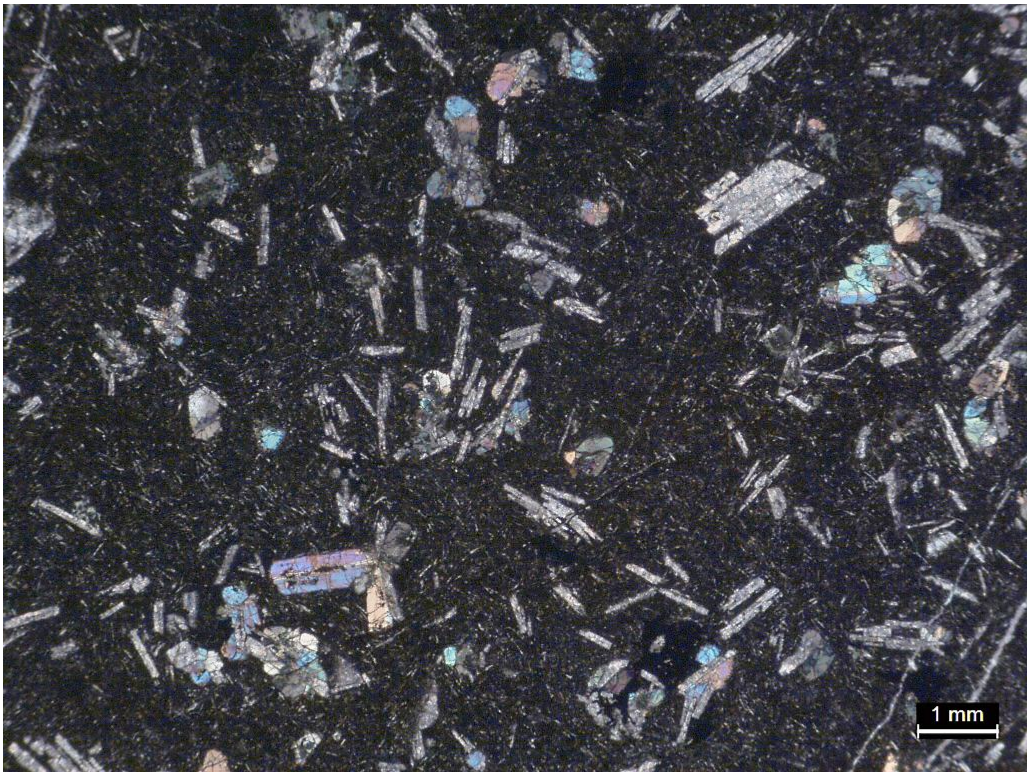
dp25: Porphyritic dolerite dike (dp) cutting through the Spot Pond Granodiorite (Zsg) east of Woodland Road in Stoneham (site 10266). Thin section in plane polarized light. Intergranular texture of altered plagioclase and clinopyroxene altered to chlorite and actinolite. Plagioclase phenocrysts are heavily altered to sericite and epidote. Amygdules are filled with chlorite and epidote with calcite cores.



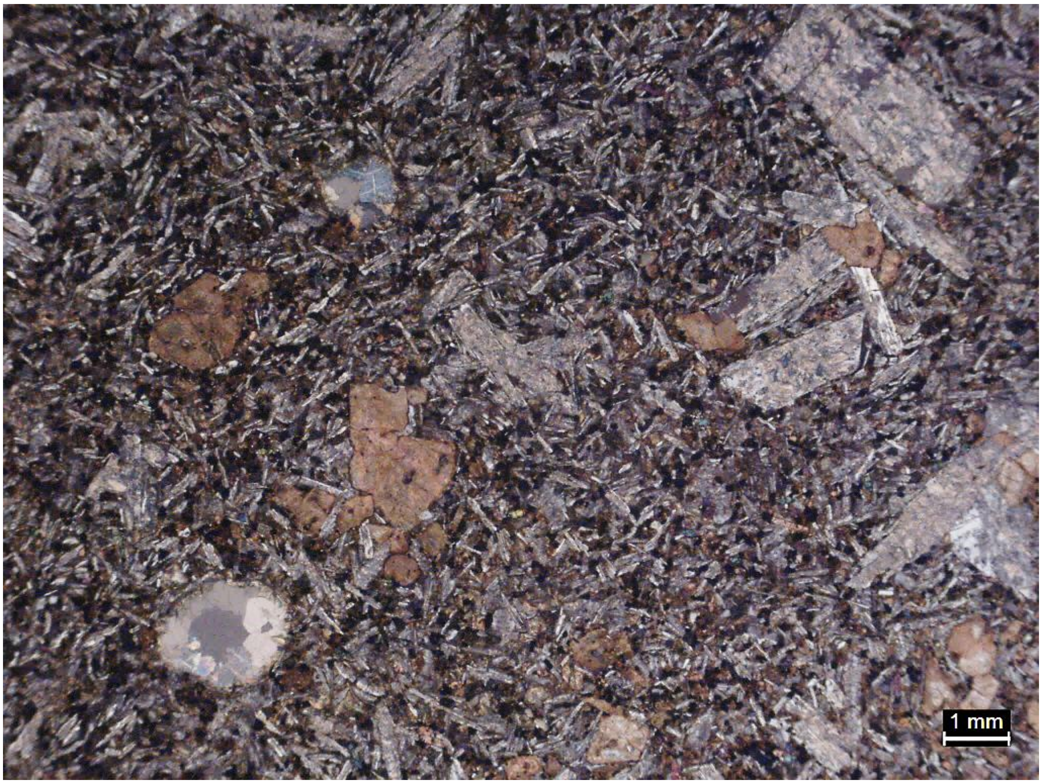
dp26: Porphyritic basalt dike (dp) in Westboro Formation (Zvwq) on Crystal Path in Stoneham (site 484BN). Thin section with crossed polarizers. Amygdule within a coarse plagioclase phenocryst highly altered to epidote. Amygdule filled with chlorite and radiating prehnite with a calcite core.



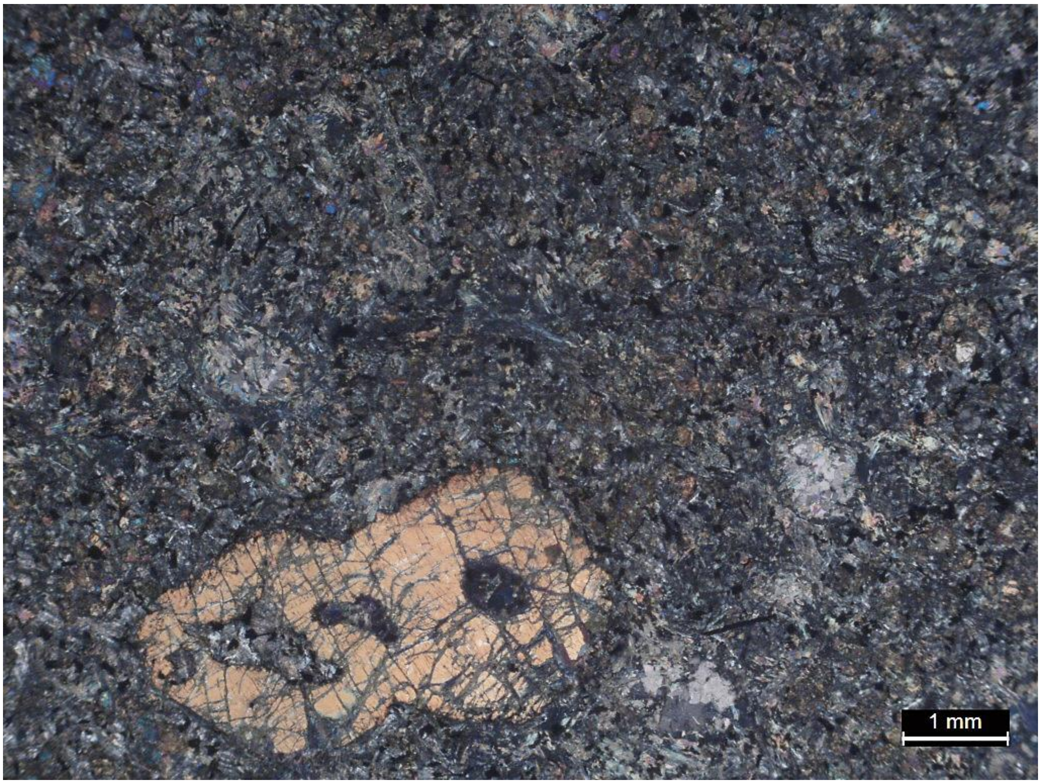
dp27: Porphyritic dolerite dike (dp) cutting through the Rams Head Porphyry (Zrhp) north of Rock Hill in Medford (site 11005). Thin section with crossed polarizers. Matrix plagioclase is pilotaxitic and clinopyroxene is altered to chlorite and actinolite. Plagioclase phenocrysts are heavily altered to sericite and epidote while sparse clinopyroxene phenocrysts are lightly altered and cumulophyric. In upper left, opaque area is pyrite.



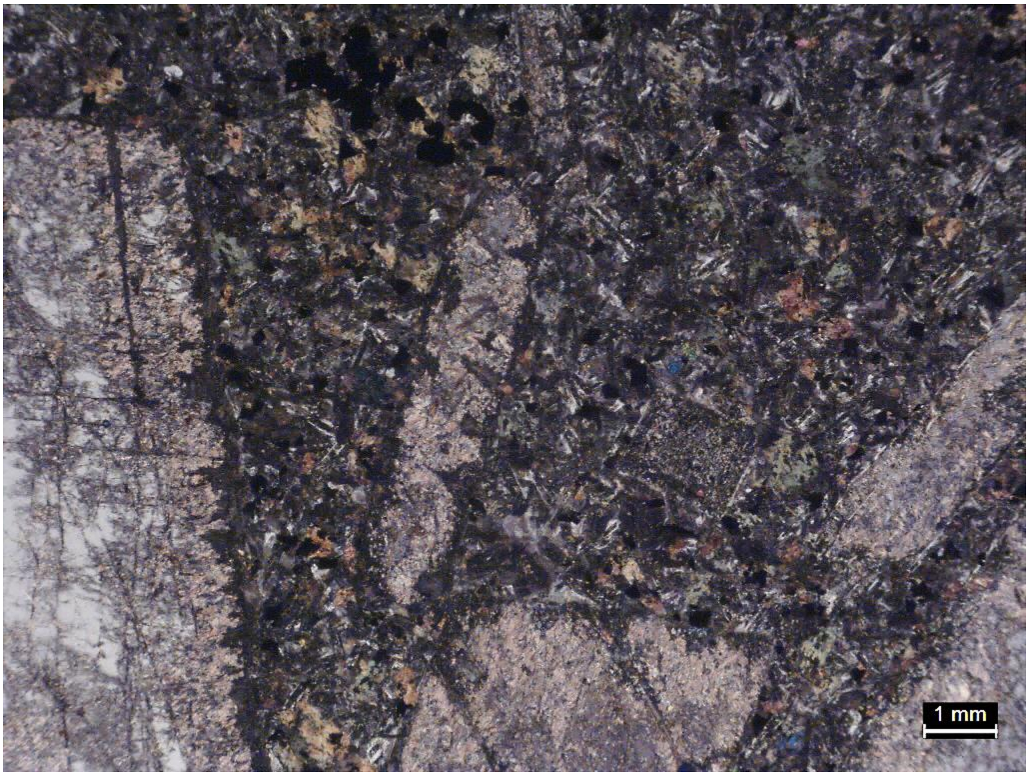
dp28: Porphyritic basalt dike (dp) in Boojum Rock Tuff (Zbrc) near Black Rock in Melrose (site 10049). Thin section with crossed polarizers. Groundmass has very fine pilotaxitic texture. Phenocrysts are altered plagioclase and lightly altered cumulophyric clinopyroxene.



dp29: Porphyritic dolerite dike (dp) cutting through the Westboro Formation (Zwp) at south end of Whip Hill in Stoneham (site 10372). Thin section with crossed polarizers. Pilotaxitic texture of plagioclase and clinopyroxene altered to chlorite and actinolite. Cumulophyric plagioclase is heavily altered to sericite and olivine phenocrysts (brown) are heavily altered. Amygdule (lower left) is filled with chlorite and a dominant calcite core.

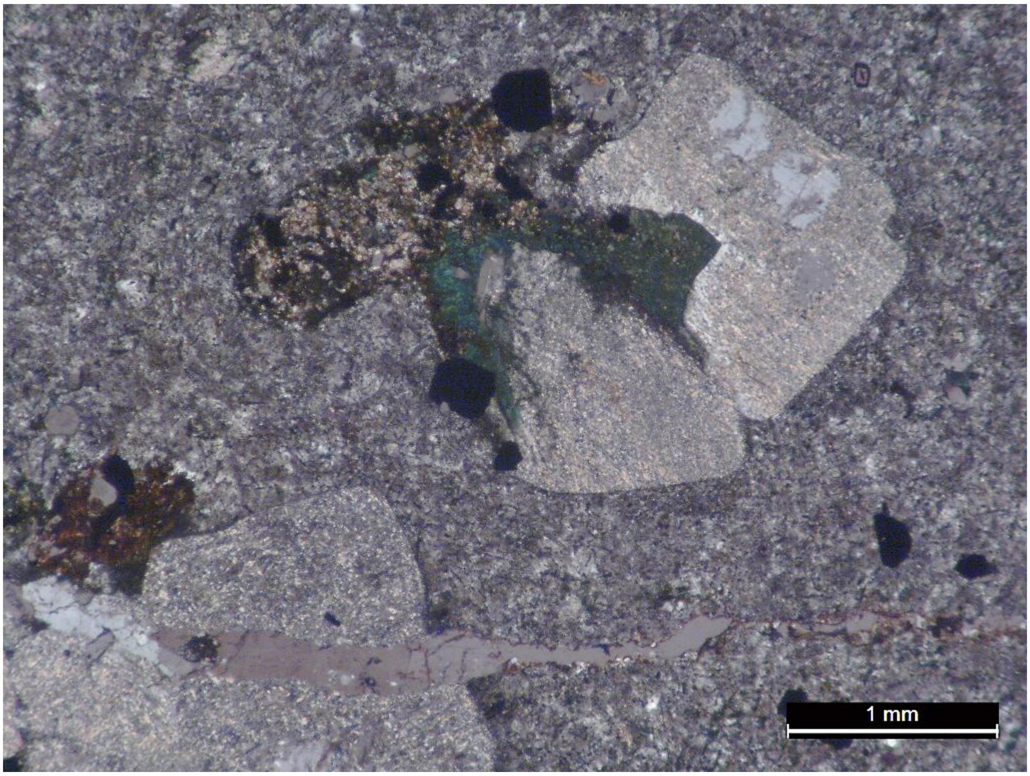


dp30: Porphyritic basalt dike (dp) cutting through the Nanepashemet Formation (Znpm) on the west shore of Spot Pond in Stoneham (site 10439). Thin section with crossed polarizers. Pilotaxitic texture of plagioclase and clinopyroxene partly altered to chlorite and actinolite. Large phenocryst is olivine. Amygdules are filled with chlorite and actinolite with calcite cores.

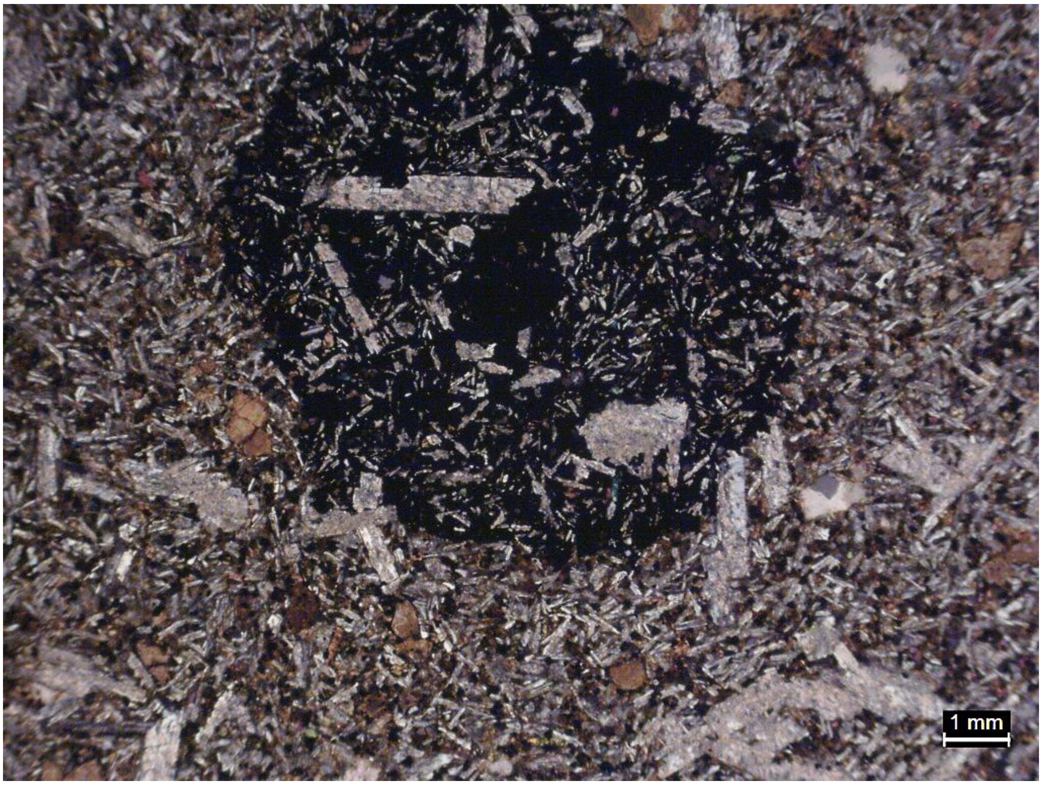


dp31 (see also Fig. dp6-7): Porphyritic basalt dike (dp) in Nanepashemet Formation (Znpm) east of Long Pond in Winchester (site 11084). Thin section with crossed polarizers. Fine intergranular texture with partly altered plagioclase and clinopyroxene altered to chlorite and actinolite with very coarse plagioclase phenocrysts altered to sericite and epidote.

dp32 (see also Fig. dp13): Porphyritic basalt dike (dp) in Lynn Volcanic Complex (Zlvx) on Middle Hill in Medford (site 10528). Thin section in plane polarized light. Pilotaxitic texture with partly altered plagioclase and mafic minerals altered to chlorite and opaque minerals. Plagioclase phenocrysts are heavily altered, and hornblende phenocrysts are altered to green chlorite and opaque minerals. This rock may be a lamprophyre.



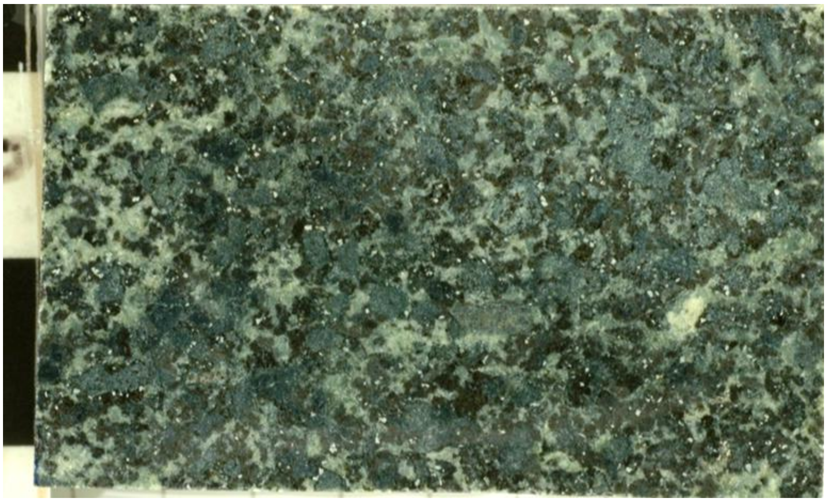
dp33 (see also Fig. dp12): Porphyritic basalt dike (dp) in Lynn Volcanic Complex (Zlvx) on Middle Hill in Medford (site 10526). Thin section in plane polarized light. Fine pilotaxitic texture with partly altered plagioclase and mafic minerals altered to chlorite (green) with altered cumulophyric plagioclase and hornblende or biotite phenocrysts altered to chlorite, opaque minerals, and epidote. This rock may be a lamprophyre.



dp34: Porphyritic dolerite dike (dp) cutting through the Westboro Formation (Zwp) at south end of Whip Hill in Stoneham (site 10372). Thin section with crossed polarizers. Pilotaxitic texture of plagioclase and clinopyroxene altered to chlorite and actinolite. Cumulophyric plagioclase is heavily altered to sericite and olivine phenocrysts (brown) are heavily altered. Dark area is spherical growth of pyrite.

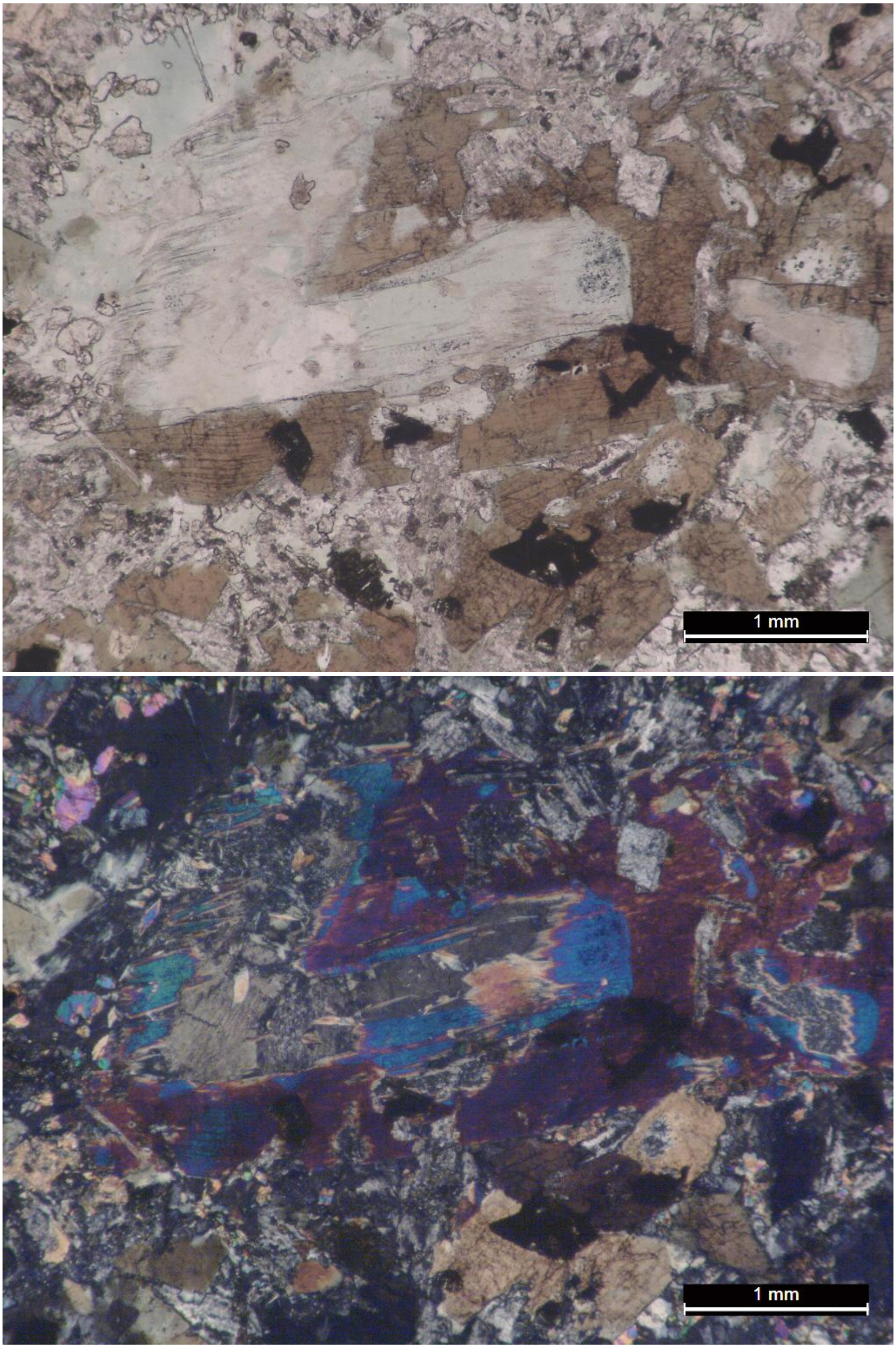
gb

Gabbro dikes (Neoproterozoic to Paleozoic) – Dark greenish-gray (5G 4/1), medium to coarse-grained, phaneritic, equigranular gabbro dikes (Fig. gb1). Mineralogy is like dolerite dikes (d) described above, but noticeably coarser and usually heavily altered with plagioclase replaced by sericite and pyroxene (augite) altered to amphibole (actinolite) and chlorite. The alteration of these dikes and the fact that that they are crosscut by younger dolerite dikes suggests that they are among the older mafic dikes in the Fells. Crosscut by at least one dolerite dike trending NW-SE and therefore pre-dates the Medford Dike (T_Rm). A whole rock $^{40}Ar/^{39}Ar$ age determination by Ross (2001) for the gabbro dike pictured below is 403 $\pm$ 3 Ma but this dike is heavily altered. The Medford Dike, also gabbro, is mapped as a separate unit.



gb1: Altered gabbro dike on west side of Middle Hill in Medford (site 10530).

<u>Thin section description</u> – Gabbro dikes have a mineralogy like dolerite with plagioclase and clinopyroxene, but gabbro dikes are generally more altered than the youngest dolerite dikes (Fig. gb2-3). The gabbro dikes differ in that they generally have or had a higher mafic mineral (pyroxene) content than dolerite with original plagioclase being finer than pyroxene and interstitial. Plagioclase made up as little as 20-25% of the rock (Fig. gb2). [*Note: This estimate percentage counts alteration products such as actinolite and chlorite as part of the original clinopyroxene mineral content.*] Plagioclase is heavily altered to sericite and epidote and may have reacted with the byproducts of mafic mineral alteration. There is little original pyroxene left due to alteration to chlorite, actinolite, and minor epidote (Fig. gb2). Gabbro dikes appear to be intergranular but original crystal forms are difficult to discern. Opaque minerals are likely titanomagnetite and are also altered. Gabbro dikes have conspicuous apatite that shows up as slender needles and white spots in opaque minerals and mafic minerals when viewed on end (Fig. gb3).

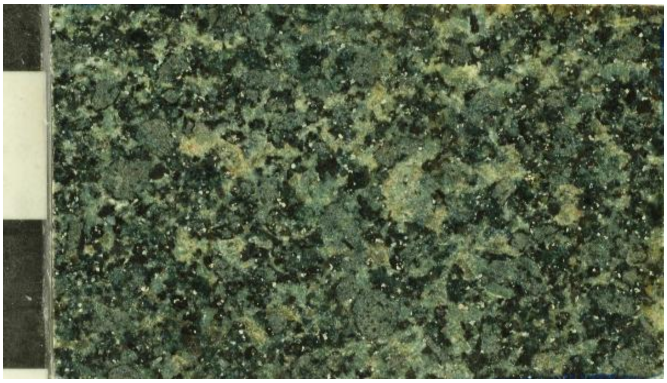


gb2 (see also Fig. gb1): Thin section in plane polarized light above and with crossed polarizers below. Gabbro dike (gb) cutting through the Lynn Volcanic Complex (Zlvx) on Middle Hill in Medford (site 10530). Intergranular and interstitial plagioclase altered to sericite with chlorite and actinolite (bright colors below) formed by alteration of clinopyroxene (augite). In upper left is epidote (high relief grains in green chlorite above, pink in black chlorite below) formed by possible combined alteration of plagioclase and clinopyroxene.

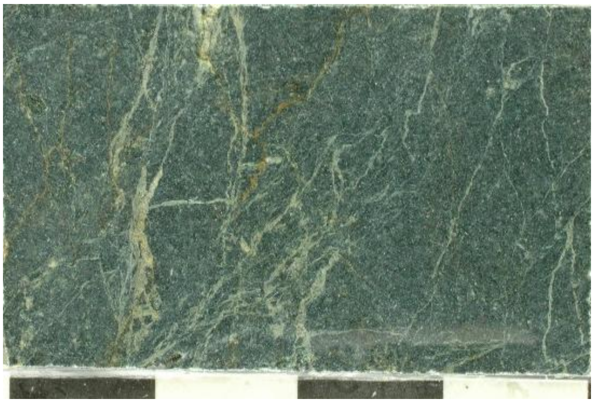
gb3: Gabbro dike (gb) on Roosevelt Road near Forest Street in Medford south of Pine Hill (site 299BN). Thin section in plane polarized light above and with crossed polarizers below. Intergranular plagioclase altered to sericite with chlorite and actinolite (pale green to tan above) mostly replacing clinopyroxene (augite; bright colors below). Bright white areas (below) are quartz and plagioclase produced by alteration. Slender crystals and white spot clusters (circled above) are apatite.

ad

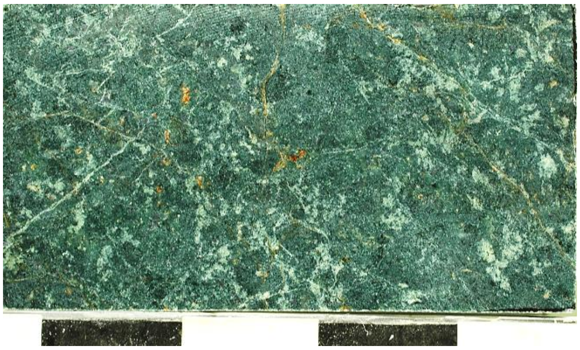
Highly altered mafic dikes (Neoproterozoic through Paleozoic) – Green (5G 4-2/4-6) heavily veined dikes of highly altered fine gabbro, dolerite, and basalt (Figs. ad1-3). All mafic dikes are altered to some degree, but this unit identifies extreme cases. Alteration includes complete replacement of feldspar by very fine sericite and epidote (Fig. ad1) and replacement of pyroxene by amphibole (uralite or actinolite) and chlorite in addition to secondary chlorite and amphibole growth (Figs. ad2-3). There are sometimes porphyroblasts developed through contact metamorphism adjacent to younger igneous bodies (Fig. ad3). Included in this unit are highly altered (oxidized), dark reddish-gray (5R 2/2 to 4-2/1), hematite-rich dolerite dikes (Figs. ad4-5). These dikes are older than less altered dolerite dikes (d) in the same area because: 1) they are crosscut by the less altered dikes, 2) they may show the same deformation (fractures and foliation) as the rock units they intrude (Fig. ad4), and 3) they may have a highly irregular trace because of deformation with the host rock unit. Alteration may be the result of 1) tectonic deformation, 2) intrusion into solid but still hot igneous bodies, 3) reheating in proximity to younger intrusions including younger dolerite dikes, 4) intrusion into water-laden sediment, or 5) assimilation of surrounding materials that had elevated temperatures and a water content that facilitated hydrothermal reactions.



ad1: Fine gabbro with plagioclase (light green, gritty texture) altered to sericite and epidote on Boojum Rock in Malden (site 10005).

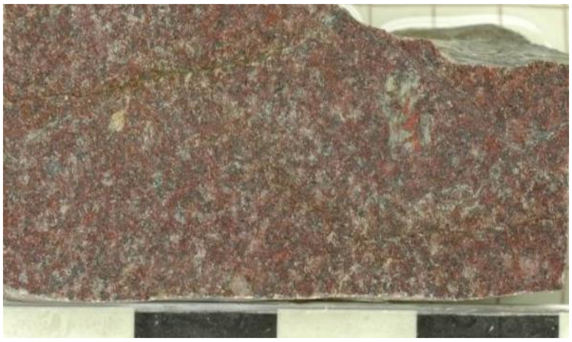


ad2: Basalt with plagioclase altered to sericite and epidote, and mafic minerals altered to chlorite as well as abundant epidote and quartz veins south of Doleful Pond in Stoneham (site 10587).



ad3 (left): Dolerite with epidote veins and development of actinolite porphyroblasts on the east shore of Middle Reservoir in Stoneham (site 11150).

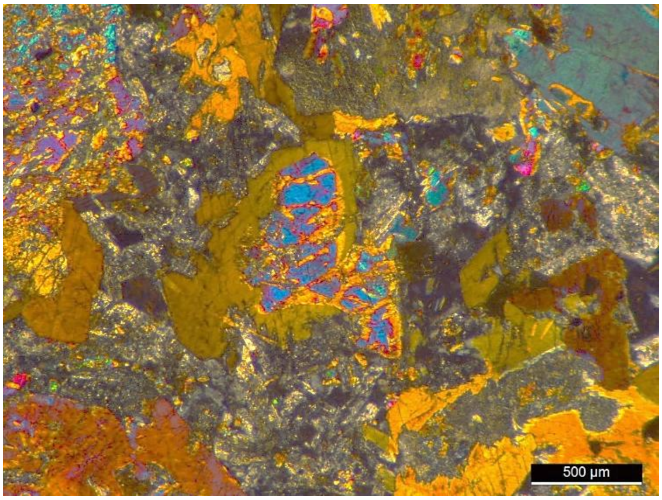
ad4: Outcrop of heavily oxidized dolerite dike with pervasive fractures that are also found in the Boojum Rock Tuff (Zbrc) host rock near Hemlock Pool in Medford (site 10633). Contact (yellow line) of dike on left and tuff on right that are similarly fractured.



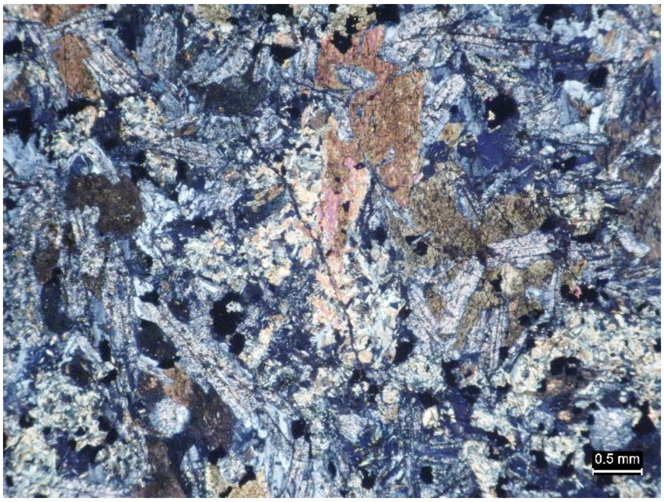
ad5: Cut sample of oxidized dolerite in Fig. ad4.

Altered basalt, dolerite and gabbro dikes (cont.)

Thin section description – Altered dikes of this type had the mineralogy of dolerite dikes (d) prior to alteration. Clinopyroxene has been almost completely (Fig. ad6) or completely (Fig. ad7) altered to actinolite with minor chlorite. Tabular plagioclase was heavily altered to sericite (Figs. ad6-7) with some plagioclase recrystallized (Figs. ad8-9). Actinolite crystals can be more than 3 mm suggesting porphyroblastic growth, especially where alteration is the result of contact metamorphism. Contact metamorphism has also created epidote and garnet in some cases (Fig. ad10). Opaque minerals are dominantly titanomagnetite and possibly ilmenite, which in some cases are altered to the point of being faintly transparent and brown (ad9). In a few cases the opaque minerals are altered to hematite and these rocks generally have a red color in the field (Figs. ad4-5 and ad11).

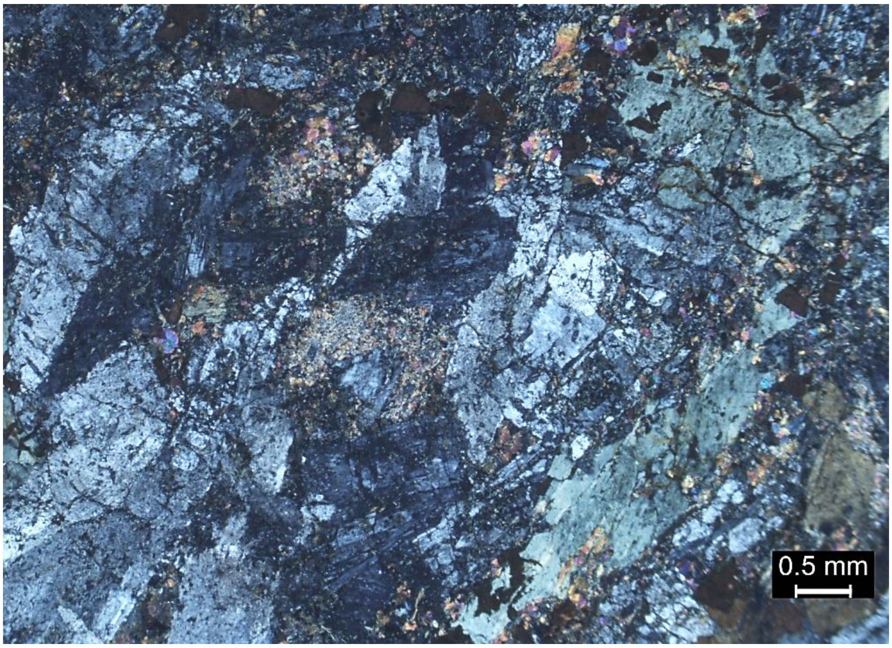


ad6: Mostly altered clinopyroxene enclosed in actinolite and minor chlorite with tabular plagioclase altered to sericite and epidote on Boojum Rock in Malden (site 10005). See also Fig. ad1. View with crossed polarizers.

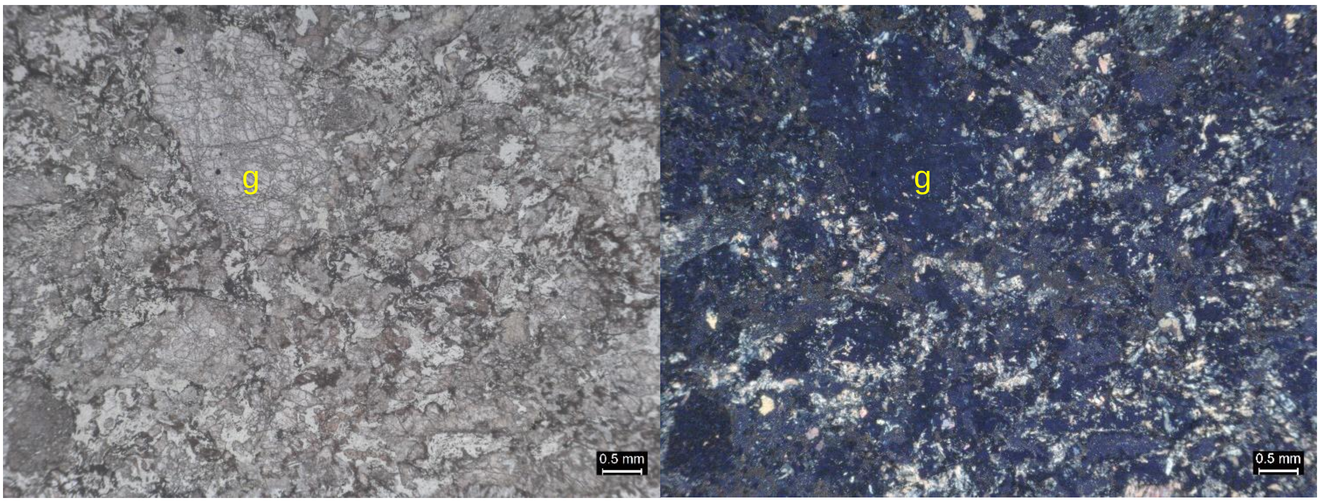


ad7: Clinopyroxene altered to actinolite and chlorite with tabular plagioclase altered to sericite and epidote on Wanapanaquin Hill in Stoneham (site 11143). See also Fig. ad2. View with crossed polarizers.

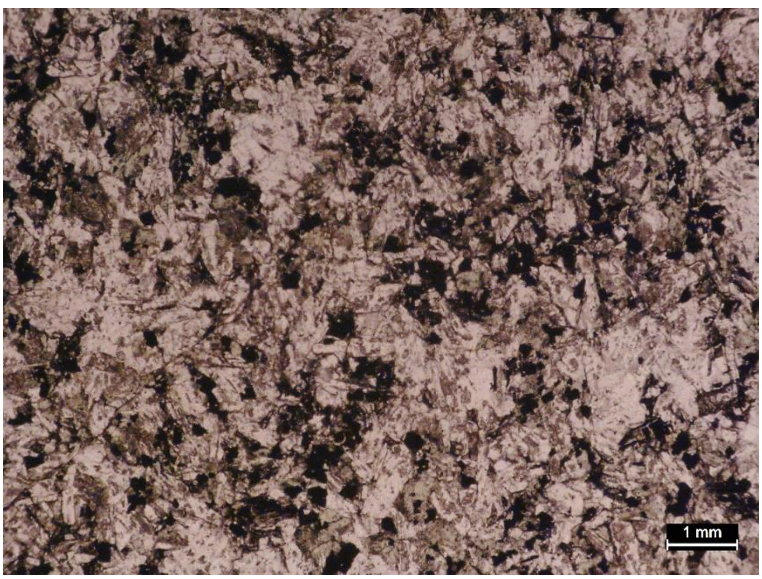
ad8: Clinopyroxene completely altered to actinolite and chlorite with plagioclase altered to sericite and partly recrystallized (clear crystals). Actinolite forms porphyroblasts as well. East shore of Middle Reservoir south of Wanapanaquin Hill in Stoneham (site 11150). See also Fig. ad3. View with crossed polarizers.



ad9: Dike heavily altered to actinolite and partly recrystallized plagioclase with ilmenite or titanomagnetite altered to the point of slight transparency (dark brown grains near top) on east shore of Middle Reservoir south of Wanapanaquin Hill (site 11155) in Stoneham. View with crossed polarizers.



ad10: Dike heavily altered by contact metamorphism with chlorite and garnet (g) on South Border Road in Winchester (site 11266). Plane polarized light view on left, crossed polarizers on right.

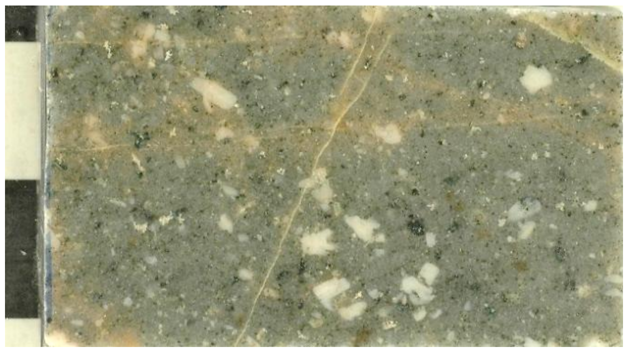


ad11: Dike with altered opaque minerals, originally titanomagnetite. Dike now has a high percentage of other oxides, mostly hematite near Hemlock Pool in Medford (site 10633). See also Figs. ad4-5.

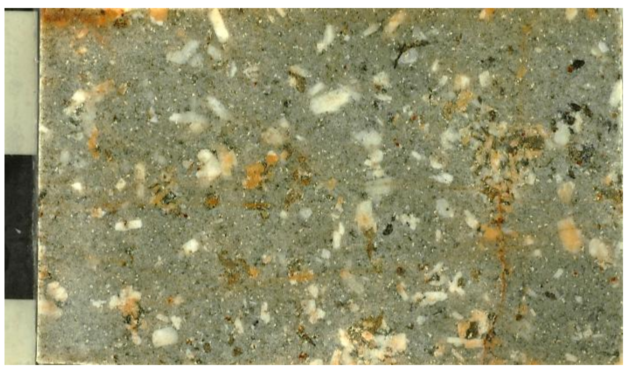
ap

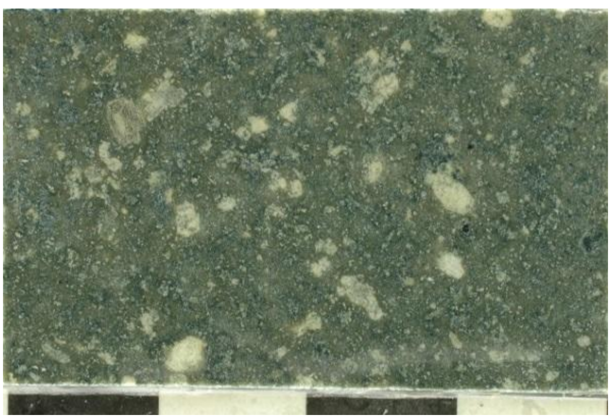
Gray Porphyritic andesite to dacite dikes (Neoproterozoic?) – Greenish-gray (5GY 5/1) to light to medium gray (N 5-7/0) weathering, dark to medium gray (N 2-3/0) when non-weathered, porphyritic, sometimes cumulophyric, aphanitic andesite to dacite dikes (Figs. ap1-5). These dikes are devoid of pyroxene. Phenocrysts are plagioclase with much lesser euhedral hornblende (Figs. ap3-4). Darker where argillite/quartzite units are intruded. Most common in the Westboro Fm. and can have abundant quartzite, argillite, and volcanic xenoliths as well as possible andesite autoliths from dike margins (Fig. ap2). Coarse quartz and feldspar xenocrysts are absent. On east side of Spot Pond near the Stone Zoo dikes may be offshoots of dioritic Stoneham Granodiorite (Zst) underlying the north end of the pond. Possibly more than one age. 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 (see symbols below).

ap1 (above): Gray porphyritic andesite dike on east side of Pond Street just south of the Stone Zoo in Stoneham (site 10329). Intrudes the Westboro Formation (Zvwq). Quarter for scale.
ap2 (upper right): Part of same dike as in Fig. ap1 with abundant argillite and andesite xenoliths that may be autoliths from the dike margin. Quarter for scale.
ap3 (right): Close up of surface of rock in Fig. ap1 with plagioclase and fine hornblende phenocrysts.



ap4 (right): Gray porphyritic andesite dike on Whip Hill in Stoneham. Dike intruded the Westboro Formation (Zwp; site 10388) and has tabular plagioclase and hornblende phenocrysts.

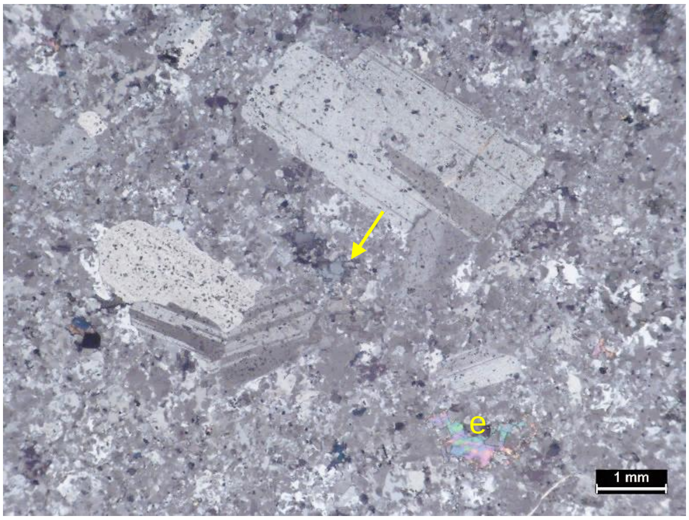




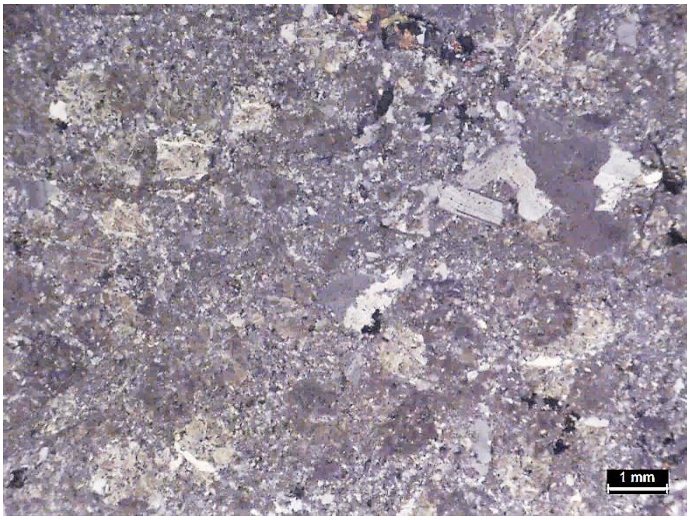
ap5 (left): Porphyritic andesite dike on Whip Hill in Stoneham (site 10582). Dike intruded the Westboro Formation (Zwp) and has heavily altered plagioclase and sparse hornblende phenocrysts.

Gray porphyritic andesite to dacite dikes (cont.)

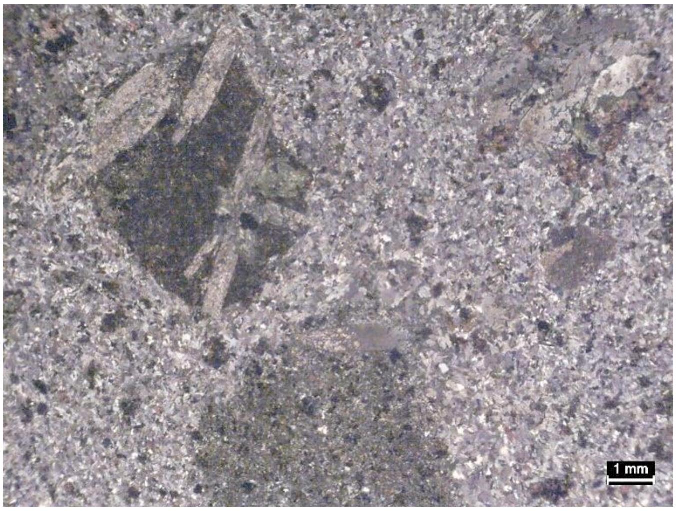
Thin section description – Gray andesitic to dacitic dikes that are porphyritic with a matrix that is dominated by plagioclase either as: 1) a micropoikilitic texture with quartz and secondary alkali feldspar (Figs. ap6-7), or 2) dominantly pilotaxitic plagioclase (Figs. ap8-9). Phenocrysts are dominantly cumulophyric plagioclase that is fresh (Figs. ap6-7) to highly altered to sericite (Fig. ap8) sometimes with sieve texture (Fig. ap10). Hornblende also occurs as phenocrysts that are euhedral, zoned, and twinned (Fig. ap11) and that are often altered to epidote, chlorite, and opaque oxides (Fig. ap12). Alteration of mafic minerals in these dikes also produces zoisite (Figs. ap6, 10, and 12) that can occur as veins. Andesitic dikes have abundant inclusions of host rocks including very fine quartz xenocrysts (Figs. ap9 and 13), xenoliths of quartzite/argillite (Fig. ap2), basalt, porphyritic basalt, and andesite (Figs. ap8 and 13). Coarse quartz and feldspar xenocrysts are absent.



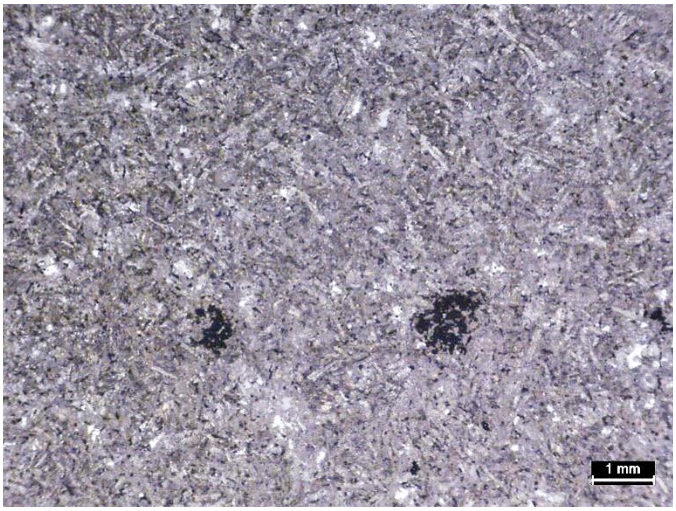
ap6: Micropoikilitic gray dacitic dike with fresh cumulophyric plagioclase. Dike intruded the Westboro Formation (Zvwq). Alteration has formed areas of epidote (bright colors, e) and zoisite (false blueish gray, arrow). East side of Pond Street near Stone Zoo in Stoneham (site 10329). See also Figs. ap1-3. Crossed polarizers.



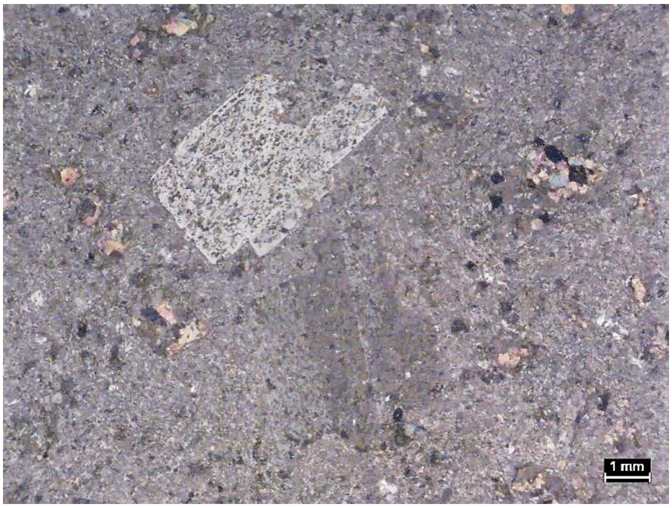
ap7: Micropoikilitic gray dacitic dike with fresh cumulophyric plagioclase. Dike intruded the Westboro Formation (Zwp) on the east side of Whip Hill in Stoneham (site 10576). Crossed polarizers.



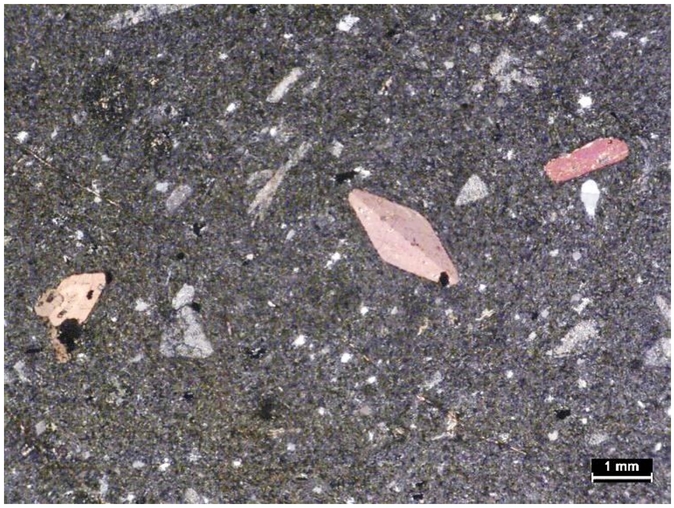
ap8: Faintly pilotaxitic (plagioclase-dominated) gray dacitic/andesitic dike with altered cumulophyric plagioclase and xenoliths of basalt and porphyritic basalt. Dike intruded Spot Pond Granodiorite (Zsg) and Lynn Volcanic Complex (Zlvx) northwest of Wrights Pond in Medford (site 10470). Crossed polarizers.



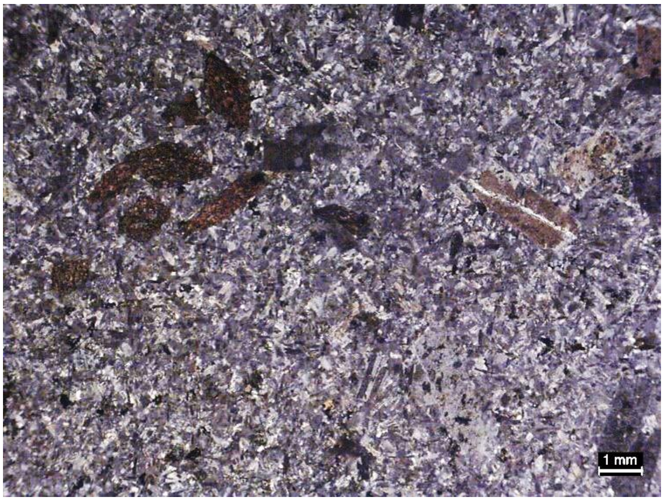
ap9: Pilotaxitic (plagioclase-dominated) gray andesitic dike. Opaque splotches are pyrite. Dike intruded the Westboro Formation (Zvwq) and appears to have fine quartz xenocrysts. Southern end of northeast island in Spot Pond (site 10866). Plane polarized light.



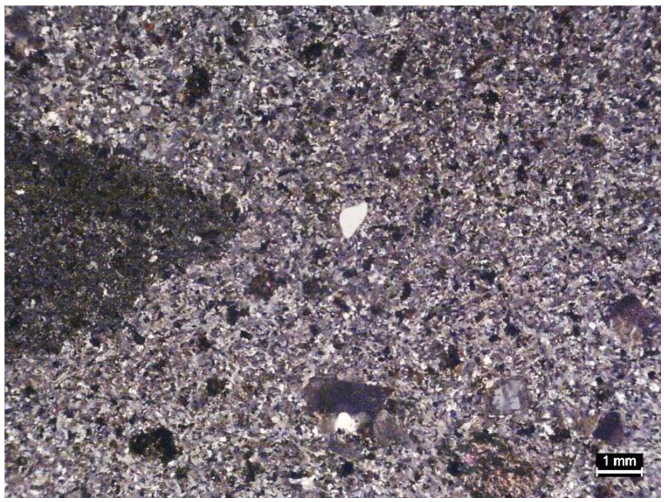
ap10: Gray dacitic/andesitic dike with plagioclase phenocrysts altered with sieve texture. Dike intruded the Westboro Formation (Zwp) on Whip Hill in Stoneham (site 10582). Mafic minerals (originally hornblende) are altered to epidote (bright colors), chlorite, and opaque oxides. See also Fig. ap5. Crossed polarizers.



ap11: Gray dacitic/andesitic dike with plagioclase and euhedral, zoned and twinned hornblende phenocrysts. Bright spots are very fine quartz xenocrysts. Dike intruded the Westboro Formation (Zwp) northeast of Greenwood Park in Stoneham (site 11257). Crossed polarizers.



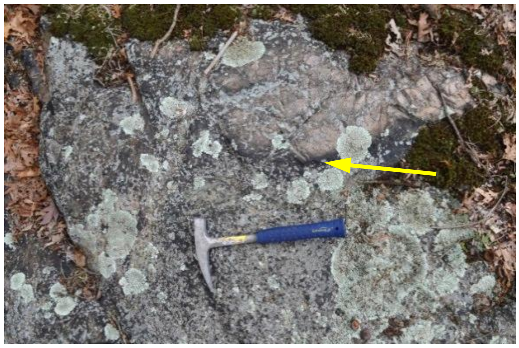
ap12: Gray dacitic/andesitic dike with highly altered plagioclase phenocrysts and euhedral hornblende phenocrysts (diamond shapes) altered to epidote, chlorite, and opaque oxides. Dike intruded the Westboro Formation (Zwp) on Whip Hill in Stoneham (site 10388). See also Fig. ap4. Crossed polarizers.



ap13: Faintly pilotaxitic (plagioclase-dominated) gray dacitic/andesitic dike with basalt xenoliths and medium quartz xenocrysts (bright grains, center and bottom). Dike intruded the Spot Pond Granodiorite (Zsg) and Lynn Volcanic Complex (Zlvx) northwest of Wrights Pond in Medford (site 10470). Crossed polarizers.

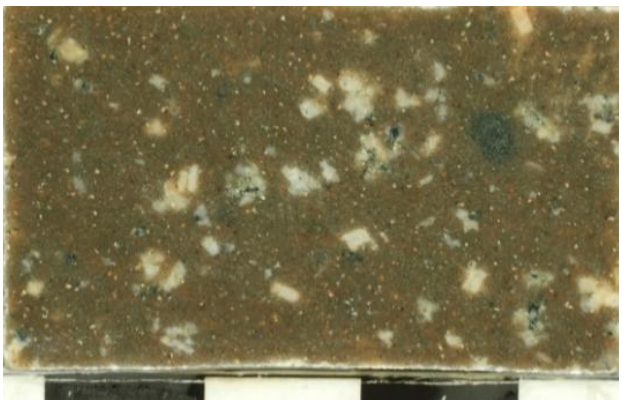
fp

Pink porphyritic dacite to rhyolite dikes (Neoproterozoic?) – Reddish- to orangish-gray (5R 3/2 to 2.5YR 4/2) weathering, 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 (Figs. fp1-5). Phenocrysts are plagioclase and usually cumulophyric. Possibly more than one age. A reddish variety crosscuts the Spot Pond Granodiorite (Zsg) and is crosscut by the Rams Head Porphyry (Zrhp) at Wenepoykin Hill (Figs. Zfp1-4). Rhyolite/dacite dikes also do not occur in the Stoneham Granodiorite (Zst). North-south trending lenticular reddish-gray rhyolite dikes also occur in the Winchester Granite (Zwg) and elongate lenticular rhyolite dikes in the Nanepashemet Formation (Znpm) appear to be associated with intrusion of the Winchester Granite. Mapped only where dikes exceed a width of 1.0 m. Thinner dikes that are not as traceable are shown with a separate symbol (see symbols below). Felsic dikes with abundant quartz and plagioclase xenocrysts are mapped as a separate unit (fq).

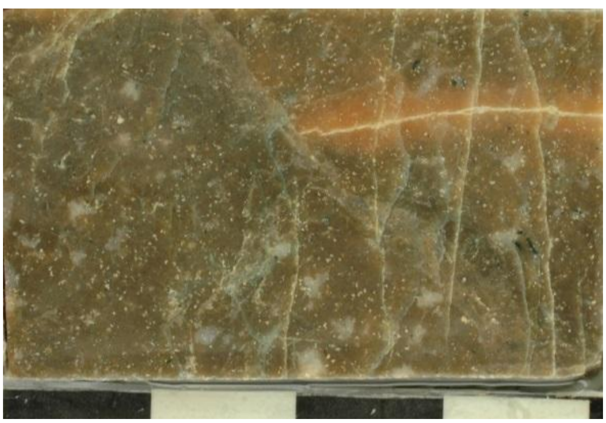


fp1 (far left): Contact (arrow) of rhyolite dike (left) and Spot Pond Granodiorite (Zsg) on the east side of Wenepoykin Hill in Medford (site 10718).

fp2 (near left): Contact (arrow) of rhyolite dike (top) and Spot Pond Granodiorite (Zsg) on the west side of Silver Mine Hill in Medford (site 10734).



fp3 (left): Reddish-gray porphyritic rhyolite dike with cumulophyric plagioclase on the east side of Wenepoykin Hill in Medford (site 10719). Outcrop in Fig. fp1.

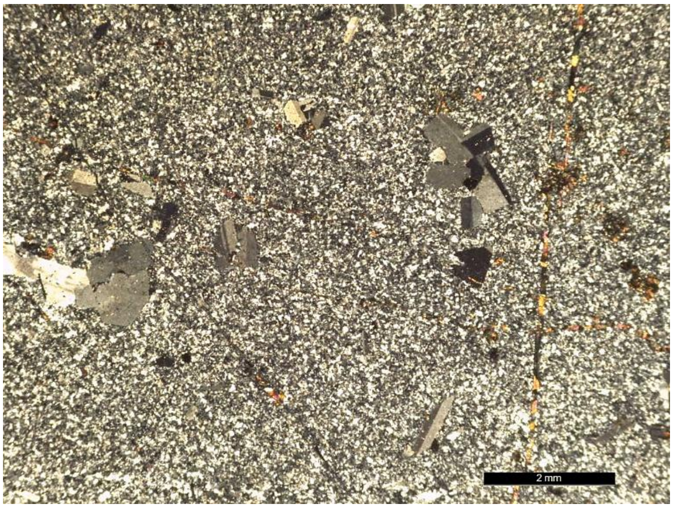


fp4 (above): Reddish-gray porphyritic rhyolite dike southeast of South Reservoir in Medford (site 10960).

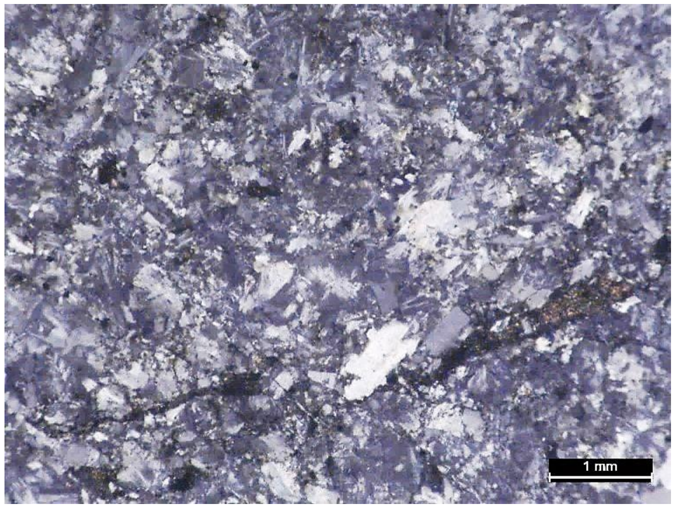
fp5 (above): Tannish-gray porphyritic rhyolite dike with faint plagioclase phenocrysts west of Little Pine Hill in Medford (site 10689).

Pink porphyritic dacite to rhyolite dikes (cont.)

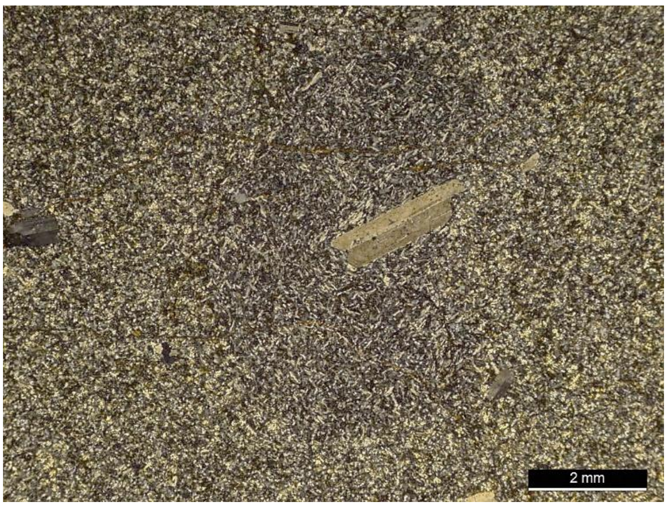
Thin section description – Red, pink, and tan porphyritic dacite and rhyolite dikes. Matrices are mostly plagioclase and quartz with significant potassium (alkali feldspar) evident from staining. Matrices include fine patchy equigranular crystals (Fig. fp6) that sometimes have radiating feldspar and quartz (Fig. fp7), felty to tabular feldspar (Fig. fp8-9), micropoikilitic to poikilomosaic textures (Fig. fp10), and equigranular plagioclase with interstitial granophyric quartz and alkali feldspar (Fig. fp11). Phenocrysts are dominantly unaltered cumulophyric plagioclase (Figs. fp8-10, and 12). Mafic minerals were biotite and hornblende mostly altered to actinolite, epidote, chlorite and opaque oxides (Figs. fp9-10). The dikes also contain sphene (titanite; Fig. fp12) and in one place spherical growths of hematite (Figs. fp13-14). Dispersed fine hematite creates the red color distinctive of these dikes.



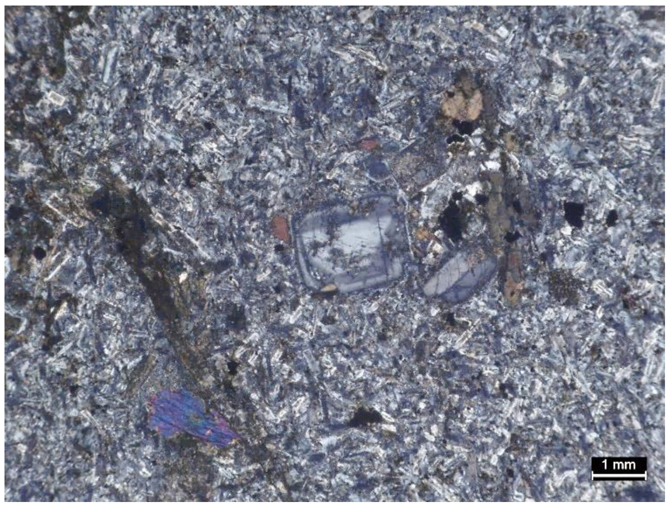
fp6: Red rhyolite dike with cumulophyric plagioclase. Matrix is a very fine patchy texture of quartz and feldspar. Rock has epidote veins (bright colors). This dike intruded the Spot Pond Granodiorite (Zsg) west of Middle Hill and Red Cross Path in Medford (site 10712). Crossed polarizers.



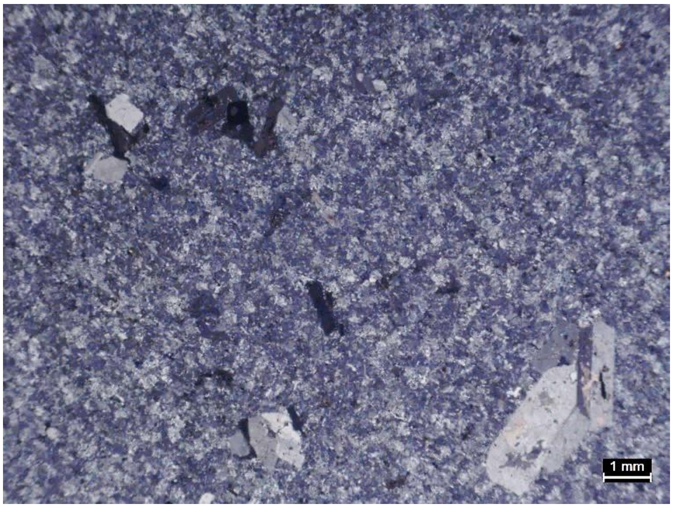
fp7: Orangish-tan rhyolite dike with radiating granophyric feldspar-quartz growths and plagioclase phenocrysts. Intruded the Spot Pond Granodiorite (Zsg) on the east side of Woodland Road near Flynn Ice Rink in Medford (site 10744). May be an offshoot of the Lawrence Woods Granophyre (Zlwg). Crossed polarizers.



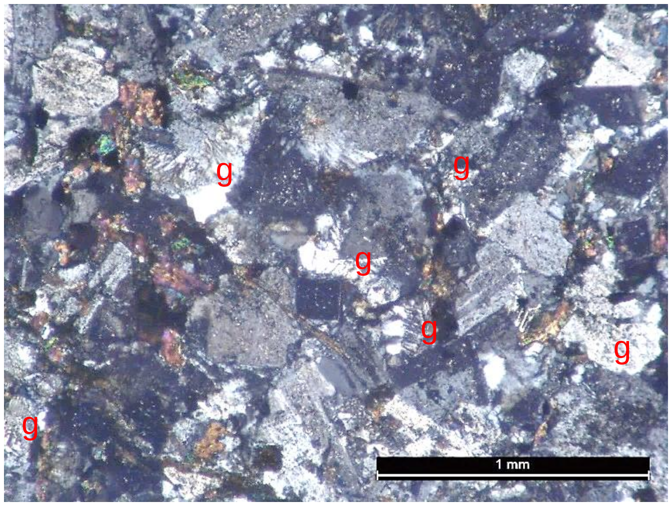
fp8: Orangish-tan rhyolite dike with pilotaxitic texture near plagioclase phenocrysts. Dike intruded Spot Pond Granodiorite (Zsg) just east of Middle Road and southeast of South Reservoir in Medford (site 10961). Crossed polarizers.



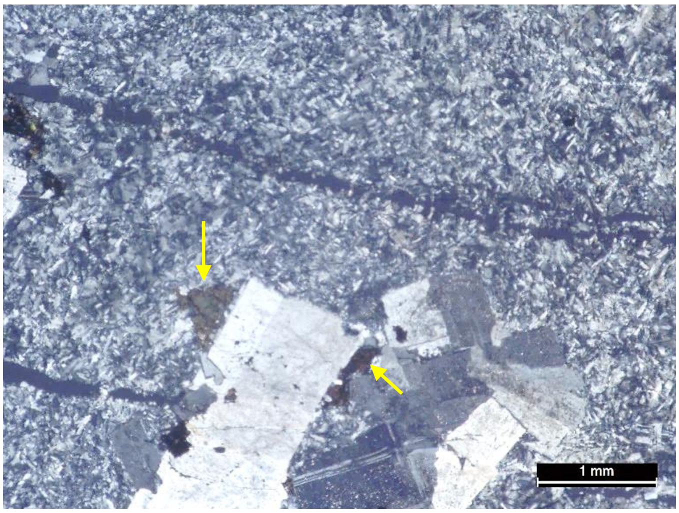
fp9: Tan dacite dike with matrix of tabular plagioclase and plagioclase phenocrysts. Biotite and hornblende are altered to actinolite, chlorite and opaque oxides. Dike intruded the Nanepashemet Formation (Znpm) and is likely a branch of the Winchester Granite (Zwg) west of Middle Reservoir in Stoneham (site 11103). Crossed polarizers.



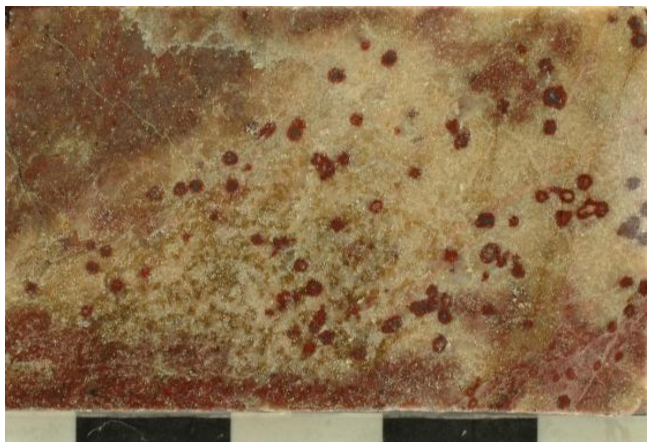
fp10: Reddish-brown rhyolite dike with poikilomosaic texture and cumulophyric plagioclase. Biotite crystals are altered to chlorite and opaque oxides. Dike intruded the Spot Pond Granodiorite (Zsg) south of Wenepoykin Hill in Medford (site 10719). Crossed polarizers.

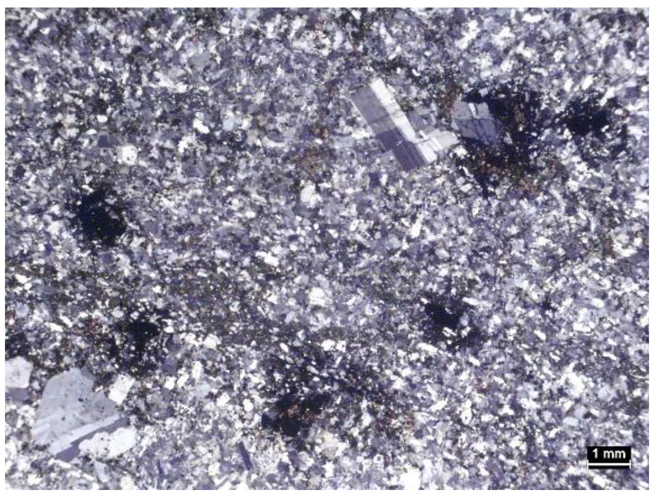


fp11: Tan rhyolite dike with matrix of plagioclase crystals surrounded by granophyric grains (g). Mafic grains are altered to chlorite and epidote (bright colors). Dike intruded the Nanepashemet Formation (Znpm) west of Middle Reservoir in Stoneham and is likely a branch of the Winchester Granite (Zwg; site 11105). Crossed polarizers.



fp12: Orangish-tan dacite dike with matrix of fine tabular plagioclase (pilotaxitic) with quartz. Phenocrysts are cumulophyric plagioclase. Dark grains are sphene (titanite; arrows). Dike intruded the Nanepashemet Formation (Znpm) on Wanapanaquin Hill in Stoneham and is likely related to the Stoneham Granodiorite (Zst; site 11145). Crossed polarizers.

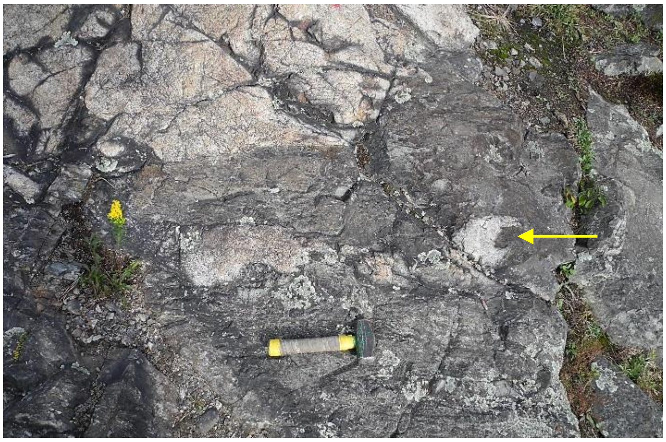




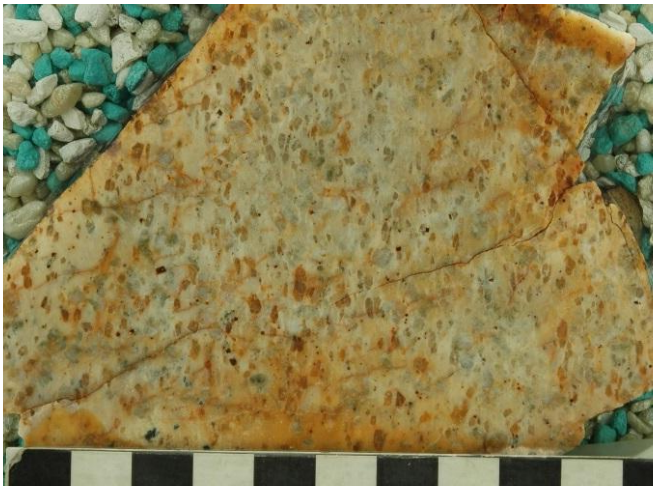
fp13 (above right): Tan to dark red rhyolite dike with spherical hematite growths north of Hemlock Pool in Stoneham. Dike intruded the Spot Pond Granodiorite (Zsg; site 10943). Cut rock sample.
fp14 (right): Same rock as Fig. fp13 with crossed polarizers. Matrix is mostly fine quartz and plagioclase with cumulophyric plagioclase. Dark spots are hematite.

fq

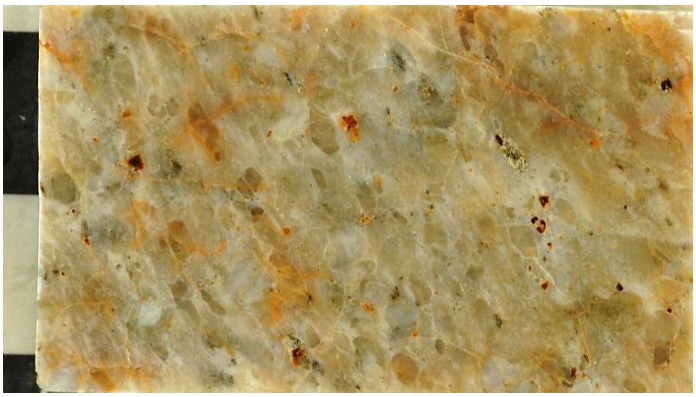
Dacite to rhyolite dikes with coarse quartz and feldspar xenocrysts (Neoproterozoic?) – White (10YR 8/1) weathering, light gray (10YR 7/1) rhyolite to dacite dikes with medium to coarse (up to 1.5 cm) rounded, resorbed, and embayed feldspar and quartz xenocrysts and multi-grain granitic xenoliths. Based on grain size the xenocrysts appear to have been acquired while the source magma passed through a coarse granitic intrusion such as the Spot Pond Granodiorite (Zsg) or Winchester Granite (Zwg). Color varies 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 matrix grain size, weathering, and assimilation of host units. Unit can weather to a chalky surface with protruding xenocrysts. Only found on Whip Hill (Figs. fq1-4), in the MWRA excavation south of Ravine Road (Figs. Fq5-8), at the east shore of the peninsula in the Fells Reservoir and extending southeast across the Fellsway East (same type as at MWRA site), and in the Winchester Granite (Zwg) near South Border Road (Fig. fq9). On Whip Hill, the dike displays peculiar pinched and necked ends on pods in the Westboro Formation (Zwp; Fig. fq1-2) and contains euhedral fluorite crystals coated with hematite (Fig. fq3-4). Possibly multiple ages.



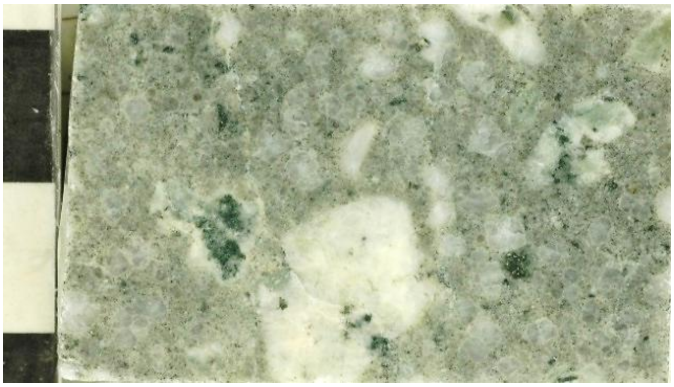
fq1 (above left): Rhyo-dacitic dike in Westboro Formation (Zwp) on northern crest of Whip Hill in Stoneham (site 10377).
fq2 (above right): South end of rhyo-dacitic dike in Fig. fq1 showing pinched and cusped end of dike (arrow).



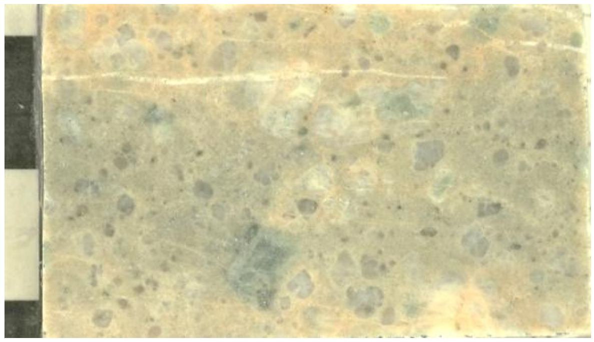
fq3 (left): Cut rock slab showing aligned, rounded, and resorbed quartz and plagioclase grains in rhyo-dacitic dike in Westboro Formation (Zwp) on northern crest of Whip Hill in Stoneham (site 10377).



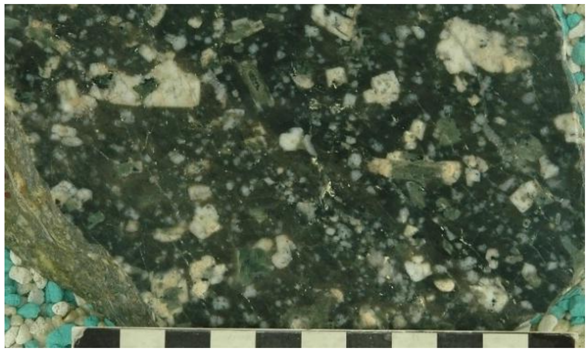
fq4 (right): Close up of cut rock slab showing rounded and resorbed quartz and plagioclase grains in rhyo-dacitic dike in Westboro Formation (Zwp) on northern crest of Whip Hill in Stoneham (site 10377). Square crystals with dark red hematite stain are fluorite.



fq5 (above): Porphyritic rhyo-dacitic dike with abundant coarse xenocrysts in 2013 MWRA excavation south of Ravine Road in Stoneham (site 10285). This dike intruded the Spot Pond Granodiorite (Zsg).
fq6 (upper right): Close up of cut surface of rock in Fig. fq5 showing resorbed feldspar and quartz xenocrysts and multi-grain granitic xenoliths.
fq7 (right): Close up of yellowish-gray area of same dike as in Fig. fq5 with abundant resorbed quartz and feldspar xenocrysts.

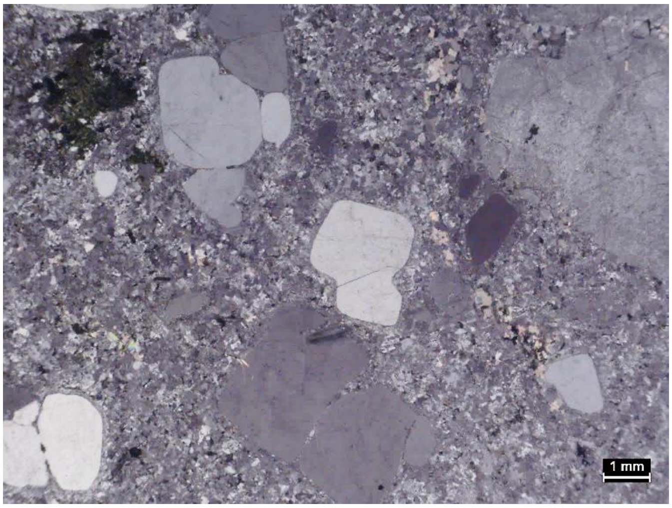


fq8 (right): Dark-colored center of dike shown in Fig. fq5 above with finer matrix and plagioclase and quartz xenocrysts.



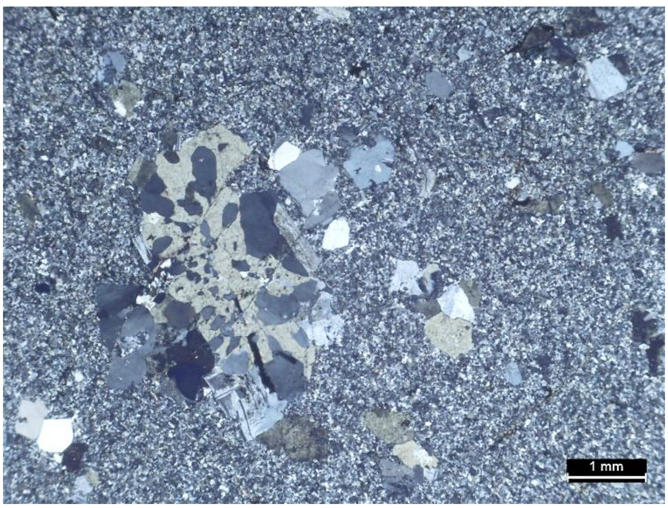
fq9 (left): Tan-colored rhyolite dike with resorbed feldspar and quartz xenocrysts in the Winchester Granite east of South Border Road in Winchester (site 11059).

<u>Thin section description</u> – Light tan to dark gray dacite to rhyolite dikes with abundant granite-derived xenocrysts and xenoliths. Matrices are a micropoikilitic (Fig. fq10) to fine to very fine equigranular (Fig. fq11) mixture of plagioclase, quartz, and alkali feldspar with conspicuous staining for potassium. Crystals are rounded, resorbed, and lightly embayed quartz, and rounded and resorbed plagioclase and alkali feldspar (Figs. fq10-12). Some euhedral plagioclase crystals may be phenocrysts, but the resorbed crystals are interpreted to be xenocrysts from a coarse granitic rock like the Spot Pond Granodiorite (Zsg) or Winchester Granite (Zwg). Confirming this interpretation are multi-grain granitic xenoliths with interlocking quartz, plagioclase, and alkali feldspar that are also rounded and resorbed (Figs. fq11-13) and pieces of strained quartz with undulatory extinction (Fig. fq13) that are the norm in the Spot Pond Granodiorite. Occurring in the dike on Whip Hill are euhedral fluorite cubes with hematite coatings (Fig. fq14).

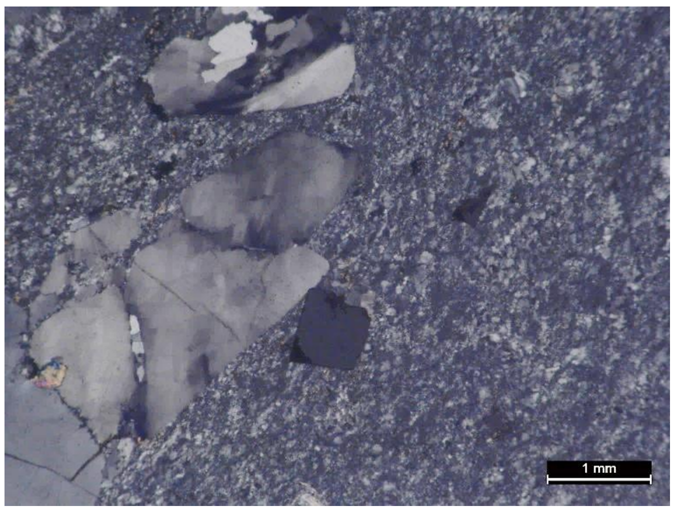


fq10: Rhyolite dike with equigranular to micropoikilitic matrix of plagioclase, quartz, and alkali feldspar and rounded and resorbed xenocrysts of quartz and feldspar. The dike passed through the Spot Pond Granodiorite (Zsg), which is the likely source of the xenocrysts. Bright colors are epidote. 2013 MWRA excavation east of Woodland Road in Stoneham (site 10285). Same dike as in Figs. Fq5-8 and 11. Thin section in crossed polarizers.

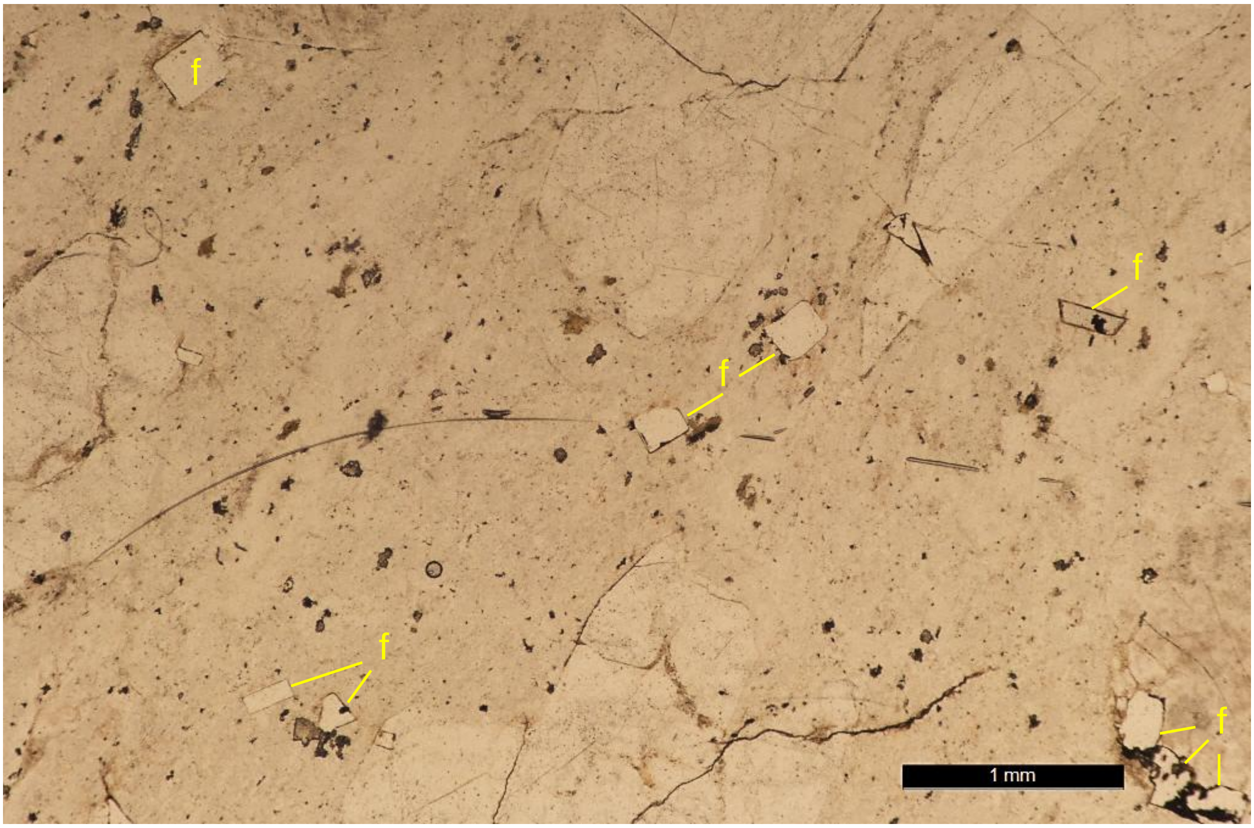
fq11: Rhyolite dike with very fine matrix of plagioclase, quartz, and alkali feldspar and rounded and resorbed xenocrysts of quartz and feldspar and granitic xenoliths. The dike passes through the Spot Pond Granodiorite (Zsg), which is the likely source of the xenocrysts. 2013 MWRA excavation east of Woodland Road in Stoneham (site 10285). Same dike as in Figs. Fq5-8 and 10. Thin section in crossed polarizers.



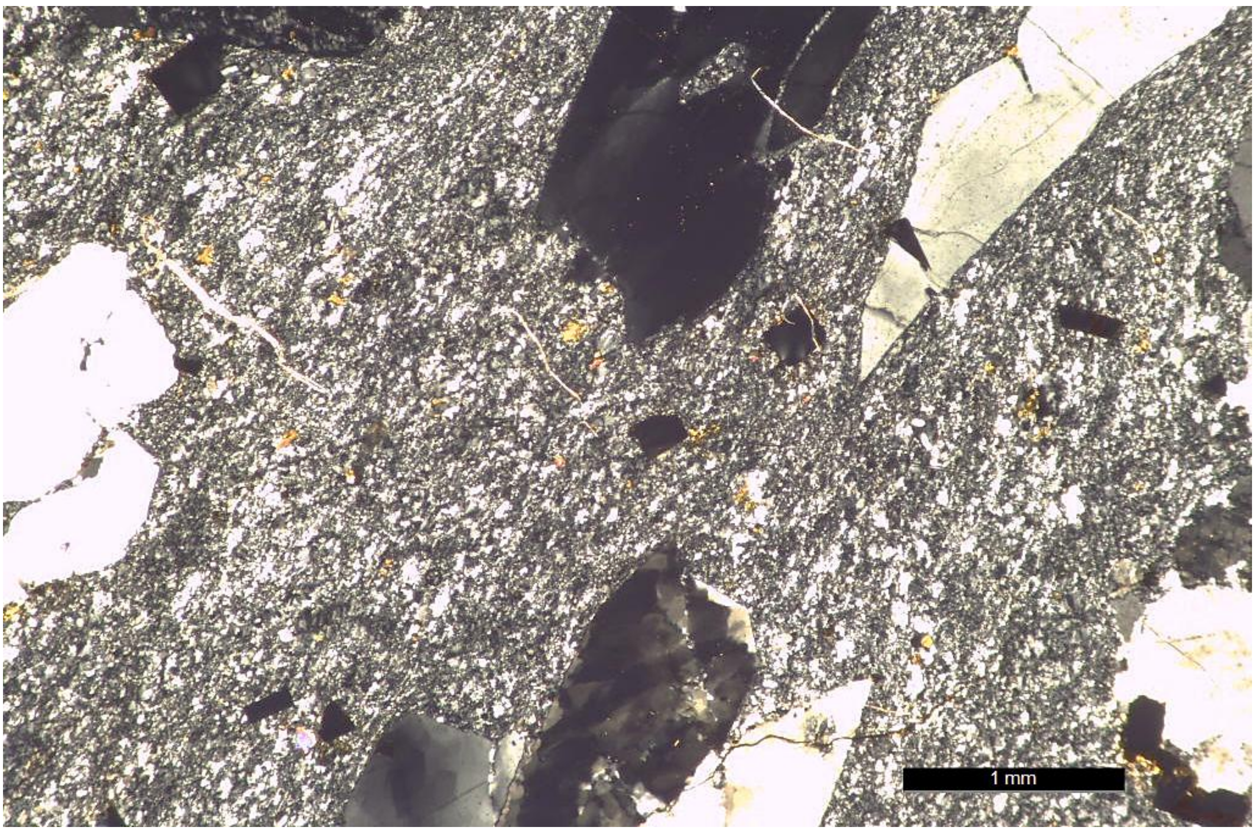
fq12: Rhyolite dike with fine equigranular matrix of plagioclase, quartz, and alkali feldspar; rounded and resorbed xenocrysts of quartz and feldspar and multi-grain granitic xenolith with ophitic texture. Tan grains are alkali feldspar. Dike intruded the Winchester Granite (Zwg), which is the likely source of the xenocrysts and xenoliths. East of South Border Road in Winchester (site 11059). See also Fig. fq9. Thin section with crossed polarizers.



fq13: Rhyolite dike with fine equigranular matrix of plagioclase, quartz and alkali feldspar, and rounded and resorbed xenocrysts of quartz and feldspar. Also shown is a fractured granitic xenolith with strained quartz. Dark, cubic grain in center is fluorite. Dike occurs in the Westboro Formation (Zwp) on Whip Hill in Stoneham (site 10377). See also Figs. fq1-4 and 14. Thin section with crossed polarizers.



fq14: Rhyolite dike with equigranular matrix of plagioclase, quartz, and alkali feldspar and partly resorbed xenocrysts of quartz and feldspar. Dike occurs in the Westboro Formation (Zwp) on Whip Hill in Stoneham (site 10377). Above in plane polarized light and below with crossed polarizers. This dike has euhedral fluorite (f) with coatings of hematite. Fluorite is black in crossed polarizers below. See also Figs. fq1-4 and 13.



Rock Units North of the Walden Pond Fault of Kaye (1980)

(All descriptions are modified from Castle and others (2005) for the Reading, Mass. Quadrangle.)

Dp

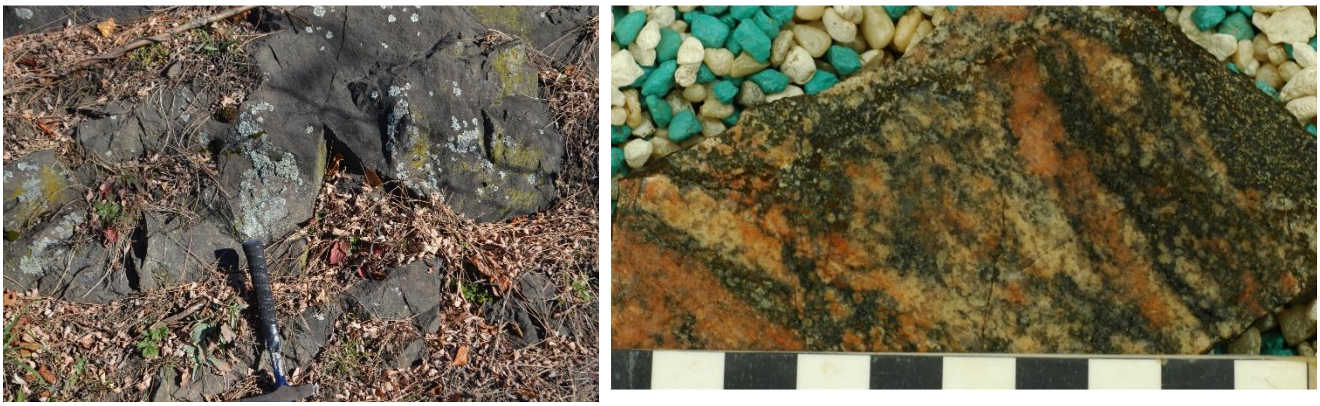
Peabody Granite (Late and Middle Devonian) – Medium to coarse-grained, orange syenogranite (Fig. Dp1) composed chiefly of microperthite, quartz, hornblende and plagioclase. In the Boston North Quadrangle, it occurs as a large intrusive body and as small, roughly north to northeast oriented pods intruding the Diorite at Lake Quannapowitt and vicinity (Castle and others, 2005) described below. Biotite occurs in peripheral rocks. Included with "alkalic" intrusive series of Toulmin (1964). Age about 360 ± 24 (Rb-Sr) to 395 ± 20 (U-Pb).

Dp1: Syenogranite outcrop of Peabody Granite (Dp) as mapped by Castle and others (2005) in the Reading Quadrangle. Northeast corner of Lindenwood Cemetery on Montvale Ave. in Stoneham (site 11660). On left is outcrop, rock hammer for scale, and on right is cut rock sample.

Diorite at Lake Quannapowitt and vicinity (Silurian or Ordovician) – Age about 444 ± 3 (U-Pb). Two facies of Castle and others (2005) occur in Boston North Quadrangle.

SOqd

Hornblende diorite facies - Chiefly massive, medium grained, gray to black, alkali-rich diorite (Fig. SOqd1). Composed mainly of plagioclase and hornblende along with variable but generally small amounts of quartz and biotite. Alkali feldspar occurs in small bands and pods. Accessory minerals are chiefly magnetite and sphene.



SOqd1: Dark gray hornblende alkali diorite facies as mapped by Castle and others (2005) in the Reading Quadrangle. Just south of intersection of Montvale Ave. on east side of Maple Street in Stoneham (site 11659). Rock is heavily fractured along Walden pond Fault. On left is outcrop, rock hammer for scale, and on right is cut rock sample.

SOqt

Biotite-hornblende tonalite facies - Chiefly massive, medium-grained gray, alkali-rich tonalite (Fig. SOqt1). Composed largely of plagioclase, hornblende, quartz and biotite. Contains abundant epidote.

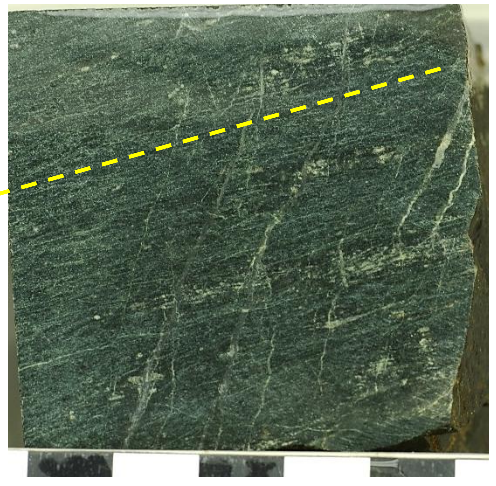
SOqt1: Biotite-hornblende tonalite facies as mapped by Castle and others (2005) in the Reading Quadrangle. Along north side of entry driveway to Stonehill Towers on west side of Rt. 28 just south of Rt. 128/95 in Stoneham (site 11662). On left is outcrop and on right is cut rock sample.

Waltham Tectonic Melange (Late Proterozoic to Silurian?) – Description modified from Castle and others (2005) as modified from LaForge (1932).

Zwba

Amphibolite facies of B member - Chiefly fine-grained, distinctly foliated and locally thinly layered, gray to black amphibolite and plagioclase amphibolite (Figs. Zwba1-2). Composed mainly of hornblende and plagioclase with lesser amounts of magnetite, chlorite and calcite. Occasional bands of sheared quartzite. Epidote conspicuous locally. Mapped only where amphibolite or plagioclase amphibolite is the predominant rock type.

Zwba1: Dark greenish-gray amphibolite of the B Member of the Waltham Tectonic Melange (Zwba) as mapped by Castle and others (2005) on Melvin Street in Wakefield (site 11719). Foliation trends north-south (dashed line). Rock hammer for scale.



Zwba2: Dark greenish-gray amphibolite of the B Member of the Waltham Tectonic Melange (Zwba) as mapped by Castle and others (2005) on Melvin Street in Wakefield (site 11718). Foliation trends north-south (dashed line). Cut rock sample.

Named Rock Units South of the Walden Pond Fault of Kaye (1980)

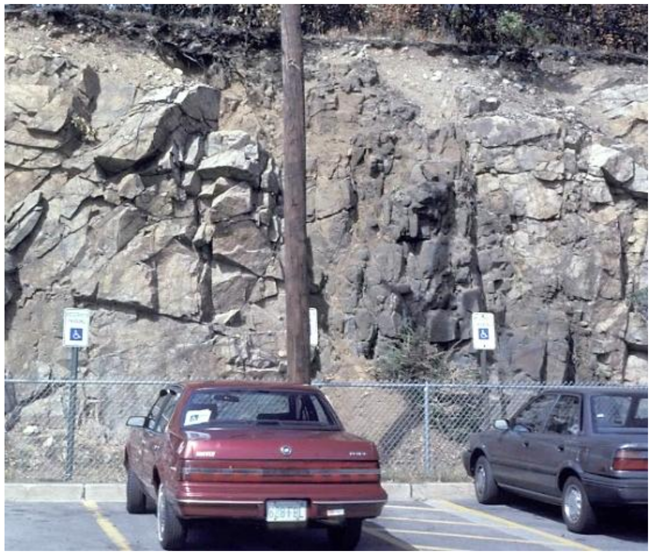
TRm

Medford Dike (middle Triassic) – Brownish- to olive-black (5YR-Y 2/1), medium to coarse-grained gabbro. This is the Medford Diabase or Medford Dike of Wilson (1901) and LaForge (1932). The unit is mostly plagioclase, augite, biotite, and accessory titanomagnetite or ilmenite (Fig. TRm1) where non-marginal areas were sampled. The unit contains abundant fine apatite needles and less than 1% interstitial calcite, which along with biotite accounts for the unit's rapid weathering. The margins of the dike have olivine while the western margin also has kaersutite, a titanium bearing amphibole (Ross, 2020). The dike is deeply weathered along fractures to depths of more than 10 m in quarry walls and reduced to grus and corestones with spheroidal weathering at the surface (Fig. TRm2). The weathering allowed it to be easily quarried in the Pine Hill area of Medford. Corestones were excavated and split for building stone, walls, monuments, and hitching posts. Samples that are completely non-weathered are difficult to find (Fig. TRm1) except in the centers of corestones split during quarrying, in lower quarry walls, and in deep excavations such as the T-station exposure at Tufts in 2022 (Fig. TRm3). In local building stone the unit contains xenoliths of felsite and quartzite. The age of weathering was debated; Wolf (1932) and Lane and Wolf (1933) argued for relict preglacial (pre-Wisconsinan) weathering, while Billings and Roy (1933) argued for postglacial weathering. The tops of *insitu* corestones at Pine Hill have truncated, glacially grooved tops and are relatively non-weathered, while also displaying deep weathering along adjacent joints indicating that the deep weathering pre-dates the last glaciation. A small weathered branch of the dike occurs on the west side of Lawrence Memorial Hospital (Fig. TRm4). The dike extends north-northeast across Rt. 93 where it pinches out east of Rt. 28 and west of Wrights Pond with a smaller branch of the dike exposed further north along the east side of Rt. 93. The unit crosscuts all adjacent dolerite dikes it encounters in the Middlesex Fells and elsewhere except for a north-south trending dike reported by Wilson (1901) in Medford and a very thin (7 cm) dike on the north side of 34 Governors Avenue at "House on Rock". The Medford Dike also crosscuts the youngest set of faults in the Fells that trend N-S. Detailed mineralogy and chemistry of the dike and field relationships to other dikes are discussed by Ross (1990, 1992, 2001, 2020, 2021). The unit has a K-Ar (biotite) age of 190 $\pm$ 6 Ma (Ross, 1981, 1990, 2001) and an $^{40}Ar/^{39}Ar$ biotite age of 304.4 $\pm$ 0.6 Ma (Ross, 2020). A newly obtained CA-ID-TIMS U-Pb zircon age is 238.07 $\pm$ 0.09 Ma (6 zircons, site 11559) and is more precise and accurate. Individual zircon measurements and their variability are shown on Fig. TRm5. This age places the unit in the middle Triassic Central New England Magmatic Province.

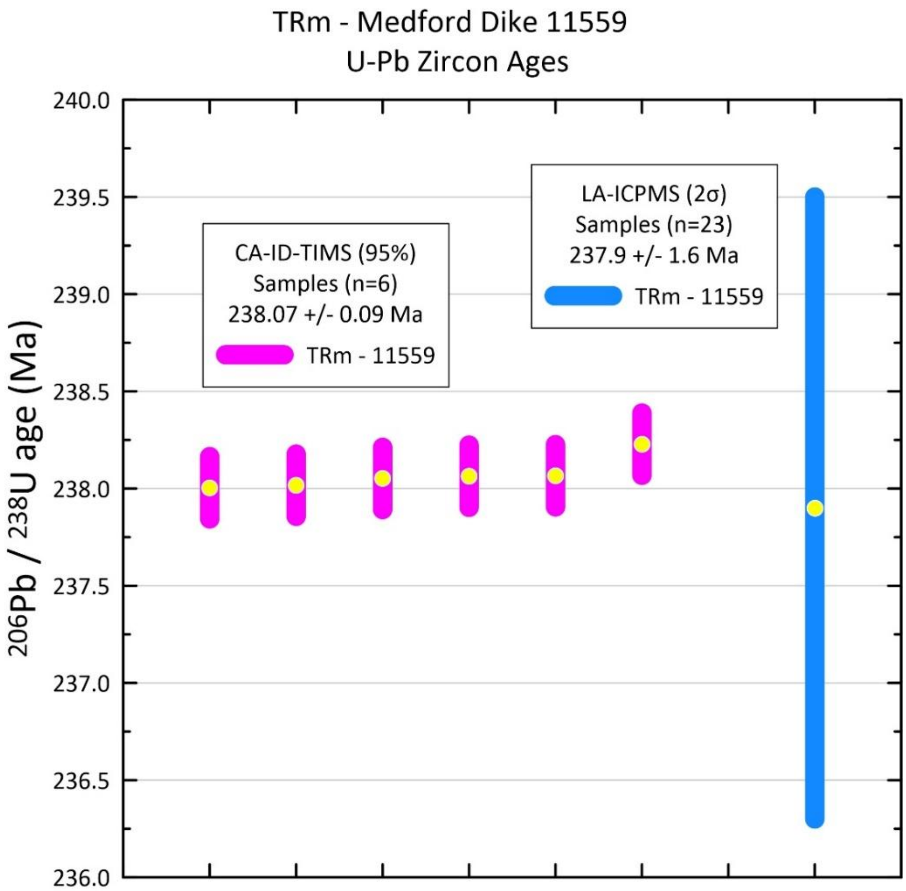
TRm1: Cut rock slab from a quarry west of northern Pine Hill in Medford (site 10484) showing tabular plagioclase and coarse grain size as compared to other mafic dikes.

TRm2: Spheroidal weathering, corestones, and grus in a quarry at the north end of Pine Hill in Medford (site 015BN).

TRm3: Deep exposure of non-weathered Medford Dike (arrows) at the 2022 excavation for the MBTA Green Line Station at Tufts University in Medford (site 11349). The dike intrudes the Cambridge Argillite at this location.



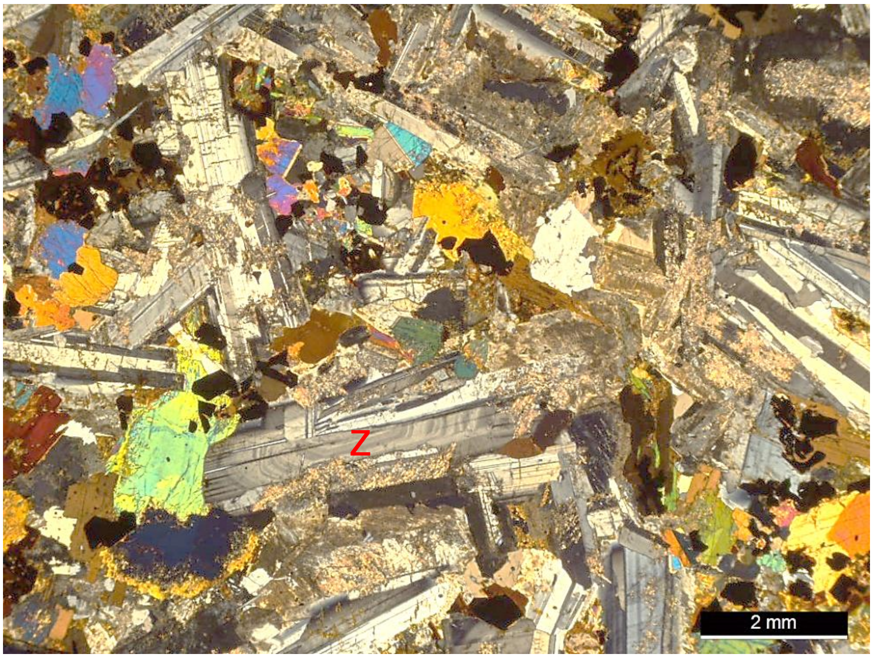
TRm4: Weathered branch of Medford Dike in fractured Lawrence Woods Granophyre (Zlwg) on the west side of Lawrence Memorial Hospital in Medford (site 177BN).



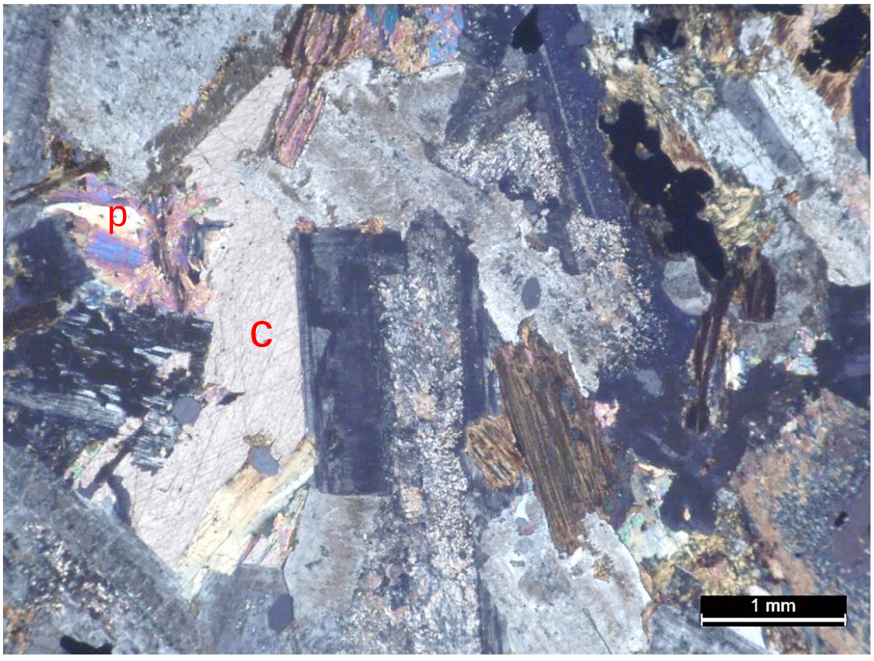
TRm5: Individual CA-ID-TIMS U-Pb ages for 6 zircon grains used to calculate the mean age of the Medford Dike from a sample in an abandoned quarry northeast of Bellevue Pond in the Middlesex Fells in Medford (site 11559). Also shown for comparison is the less precise, although very similar, LA-ICPMS U-Pb age from the same sample on 23 zircon grains.

Medford Dike (cont.)

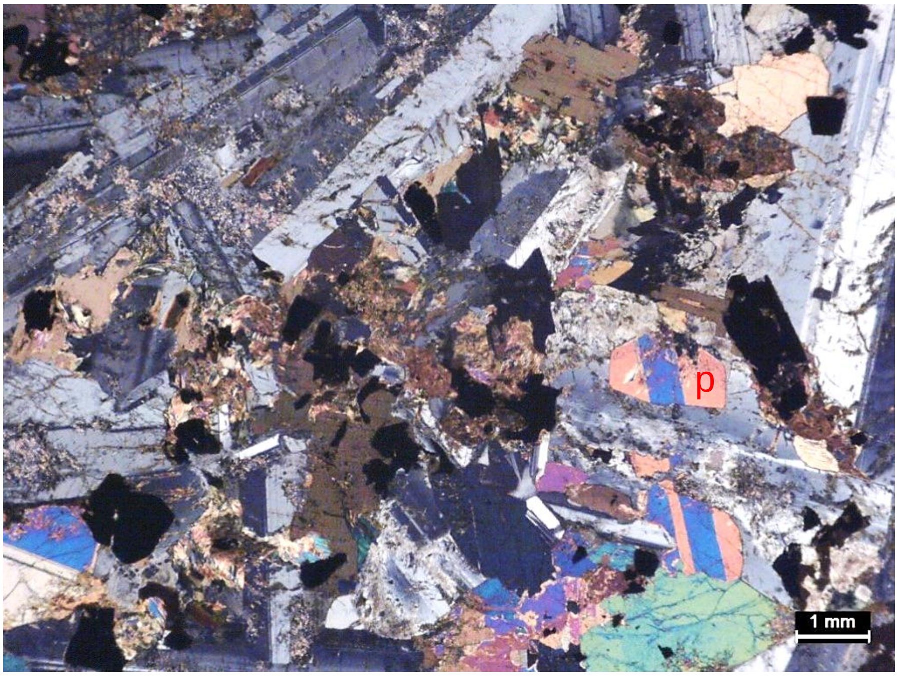
Thin section description – Like many gabbro units, the Medford Dike has intergranular plagioclase and clinopyroxene (augite). The plagioclase is in coarse tabular, twinned crystals that are sometimes zoned (Figs. TRm6-10). Plagioclase is mostly clear but has patches that are heavily altered to sericite (Figs. TRm7 and 11). Clinopyroxene occurs as large subhedral twinned augite crystals (Figs. TRm8-9). Brown biotite occurs as single crystals or areas of interstitial hash (Fig. TRm6-8) that may be partly from the alteration of pyroxene. Opaque minerals are titanomagnetite and possibly ilmenite that is mostly blocky and occasionally skeletal (all images). Ross (2020) reported that the margins of the dike have olivine and the western margin kaersutite (calcic titanium amphibole). Noteworthy is the absence of orthopyroxene or olivine in the center of the dike where samples were collected for this project. Secondary minerals include interstitial calcite (Fig. TRm7), interstitial quartz (Fig. TRm9), and occasional granophyric grains of quartz and feldspar (Fig. TRm10). Ross (2020) also reported alkali feldspar. The unit has abundant fine apatite crystals that are hexagonal, elongate to needle-like, and most abundant within plagioclase and biotite (Figs. TRm9 and 11).



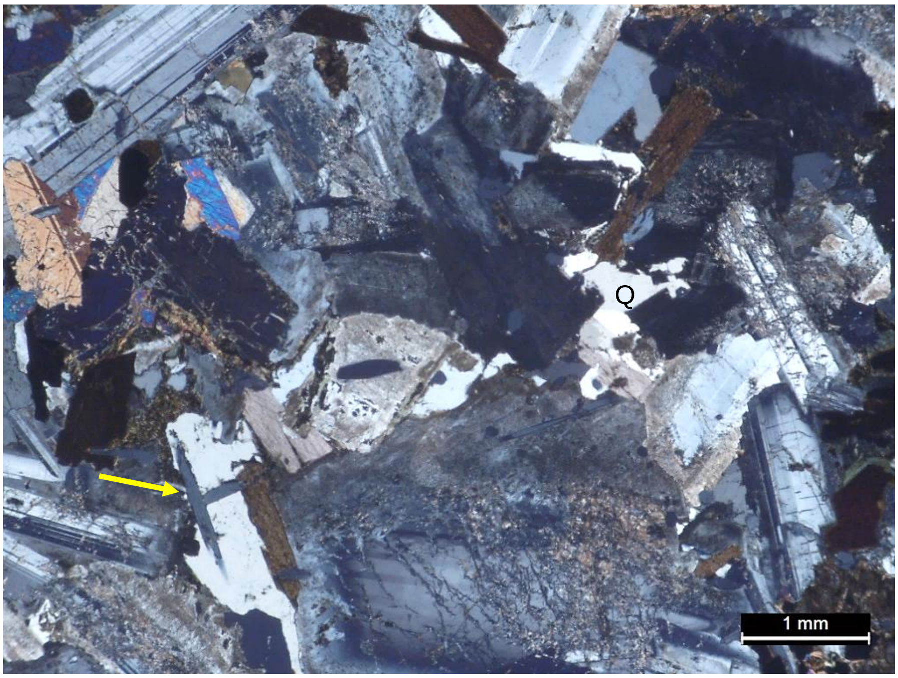
TRm6: Center of Medford Dike adjacent to Pine Hill in Medford (site 10484). Intergranular texture with tabular twinned and zoned (Z) plagioclase partly altered to sericite. Also, in the rock is twinned clinopyroxene, and brown biotite. Opaque grains are mostly titanomagnetite with possibly some ilmenite.



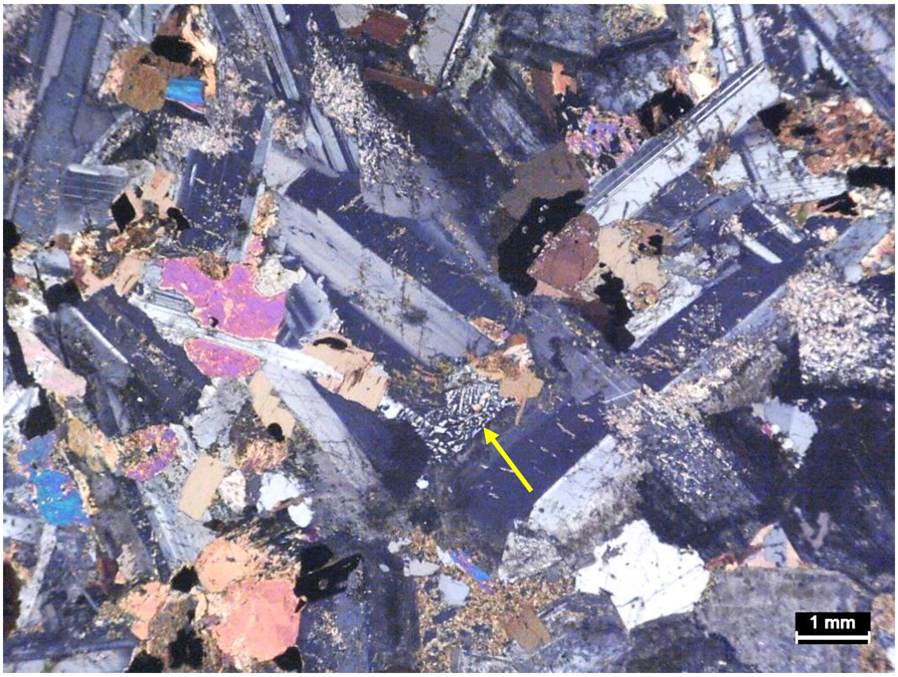
TRm7: Center of Medford Dike adjacent to Pine Hill in Medford (site 11300). Intergranular texture with tabular twinned plagioclase partly altered to sericite (speckled areas), twinned clinopyroxene (P), and brown biotite. Opaque grains are mostly blocky titanomagnetite and possibly some ilmenite. Shown here is an area of interstitial calcite (C).



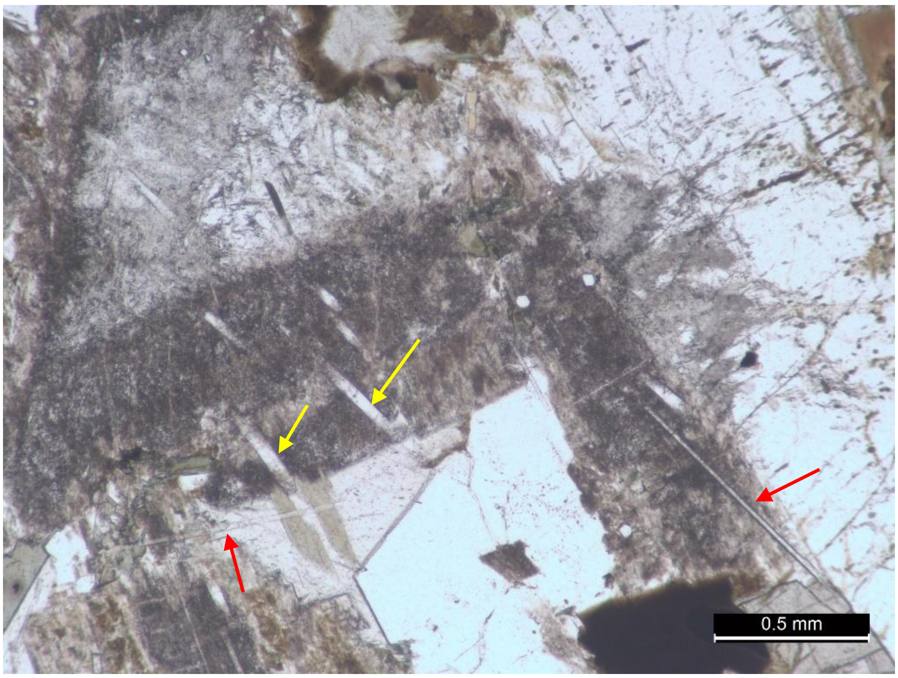
TRm8 : Center of Medford Dike adjacent to Pine Hill in Medford (site 10484). Intergranular texture with tabular twinned plagioclase partly altered to sericite, twinned clinopyroxene (P), and brown biotite that is single crystals and interstitial hash. Opaque grains are mostly equant titanomagnetite and possibly some ilmenite.



TRm9: Center of Medford Dike adjacent to Pine Hill in Medford (site 11300). Intergranular texture with tabular twinned plagioclase partly altered to sericite, twinned clinopyroxene, and brown biotite. Opaque grains are mostly equant titanomagnetite and possibly some ilmenite. Shown here are small areas (very bright) of interstitial quartz (Q). In lower left, the dark cross in the plagioclase is intersecting elongate apatite crystals (arrow).



TRm10: Center of Medford Dike adjacent to Pine Hill in Medford (site 10484). Intergranular texture with tabular twinned plagioclase partly altered to sericite, twinned clinopyroxene, and brown biotite that is single crystals and interstitial hash. Opaque grains are mostly equant titanomagnetite and possibly some ilmenite. In the center of this image is an intergrowth of quartz and feldspar as a granophyric grain (arrow).



TRm11: Center of Medford Dike adjacent to Pine Hill in Medford (site 11300). Intergranular texture with tabular twinned plagioclase partly altered to sericite. View in plane polarized light. Fuzzy areas are plagioclase altered to sericite. Shown here are elongate (yellow arrows) to needle-like (red arrows) apatite crystals that have 6-sided cross sections (2 bright spots near center).

Zca

Cambridge Argillite (Neoproterozoic) – Dark to medium gray argillite and fine sandstone (Fig. Zca1). Unit can be sulfidic and often has iron oxide precipitation along fractures. Baked in many places adjacent to diorite dikes, especially around Tufts University where surface exposures are most abundant. At Tufts University contains lens of coarse sandstone and reddish-purple argillite, the so-called “Tufts Quartzite”. No exposures are known north of the Northern Border Fault.

Zca1: Foundation excavation showing Cambridge Argillite along west side of Broadway in Somerville about 100 m west of Powderhouse Square (site 11569).

Zrx

Roxbury Conglomerate? (Neoproterozoic) – Gray to purplish-gray, moderately well-sorted, polymictic, mostly clast-supported conglomerate (Figs. Zrx1-2; also known as puddingstone in Boston) and light tannish-gray to faintly reddish-gray fine to coarse sandstone (Figs. Zrx3-4). Sandstone appears to dominate and is well cemented. Pebbles in the conglomerate are various volcanic lithologies from the Wakefield Formation of the Lynn Volcanic Complex, granodiorite, basalt, and quartzite. Unit appears to unconformably overlie fine volcanic units (vitric tuff) of the Wakefield Formation of the Lynn Volcanic Complex (Zlvv) and the Lawrence Woods Granophyre (Zlwg). In places the conglomerate beds have a poorly developed cleavage and pebbles are fractured because of local faulting (Fig. Zrx1). The most prominent outcrops are along the southwest side of Winthrop Street (Rt. 38) south of Victory Park and on the hilltop southwest of this area (Figs. Zrx1-2) as well as at the intersection of Wyman and Mystic Streets. Units in Medford were first recognized by Kaye (1980) and appear to be an outlier of the Roxbury Conglomerate at the northern edge of the Boston Basin like the Brookline member of the Roxbury Formation in Newton (Thompson, 2017).

Zrx1: Purplish-gray Roxbury Conglomerate southwest of Rt. 38 on the west side of Lawrence Road in Medford (site 11394). Note crude cleavage development.

Zrx2: Purplish-gray Roxbury Conglomerate on the south side of Wyman Street just west of Rt. 38 in Medford (site 11395).

Zrx3: Tan sandstone in the Roxbury Conglomerate on Woburn Street north of Rt. 60 in Medford (site 11590). Outcrop is glacially striated with striations oriented S23^{o}E.

Zrx4: Cut rock view of tan sandstone in the Roxbury Conglomerate on Mystic Street north of Rt. 60 in Medford (site 11589).

Zst

Stoneham Granodiorite (Neoproterozoic) – Greenish-gray (5B-GB 5-6/1) mostly granodiorite to tonalite (Fig. Zst1). Has the appearance in the field of quartz diorite or diorite because quartz is often fine-grained and inconspicuous, alkali feldspar is fine-grained and interstitial with a low abundance, and the rock can have a high mafic content for a felsic plutonic body (Figs. Zst3-9). Usually fine-grained and porphyritic in chill zones (Fig. Zst3-6) but otherwise crudely porphyritic to equigranular. Has tabular euhedral plagioclase throughout that dominates other felsic minerals with varying alteration of grain interiors to sericite and epidote. Plagioclase is often enclosed in fresher more alkaline rims (Fig. Zst6) and sometimes has a yellowish-orange iron-staining that mimics alkali feldspar in hand specimens. In terms of overall felsic mineral composition, the unit typically has about 15-30% quartz, which is interstitial and finer than plagioclase, and mostly less than 15% alkali feldspar (Figs. Zst6-9) that can be altered and difficult to distinguish from altered plagioclase without potassium staining. Mafic mineral content is usually 15-25% with biotite and hornblende that are mostly to partly altered to chlorite, epidote, and opaque oxides. Displays rapid changes in grain size and mafic mineral content. Lightly altered to mostly assimilated xenoliths are abundant in many outcrops (Figs. Zst8 and 10-12) and include quartzite and argillite from the Westboro Formation (Zvwq and Zwp), basalt from the Nanepashemet Formation (Znpm) in the Fells and Lynn Volcanic Complex (Zlbf; Fig. Zst8) at the north end of Spot Pond and in Stoneham. A chill zone contact with the rhyolite flow facies of the Lynn Volcanic Complex (Zlvf) as well as large rhyolite xenoliths occur on the western of two peninsulas at the north end of Spot Pond (Fig. Zst3-4) and at the northeastern corner of Dark Hollow Pond. At Sheepfold, Winthrop and Bear Hills, and Taylor Mountain this unit intruded and permeated the Westboro and Nanepashemet Formations, baking them to hornfels and forming areas of assimilation with small dikelets and plutonic breccia that occur in otherwise continuous outcrop areas of hornfels of the older formations (Figs. Zst13-15). The intrusive granodiorite branches appear to have a higher iron content that creates a pink to orange color in quartz and plagioclase and gives an impression in the field of a more alkaline composition. Island outcrops in Spot Pond, a chill zone at the northeast corner of Spot Pond (Zst16-17) and baked argillaceous rocks at Spot Pond near the Stone Zoo in the Westboro Formation (Zwp) suggest that the Stoneham underlies much of the northern basin of Spot Pond and may be associated with gray dacite to andesite dikes (ad) on the east side of the pond that intrude the Westboro Formation. Point counts in the Stoneham Granodiorite and the Wanapanaquin Porphyry (Zwap) at Middle Reservoir are similar (Fig. Zst1) and the Wanapanaquin appears to be an extension of the granodiorite intruding the Nanepashemet Formation. A finger of granodiorite appears to extend across the lowland of Doleful Pond beneath volcanic rocks, and the unit extends northeast with abundant basalt inclusions to Wakefield and Saugus. Key outcrops are along Rt. 93 at Deer Hill and north to Montvale Ave., along the west side of Rt. 28 south of Dark Hollow Pond, and along Pond Street in Stoneham near Rt. 93. The Stoneham Granodiorite was interpreted by Kaye (1980) and LaForge (1932) to be correlative to the Newburyport Quartz Diorite (Emerson, 1917; Clapp, 1921; now the Newburyport Complex of Zen and others, 1983 and Wones and Goldsmith, 1991). Bell (1948) classified this unit as the “Newburyport Quartz Diorite” phase of the Dedham Granodiorite. This unit was also lumped with the Dedham Granodiorite (Spot Pond Granodiorite and Winchester Granite of this map) as a dioritic phase (Kaye, 1980; Smith and Hon, 1984), but it is texturally distinct from the Spot Pond and Winchester (see note below on p. 86) and does not contact them or the Rams Head Porphyry (Zrhp) to the south. A new U-Pb age (CA-ID-TIMS) from along Pond Street northwest of Spot Pond is 595.14 +/- 0.17 Ma (6 zircons, site 10958, Fig. Zst2). This age clearly separates it from older Dedham units and eliminates correlations to any Paleozoic units.

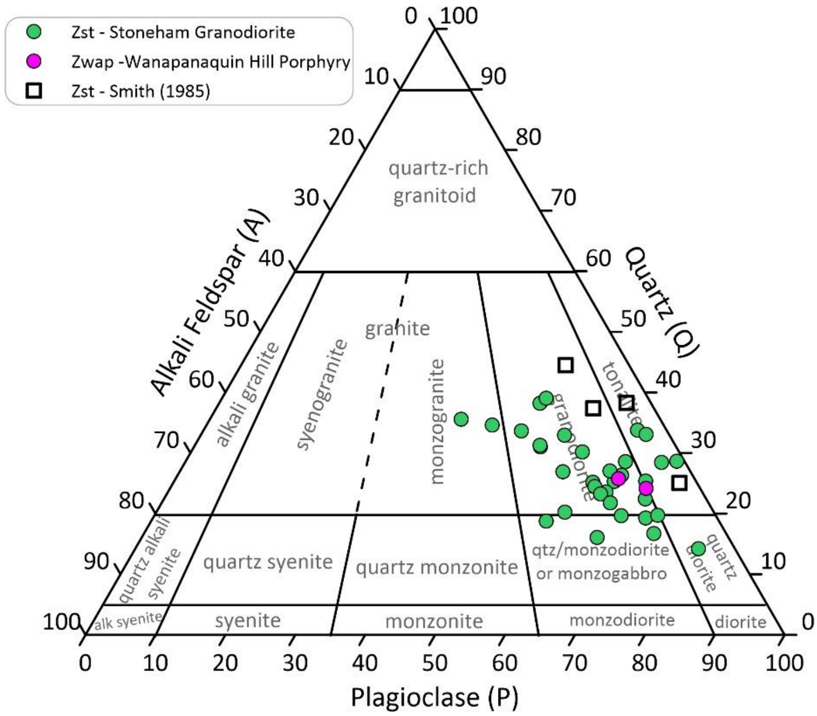
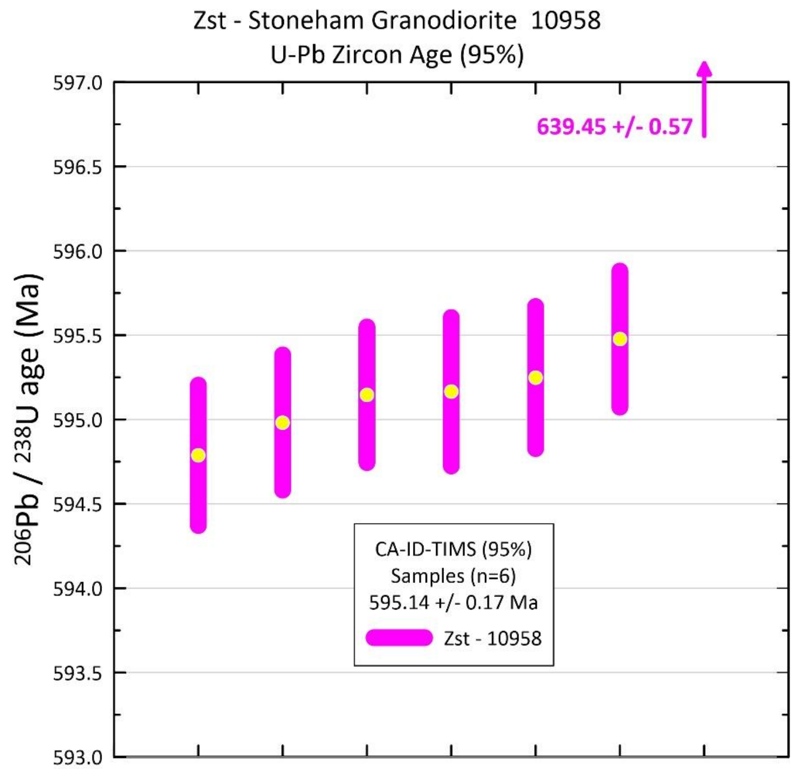
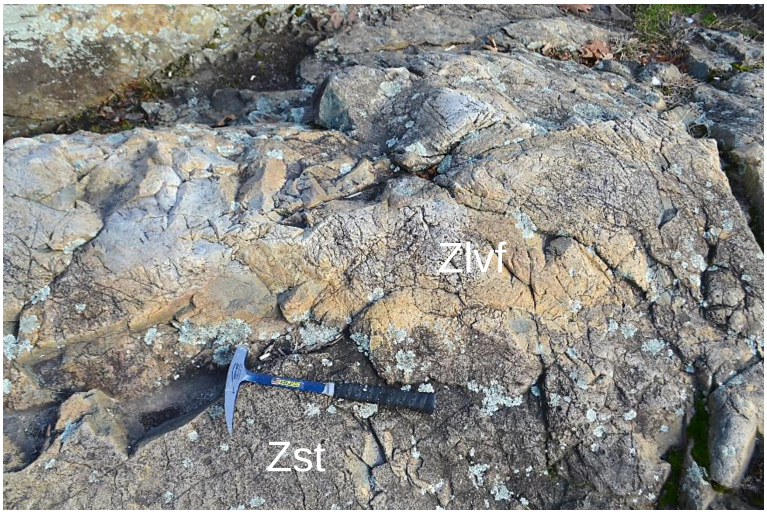


Figure Zst1: Normalized Quartz-Alkali Feldspar-Plagioclase (QAP) plot of point counts from the Stoneham Granodiorite and the Wanapanaquin Hill Porphyry. Note the similarity of these two units. Most samples are granodiorite to tonalite. Four sites in the Stoneham Granodiorite from northwest of the Fells from point counts by Smith (1985) are shown for comparison. Mapping northeast of the Fells reveals intrusion into mostly basalt of the Lynn Volcanic Complex over a wide area to Wakefield where Lynn felsic volcanic rocks are intruded. Point count data are in Appendices 1-A and 1-B.

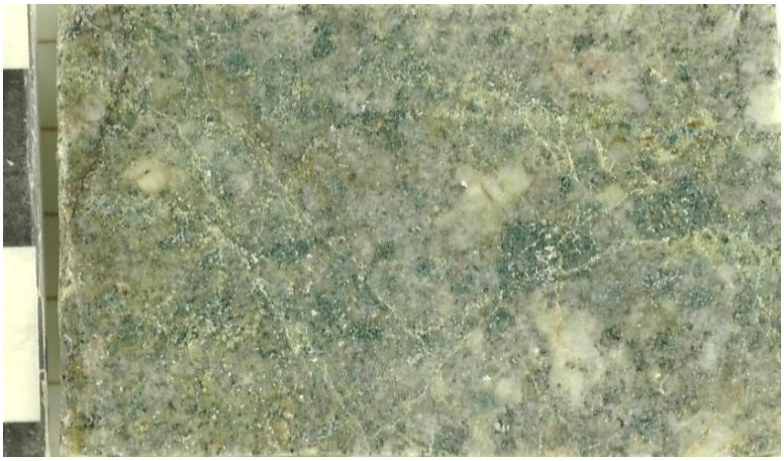
Figure Zst2: Individual CA-ID-TIMS ages used to calculate a mean age for the Stoneham Granodiorite on Pond Street northwest of Spot Pond in Stoneham (site 10958). Six zircon crystals were used while a seventh grain (>635 Ma) was an outlier that was likely inherited. An LA-ICPMS age for this sample is not available.



Zst3 (left): Chill zone of Stoneham Granodiorite (Zst) in contact with rhyolite flow facies of the Lynn Volcanic Complex (Zlvf) on northwest shore of Spot Pond in Stoneham (site 10422). The chill zone has assimilated rhyolite and rhyolite xenoliths along this contact (see Fig. Zst4).

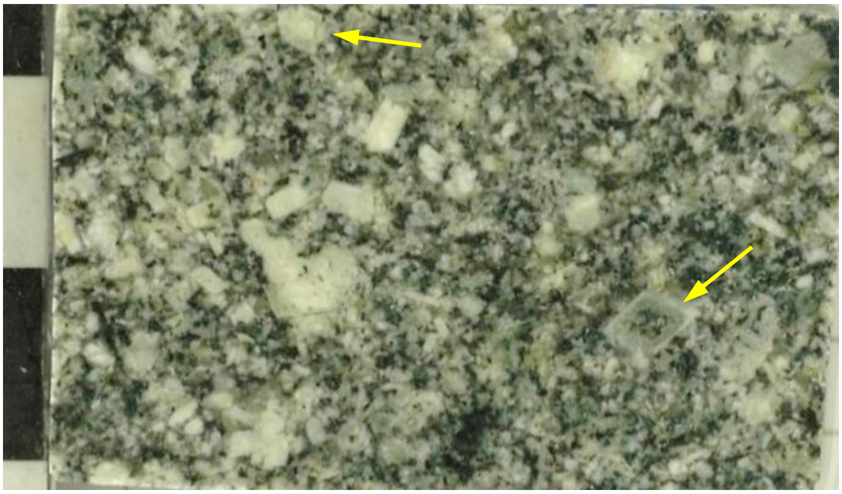


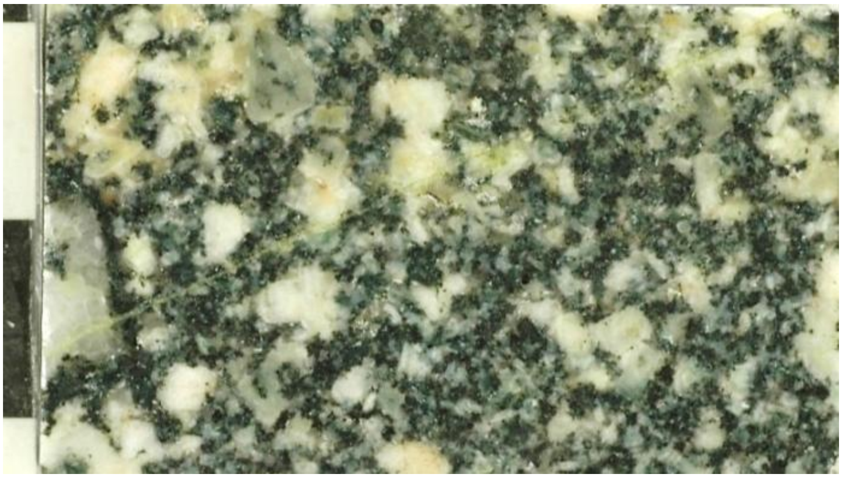
Zst4 (right): Partly assimilated xenolith of the rhyolite flow facies of the Lynn Volcanic Complex (Zlvf) in Stoneham Granodiorite (Zst) chill zone at northwest shore of Spot Pond (site 10422).



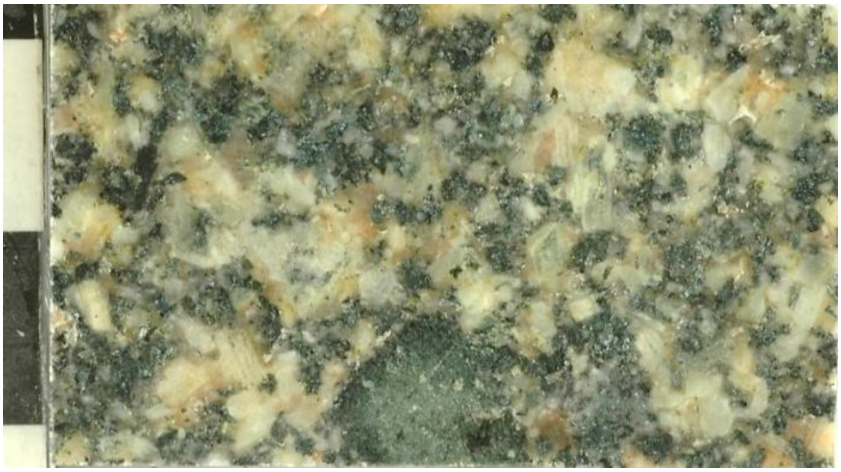
Zst5 (left): Cut rock slab of granodiorite from the chill zone at contact with rhyolite flow facies of the Lynn Volcanic Complex (Zlvf) on northwest shore of Spot Pond in Stoneham (site 10422). This rock has assimilated rhyolite in it. (See Figs. Zst3-4)

Zst6 (right): Cut rock slab of relatively fine-grained, porphyritic granodiorite near contact with Westboro Formation (Zvwq) on east side of Rt. 93 at Deer Hill in Medford (site 10461). Note scattered, rimmed, nearly perfectly euhedral plagioclase crystals with altered interiors (arrows show examples).



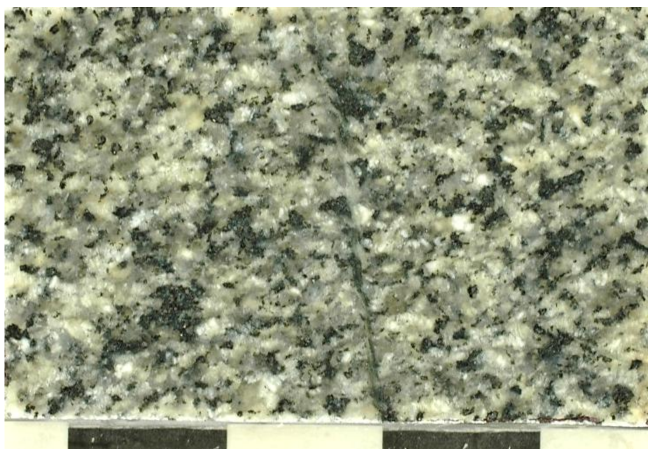


Zst7: Cut rock slab of tonalite with high mafic content near contact with basalt of the Lynn Volcanic Complex (Zlbf) at Straw Point on the northwest shore of Spot Pond in Stoneham (site 10428).



Zst8: Cut rock slab of granodiorite from along Pond Street northwest of Spot Pond in Stoneham (site 10441). Note alkali feldspar (orange) that is subordinate to plagioclase. At bottom is dark basaltic inclusion.

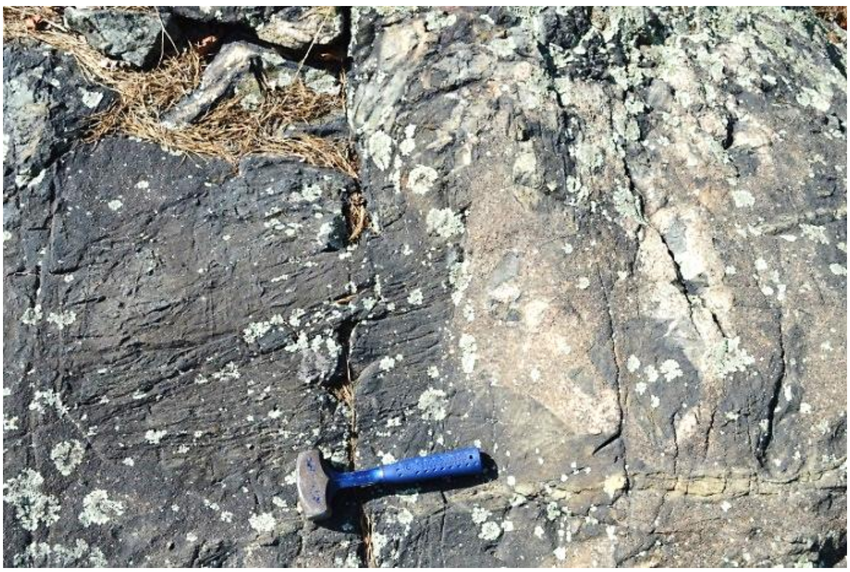
Zst9 (right): Cut rock slab of granodiorite from near the Westboro Formation (Zvwq) along the west side of Rt. 28 north of Sheepfold in Stoneham (site 10957). The rock is very equigranular and richer in quartz with less alteration of mafic minerals that are mostly biotite. Some of the quartz may be derived from the Westboro Formation.



Zst10 (left): Quartzite and dark argillite hornfels xenoliths in granodiorite near its contact with the Westboro Formation (Zvwq) along the east side of Rt. 93 and west side of Deer Hill in Stoneham (site 10462). Some very dark xenoliths are basalt from the Nanepashemet Formation (Znpm).

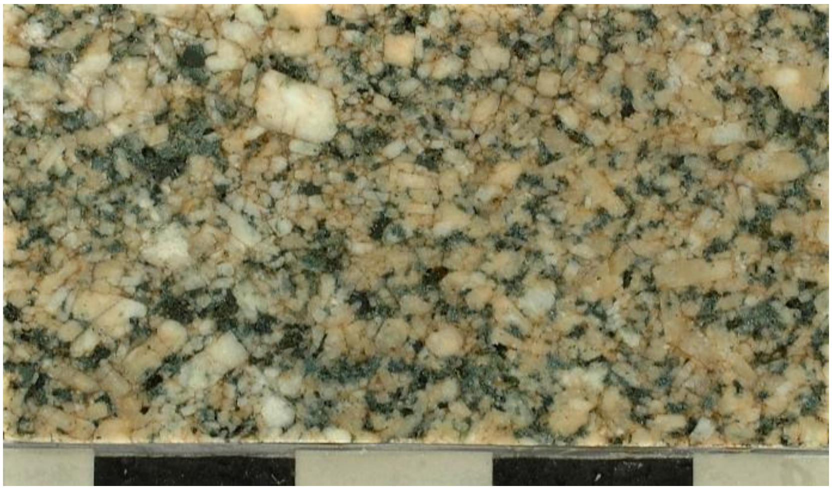
Zst11: White quartzite xenoliths from the Westboro Formation (Zvwq) in granodiorite near contact area on southeast shore of Deer Hill at Spot Pond in Stoneham (site 10455).

Zst12: Partly assimilated and stretched quartzite hornfels from the Westboro Formation (Zvwq) in granodiorite on an island offshore from Straw Point in the northern bay of Spot Pond in Stoneham (site 10869).



Zst13: Partly assimilated and brecciated basalt from the Nanepashemet Formation (Znpm) invaded by granodiorite on Winthrop Hill in Stoneham (site 11190). The intruding granodiorite forms dikes, veins, and plutonic breccia. Baking of the basalt has wiped out its original structure. This area is mapped as part of the Nanepashemet Formation.

Zst14: Partly assimilated and brecciated basalt of the Nanepashemet Formation (Znpm) invaded by porphyritic tonalite dikes east of the main Sheepfold parking area in Stoneham (site 11161). Porphyritic tonalite forms dikes, veins, and plutonic breccia. Baking has wiped out original structures in the basalt. Mapped as part of the Nanepashemet Formation.



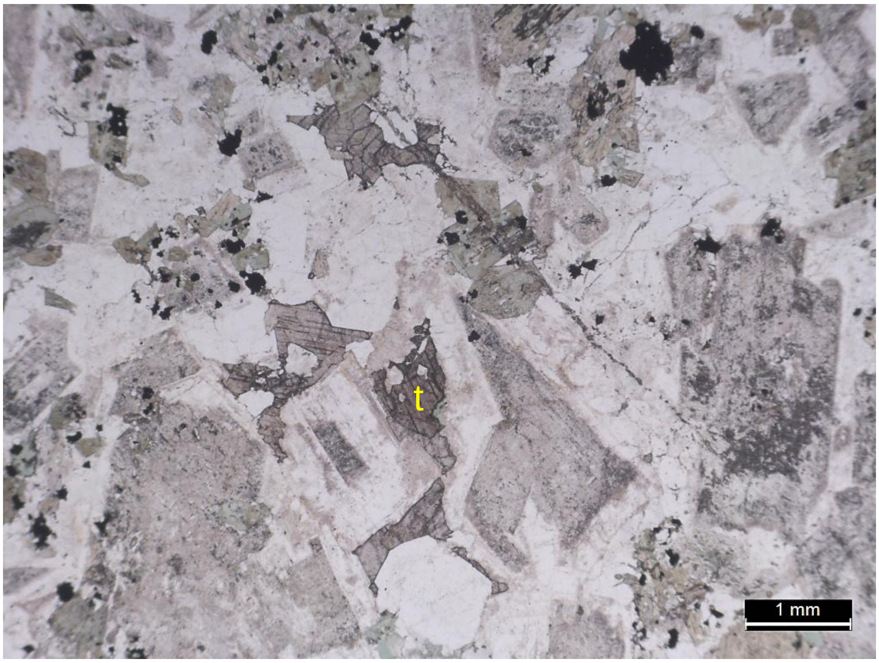
Zst15: Porphyritic tonalite from a small dike in the Nanepashemet Formation (Znpm) at Sheepfold (site 11166). The tightly packed plagioclase crystals are euhedral and have iron staining.

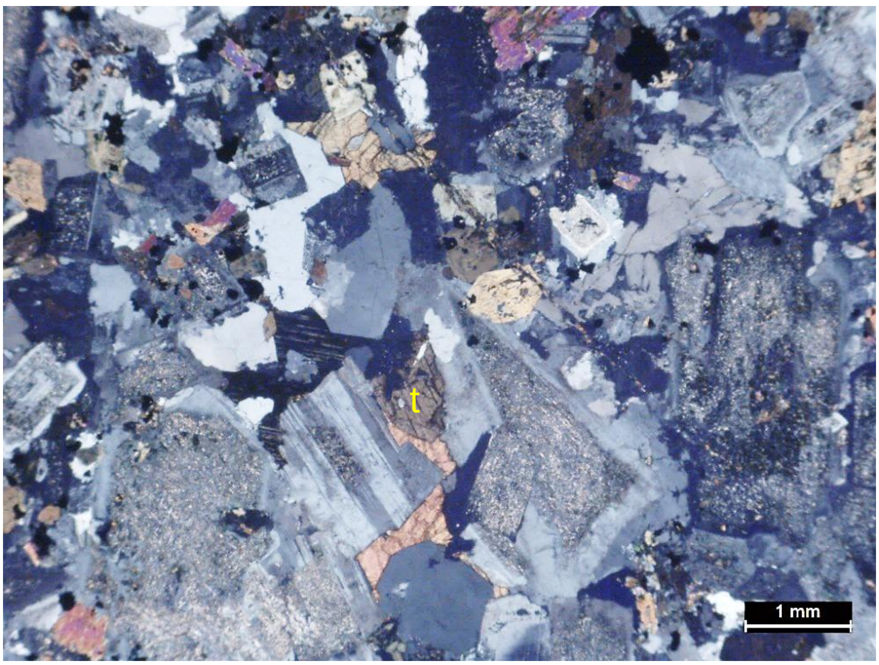
Zst16 (above left): Chill zone of Stoneham Granodiorite at contact with altered crystal tuff in the Lynn Volcanic Complex (Zlvx) at the northeast corner of Spot Pond in Stoneham (site 11778). Arrow shows location of Fig. Zst17.

Zst17 (above right): Highly brecciated crystal tuff in the Lynn Volcanic Complex (Zlvx) near contact with chill zone of the Stoneham Granodiorite at the northeast corner of Spot Pond (site 11777). See image Zst16 for location.

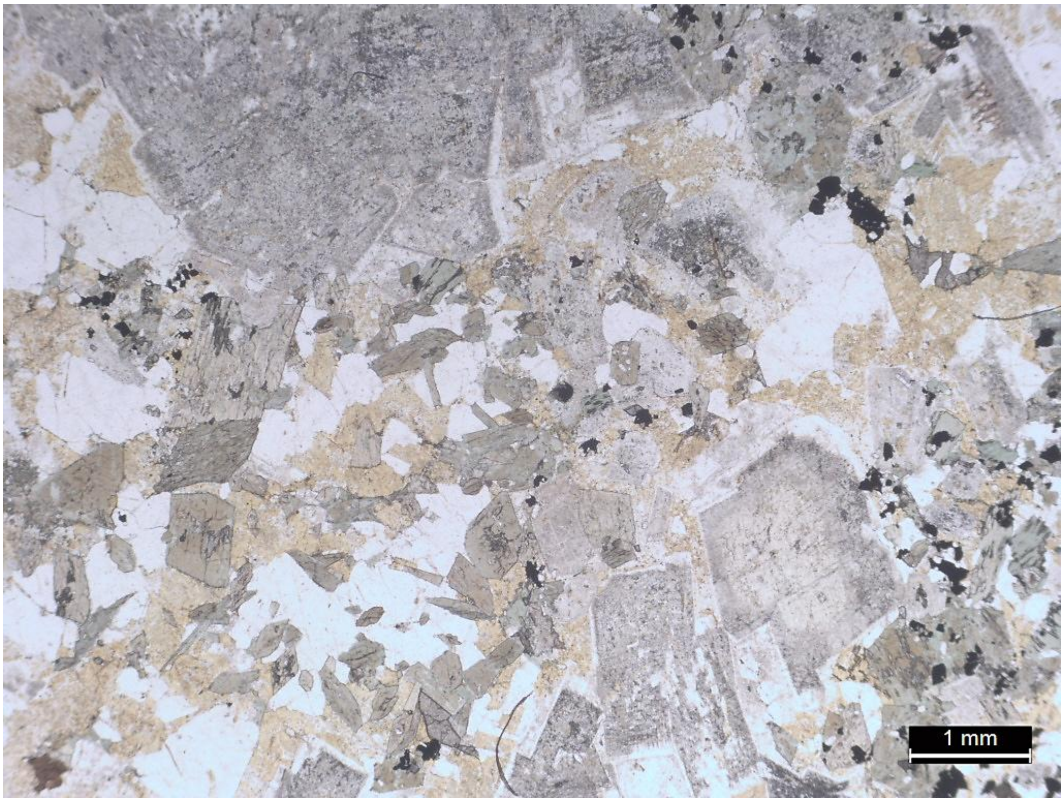
Stoneham Granodiorite (cont.)

<u>Thin section description</u> – Mostly equigranular to porphyritic granodiorite to tonalite (Fig. Zst1) with medium plagioclase crystals (Figs. Zst18-20) except in contact areas, where the rock is finer-grained and porphyritic (Figs. Zst15 and 21). Plagioclase is the rock's dominant mineral and may be tightly packed (Fig. Zst21) and up to 5 mm with cores altered to sericite and rims that are fresh (Figs. Zst18-19). The next most abundant mineral is quartz that is mostly interstitial with a few subhedral crystals (all images below). Along Rt. 28 near Sheepfold quartz may be partly derived from the Westboro Formation (Fig. Zst20). Alkali feldspar is secondary to quartz in almost all samples, is interstitial and tends to be less altered than plagioclase (Figs. Zst19-20). In some samples alkali feldspar is almost non-existent (Figs. Zst21). Mafic minerals are usually green to brown hornblende (Figs. Zst18-19) but near contacts with the Westboro (Zvwq) and Nanepashemet (Znpm) Formations is biotite (Fig. Zst20). Both hornblende and biotite can be altered, sometimes completely, to chlorite (Figs. Zst21-23). Scattered throughout is fine titanomagnetite and possibly some ilmenite. Sphene (titanite) is a common accessory mineral (Figs. Zst18, 22-23). A few samples had granophyric or myrmikitic growths in interstitial areas (Fig. Zst24).

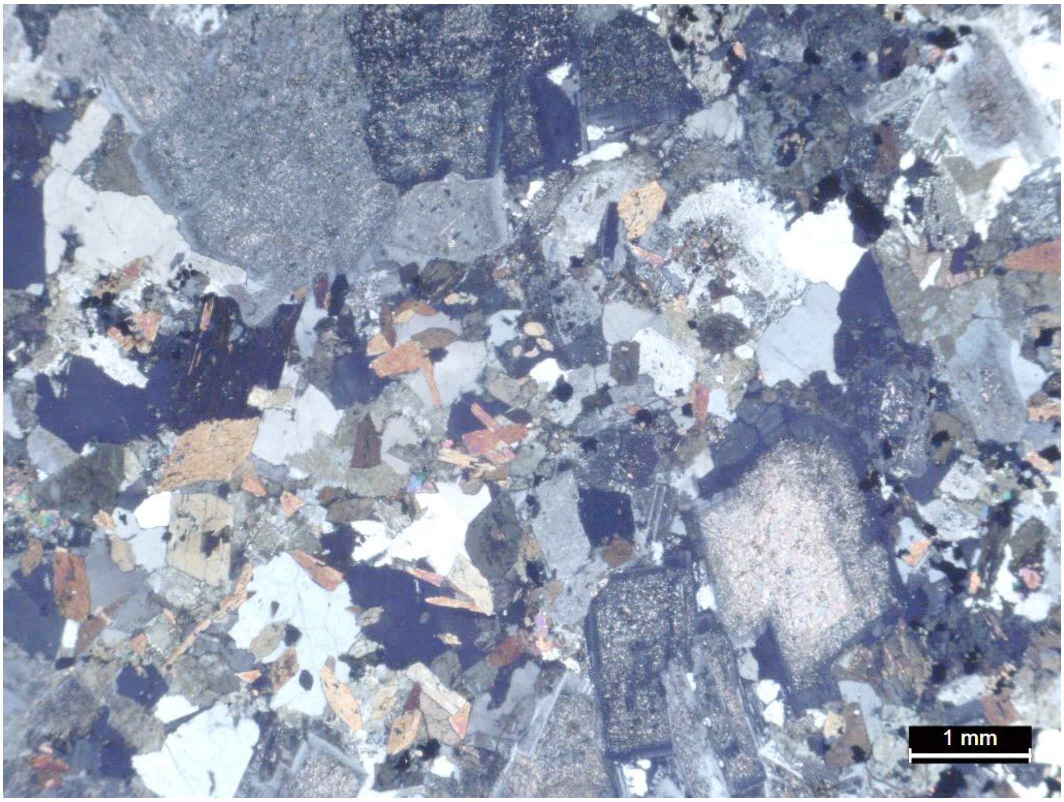


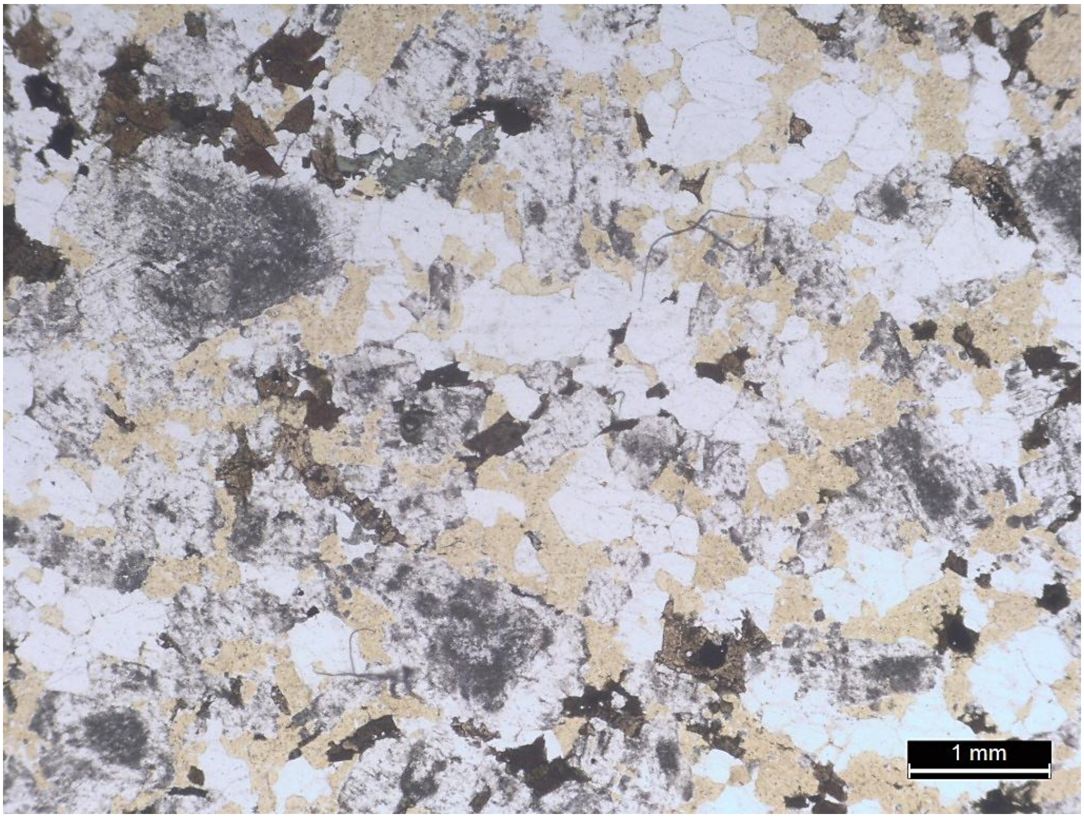


Zst18: Porphyritic granodiorite (above left in plane polarized light, below with crossed polarizers) with medium plagioclase phenocrysts that have cores altered to sericite and fresh rims. Interstitial areas are quartz and minor alkali feldspar. Mafic minerals are green to brown hornblende and scattered opaque grains that are titanomagnetite with possibly some ilmenite. In the center is sphene (titanite, t). Northwest of Spot Pond in Stoneham (site 10441, see also Fig. Zst8).

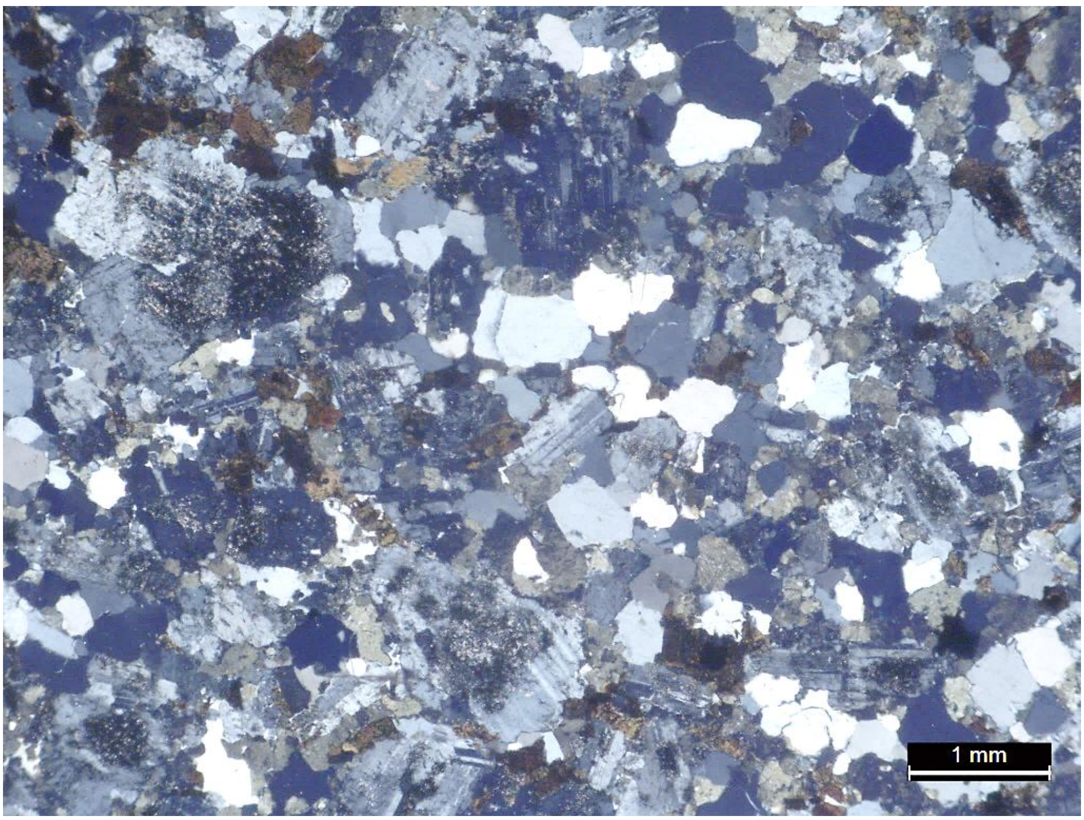


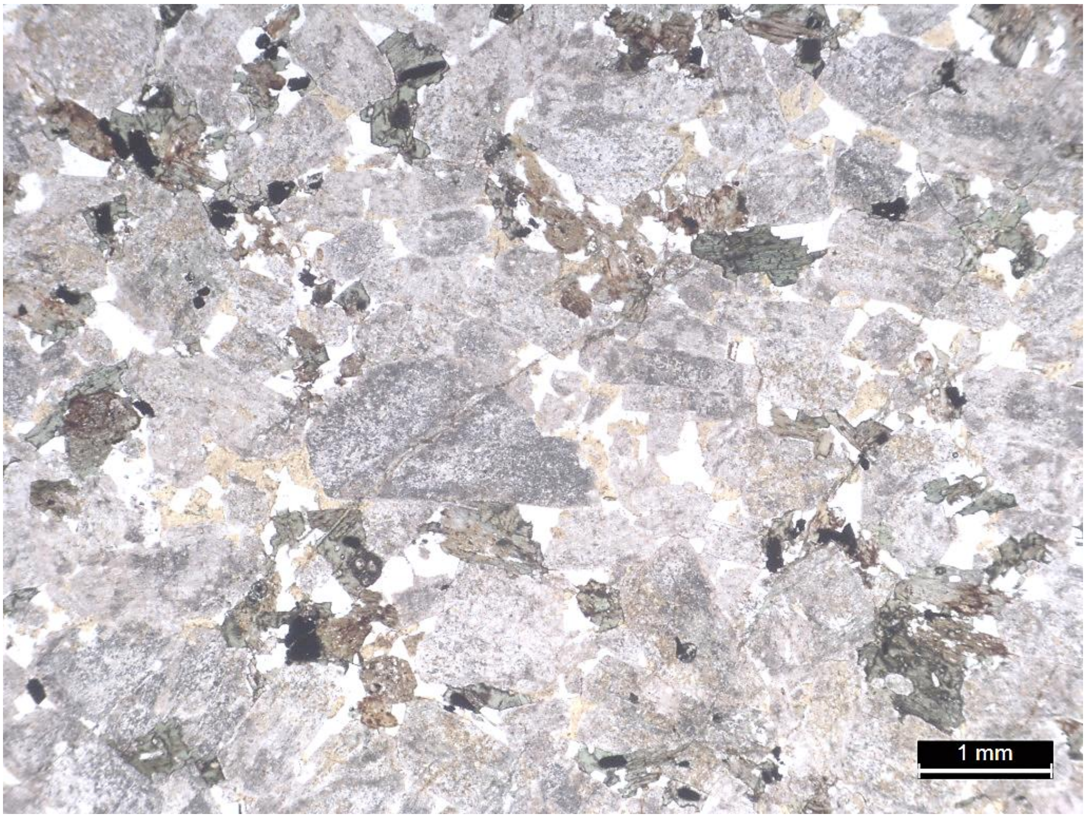
Zst19: Porphyritic granodiorite (above in plane polarized light, below with crossed polarizers) with medium plagioclase phenocrysts that have cores altered to sericite and fresh rims. Interstitial areas are quartz and alkali feldspar (stained yellow above). Mafic minerals are hornblende lightly altered to chlorite. Scattered opaque grains are titanomagnetite and possibly ilmenite. Northwest of Spot Pond along Pond Street in Stoneham (site 10958). A new U-Pb zircon age from this site is 595.14 +/- 0.17 Ma (CA-ID-TIMS, 6 zircon crystals; Fig. Zst2).



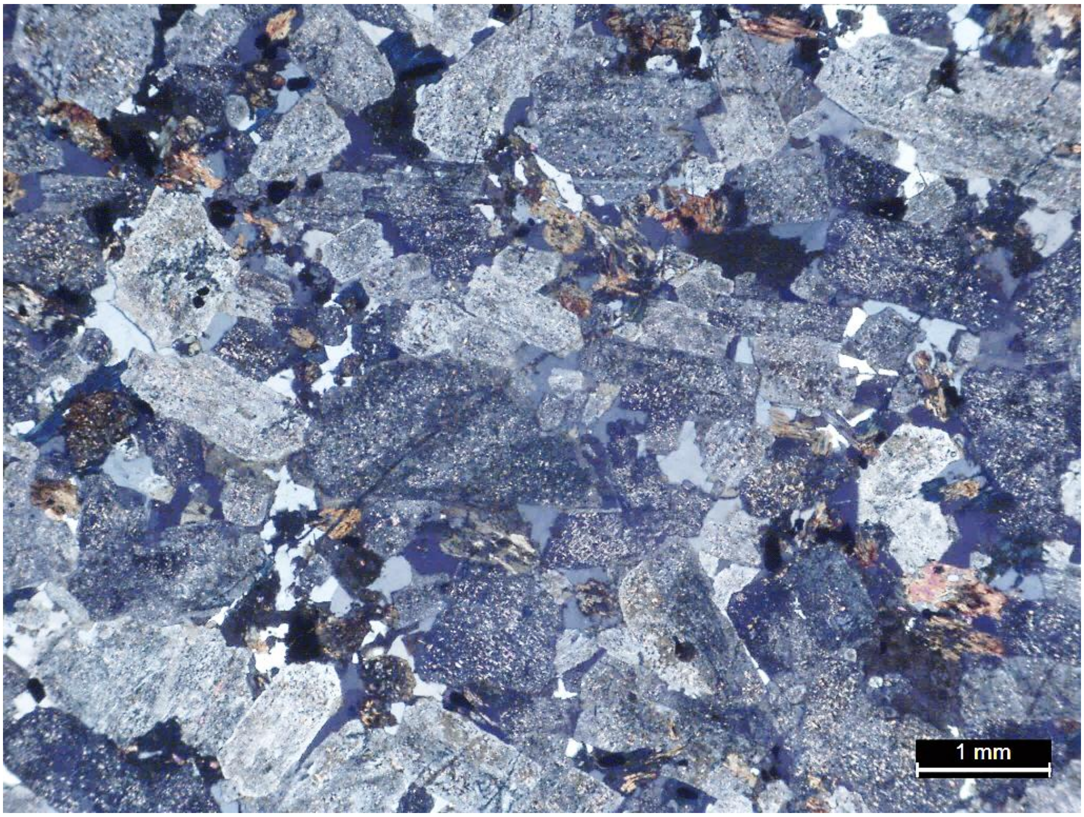


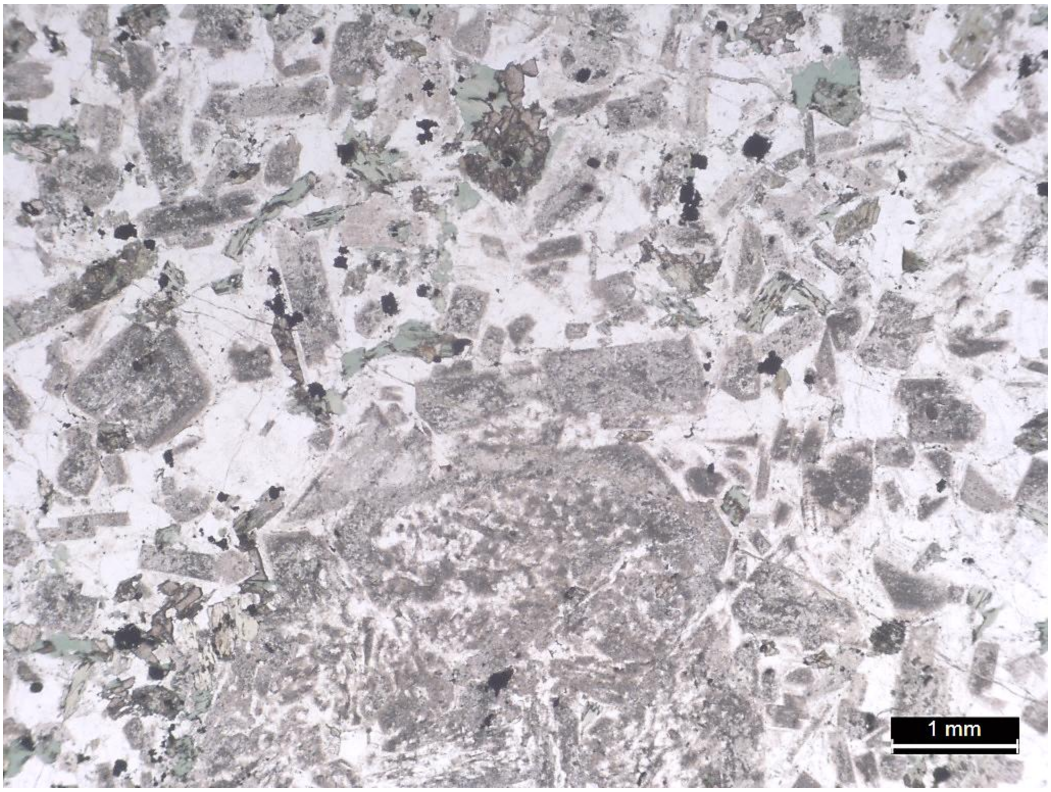
Zst20: Porphyritic to equigranular granodiorite (above in plane polarized light, below with crossed polarizers) with medium plagioclase crystals that have cores partly altered to sericite. Quartz is interstitial to equant and alkali feldspar is interstitial (stained yellow above). Mafic minerals are biotite (brown above) lightly altered to chlorite in places. South of Dark Hollow Pond along west side of Rt. 28 in Stoneham (site 10957, see also Fig. Zst9). Some quartz grains may be derived from the Westboro Formation (Zvwq).





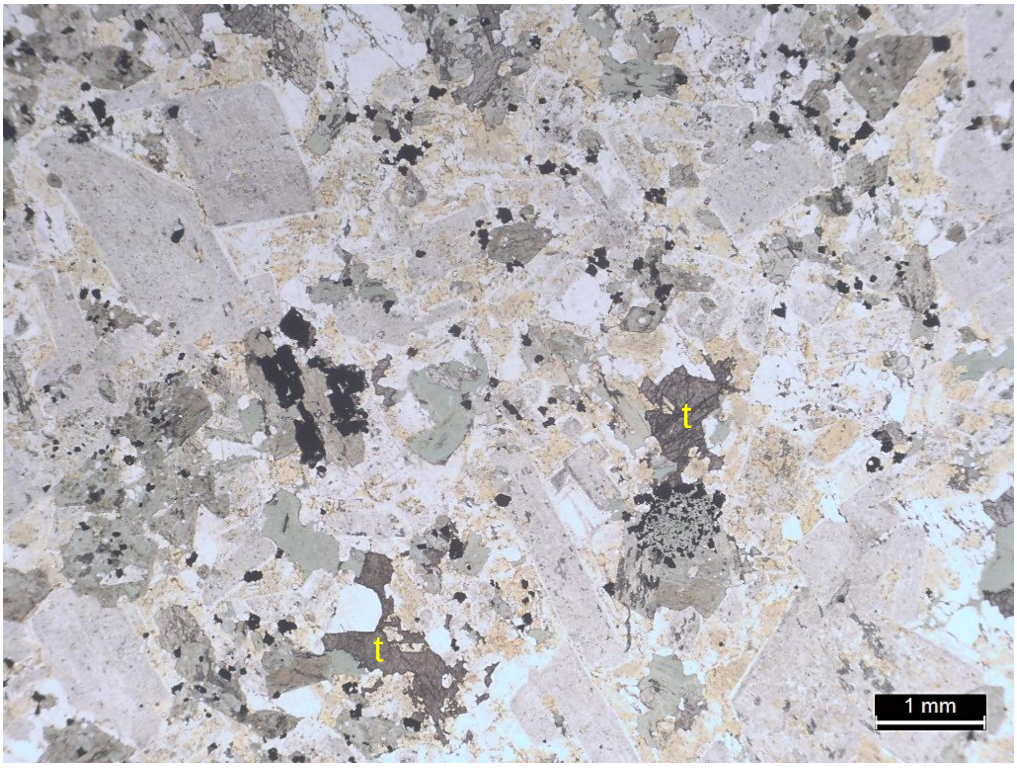
Zst21: Porphyritic tonalite (above in plane polarized light, below with crossed polarizers) with tightly packed, zoned, medium plagioclase crystals altered to sericite. Quartz is interstitial and alkali feldspar is interstitial with a very low abundance (stained yellow above). Mafic minerals are biotite largely altered to chlorite, and scattered titanomagnetite with possibly some ilmenite. At Sheepfold along contact with Nanepashemet Formation in Stoneham (Znpm; site 11166, see also Fig. Zst15).

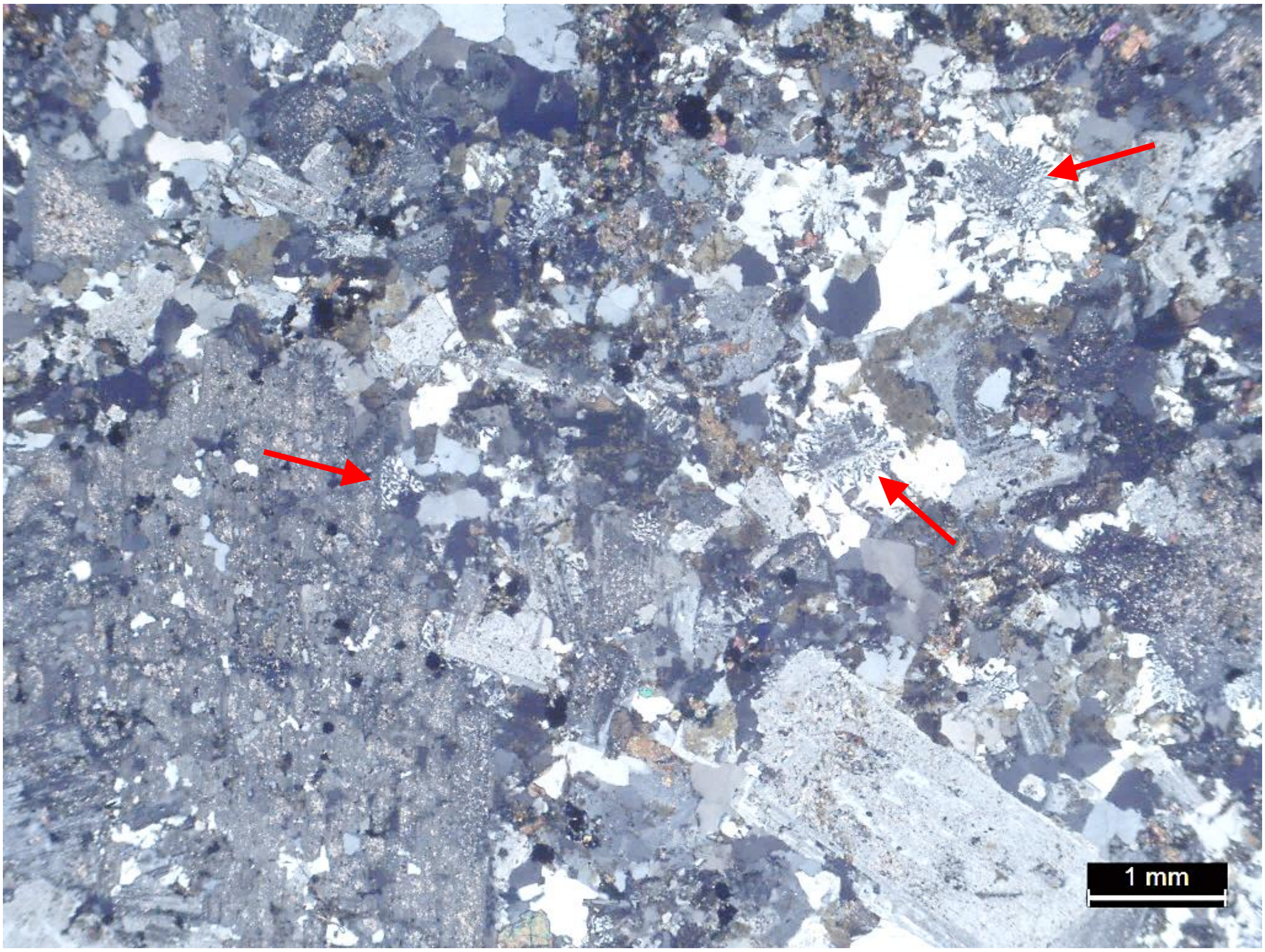




Zst22 (above): Porphyritic granodiorite (plane polarized light) with medium plagioclase phenocrysts altered to sericite. Quartz is interstitial to equant and alkali feldspar is interstitial with very low abundance. Mafic minerals are biotite altered to chlorite, and opaque minerals are titanomagnetite with possibly some ilmenite. East side of Rt. 93 at Deer Hill in Stoneham (site 10461, see also Fig. Zst6). Dark grain near top center is sphene (titanite).

Zst23 (below): Porphyritic granodiorite (in plane polarized light) with fine to medium plagioclase phenocrysts altered to sericite and having fresh rims. Quartz and alkali feldspar (stained yellow) are interstitial. Mafic minerals are altered to chlorite (green). Opaque minerals are titanomagnetite with possibly some ilmenite. Along contact with Nanepashemet Formation (Znpm) on west side of Bear Hill (site 11241). Dark high relief grains are sphene (titanite, t).





Zst24: Porphyritic granodiorite (crossed polarizers) with medium plagioclase phenocrysts altered to sericite with fresh rims. Quartz and alkali feldspar are interstitial. Mafic minerals are partly altered to chlorite. Granophyric or myrmikitic grains (arrows) occur as blobs surrounded by quartz and as interstitial grains. East flank of Winthrop Hill along Bear Hill Road in Stoneham (site 11200).

A note on distinguishing the Stoneham Granodiorite (Zst) and Winchester Granite (Zwg):

The Winchester Granite and Stoneham Granodiorite are both plutonic bodies in the northern Fells that are now known to have radiometric ages different by 14 Myr but they can be challenging to distinguish in the field. They do have distinct petrographic properties. Unlike on previous maps (LaForge, 1932; Kaye, 1980), they have been mapped as separate bodies based on compositional and textural differences as well as contact relationships with other rock units, particularly the Lynn Volcanic Complex. Here are field and petrographic differences that have been recognized:

1.The Winchester Granite has conspicuous alkali feldspar that can be dominant over or equal to plagioclase in many places. The Stoneham Granodiorite has much lower alkali feldspar percentages (usually <15% and interstitial) that are almost always less than quartz, and it is sometimes absent with plagioclase always dominating alkali feldspar and quartz.

2. The Winchester Granite tends to have a pink or orange color in the field, while the Stoneham Granodiorite appears gray unless it is iron-stained from assimilated rock, particularly the Nanepashemet Formation (Znpm). Iron-staining can give plagioclase in the Stoneham Granodiorite an orange alkali feldspar-like appearance.

3. The Winchester Granite is equigranular and has large quartz grains while quartz grains in the Stoneham Granodiorite are smaller and interstitial, except where they are xenocrysts from the Westboro Formation (Zvwq).

4. The Stoneham Granodiorite tends to have a higher mafic content, and darker color than the Winchester Granite but the two rock formations overlap in mafic mineral content depending on location. Mafic content may depend on proximity to the Nanepashemet Formation, which is a contributor of assimilated mafic materials to both formations. Contact areas of the Winchester Granite are noticeably darker and more alkali feldspar-rich than areas away from this contact.

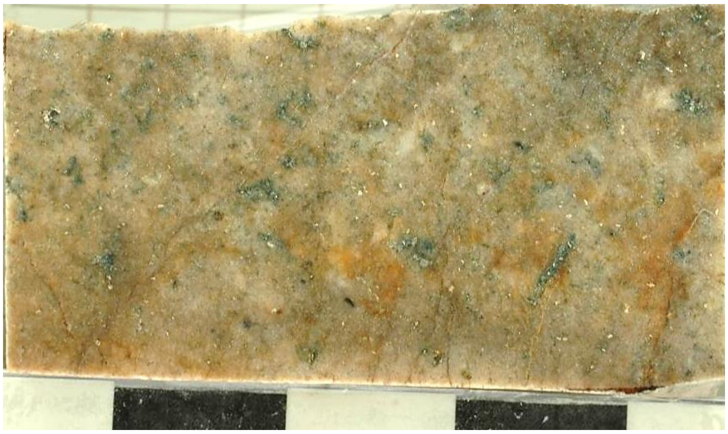
5. The Stoneham Granodiorite forms wide areas of assimilation with the Nanepashemet and Westboro Formations. It has many small porphyritic dikes and plutonic breccia that penetrate these formations with many lightly to heavily altered xenoliths. The Winchester Granite forms a much sharper intrusive contact with these older formations that is easily defined in the field, and it has few xenoliths. The Winchester Granite is finer in chill zones but is not porphyritic. The Wanapanaquin Porphyry may be a branch of the Stoneham Granodiorite, but it has not been possible to map a direct physical connection with the Stoneham across a major fault on the west side of Bear Hill (Bare Hill on older topographic maps).

6. The Winchester Granite occurs west of the major fault on the west side of Bear Hill, while the Stoneham Granodiorite is east of this fault except for the possible branch forming the Wanapanaquin Porphyry.

7. The Winchester Granite has many light-colored rhyolite dikes that do not occur in the Stoneham Granodiorite (Zst). These dikes appear to be younger than the Stoneham Granodiorite.

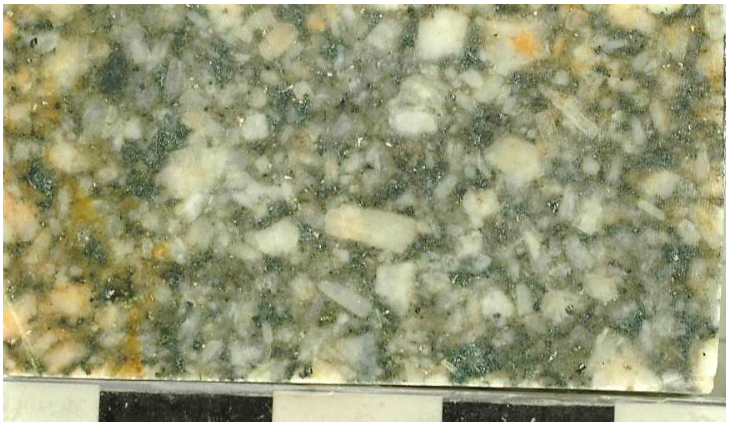
Zwap

Wanapanaquin Hill Porphyry (Neoproterozoic) – Pinkish-tan to gray aphanitic granodiorite porphyry (nearly tonalite; see Fig. Zst1 above) at the south end of Wanapanaquin Hill and along the east shore of Middle Reservoir in Stoneham (Figs. Zwap1-3). Phenocrysts are well formed, tabular plagioclase in a much finer matrix of quartz, altered mafic minerals, and very minor alkali feldspar that occurs in granophyric grains. A red to orange matrix color is mostly due to iron oxide staining. The unit is no more than 100 m across and intrudes the Nanepashemet Formation (Znpm). The relationship of the porphyry to surrounding plutonic bodies remains uncertain, however, it is compositionally like the porphyritic chill zone of the Stoneham Granodiorite (Figs. Zst2-4 and 15), and it appears to be a branch off this unit separated from the main body by faults. These units also have a similar point count mineralogy (see Fig. Zst1). The porphyry has a pinkish-orange color at first glance that suggests a connection to the Winchester Granite (Zwg), but it has a low alkali feldspar abundance, and margins of the Winchester are never porphyritic. The images below show the range of grain size and color in the unit (Figs. Zwap1-3). First recognized by Hampton (2017) and is not shown on the maps of LaForge (1932) or Kaye (1980).



Zwap1: Chill zone in dike splitting off main body of the porphyry intruding the Nanepashemet Formation (Znpm) on Wanapanaquin Hill in Stoneham (site 11144).

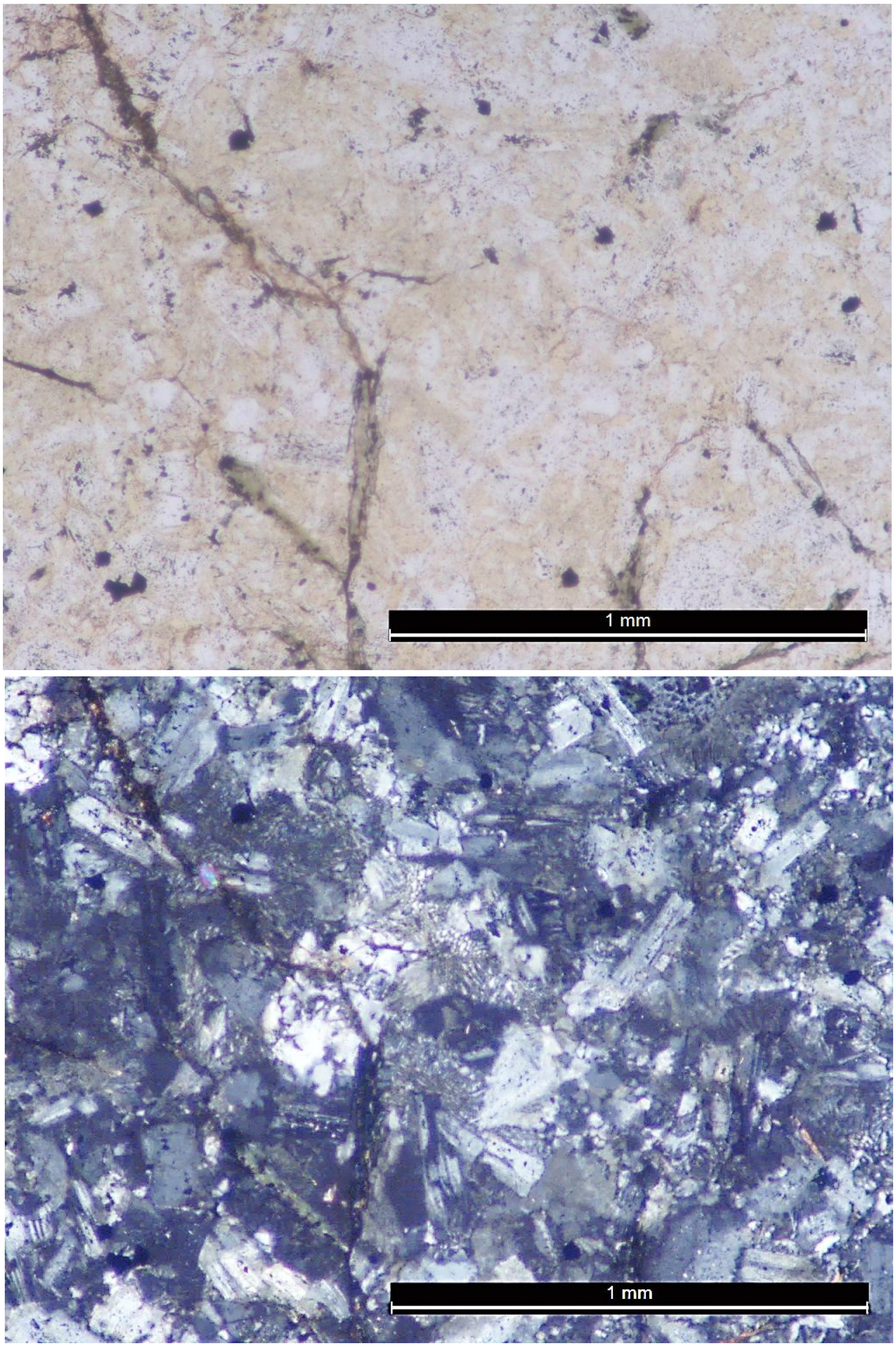
Zwap2: Fine porphyry on island along shore of Middle Reservoir at the south end of Wanapanaquin Hill in Stoneham (site 11149). The matrix gives the rock a pink color on weathered surfaces.



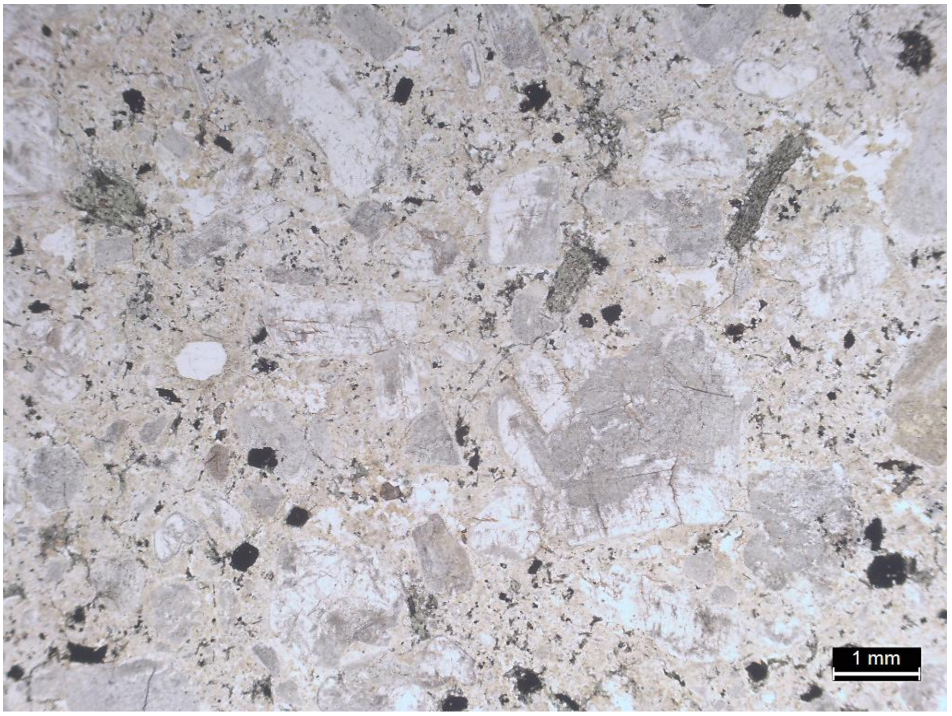
Zwap3: Porphyry in the core of the intrusion at the southern end of Wanapanaquin Hill in Stoneham (site 11156). Weathering of the matrix gives the rock an orangish-pink color on exposed surfaces (left side of image).

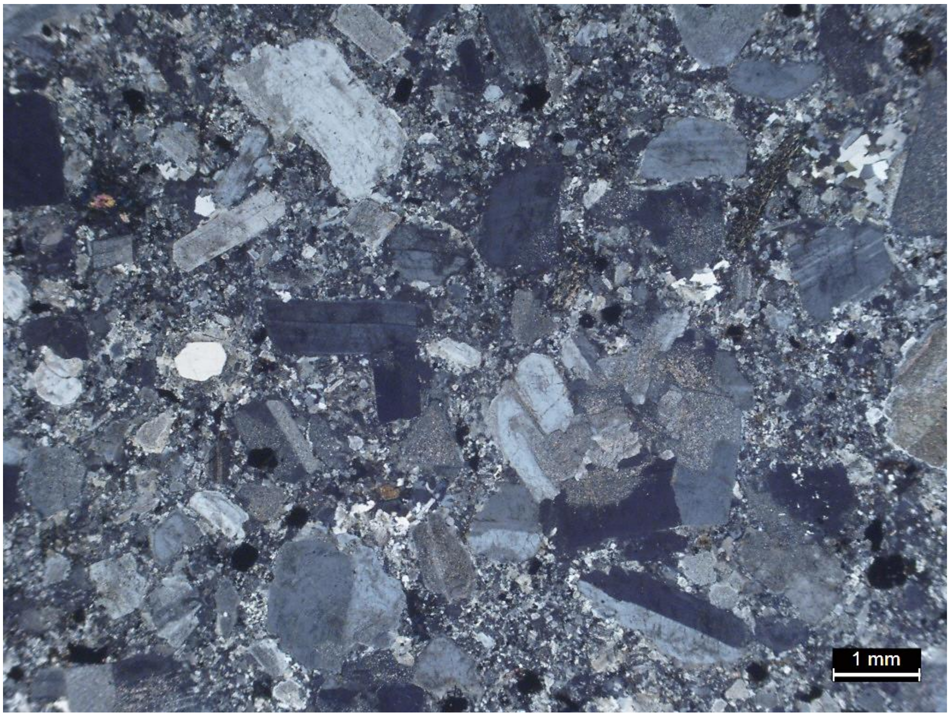
Wanapanaquin Hill Porphyry (cont.)

Thin section description – Porphyritic granodiorite to tonalite with medium plagioclase phenocrysts (Figs. Zwap4-6). Plagioclase crystals are up to 3 mm and have cores altered to sericite and fresh rims (Figs. Zwap5-6). The next most abundant mineral is quartz that is mostly interstitial with occasional euhedral crystals (Figs. Zwap4-6). Alkali feldspar is secondary to quartz and occurs in interstitial granophyric grains with quartz. Mafic minerals are biotite altered to chlorite (Fig. Zwap4) and hornblende altered to chlorite and epidote (Figs. Zwap5-6). Scattered throughout is fine opaque titanomagnetite, hematite, and possibly some ilmenite. Sphene (titanite) is an infrequent accessory mineral.

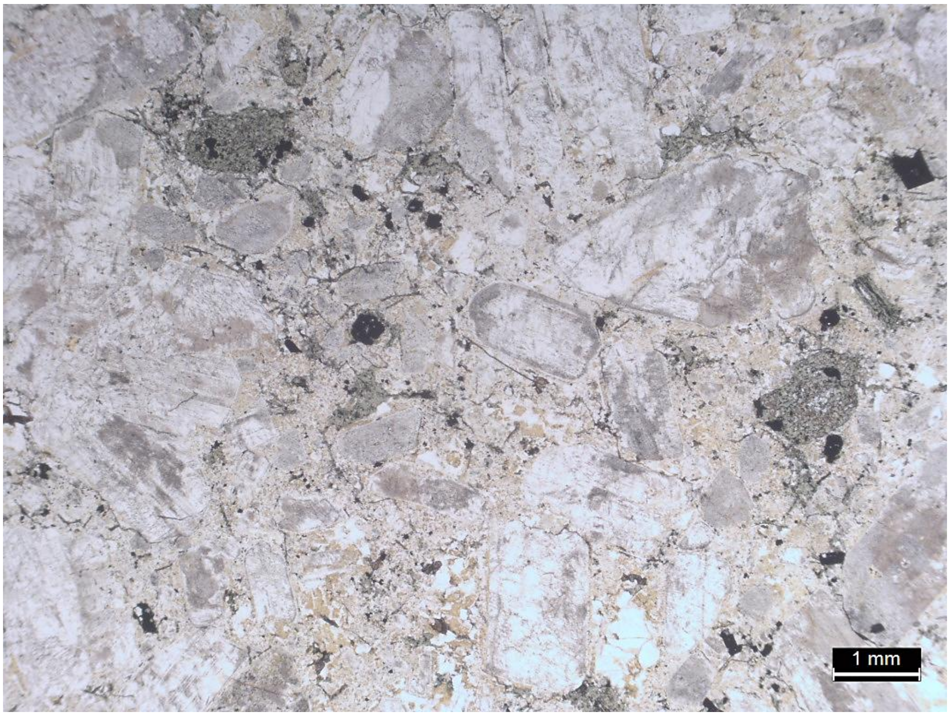


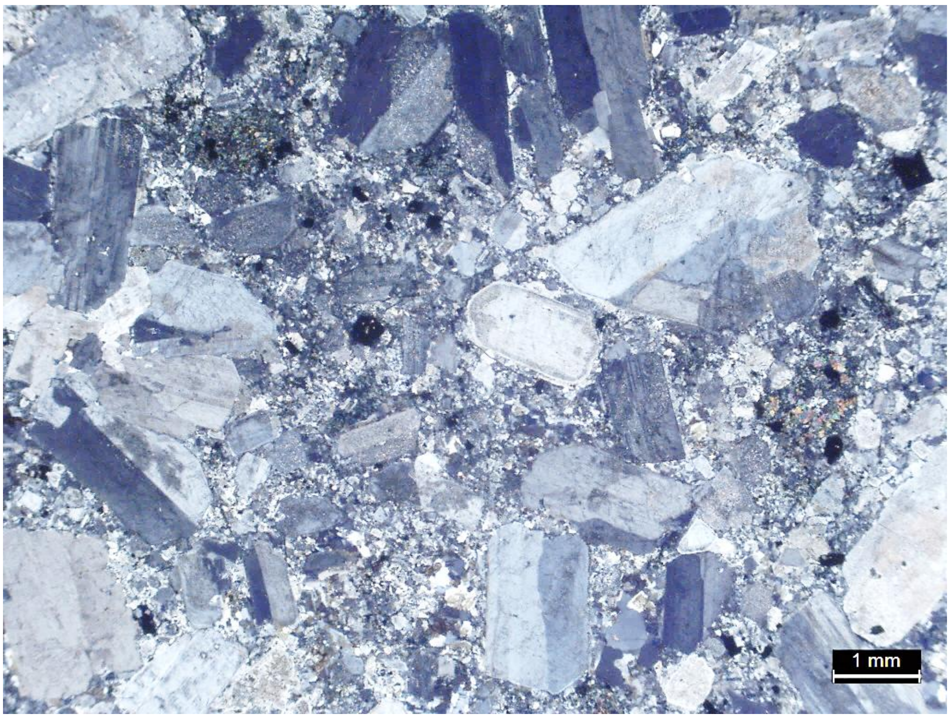
Zwap4: Porphyritic granodiorite (above left in plane polarized light, below with crossed polarizers) with medium to fine plagioclase phenocrysts that have cores altered to sericite and fresh rims. Other minerals are interstitial quartz and granophyric grains of quartz and alkali feldspar (faint yellow stain color above). Mafic minerals are biotite altered to chlorite and opaque oxide and scattered opaque grains that are titanomagnetite, hematite, and possibly some ilmenite. Dike splitting off main body of the porphyry intruding the Nanepashemet Formation (Znpm) on Wanapanaquin Hill in Stoneham (site 11144). See Fig. Zwap1 for cut rock view.





Zwap5: Porphyritic granodiorite (above in plane polarized light, below with crossed polarizers) with medium to fine plagioclase phenocrysts that have cores altered to sericite and fresh rims. Other minerals are interstitial quartz and granophyric grains of very fine quartz and alkali feldspar (faint yellow stain color above). Note isolated euhedral quartz grain on left. Mafic minerals are hornblende altered to chlorite and epidote and scattered opaque grains that are titanomagnetite with possibly some ilmenite. Shore of middle Reservoir in Stoneham (site 11149). See Fig. Zwap2 for cut rock view.



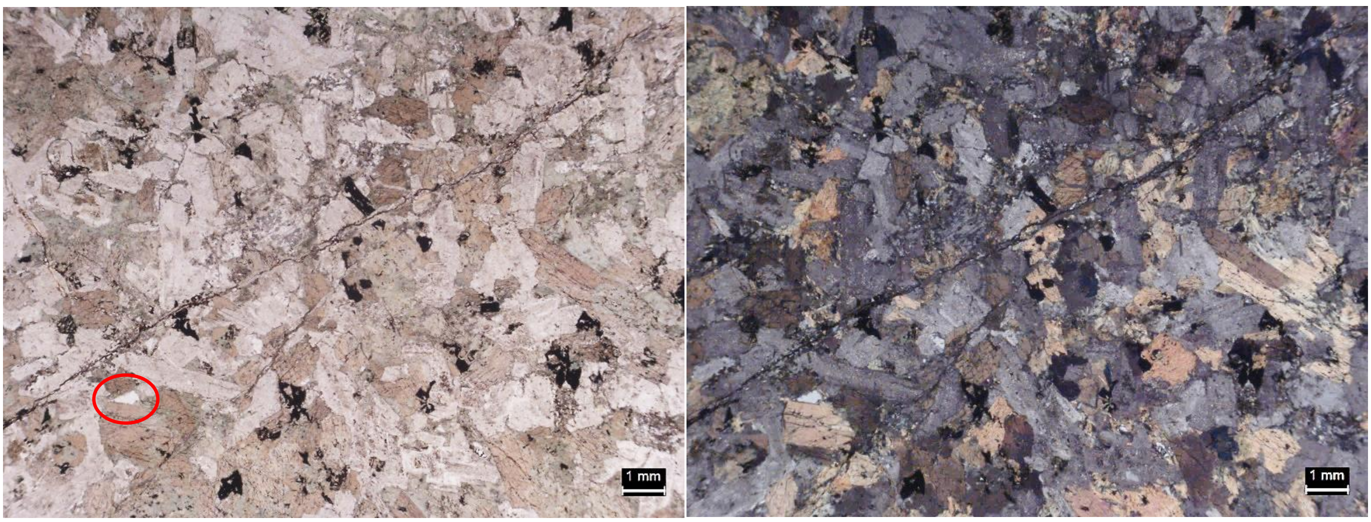


Zwap6: Porphyritic tonalite (above left in plane polarized light, below with crossed polarizers) with medium to fine, twinned plagioclase phenocrysts that have cores altered to sericite and fresh rims. Other minerals are interstitial quartz and granophyric grains of quartz and alkali feldspar (faint yellow stain color above). Mafic minerals are hornblende altered to chlorite and epidote and scattered opaque grains that are titanomagnetite with possibly some ilmenite. South end of Wanapanaquin Hill in Stoneham (site 11156). See Fig. Zwap3 for cut rock view.

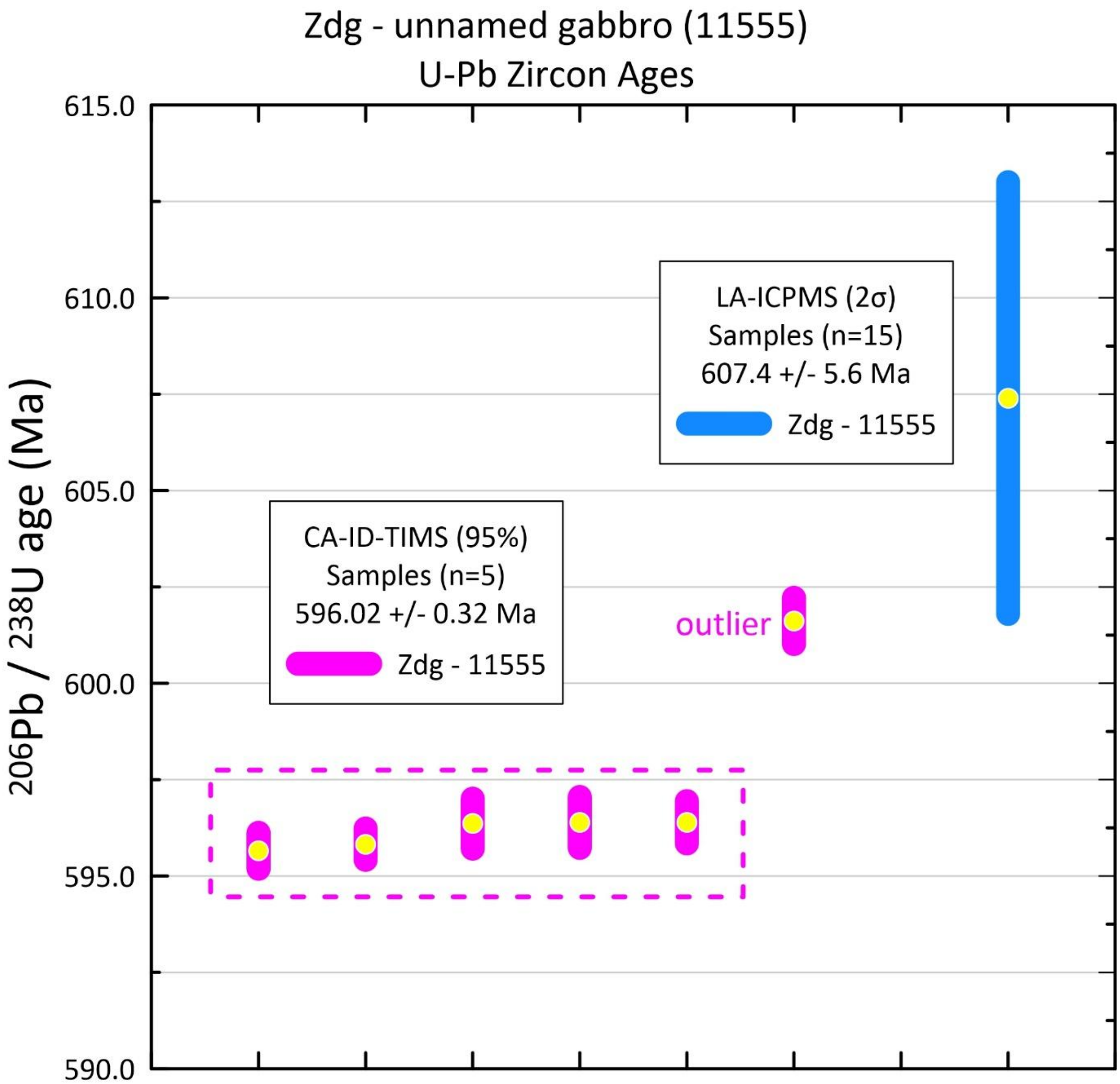
Zdg **Diorite-Gabbro (Neoproterozoic)** – Previously unrecognized, greenish-gray (5G 4/1) diorite/gabbro (Figs. Zdg1-2) in the southwestern Fells. Composed of 40-50% zoned euhedral plagioclase with the remainder of the rock composed of hornblende that is partly altered to chlorite and opaque oxide (Fig. Zdg3). Point count data and normalized plot is on Figure Zrhp1 for comparison with Rams Head Porphyry (see Appendix 1-E). Plagioclase is partly altered to sericite. Skeletal titanomagnetite or ilmenite, and sparse interstitial sphene (titanite) are accessory minerals. This unit has a single lenticular outcrop area (150 x 30 m) west of South Reservoir. It intrudes the Westboro Formation (Zvwq) on its north side and is bounded on its south by an E-W trending fault. The unit contains Westboro xenoliths (Fig. Zdg2). Fractures and abundant veins in the diorite suggest that it is cut by the fault to the south. Except for rare interstitial quartz grains, quartz and alkali feldspar are absent, making the unit difficult to associate with the felsic intrusive bodies in the Fells. The quartz may be recrystallized xenocrysts from the adjacent quartzite. This unit occurs as an isolated outcrop of a subsurface diorite/gabbro but has a feldspar chemistry like felsic plutonic units in the Fells. It most resembles the Rams Head Porphyry (Zrhp; see Fig. Zrhp1). A new U-Pb zircon age for the unit is 596.02 $\pm$ 0.32 Ma (5 zircons, CA-ID-TIMS, Fig. Zdg4).

Zdg1: Cut rock slab of diorite west of South Reservoir in Medford (site 11267).

Zdg2: Quartzite xenolith (arrow) in diorite near its north side contact with the Westboro Formation (site 11369).



Zdg3: Thin section view in plane polarized light (left) and same image with crossed polarizers (right) of diorite west of South Reservoir in Medford (site 11267). Tan to brown grains are hornblende. In the lower left, the bright grain is rare quartz (circle).



Zdg5: Individual CA-ID-TIMS U-Pb ages (in dashed box) used to calculate the mean age of the unnamed diorite/gabbro in the southwest Middlesex Fells in Medford (Zdg, site 11555). An additional measurement (>600 Ma) is considered an outlier. Shown for comparison is a far less precise LA-ICPMS U-Pb age from the same sample. For comparison a CA-ID-TIMS U-Pb age for the Rams Head Porphyry (Zrhp) is given in the description of the Rams Head (Fig. Zrhp5).

Zlwg

Lawrence Woods Granophyre (Neoproterozoic) – Porphyritic granophyre in the southern Fells and through North Medford. Similar rocks further east in Malden, Wakefield, Lynn, and Saugus (Smith and Hon, 1984; Smith,1985) are included with this unit. In all places this unit is a 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) monzogranite granophyre (Fig. Zlwg1) with phenocrysts of plagioclase and hornblende. The unit's granophyric and micrographic alkali matrix heavily stains for potassium and gives the unit its red to pink color. Chill zones are very fine-grained, porphyritic, and distinctly reddish-orange to pink (Figs. Zlwg2-4) where the granophyre intruded the Wakefield Formation (Zlvc and Zlvx) of the Lynn Volcanic Complex and the Spot Pond Granodiorite (Zsg) in the southern Fells. The granophyre is progressively coarser to the south away from these contacts (Figs. Zlwg5-9). It contains xenoliths from the Wakefield Formation (Zlvx) west of Middle Hill (Zlwg10), has a large tonalitic inclusion of the Rams Head Porphyry (Zrhp) in northeast Lawrence Woods (Fig. Zlwg11), and has a chilled margin against the Rams Head at the entrance to Medford High School. These field relationships contradict the new radiometric ages for the Lawrence Woods and Rams Head, which is discussed below. These subvolcanic units appear to be phases of the same general period of magmatic activity associated with the Lynn Volcanic Complex. The granophyre is cataclastic along a major NW-SE trending fault on South Border Road (Fig. Zlwg12).

On previous maps the Lawrence Woods Granophyre in the southern Fells was mapped as part of the Dedham Granodiorite (LaForge, 1932; Kaye, 1980; Smith and Hon, 1984; Smith, 1985; Hepburn and others, 1993). Bell (1948) classified it as the "porphyritic micrographic granodiorite" and "micrographic granodiorite" phases of the Dedham. Kaye (1980) mapped the finer chilled margin as part of crystal tuff of the Boojum Rock Tuff of the Lynn Volcanic Complex of this map, likely because they were difficult to distinguish in the field. Detailed mapping here shows a different map configuration. Granophyre was recognized by Smith and Hon (1984) and Smith (1985) in Malden and further east (but not in the southern Fells) as a subvolcanic facies of the Lynn Volcanic Complex as is inferred across the southern Fells on the current map. Current mapping reveals a sharp contact of the chilled margin with the Spot Pond Granodiorite (Dedham Complex) and the Lynn Volcanic Complex in the southern Fells, and the unit coarsens away from these contacts to the south. The Lawrence Woods Granophyre displays a variety of outcrop appearances (color and grain size), and it is possible that it is composed of several closely related granophyric plutonic bodies that have indistinguishable ages defining a "composite pluton" (Wones and Goldsmith, 1991). During mapping east of the Fells, all alkaline granophyric, subvolcanic units like the Lawrence Woods, apparently associated with the Lynn Volcanic Complex (Zlwg13-14), were grouped as part of the Lawrence Woods Granophyre.

Means for new maximum U-Pb CA-ID-TIMS zircon ages in this unit range from 596.8-596.5 Ma with some older individual ages. The spread of ages is partly due to older inherited zircon crystals, but prolonged crystallization may also be a factor (Fig. Zlwg15). At Elm Street (site 10478 in North Medford near Wrights Pond) there appear to be two separate populations (3 crystals each). The older population has an age of 598.13 $\pm$ 0.27 Ma and may be inherited or influenced by prolonged crystallization. The younger population has an age of 596.77 $\pm$ 0.54 Ma. A second site chosen for U-Pb zircon CA-ID-TIMS analysis at the southeast corner of Pine Hill along Rt. 93 (site 10516) also has a spread in ages. The 3 youngest zircons have a mean of 596.50 $\pm$ 0.53 Ma. Of three older zircons, one may have experienced prolonged crystal growth while the remaining two appear to have inherited ages at greater than 609 Ma (Fig. Zlwg15). The ages at both sites are consistent in terms of their means and distribution pattern and clearly the crystallization of the Lawrence Woods is complex. However, the younger age means from both sites confirm an age significantly younger than the Spot Pond Granodiorite (Zsg) and Winchester Granite (Zwg) in the Dedham Complex (Fig. Zlwg15). The youngest ages discussed above give the impression that this unit may be older than the Rams Head Porphyry (Zrhp), which violates field relationships. However, the younger zircon ages in both units are statistically indistinguishable while potential prolonged crystallization in the Lawrence Woods makes an age distinction inconclusive.

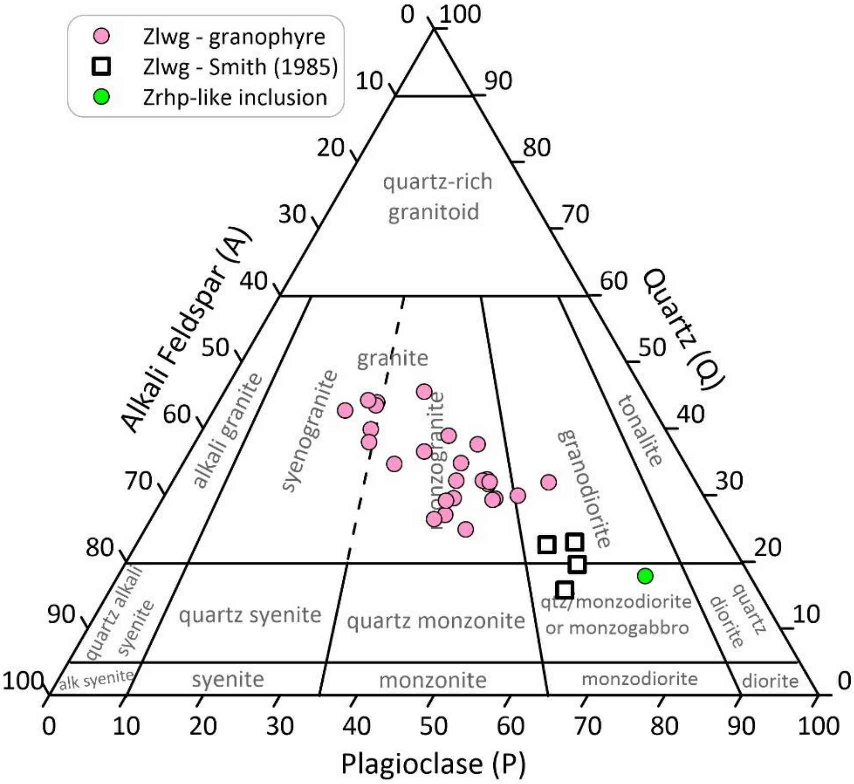
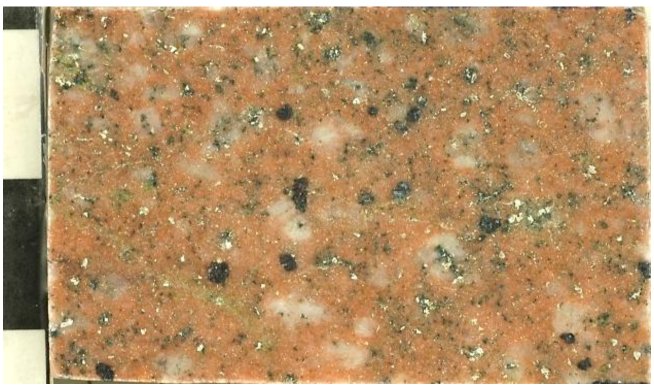
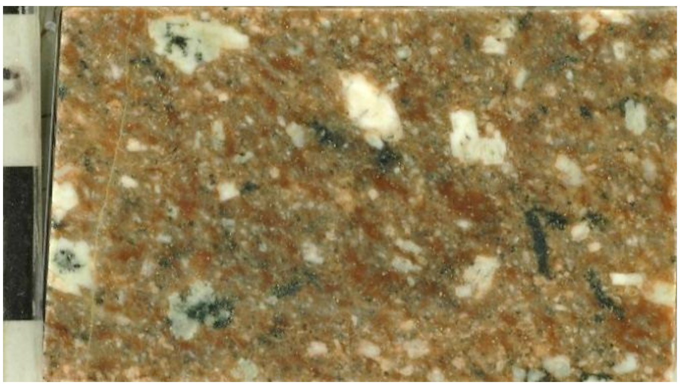


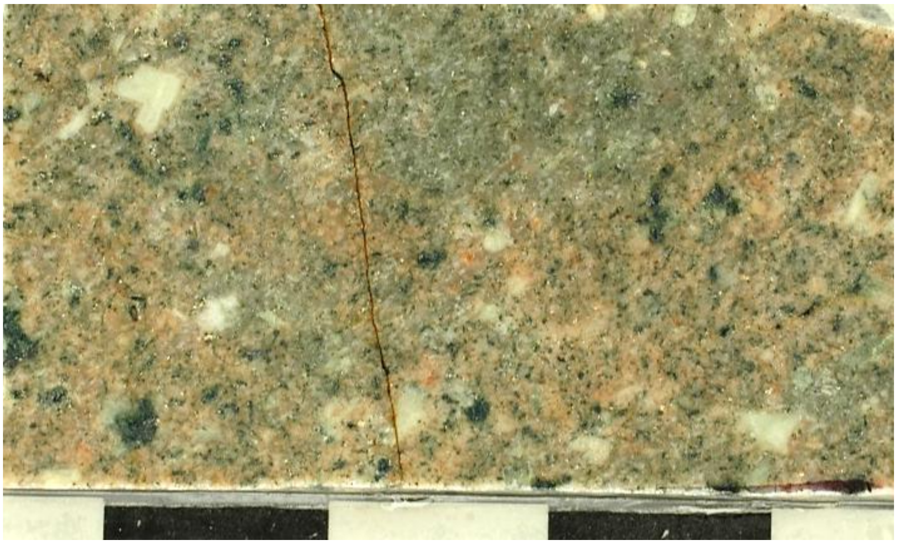
Figure Zlwg1. Normalized Quartz-Alkali Feldspar-Plagioclase (QAP) plot of point counts from the Lawrence Woods Granophyre. To obtain a representative composition for placing granophyric grains on the QAP plot they were tabulated as ½ Q and ½ A. This tends to enrich them in quartz as compared to norm %s calculated from XRF data. For comparison is point count data from Smith (1985) in which point quartz and alkali feldspar counts were collected from the granophyric groundmass. Most point count samples are monzogranite. An inclusion in the Lawrence Woods that is like the Rams Head Porphyry is also shown for comparison (see Fig. Zlwg11 below). Point count data are in Appendix 1-D.



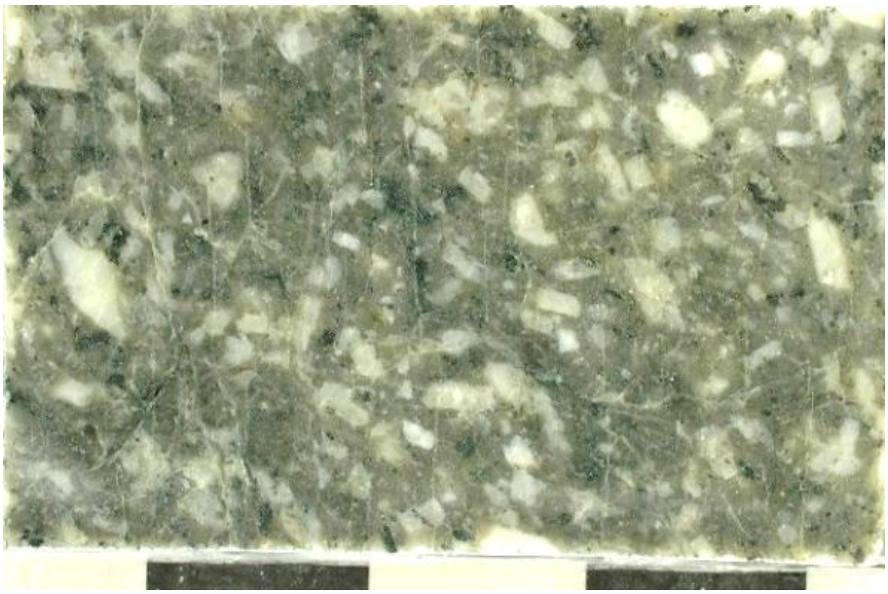
Zlwg2: Cut rock slab of chill zone along contact with volcaniclastic unit in the Lynn Volcanic Complex (Zlvc) west of Boojum Rock in Medford (site 10255).



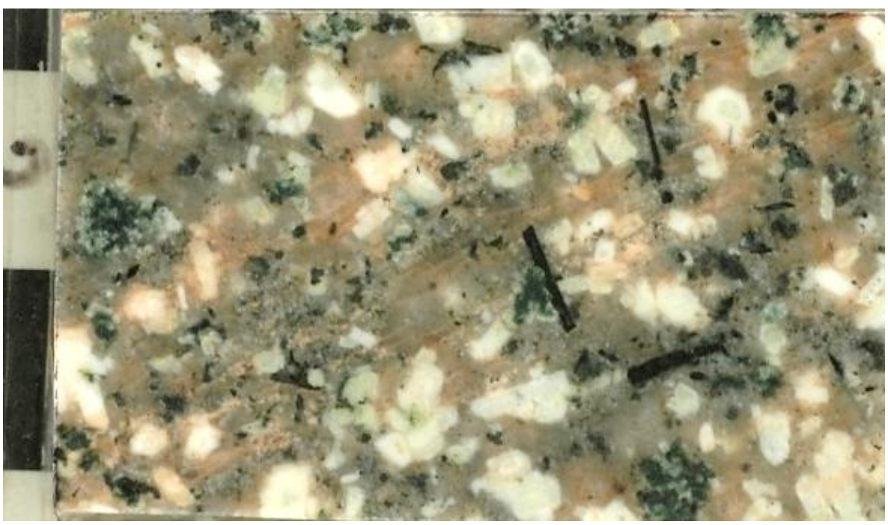
Zlwg3: Cut rock slab of chill zone along contact with Lynn Volcanic Complex (Zlvx) at the Wrights Pond Dam in Medford (site 10480).



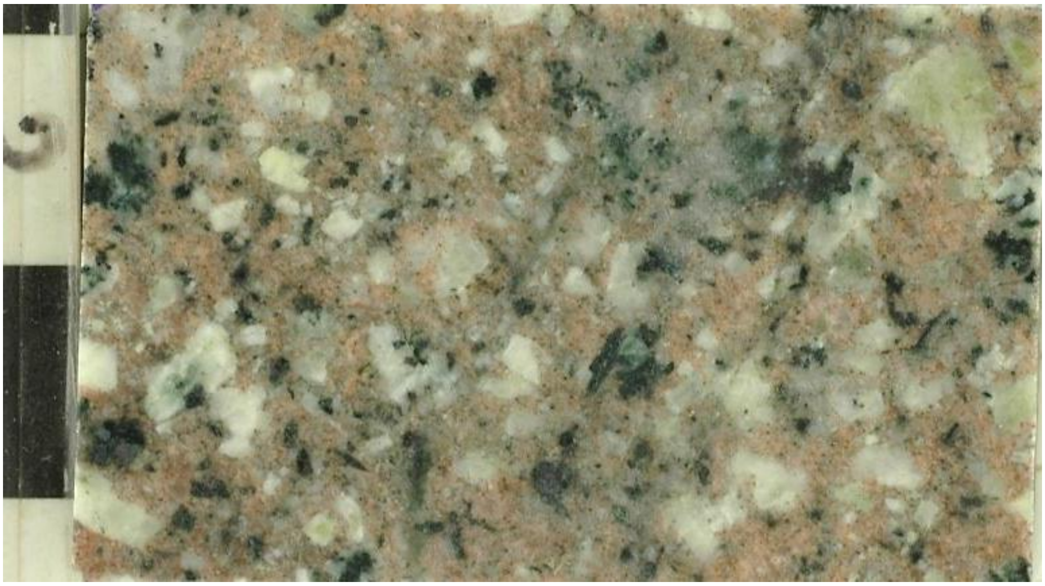
Zlwg4: Cut rock slab of fine-grained chill zone at contact with Spot Pond Granodiorite in Lawrence Woods in Medford (site 11002).



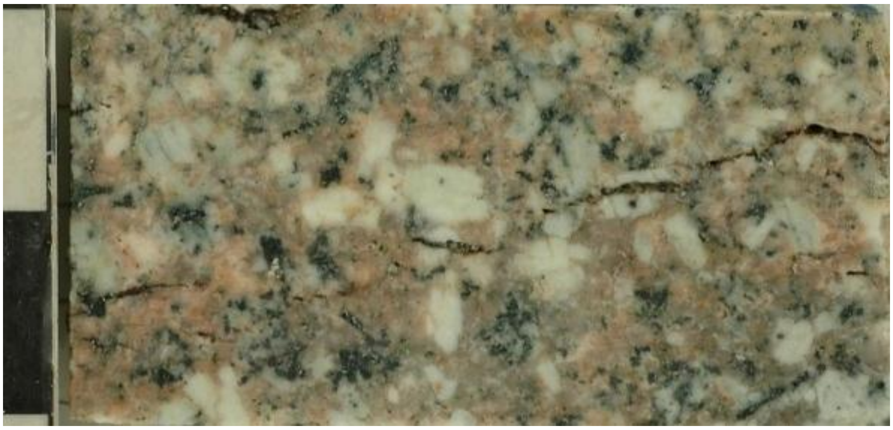
Zlwg5: Cut rock slab of tannish-gray phase of porphyritic granophyre on northern Middle Hill in Medford (site 10632).



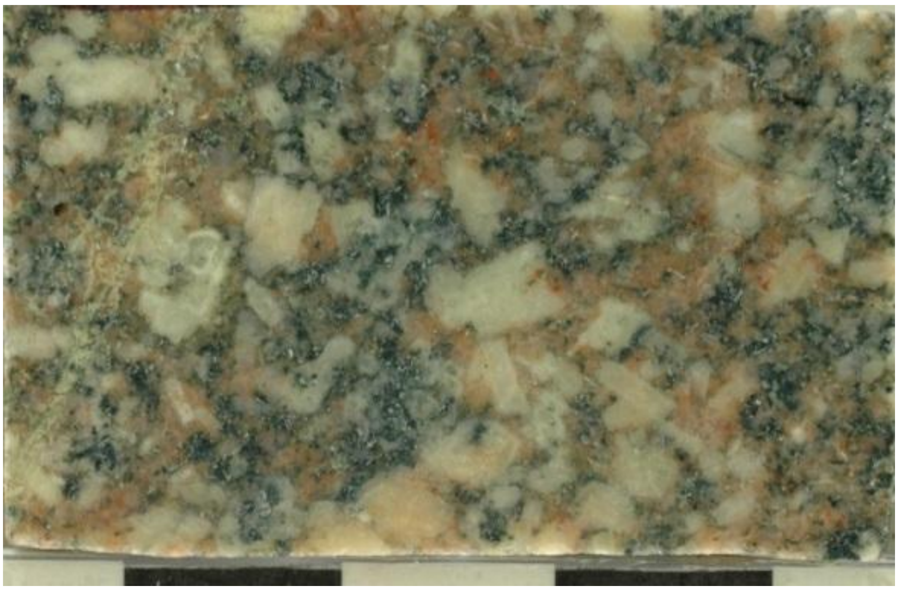
Zlwg6: Cut rock slab of coarse porphyritic phase of granophyre with needle-like hornblende on Elm Street in Medford (site 10478). U-Pb zircon ages (CA-ID-TIMS) for two populations of zircons (3 crystals each) were obtained at this site: 598.13 $\pm$ 0.27 Ma and 596.77 $\pm$ 0.54 Ma (see U-Pb zircon age discussion above and Fig. Zlwg15).



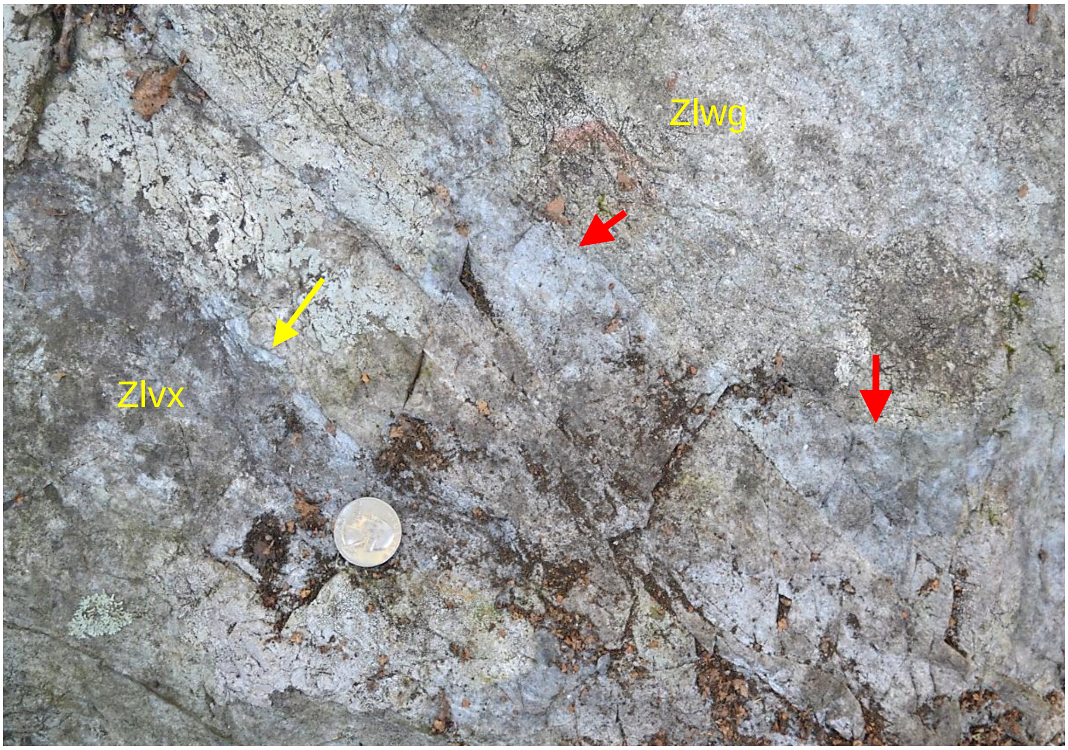
Zlwg7: Cut rock slab of moderately coarse porphyritic granophyre with hornblende along Rt. 93 at southern Pine Hill in Medford (site 10516). U-Pb zircon ages (CA-ID-TIMS) for two populations of zircons (3 crystals each) were obtained at this site: 596.50 ± 0.53 Ma and much older crystals (see U-Pb zircon age discussion above and Fig. Zlwg15).



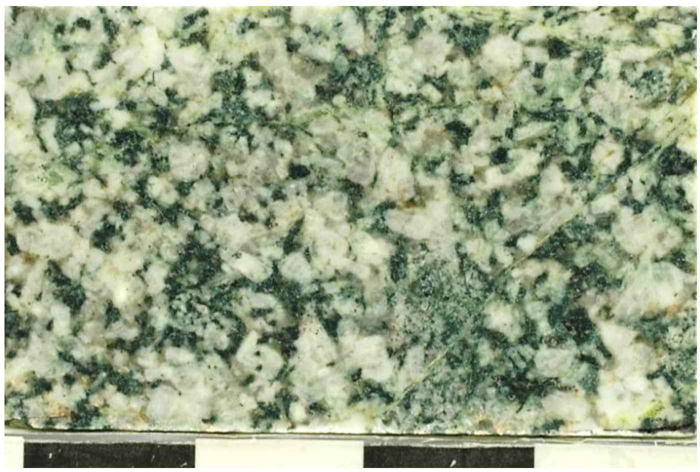
Zlwg8: Cut rock slab of moderately coarse porphyritic granophyre on Fulton Street in Medford (site 864BN). This sample is altered in an area of dense fractures. It appears identical to the rock in Fig. Zlwg7.



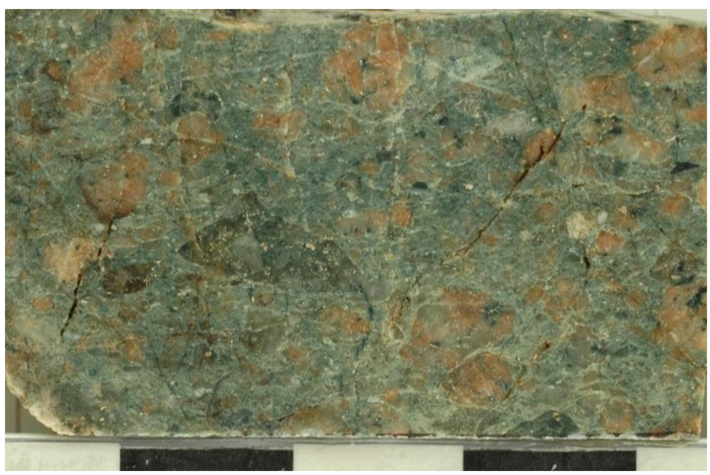
Zlwg9: Cut rock slab of coarse porphyritic granophyre in northeast Lawrence Woods in Medford (site 10981).



Zlwg10 (above): Gray crystal to vitric tuff in the Lynn Volcanic Complex (Zlvx) at an irregular contact (yellow arrow) with porphyritic granophyre of the Lawrence Woods Granophyre (Zlwg) west of Bellevue Pond and Middle Hill in Medford (site 10619). Red arrows point to tuff inclusions in porphyry. Quarter for scale.



Zlwg11 (right): Cut rock slab from a small area that lacks a granophyric texture and has very little alkali feldspar in northeast Lawrence Woods in Medford (site 10979). This rock appears to be an inclusion of the Rams Head Porphyry (Zrhp). This conflicts with radiometric age means from both units, but they are statistically indistinguishable (see U-Pb zircon age discussion above and Fig. Zlwg15 below).



Zlwg12 (right): Heavily fractured, cataclastic Lawrence Woods Granophyre (Zlwg) along South Border Road in Medford (site 10980) near bend in N-S trending fault. Orange fragments are pieces of the granophyre.

Figure Zlwg13-14. Outcrop with rock hammer for scale (left) and cut rock sample (right) of rhyolitic granophyric intrusion on Spring Street in Wakefield (site 11635). Note reddish-gray to gray color and cumulophyric plagioclase. Dark inclusions in both images are basalt from the local basalt facies (Zlbf) of the Wakefield Formation.

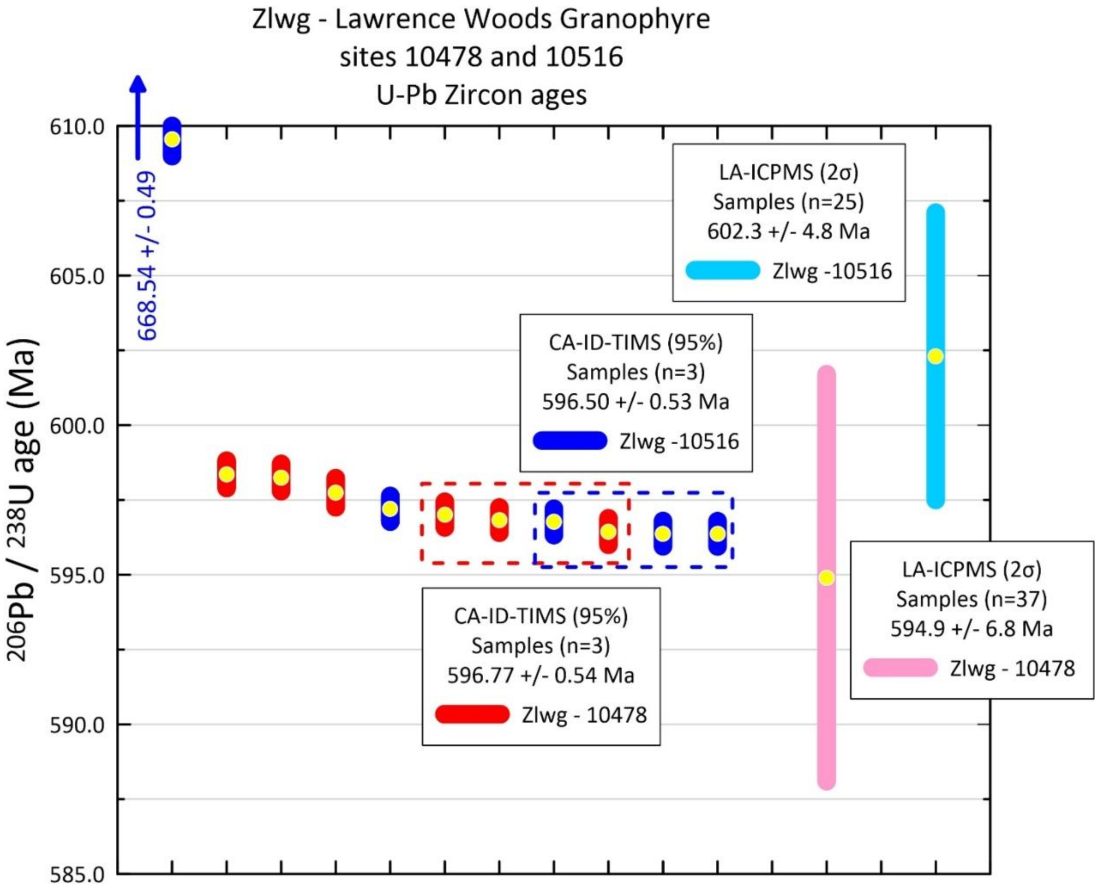
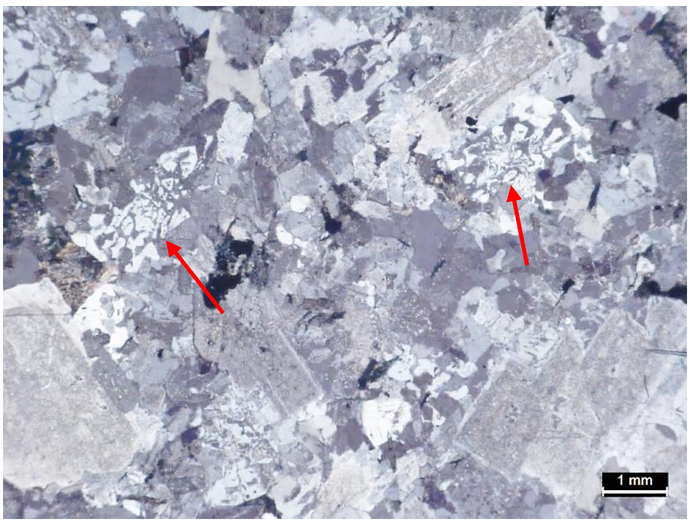


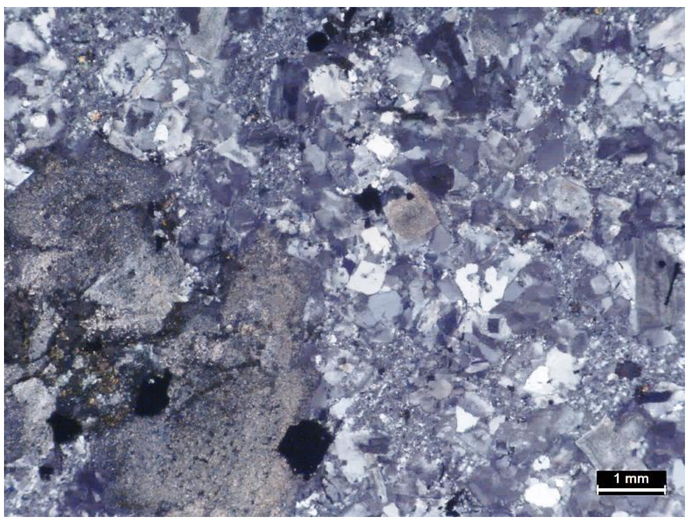
Figure Zlwg15. Individual CA-ID-TIMS U-Pb zircon ages from the Lawrence Woods Granophyre at sites 10478 on Elm Street in North Medford (red) and site 10516 at the southeast corner of Pine Hill along Rt. 93 in Medford (blue). Two outlier ages from site 10516 are shown at the graph's margin, one at upper left and the other off the graph. This unit has a wide distribution of ages that provide evidence of delayed crystallization or inheritance. The 3 youngest ages from each site (enclosed by dashed line boxes) were chosen for maximum age calculations. On the right for comparison are less precise LA-ICPMS U-Pb ages for the two sample sites.

Lawrence Woods Granophyre (cont.)

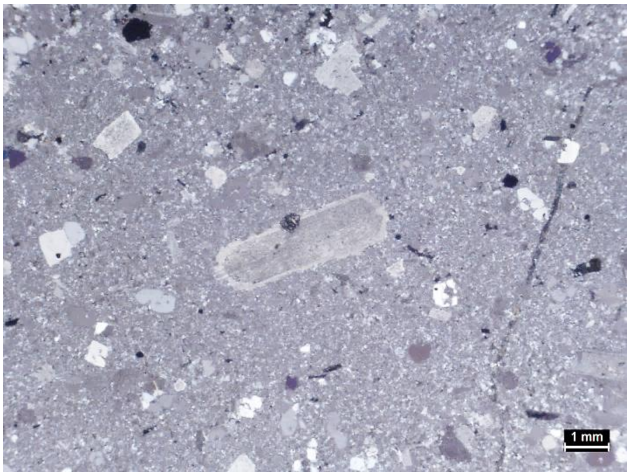
Thin section description – Gray to reddish-orange porphyritic and granophyric monzogranite (Fig. Zlwg1) with plagioclase phenocrysts that have moderate to no alteration (all images below; see also cut rock images above for porphyritic character of unit) and hornblende phenocrysts. This formation is unlike any other in the Middlesex Fells in that it contains abundant grains and interstitial areas of granophyric texture (Figs. Zlwg 16-17) in ***all*** exposures while granophyric textures are sparse or non-existent in other plutonic units. The fine grain size and granophyric texture of the matrix indicate that the unit is subvolcanic. In contact areas or chill zones, the granophyric texture manifests itself as ultrafine granophyric grains in a very fine to fine patchy matrix texture that appears to be granular to fine equigranular (Figs. Zlwg18-19). In coarser areas, granophyric grains are up to 3 mm (Figs. Zlwg20-21) and are often found as growths on plagioclase (Fig. Zlwg22) and hornblende (Fig. Zlwg23), or they can be separate as micropoikilitic to myrmikitic grains. When coarser the granophyric grains can have a graphic texture (Fig. Zlwg16). The granophyric grains are quartz and alkali feldspar, as revealed by potassium staining (Fig. Zlwg24), and the alkali feldspar is responsible for the pinkish- to reddish-color of the rock's matrix in hand specimens and outcrops. Coarser parts of the rock formation have plagioclase phenocrysts up to 6 mm (Figs. Zlwg17, 25-26 and 28) with interstitial coarse to fine granophyric grains as well as larger interstitial intergrowths of alkali feldspar and quartz (Figs. Zlwg24-25, 29-30). Quartz crystals up to 2 mm occur in all the rock types above and are rounded and often embayed (Figs. Zlwg17-18). These grains may be partly resorbed primary crystals or xenocrysts. Mafic minerals are mostly hornblende (Figs. Zlwg23-24) with minor biotite. In most cases, hornblende is altered to chlorite and minor magnetite and epidote (Figs. Zlwg24, 27-28), while biotite is altered to chlorite and magnetite. Separate equant opaque grains up to 1 mm are either titanomagnetite or ilmenite (Fig. Zlwg27). Accessory minerals include patches of granular and dirty epidote, mostly formed by alteration of other minerals, but there are also infrequent well crystallized, single, interstitial epidote grains up to 3 mm (Figs. Zlwg25, 26 and 28). Associated with epidote in one case are radiating zoisite crystals (Fig. Zlwg24). Another accessory mineral is sphene (titanite; Fig. Zlwg29), which is not abundant but is likely altered in most places where it could not be identified.

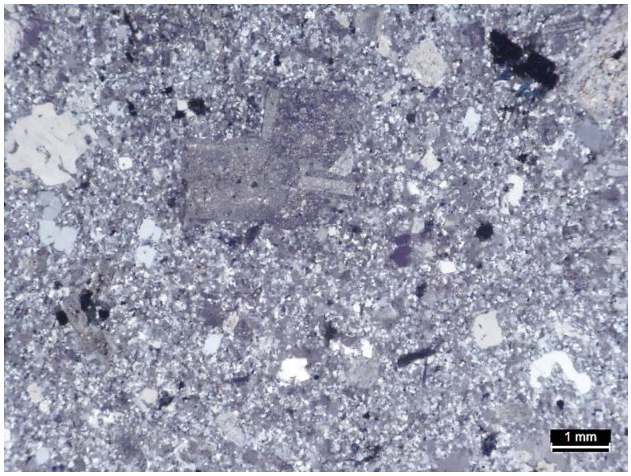


Zlwg16: Porphyritic granophyre with large euhedral plagioclase phenocrysts and relatively coarse graphic granophyric grains (arrows) west of Boojum Rock (site 10253). Plagioclase grains are lightly altered with thin unaltered rims. Thin section with crossed polarizers.



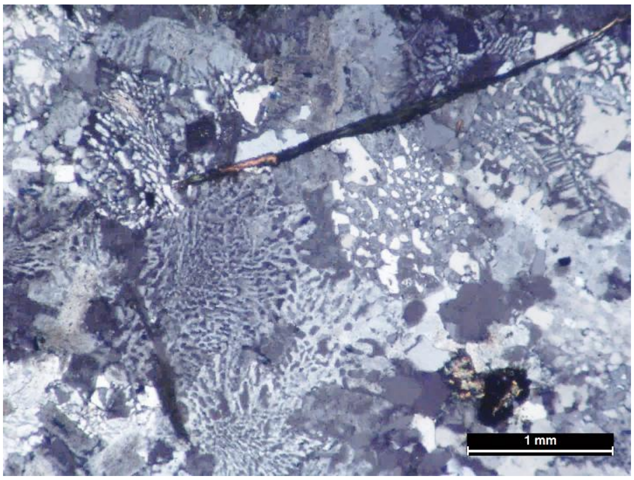
Zlwg17: Porphyritic granophyre with large altered, euhedral plagioclase phenocrysts and a patchy texture of equigranular feldspar and embayed and rounded quartz grains south of Pine Hill on South Border Road (site 10488). Thin section with crossed polarizers. Granophyric grains are very fine.

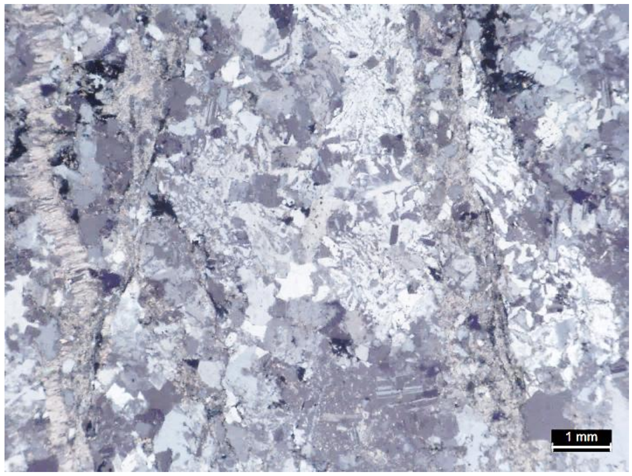




Zlwg18: Porphyritic granophyre with euhedral plagioclase phenocrysts and rounded and embayed quartz grains in a very fine patchy granophyric matrix in the chill zone at the Wrights Pond Dam (site 10480). Plagioclase phenocrysts are lightly altered with fresh rims. Thin section with crossed polarizers. See Fig. Zlwg3 for cut rock view.

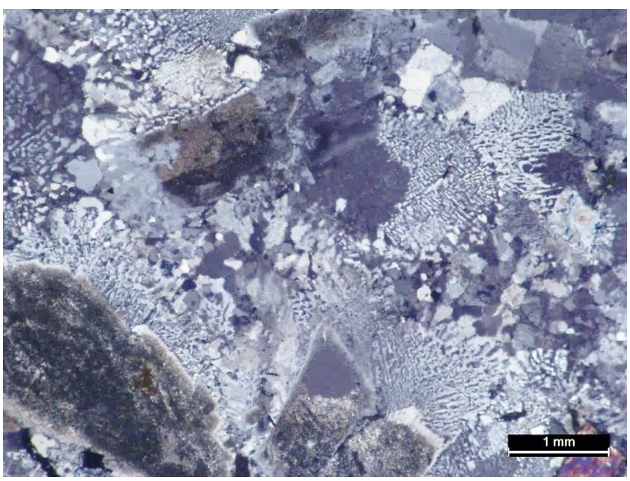
Zlwg19: Porphyritic granophyre with euhedral plagioclase phenocrysts and rounded and embayed quartz grains in a fine patchy granophyric matrix at the southern end of Pine Hill (site 882BN). Thin section with crossed polarizers.

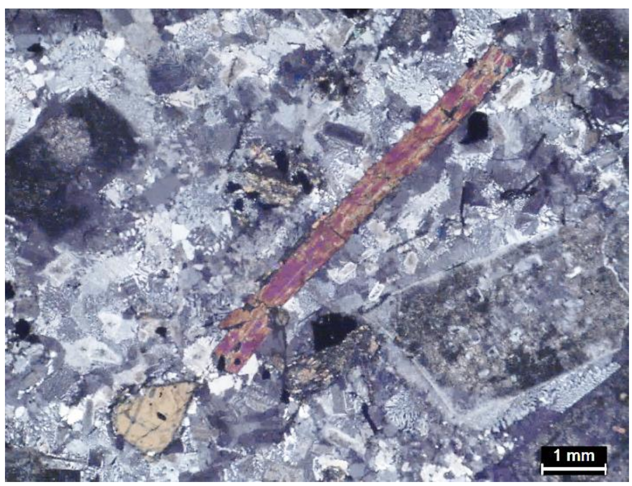




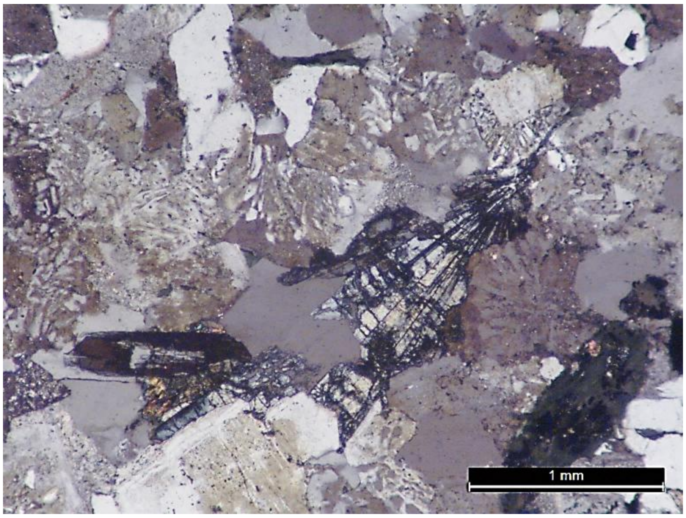
Zlwg20: Granophyric grains in porphyritic granophyre along Elm Street near Wrights Pond (site 10478). In lower right is magnetite and epidote. Thin section with crossed polarizers. See Fig. Zlwg7 for cut rock view.

Zlwg21: Porphyritic granophyre with coarse graphic to myrmikitic granophyric grains west of Boojum Rock (site 10234). Thin section with crossed polarizers.

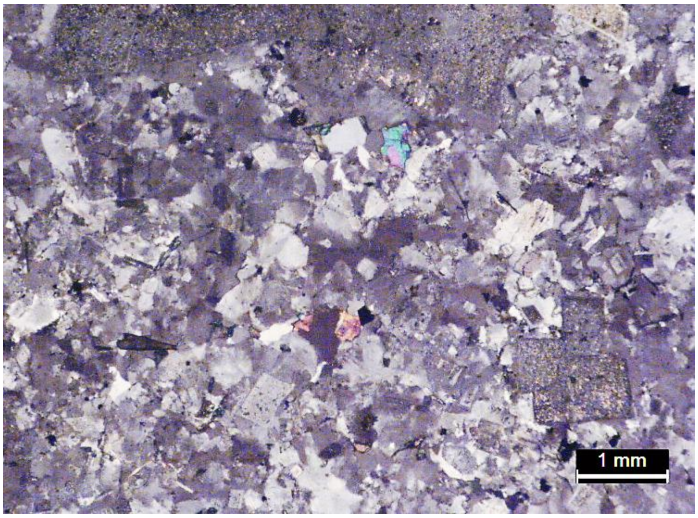




Granophyric grains in porphyritic granophyre along Elm Street near Wrights Pond (site 10478). See Fig. Zlwg5 for cut rock view. **Zlwg22** (left): Myrmikitic granophyric grains grown on plagioclase. **Zlw23** (right): Granophyric grains grown on hornblende and plagioclase.



Zlwg24: Granophyric grains in porphyritic granophyre in southeast Lawrence Woods (site 10990). The faint yellow color in the granophyric grains is a potassium stain. Radiating crystals in center are zoisite with faint anomalous blue-gray coloration. The brown crystal on the left is zoisite near extinction (parallel) and beneath it the colorful grains are epidote. In the lower right is hornblende altered to pseudomorphic chlorite with minor magnetite and epidote. Thin section with crossed polarizers.

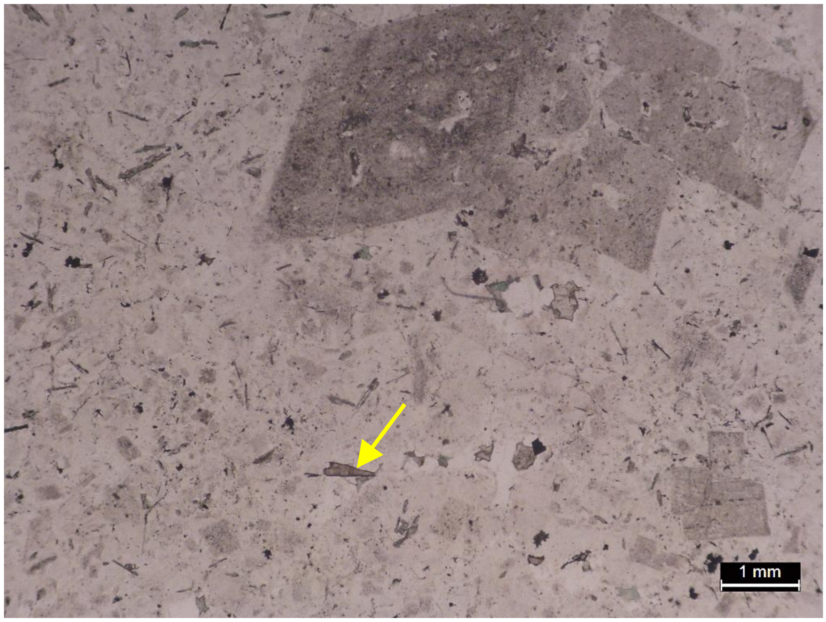


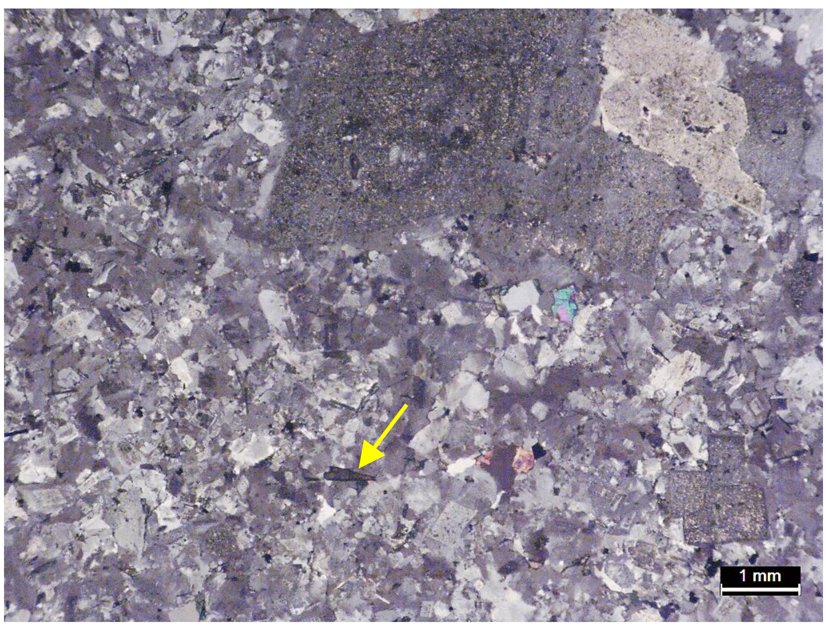
Zlwg25: Patchy equigranular matrix in porphyritic granophyre along Rt. 93 on east side of Pine Hill (site 10511). Colorful grains are epidote. Thin section with crossed polarizers.

Zlwg26: Patchy equigranular matrix in porphyritic granophyre along Rt. 93 on east side of Pine Hill (site 10981). Note occasional, interstitial granophyric grains. Colorful grains are epidote. Faint tan to yellowish colors are a potassium stain. Thin section with crossed polarizers. See Fig. Zlwg9 for cut rock view.

Zlwg27: Porphyritic granophyre with interstitial quartz, alkali feldspar and granophyric grains on Fulton Street (site 864BN). Green crystals are hornblende altered to mostly pseudomorphic chlorite with minor epidote and magnetite. Colorful grain is epidote. Opaque grains are titanomagnetite or ilmenite. Thin section with crossed polarizers. See Fig. Zlwg8 for cut rock view.

Zlwg28: Porphyritic granophyre with euhedral hornblende altered to mostly chlorite (green) west of Middle Hill (site 10532). Thin section in plane polarized light.





Zlwg29 Thin section in plane polarized light (above) and same view with cross polarizers (below): Porphyritic granophyre with lightly altered cumulophyric plagioclase phenocrysts along Rt. 93 on the east side of Pine Hill (site 10511). See also Fig. Zlwg25. High relief grains are epidote and sphene (titanite; arrow). Thin tabular crystals are fine hornblende and/or biotite altered to chlorite. Scattered colorful grains below are epidote. At arrow is sphene (titanite).

Zrhp

Rams Head Porphyry (Neoproterozoic) – Greenish-gray to gray (5G 4-5/1) porphyritic tonalite to quartz diorite (Fig. Zrhp1). Looks like diorite in the field because: 1) quartz and alkali feldspar (orange and pink areas on Figs. Zrhp2-3) form fine interstitial pockets lying inconspicuously between much larger euhedral zoned plagioclase phenocrysts that dominate the rock, and 2) mafic mineral content is relatively high. Typically, the non-mafic component is about 10-25% quartz and <10% alkali feldspar (Fig. Zrhp1). Mafic mineral content is usually about 15-25% of the rock and is mostly hornblende with lesser biotite. They are usually partly altered to chlorite, calcite, epidote, and opaque oxide minerals. Accessory minerals are interstitial sphene (titanite) and occasional rutile. This unit intrudes the Spot Pond Granodiorite (Zsg) over a wide area and as offshoots from the main body. In contact with the Spot Pond Granodiorite the unit has chilled margins with assimilation and inclusions of the granodiorite (Fig. Zrhp4). Southeast of South Reservoir and near Medford High School are dismembered rafts of the Spot Pond Granodiorite (Zsg) that may form a roof pendant. It intrudes the Westboro Formation (Zvwq) near Rams Head Hill in northern Lawrence Woods and on Silver Mine Hill. What appears to be an inclusion of the Rams Head occurs in the Lawrence Woods Granophyre in Lawrence Woods (Fig. Zrhp1 and Fig. Zlwg11), but the Lawrence Woods has an older U-Pb zircon age mean. However, age means for the Rams Head and Lawrence Woods are statistically indistinguishable with overlapping confidence intervals and the Lawrence Woods shows evidence of zircon inheritance and prolonged crystal growth. The Rams Head crosscuts and terminates reddish-colored rhyolite dikes (fp) that pass through the Spot Pond Granodiorite at Wenepoykin Hill. These dikes may be related to late-stage formation of the Spot Pond Granodiorite. The Rams Head has an age indistinguishable from the Boojum Rock Tuff of the Lynn Volcanic Complex and the Rams Head may be subvolcanic to the Boojum Rock. The two units also have similar compositions. 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 Granodiorite of this map) and classifies the unit as "tonalite-granodiorite", but the unit generally doesn't have enough alkali feldspar to be granodiorite in almost all places. Kaye equates the Rams Head with the Stoneham Granodiorite (Zst) of this map in the northern Middlesex Fells. The unit's relative age with the Stoneham Granodiorite (Zst) has not been determined with field relationships. However, the Stoneham has a radiometric age younger than the Rams Head by over 1 Myr, and the Stoneham also intrudes volcanic units younger than the Rams Head. Kaye (1980) correlates the Rams Head with the Newburyport Quartz Diorite of Emerson (1917) and LaForge (1932), now the Newburyport Complex of Zen and others (1983) and Wones and Goldsmith (1991). A U-Pb zircon age for the Rams Head is 596.24 $\pm$ 0.21 Ma (site 10969, 6 zircons, CA-ID-TIMS; Fig. Zrhp5) and disproves the Newburyport correlation.

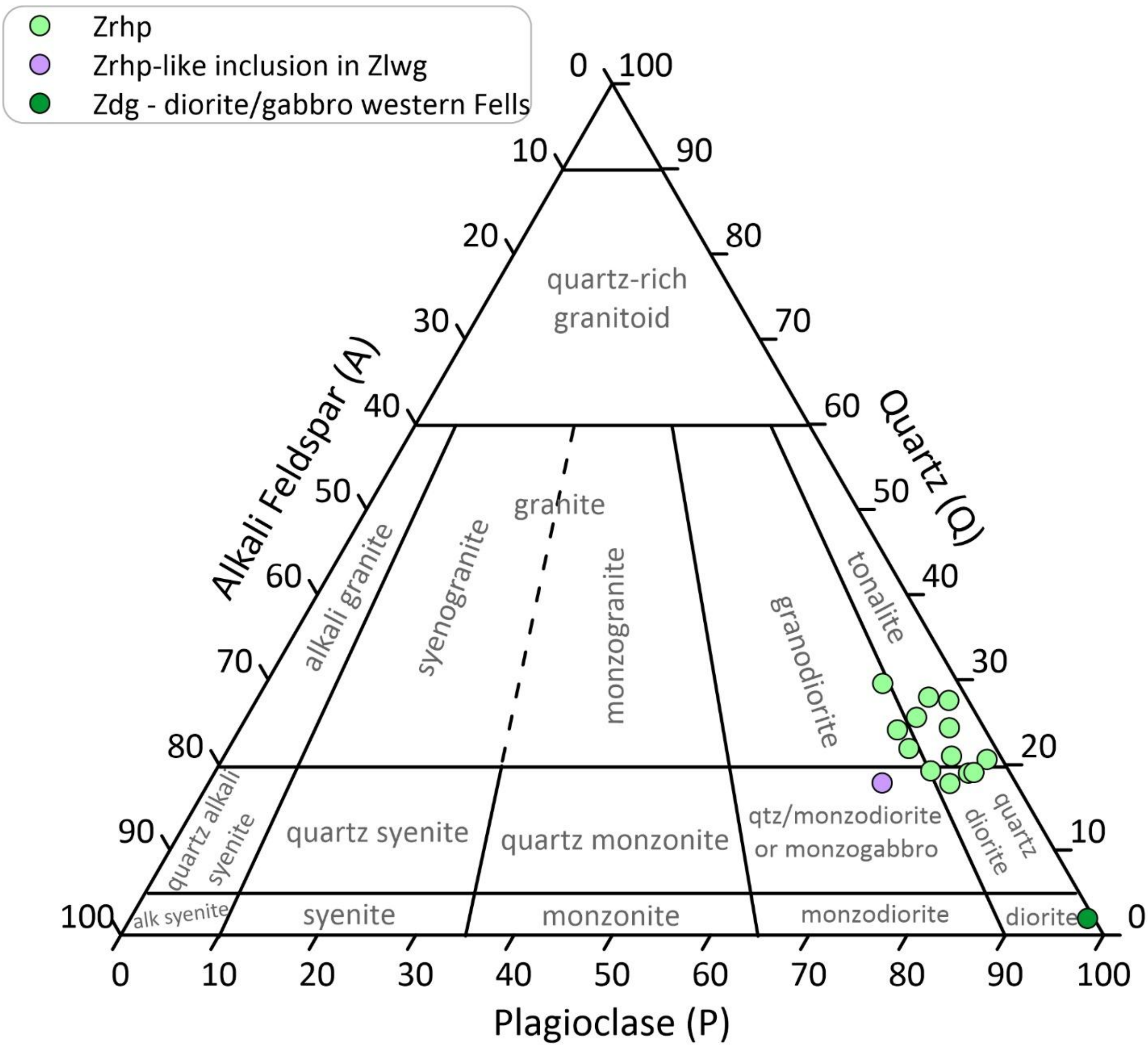
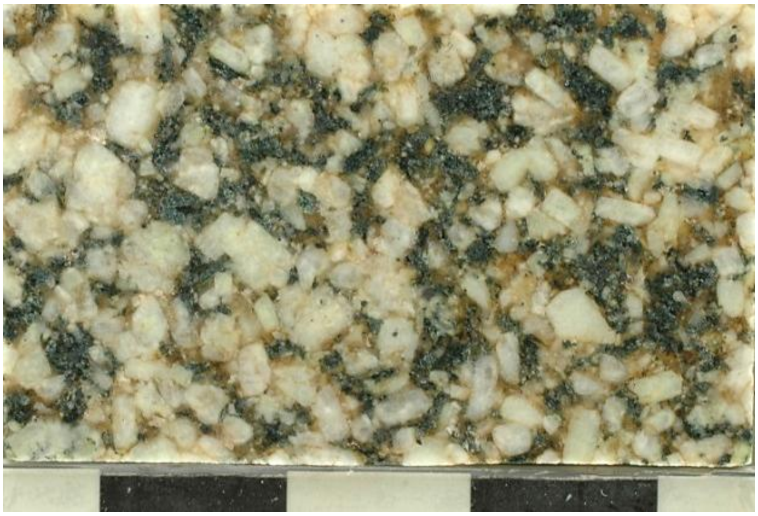
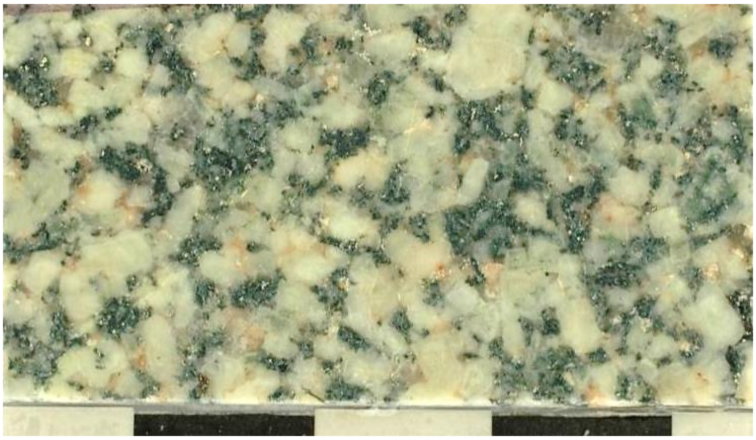


Figure Zrhp1. Normalized Quartz-Alkali Feldspar-Plagioclase (QAP) plot of point counts from the Rams Head Porphyry and a likely inclusion of the Rams Head Porphyry in the Lawrence Woods Granophyre (Zlwg) in Lawrence Woods. Unlike the Lawrence Woods the Rams Head does not have granophyric grains. Most samples are tonalite to quartz diorite. Also shown for comparison is a point count from a small area of diorite or hornblende gabbro (Zdg) along a fault in the Westboro Formation in the southwestern Fells. This gabbro/diorite area appears to be distinct from the Rams Head in both its high hornblende content (~60%) and nearly complete lack of quartz and alkali feldspar but has a similar age and shares some similarities such as relatively high mafic mineral abundance. Point count data for this plot are in Appendix 1-D including the gabbro (Zdg) in the southwestern Fells. The data for the inclusion is in Appendix 1-E.

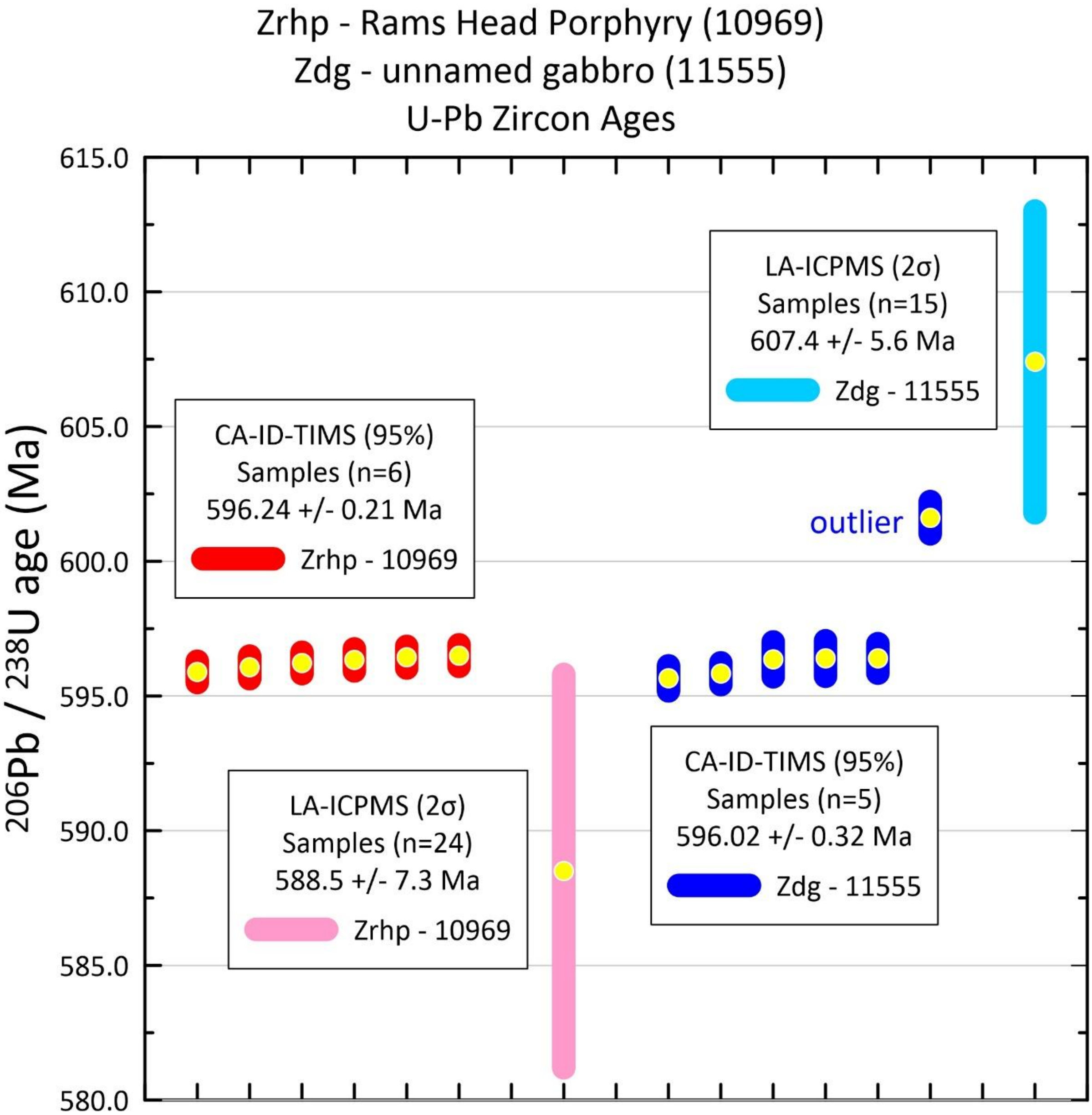


Zrhp2: Cut rock slab of porphyritic tonalite southeast of South Reservoir in Medford (site 10730). Note small areas of interstitial alkali feldspar and quartz (brown) surrounding closely-packed, euhedral plagioclase grains. This sample is typical of the core of the intrusion away from contact areas.



Zrhp3: Cut rock slab of porphyritic tonalite south of Rams Head Hill in Medford (site 11004). Note small areas of interstitial alkali feldspar and quartz (pinkish-orange) surrounding euhedral plagioclase grains. This lithology is typical of the core of the intrusion away from contact areas and is more altered than the sample above in Fig. Zrhp2, giving grains a faint greenish appearance.

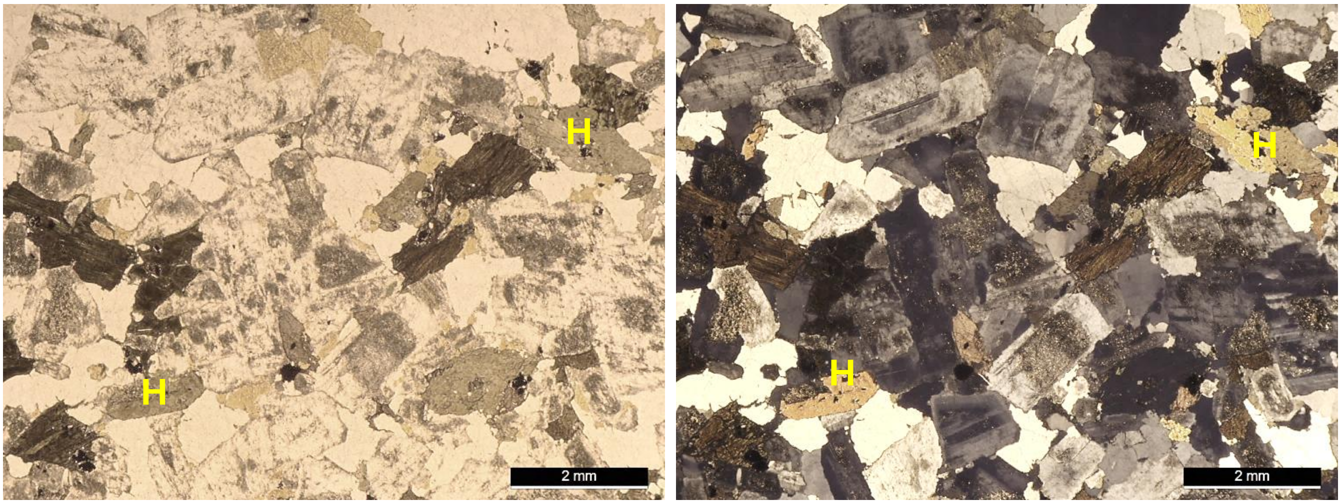
Zrhp4: Chill zone contact area of the Rams Head Porphyry with coarse Spot Pond Granodiorite (Zsg) where xenoliths of the granodiorite (right of hammer) are being assimilated on the southeast shore of South Reservoir in Medford (site 10968).



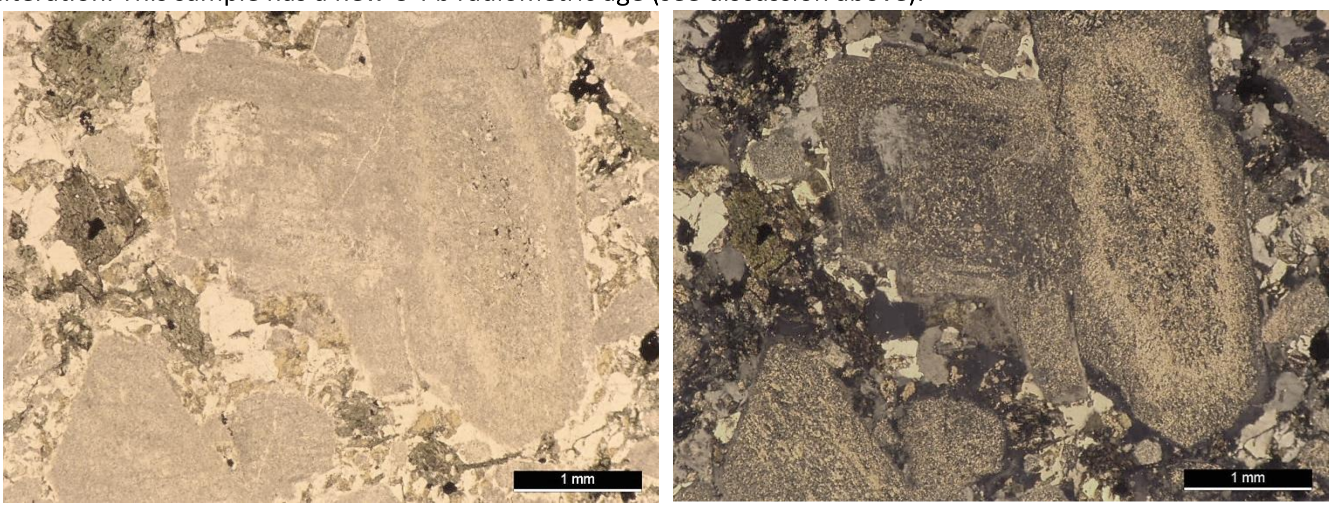
Zrhp5: Individual CA-ID-TIMS U-Pb ages used to calculate mean ages for the Rams Head Porphyry (Zrhp, site 10696; red) from southeast of South Reservoir in Medford and an unnamed gabbro in the southwestern Middlesex Fells in Medford (Zdg, site 11555; blue). One grain in the gabbro/diorite sample is an outlier (>600 Ma) and may be inherited. The two rock units are shown together here because of their similar CA-ID-TIMS ages. Also shown for comparison are less precise LA-ICPMS U-Pb ages for the same samples.

Rams Head Porphyry (cont.)

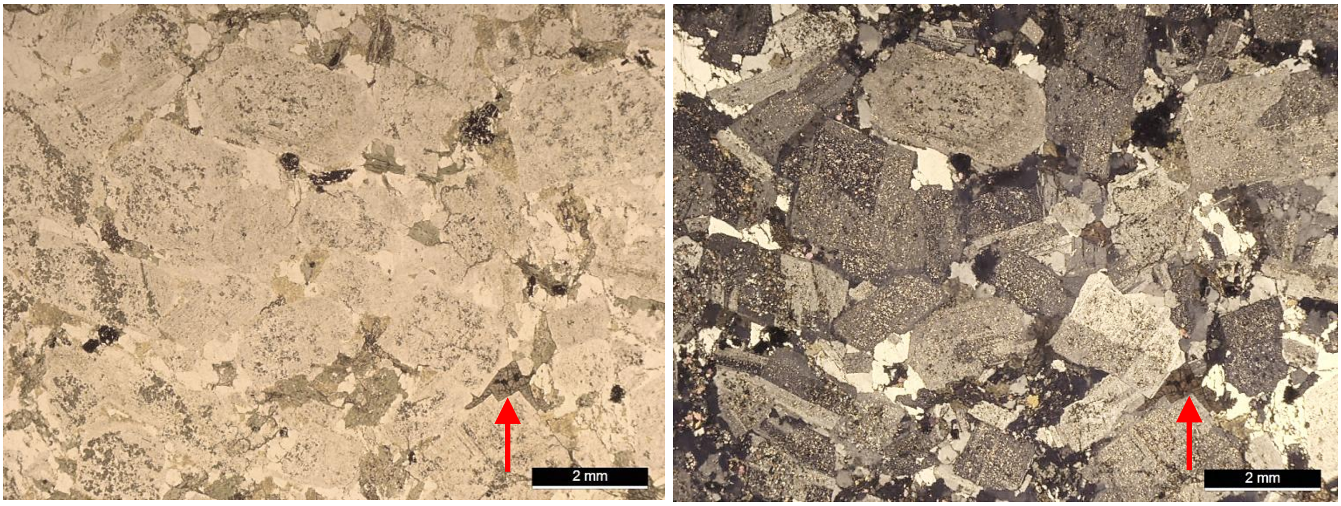
Thin section description: Medium-grained tonalite to quartz diorite porphyry (Fig. Zrhp1). Plagioclase dominates the rock with large euhedral, zoned, and twinned phenocrysts that are lightly to heavily altered to sericite and epidote but in most cases have unaltered rims (Figs. Zrhp6-8). Plagioclase crystals can be closely packed (face to face) leaving only small interstitial spaces or are separated by quartz, alkali feldspar, and mafic mineral grains (Figs. Zrhp7-9). Quartz is often the second most abundant constituent in the rock, making up 15-30% of felsic minerals, but mafic minerals can be higher. Alkali feldspar is about 10% or less of felsic minerals and in some cases is almost absent (Fig. Zrhp8). Mafic minerals (15-25%) are more abundant than in other plutonic felsic plutonic rocks of the area and are mostly hornblende with lesser amounts of biotite (Figs. Zrhp6 and 9-10). The mafic minerals are usually partly altered to chlorite with some epidote replacement of the hornblende. Biotite tends to be more altered than hornblende with replacement by chlorite and magnetite (Fig. Zrhp11). In addition to a few scattered opaque mineral grains that are titanomagnetite or ilmenite, well preserved sphene (titanite) occurs in almost all non-altered samples (Figs. Zrhp8-9 and 12) and rutile occurs in a few samples (Fig. Zrhp13). The porphyry is cataclastically deformed along some major faults (Fig. Zrhp14).



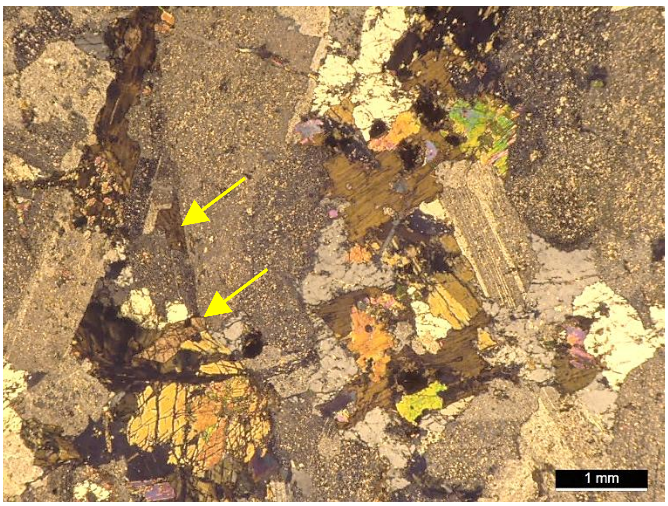
Zrhp6 (left): Thin section in plane polarized light. (right): Same view with crossed polarizers. Tonalite porphyry east of Pasture Hill in Medford (site 10969) with euhedral, zoned and twinned plagioclase, interstitial quartz (clear), very minor alkali feldspar (yellow stain), euhedral (diamond-shaped) hornblende (pale green, H) and biotite (dark brown). Sample is relatively fresh with light alteration of plagioclase, which has rims with lower alteration. This sample has a new U-Pb radiometric age (see discussion above).

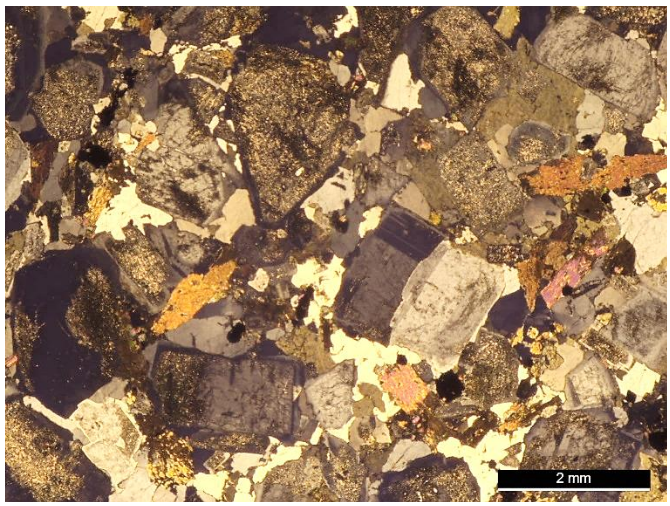


Zrhp7 (left) Thin section in plane polarized light. (right) Same view with crossed polarizers. Tonalite porphyry in Lawrence Woods in Medford (site 11017) with coarse, euhedral, zoned, and twinned plagioclase that is heavily altered to sericite. Between plagioclase grains are interstitial quartz (clear), very minor alkali feldspar (yellow stain, almost absent), and minor hornblende and biotite (green and brown) altered to chlorite.



Zrhp8 (left) Thin section in plane polarized light, (right) same view with crossed polarizers. Quartz diorite porphyry east of Rock Hill in Medford (site 10992) with euhedral zoned and twinned plagioclase that is closely packed leaving little space for other minerals. In lesser quantities are interstitial quartz (clear), very minor alkali feldspar (yellow stain), and minor hornblende and biotite partly altered to chlorite. Plagioclase has rims less altered than interiors. High relief mineral in lower right (arrow) is sphene (titanite).

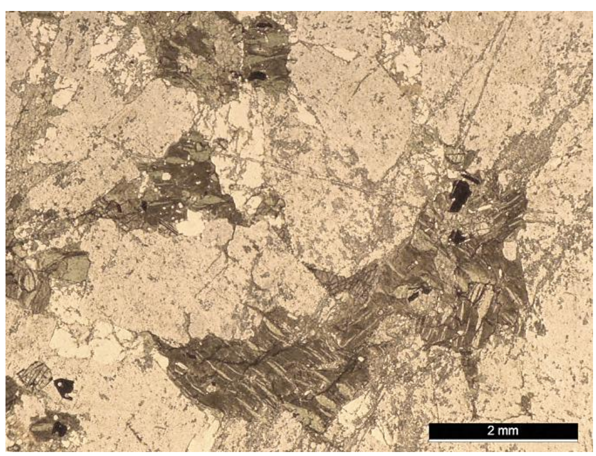


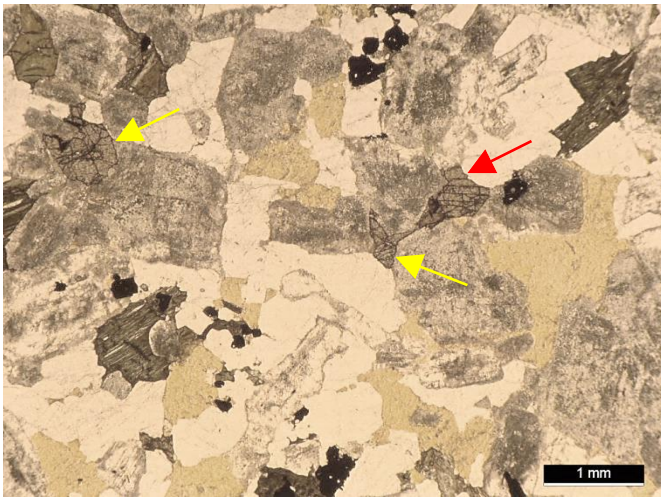


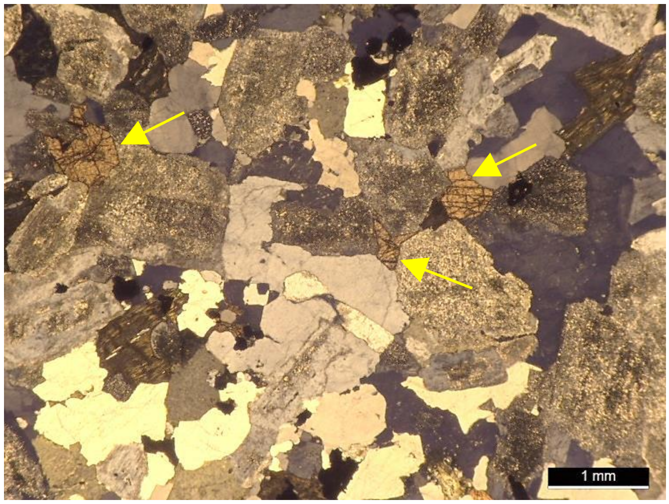
Zrhp9 (left): Tonalite porphyry south of South Reservoir in Medford (site BN818) with altered plagioclase, minor interstitial quartz (clear), and intergrown hornblende (bright colors) and biotite (brown). High relief mineral grains on left side (arrows) are sphene (titanite). Thin section with crossed polarizers.

Zrhp10 (right): Tonalite porphyry southeast of South Reservoir in Medford (site 10730) with partly altered plagioclase, minor interstitial quartz (clear), alkali feldspar (yellowish-gray), and euhedral hornblende (bright colors) with lesser biotite (brown). Thin section with crossed polarizers. See Fig. Zrhp2 for cut rock view.

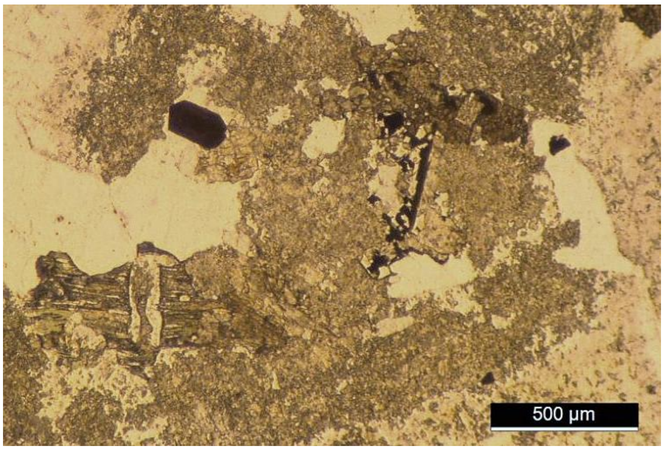
Zrhp11 (right): Quartz diorite porphyry on Silver Mine Hill in Medford (site 10733) with biotite partly altered to chlorite (dark green). Tiny white crystals in biotite (left center of image) are apatite. Thin section in plane polarized light.

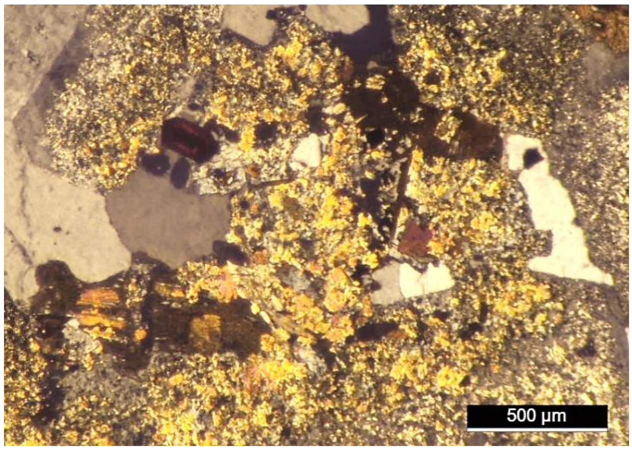






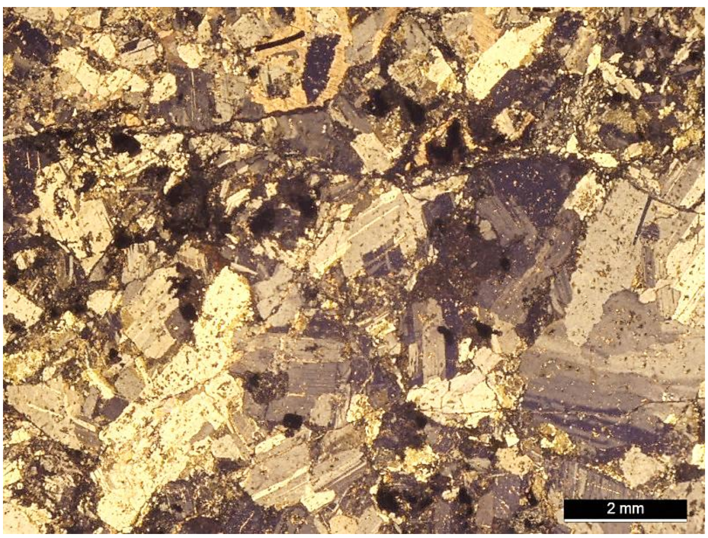
Zrhp12: Granodiorite porphyry in Lawrence Woods in Medford (site 10993) with altered plagioclase, interstitial quartz (clear), a relatively high amount of alkali feldspar, and biotite partly altered to chlorite (green). High relief minerals (arrows) are sphene (titanite). (left): Thin section in plane polarized light. (right): Same view with crossed polarizers.





Zrhp13: Quartz diorite porphyry south of South Reservoir in Medford (site 10963) with plagioclase altered to sericite and epidote, interstitial quartz (clear), and some biotite partly altered to chlorite. (left): Thin section in plane polarized light. (right): Same view with crossed polarizers. Barely transparent, very dark red, euhedral, zoned crystal in upper left is rutile. Note red tint to rutile on right. Patchy colorful areas are epidote formed by alteration of mafic minerals and plagioclase.

Zrhp14: Tonalite porphyry on Rock Hill in Medford (site 10991) that is cataclastically deformed. Pale pinkish-orange areas at top of image and in lower left are calcite veins. Thin section with crossed polarizers.



The Lynn Volcanic Complex, originally called the “Lynn volcanics” by Clapp (1921), is here given group status and is subdivided into two formations that are then classified into facies. The two formations are the older Boojum Rock Tuff and the younger Wakefield Formation, which are separated by an unconformity. Future mapping may allow the separation of the Wakefield into separately named formations or members, but a subdivision at this point is premature before new areas are mapped in Melrose, Wakefield, and Saugus. For explanations of the subdivision of volcanic rocks in the area see pages 10-12 and 14-18. These explanations include the details of the distinction between the basaltic units of the Nanepashemet and Wakefield Formations as well as details of the separation of the Lynn Volcanic Complex into the formations discussed here.

Splitting of the Lynn Volcanic Complex into two formations is warranted because of lithologic, geochemical (Fig. Zlv1), mineralogical, and radiometric age differences. The units are also separated by an unconformity. The Boojum Rock Tuff is 597-596 Ma while the Wakefield units have an age range of 596-594 Ma. The Boojum Rock Tuff has a dacitic to andesitic composition (Fig. Zlv1) and is entirely made of felsic pyroclastic rocks with abundant hornblende crystals and rare fine-grained quartz crystals that are never embayed. Facies of the Wakefield are basaltic and rhyolitic to dacitic flows, volcaniclastic units, and pyroclastic rocks (Fig. Zlv1). In the Wakefield, felsic tuff units commonly contain coarse, embayed quartz crystals and occasional alkali feldspar crystals (see Figs. 1-6B-C on p. 17 and sections below for the comparisons of crystals.

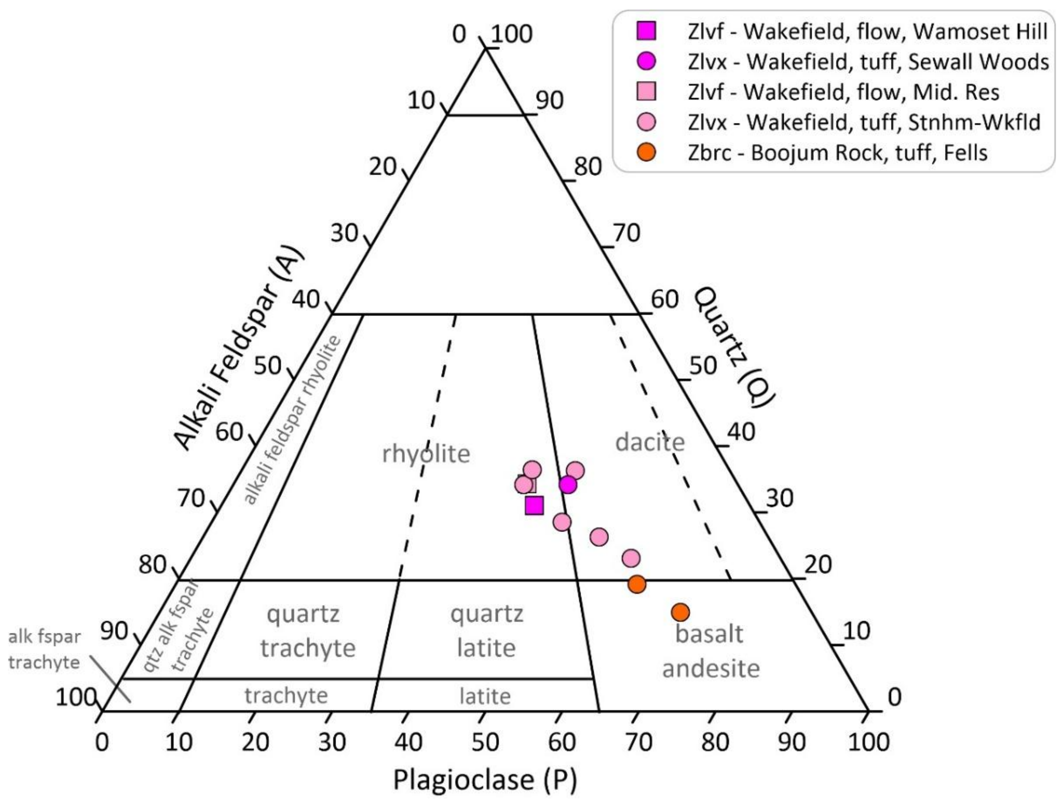


Figure Zlv1. Normalized Quartz-Alkali Feldspar-Plagioclase (QAP) plot of felsic volcanic units in the Lynn Volcanic Complex. Data is CIDW Norm% calculations from XRF analyses of tuffs (circles) by Smith (1985) and LA-ICPMS data from flows (squares) by Hampton (2017). Note that the felsic units are andesite to rhyolite. Data in Appendices 1-C and 1-F.

Facies of the Wakefield Formation

The Wakefield Formation is subdivided into two groups of facies based on composition and volcanic rock types as listed below. The Wakefield has not yet been further divided into lithostratigraphic units of formation or member status. It is clear that there are multiple areas of the same facies and some repeated sequences. Therefore, it is anticipated that the Wakefield might eventually be further subdivided when a complete mapping of the unit continues further east in Saugus and Lynn further tests the continuity of units between fault blocks.

<u>Basaltic facies</u>:

Zlbf – Basaltic flow/breccia/tuff facies
Zlbc – Basaltic volcaniclastic facies

<u>Felsic facies</u>:

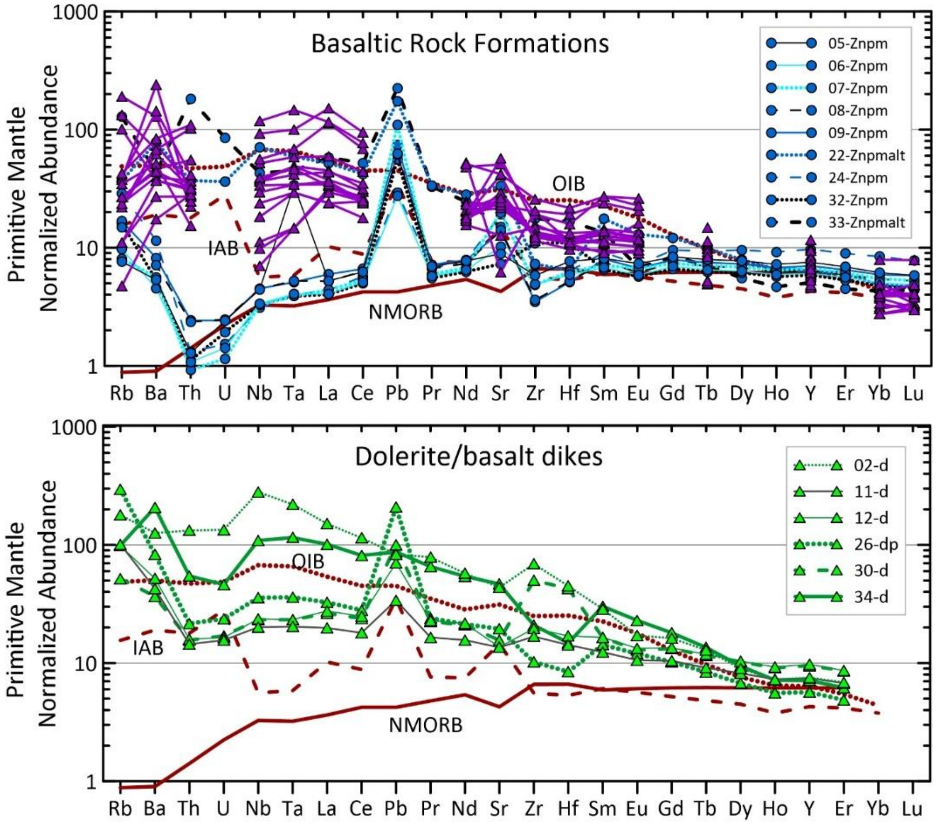
Zlvc – Felsic volcaniclastic facies
Zlvp – Rhyolite porphyry facies
Zlvv – Vitric tuff facies
Zlvx – Crystal tuff facies
Zlvl – Lithic Tuff Facies
Zlvf – Rhyolite flow facies

Basaltic Facies of the Wakefield Formation

The descriptions below are for different basaltic facies of the Wakefield Formation. Basaltic facies makeup a large area of the Wakefield Formation beginning at the north end of Spot Pond and continuing north to northeast of the Fells through Stoneham and Wakefield where they are interlayered with felsic facies and intruded by the Stoneham Granodiorite. The distinction of basaltic facies of the Wakefield Formation from altered basalt of the Nanepashemet Formation, and the replacement of the Middlesex Fells Volcanic Complex in older reports and maps is given on pages 14-15.

Removal of the old Middlesex Volcanic Complex is supported by geochemical differences recorded in basalts of the Nanapashemet Formation and Wakefield Formation (Fig. Zlbf1, same as on p. 15). Basalts in the two units have different trace element abundances. On the upper graph below are trace element plots comparing the Nanepashemet, which is >610 Ma (blue lines, LA-ICPMS data from Hampton, 2017) and the Wakefield Formation, which is 595 Ma (XRF data from north of the Fells, purple lines, from Cardoza,1987). The Nanepashemet has heavy hydrothermal alteration and contact metamorphism that likely played a role in altering at least some trace element values (see samples 22 and 33 for example). For comparison, on the lower plot in Figure Zlbf1 are trace element analyses of dolerite dikes in the Fells (LA-ICPMS data from Hampton, 2017), which are all younger than the basalt units plotted in the upper graph. Also shown are plots in red of typical NMORB (normal mid-ocean ridge basalt - solid line), IAB (island arc basalt - dashed line), and OIB (ocean island basalt - dotted line) affinities. If one ignores potential effects of alteration, samples from the Nanepashemet Formation are most like mid-ocean ridge basalts while samples from the Wakefield are most like ocean island and island arc basalts. Dolerite dikes in the Fells are also mostly like the ocean island and island arc basalts.

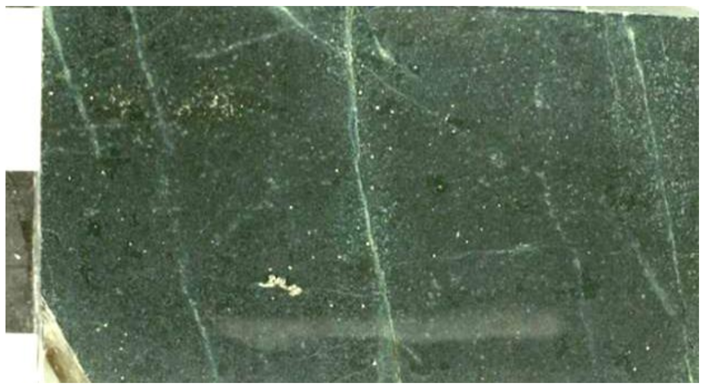
Figure Zlbf1. Spider diagram trace element plots. Above are XRF analyses of basalt in the Wakefield Formation (purple, from Cardoza, 1987) and LA-ICPMS analyses of basalt from the Nanepashemet Formation (blue, Hampton, 2017). Below for comparison are LA-ICPMS trace element plots from dolerite dikes with a variety of ages in the Fells that are younger than the two formations plotted in the upper graph (from Hampton, 2017).



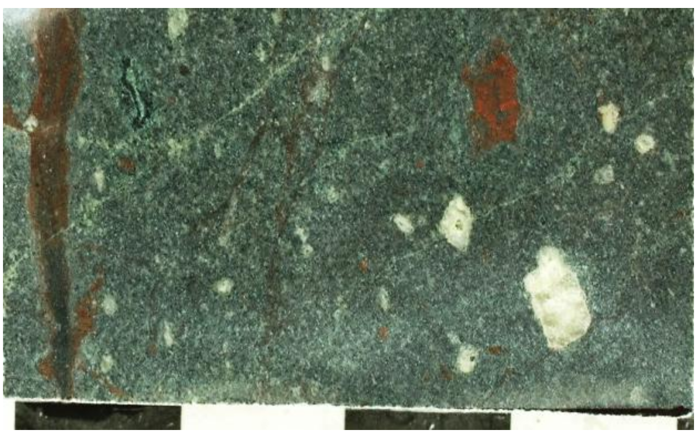
Zlbf

Basaltic flow/breccia/tuff facies – Dark greenish-gray (5BG-5G 3-4/1) to dark reddish-gray (10R 3/1) altered aphanitic to very fine phaneritic (Fig. Zlbf1-3) and occasionally amygdaloidal (Fig. Zlbf4-6) basalt and basaltic breccia and tuff (Fig. Zlbf7-10). Breccias may be autobrecciated flows or a part of tuff units with monomictic clast types. Quartz, calcite, epidote, and iron oxide mineral precipitates occur in amygdules and veins. The basalt units are sometimes interlayered with laminated to thin bedded, dark bluish- to greenish-gray (5BG-5G 3-4/1) highly altered basaltic argillite to fine sandstone (Zlbf11-18). The sedimentary units are often faulted, contorted and heavily altered with epidote and chlorite. Unlike in the Nanepashemet Formation primary bedding is easily seen in many exposures and layering is not a metamorphic foliation. At least one argillaceous unit at the base of a basalt flow is calcareous and displays alveolar weathering that mimics vesicles (Fig. Zlbf16). So far, pillows have been identified in this unit at Stoneham High School (Smith and Hon, 1984; Fig. Zlbf19) and on High Rock in Wakefield (Fig. Zlbf20). All the basaltic units described here are mapped as a single facies because they are co-mingled, and because of alteration and very fine grain sizes they cannot be consistently distinguished in field exposures without thin section analysis. This facies occurs over large areas of Stoneham and as separate layers in mostly felsic volcanic units in Wakefield. Most of the basaltic units at Straw Point at the north end of Spot Pond, flows and sediment, were mapped by Kaye (1980) as a single dolerite intrusion.

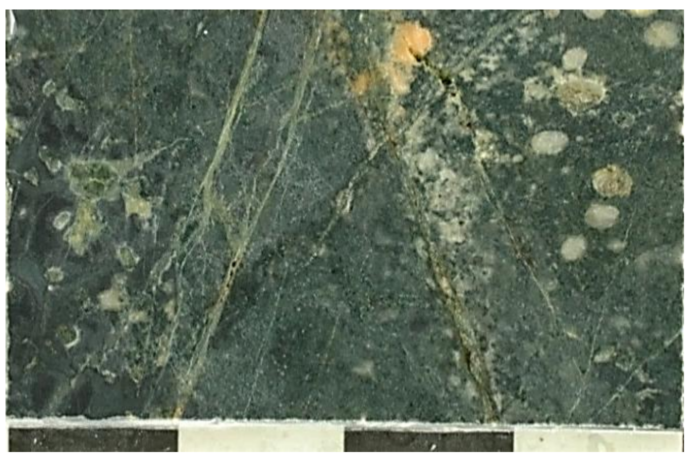
Zlbf1 (left): Typical very fine fractured basalt with epidote veins at J.J. Round Park in Wakefield (site 11676).



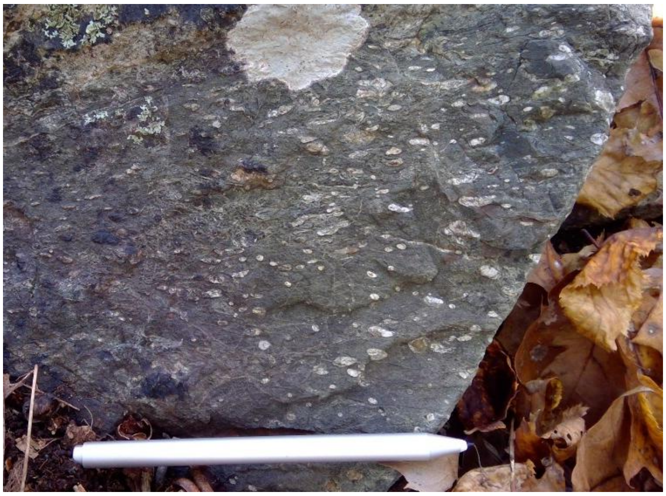
Zlbf2 (right): Cut rock view of altered basalt with quartz and epidote veins at Straw Point in Stoneham (site 10430).

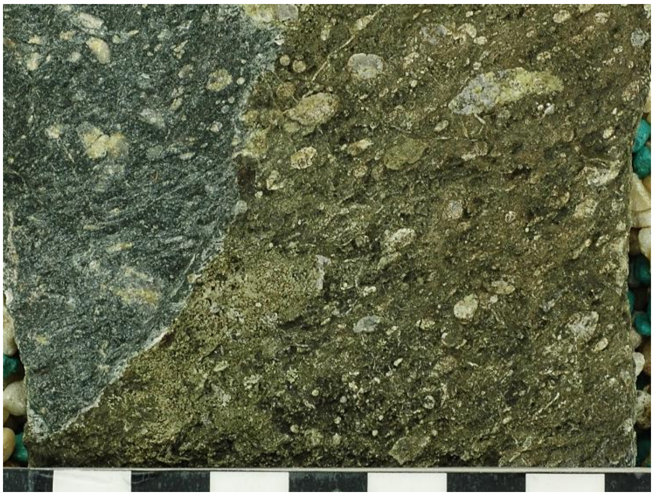


Zlbf3 (left): Cut rock view of relatively coarse porphyritic basalt with oxide veins on Straw Point in Stoneham (site 10603).



Zlbf4 (right): Cut rock view of altered amygdaloidal basalt with quartz and epidote veins on Straw Point in Stoneham (site 10610).



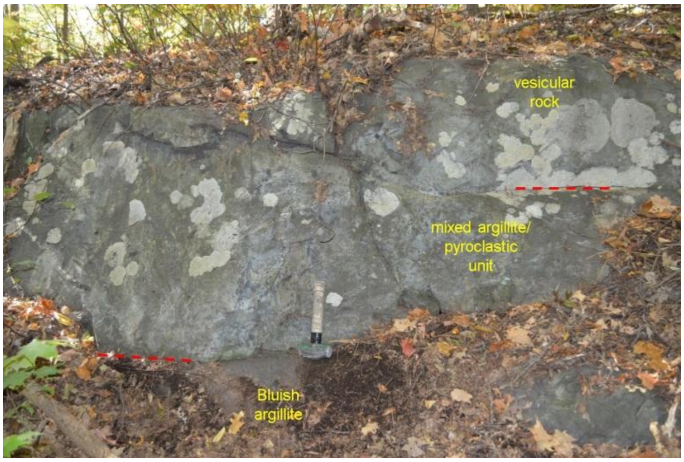


Hill slope west of Grand View Ave. in conservation land north of High Rock in Wakefield (site 11628).
Zlbf5 (left): Broken face on amygdaloidal basalt. Amygdules are filled with quartz, calcite and minor epidote. Note how amygdules are elongate and flattened. Pen for scale. **Zlbf6** (right): Broken and weathered surfaces on same amygdaloidal basalt as in Fig. Zlbf5.

Zlbf7 (above): Fresh surface of monomictic basalt breccia on Lotus Ave extension in Wakefield (site 11634). Matrix may be altered basalt or recrystallized palagonite or tuff. Pen for scale.

Zlbf8 (above): Weathered surface of basaltic tuff with angular, very fine basalt fragments and altered matrix in conservation land on High Rock in Wakefield (site 11618). Scale in cm.
Zlbf9 (below): Same rock as in Fig. Zlbf8 sliced on rock saw showing oriented, angular, altered basalt fragments and highly altered matrix.

Zlbf10 (above): Weathered surface of basaltic tuff in J.J. Round Park in Wakefield (site 11675). Note small angular basalt chunks. Rock hammer for scale.

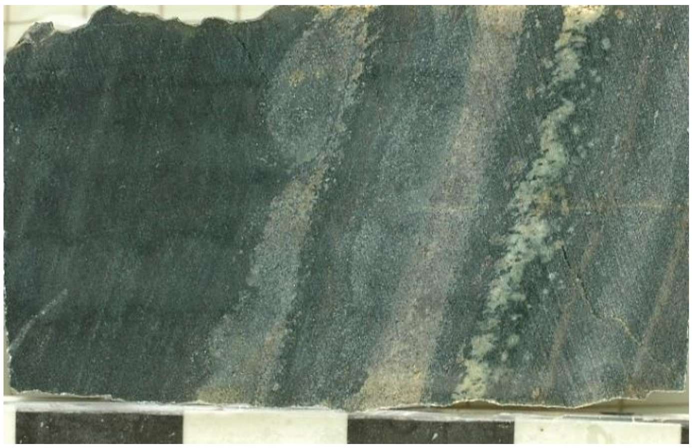


Zlbf11 (left): Short sequence of basalt, argillite, and tuff at Straw Point in Stoneham (site 10617). The strike and dip of the surface of the lowest unit is interpreted to record overall orientation. The unit dips at a very gentle angle.

Zlbf12 (right): Laminated greenish-gray, chloritic, argillaceous siltstone and fine sandstone, possibly bedded tuff, on Straw Point in Stoneham (site 11329).

Zlbf13 (left): Highly contorted beds of laminated greenish-gray chloritic argillaceous siltstone and fine sandstone on Straw Point in Stoneham (site 10612).

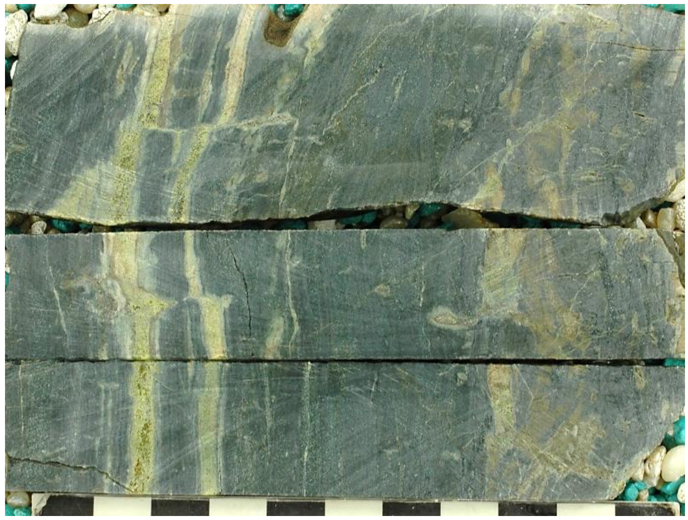
Zlbf14 (right): Altered, laminated greenish-gray chloritic argillaceous siltstone and fine sandstone on Straw Point in Stoneham (site 10614).



Zlbf15 (right): Weathered surface of dark greenish-gray, laminated, argillaceous siltstone to fine sandstone on Straw Point (site 11287).

Zlbf16 (left): Calcareous greenish-gray argillaceous siltstone and fine sandstone that displays alveolar weathering on Straw Point in Stoneham (sites 10437 and 11253). Carbonate mineralization is likely related to hydrothermal alteration.

Zlbf17 (left): Weathered surface of altered, laminated greenish-gray, chloritic, argillaceous mudstone and sandstone on hill west of the Stoneham High School football field, Stoneham (site 11361). Lens cap for scale.



Zlbf18 (left): Same rock as in Fig. Zlbf17 sliced on a rock saw. Note epidote mineralization.

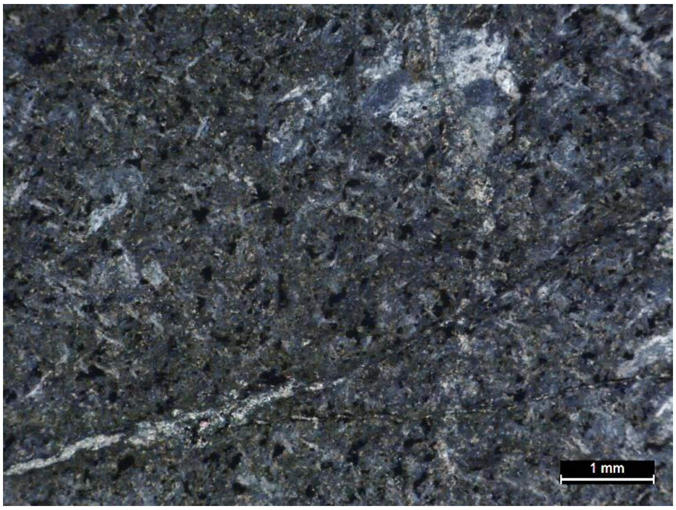
Zlbf19 (above): Pillow basalt with epidote rims on the north side of the east parking lot at Stoneham High School, Stoneham (site 11365). Rock hammer for scale.

Zlbf20 (above): Pillow basalt with epidote rims in conservation land on High Rock, Wakefield (site 11631). Rock hammer for scale.

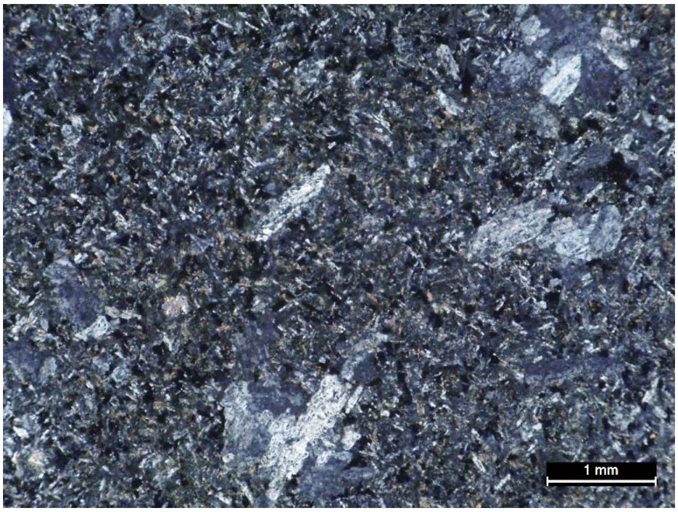
<u>Thin section description</u> – (Images below are with crossed polarizers unless otherwise indicated.) Lithologies that make up the basaltic flow/breccia/tuff facies are sometimes difficult to distinguish in the field without obvious plagioclase phenocrysts, vesicles/amygdules in the basalt, or well- preserved bedding or particles in argillite and tuff. In many cases the rock units are hydrothermally altered or contact metamorphosed near intrusions like the Stoneham Granodiorite (Zst) or dolerite dikes (d).

Basalt is generally fine-grained with relict highly altered plagioclase blades and phenocrysts (Figs. Zlbf21-22) and usually has a pilotaxitic texture (Fig. Zlbf21-23). Vesicles are filled with epidote and actinolite (Fig. Zlbf24). Original clinopyroxene is altered to amphibole (actinolite), chlorite, and epidote but never to the extent seen in the older Nanepashemet Formation in which relict plagioclase blades are often recrystallized.

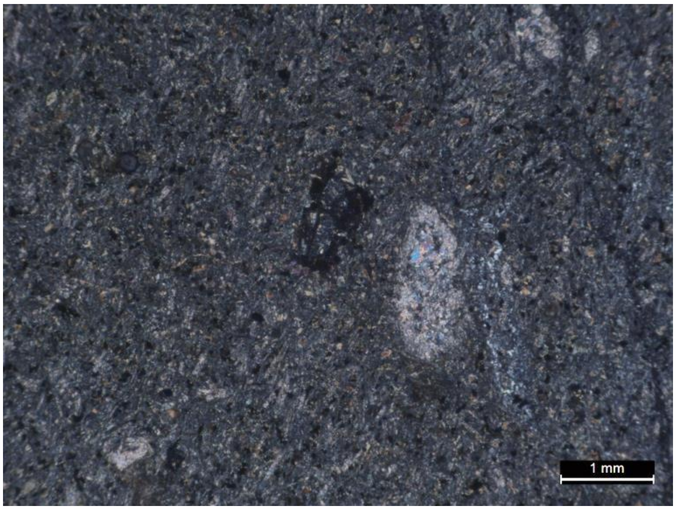
Sedimentary units and tuff are often well bedded (Fig. Zlbf25) with layers showing different degrees of alteration to chlorite, actinolite, and epidote (Fig. Zlbf26). The mineralogy of these layers, which are like basalt without preserved plagioclase blades, suggests they could be recrystallized tuff or palagonite, but they also have occasional quartz grains (Fig. Zlbf27). In one mudstone, hydrothermal alteration has disrupted bedding and produced very fine-grained intergrown actinolite, epidote, and calcite (Fig. Zlbf28). Tuff units are often breccias with angular basalt fragments, some with amygdules of quartz formed by hydrothermal activity (Fig. Zlbf29).



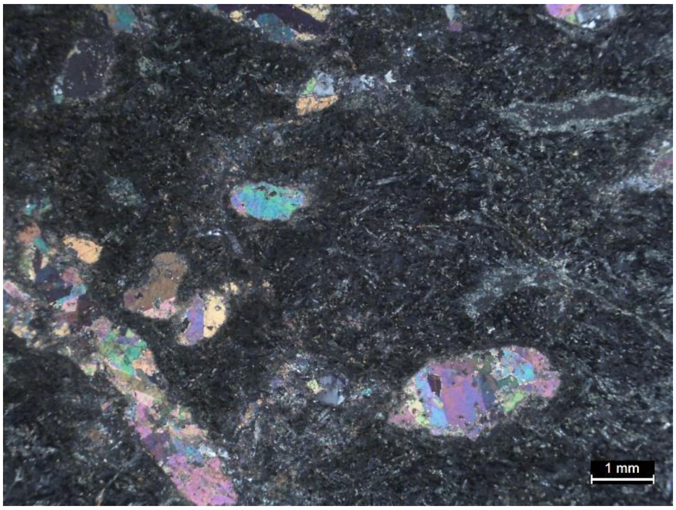
Zlbf21 (above): Altered basalt with faint altered plagioclase blades and pilotaxitic texture on Straw Point in Stoneham (see Fig. Zlbf2 for cut rock view; site 10430).



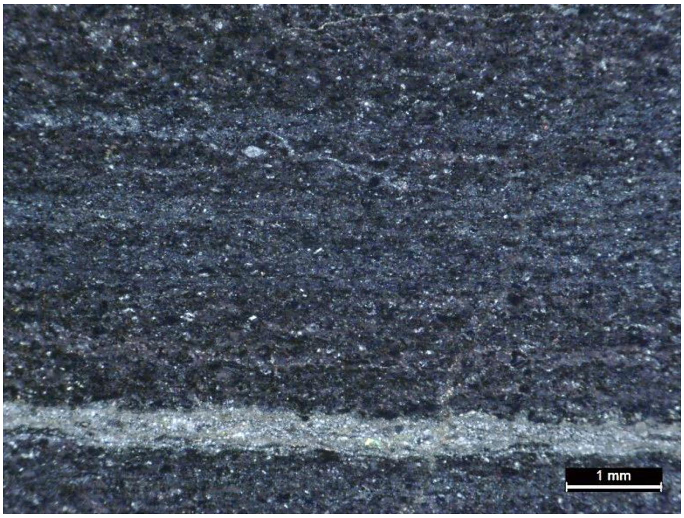
Zlbf22 (above): Pilotaxitic basalt with altered plagioclase microlites and phenocrysts on Straw Point in Stoneham (site 11255).



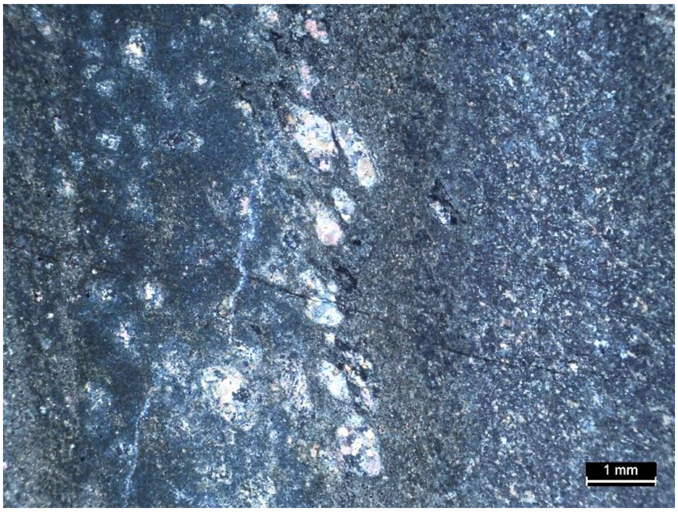
Zlbf23 (above): Altered, pilotaxitic basalt with relict plagioclase microlites and phenocrysts on Straw Point in Stoneham (see Fig. Zlbf3 for cut rock view; site 10603).



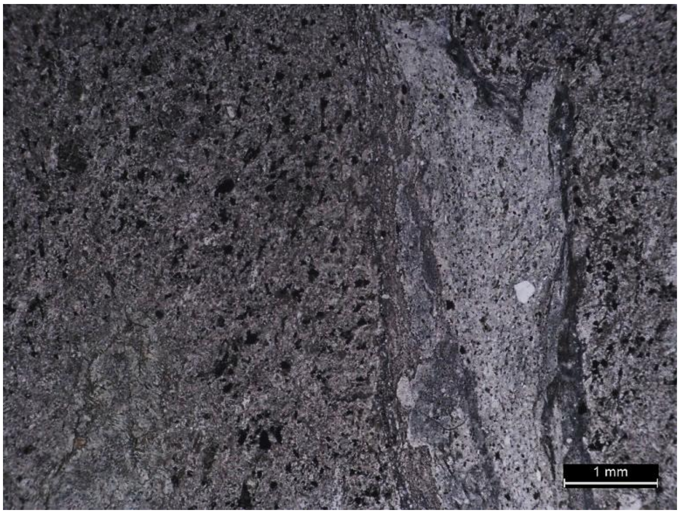
Zlbf24 (above): Altered basalt with relict plagioclase microlites and vesicles (amygdules) filled with epidote on Straw Point in Stoneham (site 11251).



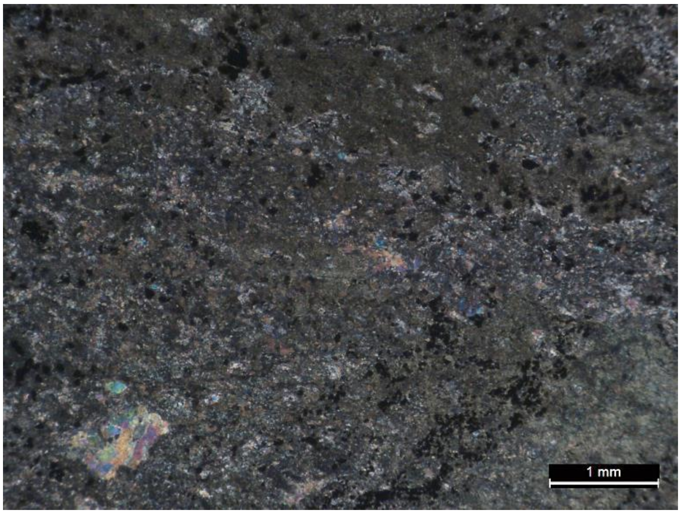
Zlbf25 (above): Argillite with scattered quartz and feldspar silt to fine sand grains and a muddy matrix altered to chlorite, actinolite, and opaque oxides on Straw Point in Stoneham (see Fig. Zlbf15 for hand sample; site 11287).



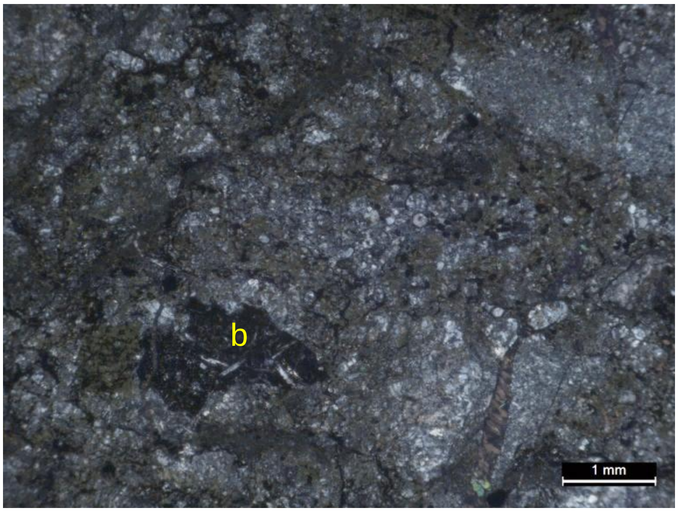
Zlbf26 (above): Altered argillite with beds (vertical on image) variably altered to actinolite, chlorite, and epidote on Straw Point in Stoneham (see Fig. Zlbf14 for cut rock view; site 10614).



Zlbf27 (above): Altered basalt right and left with fracture filling of mudstone that has a quartz grain on Straw Point in Stoneham (see Fig. Zlbf3 for cut rock view; site 10603). Plane polarized light.



Zlbf28 (above): Argillite with bedding that is hydrothermally altered with formation of chlorite, epidote, and calcite on Straw Point in Stoneham (see Fig. Zlbf16 for outcrop view; site 11253). Crossed polarizers.



Zlbf29 (left): Tuff with angular basalt fragment that has plagioclase microlites (b) on Straw Point in Stoneham (site 10432). Also present are quartz-filled vesicles. Rock was hydrothermally altered.

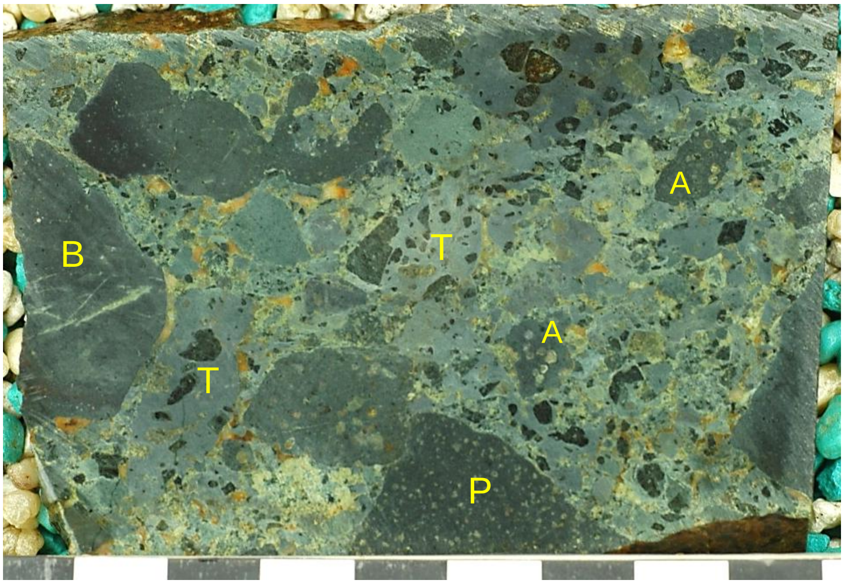
Zlbc

Basaltic volcaniclastic facies – Greenish- to bluish-gray (5GY 6/1-5B 5/1), gray weathering (5Y 6/1), polymictic conglomerate and breccia dominated by clasts of mafic volcanic rocks including very fine basaltic lava, porphyritic basalt, diabase and gabbro, amygdaloidal basalt, basaltic breccia, and basaltic tuff with granule size angular black basalt fragments (Fig. Zlbc1-5). Also includes rare clasts of felsic volcanic rock types (Fig. Zlbc5, mostly crystal tuff) and rarer quartzite. Clasts are very rounded to subangular and matrix- to clast-supported (Fig. Zlbc3-5) depending on the layer in which they occur. The matrix ranges from muddy sand to mudstone. The conglomerate has subtle bedding. Only one outcrop is known which extends from the Greenwood School northward east of Main Street in Wakefield.

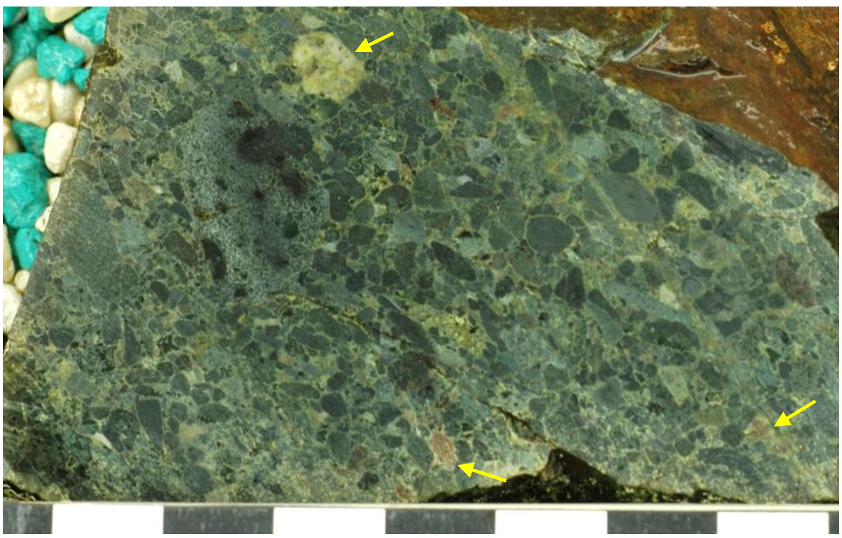
Zlbc1: Large outcrop of basaltic volcaniclastic conglomerate behind 974 Main Street in Wakefield (site 11734). This outcrop also has a gently dipping, thin basaltic dike (arrow) and the clastic unit is in contact with a basaltic lava flow (Zlbf) on the north end of the outcrop.

Zlbc2: Outcrop of poorly sorted polymictic basaltic volcaniclastic conglomerate 100 m north of the Greenwood School in Wakefield (site 11712) and 50 m south of the outcrop in Fig. Zlbc1. Clasts are subrounded to subangular. In the upper left is a tuff clast (T) with angular black lava fragments. Rock hammer for scale.

Zlbc3: Highly fractured basaltic volcaniclastic breccia on top of knob on north side of the Greenwood School in Wakefield (site 11708). Two common clast types are tuff (T) with angular black basalt fragments and fine basalt (B). All clasts are angular. Scale in cm.



Zlbc4: Polymictic basaltic volcaniclastic conglomerate with subangular to subrounded clasts. North side of knob north of the Greenwood School in Wakefield (site 11711). Common clasts are fine basalt (B), porphyritic basalt (P), amygdaloidal basalt (A), and tuff with angular dark gray basalt fragments (T). Scale in cm.



Zlbc5: Clast-supported and relatively well sorted, polymictic basaltic volcaniclastic conglomerate with mostly subrounded to rounded, pea-size clasts on north side of knob at north end of the Greenwood School in Wakefield (site 11709). This sample has a few light-colored, tan to red felsic volcanic clasts (arrows). Scale in cm.

Felsic Facies of the Wakefield Formation

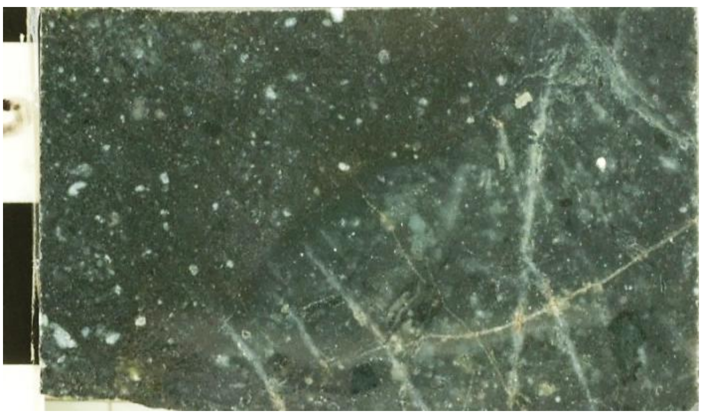
Zlvc

Felsic Volcaniclastic Facies

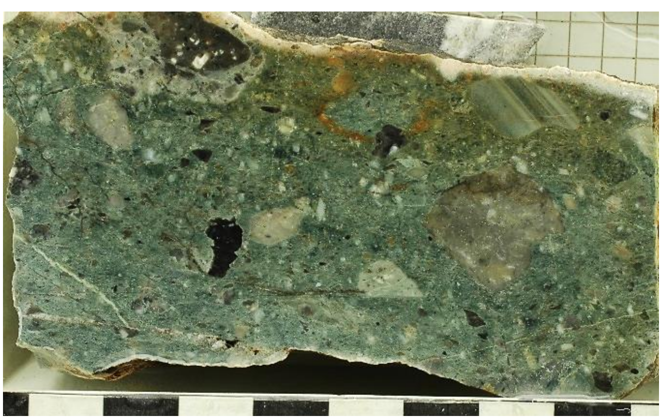
Felsic volcaniclastic conglomerate in several different places across the Middlesex Fells and further north. Each area is described separately below. Felsic volcaniclastic rocks are distinguished from other clastic facies by having: 1) many felsic volcanic as well as other clast types (polymictic), 2) a range of particle shapes from well rounded to angular, and 3) matrices that are reworked sand, muddy sand and mudstone that is not dominated by devitrified glass particles or crystals as in lithic tuff units. This facies resembles sections of the Vinegar Hill Member of the Lynn Volcanic Complex identified further east by Smith and Hon (1984) and Smith (1985).

<u>Felsic volcaniclastic rocks in the Pine Hill area of the southern Fells</u>

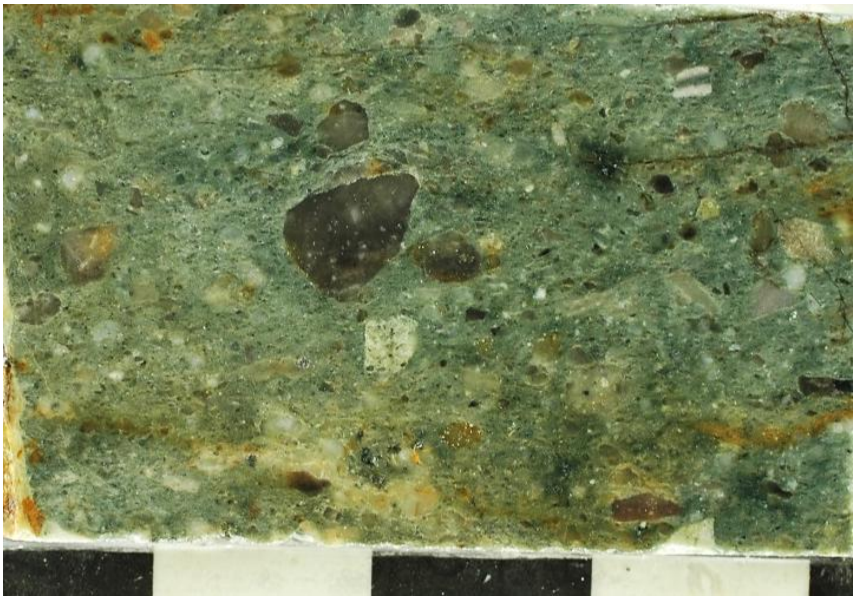
<u>Rock unit description</u>: Across the southern Fells from Middle Hill to Pine Hill are sandy mudstone, round pebble conglomerate, and diamictite with a variety of clast types that form the base of the Wakefield Formation lying on an unconformity. These lithologies include dark bluish-gray (5BG 3-4/1) to gray (N4/1) fine-grained volcaniclastic sandy mudstone (Fig. Zlvc1) to greenish-gray (5GY-G 5/1 matrix), poorly sorted, polymictic conglomerate (diamictite) with a variety of lithic grains (Fig. Zlvc2-3) including pebbles to boulders of the Spot Pond Granodiorite (Zsg; Fig. Zlvc4-6). Large Spot Pond clasts on Little Pine and Middle Hills were first recognized by Robert Reuss of Tufts University (samples and unpublished field notes, 1982-1985). On Pine and Little Pine Hills this unit includes deformed and pinched masses of light gray weathering, gray (N 5-6) vitric tuff that are sometimes banded (Fig. Zlvc7). These masses are enclosed in a rusty weathering volcaniclastic sandstone to conglomerate containing abundant rounded and broken plagioclase and quartz grains, sparse alkali feldspar, granule to boulder-sized clasts of the Spot Pond Granodiorite (Zsg), volcanic clasts, and quartzite (Fig. Zlvc8). Clast types and sizes vary over short distances. The Lawrence Woods Granophyre (Zlwg) intrudes the volcaniclastic facies on Pine, Little Pine, and Middle Hills. This unit is thought to be equivalent to the volcaniclastic units described below in the Boojum Rock area.



Zlvc1: Volcaniclastic sandy mudstone on northern Pine Hill in Medford (site 10517). This unit shows faint bedding recognized by sand grain abundance and forms the base of the volcaniclastic facies lying on the Spot Pond Granodiorite (Zsg).



Zlvc2: Poorly sorted, volcaniclastic conglomerate (diamictite) on Middle Hill in Medford (site 10626). Note the laminated quartzite clast in the upper right, the distinctive greenish gray, sandy mudstone matrix, and the partial rounding of some clasts.



Zlvc3: Poorly sorted, volcaniclastic conglomerate (diamictite) on Middle Hill in Medford (site 10626). Note the distinctive greenish-gray, sandy mudstone matrix and the partial rounding of some clasts. Same rock as on Fig. Zlvc2.

Zlvc4: Volcaniclastic conglomerate on Little Pine Hill in Medford (site 10645) with pebbles, boulders (center), and grus-like debris from the Spot Pond Granodiorite (Zsg). Penny for scale.

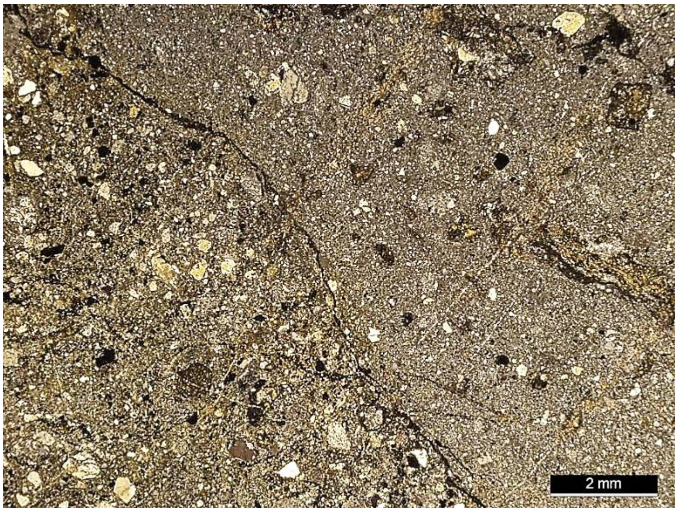
Zlvc5: Moderately to poorly sorted volcaniclastic conglomerate along Mud Road west of Little Pine Hill in Medford (site 10687) with abundant debris from the Spot Pond Granodiorite (Zsg). Matrix is a poorly sorted sandstone with abundant quartz.

Zlvc6: Volcaniclastic conglomerate on Little Pine Hill in Medford (site 10644) that contains pebbles, boulders and grus-like debris from the Spot Pond Granodiorite (Zsg) as well as volcanic clasts. Sample from Robert Reuss.

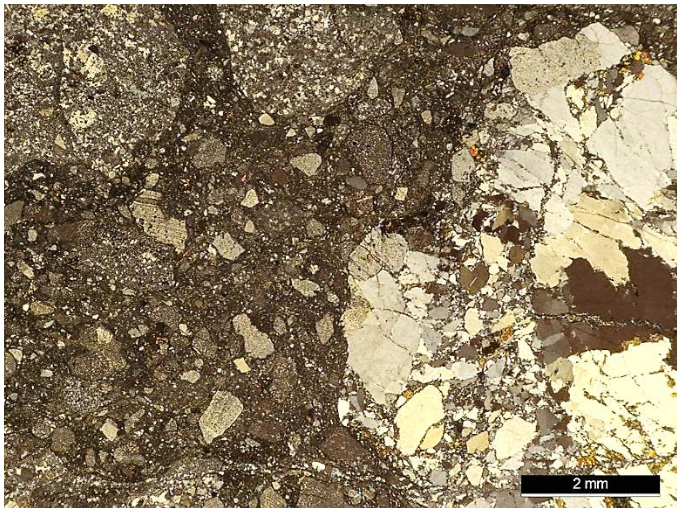
Zlvc7: Rusty weathering greenish-gray volcaniclastic sandstone and conglomerate on northern Pine Hill in Medford (site 10514) containing irregular large masses of light gray weathering tuff.

Zlvc8: Weathered surface of volcaniclastic sandstone and conglomerate on northern Pine Hill in Medford (site 10841) with abundant feldspar and volcanic pebbles and granules that are tightly grain-supported. This is the sandy conglomerate of the type shown in Fig. Zlvc7 with as much sorting as occurs in the unit.

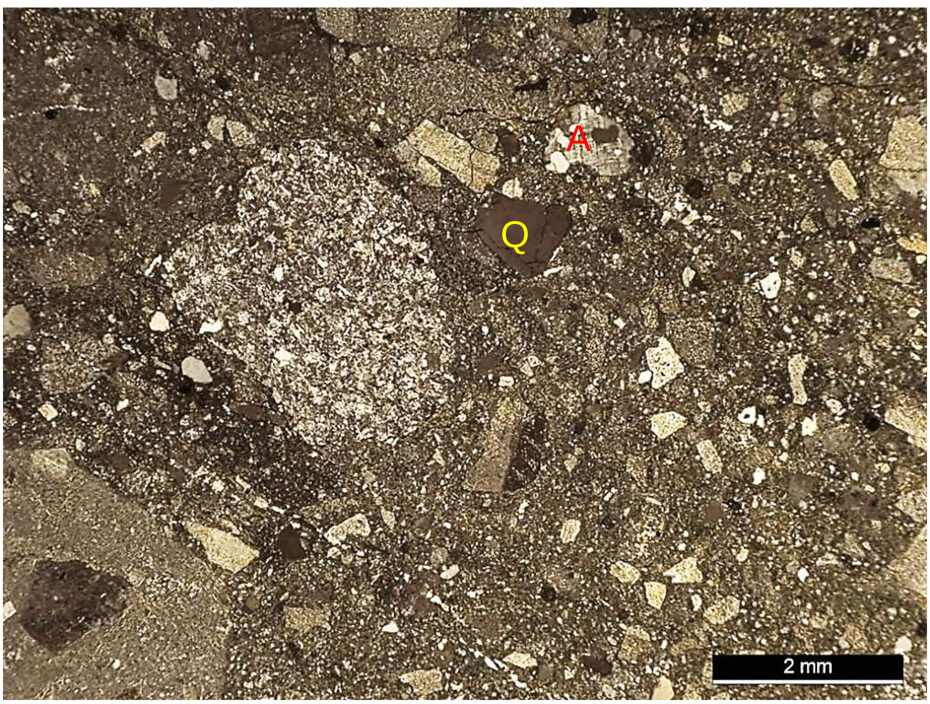
Thin section description: Volcaniclastic sandy mudstone (Fig. Zlvc9) to volcaniclastic polymictic conglomerate (Figs. Zlvc10-12) enclosing masses of vitric to crystal tuff (Fig. Zlvc13). The matrix is a granular sandy mudstone with sparse glass shards in a few places. Sand grains are predominantly rounded and broken plagioclase and subordinate broken and rounded quartz. None of the quartz grains have resorbed or embayed outlines. Twelve of 19 thin section samples had broken and subrounded to subangular alkali feldspar grains. Except for a few samples near contacts with granodiorite, volcanic clasts are abundant and most commonly very fine lithologies with plagioclase microlites and small crystals or they have a patchy to poikilomosaic texture. Also in the unit are volcanic clasts with a fibrous or axiolitic texture. A few clasts are banded, eutaxitic, or have glass shard outlines. Accidental clasts include quartzite with flattened and sutured grains from the Westboro Formation (Zvwq and Zwp; Fig. Zlvc12), and locally abundant granodiorite clasts from the Spot Pond Granodiorite (Zsg; Fig. Zlvc10).



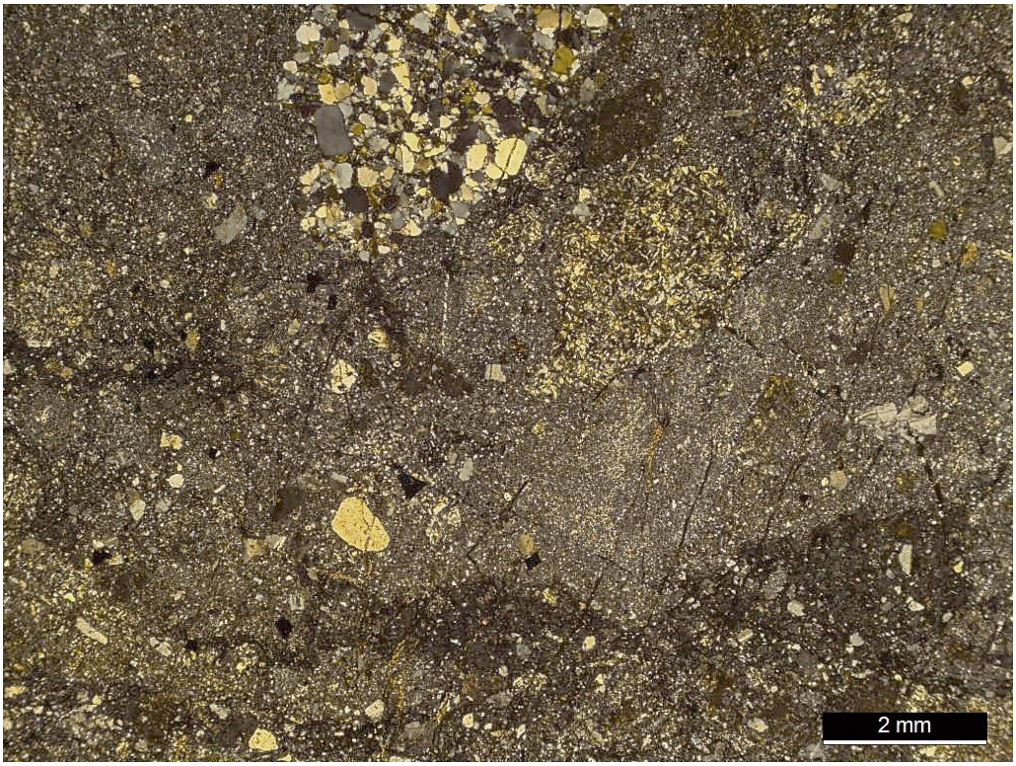
Zlvc9 (above): Volcaniclastic sandy mudstone on northern Pine Hill in Medford (site 10517). Shown is the contact between two beds with different sand concentrations. Thin section with crossed polarizers. See Fig. Zlvc1 for cut rock view.



Zlvc10 (above): Volcaniclastic polymictic conglomerate with two patchy textured volcanic clasts (upper left) and a cataclastic granodiorite clast (right) on Middle Hill in Medford (site 10626). Thin section with crossed polarizers. See Figs. Zlvc2-3 for cut rock views.

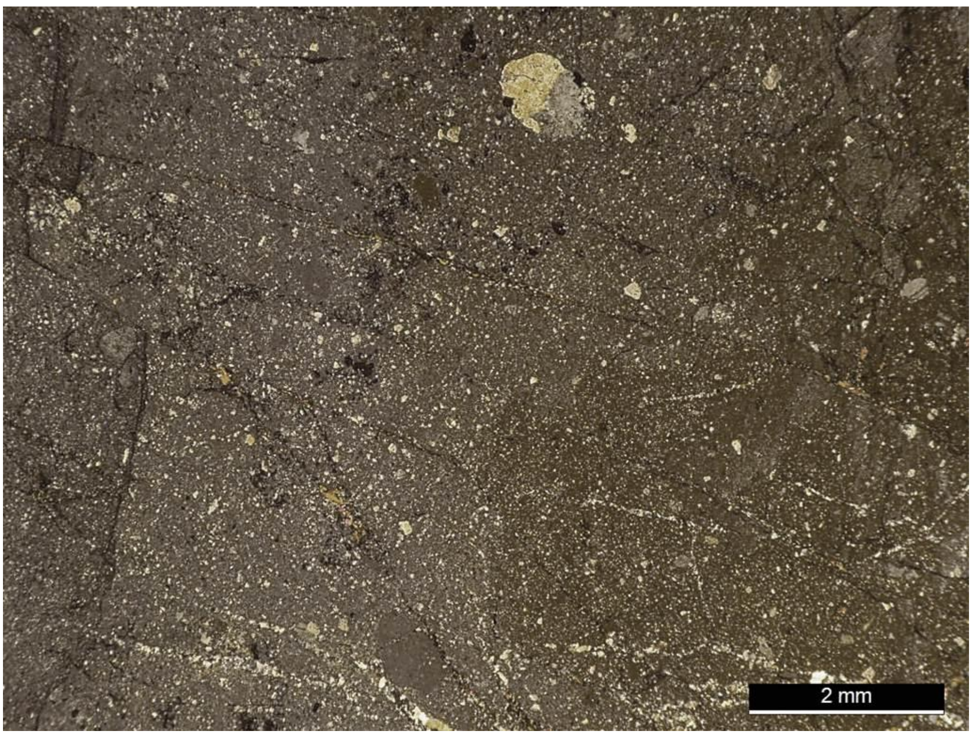


Zlvc11 (left): Poorly sorted volcaniclastic polymictic conglomerate (diamictite) with patchy textured volcanic clast containing fine tabular plagioclase crystals (middle left) and a fine eutaxitic volcanic clast (lower left corner) on Middle Hill in Medford (site 10626). In upper center is partly rounded quartz grain (Q) and alkali feldspar grain with cross-hatch twinning (A). Thin section with crossed polarizers. See Figs. Zlvc2-3 for cut rock views that show this lithology’s typical green matrix color.



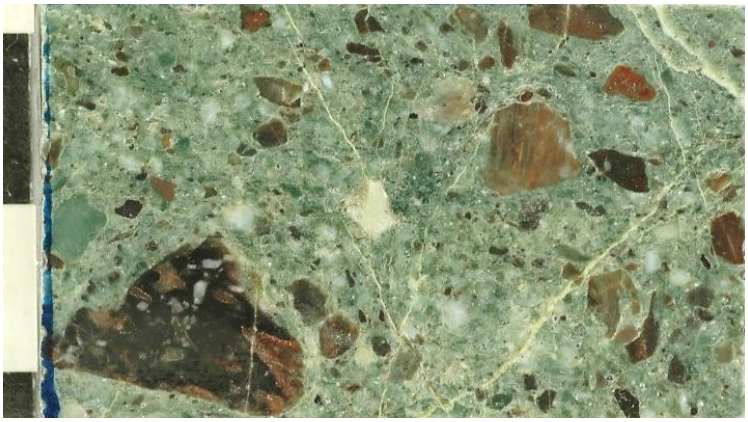
Zlvc12 (above): Volcaniclastic conglomerate west of Bellevue Pond in Medford (site 10885). At top is a quartzite clast with sutured grains from the Westboro Formation (Zvwq) and below that a fine volcanic clast. Note the rounding of some grains. Thin section with crossed polarizers.

Zlvc13 (below): Vitric tuff with fine feldspar and quartz grains and sparse coarse grains on northern Pine Hill in Medford (site 10840). Thin section with crossed polarizers.

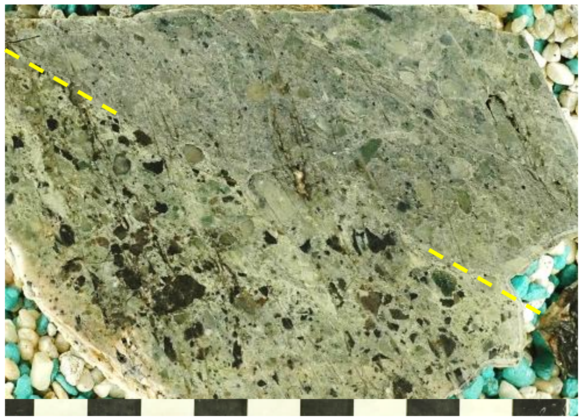


Felsic volcaniclastic rocks in the Boojum Rock area of the southern Fells and near Fellsmere Pond

Rock unit description: Medium light to dark gray (N3-6) to greenish-gray (5GY-G 5/1, matrix) volcanic breccia to volcaniclastic conglomerate (clast-supported to diamictite) like in the Pine Hill area but with different clast types, especially dark red volcanic fragments and alkali granite boulders. Rock types in the unit are interbedded but generally sorting improves upward from volcanic breccia with mostly angular volcanic clasts and a very poorly sorted green matrix (Fig. Zlvc14) to a better sorted, polymictic, clast-supported, volcaniclastic conglomerate with round pebbles and a sandy matrix (Fig. Zlvc15). In addition to volcanic lithologies, pebbles are also composed of white and gray to red, quartz sandstone (Fig. Zlvc16), laminated fine sandstone and siltstone (Fig. Zlvc17), and sparse alkali granite (Fig. Zlvc18-19) that resembles the Ball Quarry Granite of Smith and Hon (1984) and Smith (1985). Like in the Pine Hill area: 1) this facies forms the base of the Wakefield Formation in the Boojum Rock area, 2) can have a green diamictite matrix, and 3) rests on an angular unconformity that cuts across the regional trend of layering in the Boojum Rock Tuff (Zbrc) near the MIT Observatory and further north rests on the Spot Pond Granodiorite (Zsg). On the north side of the MIT Observatory the base of the unit is a greenish-gray sandstone unit overlain by volcaniclastic breccia (Zlvc 20-23). Along Woodland Road the volcaniclastic rocks are intruded by the Lawrence Woods Granophyre (Zlwg; Fig. 24). Volcaniclastic rocks at Fellsmere Pond on the Medford/Malden town line are similar with conspicuous alkali granite and red volcanic clasts (Figs. Zlvc25-27).



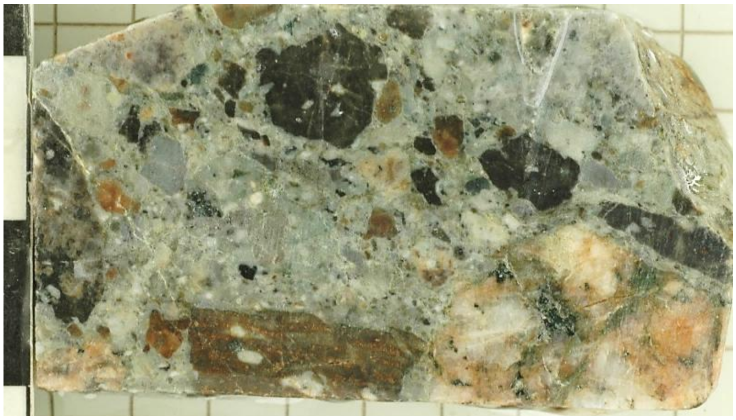
Zlvc14 (above): Volcanic breccia with dark red volcanic clasts and a few quartz, argillite, and quartzite clasts on Boojum Rock in Medford (site 10164). Note the green sandy matrix as occurs in the Pine Hill area (See Figs. Zlvc2-7).



Zlvc15 (above): Sorted polymictic conglomerate (above) in contact (yellow dashed lines) with volcanic breccia (below) on Boojum Rock in Medford (site 10553). Note dominance of angular, dark red volcanic fragments in the breccia.

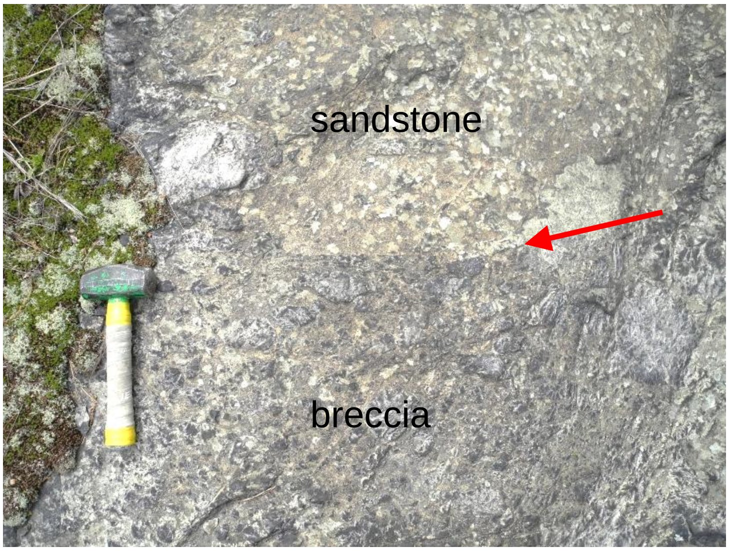
Zlvc16 (right): Outcrop view of polymictic conglomerate with rounded red sandstone pebble (below pencil) west of Boojum Rock in Medford (site 365BN).

Zlvc17: Weathered surface of polymictic conglomerate with abundant granite and quartzite debris west of Boojum Rock in Medford (site 364BN). Note non-metamorphosed laminated siltstone/fine sandstone pebble with graded beds.

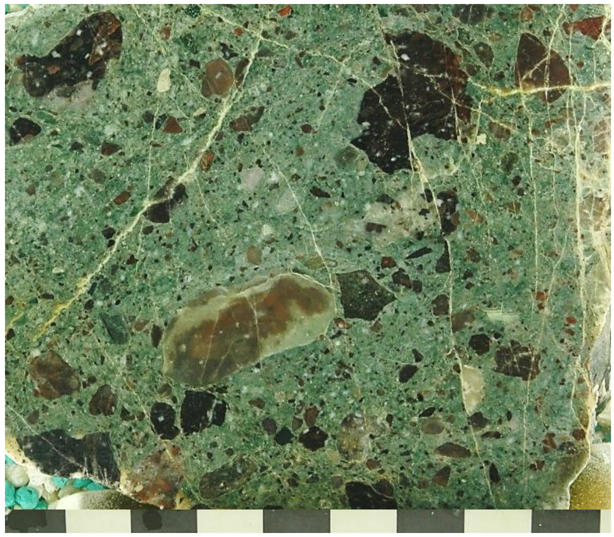


Zlvc18: Poorly sorted polymictic conglomerate south of Boojum Rock (site 364BN) with dark volcanic, quartzite, and granite-derived clasts and alkali feldspar.

Zlvc19: Very poorly sorted sandy diamictite with a rusty olive-colored sandstone matrix (to right of hammer) and alkali granite boulder (arrows) south of Boojum Rock (site 10252) above Woodland Road. The sandstone has a slightly rusty color when weathered and weathers by flaking (to right of hammer).



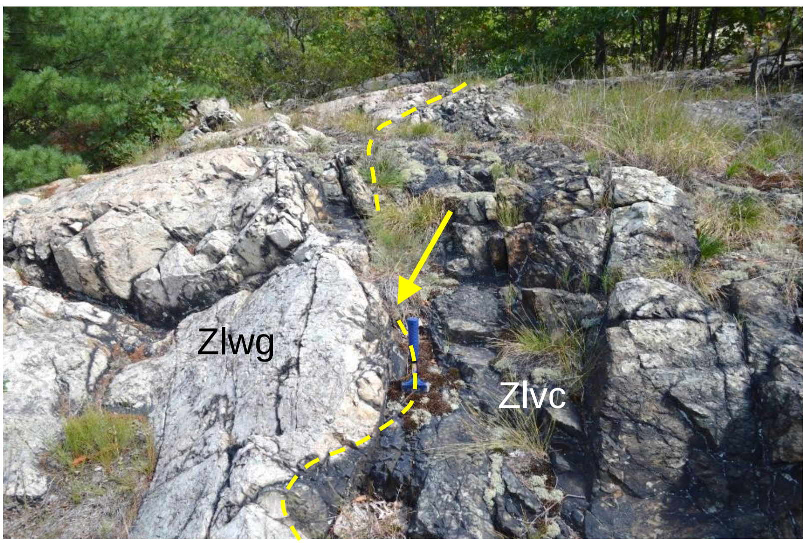
Zlvc20 (above): Contact (arrow) of volcaniclastic breccia overlying greenish-gray sandstone just north of the MIT Observatory on Boojum Rock. Hammer for scale. The sandstone weathers by flaking and oxidizes to a rusty color.



Zlvc21 (above): Greenish-gray volcaniclastic breccia just north of the MIT Observatory on Boojum Rock. Scale in cm. The breccia is dominated by volcanic clasts but also has quartz and granite debris.

Zlvc22 (above left): Fresh surface of greenish-gray sandstone just north of the MIT Observatory on Boojum Rock. Hammer for scale.

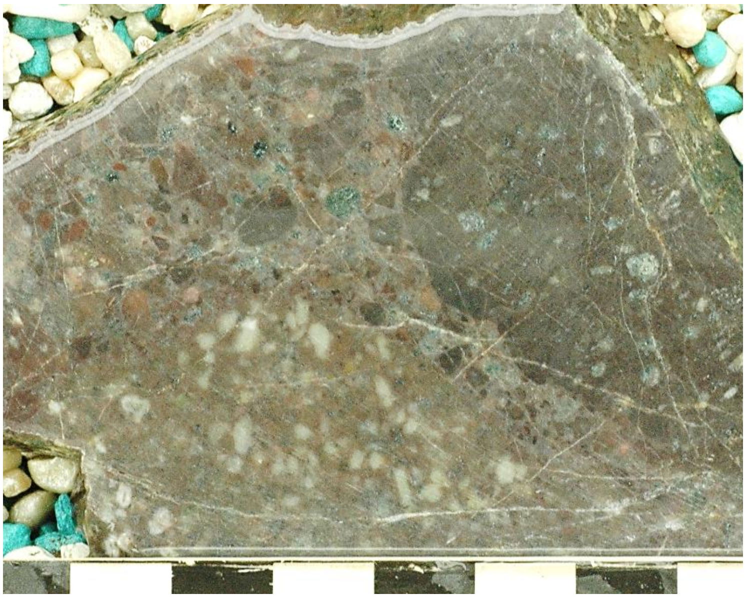
Zlvc23 (above right): Greenish-gray sandstone from same location as Fig. Zlvc22 cut on rock saw. Scale in cm.



Zlvc24 (right): Volcanoclastic conglomerate (Zlvc) intruded by the Lawrence Woods Granophyre (Zlwg) above Woodland Road west of Boojum Rock. Contact is at arrow and line. Hammer for scale.

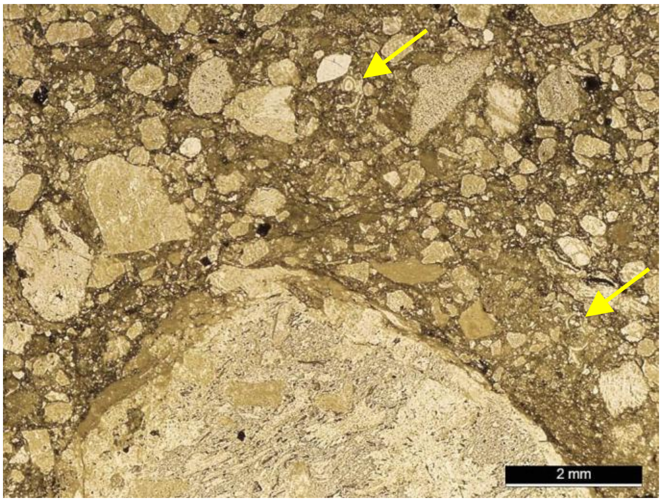
Zlvc25: Poorly sorted volcaniclastic conglomerate with greenish-gray sandy matrix and a large alkali granite clast (to right of pencil for scale) on the north side of Murray Street north of the old Malden Hospital complex in Medford (site 871BOSN).

Zlvc26: Poorly sorted volcaniclastic conglomerate with greenish-gray sandy matrix on west side of Grover Road west of the old Malden Hospital in Medford (site 11419). Scale in cm. The conglomerate has a mixture of granite, alkali granite, and red volcanic clasts.

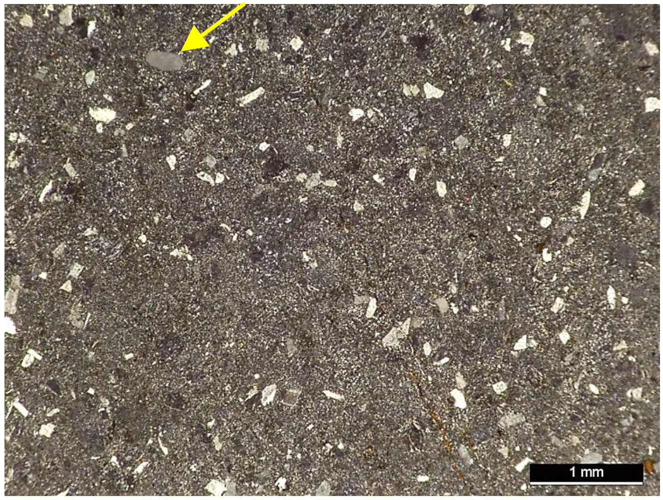


Zlvc27: Poorly sorted volcaniclastic conglomerate with pinkish-gray sandy matrix on the west side of the old Malden Hospital in Medford (site 11411). Scale in cm. The breccia has mostly dark red volcanic clasts and pinkish-tan porphyritic clasts with euhedral plagioclase crystals that may be from the Lawrence Woods Granophyre (Zlwg) that outcrops to the south.

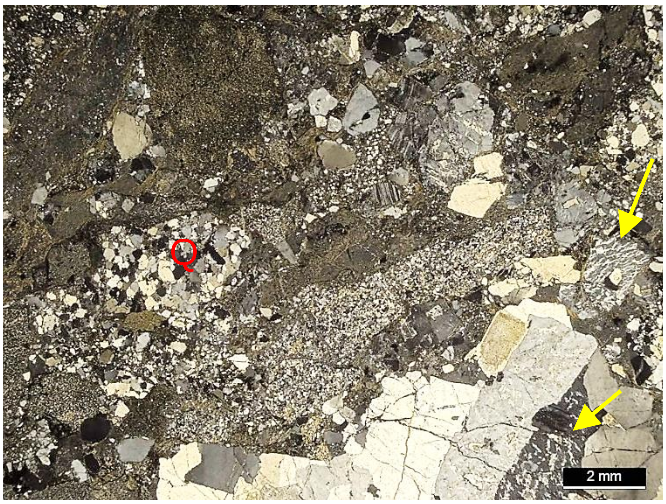
Thin section description: Gray to grayish-green, matrix-supported, polymictic volcanic breccia to clast-supported, well-sorted, volcaniclastic sandstone, conglomerate and diamictite. The breccias have a granular texture, often with a few visible devitrified glass shard outlines (Fig. Zlvc28). Sand-size grains are dominantly broken to rounded plagioclase with lesser broken to rounded quartz (Fig. Zlvc29), and occasional broken alkali feldspar that can be perthitic (Fig. Zlvc30). Volcanic lithic fragments are commonly banded (Fig. Zlvc31), eutaxitic (Fig. Zlvc28), micropoikilitic to poikilomosaic, and ultra-fine with microlites and very fine phenocrysts of plagioclase. Less common are volcanic fragments with spherulitic and perlitic textures (Fig. Zlvc32). Volcanic breccias contain abundant fragments from adjacent rock units. Locally abundant are accidental lithic clasts that include quartzite and sandstone (Zlvc16-17 and 30) with heavily sutured to perfectly rounded grains and argillite from the Westboro Formation (Zvwq and Zwp), non-metamorphosed red sandstone and laminated shale to fine sandstone of uncertain origin, and granitic clasts (Fig. Zlvc30-33).



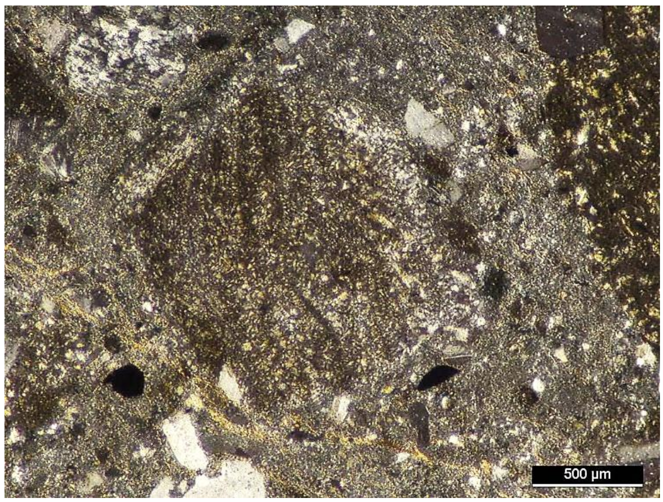
Zlvc28 (above): Volcanic breccia with glass shards in matrix (arrows) on Boojum Rock in Medford (site 10164). At bottom of image is volcanic lithic fragment with eutaxitic texture. Thin section in plane polarized light. See Fig. Zlvc14 for cut rock view.



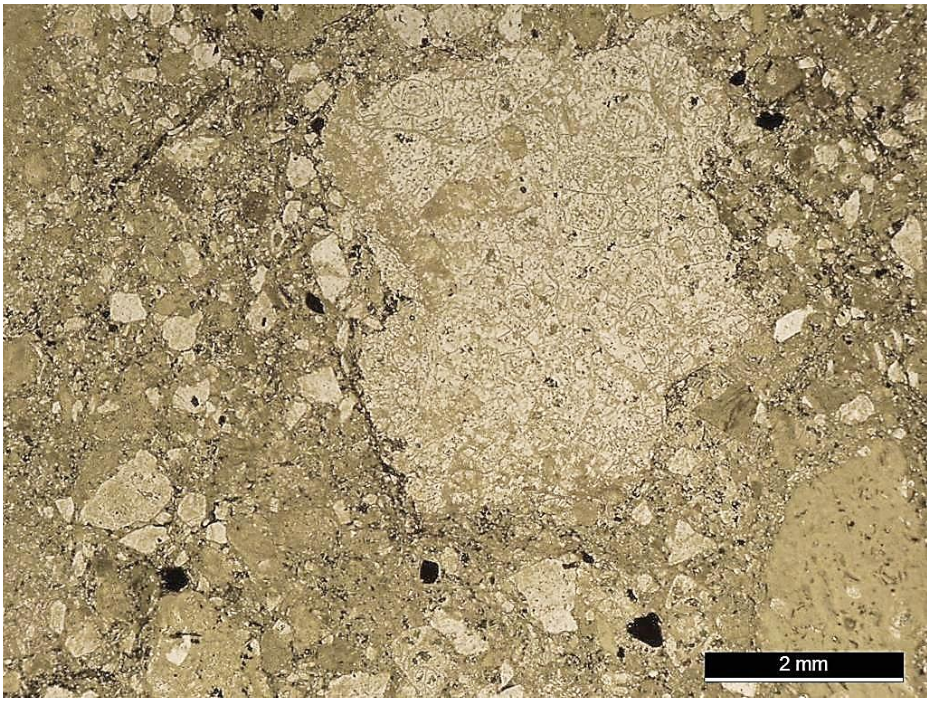
Zlvc29 (above): Volcaniclastic sandstone with mostly broken plagioclase grains and a rounded quartz grain oriented near extinction (arrow) on Boojum Rock in Medford (site 10547). This is the basal sandstone of the unit overlying the Boojum Rock Tuff (Fig. Zlvc22-23). Crossed polarizers.



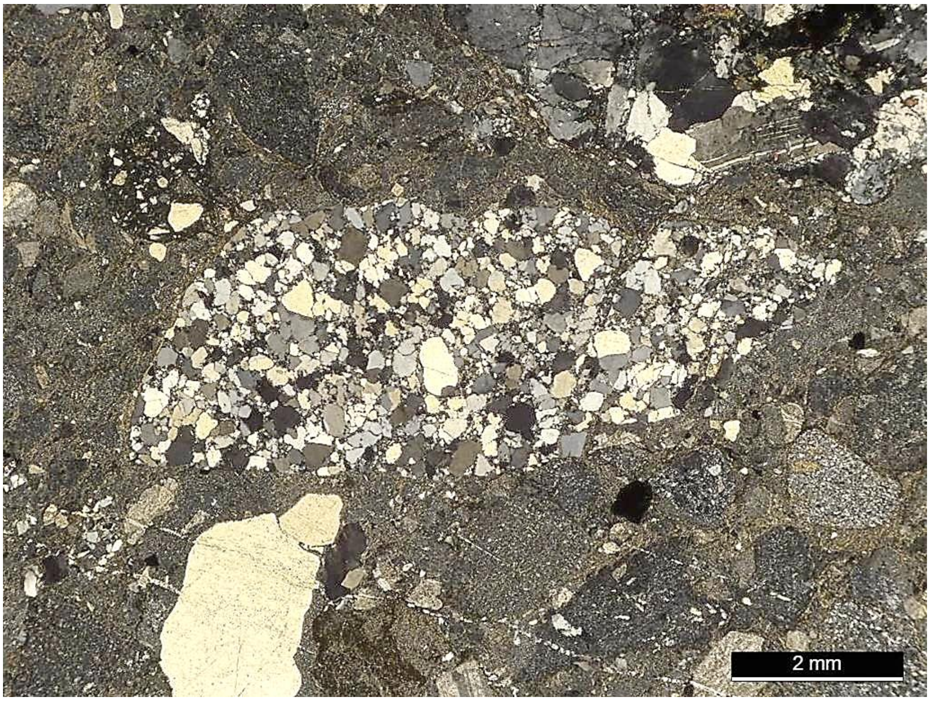
Zlvc30 (above): Volcaniclastic conglomerate with perthitic alkali feldspar grains (arrows) and quartzite clast (Q) with sutured grains west of Boojum Rock in Medford (site 365BN). The lower alkali feldspar grain is part of a multi-grain granitic clast (whole lower right of image). Crossed polarizers. See Fig. Zlvc16 for outcrop view.



Zlvc31 (above right): Volcanic breccia with volcanic lithic fragment that has pyroclastic banding and micro-spherules near Boojum Rock in Medford (site 10923). Thin section with crossed polarizers.



Zlvc32: Volcanic breccia with perlitic volcanic clast on Boojum Rock in Medford (site 10923). Thin section in plane polarized light.

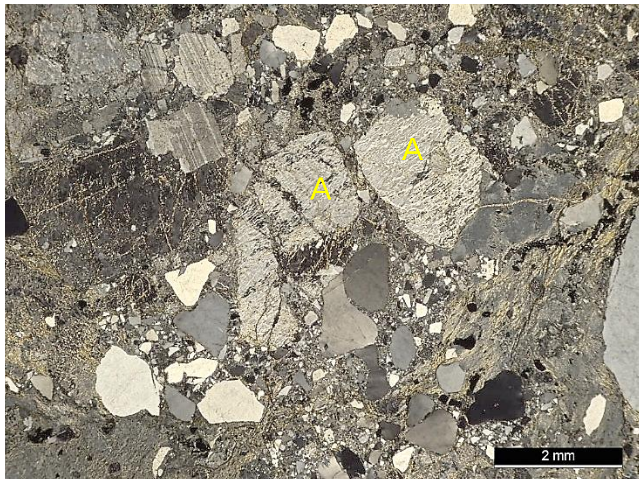


Zlvc33: Volcaniclastic conglomerate with volcanic lithic fragments and quartzite clast with sutured grains (center) west of Boojum Rock in Medford (site 364BN). Large clear grain in lower left is rounded quartz. In upper right is granitic clast. Thin section with crossed polarizers. See Figs. Zlvc17-18 for rock sample views.

Felsic volcaniclastic rocks in the northern Fells

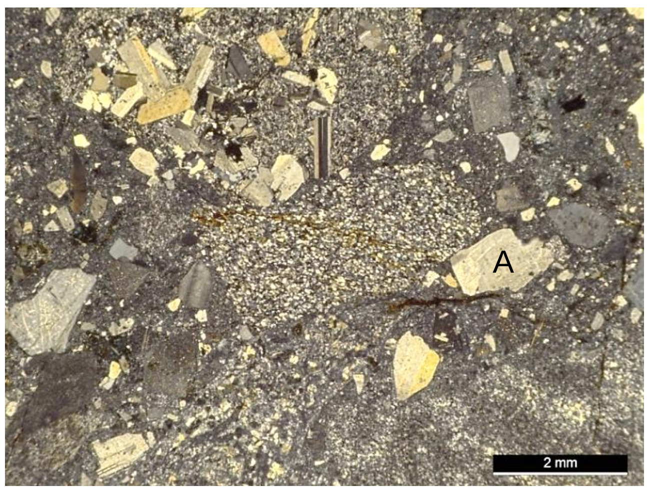
Rock unit/thin section descriptions: Outcrops of felsic volcaniclastic rocks are scarce in the northern Fells and only occur at two places. At the northeast corner of Spot Pond along the northwest side of the Stone Zoo the volcaniclastic facies rests on the Westboro Formation (Zwp) along an unconformity forming a thin layer at the base of the Wakefield Fm. The volcaniclastic conglomerate near Spot Pond is gray to greenish-gray poorly sorted sandy conglomerate (Zlvc34-35) with abundant granitic debris, quartzite and volcanic clasts and abundant quartz and feldspar sand grains. The second exposure of volcaniclastic rock in the northern Fells is on the east side of a north-south trending fault zone northwest of Whip Hill and along the west side of the swamp separating Greenwood Park from Whip Hill in Stoneham. It is also a poorly sorted sandy conglomerate with granitic debris and volcanic and quartzite clasts (Fig. Zlvc36-37).

Zlvc34 (above): Poorly sorted volcaniclastic conglomerate with volcanic and coarse granitic debris at northeast corner of Spot Pond adjacent to the Stone Zoo in Stoneham (site 10602). Dark lithic fragment in left center is dark reddish-gray volcanic clast with fine feldspar crystals.



Zlvc35 (above): Volcaniclastic conglomerate with abundant granitic debris (site 10602; same rock as Fig. Zlvc34). Note the rounded and broken quartz grains, multi-grain granitic fragments, and perthitic alkali feldspar grains (A). The size of these grains (~2 mm) indicates they are derived from a coarse granitic rock unit, likely the Spot Pond Granodiorite. Thin section with crossed polarizers.

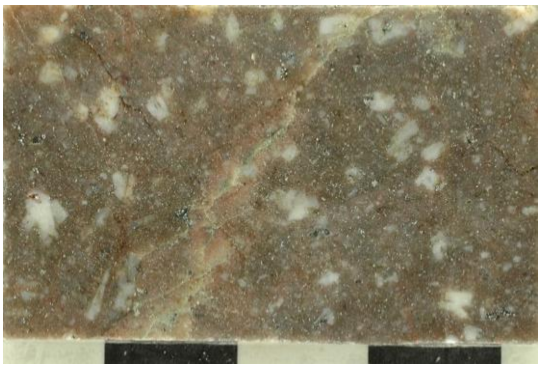
Zlvc36 (above): Volcaniclastic conglomerate west of Whip Hill in Stoneham (site 10584). Unit has granitic debris and volcanic and quartzite clasts. Cut rock sample. Scale in cm.

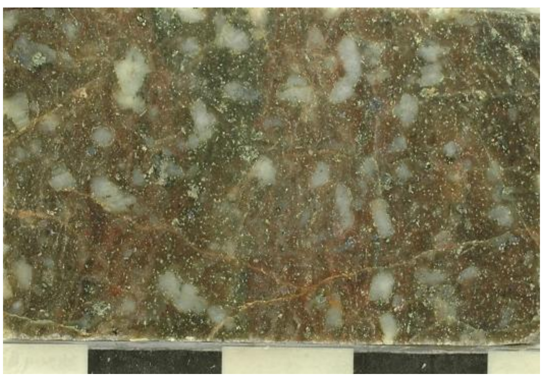


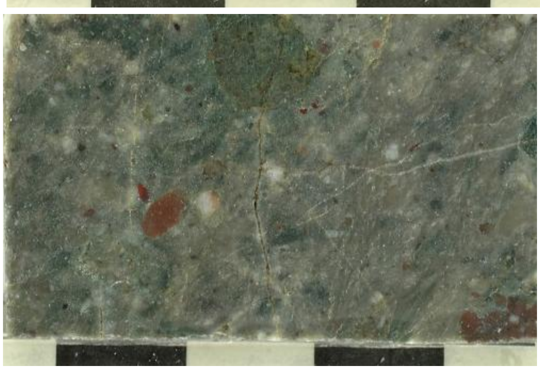
Zlvc37 (above right): Volcaniclastic conglomerate west of Whip Hill in Stoneham (site 10584; Same rock as Fig. Zlvc36). At the top is a rhyolite flow clast with cumulophyric, euhedral plagioclase. In the center is a fine quartzite clast with flattened and sutured quartz grains. In the lower right is a volcanic clast with no crystals and fine patchy to micropoikilitic texture. On the right side is an alkali feldspar grain (A). Thin section with crossed polarizers.

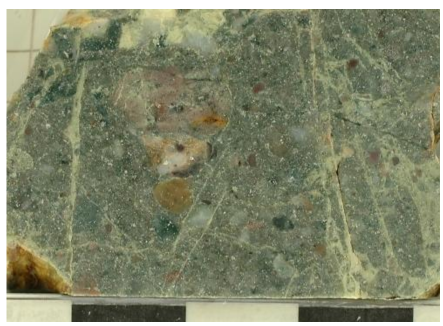
Zlvp

Rhyolite porphyry facies – Rhyolite porphyry, up to 100 m wide and trending NNE to SSW, that cuts across the Boojum Rock Tuff (Zbrc). Traced from the Boojum Rock area northward to the northeast peninsula of Fells Reservoir where it terminates at a fault. It could not be found northeast of the Fells Reservoir or southwest of a large dolerite dike (d) near the MIT Observatory. The dolerite dike intruded an E-W trending fault that displaced the porphyry. The porphyry 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) on non-weathered surfaces (Fig Zlvp1-3). This unit is distinct from the Boojum Rock Tuff because it has: 1) large, almost completely euhedral, cumulophyric plagioclase (Fig Zlvp1-3) that is fresher and larger than in the Boojum Rock Tuff, where crystals are mostly altered, broken and never cumulophyric; 2) areas of flow layering along its contact (Fig Zlvp3) with the same color characteristics and plagioclase crystals as in the more massive porphyry at the center of the unit; and 3) abundant rounded and embayed quartz crystals that do not occur in the Boojum Rock Tuff. Along the unit's contact are occasional pockets of 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 conglomerate to breccia that has red to pink and gray volcanic clasts (Fig Zlvp4-5). Based on its map geometry and composition this unit is interpreted to be a large dike-like fissure or vent that was invaded by a porphyritic subvolcanic magma. Similarities with the Lawrence Woods Granophyre (Zlwg) suggest that it is an offshoot of the subvolcanic granophyre, but no physical connection has been found.









Zlvp1 (left): Very faintly banded (upper left to lower right) cumulophyric rhyolite on the south side of the Fells Reservoir in Stoneham (site 10896).

Zlvp2 (middle left): Faintly banded (vertical in image) rhyolite porphyry on the Fells Reservoir peninsula in Stoneham (site 10906).

Zlvp3 (right): Well banded rhyolite porphyry near unit's contact (bottom of image) north of Boojum Rock in Stoneham (site 10912). Bands are parallel to contact.

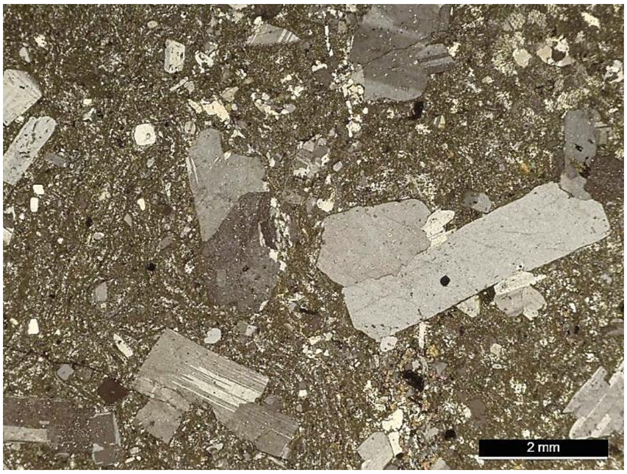
Zlvp4 (bottom left): Volcaniclastic breccia south of Fells Reservoir in Stoneham (site 10895).

Zlvp5 (bottom right): Volcaniclastic conglomerate on Fells Reservoir peninsula in Stoneham (site 10907). Pink fragment is volcanic.

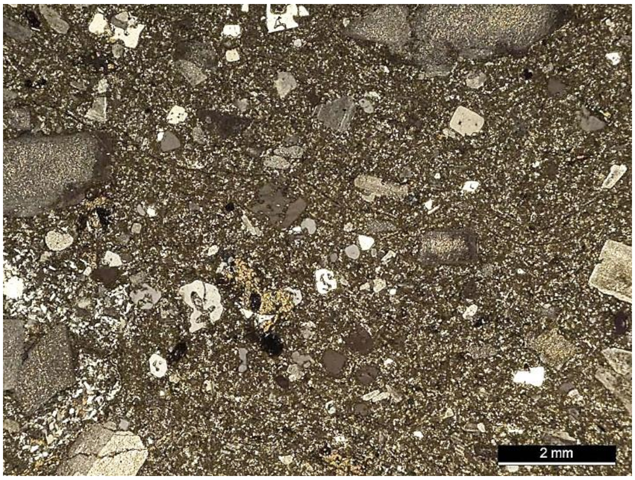
Rhyolite porphyry facies (cont.)

Thin section description: Faintly reddish-gray, flow-banded to massive, cumulophyric to porphyritic rhyolite with associated minor volcanic breccia and conglomerate at its margins. Banded parts of the matrix have long continuous strands of axiolitic texture (Fig. Zlvp6) while non-banded areas have an ultra-fine to micropoikilitic or patchy texture of intergrown feldspar and quartz with occasional myrmikitic growths on plagioclase (Fig. Zlvp7-11). Crystals are dominantly euhedral, sometimes lightly resorbed or broken, cumulophyric plagioclase (Fig. Zlvp10) and subordinate heavily embayed (Fig. Zlvp11), rounded, and sometimes broken quartz. Occasionally quartz has a euhedral double dipyramid shape (Fig. Zlvp10). Less common are broken alkali feldspar xenocrysts and volcanic xenoliths. Conspicuous to faint banding occurs in most samples and is expressed by changes in matrix grain size and alignment of tabular plagioclase crystals.

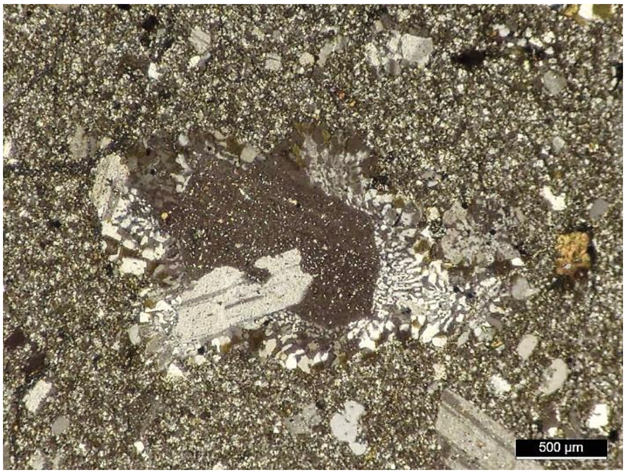
At contact areas are discontinuous greenish-gray clastic rocks with a fine to ultra-fine granular matrix (Fig. Zlvp12). Crystals are euhedral to broken, sometimes rounded, non-cumulophyric plagioclase with lesser broken and resorbed quartz as well as broken alkali feldspar crystals (Fig. Zlvp13). Also found were accidental lithic fragments of quartzite and granodiorite (Fig. Zlvp13). This appears to be debris along the sides of a fissure.



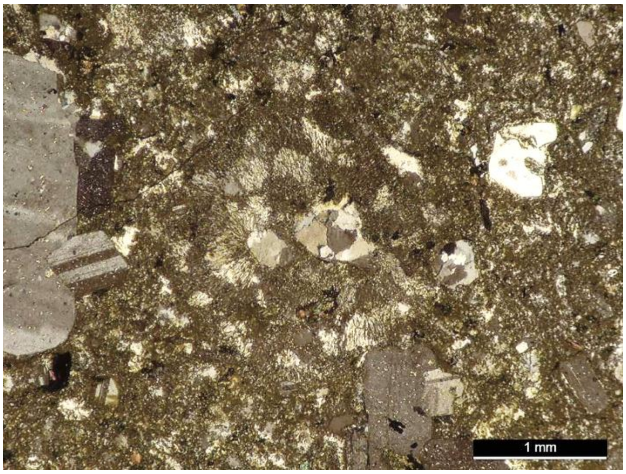
Zlvp6 (above): Banded (left side) cumulophyric rhyolite at Fells Reservoir peninsula in Stoneham (site 10906). Right side of image has patchy myrmikitic growths (see below). Thin section with crossed polarizers. See Fig. Zlvp2 for cut rock view.



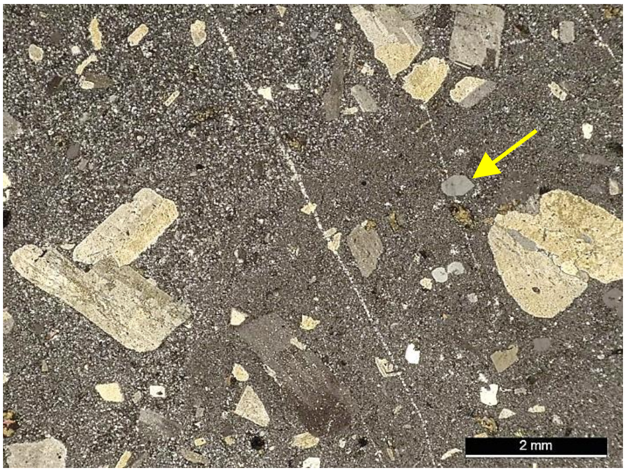
Zlvp7 (above): Non-banded, porphyritic rhyolite south of Fells Reservoir in Stoneham (site 10912). The matrix has a fine patchy to micropoikilitic texture, embayed quartz crystals, and altered euhedral plagioclase. Thin section with crossed polarizers. See Fig. Zlvp3 for cut rock view.



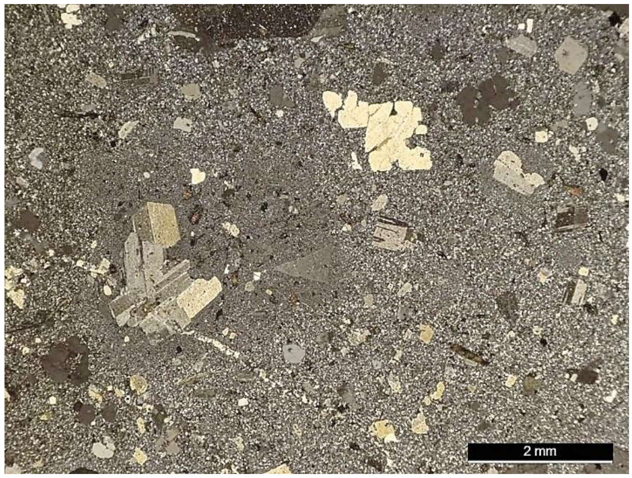
Zlvp8 (above): Granophyric growth on cumulophyric plagioclase in rhyolite at south shore of Fells Reservoir in Stoneham (site 10896). Thin section with crossed polarizers. See Fig. Zlvp1 for cut rock view.



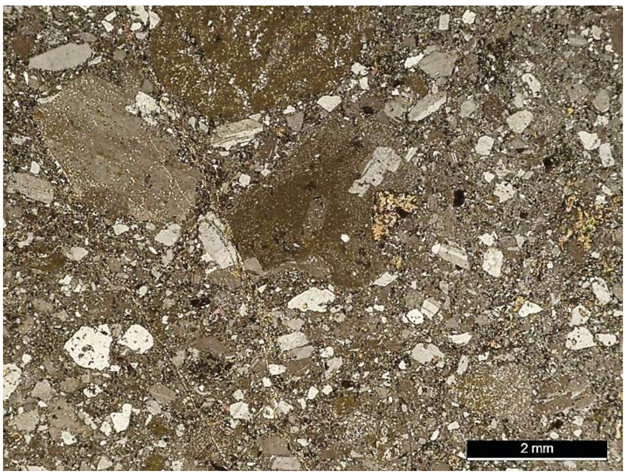
Zlvp9 (above): Area of fibrous myrmikitic growth on quartz and plagioclase in rhyolite at Fells Reservoir peninsula in Stoneham (site 10906). Note embayed quartz crystal in upper right. Thin section with crossed polarizers. Close up of upper right corner of Fig. Zlvp6 rotated 30^{o} CCW. See Fig. Zlvp2 for cut rock view.



Zlvp10: Partly resorbed cumulophyric plagioclase in rhyolite south of Fells Reservoir in Stoneham (site 405BN). Arrow indicates double dipyramid quartz crystal. The matrix is non-layered with a fine (left) to very fine (right) patchy texture. Thin section with crossed polarizers.



Zlvp11: Cumulophyric plagioclase cluster (left) surrounded by finer matrix and heavily embayed and fractured quartz crystals (upper right, one is black at extinction) in rhyolite at south shore of Fells Reservoir in Stoneham (site 10896). The matrix is non-layered with a fine patchy texture. Thin section with crossed polarizers. See Fig. Zlvp1 for cut rock view.



Zlvp12: Granular texture of volcaniclastic rock associated with margins of rhyolite porphyry at Fells Reservoir peninsula in Stoneham (site 10907). Thin section with crossed polarizers. See Fig. Zlvp5 for cut rock view. Bright colors are epidote. Note broken grains and abundant quartz.

Zlvp13: Ultra-fine granular texture of volcaniclastic rock associated with margins of rhyolite porphyry on south side of Fells Reservoir in Stoneham (site 10895). At left center is fine volcanic lithic fragment. Dark yellowish grain (stained for potassium) just to the right of center is alkali feldspar and grain in upper center is a granitic clast made of plagioclase, quartz and alkali feldspar. Thin section with crossed polarizers. See Fig. Zlvp4 for cut rock view.

Felsic Facies of the Wakefield Formation (cont.)

Zlvv

Vitric tuff facies - Rock unit description: Light bluish- to pinkish-gray (5B 7/1 to5 YR 8/1), fine vitric tuff (Figs. Zlvv1-4) with occasional faint layering (Fig. Zlvv5) and a chert-like appearance in outcrops (Fig. Zlvv3). Weathers to a white to light gray color (Fig. Zlvv1). This unit grades between almost pure fine ash tuff and fine ash tuff with sparse crystals and lithic fragments before grading into crystal tuff. In the Pine Hill area, rocks of this lithology are very small zones within crystal tuff (Figs. Zlvc7, Zlvx6 and 14). Along faults this unit deforms with a peculiar wavy, lenticular foliation (Fig. Zlvv6). Glacial erratics of this facies are found south of Crystal Lake in Wakefield and are from tuff beneath the lake.

Zlvv1: Dark gray, white weathering (see label) fine vitric tuff with fine crystals at the Mapleway Playground parking lot southeast of Oak Street in Wakefield (site 11730).

Zlvv2: Dark gray, white weathering fine vitric tuff with scattered very fine crystals at the Mapleway Playground parking lot southeast of Oak Street in Wakefield (site 11730). Outcrop view in Fig. Zlvv1.

Zlvv3: Chert-like outcrop of light gray very fine vitric tuff west of Boojum Rock in Medford (site 10248).

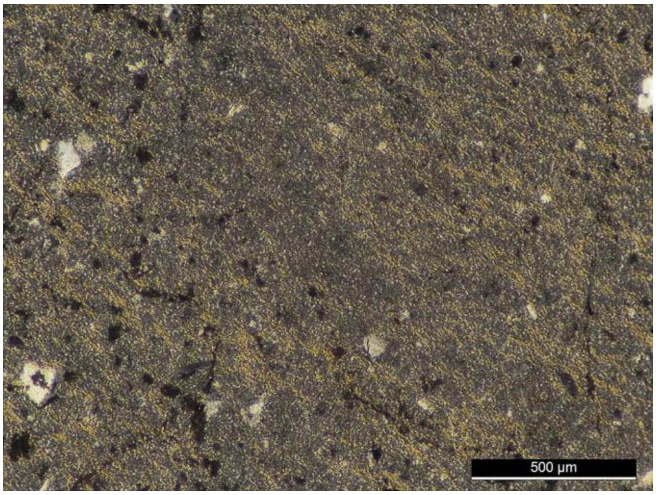
Zlvv4: Light gray very fine vitric tuff with very fine crystals west of Boojum Rock in Medford (site 10231).

Zlvv5: Light gray very fine vitric tuff with faint layering west of Boojum Rock in Medford (site 10242).

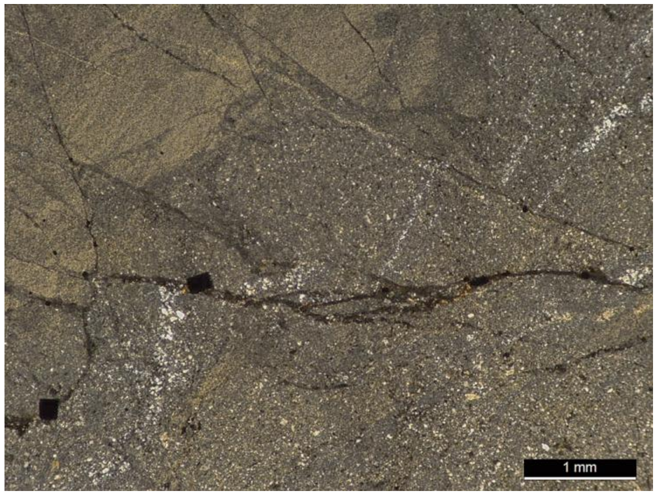
Zlvv6: Purplish-gray vitric tuff with wavy, lenticular foliation along fault in part of the Wakefield Town Forest that extends into Saugus (site 11769). Below is foliated vitric tuff while above (at hammer handle) is non-foliated vitric tuff with scattered crystals.

Wakefield Formation - vitric tuff facies (cont.)

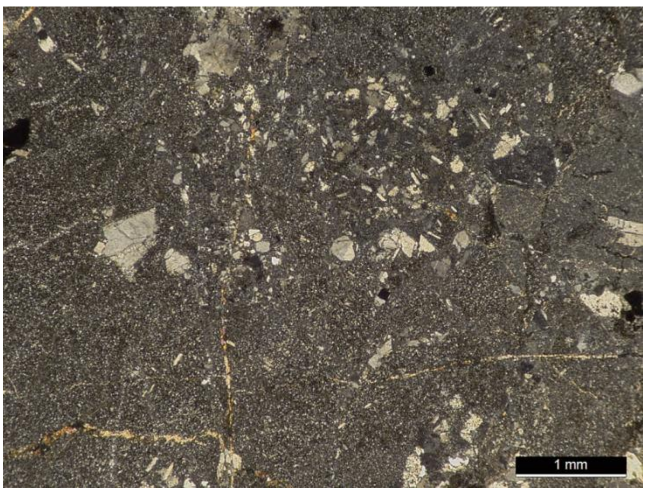
<u>Thin section description</u>: Vitric tuff with an ultra-fine granular to very fine patchy matrix of intergrown feldspar and quartz that has faint traces of glass shards, flattened pumice and obsidian fragments (Fig. Zlvv7). The tuff occasionally shows faint layering and euhedral pyrite cubes (Fig. Zlvv8). Throughout the unit, crystals and lithic fragments are small and sparse. Crystals are dominantly broken euhedral and sometimes rounded plagioclase with lesser broken and rounded quartz. One broken alkali feldspar grain was recorded. Lithic fragments are mostly very fine but when identifiable are dominantly volcanic with very fine patchy and ultra-fine textures with plagioclase microlites and small tabular plagioclase phenocrysts (Fig. Zlvv9). Some eutaxitic and pyroclastic banded volcanic fragments were also found. Like in other parts of the Wakefield Formation, this facies has small accidental lithic fragments of quartzite (Fig. Zlvv10).



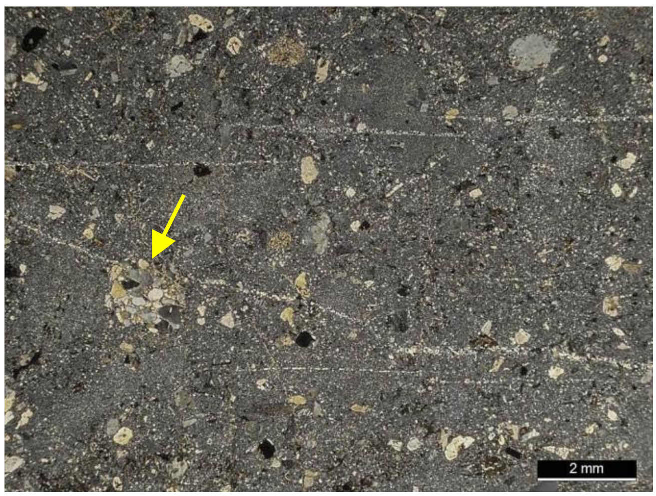
Zlvv7 (above): Vitric tuff with ultra-fine matrix and fine glass shard outlines near Boojum Rock in Medford (site 10231). Note orange wisps that are sericite formed parallel to very fine flattened glass shards. Rock has scattered fine broken crystals. Thin section with crossed polarizers. See Fig. Zlvv2 for cut rock view.



Zlvv8 (above): Ultra-fine matrix showing areas of two different grain sizes that define faint layering near Boojum Rock in Medford (site 10961). Note opaque pyrite cubes. Thin section with crossed polarizers.



Zlvv9 (above): Ultra-fine matrix and volcanic lithic fragment with fine matrix and tabular plagioclase crystals near Boojum Rock in Medford (site 10917). Rock has scattered broken crystals. Thin section with crossed polarizers. The small size of crystals makes them hard to see in outcrops or hand samples.



Zlvv10 (above): Ultra-fine matrix with quartzite lithic fragment (arrow) near Boojum Rock in Medford (site 10232). Thin section with crossed polarizers.

Zlvx

Crystal tuff facies – The crystal tuff facies occurs in three general areas in the Middlesex Fells and further north in the Boston North Quadrangle. Descriptions are given below of crystal tuff in the southern Fells (Pine Hill area to Boojum Rock), northern Fells (Straw Point to Wamoset Hill and Melrose) and Wakefield to Saugus. Crystal tuff in these areas is similar with differences being in the types of crystals and scattered lithic fragments, and occurrence of banding. Although there are local differences there are also some general characteristics of all crystal tuff units in the Wakefield Formation, which are revealed by point count data. There is considerable variation in the normalized whole rock (Matrix-Crystal-Fragment) ternary plot for crystal tuff units in the Wakefield. Average crystal abundances are 10-50% (Fig. Zlvx1). Most important is that normalized crystal percentages (plagioclase-quartz plus alkali feldspar-lithic fragments) in crystal tuffs in the Wakefield have 5-30% quartz plus alkali feldspar crystals (Fig. Zlvx2). These crystals are accidental crystals derived from granitic bodies, and they only rarely occur in the older Boojum Rock Tuff (see Fig 1-6C on p. 17). Mafic mineral grains are mostly highly altered biotite.

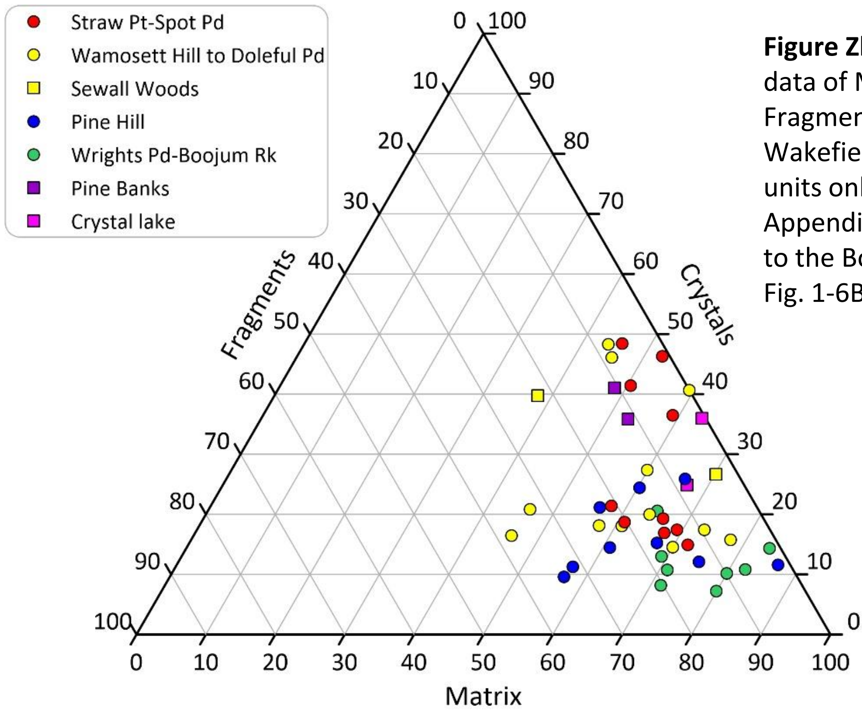


Figure Zlvx1. Whole rock point count data of Matrix-Crystal-Lithic Fragment percentages for the Wakefield Formation (crystal tuff units only) by area. Data is in Appendix 2A and 2B. A comparison to the Boojum Rock Tuff is given in Fig. 1-6B on p. 17.

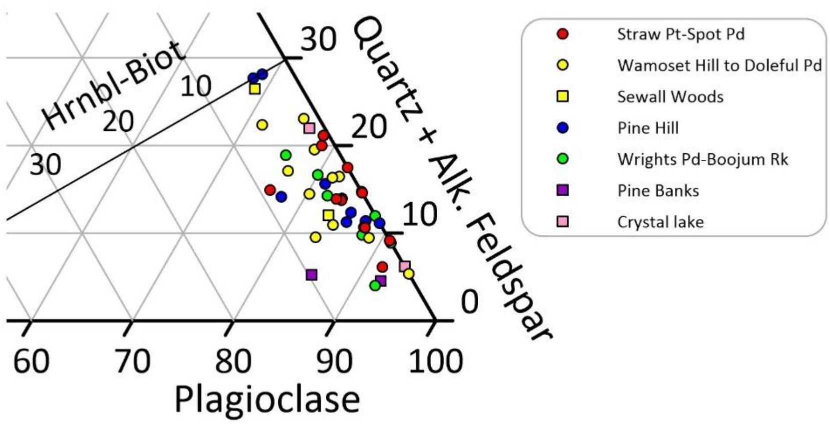
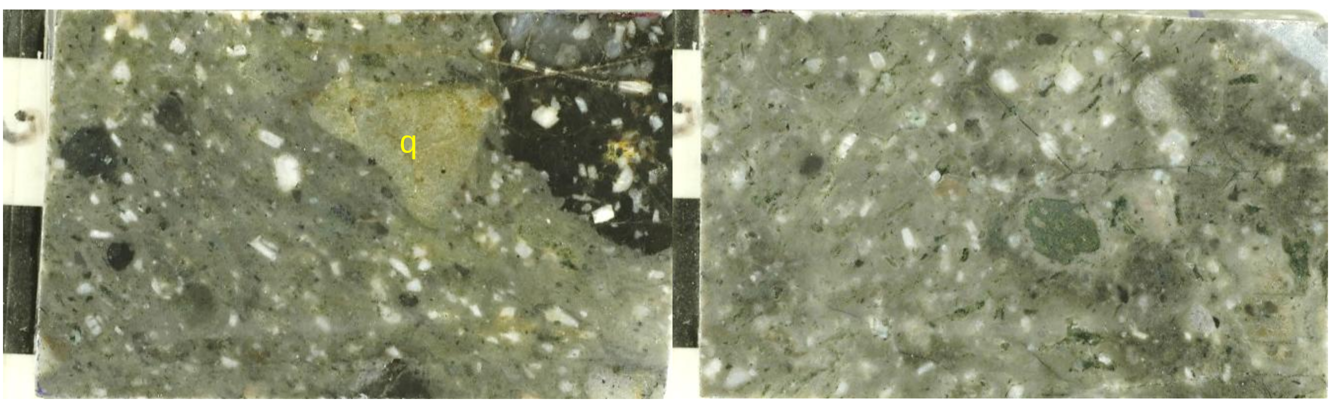


Figure Zlvx2. Ternary plot of crystal types (Quartz plus Alkali Feldspar-Mafic minerals (Hornblende plus Biotite)-Plagioclase) as normalized percentages for the Wakefield Formation (crystal tuff units only) by area. Data is in Appendix 2A and 2B. A comparison to the Boojum Rock Tuff is given in Fig. 1-6C on p. 17.

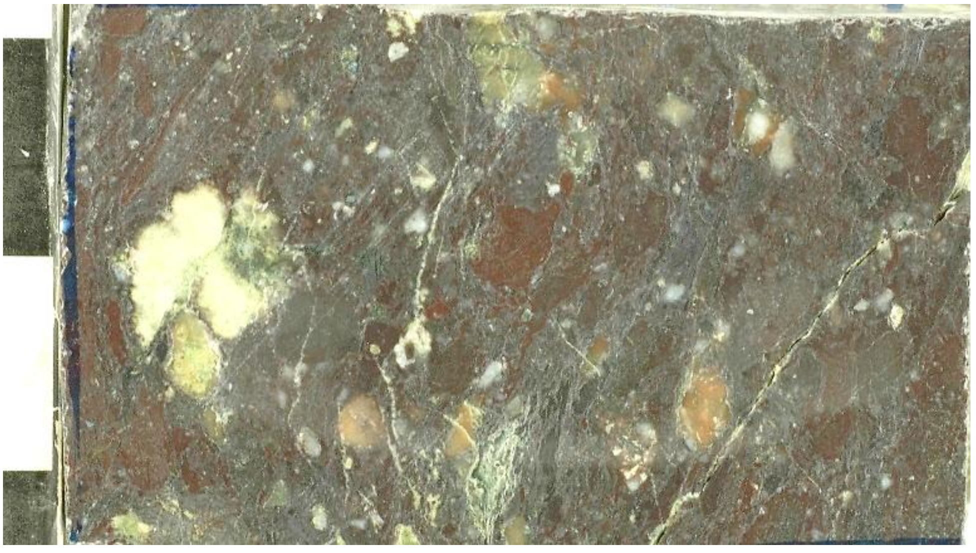
Crystal tuff facies in the southern Fells (Pine Hill, Wrights Pond, and Boojum Rock areas of Medford

Rock unit description: (*previously partly mapped as the "Tower Member" by Zarrow, 1978 at Pine Hill*) – Dusky blue to grayish-purple (5PB 4/2-6/2 to 5P 2-4/2) and dark bluish-gray (5B 4/1) to gray (N4/1) welded rhyolitic crystal tuff with varying banding and sizes and abundances of crystals and lithic fragments (Figs. Zlvx1-7). A QAP plot from normalized data for this unit and other parts of the Lynn Volcanic Complex is given with the introduction to the Lynn Volcanic Complex (p. 110; data in Appendix 1-C and 1-F from Smith, 1985 and Hampton, 2017). The unit is well exposed on the southern end of Middle Hill, on Pine Hill, at Wrights Pond and west of Boojum Rock to near Woodland Road and north of South Border Road. In all these places it is intruded by the subvolcanic Lawrence Woods Granophyre (Zlwg). The crystal tuff was not accurately separated by LaForge (1932) and Kaye (1980) from the Boojum Rock Tuff (Zbrc) or the Lawrence Woods Granophyre (Zlwg). The unit contains irregular and pinched masses of vitric tuff (Fig. Zlvx6). Thin sections and cut rock samples display flattened pumice and crystal fabrics that are warped around lithic fragments (Figs. Zlvx5-6 and 9-10) but are difficult to recognize in the field except at one place in the Boojum Rock area (Fig. Zlvx10). In the Boojum Rock area the crystal tuff displays areas of pyroclastic banding (Fig. Zlvx5-6) and large lithic fragments that are often pink vitric tuff (Fig. Zlvx11-12). Crystals are both euhedral and broken and are primarily plagioclase but also include rounded and embayed quartz crystals that are likely xenocrysts from the Spot Pond Granodiorite (Zsg), rounded dipyramid quartz crystals, and sparse alkali feldspar crystals. Lithic fragments are mostly felsic volcanic rock types. Also in the unit are quartzite fragments (Fig. Zlvx3) with preserved round grains as well as quartzite with heavily sutured and stretched grains from different parts of the Westboro Formation (Zwp and Zvwq). On the northeast shore of Wrights Pond, the unit includes reddish-black (5R 2/1), welded and banded, vitric tuff layers with minor crystals and lithic fragments (Fig. Zlvx13).



Zlvx3-4 (above left & right): Crystal tuff on Pine Hill in Medford (sites 10497 and 10513) with scattered quartzite (q) and volcanic lithic fragments.

Zlvx5: Rhyolitic welded tuff with pyroclastic banding, crystals, and lithic fragments on western Boojum Rock in Medford (site 10551).



Zlvx6: Pyroclastic banding in rhyolitic welded tuff with crystals and lithic fragments on western Boojum Rock in Medford (site 10245). Pinkish-orange fragments are volcanic (vitric tuff).

Zlvx7 (left): Welded crystal tuff with lithic fragments in contact with volcaniclastic breccia/conglomerate (left side) on Boojum Rock in Medford (site 10246).

Zlvx8: Light gray vitric tuff masses in dark gray crystal tuff on north side of Wrights Tower on Pine Hill in Medford (site 10498). Rock hammer for scale.

Zlvx9: Crystal welded tuff with flattened glass/pumice fragments (black) warped around quartzite clast on Pine Hill in Medford (site 10502).

Zlvx10: Welded tuff with black, flattened pumice fragments west of Boojum Rock in Medford (site 10552). Penny for scale.

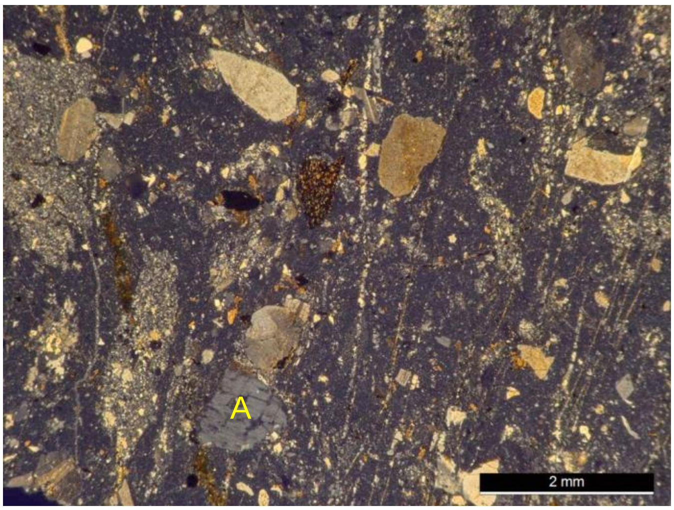
Zlvx11: Very large light gray welded crystal/lithic tuff fragment on right in darker welded crystal tuff west of Boojum Rock in Medford (site 10552). Rock hammer for scale.

Zlvx12: Pink, vitric tuff lithic fragments in light gray welded crystal tuff west of Boojum Rock in Medford (site 10552). This zone of fragments is very thin. Lens cap for scale.

Zlvx13: Dark red to gray, faintly banded crystal tuff at northeast corner of Wrights Pond in Medford (site 10467) with flattened pumice.

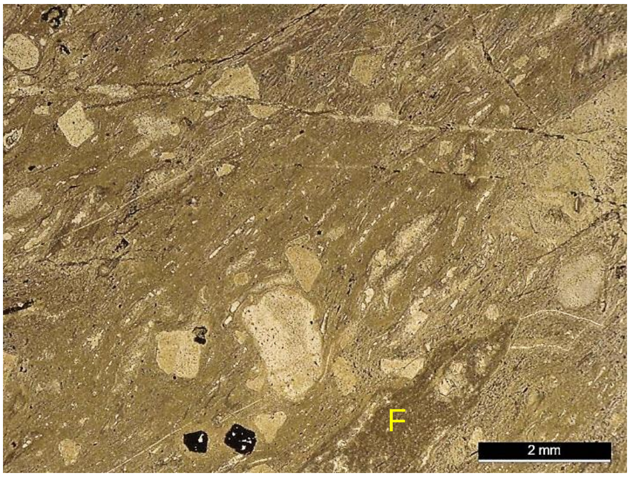
Crystal tuff facies in the southern Fells (Pine Hill, Wrights Pond, and Boojum Rock areas of Medford

Thin section description: Non-welded to mostly welded, rhyolitic crystal tuff, usually with microscopic pyroclastic banding, which is difficult to see in hand specimens, and sparse lithic fragments (Figs. Zlvx1-2 and 14-17). The matrix can be an ultra-fine granular (dusty), patchy, or poikilomosaic texture or are eutaxitic (Fig. Zlvx18) with glass shard outlines (Fig. Zlvx19). Most samples have pyroclastic layering (Figs. Zlvx14-18) with devitrified, flattened pumice and obsidian fragments (Figs. Zlvx14, 16, 18, and 20) and half of the samples have a eutaxitic texture (Fig. Zlvx16 and 21). Some samples show well developed spherulites (Figs. Zlvx22-24). Occasionally, there are axiolitic (Figs. Zlvx24-25) and rarely perlitic (Fig. Zlvx26) areas in the vitric matrices of welded units. Crystals are moderately abundant to sparse and dominantly broken, rounded, and euhedral plagioclase (Figs. Zlvx14-16, and 20 show good examples) with subordinate broken and resorbed and rounded quartz (Figs. Zlvx15, 17, 21, 24-25 and 27). Quartz is abundant, but embayed quartz crystals (Fig. Zlvx24) are sparse. Alkali feldspar grains, sometimes perthitic, are accidental and likely derived from the Spot Pond Granodiorite (Fig. Zlvx14). Volcanic lithic fragments are the most abundant type. Volcanic lithic fragments most commonly have grainy, patchy or eutaxitic (Fig. Zlvx16) textures sometimes with discernable glass shard outlines. Four common volcanic lithic fragment types are red fragments with pyroclastic banding (Figs. Zlvx15, 18), fragments with patchy (Fig. Zlvx27) and micropoikilitic to poikilomosaic textures, ultra-fine-grained fragments with plagioclase microlites, and fragments with a spherulitic texture (Fig. Zlvx24). Less common are fine volcanic lithic fragments with plagioclase phenocrysts. Accidental quartzite fragments are common (Fig. Zlvx18 and 21). A few samples had multi-grain granodiorite fragments.

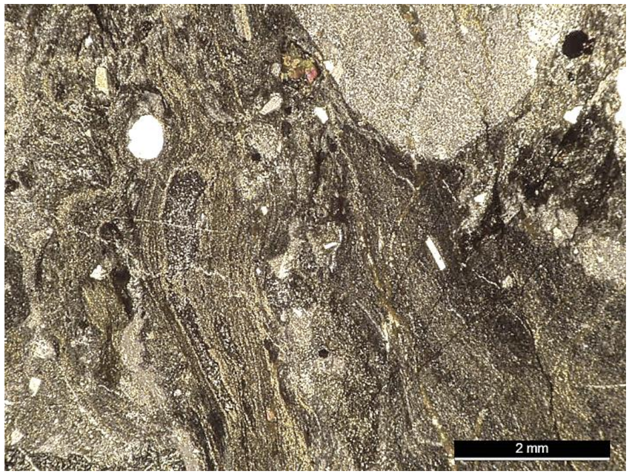


Zlvx14: Crystal tuff on Pine Hill in Medford (site 881BN). Gray, pinched, dusty grains are devitrified, flattened pumice fragments. Rock also has faint pyroclastic banding parallel to these fragments (near vertical). Gray crystal in lower left center is alkali feldspar (A). Thin section with crossed polarizers.

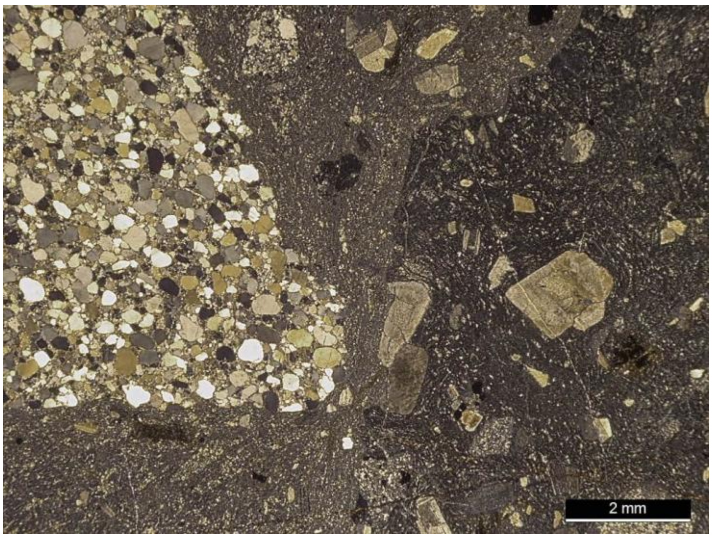
Zlvx15: Faint pyroclastic banding with fine axiolitic threads (arrow shows trend) in crystal tuff on Pine Hill in Medford (site 10493). Most grains are broken euhedral plagioclase with smaller rounded, very clear quartz grains. Thin section with crossed polarizers.



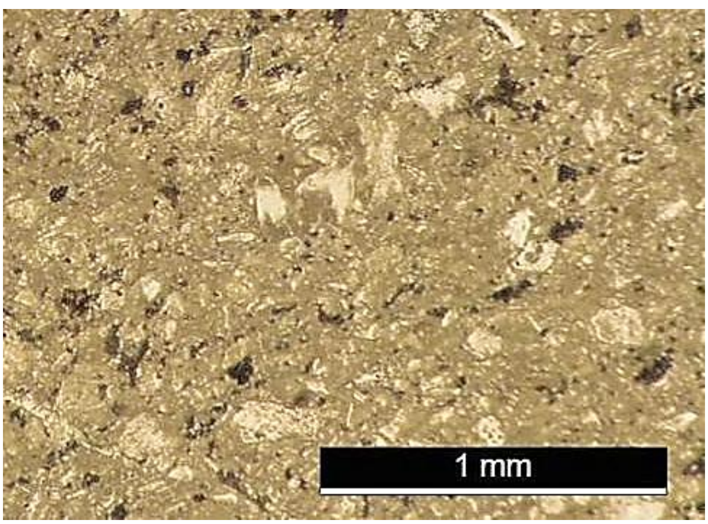
Zlvx16: Banded (lower left to upper right), eutaxitic rhyolitic crystal tuff with broken crystals and flattened glass fragments (light streaks) west of Boojum Rock in Medford (site 10236). Large dark, pinched and flattened fragment near bottom (F) is eutaxitic like the matrix. Thin section in plane polarized light.



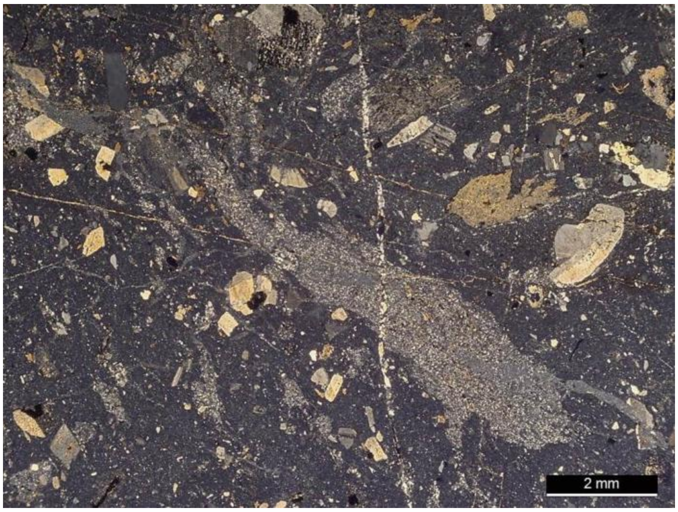
Zlvx17: Rhyolitic tuff with pyroclastic banding and thin light bands of axiolitic texture (micro-beaded lines) west of Boojum Rock in Medford (site 10245). In upper left is round quartz grain (white) and in upper right is fine patchy-textured volcanic lithic fragment. Thin section with crossed polarizers. See Fig. Zlvx6 for cut rock view.



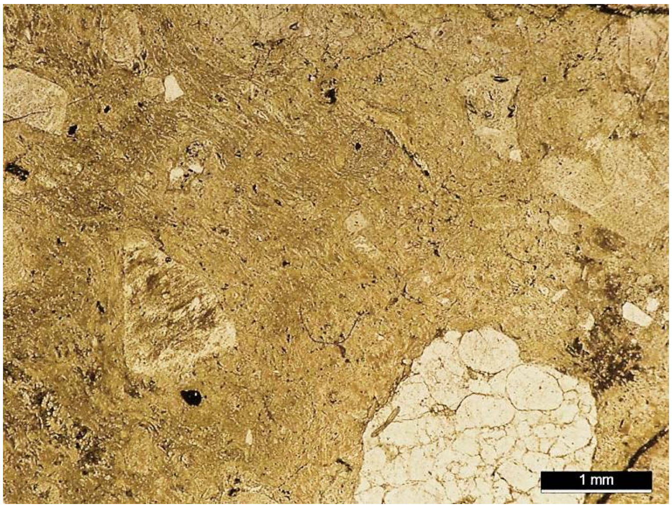
Zlvx18: Pyroclastic banding in tuff (central gray zone) with crystals and two large lithic fragments that are sandstone (left) and eutaxitic (faintly banded) crystal tuff (dark area on right, which is dark red in rock sample view) on Pine Hill in Medford (site 10497). Flattened fine patchy areas in matrix are flattened pumice fragments. Thin section with crossed polarizers. See Fig. Zlvx3 for cut rock view



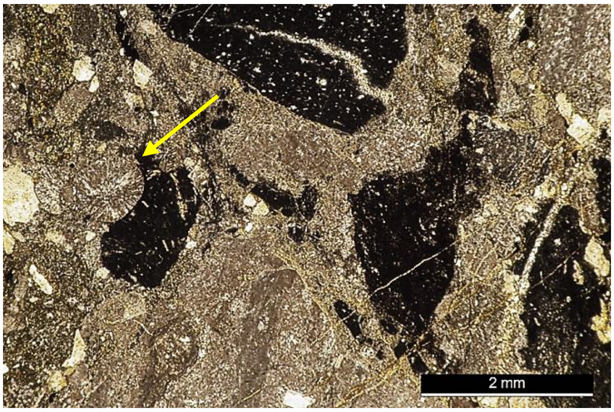
Zlvx19: Matrix of devitrified crystal tuff showing relict glass shard outlines west of Boojum Rock in Medford (site 10239). Thin section in plane polarized light.



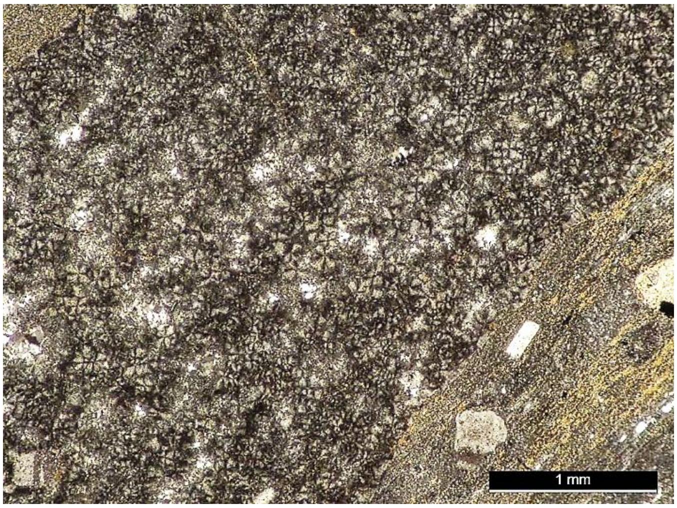
Zlvx20: Crystal tuff with flattened, devitrified pumice fragments (dusty gray) and faint banding on Pine Hill in Medford (site 881BN). Thin section with crossed polarizers.



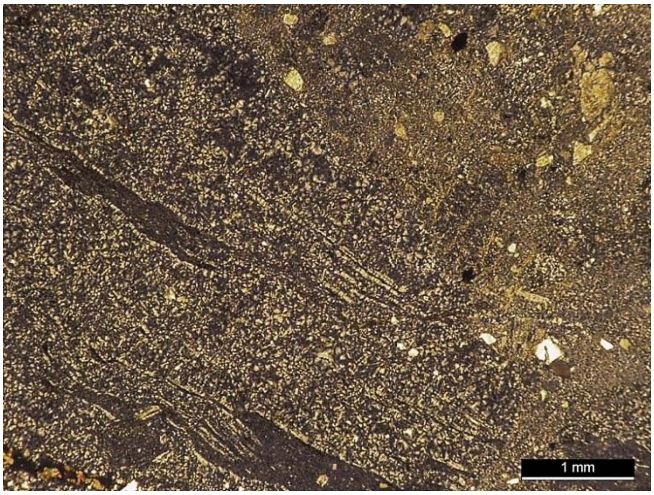
Zlvx21: Eutaxitic (especially upper left side) crystal tuff with sandstone lithic fragment (lower right) on Pine Hill in Medford (site 10513). See Fig. Zlvx2 for cut rock view. Small clear broken crystals are quartz. Thin section in plane polarized light.



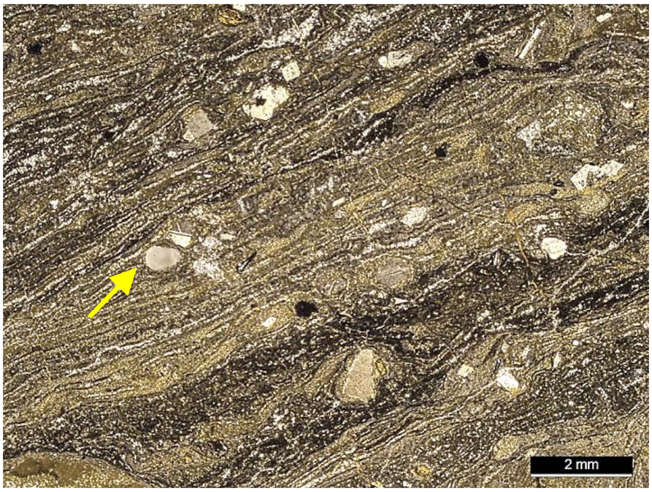
Zlvx22 (left): Tuff with spherulites (arrow) and volcanic lithic fragments with ultra-fine texture and microlites (dark fragments) west of Boojum Rock in Medford (site 10246). Thin section with crossed polarizers. See Fig. Zlvx7 for cut rock view.



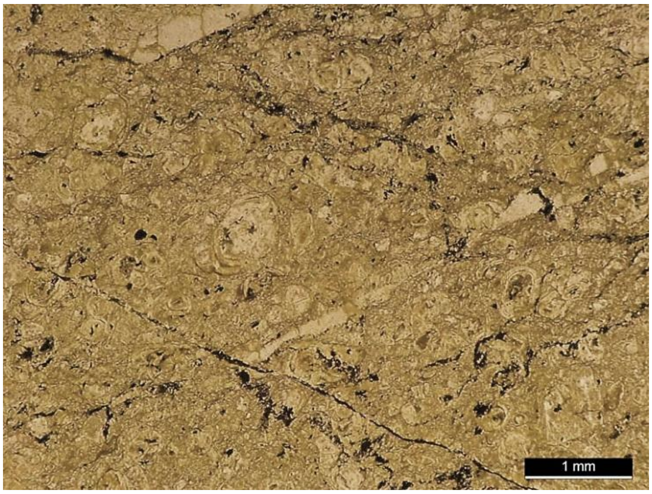
Zlvx23 (right): Zone of microspherulitic texture (crosses) between layers with fine pyroclastic banding in welded rhyolitic tuff west of Boojum Rock in Medford (site 10236). Spherulitic areas are devitrified glass. Thin section with crossed polarizers.



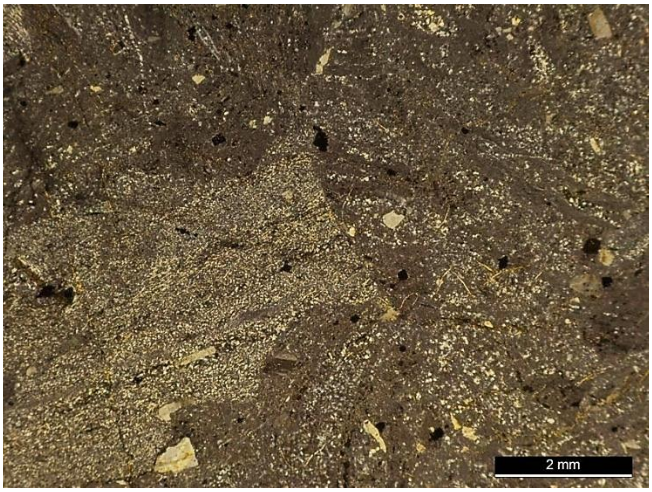
Zlvx24: Microspherulitic (small white dots) volcanic lithic fragment (left side) that has wispy, flattened pumice fragments (dark gray) with forked ends and axiolitic threads west of Wrights Pond in Medford (site 10676). In the lower right is a bright embayed quartz crystal. Thin section with crossed polarizers.



Zlvx25: Rhyolitic welded tuff with thin pyroclastic banding that has axiolitic texture and broken felspar crystals on western Boojum Rock in Medford (site 10551). Arrow indicates round quartz grain. Note how bands are warped around crystals but show little evidence of rotation due to flow. Thin section with crossed polarizers.



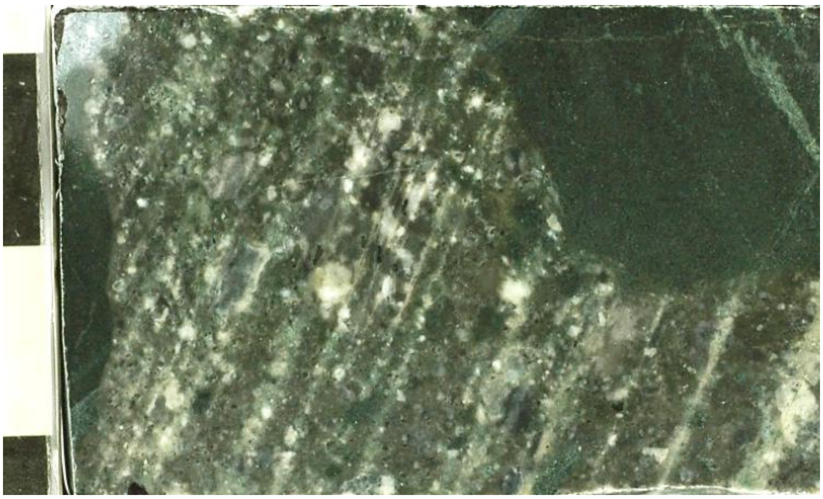
Zlvx26 (left): Vitric welded tuff layer in crystal tuff with perlitic texture (circular to oval structures) on Pine Hill in Medford (site 10524). Thin section in plane polarized light.



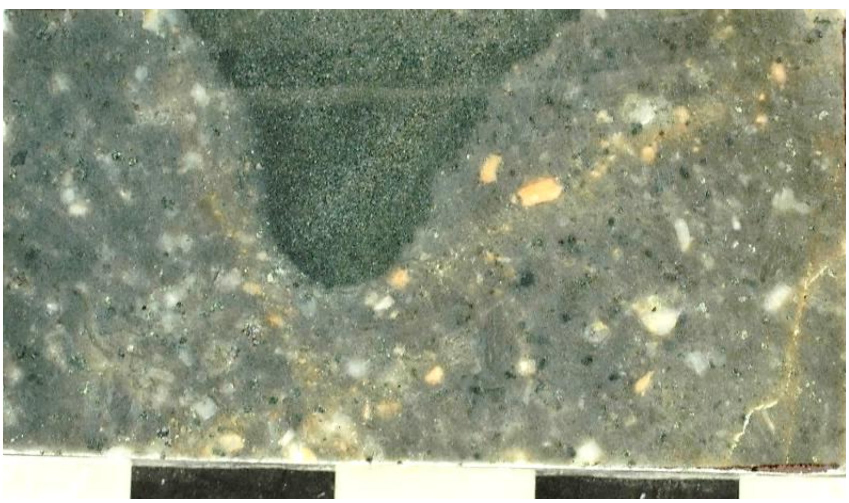
Zlvx27 (right): Rhyolitic tuff with pyroclastic banding west of Boojum Rock in Medford (site 10241). In lower left is banded, patchy textured volcanic lithic fragment from a rhyolitic flow. Near the center is a broken quartz crystal. Thin section with crossed polarizers.

Crystal tuff facies in the northern Fells (Straw Point to Melrose)

Rock unit description: Crystal tuff across the northern Fells from Straw Point to Melrose varies from west to east from light gray to gray (10YR 5-7/1), welded to non-welded, crystal tuff with lithic fragments and broken plagioclase and quartz crystals (Figs. Zlvx1-2 and 28-30) giving way to several crystal tuff types: dark gray (7.5YR 4/0), welded vitric crystal tuff with oriented fine plagioclase crystals (Fig. Zlvx31); medium to light gray (10YR 7/2), banded and welded tuff with outlines of collapsed glass shards and flattened pumice (Fig. Zlvx32); pinkish-gray (7.5YR 6/2) to gray (7.5YR 6/0), welded to non-welded, lithic crystal tuff with broken plagioclase and quartz crystals and scattered mostly volcanic lithic fragments (Figs. Zlvx33-37). Deeply embayed quartz xenocrysts become more abundant from west to east. Welded tuffs have oriented flattened glass and pumice fragments (Figs. Zlvx31 and 35-37). Crystal tuff is interbedded with the basaltic flow/breccia facies (Zlbf) at Straw Point and overlies a rhyolitic flow (Zlbf) sequence on Wamoset Hill. The crystal tuff at Straw Point contains altered basalt, argillite hornfels, and quartzite lithic fragments (Figs. Zlvx28-29). LaForge (1932) and Kaye (1980) overextended sections of crystal tuff and other volcanic facies along Pond Street, near Doleful Pond and on Wamoset Hill in Stoneham. East of the Fells in Whip Hill Park and Sewall Woods crystal tuff has a much larger outcrop area where it is interlayered with banded rhyolitic flows (Zlvf). In an enigmatic outcrop within a fault slice at the north end of Whip Hill, crystal tuff unconformably overlies the Westboro Formation (Zwp; see special discussion below of this outcrop on p.158-160). The crystal tuff facies is intruded by the Stoneham Granodiorite (Zst) at the northeast corner of Spot Pond (Fig. Zst18-19).

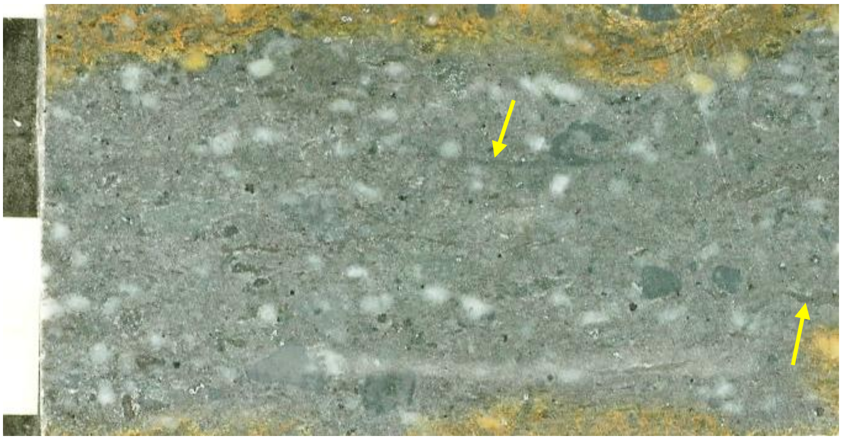


Zlvx28: Crystal tuff with altered argillite pebble (now hornfels) at Straw Point in Stoneham (site 10554). Unit also contains quartzite lithic fragments and sparse rounded and embayed quartz grains. Parallel white lines are flat, closely-spaced, mineralized fractures and are not primary layering.

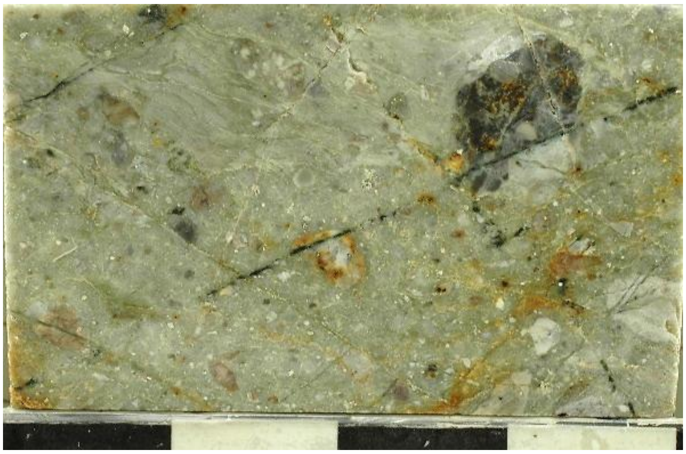


Zlvx29: Welded tuff with altered dark greenish-gray, chloritic quartzite pebble and abundant alkali feldspar at Straw Point in Stoneham (site 11254). Unit also contains sparse rounded and embayed quartz grains. White grains are broken plagioclase crystals that are also stained orange by local oxidation.

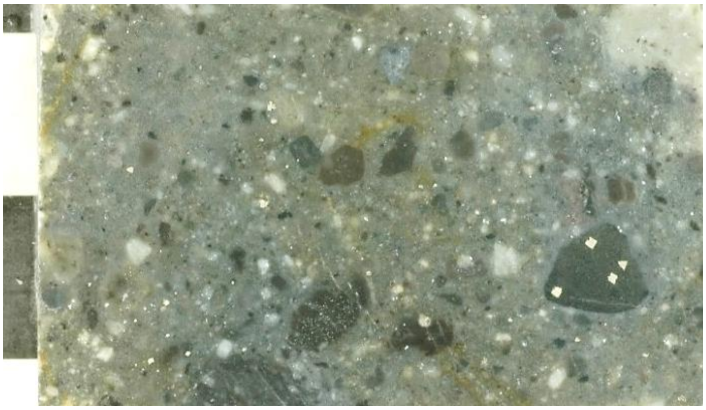
Zlvx30: Non-welded crystal tuff in Sewall Woods Park along the Fellsway East in Melrose (site 11541). Red lithic fragments are fine-grained rhyolite from the flow facies.



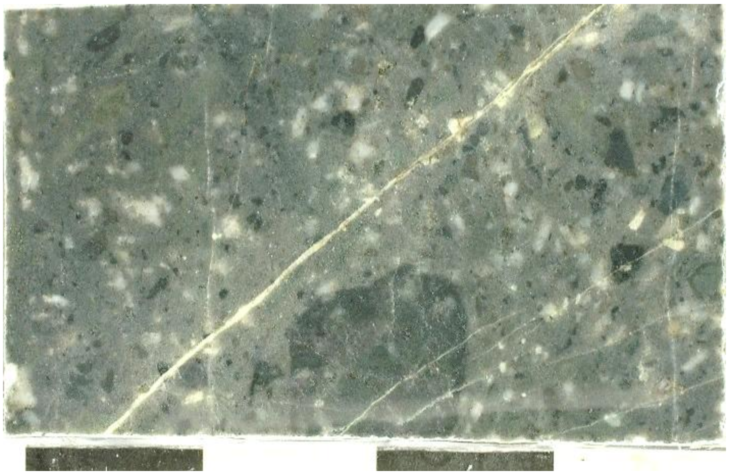
Zlvx31: Welded tuff south of Wamoset Hill in Stoneham (site 10371). Horizontal dark gray streaks (arrows) are flattened pumice.



Zlvx32: Welded vitric crystal tuff with banding due to flattened pumice and glass shards on northeast shore of Spot Pond in Stoneham (site 10599). Banding is deformed around lithic fragments. This unit also has small accidental lithic fragments of granodiorite.

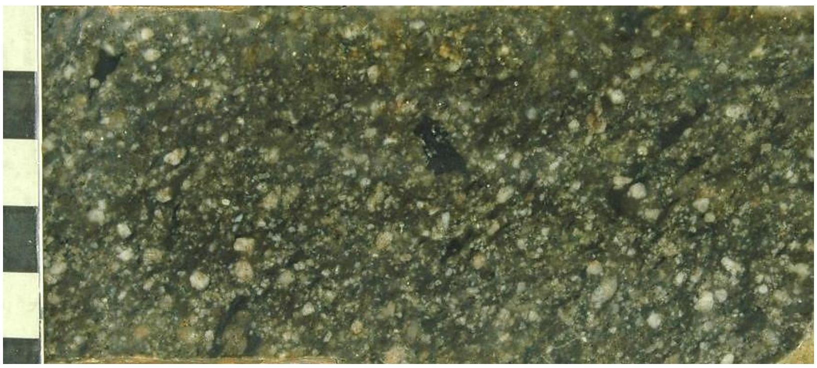


Zlvx33: Non-welded, lithic crystal tuff on Wamoset Hill in Stoneham (site 10361). Dark argillite lithic fragment on right has pyrite crystals.



Zlvx34: Partly welded lithic crystal tuff east of Doleful Pond in Stoneham (site 10593).

Zlvx35: Welded lithic crystal tuff with fabric (upper left to lower right) formed from dark flattened pumice/glass fragments east of Doleful Pond in Stoneham (site 10407). Note the warping of the dark devitrified glass fragments around the lithic fragment and crystals in the lower right and lower left.

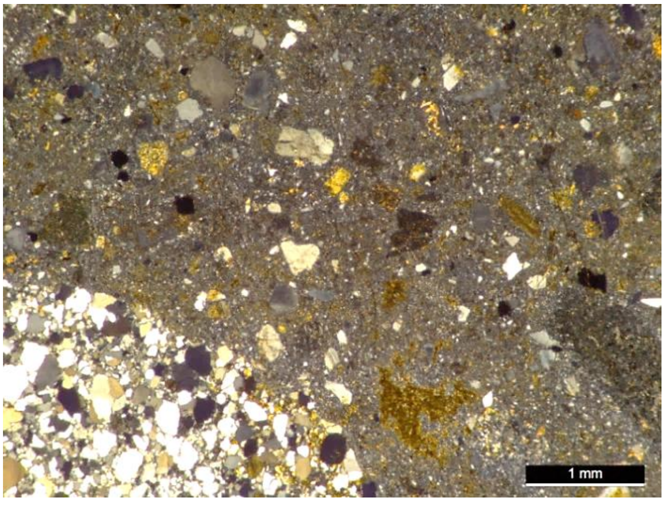


Zlvx36: Welded crystal tuff with embayed quartz xenocrysts and a distinct fabric (upper right to lower left) formed from flattened pumice/glass fragments east of Doleful Pond in Stoneham (site 10407).

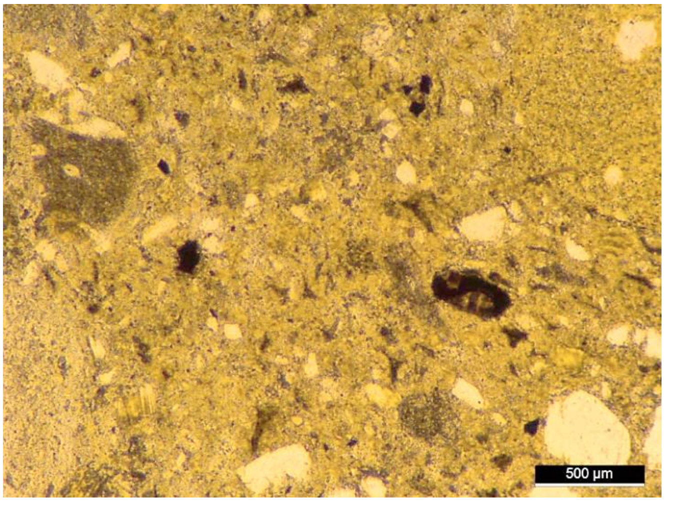
Zlvx37: Welded crystal tuff with embayed quartz xenocrysts and a distinct fabric (upper right to lower left) formed from flattened pumice/glass fragments (black) in Sewall Woods Park in Melrose (site 11537).

Thin section description: At Straw Point where pyroclastic rocks are inter-layered with basaltic units (Zlbf), tuff is welded to non-welded, crystal tuff with scattered lithic fragments and broken, rounded and resorbed quartz crystals (Figs. Zlvx1-2). The crystal tuff has a mostly granular or patchy matrix texture with occasional micropoikilitic and poikilomosaic areas (Fig. Zlvx38). A few samples have faint glass shard outlines (Figs. Zlvx39). Crystals are dominantly broken plagioclase (Figs. Zlvx38) with occasional well preserved, broken hornblende crystals (Fig. Zlvx38 and 40). Deeply embayed quartz xenocrysts are not as abundant as at Wamoset and Pine Hills. Sand to granule size volcanic lithic fragments are in most samples and mostly ultra-fine grained with microlites. Lithic fragments of quartzite, argillite hornfels, and altered basalt (Figs. Zlvx28, and 41-42) occur in the Straw Point samples.

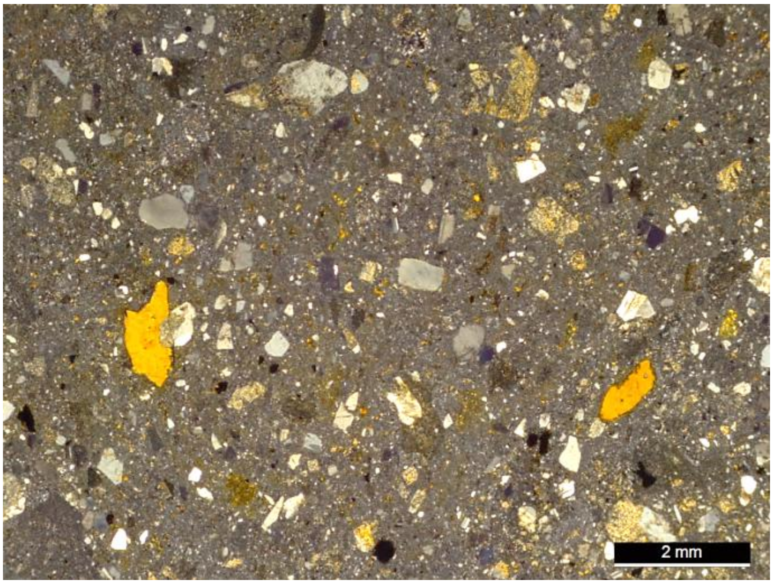
Further east the tuff is dominantly non-welded to welded rhyolitic crystal tuff with common lithic fragments. Solid glass shard outlines are common in the non-welded units (Figs. Zlvx43-44), while flattened glass shards and faint traces of flattened obsidian and pumice strands occur in the welded units (Figs. Zlvx44-47). The non-welded tuffs have a mostly granular texture. Devitrification of the welded units leads to a fine patchy matrix texture (Figs. Zlvx48-49). Crystals in the tuffs are abundant and dominated by broken plagioclase (Figs. Zlvx43-49). Crystals also include broken, resorbed, rounded, and deeply embayed quartz (Figs. Zlvx45-47 and 49-51), as well as an occasional euhedral quartz dipyramid (Fig. Zlvx47), and alkali feldspar (Figs. Zwh45 and 52). Alkali feldspar grains (sometimes perthitic) are accidental grains from older granitic units (Fig. Zlvx43). There are occasional hornblende crystals often altered to epidote (Figs. Zlvx47 and 51). Volcanic lithic fragments are common and dominantly ultra-fine lithologies (Figs. Zlvx43 and 53). Other volcanic fragment types include flow-banded rhyolite with cumulophyric plagioclase (Fig. Zlvx54) and tuff with patchy to splotchy, eutaxitic, microspherulitic, and porphyritic textures (Fig. Zlvx55-59). Accidental lithic fragments include granitic rocks, quartzite, and argillite (Figs. Zlvx38, 42-43 and 52). Also abundant in places are large lithic fragments with calcite crystals of uncertain metasedimentary origin (Zlvx43), possibly from the Westboro Formation.



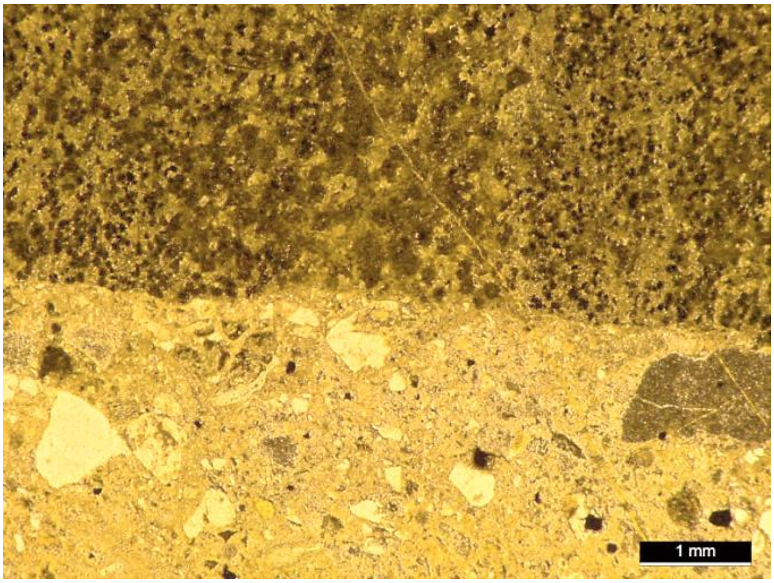
Zlvx38: Non-welded crystal tuff on Straw Point with granular matrix and a quartzite lithic fragment in the lower left (site 10554; see Fig. Zlvx28 for cut rock view). Crystals are mostly plagioclase with lesser quartz. Bright orange crystals are hornblende. Thin section with crossed polarizers.



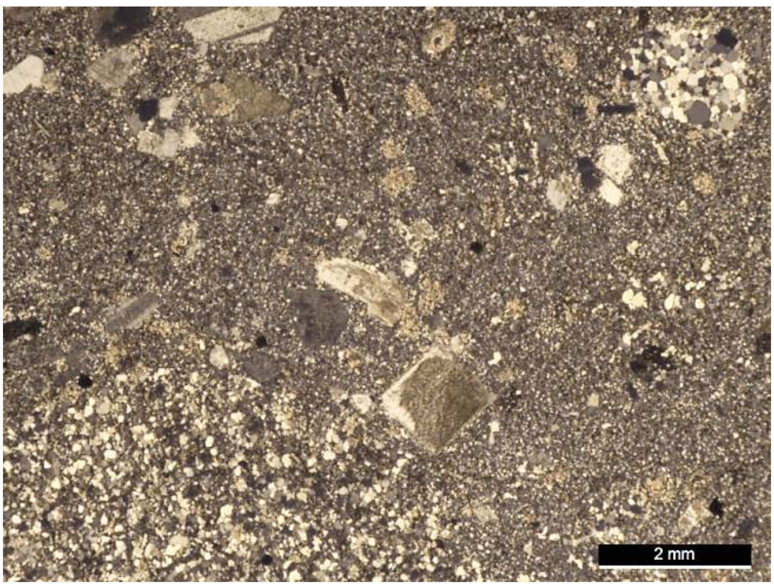
Zlvx39: Non-welded to partly welded crystal tuff on Straw Point with glass shard outlines (dark triangular grains in center) in a granular matrix (site 10554; see Fig. Zlvx28 for cut rock view). Crystals are mostly plagioclase with scattered broken and rounded quartz. Thin section in plane polarized light.



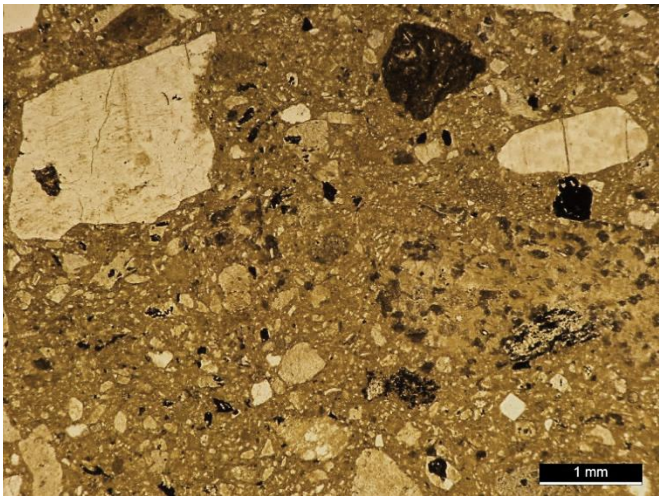
Zlvx40: Non-welded crystal tuff with two hornblende crystals (orange) in a granular matrix on Straw Point (site 10554; see Figs. Zlvx28 for cut rock view). It is unusual for the hornblende crystals to be without alteration. Crystals are mostly plagioclase with scattered rounded and broken quartz crystals. Thin section with crossed polarizers.

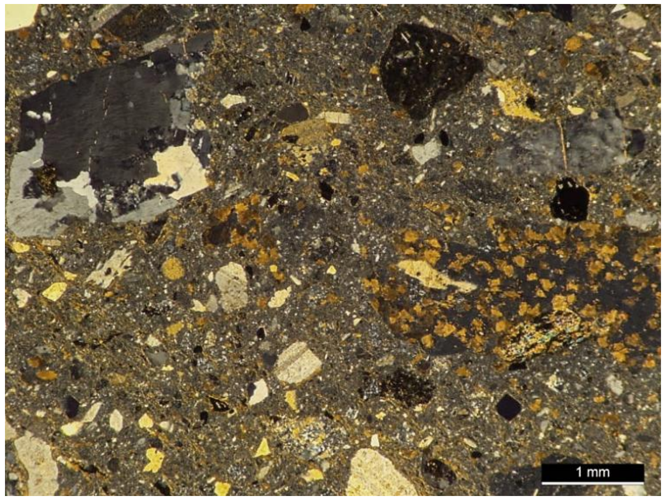


Zlvx41: Non-welded crystal tuff with a granular texture and hard glass shard outlines (site 10554; see Fig. Zlvx28 for cut rock view) on Straw Point. Large lithic fragment (top half of image) is altered argillite (now hornfels). Thin section in plane polarized light.

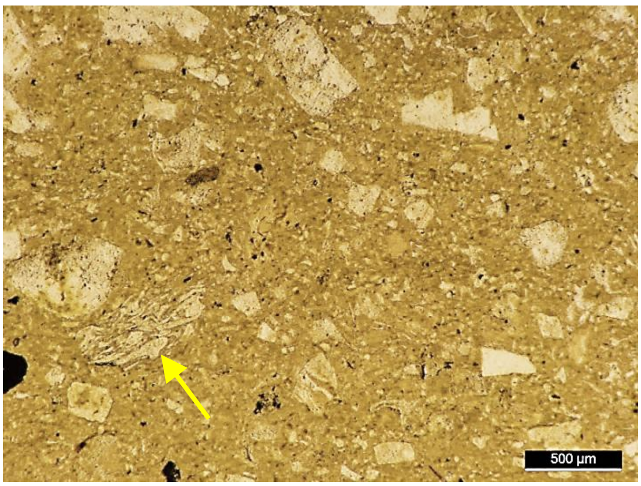


Zlvx42: Welded crystal tuff with a fine sandy quartzite hornfels fragment (lower left) in a fine granular matrix (site 11254; fragment also shown in Fig. Zlvx29) on Straw Point. In upper right is a quartzite lithic fragment with round grains. The surrounding tuff has many broken crystals. Thin section with crossed polarizers.



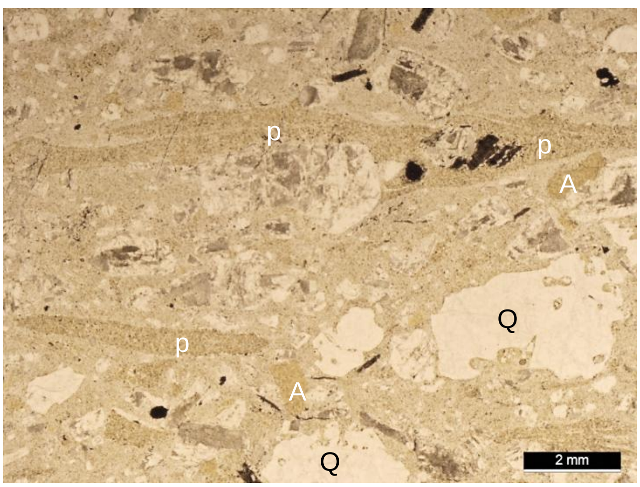


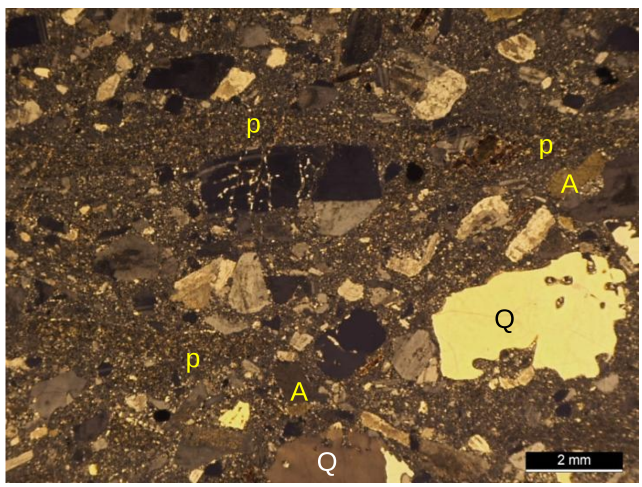
Zlvx43 (left above): Thin section in plane polarized light; (right above): Same image with crossed polarizers. Non-welded crystal tuff with scattered lithic fragments and solid glass shard outlines on the east side of Whip Hill Park in Stoneham (site 642BN). In the upper right on both images is a dark fine volcanic fragment. In the upper left is an accidental multi-grain granitic lithic fragment and in the right center is an altered fragment with calcite crystals (orange). This fragment may be an accidental, baked, calcareous argillite fragment from the Westboro Formation. Broken quartz is abundant.

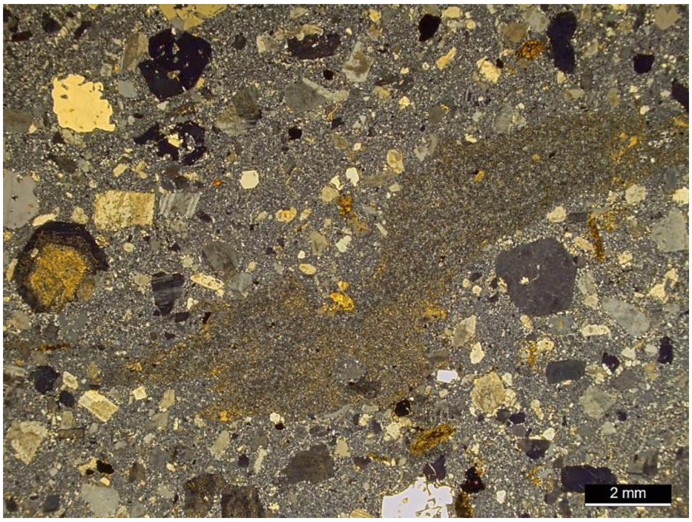


Zlvx44 (left): Non-welded crystal tuff with granular matrix texture and hard glass shard outlines (site 10600, next to Stone Zoo at Spot Pond). In lower left is a volcanic fragment with flattened soft glass shard outlines and eutaxitic texture (arrow). Thin section in plane polarized light.

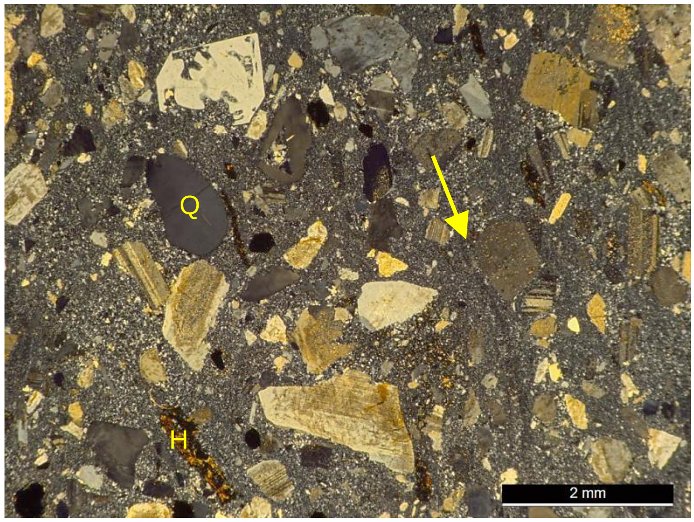
Zlvx45 (below left): Thin section in plane polarized light; (below right): Same view with crossed polarizers. Welded crystal tuff on Sheep Pasture Point (site 11245) with flattened gritty-looking pumice fragments (yellow potassium stain) oriented near horizontal (p). Large clear grains are broken, resorbed, and embayed quartz crystals (Q). There are also two yellow (stained), broken alkali feldspar crystals (A). Splinter-like dark crystals are biotite partly altered to chlorite.



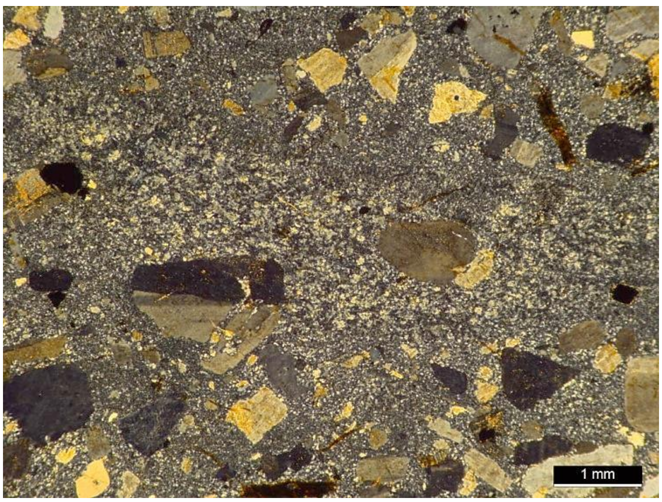




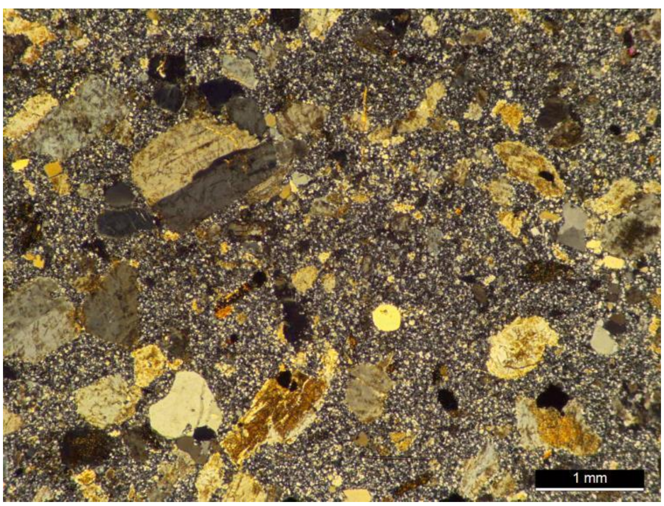
Zlvx46 (above): Non-welded to partly welded crystal tuff on Sheep Pasture Point with a flattened obsidian or pumice fragment with yellow potassium stain that lacks crystals in a surrounding granular- to patchy-textured matrix (site 10418). Crystals are mostly plagioclase with a few embayed and broken quartz crystals. Thin section with crossed polarizers.



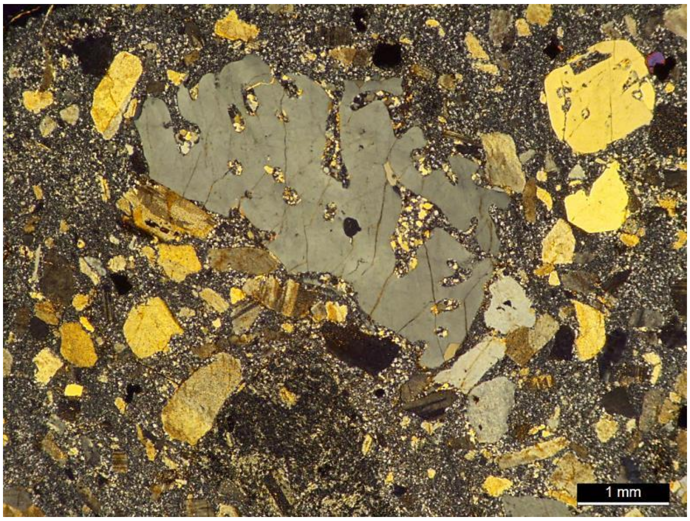
Zlvx47 (above): Non-welded to partly welded crystal tuff at Sheep Pasture Point with a highly flattened glass or pumice strand (dark band beneath arrow) that is axiolitic in a fine granular matrix (site 669BN). Crystals are mostly plagioclase with two conspicuous quartz crystals in the upper left - one is a skeletal euhedral dipyramid crystal with embayments and the other a round resorbed grain (Q, dark gray). In the lower left is an altered hornblende crystal (H). Thin section with crossed polarizers.



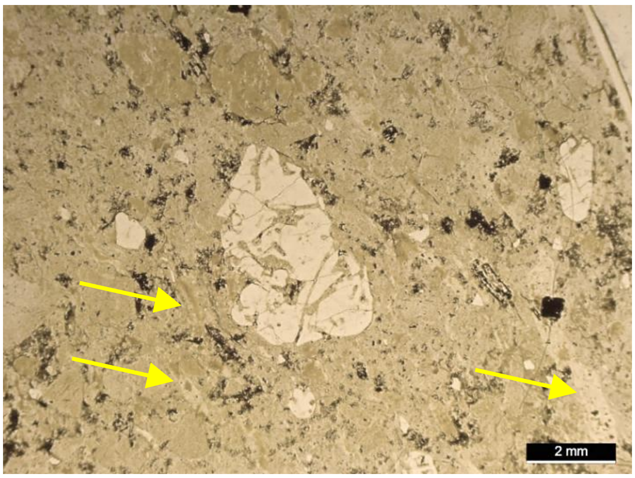
Zlvx48: Non-welded to partly-welded crystal tuff east Doleful Pond in Stoneham with a zone of micropoikilitic matrix texture in an otherwise granular texture (site 10407; see Figs. Zlvx35-36 for cut rock views). Crystals are mostly plagioclase with a few rounded (resorbed) and broken quartz crystals. Thin section with crossed polarizers.

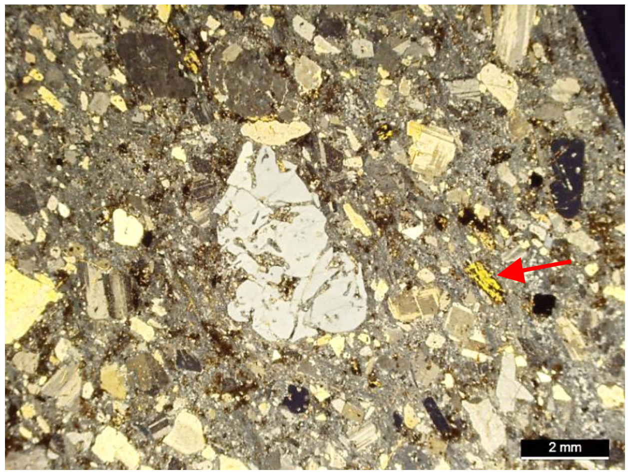


Zlvx49: Non-welded crystal tuff with a granular to patchy matrix texture (site 10411). Crystals are mostly broken plagioclase with scattered round and resorbed quartz crystals. Thin section with crossed polarizers.

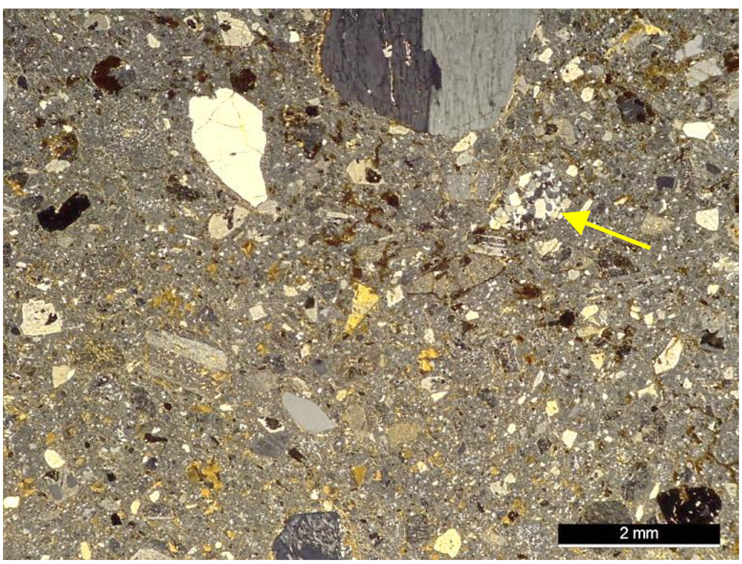


Zlvx50: Non-welded crystal tuff with large embayed and fractured quartz crystals in a granular to patchy textured matrix east of Doleful Pond in Stoneham (site 10407; see Figs. Zwh 35-36 and Figs. Zlvx28-29 for comparison). Most smaller crystals are plagioclase. Thin section with crossed polarizers.

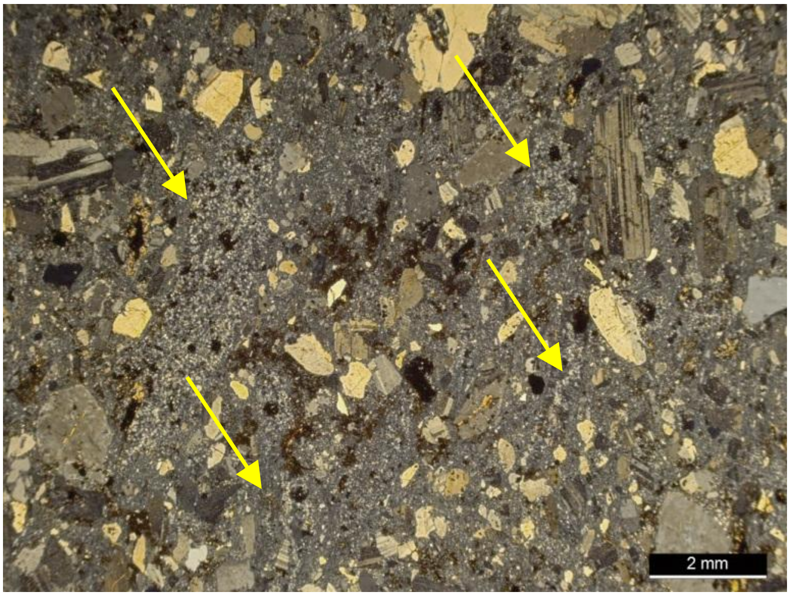




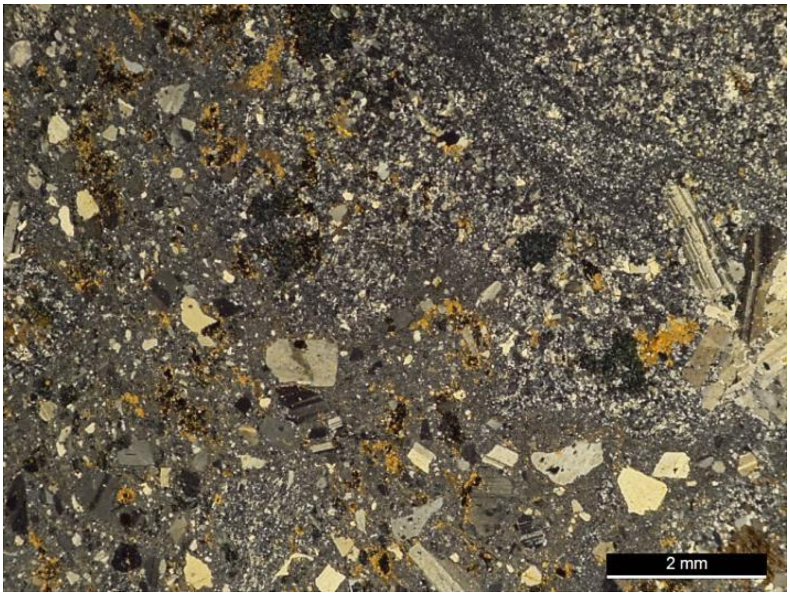
Zlvx51 (left above): Thin section in plane polarized light; (right above): Same view with crossed polarizers. Welded crystal tuff with abundant broken plagioclase crystals and small volcanic lithic fragments on Wamoset Hill in Stoneham (site 10362). In the matrix are faint traces of pyroclastic banding formed from flattened obsidian, pumice, and glass shards (yellow arrows on left side of image) that are best viewed in plane polarized light. In the center is a large embayed quartz crystal. The ragged yellow crystal (right) is hornblende (red arrow).



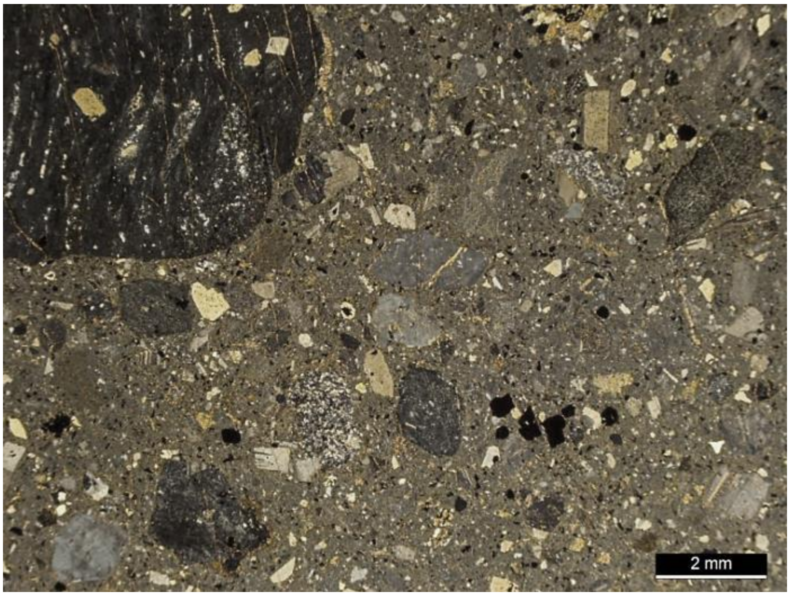
Zlvx52: Non-welded tuff with abundant crystals in a granular matrix on the east side of Whip Hill Park in Stoneham (site 642BN; see also Fig. Zlvx43). The large crystal at top is twinned alkali feldspar. Just beneath it to the right is a quartzite lithic fragment (arrow) and the large, bright grain is broken quartz. The quartz and alkali feldspar are both accidental grains derived from granitic rocks. Thin section with crossed polarizers.



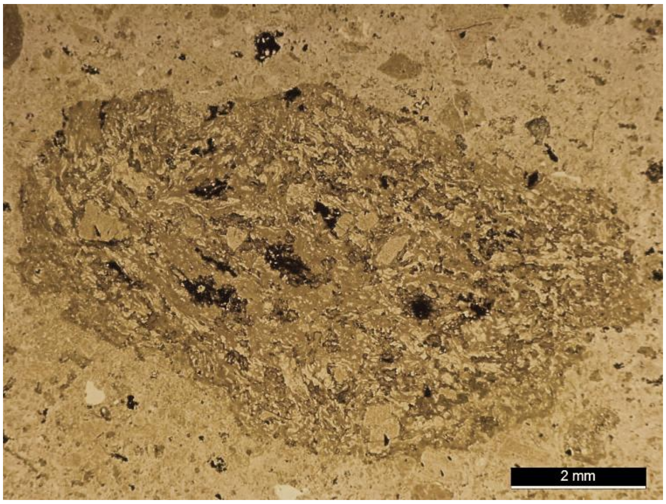
Zlvx53: Welded crystal tuff on Wamoset Hill in Stoneham (site 10362; see also Fig. Zlvx51). Faint patchy areas with no crystals and faint strand-like (axiolitic) structures, are flattened obsidian/pumice fragments (arrows). At the top center is an embayed quartz crystal. Thin section with crossed polarizers.



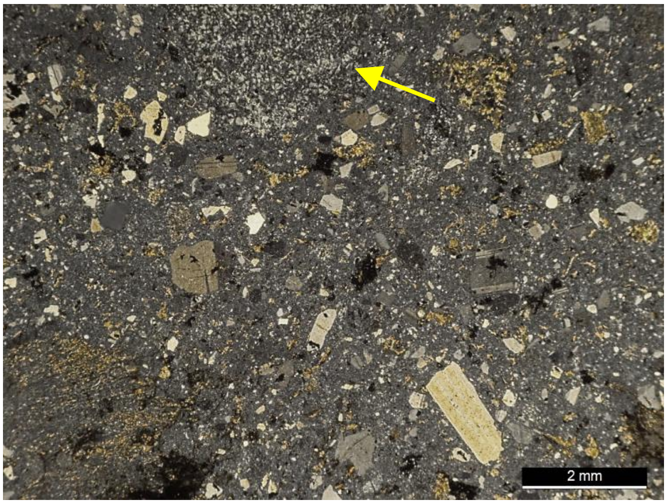
Zlvx54: Non-welded crystal tuff with a granular matrix on south end of Whip Hill in Stoneham (site 10572), just above the contact with a flow-banded unit. In the upper right 1/3 of image is a flow-banded rhyolite fragment with cumulophyric plagioclase. This fragment has sparse crystals, cumulophyric plagioclase (right side) and a patchy matrix texture. Thin section with crossed polarizers.



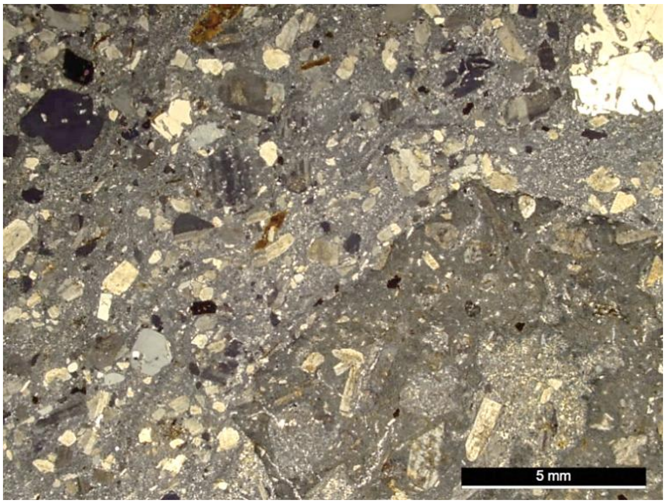
Zlvx55: Non-welded, crystal tuff with a very fine granular matrix on Wamoset Hill in Stoneham (site 10361; see also Fig. Zlvx33). Large volcanic lithic fragment in upper left has a eutaxitic texture and pyroclastic banding. Thin section with crossed polarizers.



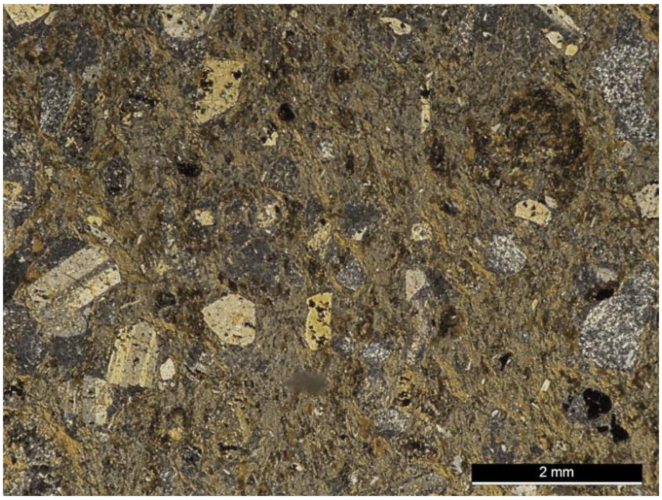
Zlvx56 (left): Non-welded crystal tuff with abundant small crystals in a granular matrix south of Whip Hill in Stoneham (site 10368) . Large volcanic lithic fragment in center has a eutaxitic texture with devitrified, flattened glass shards and fragments. Thin section in plane polarized light.



Zlvx57 (right): Non-welded, crystal tuff with a granular matrix south of Whip Hill in Stoneham (site 10368). Large volcanic lithic fragment at top (arrow) has a microspherulitic texture. In the lower left corner is a partly altered and oxidized (orange) eutaxitic volcanic fragment. Thin section with crossed polarizers.



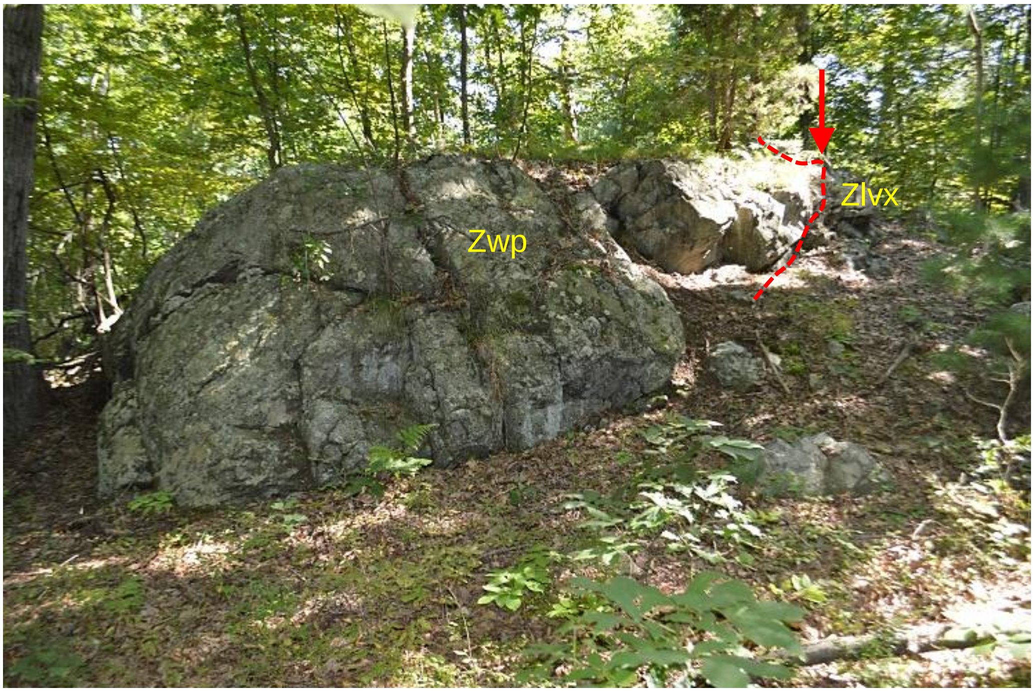
Zlvx58 (left): Non-welded to partly welded crystal tuff with large crystal tuff fragment (entire lower right 1/3) that has devitrified obsidian fragments (lighter gray) and plagioclase crystals in a dark very fine matrix (site 10407; see also Figs. Zlvx35-36, and 50). The lack of quartz crystals in this fragment and its feldspar alteration suggest that it may be derived from the Boojum Rock Tuff. The surrounding tuff has many broken and embayed quartz crystals (upper right corner). Thin section with crossed polarizers.



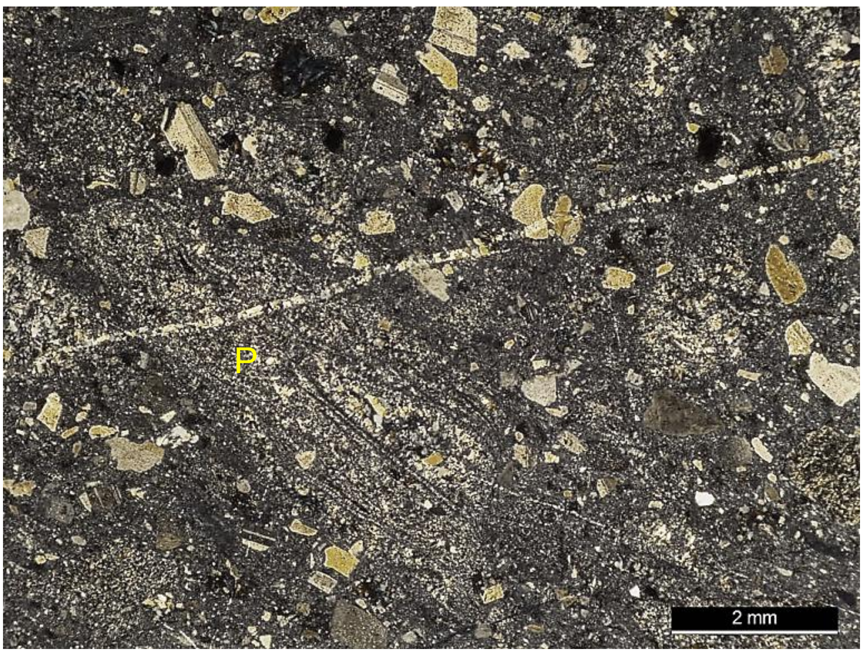
Zlvx59: Welded tuff with abundant broken crystals and lithic fragments on Wamoset Hill in Stoneham (site 10371). Yellow to orange strands are altered, flattened glass shards and relict obsidian/pumice fragments that give the rock its fabric (See Fig. Zlvx31). Note the volcanic lithic fragments on the right side with a fine patchy texture. Thin section with crossed polarizers.

Enigmatic Westboro Formation/Wakefield Formation contact - northern Whip Hill

On the northeast corner of Whip Hill is a small knob-like outcrop that deserves special attention because of its age relationships. The knob (Fig. En1) is mostly dark gray (5Y 4-3/1) mudstone and fine sandstone with faint traces of bedding in the Westboro Formation (Zwp). At the southwest corner of the outcrop is an irregular contact of the Westboro with gray (10YR 6/1) crystal tuff (Fig. En1) in the Wakefield Formation (Zlvx; Fig. En2). The tuff is a small exposure along the north side of an east-west trending fault that separates the knob from Westboro outcrops to the south. The Lynn outcrop occurs as a thin sliver along the north side of the fault (Fig. En1). The knob is not a glacially transported boulder since it has the same bedding orientation as surrounding Westboro outcrops, sides that slope gently downward on its north and south sides unlike a glacial boulder resting on a rock surface, and heavy fracturing that suggests it would have broken apart if it had been glacially transported.



En1: Enigmatic outcrop of the Westboro Formation (Zwp) with contact of crystal tuff of the Wakefield Formation (Zlvx) at the southern end of a knob on northeastern Whip Hill. The arrow shows the location of tuff in the following images, and the dashed line is the contact of the Wakefield and Westboro.



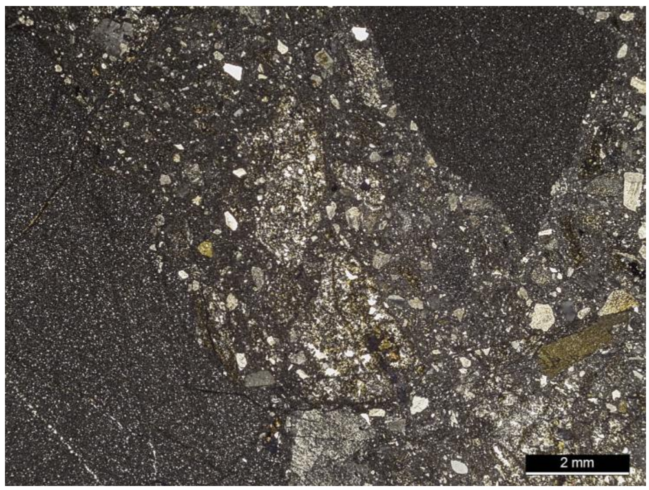
En2: Crystal tuff of the Wakefield Formation (Zlvx) on the knob at the north end of Whip Hill (site 595BOSN). Thin section in crossed polarizers. In left center is a flattened pumice fragment (P) with strands of axiolitic texture and microspherulites. There are abundant broken plagioclase crystals and a few quartz grains.

Two things make the outcrop important for inferring age relationships:

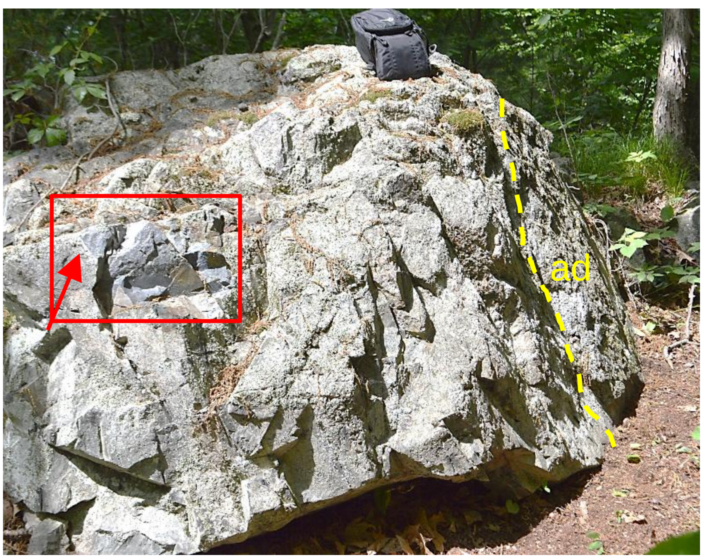
1. Along the contact between the tuff in the Lynn and mudstone in the Westboro, pieces of mudstone are found in the tuff (Figs. En3-4). The mudstone fragments are identical to the adjacent Westboro. The mudstone fragments clearly indicate that the volcanic rock is younger than the Westboro on Whip Hill.
2. The contact between the Lynn and the Westboro is highly irregular with relief indicating that it is not a fault contact but an erosion surface and unconformity (Figs. En5-8). It is also not fractured.

In early mapping, these characteristics of the outcrop were confused by the fact that the Westboro here is not regionally metamorphosed and initially looked like a sedimentary formation separate from the Westboro.

En3: Cut rock view of ragged contact of mudstone in the Westboro (left side) and crystal tuff of the Wakefield (right side) at the north end of Whip Hill in Stoneham (site 10376). The tuff has rounded and broken quartz grains and mudstone fragments from the Westboro (arrows) along the contact.



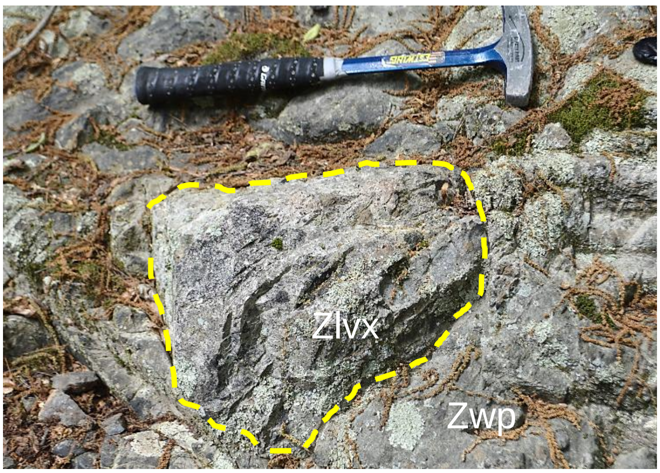
En4 (right): Contact between mudstone (lower left) and crystal tuff (right) at the north end of Whip Hill (site 10376). Note the angular lithic fragment of mudstone in the tuff (upper right). Thin section in crossed polarizers. Broken plagioclase and quartz crystals are abundant in the tuff.



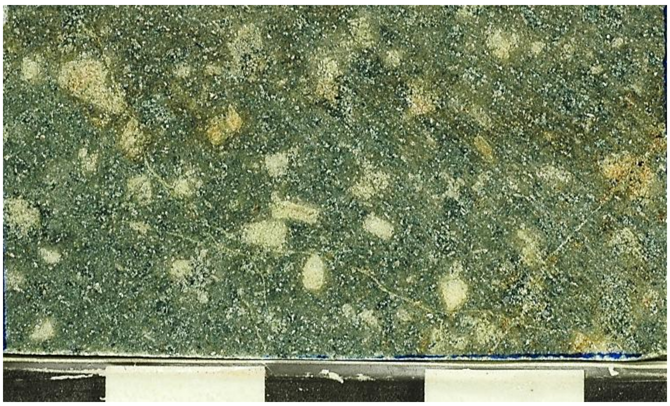
En5 (left): Irregular contact (at arrow) of tuff in the Wakefield with the Westboro (Zwp). See Figs. En6-7 for closer views. Making this outcrop more complex is an andesitic dike (ad) that trends east-west along the south side of the knob. The dashed line shows the contact of the north side of the dike with the Westboro Formation. Camera bag for scale. See Fig. En9 for a closeup view of the dike rock. The Wakefield – Westboro contact shown on Fig. En1 is along this ledge. The view in Fig. En6 is shown with the box.

En6: Irregular contact (arrows) of crystal tuff in the Wakefield Formation (Zlvx) and the Westboro Formation (Zwp) at the north end of Whip Hill in Stoneham. Shown here is the south-facing ledge on Figs. En1 and En5 and the contact (arrows). View is to north. Lens cap for scale.

En7: View of tuff (Zlvx) in Figs. En5-6 from top of ledge viewed downward. Shown here is the contact of the north side of the tuff (arrows) with deformed bedding in the Westboro (Zwp; rock hammer for scale). View vertically downward at edge of ledge with south toward top of image. Note example of mudstone breccia (red dashed line) in the Westboro that is truncated by the contact.



En8: Crystal tuff of the Wakefield Formation (Zlvx) penetrating the Westboro Formation (Zwp) at the north end of Whip Hill in Stoneham. View to north and down 50 cm north of images above (Figs. En5-7). The tuff fills a depression in the Westboro surface. Hammer for scale.

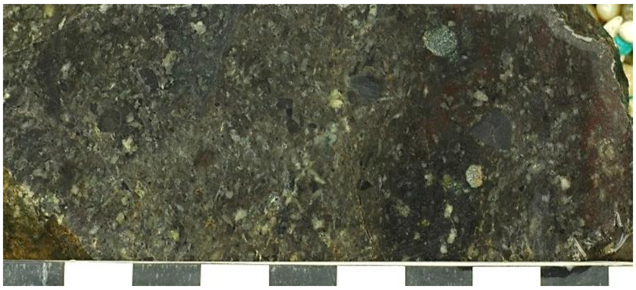


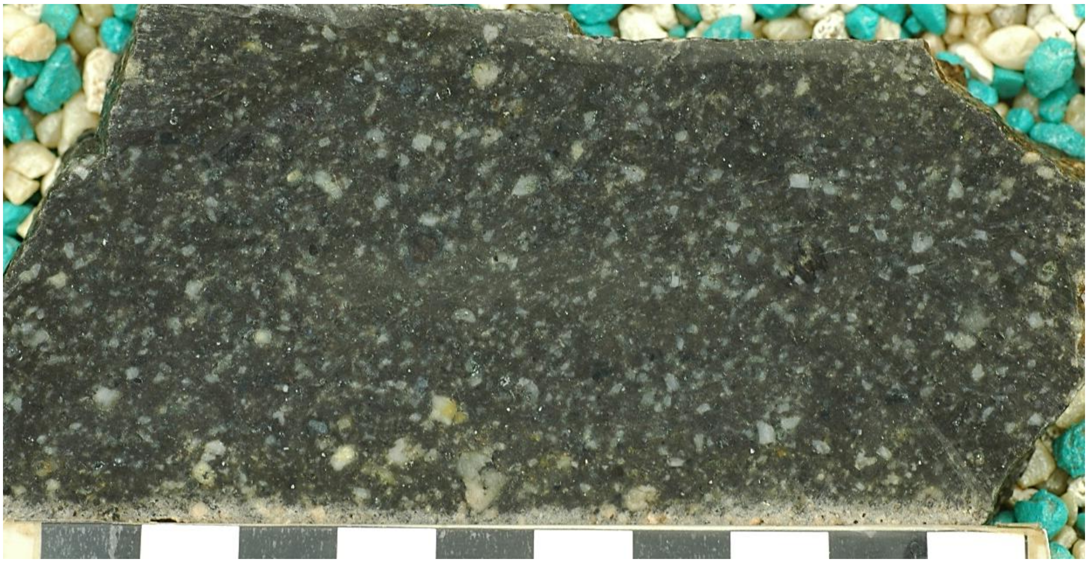
En9: Porphyritic andesite dike (ad) at south end of small knob at the north end of Whip Hill. Sample is from southeast corner of small knob (see Fig. En5). The plagioclase grains are euhedral and heavily altered. Slab cut for thin section. Scale in cm.

Crystal tuff facies in Wakefield and Saugus

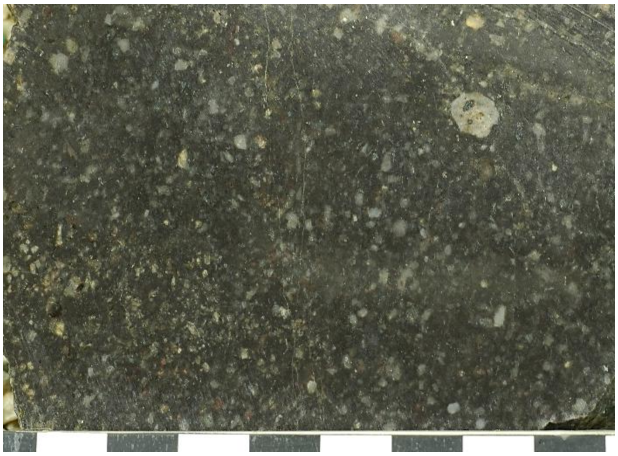
Rock unit description: A wide area of crystal tuff covers much of Wakefield and Saugus and has a relatively uniform lithology. The crystal tuff is generally welded, and very crystal-rich (Figs. Zlvx 60-65) with a dusky red 10R 2.5-3/1-3 to medium to dark gray (N4-5) matrix color that weathers to a lighter pale red (10R 6-5/1-2) to gray (N6). These colors are altered along fractures, faults, and intrusive contacts, usually becoming lighter. Crystal tuff generally has a high crystal concentration but can grade to vitric tuff (Zlvv) with sparse crystals (Figs. Zlvx66-67). Crystals include mostly plagioclase with secondary quartz. The unit has scattered dominantly felsic tuff and flow fragments (Figs. Zlvx60-65 and 68-70). Fabrics appear as flattened and oriented pumice fragments (Figs. Zlvx68-70). The crystal tuff facies is interlayered with the vitric and lithic tuff facies (Zlvl and Zlvv) and at least one basalt flow (Zlbf) in Wakefield east of Main Street. It is intruded by subvolcanic granophyre (Zlwg, Lawrence Woods Granophyre of this map) in the Greenwood area, which was not recognized by LaForge (1932) and Kaye (1980). It is also intruded by the Stoneham Granodiorite (Zst) in North Wakefield.

Zlvx60 (left): Purplish-gray crystal tuff with abundant broken crystals and scattered lithic fragments in the parking lot of the Tufts Medical clinic on Main Street in Wakefield (site 11672). Rock hammer for scale.
Zlvx61 (below): Cut rock sample from outcrop to left showing color variation and scattered lithic fragments.

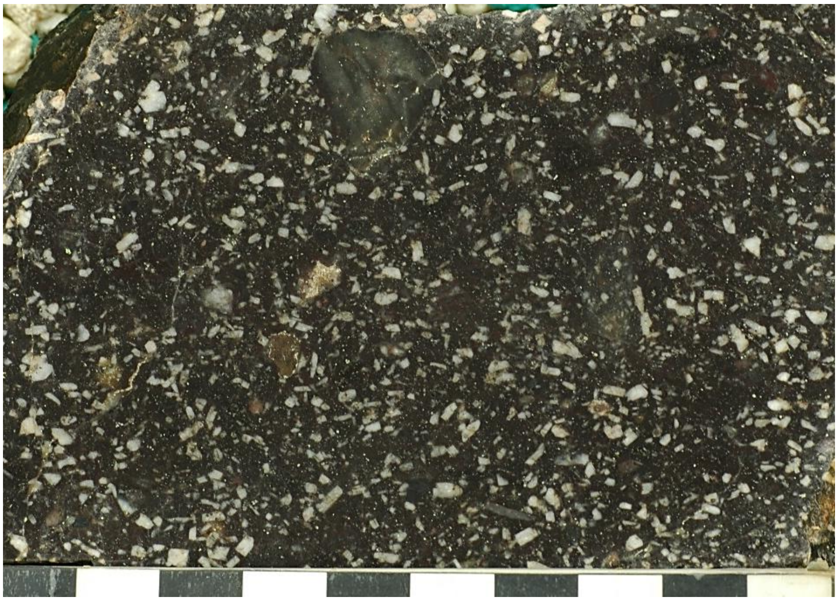




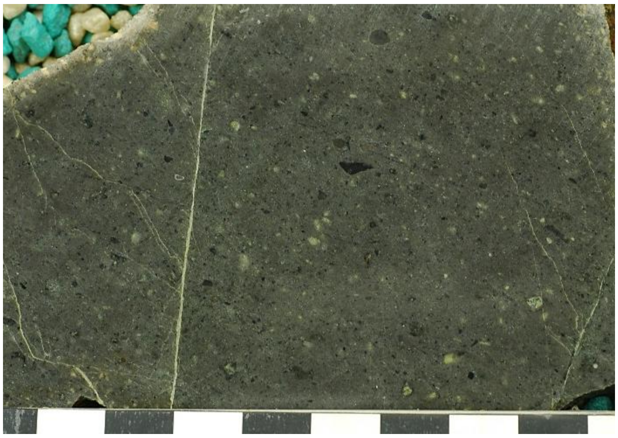
Zlvx62 (above): Dark purplish-gray crystal tuff with abundant broken crystals in the Wakefield Town Forest southeast of Oak Street (site 11727).

Zlvx63 (above left): Dark purplish-gray, lighter purplish-gray weathering, crystal tuff with abundant broken crystals in the Wakefield Town Forest southeast of Oak Street (site 11726). Rock hammer for scale. **Zlvx64** (above right): Same rock as Fig. Zlvx63 in cut sample. Note high crystal concentration and scattered lithic fragments.

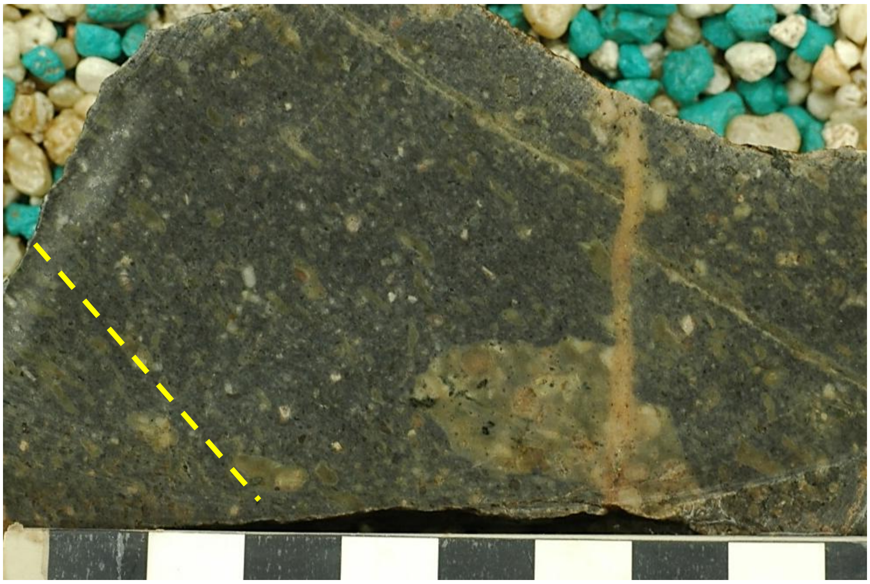


Zlvx65 (left): Dark reddish-gray crystal tuff with abundant broken crystals and conspicuous dark gray to red volcanic lithic fragments in the Town Forest south of Castle Clare Circle in Wakefield (site 11763).

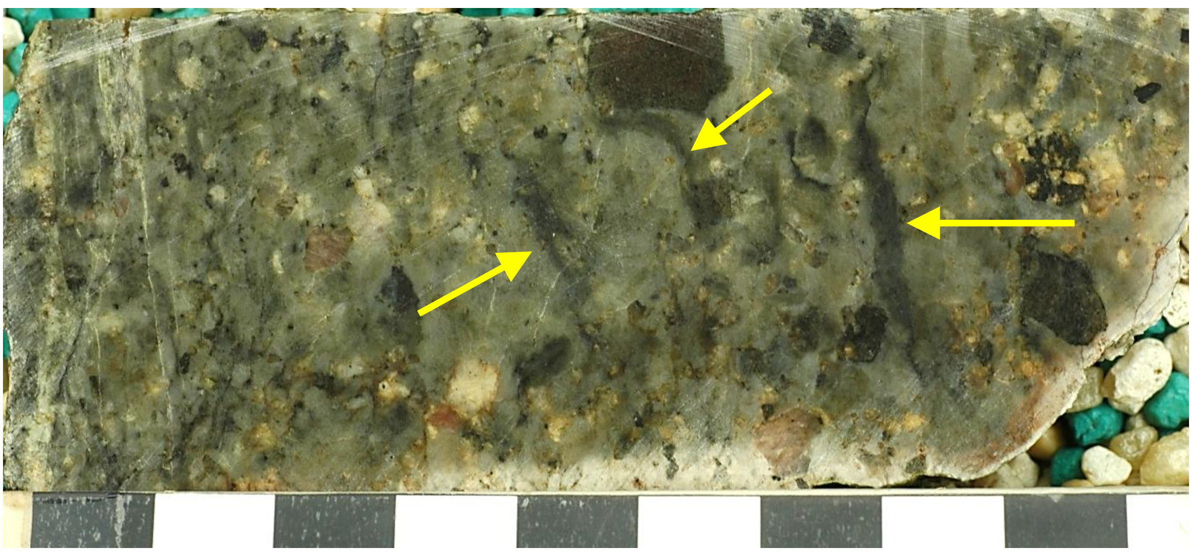



Zlvx66 (above left): Light pinkish-gray weathered surface of crystal tuff where it transitions to vitric tuff (Zlvv) in the Wakefield Town Forest southeast of Oak Street (site 11724). Rock hammer for scale. **Zlvx67** (above right): Cut sample of rock in Fig. Zlvx66. Note low crystal concentration and darker medium gray color than on weathered surfaces. This rock also has smaller and fewer lithic fragments.

Zlvx68: Dark reddish-gray, light-weathering crystal tuff with abundant broken crystals and conspicuous dark gray to red volcanic lithic fragments in the Wakefield Town Forest south of Castle Clare Circle in Wakefield (site 11748). Shown here are light gray-weathering pumice fragments (arrows) aligned from upper left to lower right.



Zlvx69: Dark gray crystal tuff with abundant broken crystals and conspicuous volcanic lithic fragments in the conservation land at J.J. Round Park in Wakefield (site 11674). Shown here is faint alignment of glass and pumice fragments from upper left to lower right (dashed line shows trend).



Zlvx70: Light gray weathering crystal tuff with conspicuous volcanic lithic fragments in the conservation land at J.J. Round Park in Wakefield (site 11700). Aligned, flattened glass or pumice fragments (arrows) have a dark color in this rock.

Felsic Facies of the Wakefield Formation (cont.)

Zlvl

Lithic tuff facies - Lithic tuff is distinguished from felsic clastic units by having more angular and fewer fragment types that are almost entirely felsic pyroclastic volcanic and felsic flow fragments. Lithic tuff units have a matrix of crystal tuff with no evidence of sorting. However, included with lithic tuff may be rocks formed as debris flows or lahars, i.e., reworking of volcanic materials and therefore technically volcaniclastic, that are rich in angular fragments but with a few subangular to subrounded accidental clasts. These units with large clasts appear to form the base of units mapped here. The lithic tuff facies occurs near Boojum Rock, at Wrights Pond in Medford, in Pine Banks Park in Malden, and in what so far appears to be a single continuous lithic tuff layer in Wakefield and Saugus. Lithic tuff layers near Boojum Rock are too thin to map separately and are mapped as part of the felsic clastic (Zlvc), crystal tuff (Zlvx) and vitric tuff (Zlvv) facies within which they occur as discontinuous layers or lenses. The lithic tuff facies in Wakefield is a thick layer within a very thick crystal tuff (Zlvx) sequence and is bounded to the south by a basalt flow (Zlbf). Lithic tuff units are medium to dark gray (N5-4; Figs. Zlvl1-3) to weak red (10R 4/1; Fig Zlvl4), easily weathering to light gray (N7) to red colors (10R 5/3; Fig. Zlvl5-7) and have a crystal tuff matrix (Fig. Zlvl1-6). Matrix crystals are mostly plagioclase with secondary quartz. Fragments are dominantly felsic tuff and flow fragments that are mostly dark gray to black (Zlvl1-2 and 5) and can weather to a red color (Figs. Zlvl4 and 6). A mixture of black and red fragments (Fig. Zlvl4) suggests that some were weathered red prior to deposition. Accidental quartzite (Fig. Zlvl7-8), basalt, and granite (Zlvl4 and 9) fragments are not uncommon. Flattened and oriented pumice fragments are common, and they are aligned in some samples (Figs. Zlvl6-8 and 10-11).

Zlvl1 (above): Non-weathered, medium gray lithic tuff with mostly black angular volcanic lithic fragments on Holland Road in Wakefield (site 11716). Matrix is crystal tuff. Pencil for scale on a mineralized fracture plane.

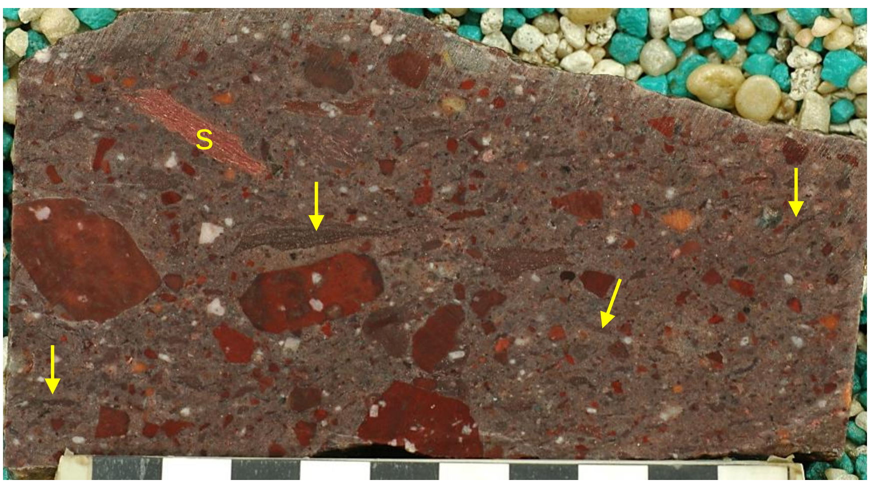
Zlvl2 (left): Non-weathered, medium gray lithic tuff with mostly black, angular volcanic lithic fragments on Acorn Avenue in Wakefield (site 11739). Matrix is crystal tuff. Rock hammer for scale.

Zlvl3: Non-weathered, light gray lithic tuff with mostly red angular volcanic lithic fragments in Pine Banks Park in Malden (site 11461).

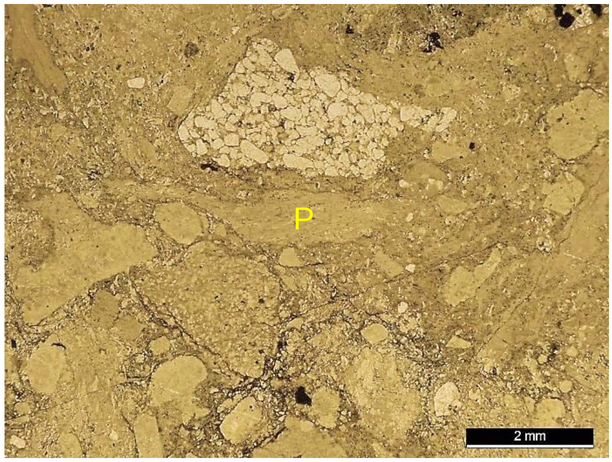
Zlvl4: Non-weathered, slightly purplish, medium gray lithic tuff with black and red (apparently weathered) angular volcanic lithic fragments south of Castle Clare Circle in Wakefield (site 11747). Rock also has an accidental granite fragment (arrow). Rock hammer for scale.

Zlvl5: Lithic tuff weathered light gray with mostly black angular volcanic lithic fragments in the J.J. Round Park conservation area in Wakefield (site 11680).

Zlvl6 (right): Lithic tuff weathered pale reddish-gray with mostly red angular volcanic lithic fragments south of Castle Clare Circle in Wakefield (site 11747). In this rock are solid pumice fragments (S) and aligned flattened pumice fragments that define a fabric (arrows). The red lithic fragments are weathered felsic fragments.



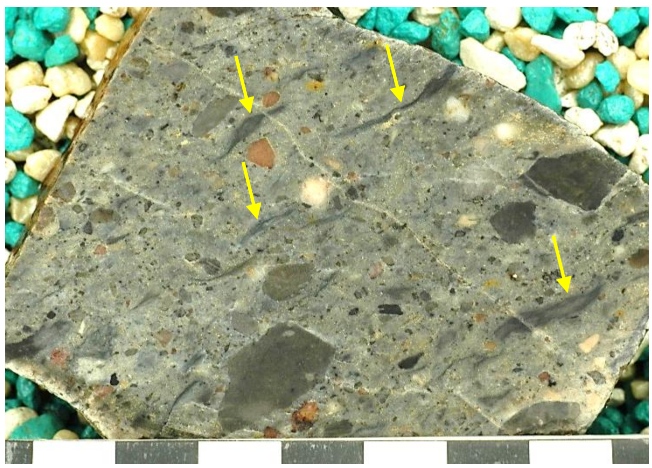
Zlvl7: Lithic tuff weathered light gray with pumice and other volcanic fragments at Wrights Pond in Medford (site 10954). This rock has an accidental quartzite fragment (arrow) and just beneath it are flattened pumice fragments. These clasts are shown on Fig. Zlvl8.



Zlvl8: Lithic tuff with flattened pumice fragments (P) and accidental quartzite fragment (top center; same fragments as on Fig. Zlvl7 but inverted 180^{o}) at Wrights Pond in Medford (site 10954). Thin section in plane polarized light.

Zlvl9 (left): Lithic tuff weathered light gray with accidental granite lithic fragment on Acorn Ave. in Wakefield (site 11739). See Fig. Zlvl2 for same rock without weathering. Rock hammer for scale.

Zlvl10 (below): Gray Lithic tuff with black flattened pumice fragments (arrows) defining a fabric in conservation land east of Holland Street in Wakefield (site 11713).



Zlvl11 (left): Pinkish-gray lithic tuff with white flattened pumice fragments defining a crude fabric (dashed line) in Pine Banks Park in Malden (site 11465).

Felsic Facies of the Wakefield Formation (cont.)

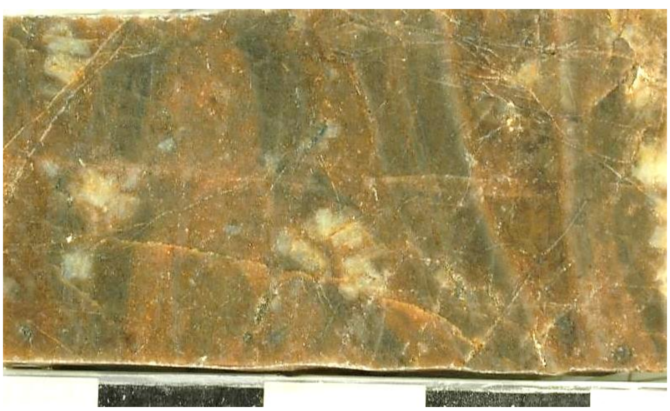
Zlvf

Rhyolite flow facies – Rock description: At Straw Point on Spot Pond, Middle Reservoir and Wamoset Hill the base of the Wakefield Formation is a banded rhyolite. At Straw Point these units are light gray (10YR 7/1) to gray (10YR 6/1), recrystallized, faintly-banded rhyolite with scattered lithic inclusions (Fig. Zlvf1) and at Middle Reservoir is very dark grayish-brown to reddish-brown (5YR 5-4/4-6) banded rhyolite (Fig. Zlvf2-3) both interpreted to be flows with euhedral cumulophyric plagioclase. Faint layering on the east side of Straw Point (Fig. Zlvf1) defines the unit's gentle dip, which parallels overlying basaltic units (Zlbf). At Straw Point the unit has a micropoikilitic ("snowflake") texture due to devitrification and recrystallization, possibly related to contact metamorphism adjacent to the Stoneham Granodiorite (Zst). This texture gives hand samples and weathered surfaces on outcrops a spotted appearance (Figs. Zlvf4-5). U-Pb zircon ages at Middle Reservoir are: 601.2 ± 5.6 Ma (LA-ICPMS, 17 zircons from Hampton, 2017) and 594.70 ± 0.32 Ma (zircon CA-ID-TIMS, ± 2σ F. MacDonald, pers. comm.). A rhyolite flow at the north end of Spot Pond has an age of 595.27 ± 0.34 Ma (4 zircons, CA-ID-TIMS; Fig. Zlvf6).

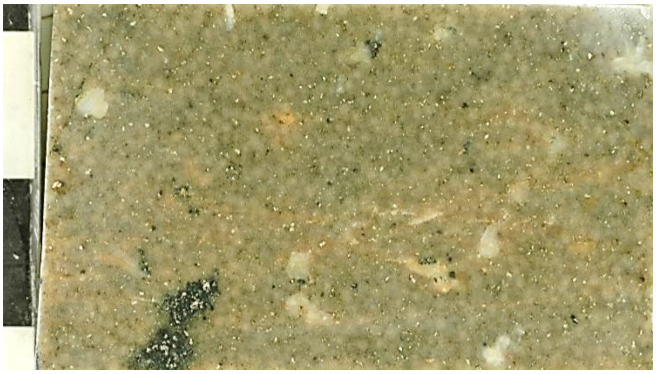
On Wamoset Hill and extending eastward through Whip Hill Park and into Melrose are very dark gray (7.5R 3/0), banded, rhyolitic lava flows with cumulophyric feldspar (Figs. Zlvf7-8). The top of a banded flow unit in Whip Hill Park displays macro-spheroidal texture (relict lythophysae; Fig. Zlvf9). The basal contact of a flow on Wamoset Hill (the flow is shown on Fig. Zlvf7) is an unconformity that truncates metamorphic foliation in the Westboro Formation (Zvwq). The flow unit lacks the Westboro's deformation and metamorphism. Above the flow unit is crystal tuff with flattened pumice and flow fragments. A U-Pb zircon age in the flow unit at Wamoset Hill is 595.82 ± 0.23 Ma (5 zircons, CA-ID-TIMS, ± 2σ; F. MacDonald, pers. comm.). East of Whip Hill in Sewall Woods there are at least two similar flow units with abundant outcrops of banded flows with cumulophyric plagioclase (Figs. Zlvf10-12). These flow units are separated by crystal tuff units.

Zlvf1 (above)**:** Highly fractured banded rhyolite on the west side of a nearly vertical fault at Straw Point in Stoneham (site 10605). Trace of banding (arrows) is parallel to pencil for scale and has a low dip angle.

Zlvf2: Banded rhyolitic flow at north end of Middle Reservoir in Stoneham (site 11139). Trend of banding shown with arrow. Note cumulophyric plagioclase crystal clusters (tiny white spots). This site has a radiometric age discussed above. Rock hammer for scale. See Fig. Zlvf3 for sample view.

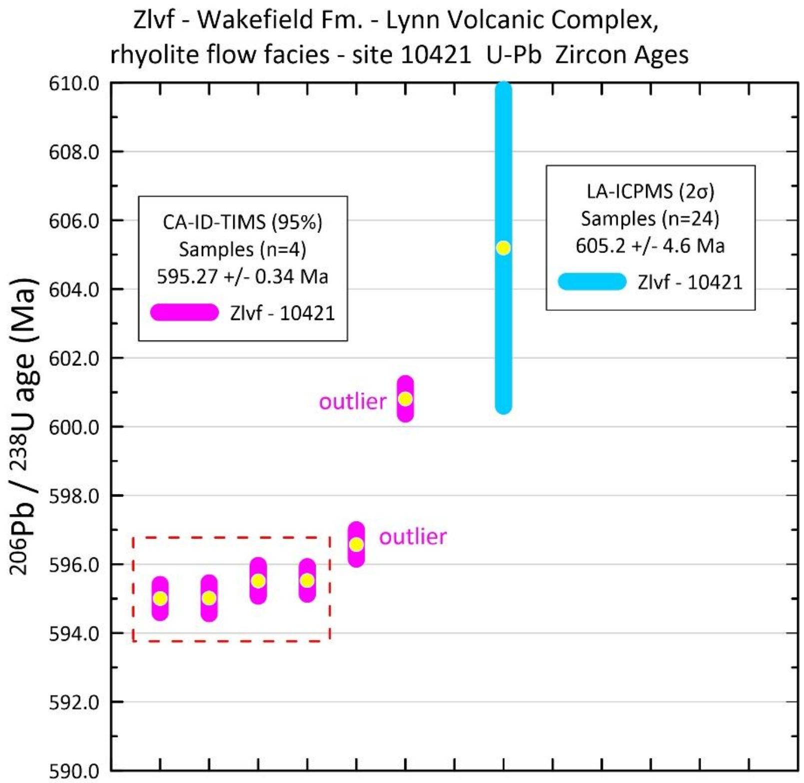


Zlvf3: Banded rhyolitic flow at north end of Middle Reservoir in Stoneham (site 11139). Note cumulophyric plagioclase crystals. This site has a radiometric age listed above. See Fig. Zlvf2 for outcrop view.



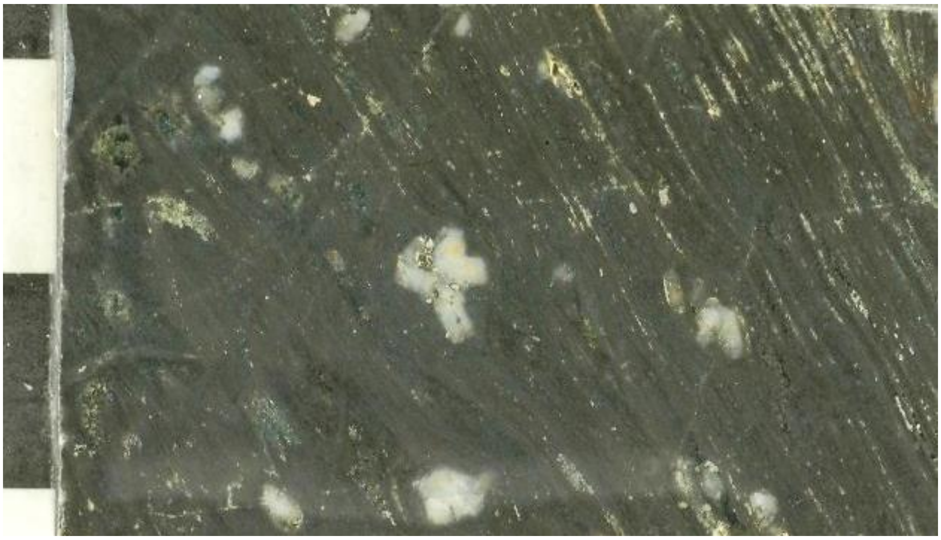
Zlvf4: Banded rhyolite on Straw Point in Stoneham (site 10425). Cut rock shows spots, which are a micropoikilitic (”snowflake”) texture due to devitrification and contact metamorphism of the rock’s matrix adjacent to a contact with the Stoneham Granodiorite (Zst).

Zlvf5: Weathered surface of rhyolitic flow at north shore of Spot Pond in Stoneham (site 10421) that shows spots from a micropoikilitic texture and gray, pinched volcanic inclusions (upper left and right side). This site has a radiometric age discussed above (see Fig. Zlvf6 below).



Zlvf6: Individual CA-ID-TIMS U-Pb ages used to calculate the age of a rhyolite flow within the Wakefield Formation at Straw Point in Stoneham (site 10421). The red box shows the 4 measurements used to calculate the mean age. Two grains are outliers that have uncertainties that do not overlap the four youngest ages. These outliers provide evidence of inheritance or prolonged crystal growth prior to the lava’s eruption and cooling. Also shown for comparison is a less precise LA-ICPMS U-Pb age for the same sample.

Zlvf7: Rhyolitic lava flow sequence with flow-banding, plagioclase phenocrysts, and cumulophyric plagioclase on Wamoset Hill in Stoneham (10366). Red arrow points to fold in banding.

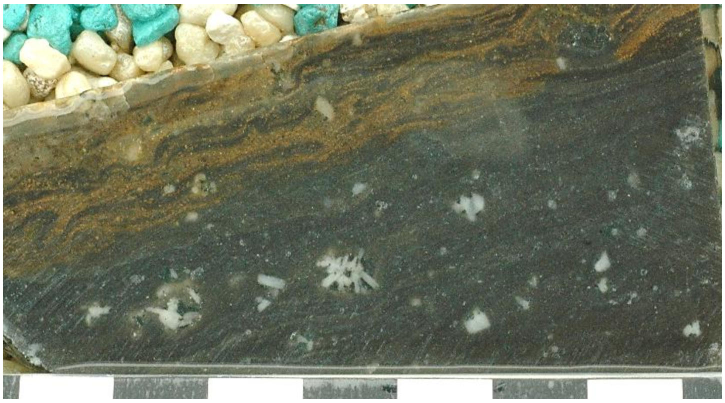


Zlvf8: Rhyolitic lava with flow-banding and cumulophyric plagioclase on Wamoset Hill in Stoneham (10366). Sample is from unit with arrow on right side of Fig. Zlvf7.

Zlvf9: Rhyolitic lava with macroscopic relict spherules (relict lythophysae) at Whip Hill Park in Stoneham (site 10398).

Zlvf10: Rhyolitic lava with flow-banding and cumulophyric plagioclase (white specks) in Sewall Woods in Melrose (11538).

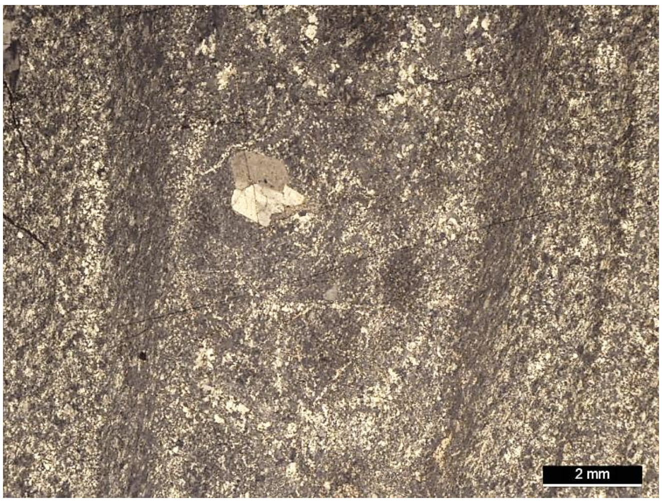
Zlvf11: Rhyolitic lava with flow-banding and cumulophyric plagioclase in Sewall Woods in Melrose (11538). In the lower center is a fold.



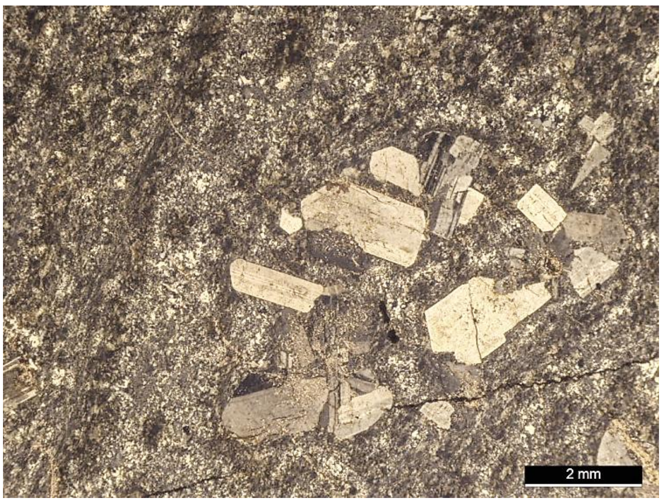
Zlvf12: Rhyolitic lava with flow-banding and cumulophyric plagioclase in Sewall Woods in Melrose (11536). Note also how oxidation during weathering accentuates the banding.

Thin section description: At Middle Reservoir is a flow-banded rhyolitic flow that has continuous matrix layers with varying sizes, shapes, and orientations of mineral grains. Stretching and shearing of original molten glass and incipient crystals may have influenced later crystallization during devitrification leading to distinct bands of oriented, elongate, very fine, fibrous crystals (Figs. Zlvf13-14). Matrices vary from a fine patchy or splotchy (Figs. Zlvf13-15) to micropoikilitic ("snowflake") texture (Figs. Zlvf16-18) that probably depends on the rate of recrystallization and original glass fabric. Staining reveals a high matrix potassium concentration (Fig. Zlvf15). In 11 thin section samples: flow-banding is preserved and easily seen at the north end of Middle Reservoir but only seen in a few isolated areas at the north end of Spot Pond where flows have a micropoikilitic texture. Micropoikilitic textures that obscure banding developed during devitrification or heating by intrusion of the Stoneham Granodiorite (Zst) (Figs. Zlvf16-18). All flow units, regardless of matrix texture or recrystallization, have well developed porphyritic or cumulophyric, euhedral plagioclase (Figs. Zlvf11-16 and 18). No large quartz crystals, either as accidental or juvenile crystals, that occur in the pyroclastic facies, have been found. The only mafic mineral grains are a few isolated biotite crystals at Straw Point (Figs. Zlvf15 and 18). Inclusions are very sparse, and none were seen in thin section.

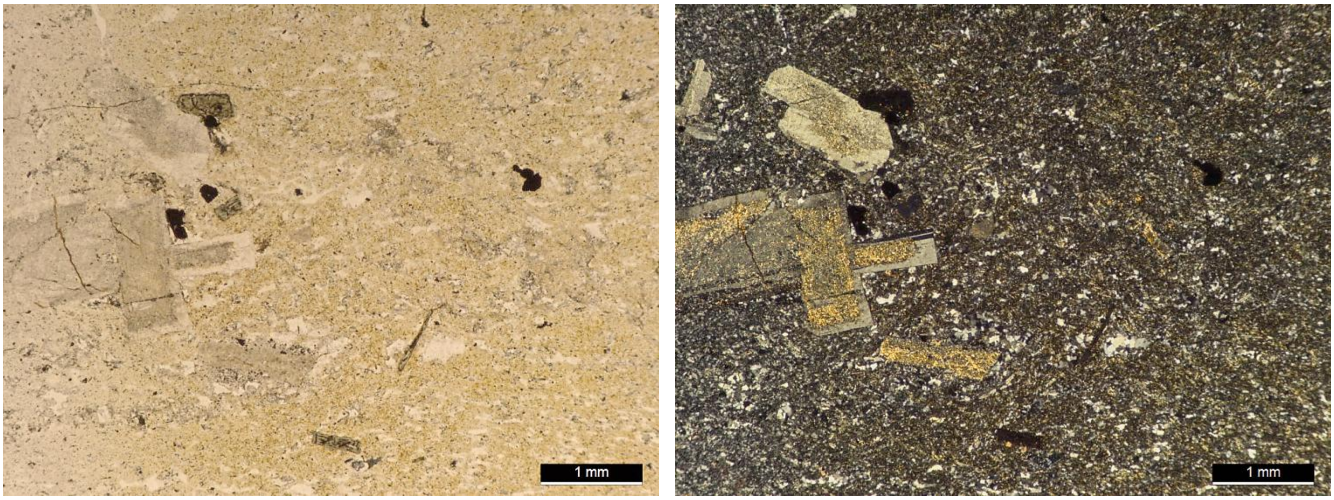
In the banded rhyolite flows on Wamoset Hill and further east in Melrose (Sewall Woods) is abundant to sparse cumulophyric and porphyritic plagioclase (Figs. Zlvf19-24). Bands are a manifestation of layers with different crystal sizes, shapes, orientation, and potassium concentrations (Figs. Zlvf19 and 21-22). Flow units sometimes contain angular fragments of flow-banded rhyolite suggesting autobrecciation (Fig. Zlvf23), and glassy flows can devitrify to a micropoikilitic texture (Fig. Zlvf24). The surfaces of flow units are composed of very thin, contorted bands and can have spherulites (Fig. Zlvf25) and relict perlitic texture (Fig. Zlvf26).



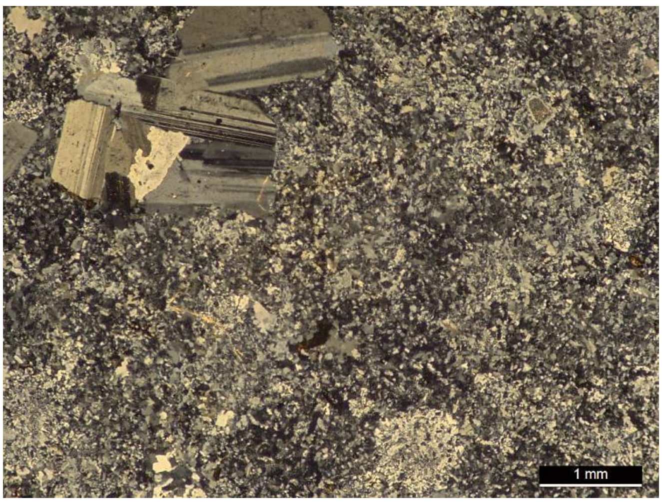
Zlvf13: Flow-banded rhyolite with layers of different grain size and crystal elongation (site 11139 at Middle Reservoir in Stoneham; see also Fig. Zlvf2-3). Along the center of a fold (center of image) is a fine patchy and splotchy texture with cumulophyric plagioclase while adjacent bands have elongated fibrous crystals. Thin section with crossed polarizers.



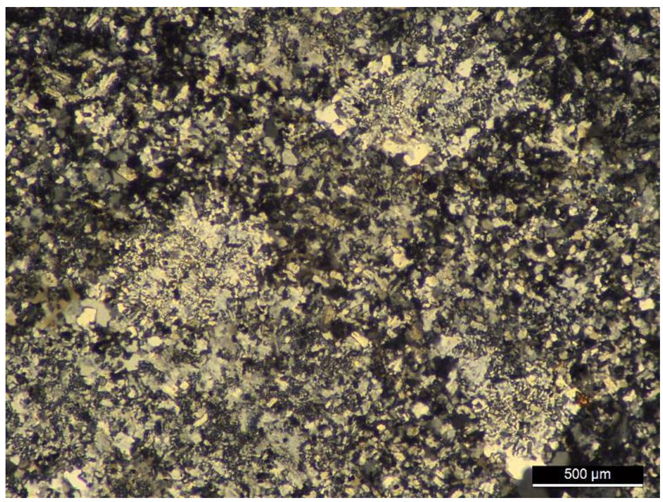
Zlvf14: Flow-banded rhyolite with layers of different grain size and elongation of crystals (site 11139 at Middle Reservoir in Stoneham; see also Fig. Zlvf2-3). On the right is a fine patchy micropoikilitic area surrounding cumulophyric euhedral plagioclase. Thin section with crossed polarizers.



Zlvf15 (left): Thin section in plane polarized light. (right): Same view with crossed polarizers. Rhyolite flow with a fine patchy texture and yellow stain (only right ¾ of image is stained) indicating a high potassium concentration (site 10604 at Straw Point in Stoneham; see also Figs. Zlvf1 and 4-5). On the left side of the images is a cumulophyric cluster of euhedral plagioclase crystals internally altered to sericite. The elongate green crystals (left; black on right) are biotite partly altered to chlorite.

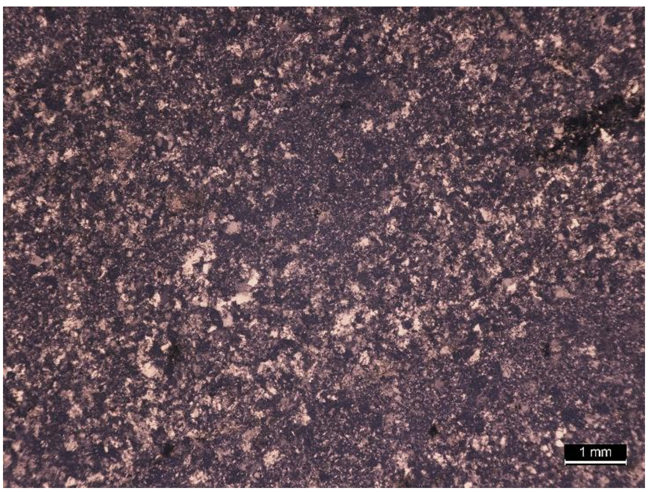


Zlvf16: Rhyolite flow with well developed micropoikilitic ("snowflake") texture of quartz surrounding finer feldspar grains (site 10425 at Straw Point in Stoneham; see also Fig. Zlvf4-5). In upper left is very clean, cumulophyric euhedral plagioclase. Thin section with crossed polarizers.

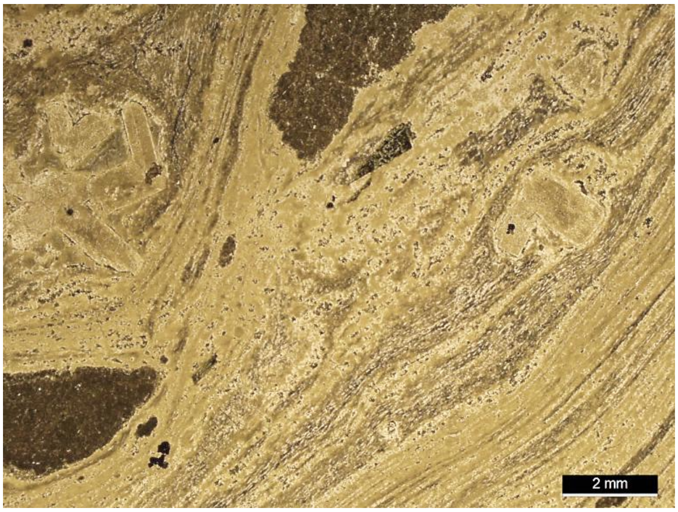


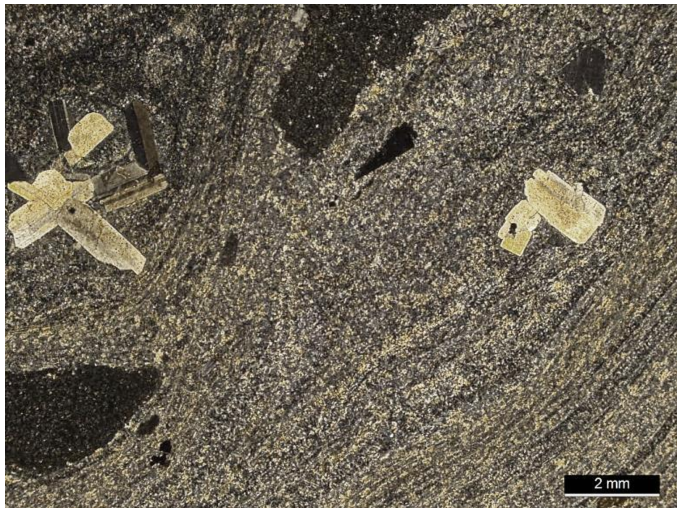
Zlvf17: Close up of micropoikilitic ("snowflake") matrix texture of quartz surrounding finer feldspar and very fine granophyric grains in a rhyolitic flow (site 10421 at western Sheep Pasture Point in Stoneham; see also Fig. Zlvf4-5). Thin section with crossed polarizers.

Zlvf18: Rhyolite flow with patchy to micropoikilitic (“snowflake”) matrix texture of quartz surrounding finer feldspar and very fine granophyric grains (site 10442, western Sheep Pasture Point). Cumulophyric plagioclase is partly altered to sericite. Brown tabular crystals are biotite. Thin section with crossed polarizers.

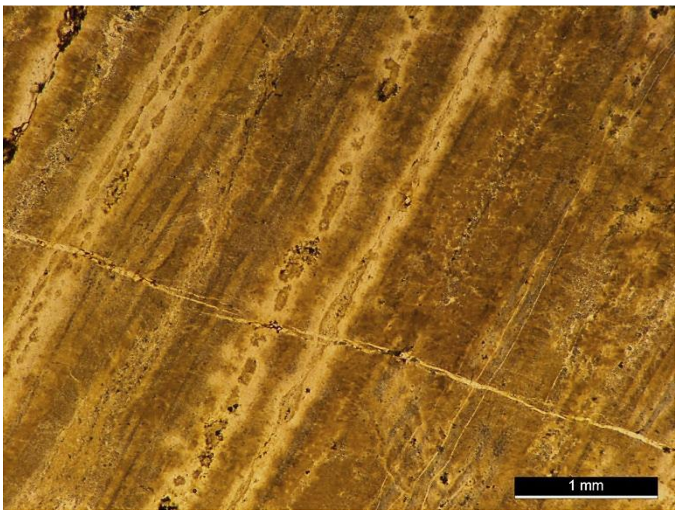


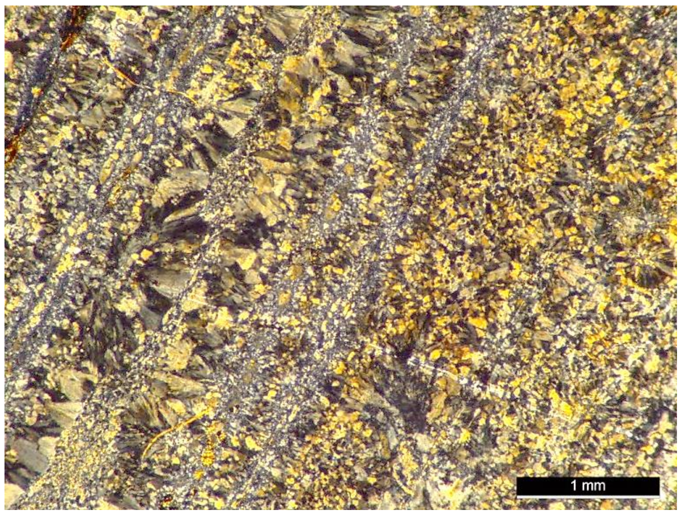
Flow-banded rhyolite on the northwest side of the Fellsway East in Melrose (site 11534). Thin section views with crossed polarizers.
Zlvf19 (above left): Bands (lower left to upper right) are barely visible except for slight grain size differences.
Zlvf20 (above right): Cumulophyric plagioclase.



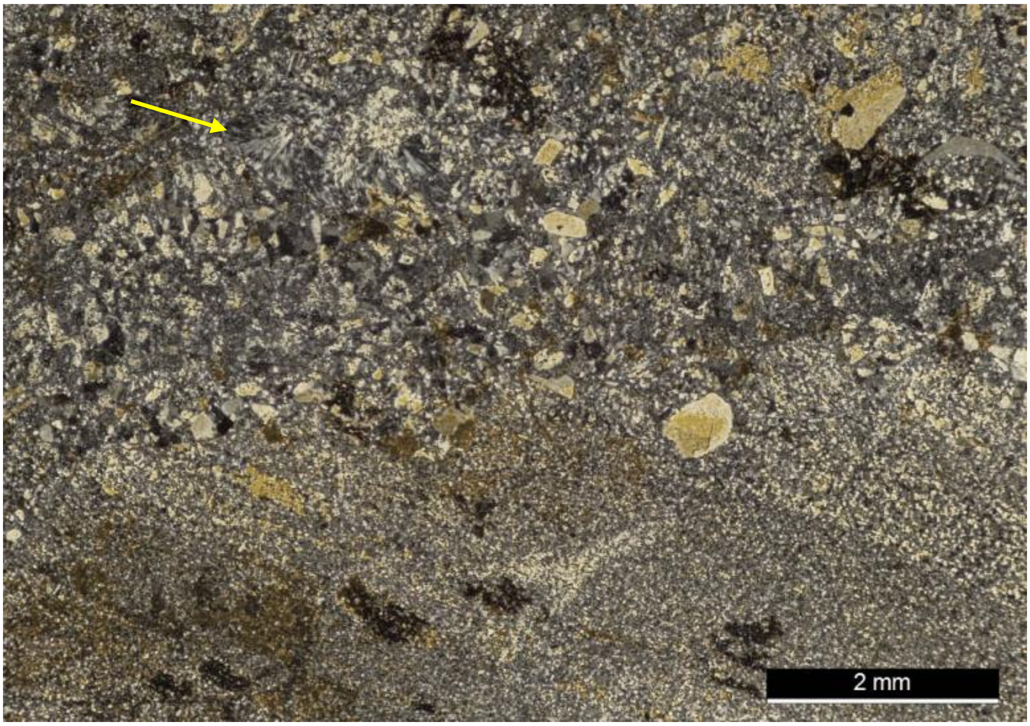


Zlvf21 (left): Thin section in plane polarized light. (right): Same view with crossed polarizers. Flow-banded rhyolite with cumulophyric plagioclase clusters on Wamoset Hill in Stoneham (site 10346) . Bands alternate between layers with intense yellow potassium staining and fine grain size and slightly coarser bands with less intense staining and oriented fine plagioclase crystals. Dark lithic fragments are argillite hornfels from the Westboro Formation.

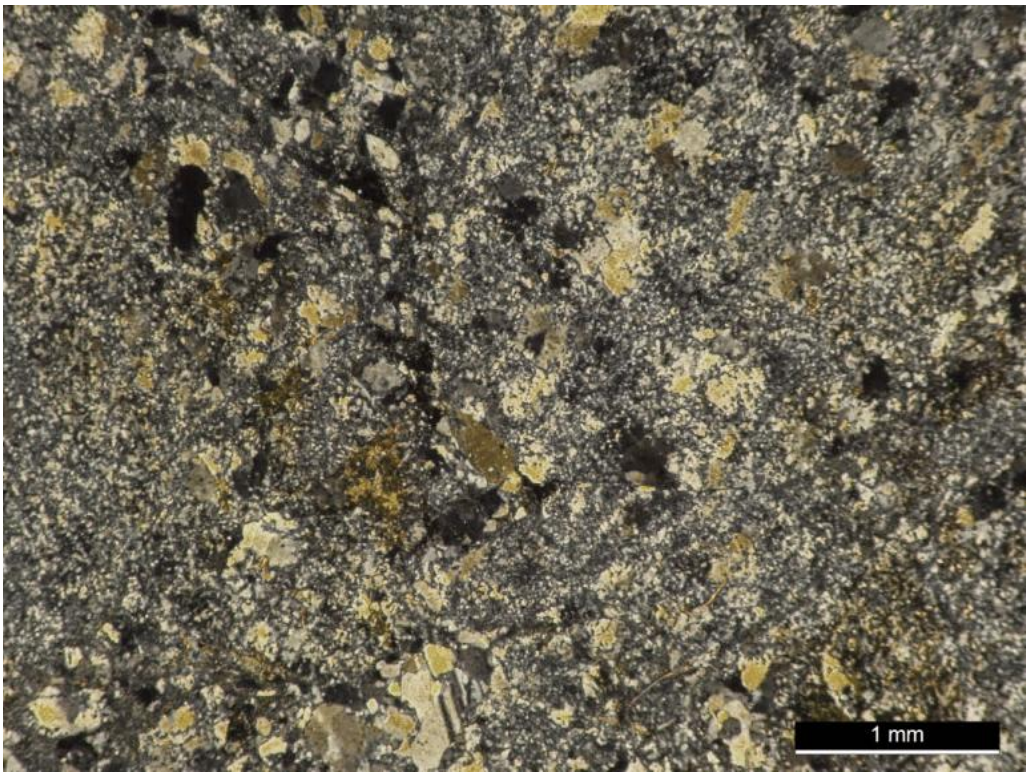




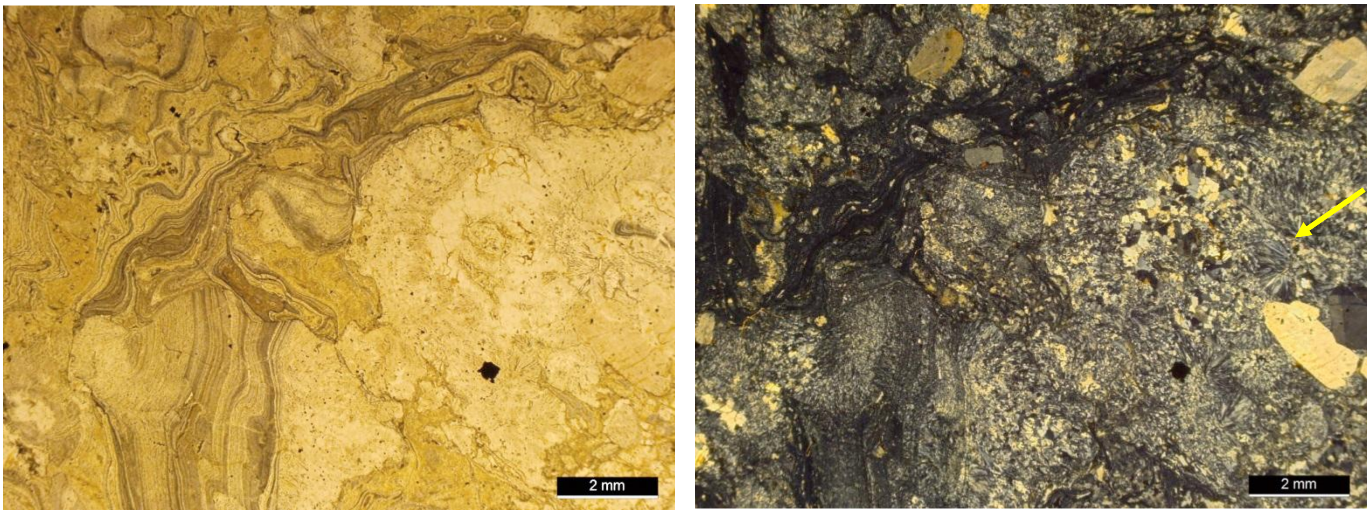
Zlvf22: (left): Thin section in plane polarized light. (right): Same view with crossed polarizers. Close up of flow-banding in rhyolite on Wamoset Hill in Stoneham (site 10366; see also Fig. Zlvf7-8). Bands alternate between layers with intense dark orange potassium staining and less intense staining. In this case, the apparently coarser grains with radiating spherulitic texture (image on right) have a darker stain (image on left). The lighter layers (across center, image on left) have more plagioclase and quartz (image on right).



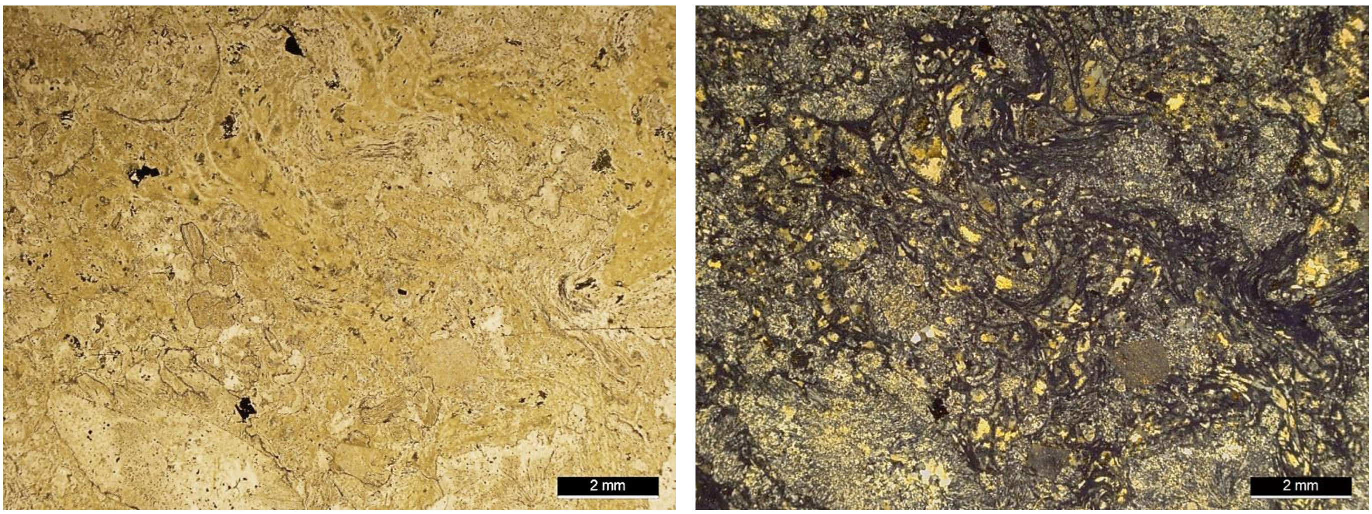
Zlvf23: Rhyolitic flow (top) with flow-banded fragment (bottom) likely formed by autobrecciation on Wamoset Hill in Stoneham (site 10366; see also Fig. Zlvf7-8). The flow unit has large (up to 1 mm) partial spherulites with radiating crystals (arrow). Thin section with crossed polarizers.



Zlvf24: Flow unit with faint micropoikilitic (“snowflake”) texture formed during devitrification on Wamoset Hill in Stoneham (site 10366; see also Fig. Zlvf8). Thin section with crossed polarizers.



Zlvf25 (left): Thin section in plane polarized light. (right): Same view with crossed polarizers. Surface of rhyolitic flow with very thin, contorted flow-banding and partial spherulites (fibrous area at arrow on right image) on east side of Whip Hill Park in Stoneham (site 10398; See Fig. Zlvf9).

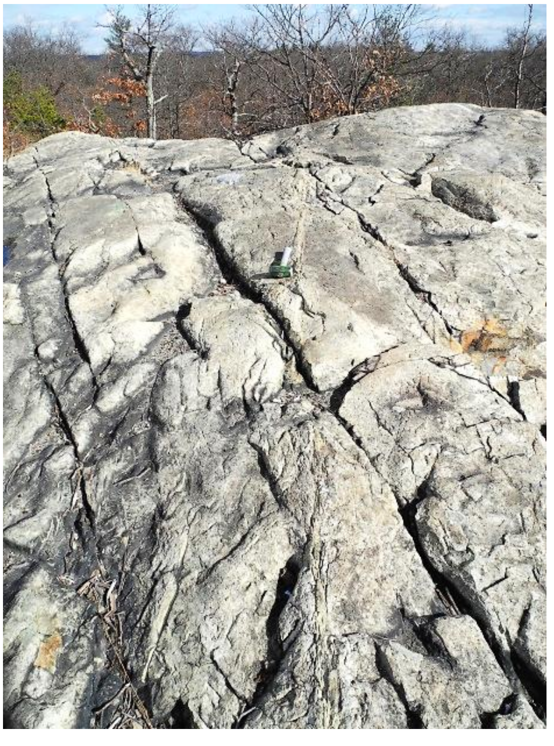


Zlvf26 (left): Thin section in plane polarized light. (right): Same view with crossed polarizers. Surface of rhyolite flow with relict perlitic texture on east side of Whip Hill Park in Stoneham (site 10398; see also Fig. Zlvf9). The perlitic texture is more apparent with crossed polarizers.

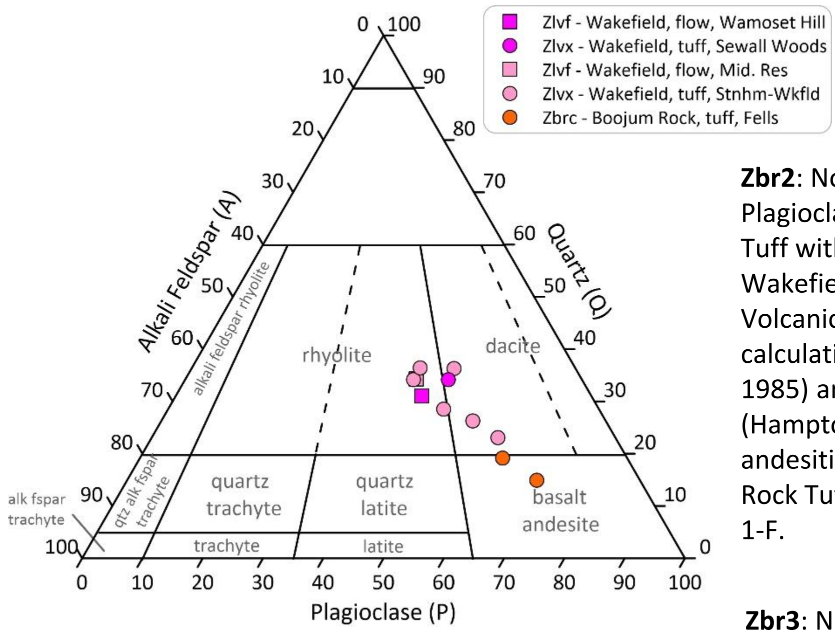
Lynn Volcanic Complex - Boojum Rock Tuff

Massive dacitic to andesitic tuff of formation status in the Lynn Volcanic Complex in the southeastern Fells (Fig. Zbr1-2) and extending southward and eastward into Malden and Melrose. Three dacitic to andesitic facies of the unit are recognized in the Middlesex Fells where they form an eastward-dipping sequence west of a major fault in the Malden to Melrose valley. East of this fault the orientation of the unit is not known but the unconformity on which it rests east of the fault appears to have a gentler southern dip. The unit has coarser crystals and a redder color to the east with a separate red facies (Zbrr) recognized in Malden and Melrose. The unit is dominated by massive crystal tuff with a very high crystal density (mostly 40-50% crystals, Fig. Zbr3) and many volcanic lithic fragments as well as accidental quartzite and argillite fragments from the Westboro Formation (see data in Appendix 2-B). The unit is dominated by plagioclase crystals with secondary mafic crystals (hornblende with very scarce biotite) and has very rare quartz fragments that are mostly fine and derived from broken quartzite (Fig. Zbr4). Most point counts (>300 counts) had no quartz or alkali feldspar crystals. The unit has none of the coarse, embayed and rounded quartz crystals as are found throughout the younger Wakefield Formation.

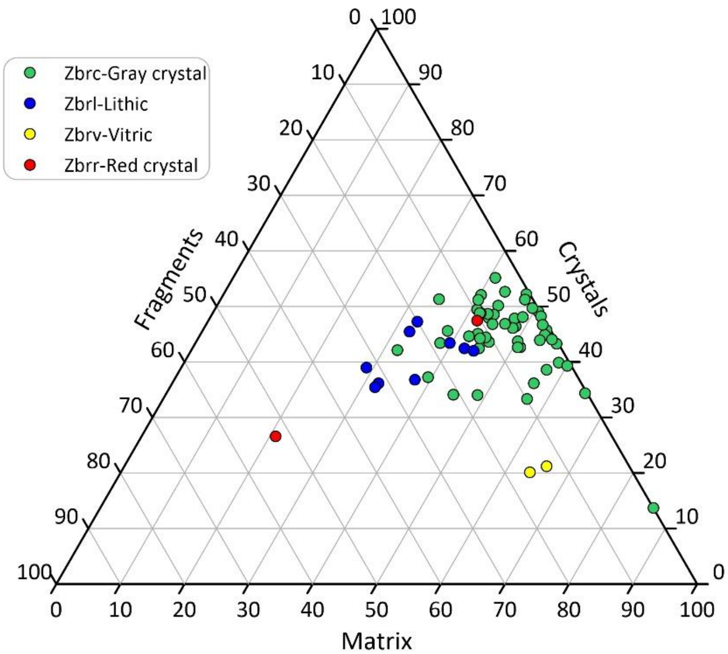
The Boojum Rock Tuff forms the basal unit of the Lynn Volcanic Complex and unconformably rests on the Spot Pond Granodiorite and Westboro Formation. The contact with the Spot Pond occurs north of Hemlock Pool where the tuff is heavily altered. The contact with the Westboro occurs in Pine Banks Park in Melrose. In the Fells South of Virginia Wood there may be an unconformable contact concealed by glacial sediment. The Boojum Rock Tuff is heavily fractured with well-oriented joint sets and, in places, has a closely-spaced wavy cleavage with slickensides that are mineralized by hematite. Kaye (1980) correlated the Boojum Rock to the Lynn Volcanic Complex of LaForge (1932; “Lynn volcanics” of Clapp, 1921) and it was partly interpreted as lahar and a subvolcanic pluton by Smith and Hon (1984) and Smith (1985). The unit has a new CA-ID-TIMS U-Pb zircon age of 596.35 $\pm$ 0.21 Ma (Fig. Zbr5), similar to the subvolcanic Rams Head Porphyry.



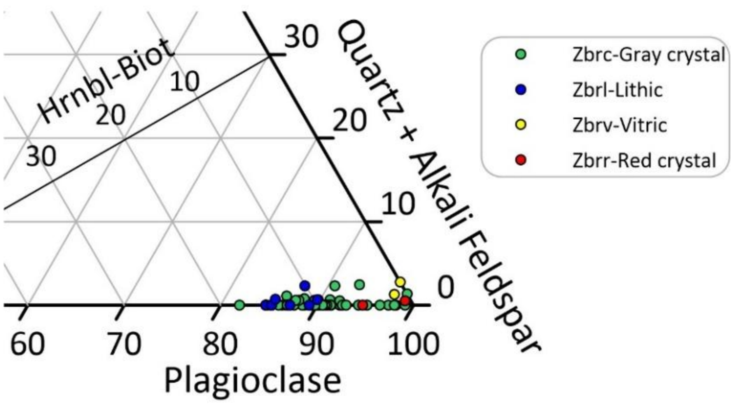
Zbr1: Typical outcrop of crystal tuff facies of the Boojum Rock Tuff (Zbrc) on Boojum Rock in Medford (site 10028). Note well oriented joints. Rock hammer for scale.



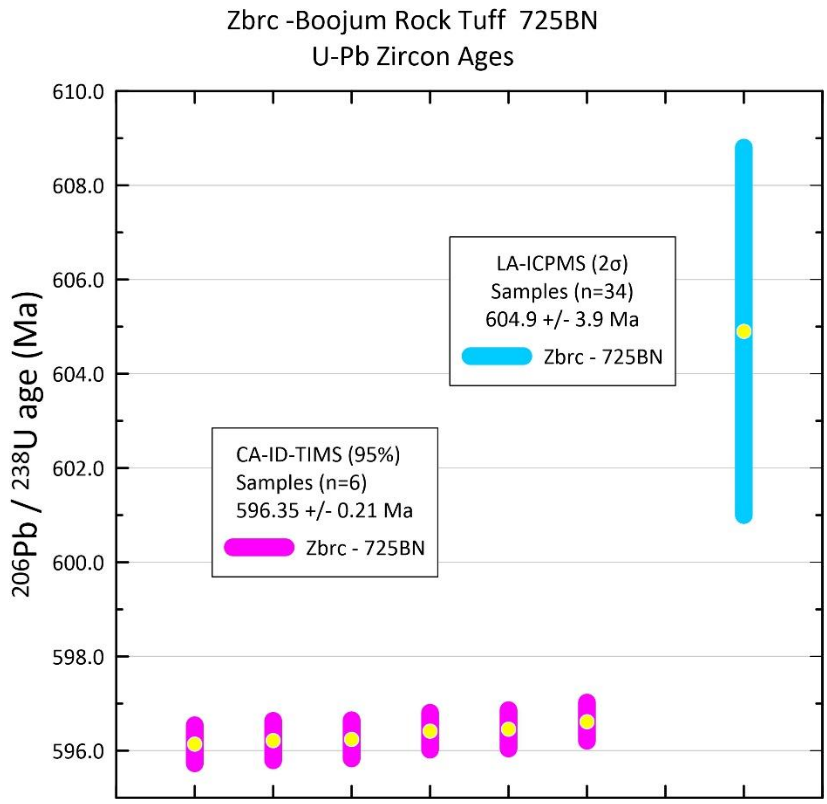
Zbr2: Normalized Quartz-Alkali Feldspar-Plagioclase (QAP) plot of Boojum Rock Tuff with a comparison to units in the Wakefield Formation of the Lynn Volcanic Complex from CIDW Norm% calculation of XRF data from tuffs (Smith, 1985) and LA-ICPMS data from flows (Hampton, 2017). Note the more andesitic composition of the Boojum Rock Tuff. Data is in Appendices 1-C and 1-F.



Zbr3: Normalized ternary plot of normalized crystal-lithic fragment-crystal percentages for point counts in facies of the Boojum Rock Tuff. As expected, the lithic tuff facies shows a generally higher percentage of lithic fragments. The actual percentage is higher than reported here because thin sections were chosen to study mostly crystal types thus avoiding thin sections with a high density of fragments. In many cases lithic fragments were also bigger than a thin section and samples of these areas were avoided. The vitric tuff facies not only has fewer crystals, but crystals are smaller and lithic fragments in this facies are dominated by banded and eutaxitic volcanic fragments that are devitrified glass. Data is in Appendix 2-B. A comparison to crystal tuff in the Wakefield Fm. is given in Fig. 1-6B on p. 17.



Zbr4: Normalized ternary plot of normalized quartz plus alkali feldspar-mafic crystals (hornblende and biotite)-plagioclase percentages in facies of the Boojum Rock Tuff. Plagioclase dominates crystals with secondary hornblende while combined quartz and alkali feldspar crystals have a very low percentage. Note how samples hug the bottom axis, and most samples have no quartz or alkali feldspar crystals. Data is in Appendix 2-B. A comparison to crystal tuff in the Wakefield Fm. is given in Fig. 1-6C on p. 17.



Zbr5: Individual CA-ID-TIMS U-Pb ages used to calculate the mean age of the Boojum Rock Tuff in the Lynn Volcanic Complex. The sample is from the middle of the crystal tuff facies (Zbrc) and east of the lithic tuff facies layer northeast of Pinnacle Rock in Medford. Also shown is a less precise LA-ICPMS U-Pb age for the same sample.

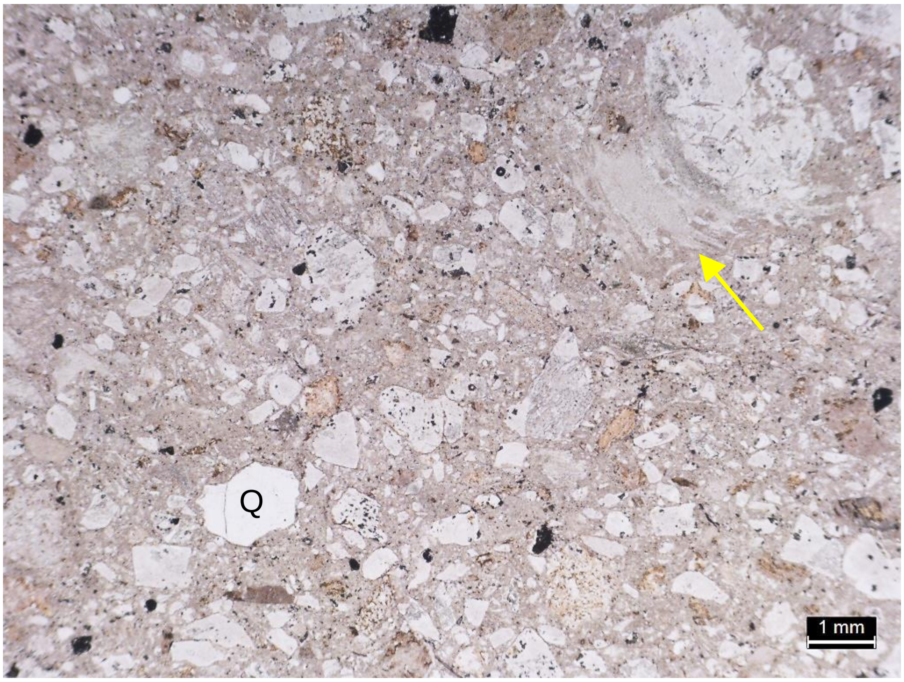
Zbrv

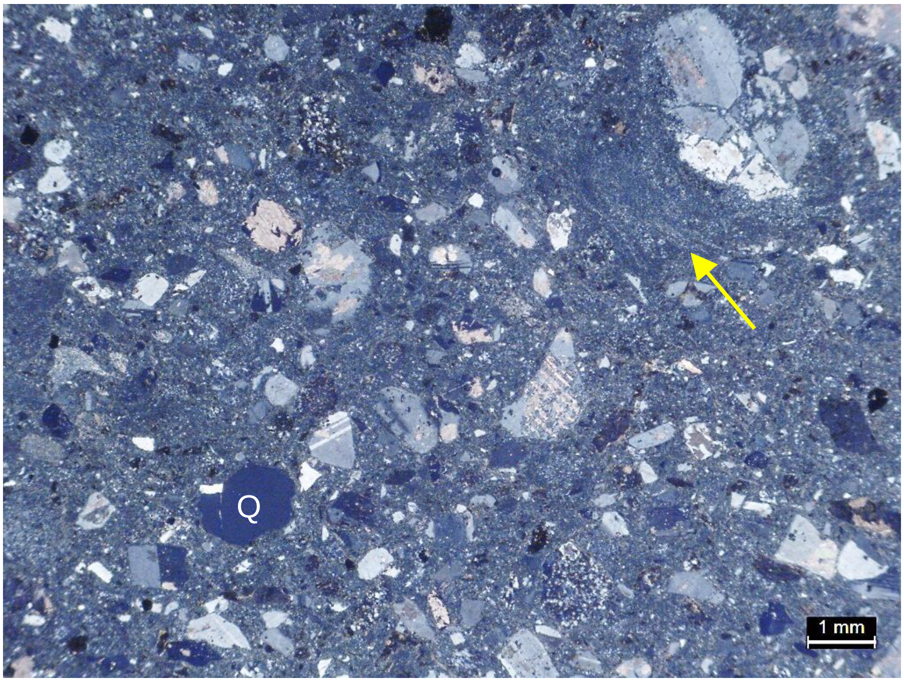
Vitric (fine-crystal) tuff facies – Light bluish- to pinkish-gray (5B 7/11 to5 YR 8/1), fine, mostly vitric tuff (Figs. Zbr3-4). Weathers to light colors (very pale orange to very light gray to almost white (10 YR 8/2 – N8) and in places has faint, steeply eastward-dipping layers (pyroclastic banding) that define layering (Fig. Zbrv1). Can have a chert-like appearance and crystals greater than 1 mm are sparse. This unit only occurs in a small outcrop area at the southeastern border of the Fells in Malden and Melrose where it is truncated by a major fault zone on its eastern side. Other vitric tuff occurrences in the Lynn Volcanic Complex are in the Wakefield Formation.

Zbrv1: Vitric tuff with faint pyroclastic banding (arrows along strike, east dipping) southeast of Black Rock in Medford (site 10083).

Boojum Rock Tuff - vitric tuff facies (cont.)

Thin section description: Welded, dacitic to andesitic, mostly vitric tuff with matrix textures like other facies described in more detail below. Crystal concentrations can appear high but crystals greater than 1 mm are sparse (Fig. Zbrv2; Fig. Zbr3-4). Included in the matrix are large, devitrified, pinched and flattened pumice and obsidian fragments that are warped around surrounding grains and have a eutaxitic or banded texture. Almost all crystals are partly altered, broken, euhedral plagioclase. Also present in almost all samples are euhedral to broken hornblende crystals that are slightly to entirely altered to chlorite, epidote, and magnetite. Also in the tuff are visible outlines of glass shards, which are generally harder to see in the other facies. Lithic fragments are small as compared to lithic fragments in the other facies and are volcanic. Quartzite and argillite fragments from the Westboro Formation may occur in this unit but were not seen in the two thin sections examined.





Zbrv2: (above) Thin section in plane polarized light; (below) Same view with crossed polarizers. Crystal vitric tuff from southeastern corner of Fells in Melrose (site 11349) with mostly small broken plagioclase crystals that are altered. Orange grains are broken hornblende partly altered to epidote and chlorite. Note rare bright quartz grain in lower left (Q) and pinched, eutaxitic devitrified pumice/obsidian fragment (arrow) wrapping around larger solid crystal. Matrix has abundant relict outlines of broken glass shards in upper image.

Boojum Rock Tuff - Lynn Volcanic Complex (cont.)

Zone with flattened pumice fragments – Recrystallized, coarse, flattened, heavily-altered glass/pumice fragments (fiammé) at the top (east side) of the lithic crystal tuff facies (Zbrl). The fragments are up to 10 cm long, but usually on the order of 2-4 cm, weather to a dark color, and are recessed from the rock surface by weathering. The mineralized pockets parallel the overall layering depicted by the lithic tuff unit and infrequent banding measured throughout the Boojum Rock Tuff. Measurements of the strike and dip of the foliation defined by the flattened pumice fragments are indicated with a separate symbol.

Zbrf1: Flattened pumice/glass fragments (pod-like depressions in lithic crystal tuff at the top of the lithic tuff facies (Zlvl) near Black Rock in Melrose (site 10024). Flattened fragments dip from upper right to lower left on the vertical face shown here that is perpendicular to strike. Rock hammer for scale.

Zbrf2: Differentially weathered flattened pumice/glass fragments (trace parallel to pencil for scale) at the top of the lithic crystal tuff near Melrose Rock in Melrose (site 10038).

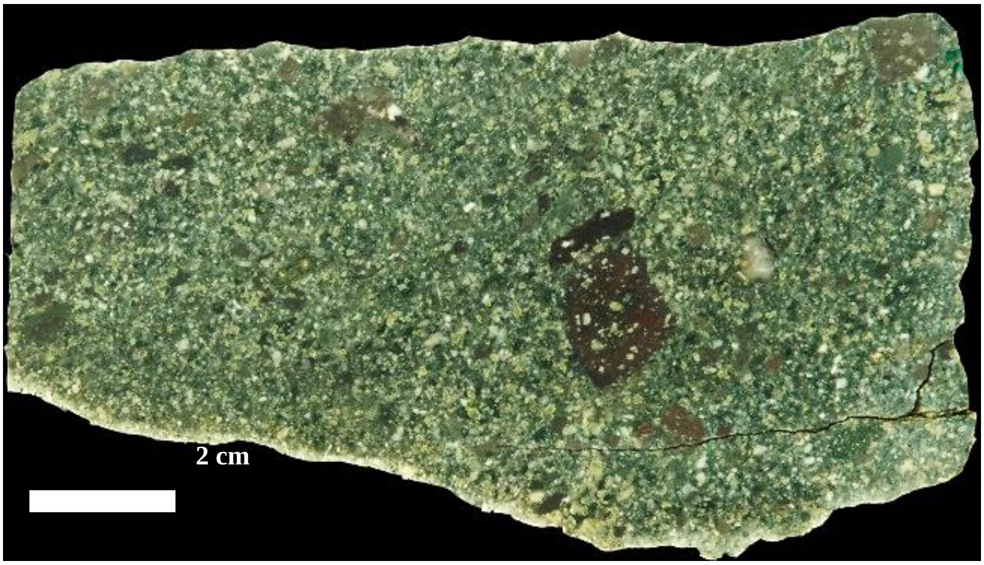
Boojum Rock Tuff - Lynn Volcanic Complex (cont.)

Zbrl

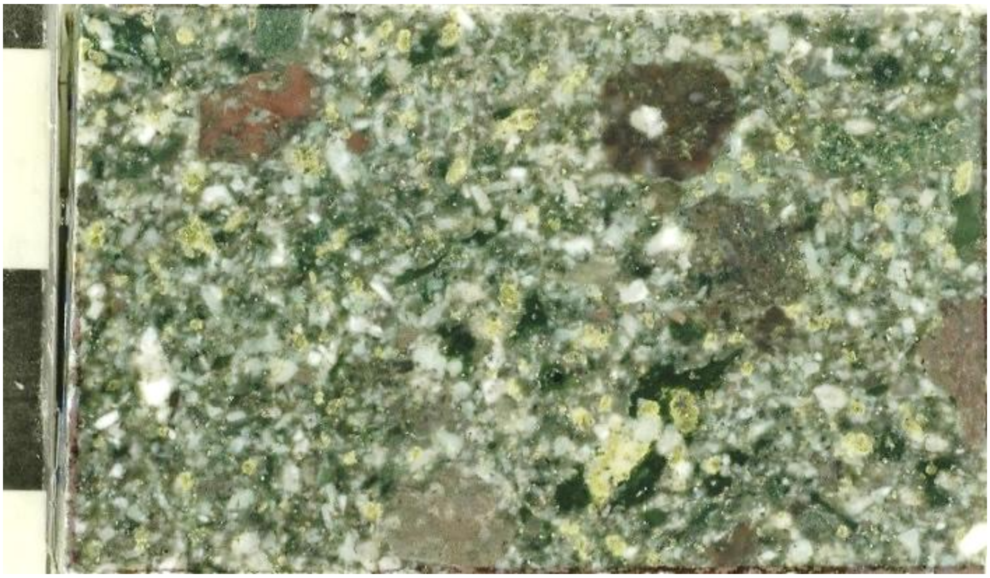
Lithic crystal tuff facies – A traceable N-S striking, steeply east-dipping layer within the crystal tuff facies (Zbrc) in the southeastern Fells (Fig. Zbrl1-2) that is like the crystal tuff facies but with the addition of up to 20% mostly volcanic lithic fragments more than 0.5 cm in diameter (Figs. Zbrl3-5; Zbr3-4). Subrounded to angular lithic volcanic fragments are 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 volcanic rock, sparse amygdaloidal fragments (Fig. Zbrl5), highly foliated very fine-grained banded felsite, lithic fragments with flattened glass or pumice, flattened porphyritic felsic lava fragments (originally obsidian), and occasional accidental quartzite and argillite fragments. Important is this unit’s lack of accidental material derived from coarse granitic plutonic rocks. This unit 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 back to the crystal tuff facies. The east side also has the flattened pumice fragments described above. This suggests that the unit is upright and younger to the east. Layering defined by the unit matches the layering trend occasionally seen in the adjacent crystal tuff facies and internal to the unit (see crystal tuff facies below). LaForge (1932) identified this unit as a breccia with a dacitic matrix in the Melrose Highlands (Melrose Rock) and Oak Grove area of Malden (near Black Rock).

Zbrl1: Lithic crystal tuff west of Melrose Rock in Melrose (site 10044) with large volcanic lithic fragments. Pencil for scale.

Zbrl2: Lithic crystal tuff west of Black Rock in Melrose (site 10353) with volcanic lithic fragments.



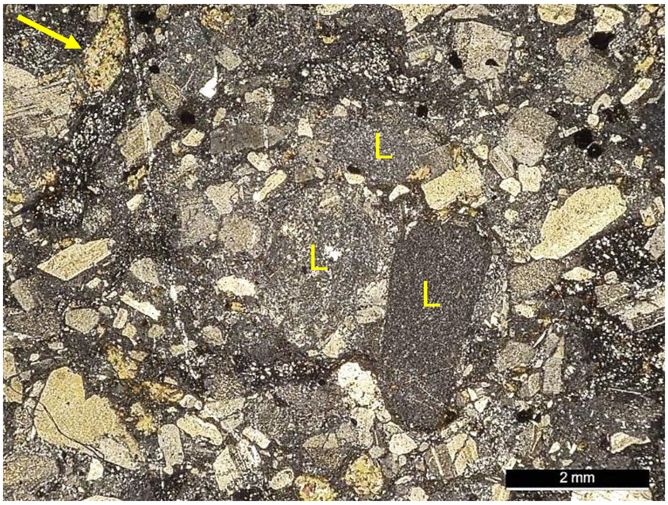
Zbrl3: Lithic crystal tuff near Melrose Rock in Melrose (site 10020) with red volcanic lithic fragments.

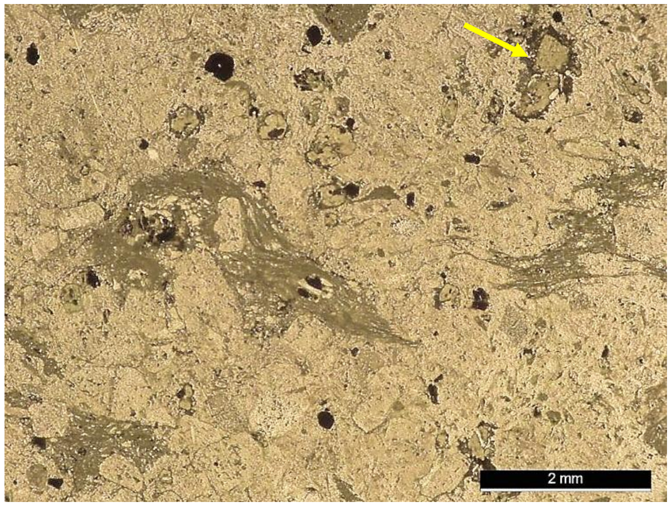


Zbrl4: Lithic crystal tuff west of Black Rock in Melrose (site 10020) with pink and red volcanic lithic fragments and areas of epidote mineralization.

Zbrl5: Lithic crystal tuff west of Black Rock in Melrose (site 10355) with dark volcanic lithic fragments, an amygdaloidal devitrified glass fragment (top center, amygdules filled with epidote), and a fine-grained basalt fragment (B). This sample is permeated with epidote.

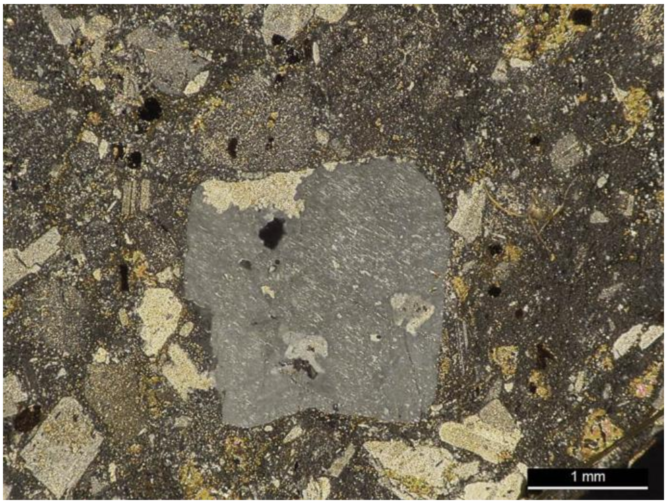
Thin section description: Welded, dacitic to andesitic (Figs. Zbr2 on p. 178), lithic crystal tuff with a fine granular, patchy, and poikilomosaic to micropoikilitic matrix texture (Fig. Zbrl6) and common areas of spherulitic and axiolitic growths. Crystal and lithic fragment concentrations are high (up to 55% of the whole rock; Figs Zbr3-4 and Zbrl6). Included in the matrix are large, pinched fragments with axiolitic strands and fine patchy texture that are devitrified, flattened, phyric pumice and obsidian fragments (Figs. Zbrl7-8). Many of the pinched fragments have euhedral plagioclase crystals while the rock’s matrix has mostly broken, twinned, frequently zoned, and altered crystals (Fig. Zbrl6). The fragments also have a different crystal concentration (higher or lower) and texture (finer or coarser) than the rock’s matrix. The flattened fragments are warped around crystals. Also present are scattered euhedral to broken hornblende crystals that are slightly to entirely altered to epidote and chlorite (Fig. Zbrl 6 and 7). Quartz crystals are present but rare (not in most samples), broken and small, indicating an accidental origin associated with quartzite (Fig. Zbrl8). Out of 11 samples there were only two broken, perthitic alkali feldspar crystals, from an unknown accidental source (Fig. Zbrl9). Lithic fragments are abundant, often larger than a standard thin section, and almost entirely volcanic with fine granular, patchy (Fig. Zbrl10), and fine poikilomosaic textures or they are ultra-fine with plagioclase microlites (Fig. Zbrl11) or phenocrysts (Fig Zbrl12). Occasionally, there are banded, spherulitic and axiolitic fragments (Fig. Zbrl13). Eutaxitic fragments are not as common (Fig. Zbrl14), but devitrification and alteration may obscure this texture. Quartzite and argillite (Fig. Zbrl15) lithic fragments are accidental and derived from the Westboro Fm.



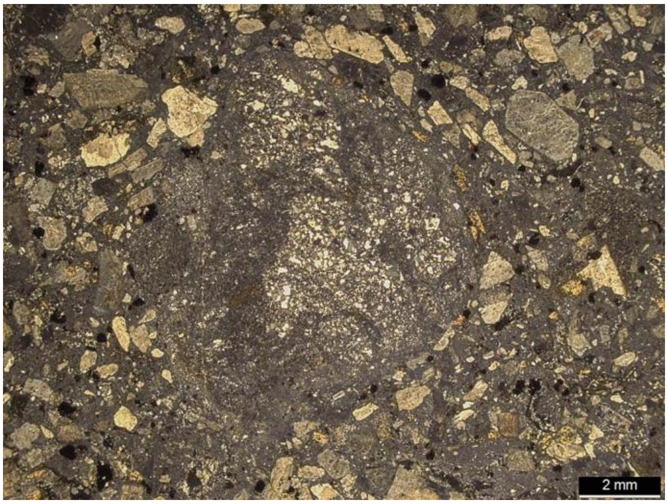


Zbrl6 (above left): Lithic crystal tuff with high concentration of broken and altered plagioclase crystals on Pinnacle Rock in Medford (site 10354). In the center are three volcanic lithic fragments (L, no crystals). Thin section with crossed polarizers. At arrow is an altered (now epidote), diamond-shaped, hornblende crystal. **Zbrl7** (above right): Lithic crystal tuff with pinched and flattened pumice fragments (olive green with internal banding from flattened bubbles) west of Melrose Rock in Melrose (site 10352). In the upper right (arrow) is an altered hornblende crystal. Thin section in plane polarized light.

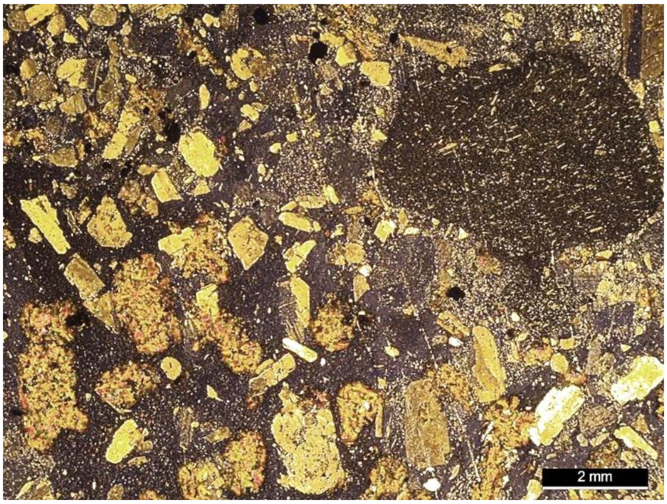
Zbrl8: Lithic crystal tuff with a high concentration of broken and altered plagioclase crystals near Melrose Rock in Melrose (site 10042). Black, pinched blob on right is a flattened porphyritic glass fragment with a lower crystal concentration than the surrounding matrix. Crystals in this fragment are euhedral. It may depict the crystal concentration in the erupting magma, while in the surrounding matrix crystals were concentrated during pyroclastic deposition. In left center is a rare quartz fragment (white at arrow). Thin section with crossed polarizers.



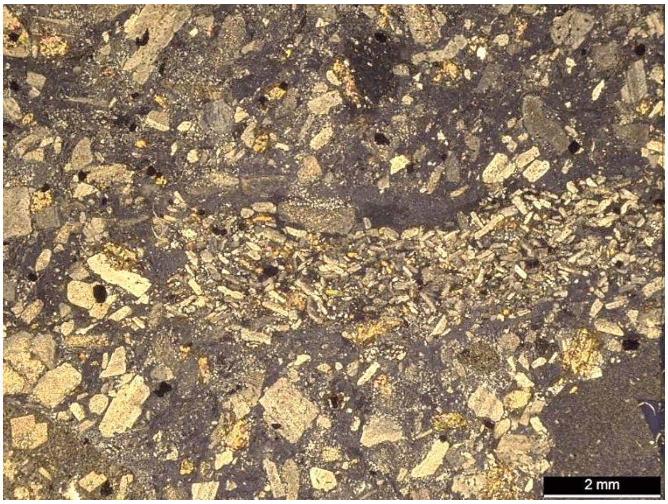
Zbrl9: Lithic crystal tuff with a rare, broken, perthitic alkali feldspar crystal (one of only two found in all samples of this facies) on Pinnacle Rock in Medford (site 10354). Thin section with crossed polarizers.



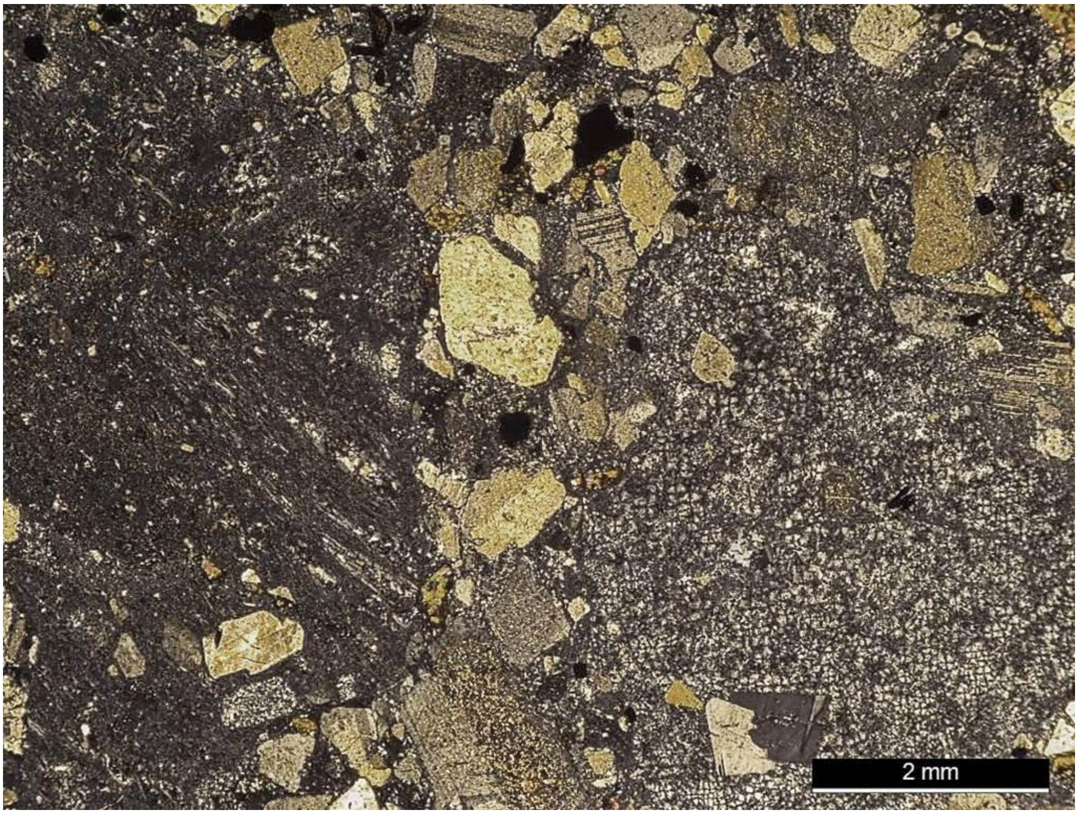
Zbrl10: Lithic crystal tuff with volcanic lithic fragment with fine patchy texture on Black Rock in Melrose (site 10024). Note how matrix plagioclase crystals are aligned with the sides of the fragment. Thin section with crossed polarizers.



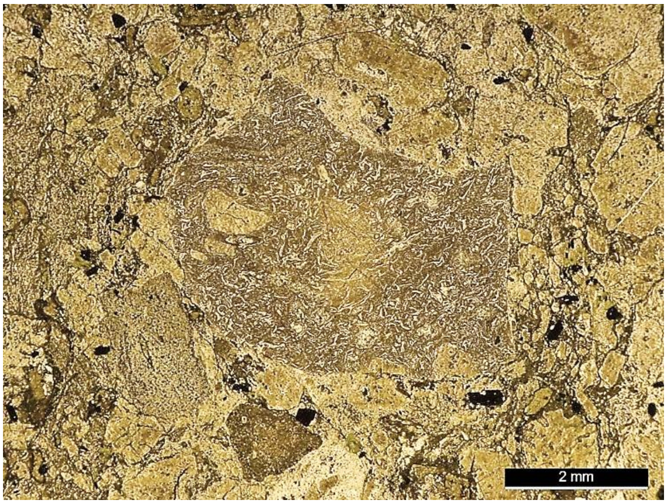
Zbrl11: Lithic crystal tuff with a trachytic basalt lithic fragment (upper right) that is ultra-fine and has plagioclase microlites on Pinnacle Rock in Medford (site 10355). In the lower left half of the image is a dark area with amygdules (filled with epidote - irregular colorful spots with red patches) in an ultra-fine dark matrix area. This was a porphyritic vesicular glass fragment prior to devitrification and alteration. Thin section with crossed polarizers. See Fig. Zbrl5 for cut rock view.



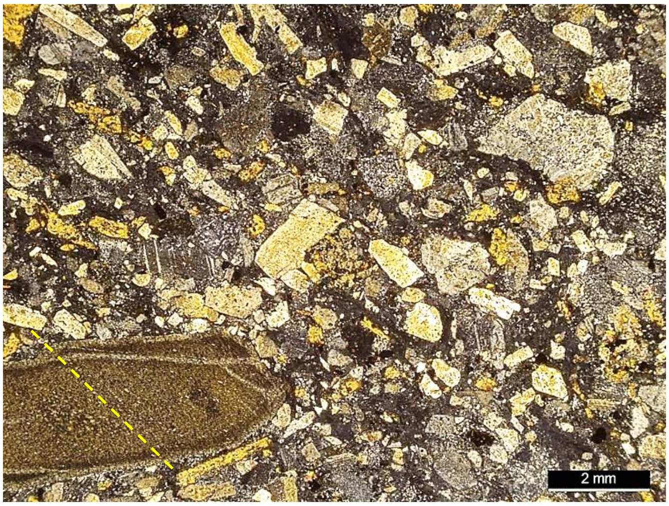
Zbrl12: Lithic crystal tuff with a volcanic lithic fragment that has a high concentration of fine, euhedral, tabular plagioclase phenocrysts west of Melrose Rock in Melrose (site 10020). This was a flattened, highly porphyritic glass fragment prior to devitrification. In the lower right corner is a very fine-grained, dark volcanic lithic fragment with a few microlites. Thin section with crossed polarizers. See Fig. Zbrl3-4 for cut rock views.



Zbrl13 (above): Lithic crystal tuff with volcanic lithic fragments on Pinnacle Rock in Medford (site 10355). On the left is a fragment with pyroclastic banding while on the right is a fragment with a microspherulitic texture. Thin section with crossed polarizers. See Fig. Zbrl5 for cut rock view.



Zbrl14: Lithic crystal tuff with a volcanic lithic fragment (center) that has a eutaxitic texture (wormy, flattened glass shards) on Pinnacle Rock in Medford (site 10355). Thin section in plane polarized light. See Fig. Zbrl5 for cut rock view.



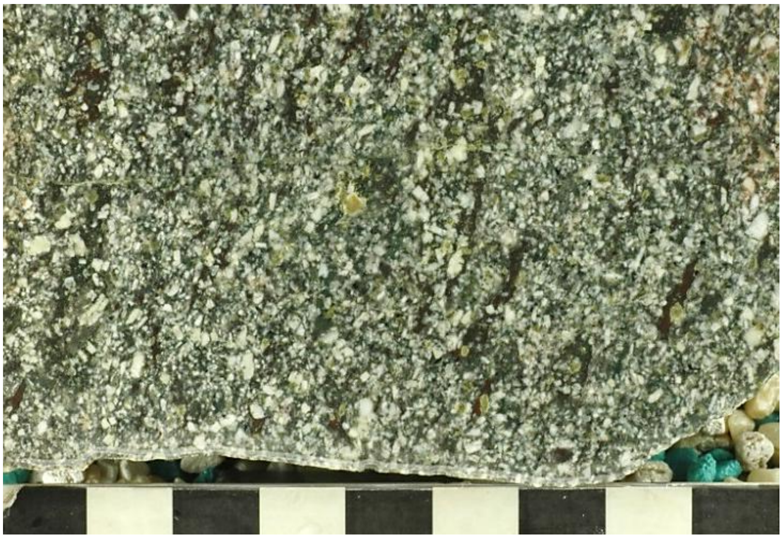
Zbrl15: Lithic crystal tuff with an accidental argillite lithic fragment on Black Rock in Melrose (site 688BN). The dashed line shows the trace of foliation in the fragment. Note alteration of the outer rim and fractures in the argillite fragment. The matrix has an extremely high concentration of broken plagioclase and altered hornblende crystals (yellowish-orange grains now partly epidote). Thin section with crossed polarizers.

Zbrc

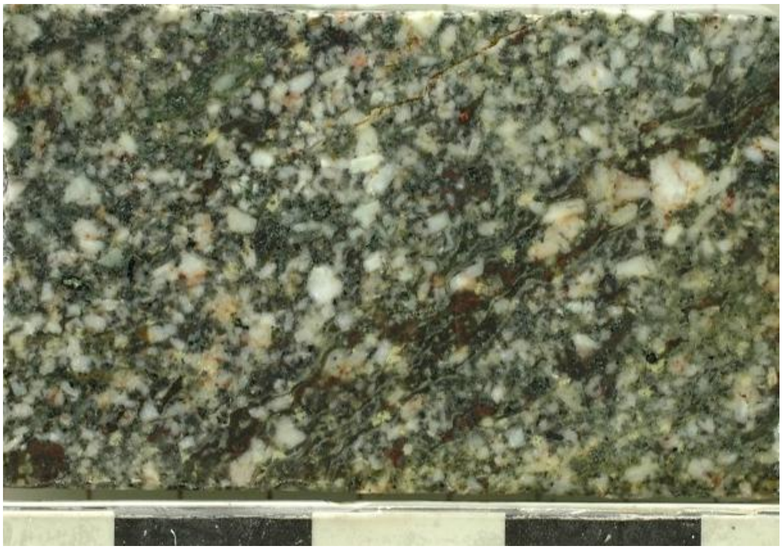
Crystal tuff facies – The dominant facies of the Boojum Rock Tuff is light to dark gray (N3-6 with slight greenish or reddish tones), welded crystal tuff (Fig. Zbrc1) that weathers by flaking (Fig. Zbrc2). Reddish color intensifies as does crystal size to the south and east in Melrose and Malden (see special section below). Surface of unit weathers to a very pale orange (10YR 8/2) to yellowish-gray (5Y 8/1) color (Fig. Zbrc1). Up to 55% of the rock is crystals of white, altered plagioclase sitting in a very hard, dark, aphanitic ground mass of finely intergrown quartz and feldspar formed from devitrified glass (Figs. Zbr3-4). Matrix areas stain very weakly for potassium indicating a more dacitic to andesitic rather than rhyolitic composition (see ternary normalized QAP plot on Fig. Zbr2). Crystals are 0.5-3 mm, tabular to blocky, euhedral, partly broken plagioclase (Figs. Zbrc3-4) with less abundant hornblende crystals that are usually altered to pseudomorphic chlorite and epidote. The matrix occasionally shows faint microscopic bands warped around crystals and lithic fragments, and faint layering defined by flattened and pinched black to reddish-black porphyritic lenses that stain heavily for potassium (Figs. Zbrc3-6), especially at Black Rock in Melrose. These elongate masses are barely recognizable in outcrop and have spherulitic and axiolitic microscopic textures indicating devitrified flattened glass or pumice fragments. Scattered lithic fragments of volcanic lithologies, argillite, and quartzite are generally 0.2-1.0 cm (Fig. Zbrc5). The unit has a very high crystal density (usually 40-50%) throughout except in a narrow, very altered band along the contact with the Spot Pond Granodiorite north of Hemlock Pool. The massive, homogeneous character of the unit across its entire outcrop area supports well-organized joint patterns (Fig. Zbrc7). The unit has mineralized (specular hematite), closely-spaced, slickensided surfaces that form a crude cleavage or shear foliation (Fig. Zbrc8) that doesn't appear in the Wakefield Formation. A new CA-ID-TIMS U-Pb zircon age near Pinnacle Rock (site 725BN) is 596.35 ± 0.21 Ma (6 zircons; see Fig. Zbr5 on p. 179).

Zbrc1: Outcrop of crystal tuff facies showing fresh and weathered surfaces on upland south of Ravine Road in Medford (site 10289).

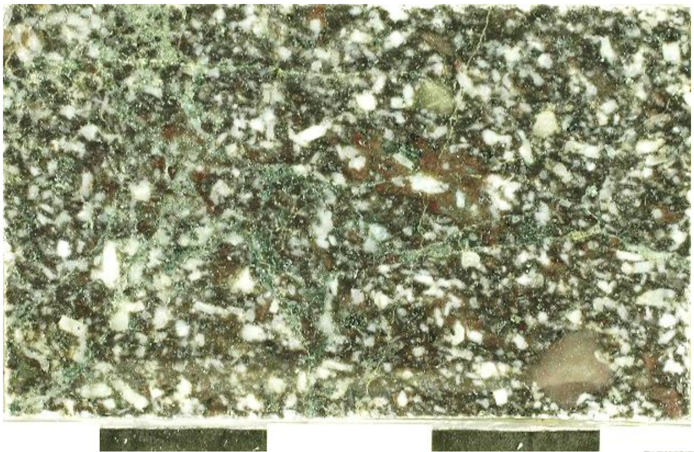
Zbrc2: Flake weathering at surface of crystal tuff west of the Fellsway East in Melrose (sites 10011 and 430BN). Light patches are where recent flaking has removed a soot layer and exposed the rock's light-colored weathering rind. Penny for scale.



Zbrc3: Dark red to black, devitrified, flattened glass fragments in crystal tuff showing a faint fabric (trace near vertical on image) at Black Rock in Melrose (site 10023).



Zbrc4: Alignment of dark red, devitrified, flattened porphyritic glass fragments and zones with different crystal densities (trace is upper right to lower left) in crystal tuff east of the Fellsway East in Melrose (site 10022).



Zbrc5: Red, devitrified glass fragments and volcanic lithic fragment (lower right) in crystal tuff on peninsula in Fells Reservoir in Stoneham (site 10908). Flattened glass fragments are here viewed at a steep angle to the flattened fragments.

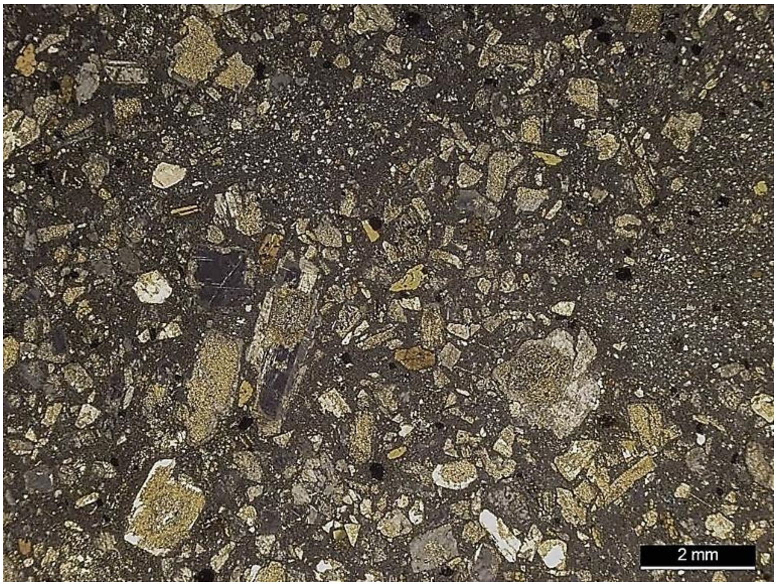
Zbrc6 (right): Fresh surface of crystal tuff with large, flattened (viewed from above), porphyritic, devitrified glass fragments (arrows) on Boojum Rock in Medford (site 11280). The fragments have euhedral, non-broken plagioclase crystals that are coarser than in the rest of the rock. The flattened glass fragments dip to the east. Keys for scale.

Zbrc7 (left): Well oriented joint sets in crystal tuff east of Boojum Rock in Malden (site 10184). Rock hammer for scale.

Zbrc8 (right): Shear surface in crystal tuff with slickensides (parallel to pencil) and hematite mineralization on Boojum Rock in Malden (site 10139).

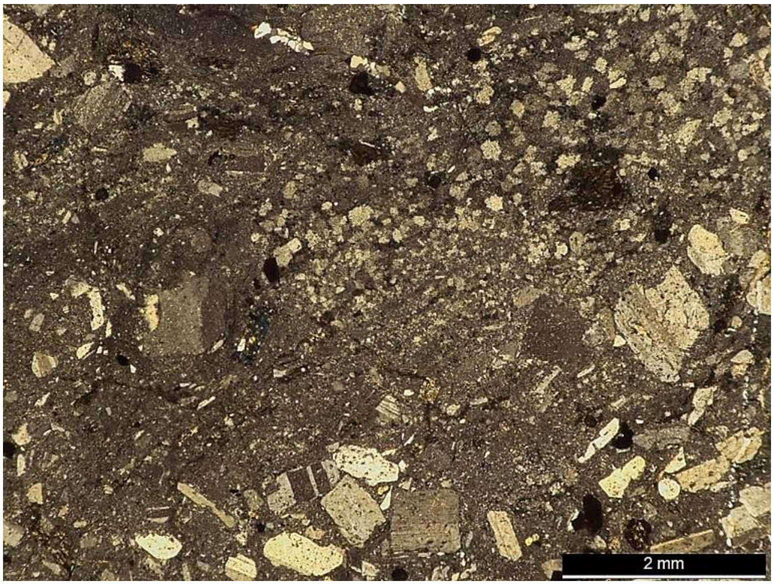
Thin section description: Welded dacitic to andesitic crystal tuff with fine granular, patchy, and poikilomosaic to micropoikilitic matrix textures (Figs. Zbrc9-12) and occasional spherulitic and axiolitic areas (Figs. Zbrc13-16). Crystal concentrations are high, and crystals are usually 40-50% of the whole rock (Figs. Zbr3-4 on p. 178). Included in the matrix are large pinched fragments with axiolitic strands and fine patchy texture that are devitrified, flattened, porphyritic pumice and obsidian fragments (Fig. Zbrc15-17). The pinched fragments have euhedral plagioclase crystals and as compared to adjacent areas, a different texture (finer or coarser) and plagioclase crystal concentration (usually lower). The glass fragments are warped around crystals in the adjacent matrix. Almost all matrix crystals are partly altered, partly broken, euhedral plagioclase that is twinned and frequently zoned (all figures, especially Figs. Zbrc9-10, 13-14, 16 and 18-20). Present in almost all samples are euhedral to broken hornblende crystals that are slightly to entirely altered to pseudomorphic chlorite and epidote (Fig. Zbrc16, 18 and 20). Only one thin section sample out of 45 had a few broken alkali feldspar fragments from an unknown accidental source. Quartz crystals are rare and are broken and small, indicating an accidental origin associated with accidental quartzite (Fig. Zbrc21 and Zbr4). Lithic fragments are not very abundant and are mostly volcanic with fine patchy or poikilomosaic to micropoikilitic texture (Fig. Zbrc19) or are ultra-fine with plagioclase microlites and small phenocrysts. Less common are volcanic lithic fragments with spherulitic (Fig. Zbrc20), vesicular, and banded textures. Fragments with eutaxitic textures and glass shards are not common. Quartzite and argillite from the Westboro Formation occur as accidental fragments.

Zbrc9: Crystal tuff with very fine granular matrix and high concentration of broken plagioclase crystals from west of the Fells Reservoir in Stoneham (site 10903). This is an unusually fresh, unaltered sample. Compare to Fig. Zbrc10. Thin section with crossed polarizers.

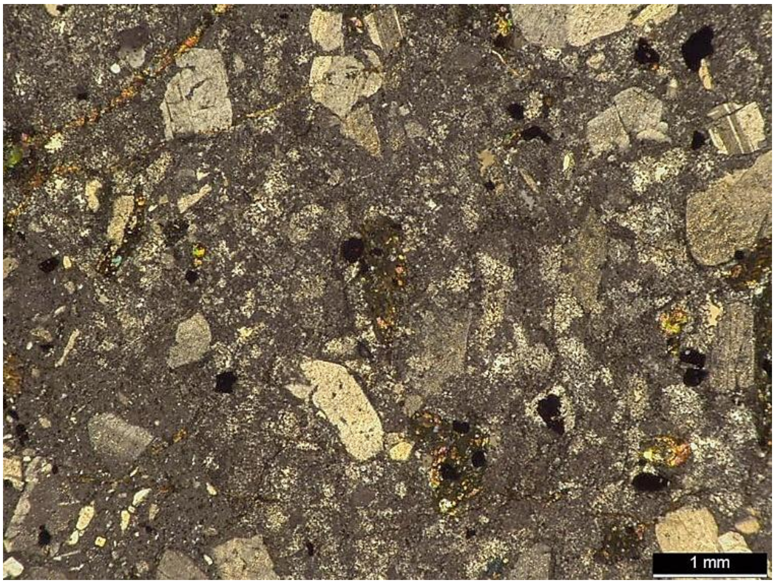


Zbrc10: Crystal tuff with fine granular texture and high concentration of broken plagioclase crystals that are highly altered to sericite and epidote near Hemlock Pool in Medford (site 10918). Note the two granular areas (upper left and right center) that have no large crystals. Thin section with crossed polarizers.

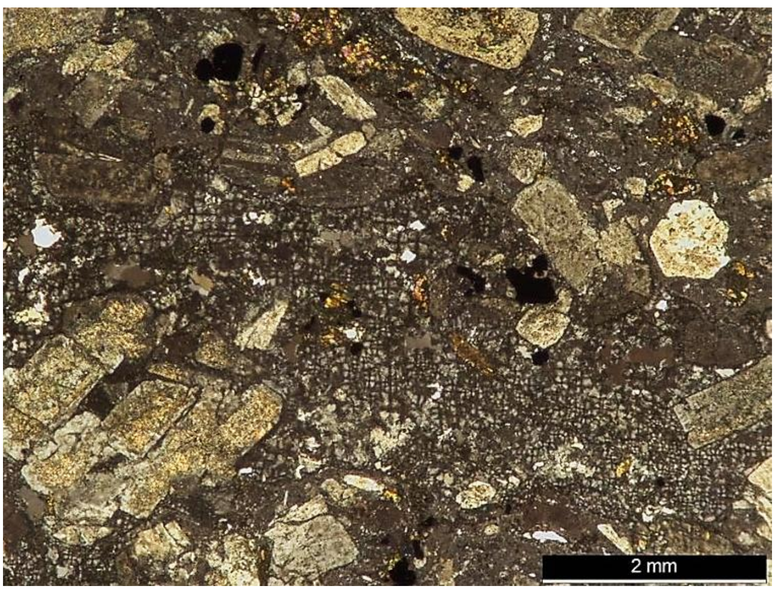
Boojum Rock Tuff - crystal tuff facies (cont.)



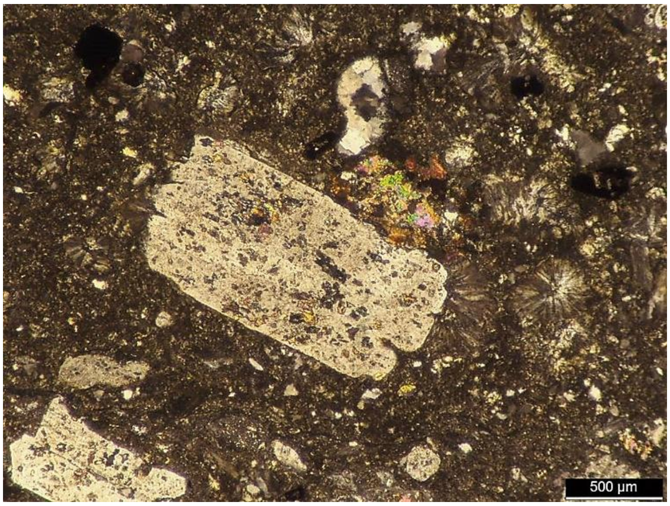
Zbrc11: Crystal tuff with poikilomosaic (patches in upper right) and granular (left and bottom) matrix textures from north of the Fells Reservoir in Stoneham (site 10274). Thin section with crossed polarizers.



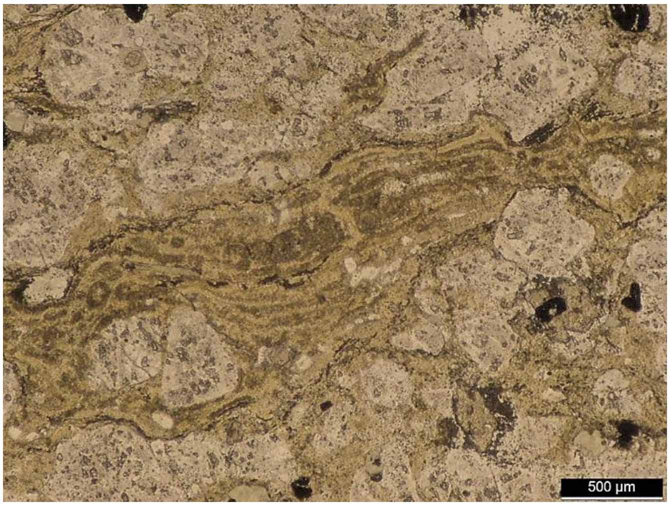
Zbrc12: Crystal tuff with micropoikilitic texture south of Ravine Road in Stoneham (site 10294). Thin section with crossed polarizers. Orange grains are hornblende altered to epidote. In upper left is an epidote vein.



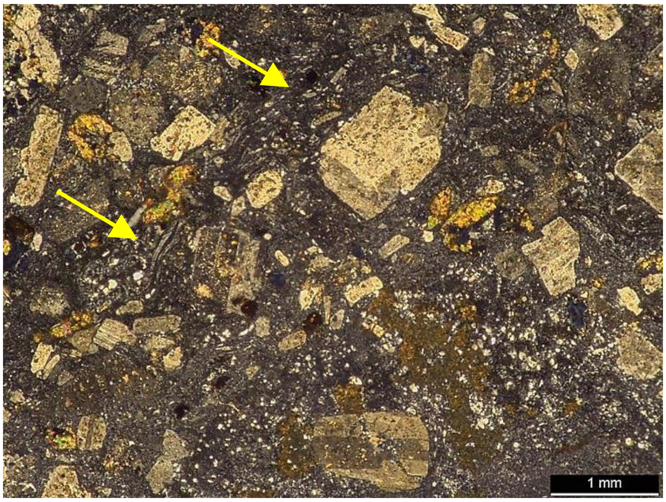
Zbrc13: Crystal tuff with area of spherulitic texture (across lower center) that is a devitrified glass fragment on Boojum Rock in Medford (site 10013). Thin section with crossed polarizers.



Zbrc14: Crystal tuff with matrix containing fibrous spherulites (right of large sieve-textured plagioclase crystal) at Black Rock in Melrose (site 10027). Colorful area is epidote formed by alteration of hornblende. Thin section with crossed polarizers.

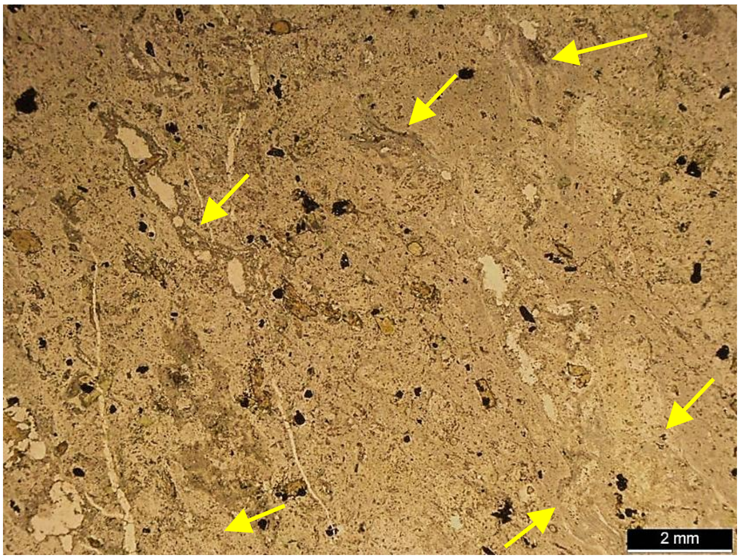


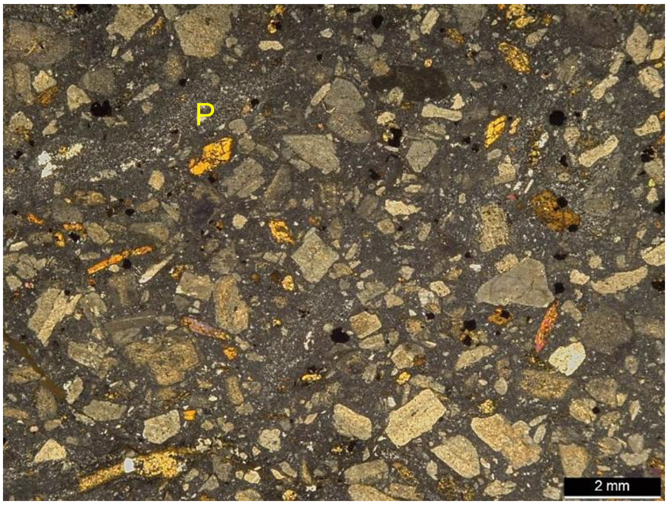
Zbrc15: Crystal tuff with area of axiolitic strands at Black Rock in Melrose (site 10027). Thin section in plane polarized light with yellow potassium stain indicating axiolitic area is richer in potassium.



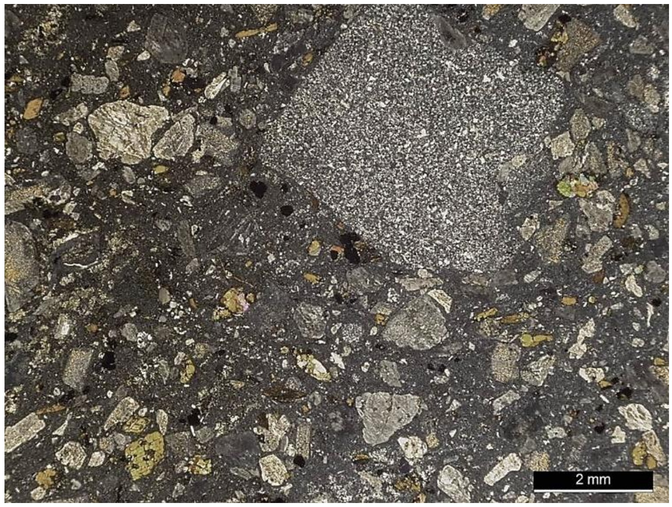
Zbrc16: Crystal tuff with areas of axiolitic strands that are devitrified and flattened pumice or obsidian (arrows) on Black Rock in Malden (site 10023). Orange grains are altered hornblende. Thin section with crossed polarizers. See Fig. Zbrc3 for cut rock view.

Zbrc17: Crystal tuff with flattened pumice fragments (arrows) defining a foliation from upper left to lower right north of the Fells Reservoir in Stoneham (site 10289). The foliation is rarely recognizable on outcrop surfaces. Thin section in plane polarized light. See Fig. Zbrc1 for outcrop view.

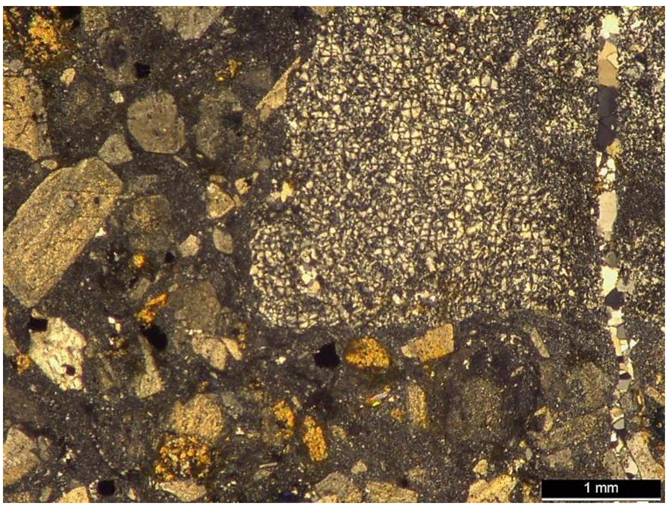




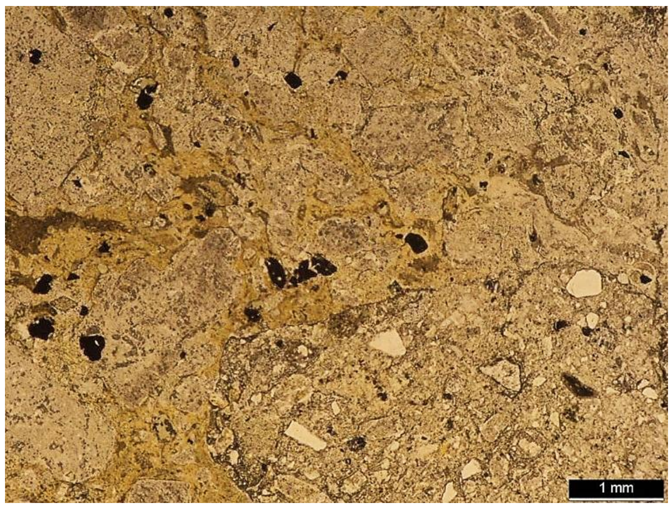
Zbrc18: Crystal tuff with euhedral and broken, lightly altered hornblende crystals (orange) east of Fells Reservoir in Stoneham (site 10011). In upper left is a flattened pumice fragment (P). Thin section with crossed polarizers. See Fig. Zbrc2 for weathered outcrop view.



Zbrc19: Volcanic lithic fragment with fine patchy texture in crystal tuff on the Fells Reservoir peninsula in Stoneham (site 10908). Thin section with crossed polarizers. See Fig. Zbrc5 for cut rock view.



Zbrc20: Volcanic lithic fragment with microspherulitic texture in crystal tuff on east side of Fellsway East near Melrose Rock in Melrose (site 10010). Orange grains are hornblende partly altered to epidote. Thin section with crossed polarizers.



Zbrc21: Crystal tuff at Black Rock in Melrose (site 10027) with rare broken quartz fragments that are likely accidental crystals from quartzite (light grains in lower right) in a lithic fragment. Thin section in plane polarized light.

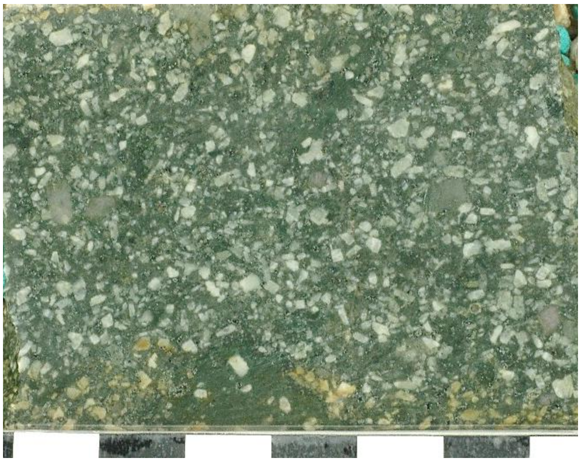
Zbrc

Zbrr

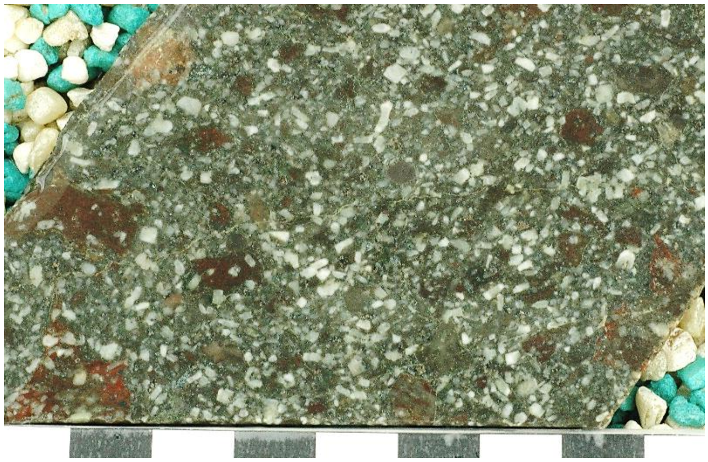
Crystal tuff facies in Malden and Melrose – The dominant crystal tuff facies of the Boojum Rock Tuff occurs in areas south of the Fells and east of the major north-south trending valley in western Malden and Melrose. This includes exposures in the Fellsmere Pond, Waitts Mount, Pine Banks and Wyoming Hill areas. The crystal tuff facies is like the crystal tuff in the Middlesex Fells and in Medford with the same crystals, lithic fragments and matrix features except that: 1) crystal sizes gradually increase eastward (Figs. Zbrm1-3), 2) a faint dark reddish-gray to purplish-gray (10R 2/1) matrix color (Figs. Zbrm1 and Zbr3-4) becomes progressively more prevalent in Malden, 3) red-colored (10R 4/4) volcanic lithic fragments become larger and more frequent (Fig. Zbrm4), and 4) the tuff has rare but conspicuous accidental granitic lithic fragments (Fig. Zbrm5) and quartz derived from granite. These subtle trends start south of the Fells in Medford and Malden and are interpreted to represent closer proximity to an eruptive center to the east or southeast. Some large areas with a distinct red color (10R 3-5/4-8) have been identified and mapped separately as a red crystal tuff facies (Zbrr) within the dominantly gray crystal tuff facies (Zbrc). These red areas also appear as small regions that are too small to map separately within otherwise gray crystal tuff. The red facies has both a red matrix and red lithic fragments (Figs. Zbrm6-8). The origin of the red hematitic matrix remains uncertain but is thought to be a produced by local alteration along faults or by hydrothermal alteration rather than a separate stratigraphic unit. The red coloration occurs beneath an unconformity overlain by facies of the Wakefield Formation on the southern hill at Pine Banks where red lithic fragments of the Boojum Rock occur in vitric and crystal tuff units of the Wakefield Formation (Fig. Zbrm9-10). The crystal tuff facies at Pine Banks and on the north side of Wyoming Hill is interpreted to rest on an unconformity on the Westboro Formation (Zvwq). At Pine Banks Park the crystal tuff and the underlying Westboro are silicified along their contact, and the crystal tuff is highly altered with abundant silicified Westboro inclusions within 20 m of the contact (Fig. Zbrm11) while 15 meters further from the contact the rock is not nearly as altered or silicified (Fig. Zbrm12). Bedding in the Westboro is crosscut by the unconformity. On the south end of Waitts Mount in Malden the crystal tuff facies is intruded by a very fine chill zone of the Lawrence Woods Granophyre (Zlwg).

Zbrm1: Crystal tuff facies at Fellsmere Pond in Malden (site 11422) with dark purplish-gray colors. In the lower left is an accidental quartzite lithic fragment.

Zbrm2: Gray crystal tuff facies on the northern part of the western hill at Pine Banks Park in Melrose (site 11440) with volcanic lithic fragments. Average crystal size is larger than in the specimen in Fig. Zbrm1.

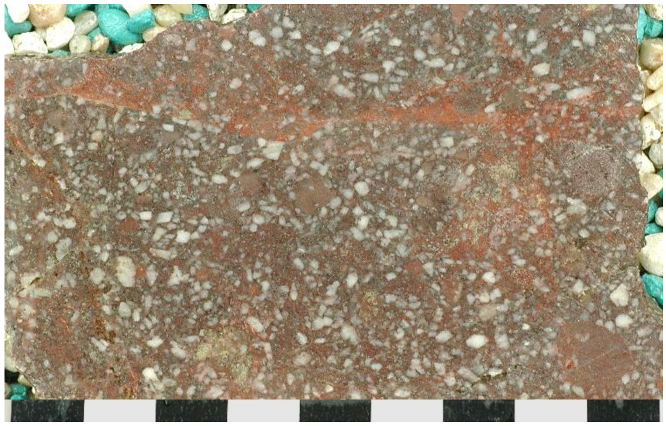


Zbrm3 (above): Gray crystal tuff facies on the northeastern hill at Pine Banks Park in Melrose (site 11466) with volcanic and quartzite lithic fragments. Average crystal size is larger than in the specimens in Figs. Zbrm1-2. Samples in Figs. Zbrm1-3 are shown at the same scale.



Zbrm4 (above): Gray crystal tuff facies with red volcanic lithic fragments on the southern part of the western hill at Pine Banks Park in Malden (site 11434).

Zbrm5 (above): Gray crystal tuff facies with boulder-size accidental alkali granite lithic fragment at Waitts Mount Park in Malden (site 11480).

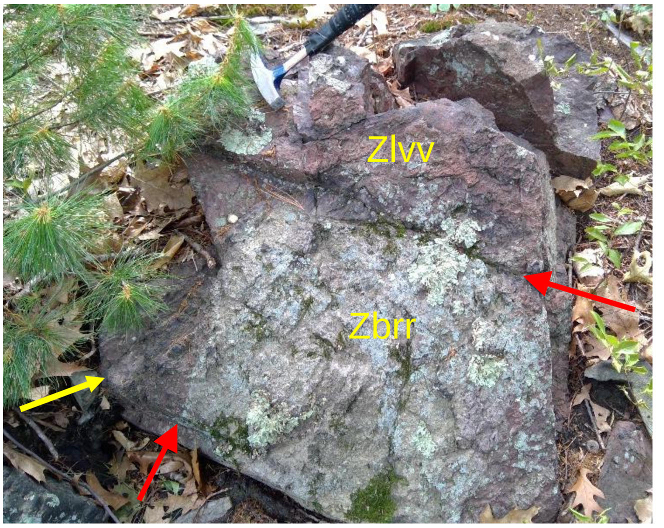


Zbrm6 (above): Red crystal tuff facies (Zbrr) with red volcanic lithic fragments on west side of Main Street in Malden across from the entrance to Forest Dale Cemetery (site 11447). Note hematitic matrix and lithic fragments as well as veins.

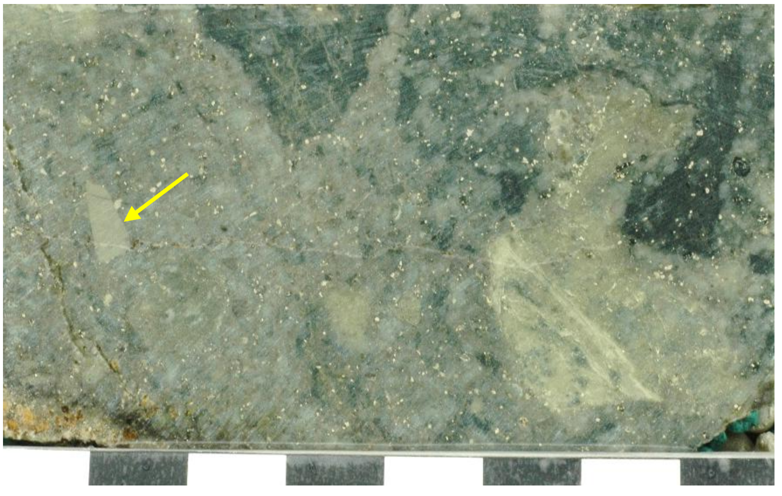
Zbrm7 (above): Red crystal tuff facies (Zbrr) with many red volcanic lithic fragments on northeastern hill of Pine Banks Park in Malden (site 11469).

Zbrm8: Red crystal tuff with quartzite and argillite (Westboro) accidental lithic fragments and a high crystal concentration on Sylvan Street on south side of Wyoming Hill in Melrose (site 11496). Red tuff occurs over a small area within gray tuff along dikes and a fault.

Zbrm9: Red crystal tuff lithic fragment (arrow) from the Boojum Rock Tuff in gray crystal tuff of the Wakefield Formation (Zlvx) on the eastern hill of Pine Banks Park in Malden (site 11463). The red color was likely obtained before the fragment was deposited.

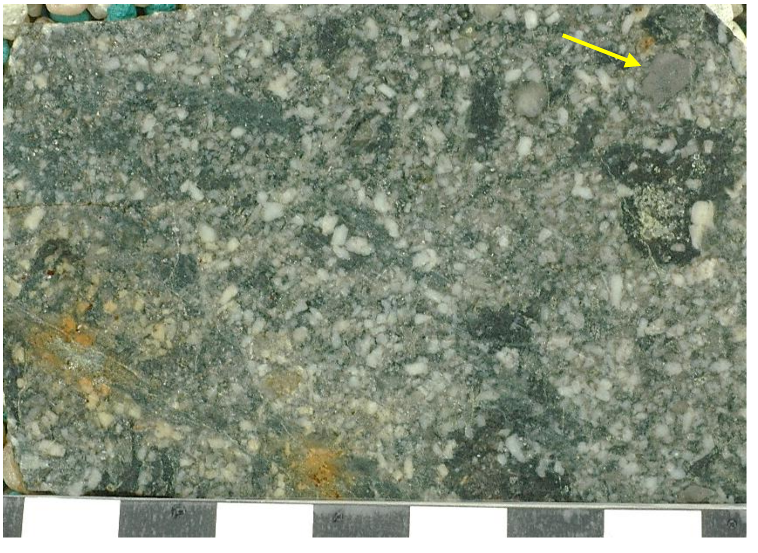


Zbrm10: Crystal tuff lithic fragment from the Boojum Rock Tuff (red arrows show contact) in very fine red vitric tuff of the Wakefield Formation (Zlvv) on the southeastern hill of Pine Banks Park in Malden (site 11464). Another small Boojum Rock crystal tuff fragment is at the yellow arrow.



Zbrm11: Silicified and highly altered crystal tuff on the west side of the northeastern hill at Pine Banks Park in Melrose (site 11457). This sample is about 20 m from the unconformity with the Westboro Fm. Crystals are difficult to discern in hand specimen. On the left side (arrow) is an accidental quartzite lithic fragment from the Westboro Formation (Zvwq).

Zbrm12 (right): Non-silicified and lightly altered crystal tuff on the west side of the northeastern hill at Pine Banks Park in Melrose (site 11458). This sample is about 35 m from the unconformity with the Westboro Fm. Crystals are easily discerned in hand specimen. On the right side (arrow) is an accidental quartzite lithic fragment from the Westboro Formation (Zvwq).



Zsg

Spot Pond Granodiorite (Neoproterozoic) – Coarse-grained, partly leucocratic, equigranular granodiorite and lesser areas of tonalite and granite (Fig. Zsg1-5). Plagioclase is creamy white or light greenish-gray (5GY 8/1), euhedral to subhedral (Fig. Zsg3-4) and usually at least partly altered to epidote and sericite. Subordinate pale red (10R 5-6/2), perthitic, interstitial alkali feldspar (microcline; see also Zsgk below) is occasionally a poikilitic host to euhedral plagioclase. Feldspar colors determine overall color of the rock, and the rock appears white when alkali feldspar is very low (Zsg5). Quartz occurs as abundant (up to 50% of whole rock), coarse, anhedral, strained and sometimes polycrystalline grains. Mafic minerals (usually <15%), are chlorite, epidote, and opaque minerals formed together by the alteration of biotite (Figs. Zsg3-6) with scattered primary opaque minerals. Hornblende occurs in the unit but is less abundant than biotite and is usually altered to chlorite and epidote. Local variations occur in alkali feldspar and mafic mineral concentrations and as minor grain size changes. Areas of higher alkali feldspar have fewer mafic minerals. Accessory minerals are sphene (titanite), which occurs in almost every non-deformed sample, and apatite, which occurs as small elongate crystals mostly in areas of biotite alteration. Occurs south and southeast of Spot Pond and extends west of Rt. 93 through the northern Pine and Gerry Hill areas to Lawrence Woods as rounded glacially streamlined outcrops (Fig. Zsg2). Other outcrop areas occur northeast and east of the Fells near Doleful Pond and in Saugus. The unit has baked quartzite and argillite hornfels xenoliths (pebbles to 150 m in length) from the Westboro Formation (Fig. Zsg7-8) that are sometimes partly assimilated and may form roof pendants south of Spot Pond and on Gerry Hill. The Spot Pond has rare and isolated felsite xenoliths of unknown origin (see Zfi below).

The Spot Pond Granodiorite has a strong foliation with polycrystalline quartz and aligned plagioclase and mafic minerals within a kilometer of its contact with the Westboro Formation on Gerry Hill (Fig. Zsg9-12). Elongate Westboro xenoliths are aligned with the foliation. A special symbol shows the foliation orientation. The foliation is near a major E-W trending fault. However, the fault cuts dolerite dikes in this area that are not deformed, and the dikes cut across the foliation, which seems to indicate that the foliation is older and not related to the fault. Anisotropy of magnetic susceptibility shows a steep ENE-WSW trending magnetic foliation parallel to the macroscopic foliation (Fig. Zsg12) and has a nearly horizontal, well-defined lineation (maximum susceptibility direction). Therefore, the foliation appears to be associated with a horizontal shear direction on the vertical foliation plane.

The contact of the unit with the Westboro has no chill zone. Dismembered masses of granodiorite in the Rams Head Porphyry (Zrhp) southeast of South Reservoir may form a roof pendant on the porphyry. The Rams Head has a chilled margin against the granodiorite with varying amounts of granodiorite assimilation and granodiorite xenoliths (see Fig. Zrhp4). The Lawrence Woods Granophyre in Lawrence Woods also has a chill zone against the Spot Pond and clasts of the Spot Pond are in volcaniclastic rocks of the Wakefield Formation (Zlvc; Lynn Volcanic Complex) on Middle, Little Pine, and Pine Hills. Field exposures of the contact with the Boojum Rock Tuff (Zbrc) have been difficult to interpret. Radiometric ages for both units indicate that the tuff is younger by about 13 Myr and thus appears to unconformably rest on the granodiorite.

The Spot Pond is the ideal “Dedham” lithology of previous studies and Bell’s (1948) “normal” variety of the Dedham Granodiorite. The Spot Pond is the main part of the Dedham Granodiorite of Emerson (1917) and LaForge (1932), who lumped several plutonic bodies with it. These other plutonic units are now known to have sharp contacts with the Spot Pond Granodiorite and occur as separate bodies with distinctly different lithologies and radiometric ages. Mapped as trondhjemite by Kaye (1980) but it is too rich in potassium feldspar for this to be the case. Kaye grouped several plutonic bodies with the Spot Pond mapped here and because of this makes the claim that it intrudes surrounding felsic volcanic rocks. No evidence for this intrusive relationship has been found for the Spot Pond with either the Wakefield Formation or Boojum Rock Tuff of the Lynn Volcanic Complex mapped here. The tuff units in the Wakefield have embayed, rounded quartz grains (xenocrysts) thought to be derived from the Spot Pond. The Spot Pond east of the Fells was mapped as the Dedham North Granodiorite and lumped with the Stoneham Granodiorite of the current map by Smith and Hon (1984) and Smith (1985). The Spot Pond and Stoneham have an age difference of about 14 Myr.

The Spot Pond Granodiorite has U-Pb zircon ages (Fig. Zsg13) west of Red Cross Path (site 10700) that are 602.2 ± 4.4 Ma (LA-ICPMS, 38 zircons) and 609.45 ± 0.25 Ma (CA-ID-TIMS; F. MacDonald, pers. comm., 5 zircons). A new U-Pb CA-ID-TIMS age south of Spot Pond (site 11368, 5 zircons) is 609.11 ± 0.22 Ma and near Doleful Pond (site 10409; CA-ID-TIMS, 5 zircons) is 609.08 ± 0.24 Ma. In Fig. Zsg14 is a view of zircon crystals in thin section near Doleful Pond.

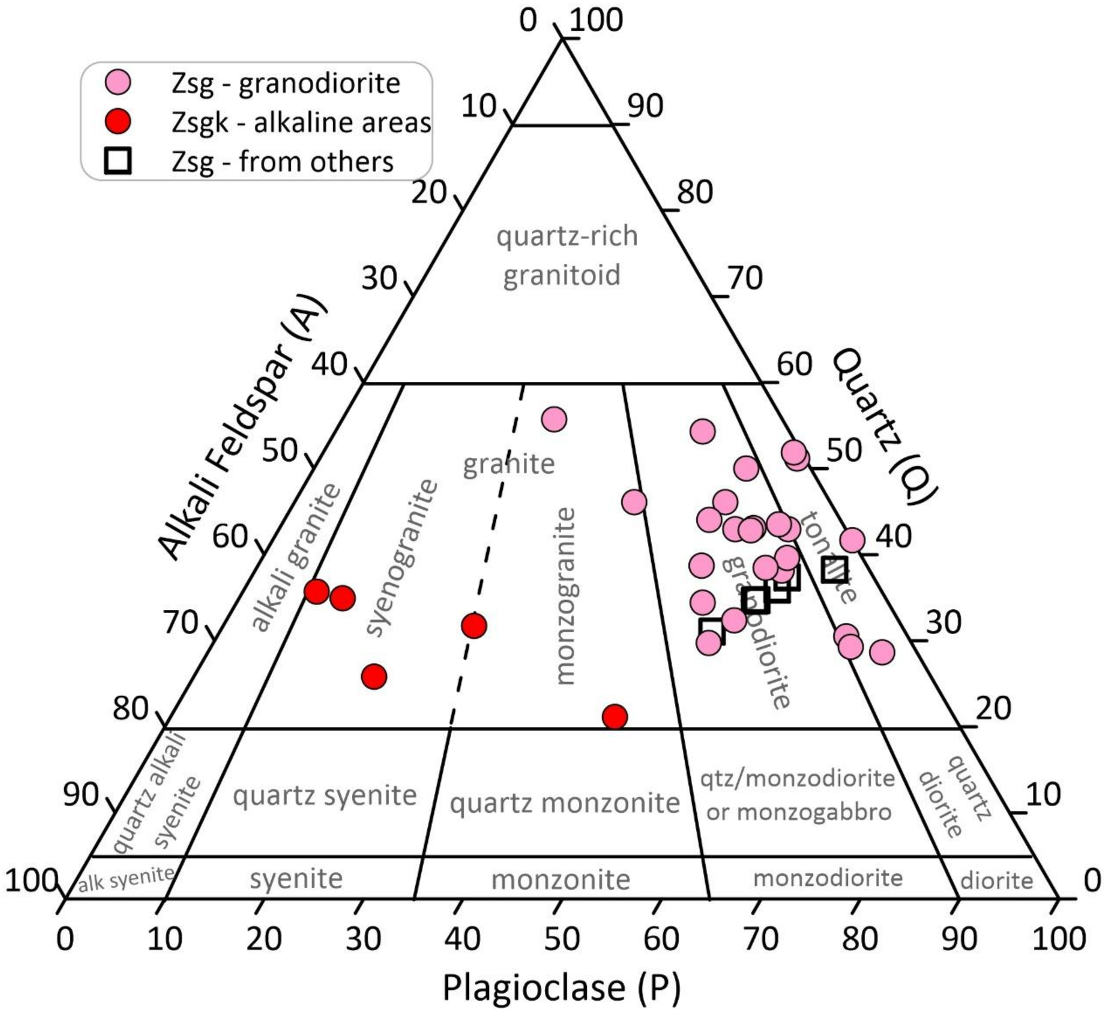
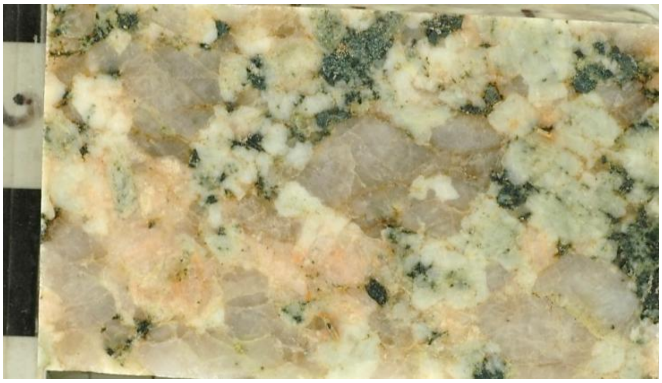
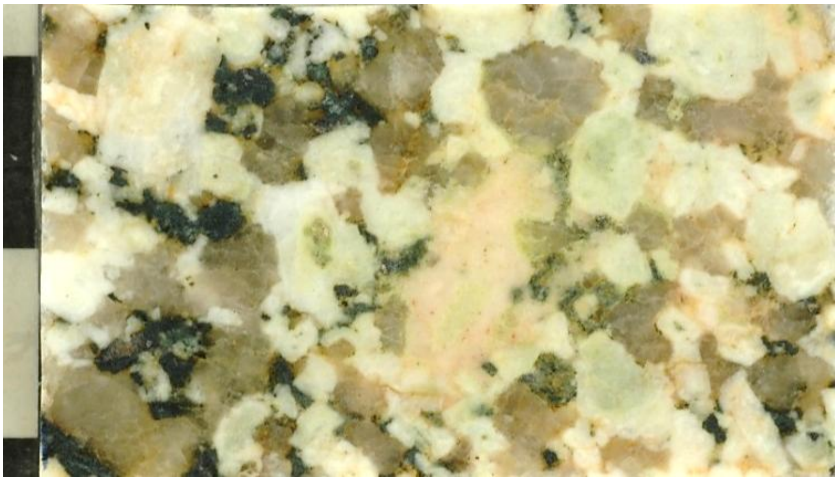


Figure Zsg1. Normalized Quartz-Alkali Feldspar-Plagioclase (QAP) plot of point counts from the Spot Pond Granodiorite and areas of alkali granite within the unit (Zsgk; >30% normalized alkali feldspar) that may be inclusions. Most Spot Pond samples are granodiorite to tonalite. Point count data from Smith (1985; Dedham North Granodiorite northeast of the Fells) and CIDW Norm% calculation of whole rock LA-ICPMS data of Hampton (2017) from the Fells are shown for comparison. Data for this plot are in Appendix 1-G.

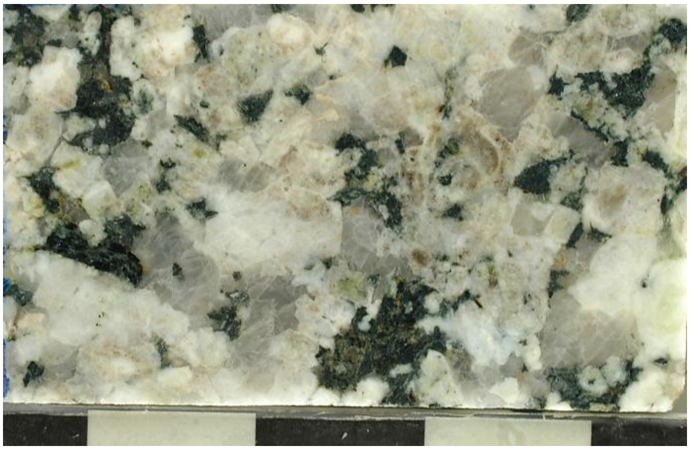
Zsg2: Glacially smoothed outcrops of the Spot Pond Granodiorite on northern Middle Hill in Medford just west of the Mud Road Fault (site 10682). Backpack on outcrop for scale.



Zsg3: Coarse granodiorite west of Wrights Pond on Rt. 28 in Medford (site 10477) with pale green plagioclase resulting from alteration to sericite and epidote.



Zsg4: Coarse granodiorite northeast of Doleful Pond and south of Stoneham High School in Stoneham (site 10409). Note pistachio to pale green colors of plagioclase and in alkali feldspar resulting from alteration to epidote and sericite. This is the site of a radiometric age described above.



Zsg5: Coarse tonalite along Red Cross Path in Medford (site 10700). Tan areas are very minor alkali feldspar. This is the site of a radiometric age described above.

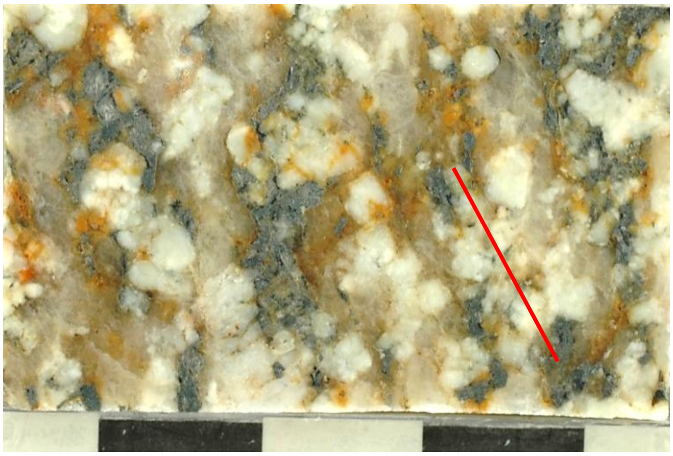
Zsg6: Coarse monzogranite east of Woodland Road in Medford (site 10261) in an alkaline area of the unit. The rock here has more perthitic alkali feldspar and a lower mafic content than is typical of the unit. (see Zsgk below).

Zsg7: Coarse granodiorite with rusty, layered and partly assimilated argillaceous quartzite xenolith from the Westboro Formation south of Wenepoykin Hill in Medford (site 844BN). Pencil for scale.

Zsg8: Coarse granodiorite with white quartzite xenolith from the Westboro Formation on Gerry Hill in Medford (site 10811). The rock also has a foliation parallel to the hammer and aligned with the xenolith.

Zsg9 (left): Coarse granodiorite with foliation (parallel to pencil for scale) on southwest side of Gerry Hill in Medford (site 10775).

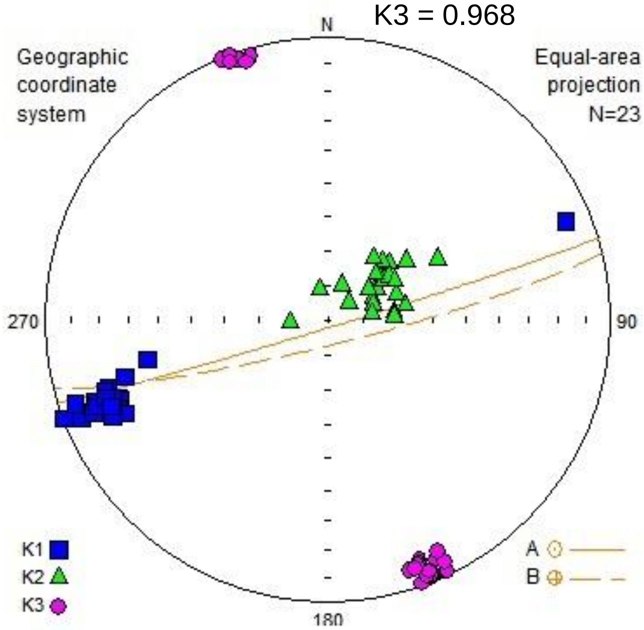
Zsg10 (right): Coarse granodiorite with foliation (roughly parallel to hammer) south of Gerry Hill in Medford (site 10834).

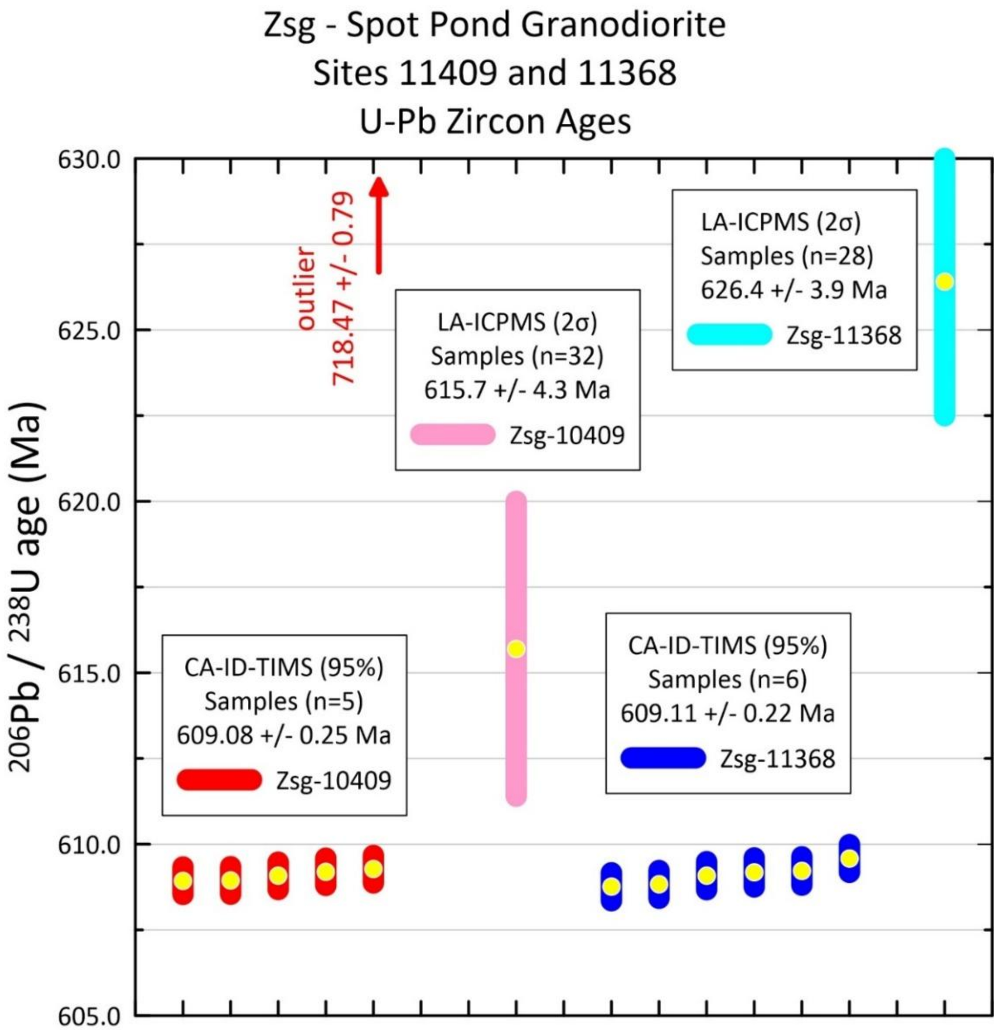


Zsg11 (left): Coarse foliated granodiorite on west side of Gerry Hill in Medford (site 10817). Line shows trace of foliation formed by stretched and aligned polycrystalline quartz and mafic grains parallel to line).

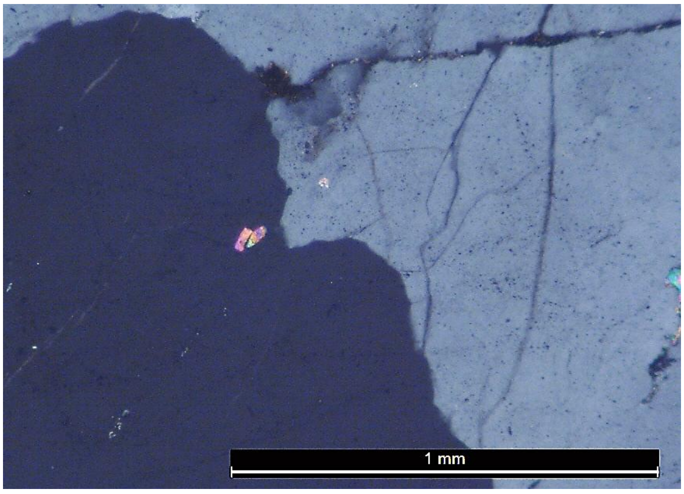
Zsg12: Foliation south of Gerry Hill (image below; sites 10766 and 11291). Foliation is formed by stretched polycrystalline quartz and mafic grains as well as alignment of plagioclase. Axes of a magnetic susceptibility ellipsoid (below left) are plotted as points in the lower hemisphere: K1 = maximum, K2 = intermediate, and K3 = minimum. The K1-K2 plane defines a great circle that is the magnetic foliation, while K1 is a well-defined (K1>K2) magnetic lineation. The foliation is almost vertical, while lineation on the foliation plane has a low WSW dip angle and indicates that the unit was sheared nearly horizontally. Brown lines are field measurements of the foliation (sites 10766 and 11291) that match the magnetic foliation. (Susceptibility measurements by Jenna Mello at Tufts University.)

K1 = 1.022
K2 = 1.010
K3 = 0.968





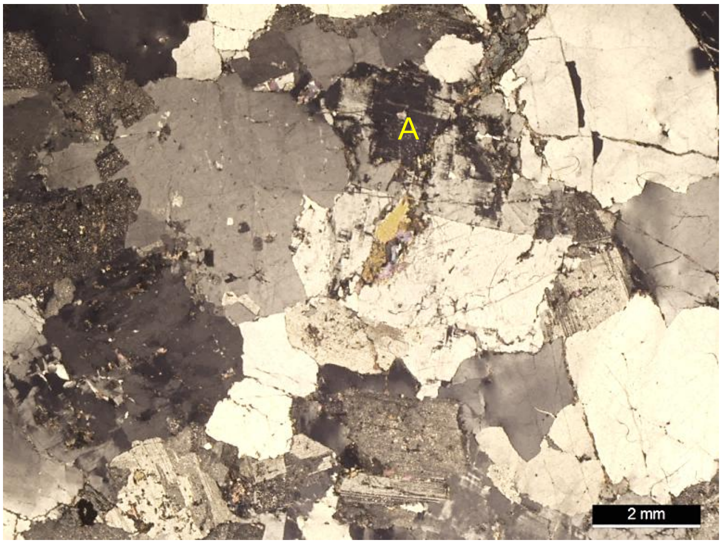
Zsg13: Individual CA-ID-TIMS U-Pb ages used to calculate almost identical age means for the Spot Pond Granodiorite near Doleful Pond in Stoneham (site 10409) and south of Spot Pond near Wrights Pond in Medford (site 11368). One grain at site 10409 is an inherited outlier (~718 Ma). Shown for comparison are less precise LA-ICPMS U-Pb ages for the same samples.



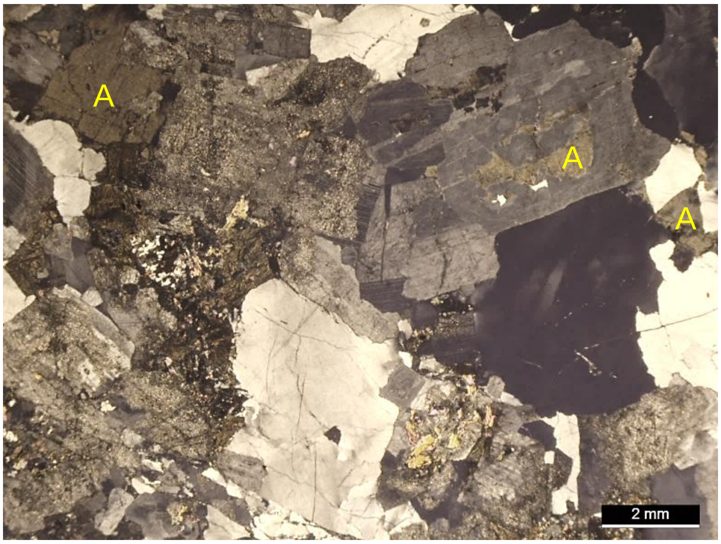
Zsg14: Zircon crystals (bright colors) in quartz in the Spot Pond Granodiorite near Doleful Pond in Stoneham (site 10409). The dark area is a quartz crystal at extinction in a thin section with crossed polarizers.

Spot Pond Granodiorite (cont.)

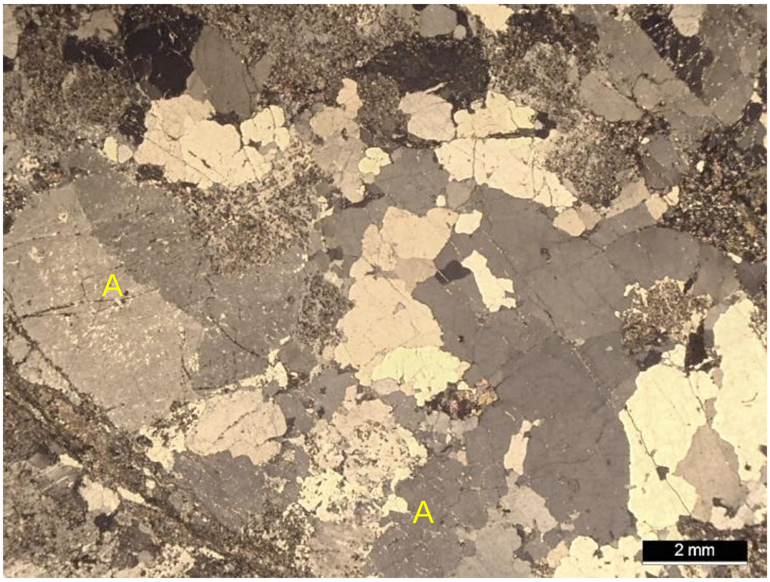
<u>Thin section description</u>: Coarse-grained partly leucocratic granodiorite to tonalite with granitic texture (Figs. Zsg15-16). Almost always, plagioclase dominates over alkali feldspar and together they are about equal to or somewhat greater than quartz. Quartz is very clear, has undulatory extinction, can be polycrystalline, and is frequently fractured (Figs. Zsg15-18 and all others). Plagioclase is sometimes zoned and is lightly to heavily altered to sericite and epidote (Fig. Zsg17-18) giving it a dusty appearance or fine sieve texture, especially in the centers of grains (Fig. Zsg19). Alkali feldspar (microcline) is only occasionally equal to plagioclase and is usually interstitial (Figs. Zsg15-16). It is sometimes perthitic, has crosshatch twinning, and is always less altered than plagioclase (Figs. Zsg17-20). The alkali feldspar occasionally forms a poikilitic host to euhedral plagioclase (Fig. Zsg20). Mafic minerals are usually dominated by chlorite that is formed by alteration of biotite (Fig. Zsg21). This alteration also produces smaller quantities of epidote, sericite and opaque minerals. In only a few places hornblende is present and is usually altered to a combination of intergrown epidote, chlorite, and minor sericite that have a pseudomorphic diamond shape (Fig. Zsg22). Biotite seems to have dominated mafic minerals prior to alteration. In addition to a few scattered opaque mineral grains, well preserved sphene (titanite) occurs in almost all non-altered samples along with the by-products of biotite and hornblende alteration (Figs. Zsg23-25). Accessory rutile was found in one sample (Fig. Zsg26). Deformation of the granodiorite south of Sheepfold (see Figs. Zsg9-12) is associated with development of polycrystalline quartz, dismembered alkali feldspar, bent twinning in plagioclase, alignment of rigid plagioclase crystals, and shearing of mafic minerals such that biotite was heavily deformed and hornblende and sphene (titanite) are seldom preserved (Figs. Zsg27-28). Along some major faults the rock is cataclastically deformed (Fig. Zsg29-30). Near the Medford Dike along Rt. 28, contact metamorphism caused melting along grain boundaries and recrystallization as granophyric seams between grains (Fig. Zsg31).



Zsg15: Granodiorite along Rt. 28 west of Wrights Pond in Medford (site 10477). Rock is dominated by quartz (clear grains) and plagioclase (dusty alteration and closely-spaced twinning). One alkali feldspar grain (A) is visible. The yellow grain is epidote (center). Thin section with crossed polarizers. See Fig. Zsg3 for cut rock view.

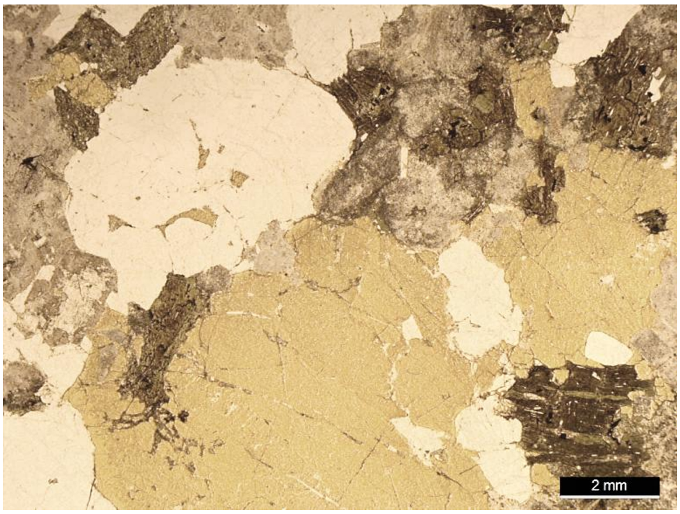


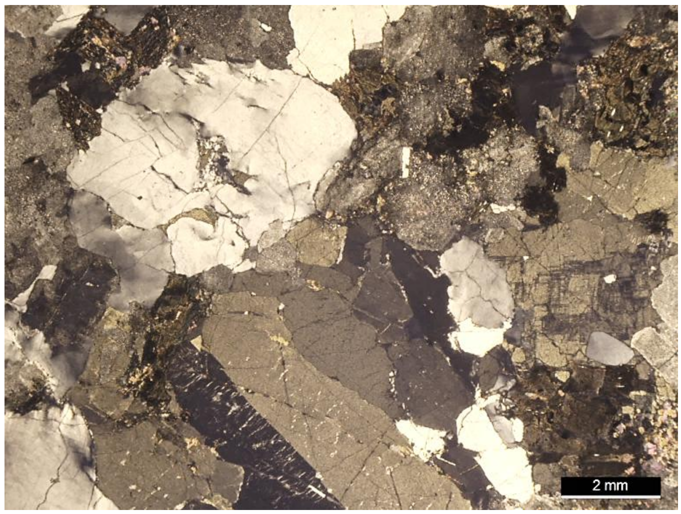
Zsg16: Tonalite along Red Cross Path in Medford (site 10700). Rock is dominated by quartz (clear grains) and plagioclase (dusty alteration and closely-spaced twinning). Quartz has undulatory extinction. Several interstitial alkali feldspar grains (A) are visible and yellow due to potassium staining. Thin section with crossed polarizers. See Fig. Zsg5 for cut rock view. This is the site of a radiometric age described above.

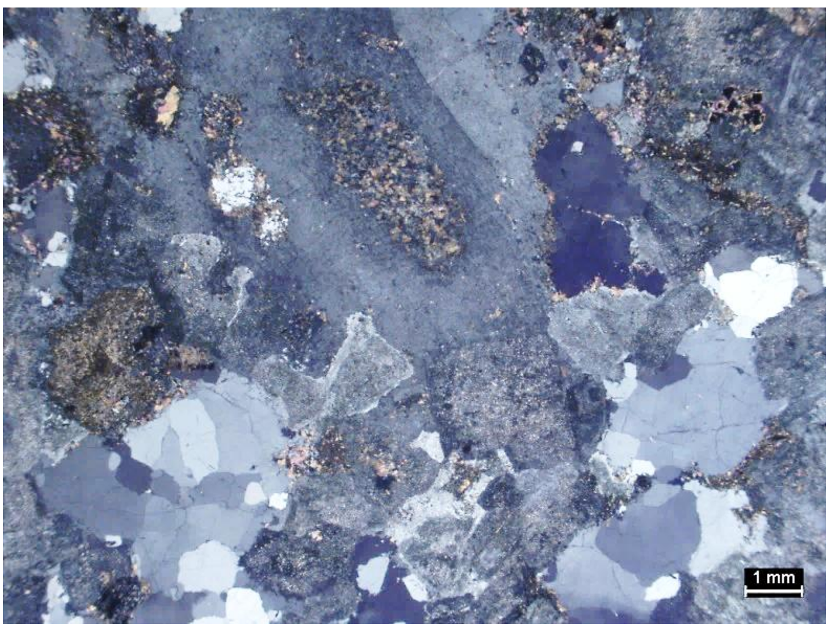


Zsg17 (left): Granodiorite southeast of South Reservoir in Medford (site 10732). Rock has large perthitic alkali feldspar grains (A). Other large grains are quartz (clear grains) and plagioclase which is heavily altered to epidote and sericite. Mafic minerals are altered to chlorite. Thin section with crossed polarizers.

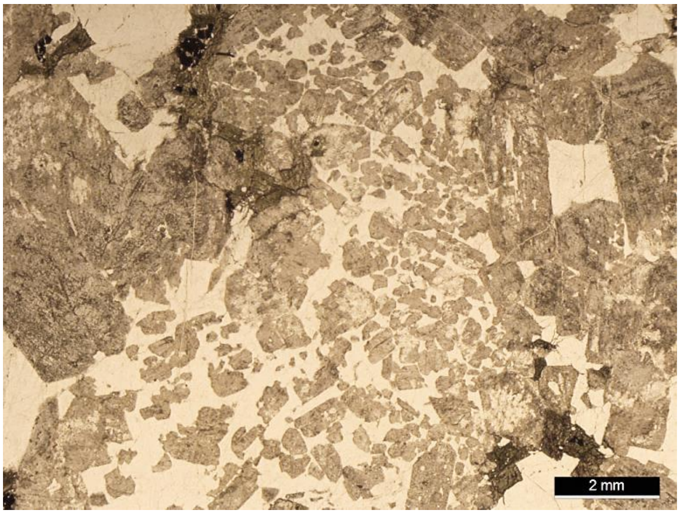
Zsg18 (below left): Thin section in plane polarized light; (below right): Same thin section view with crossed polarizers. Granodiorite from Lawrence Woods in Medford (site 11001). View is dominated by alkali feldspar (yellow stain) and plagioclase (dusty alteration). Quartz grains are clear. In lower right and upper right of images is biotite partly altered to chlorite. Alkali feldspar in lower center is lightly perthitic while also having crosshatch twinning in right center. Quartz has undulatory extinction.



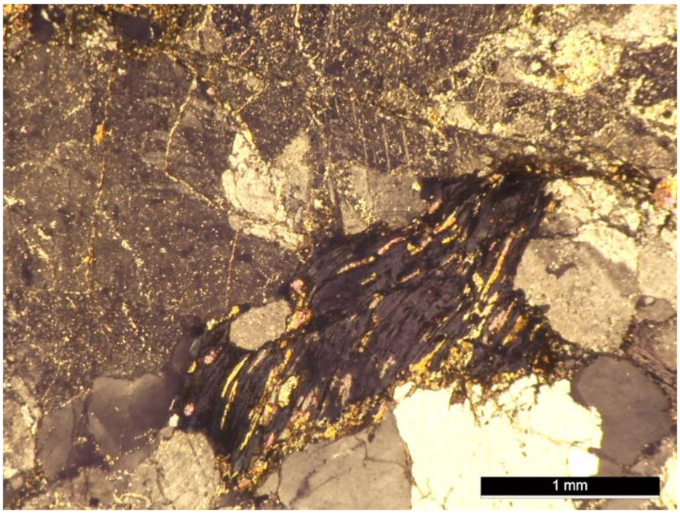




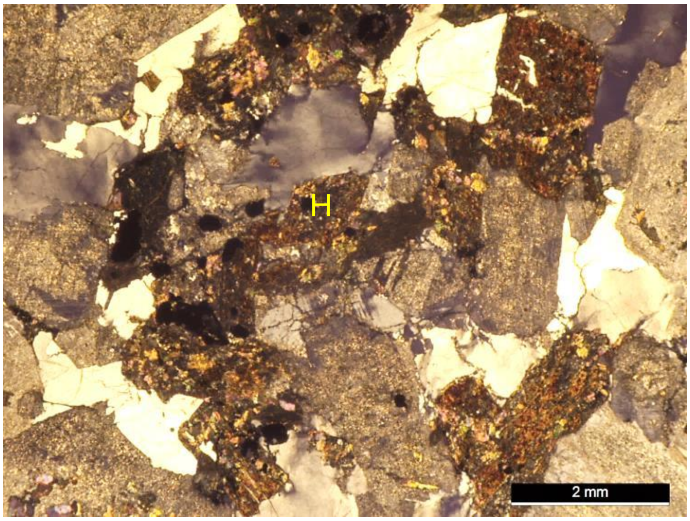
Zsg19: Coarse granodiorite northeast of Doleful Pond near Stoneham High School in Stoneham (site 10409). Cores of alkali feldspar are altered to epidote. Quartz is polycrystalline and very lightly strained with faint undulatory extinction. Zircon crystals from this site are shown in Fig. Zsg14 above.



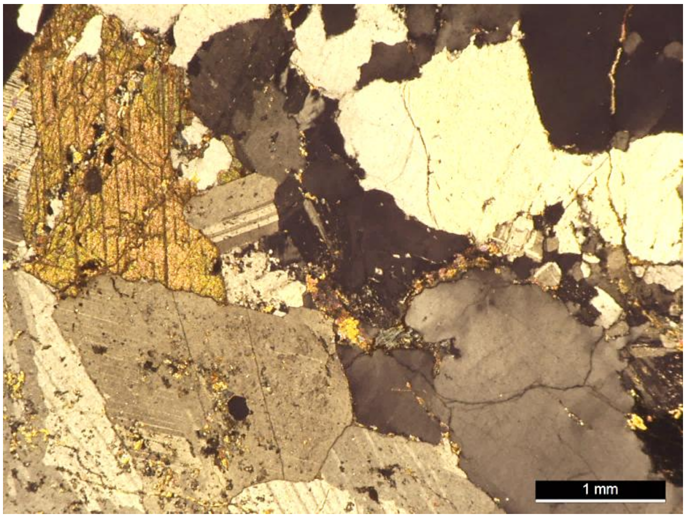
Zsg20: Granodiorite from Lawrence Woods in Medford (site 10986) with poikilitic alkali feldspar (white) hosting plagioclase (dusty gray). Thin section in plane polarized light.



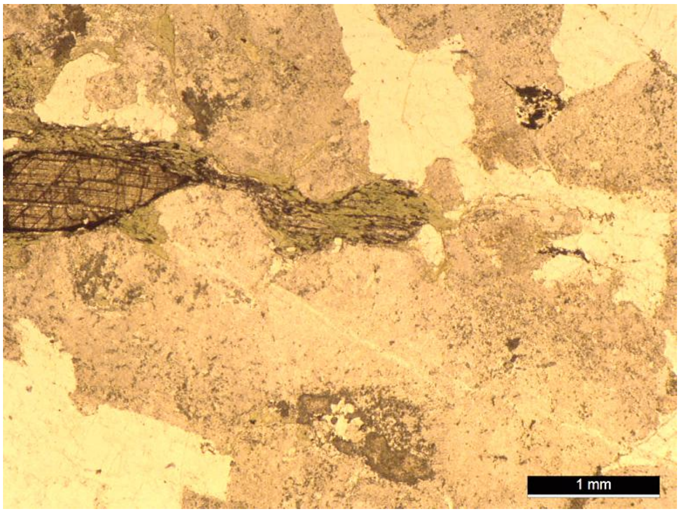
Zsg21: Biotite altered to chlorite (dark purplish-gray interference color), opaque minerals, and epidote (colorful seams) surrounded by altered plagioclase above and quartz (clear below) in granodiorite east of Woodland Road in Medford (site 10550). Thin section with crossed polarizers.



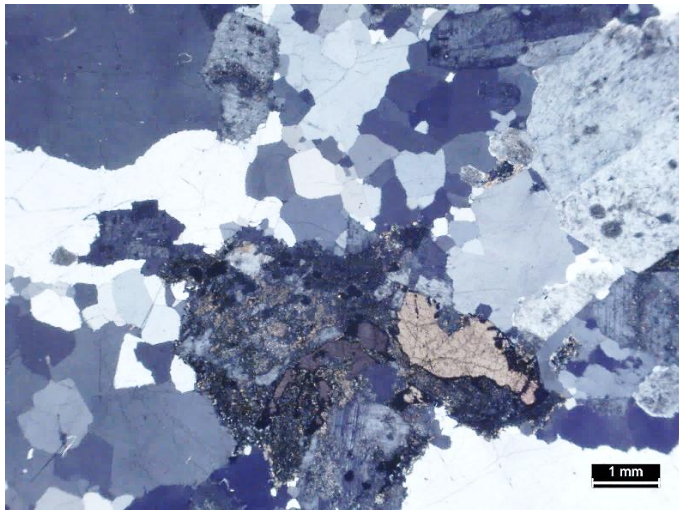
Zsg22: Hornblende crystals altered to pseudomorphic epidote and chlorite in tonalite in Lawrence Woods (site 10986). The diamond-shaped outline of hornblende in center is still faintly visible (H) but is now mostly epidote. Quartz has undulatory extinction. Thin section with crossed polarizers.



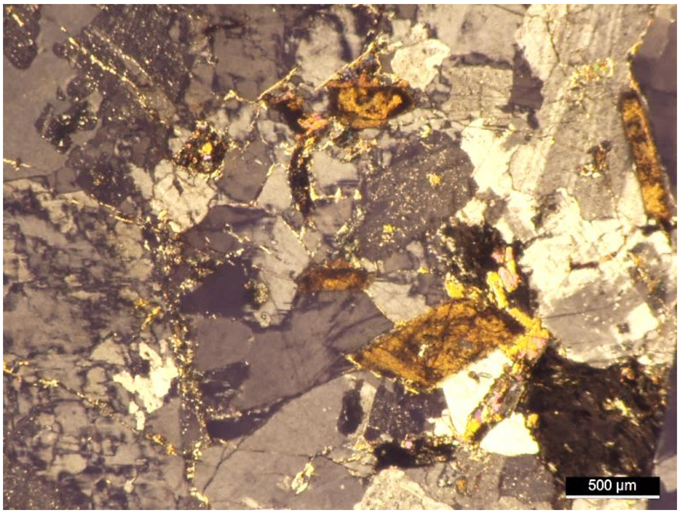
Zsg23: Sphene (titanite; upper left) in granodiorite north of Bellevue Pond in Medford (site 10675). Thin section with crossed polarizers.



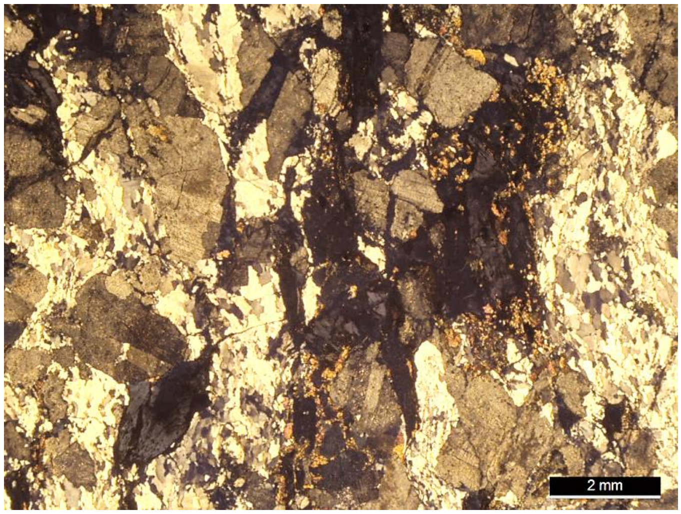
Zsg24: Sphene (titanite; left side) with biotite altered to chlorite in foliated granodiorite south of Sheepfold in Stoneham (site 11291). Thin section in plane polarized light. Outcrop in Fig. Zsg12.



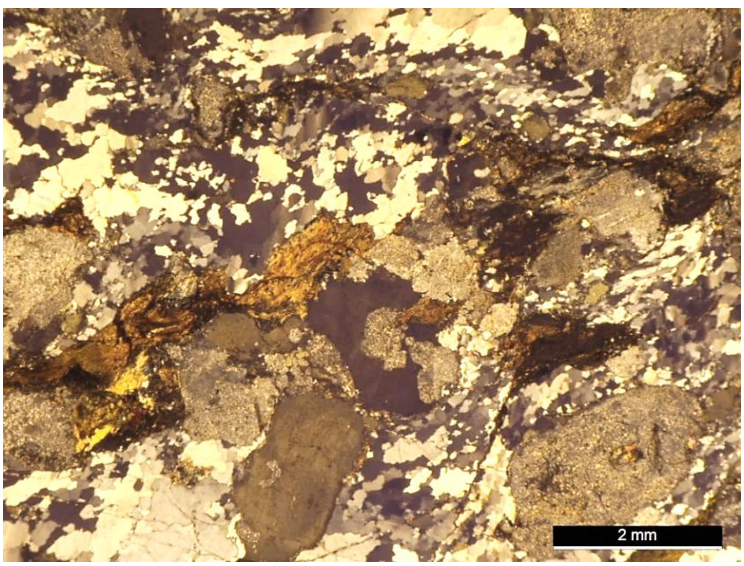
Zsg25 (right): Coarse granodiorite northeast of Doleful Pond in Stoneham (site 10409). Dark brown (near extinction) and tan high relief grains are sphene (titanite).



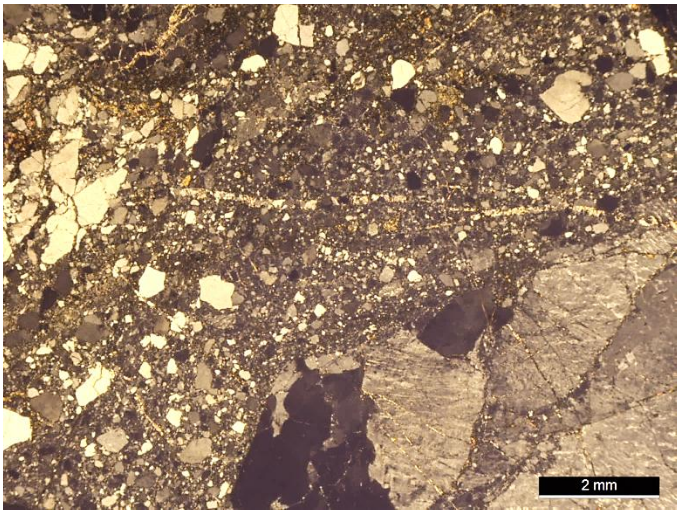
Zsg26: Granodiorite from east of Woodland Road in Medford (site 10941) with accessory rutile (dark orange). Thin section with crossed polarizers.



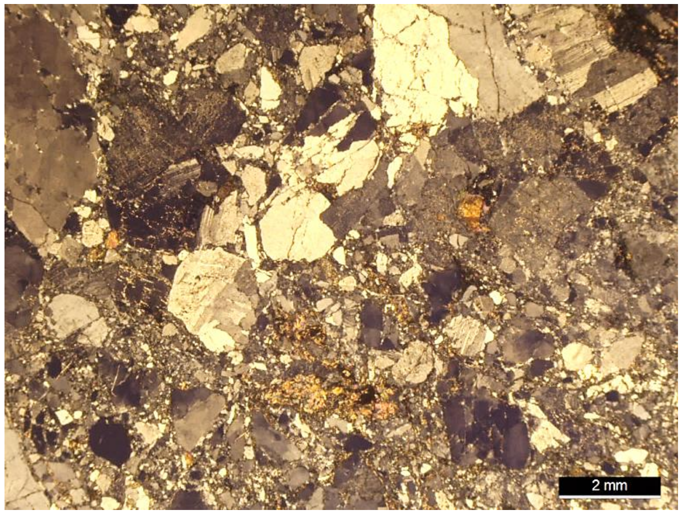
Zsg27 (above): Sheared polycrystalline quartz in foliated tonalite south of Sheepfold in Stoneham (site 11291). Dark areas in center are deformed biotite altered to chlorite and epidote. In lower left is dark gray pseudomorphic chlorite after hornblende. Thin section with crossed polarizers. See Fig. Zsg11 for outcrop view.



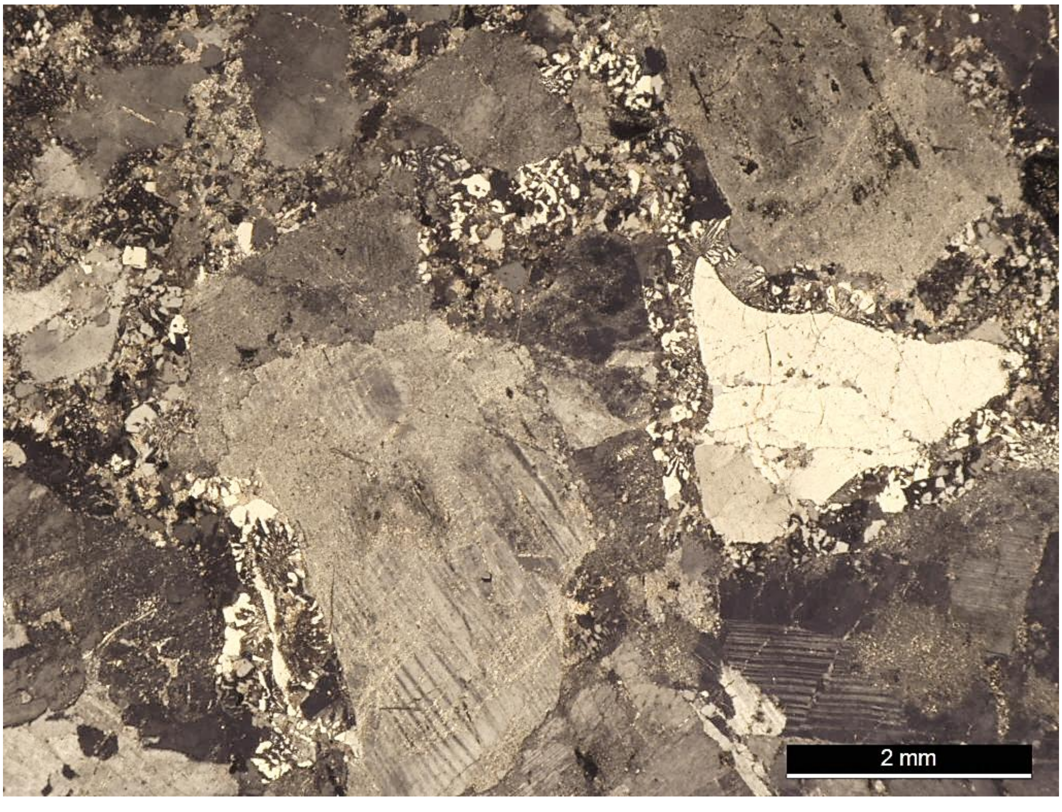
Zsg28: Fine polycrystalline quartz in foliated granodiorite south of Sheepfold in Stoneham (site 10817). Mafic grains (hornblende) are altered and deformed. Thin section with crossed polarizers.



Zsg29: Cataclastically deformed granodiorite from north of Bellevue Pond in Medford (site 10550). In lower right is perthitic alkali feldspar. Thin section with crossed polarizers.



Zsg30: Cataclastically deformed granodiorite from west of Wrights Pond in Medford (site 10490). Colorful area in lower center is epidote formed by alteration of mafic minerals. Thin section with crossed polarizers.

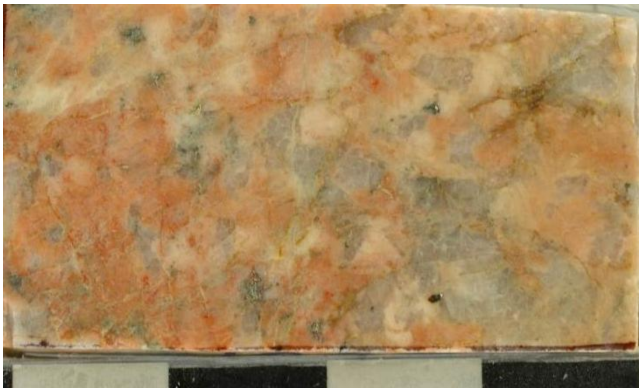


Zsg31: Granodiorite adjacent to Medford Dike along east side of Rt. 28 in Medford (site 10564). Re-heating of the granodiorite adjacent to dike caused melting along grain boundaries and later recrystallization of granophyric seams. Thin section with crossed polarizers. Note smooth, curved embayed boundaries of mineral grains along granophyric seams.

Zsgk

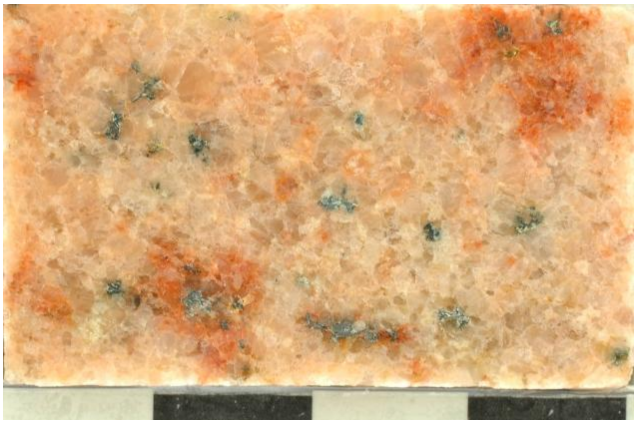
Spot Pond Granodiorite, leucocratic alkali feldspar granite zones (Neoproterozoic) – Coarse-grained leucocratic and alkali-rich areas within the Spot Pond Granodiorite (see Fig. Zsg1 for point counts) that have alkali feldspar dominant over plagioclase, almost no mafic minerals, and generally a bright orangish-red color (2.5YR 6/6-5/8). Two types of areas have been mapped. One type is more abundant and is monzo- to syenogranite as coarse as the host Spot Pond Granodiorite with abundant light red (2.5YR 6/8), coarse alkali feldspar crystals (up to 65%), few mafic minerals, and less than 15% plagioclase. This granite may be a local variation of the granodiorite (enclaves), or large xenoliths of a unit not exposed at the surface (Figs. Zsgk1-2 and 5). 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 this type has also been mapped in the Winchester Granite (Zwg) west of Bear Hill and is identical to what is described here (See Fig. Zwg9). This lends support for these areas being xenoliths. The alkali areas resemble the Ball Quarry Granite to the east described by Smith and Hon (1984) and Smith (1985). A second type of syenogranite occurs at only one place on a hilltop northwest of Wrights Pond and is finer-grained than the host granodiorite with a granular outcrop appearance (Figs. Zsgk3-4 and 6). It has sharp contacts with the granodiorite and may be a xenolith.

Zsgk1: Coarse syenogranite along Rt. 28 northwest of Wrights Pond in Medford (site 10634).

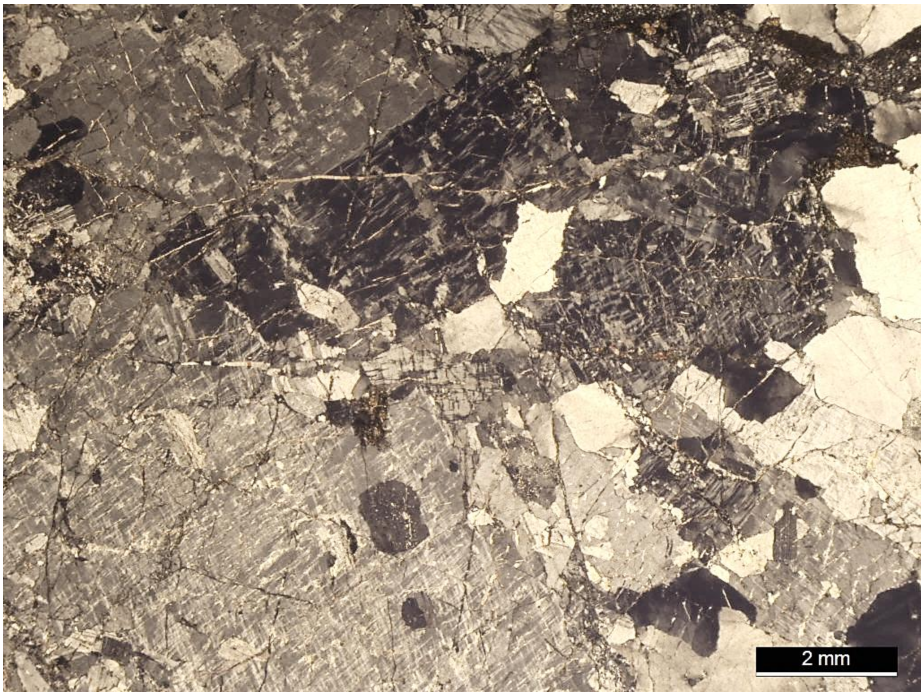


Zsgk2: Coarse syenogranite south of Rams Head Hill in Medford (site 11008).

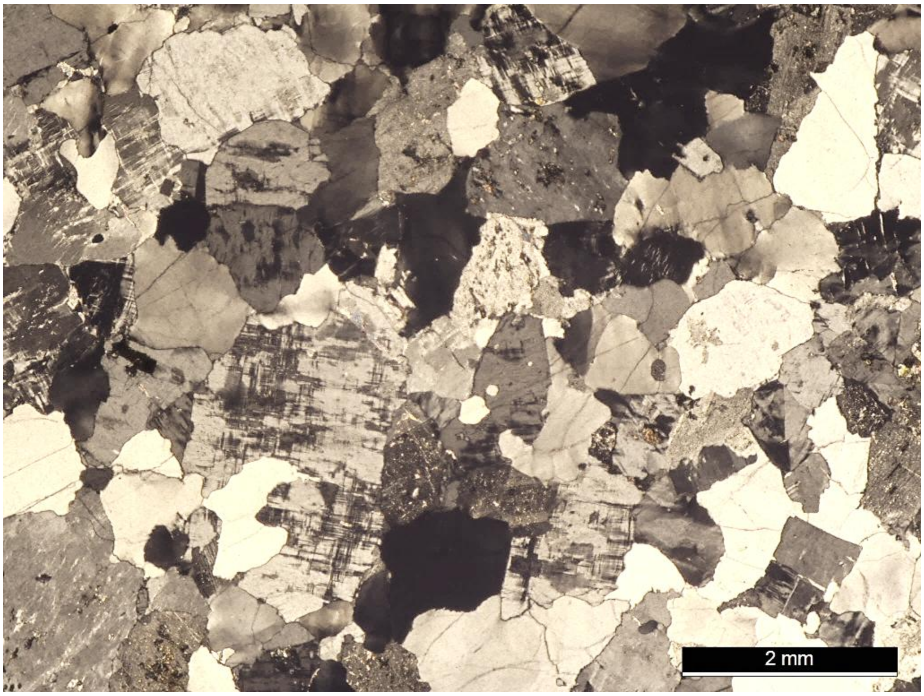
Zsgk3: Outcrop view of contact between finer syenogranite (left, Zsgk) and regular coarse Spot Pond Granodiorite (Zsg, beneath hammer) east of Rt. 28 and northwest of Wrights Pond in Medford (site 10469).



Zsgk4: Fine syenogranite east of Rt. 28 and northwest of Wrights Pond in Medford (site 10469) shown in outcrop on Fig. Zsgk3.



Zsgk5: Syenogranite area in Spot Pond Granodiorite along Rt. 28 in Medford (site 10634). Alkali feldspar is perthitic with crosshatch twinning. See Figs. Zsgk1-2 for cut rock view. Thin section with crossed polarizers.



Zsgk6: Syenogranite in Spot Pond Granodiorite east of Rt. 28 in Medford (site 10469). Alkali feldspar is perthitic and has crosshatch twinning. Quartz is lightly strained and has undulatory extinction. See Figs. Zsgk3-4 for outcrop and cut rock views. Thin section with crossed polarizers.

Zwg

Winchester Granite (Neoproterozoic) – Reddish- to pinkish-tan, medium-grained, equigranular monzogranite to tonalite (mostly granodiorite) in the northwestern Fells west of South, Middle, and North Reservoirs (Figs. Zwg1-6). The reddish color is derived from moderate reddish-orange (10R 6/6) to moderate reddish-brown (10R 4/6) alkali feldspar that is 5-30% of felsic minerals in the rock (Fig. Zwg1). The red color can be misleading in some areas and results from iron oxide staining. Mafic minerals can be up to 25% of the total rock in the main body of the unit and up to 50% along contacts with the Nanepashemet Formation (Znpm). Quartz is 25-35% and plagioclase is 40-60% of felsic minerals (Fig. Zwg1). This unit is distinct from the Stoneham Granodiorite (Zst) in being everywhere equigranular (non-porphyritic) and having larger quartz grains and more abundant alkali feldspar (see special comparison with description of Stoneham Granodiorite on p. 86). Color and composition have a large range and can change over short distances (Figs. Zwg2-6). Two areas with atypical lithologies, which may be xenoliths, have been mapped as separate units on Money Hill (diorite, Zwgd) and west of Bear Hill (alkaline granite, Zsgk). The unit displays rapid changes in grain size and mafic mineral content at the northeast end of North Reservoir suggesting assimilation of mafic-rich quartz diorite or diorite (Figs. Zwg7-8 and see unit Zwgd below) or altered basalt from the Nanepashemet Formation (Znpm). Also included is sharply bounded coarse alkaline granite (Fig. Zwg9; see description of alkaline bodies associated with the Spot Pond Granodiorite, Zsgk). In the northwest Fells along Wyman Path and along Middle Reservoir this unit has occasional basalt xenoliths from the Nanepashemet Formation. The granite is heavily sheared in some places near faults. Bell (1948) classified this rock as the “Stoneham red granite stock” part of the Dedham Granodiorite and identified it as different than the more tonalitic rocks at Bear Hill and further east to northeast in Stoneham (Stoneham Granodiorite of this map). Kaye (1980) classified the Winchester Granite as tonalite-granodiorite and lumped it with the Stoneham Granodiorite (Zst) of this study, but when mapped in detail these units are distinct. Kaye, like Emerson (1917) and LaForge (1932), correlated it with the Paleozoic Newburyport Quartz Diorite (Clapp, 1921). U-Pb zircon ages east of Long Pond are 605.7 $\pm$ 3.3 Ma (LA-ICPMS, 40 zircons; Hampton, 2017) and 609.72 $\pm$ 0.24 (CA-ID-TIMS, 4 zircons; F. MacDonald, pers. comm.), giving it an age like the Spot Pond Granodiorite and disproving a correlation with the Newburyport Quartz Diorite (Newburyport Complex of Zen and others, 1983; Wones and Goldsmith, 1991) and the Stoneham Granodiorite. Like the Spot Pond Granodiorite, the Winchester Granite is part of the Dedham Complex. They may be part of a composite pluton given their similar radiometric ages.

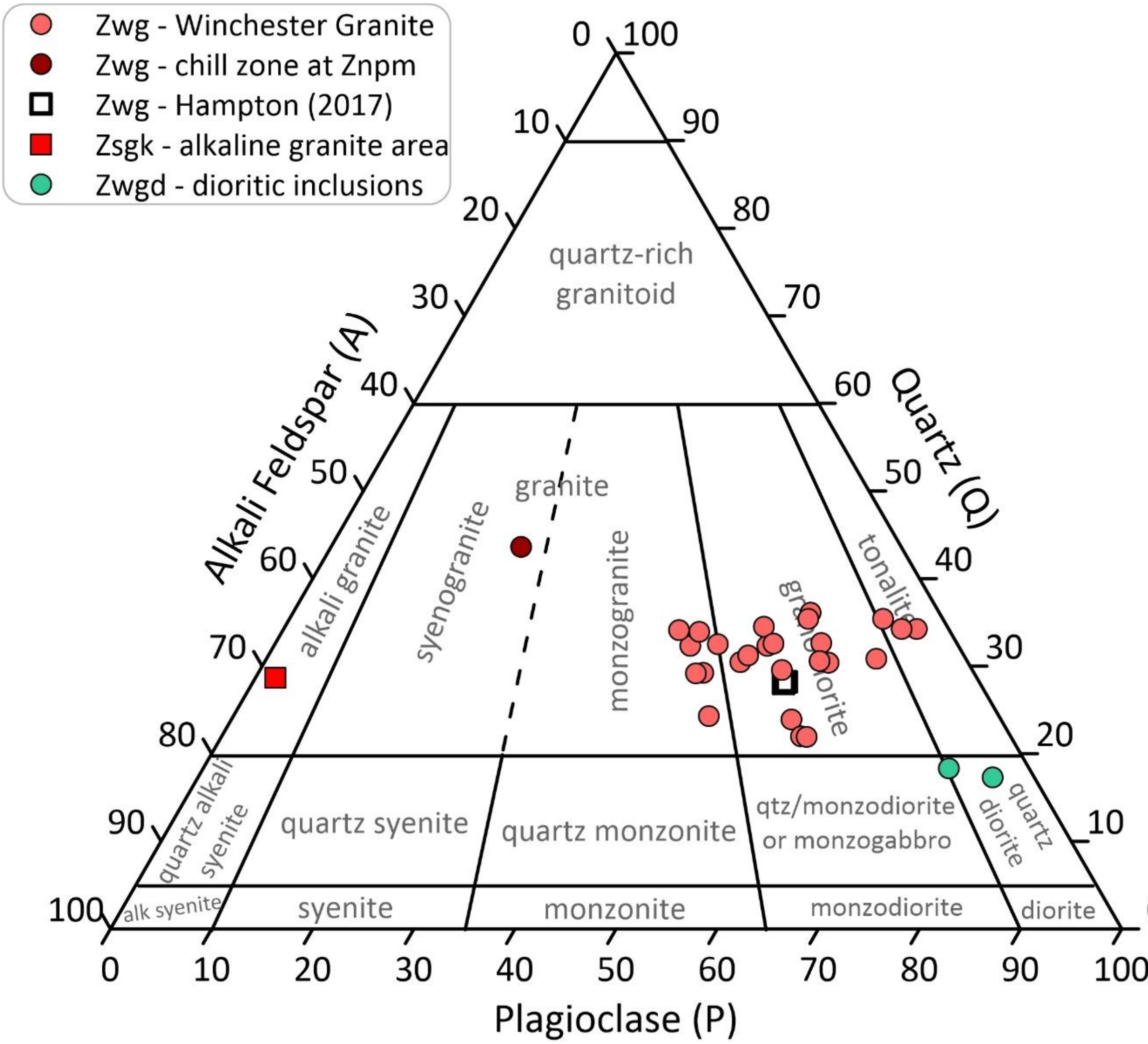
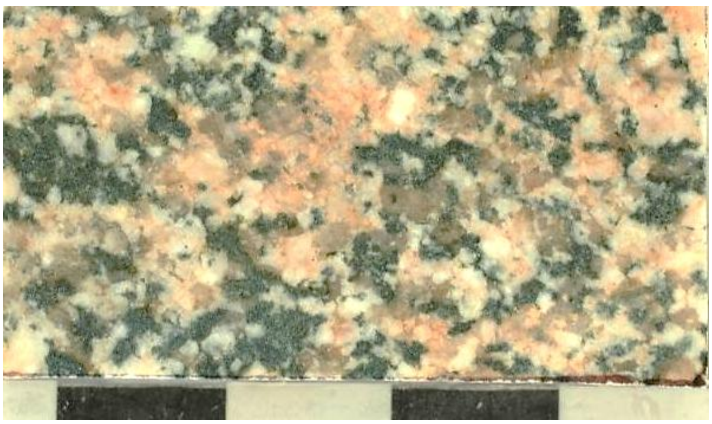


Figure Zwg1. Normalized Quartz-Alkali Feldspar-Plagioclase (QAP) plot of point counts from the Winchester Granite along with an alkaline chill zone sample at a contact with the Nanepashemet Formation (Znpm) at the north end of Middle Reservoir, an alkaline granitic area that may be an inclusion (see description in Zsgk section above), and dioritic inclusions (Zwgd). Most Winchester Granite samples are granodiorite to monzogranite with a few that are tonalite. Shown for comparison are CIDW Norm% calculations from LA-ICPMS data of Hampton (2017) on the Winchester Granite. Point count data for this plot are in Appendix 1-H. Alkali granite sample is in Appendix 1-G.

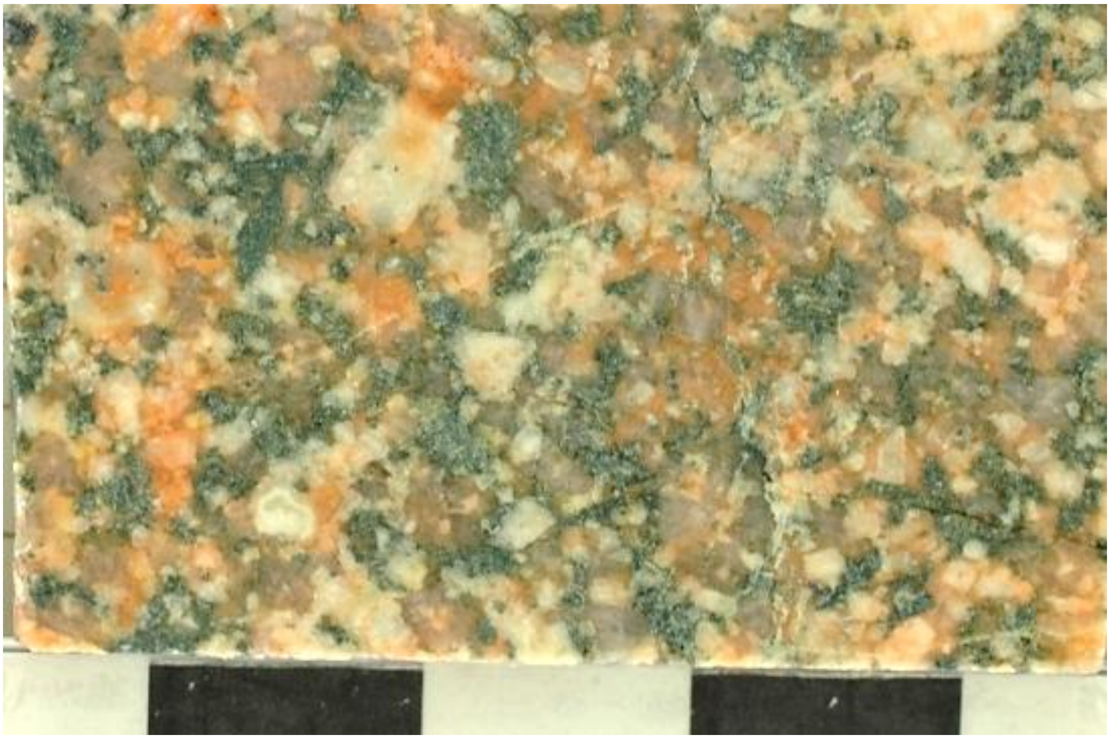
Zwg2: Cut rock slab of equigranular granodiorite south of Molly’s Spring Road in Medford (site 11065).

Zwg3: Cut rock slab of equigranular granodiorite on Quigley Hill in Winchester (site 11071).



Zwg4: Cut rock slab of equigranular granodiorite with orange alkali feldspar at south end of Long Pond in Winchester (site 11077).

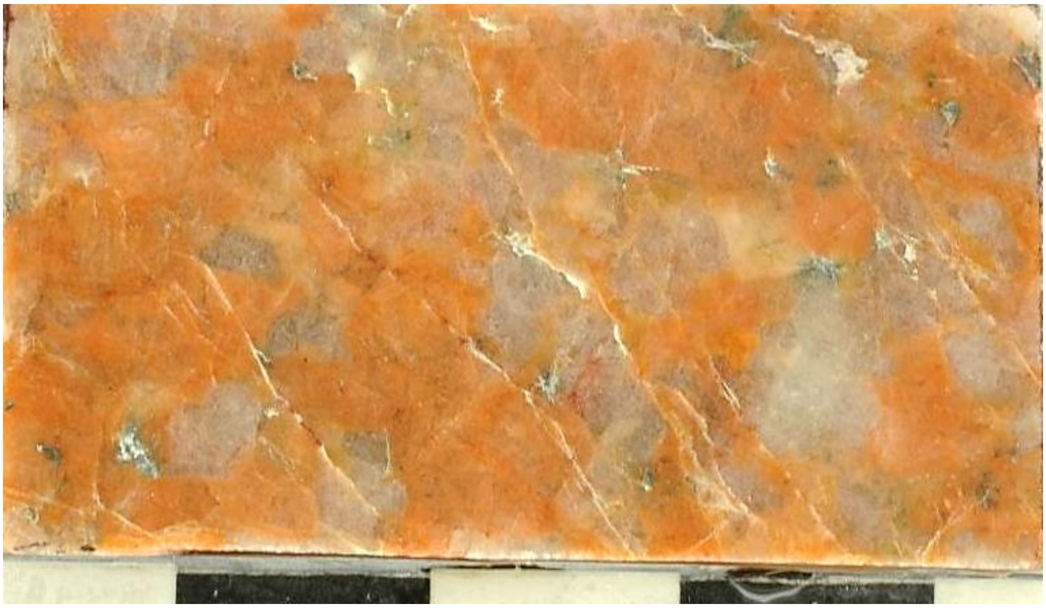
Zwg5: Cut rock slab of equigranular granodiorite with orangish-brown alkali feldspar along Hillcrest Parkway in Winchester (site 11097).



Zwg6: Cut rock slab of granodiorite with orangish-red alkali feldspar at north end of Middle Reservoir near contact with Nanepashemet Formation (Znpm) in Winchester (site 10838).

Zwg7: Granodiorite with areas of mostly assimilated diorite/gabbro at northeast shore of North Reservoir in Winchester (site 11232).

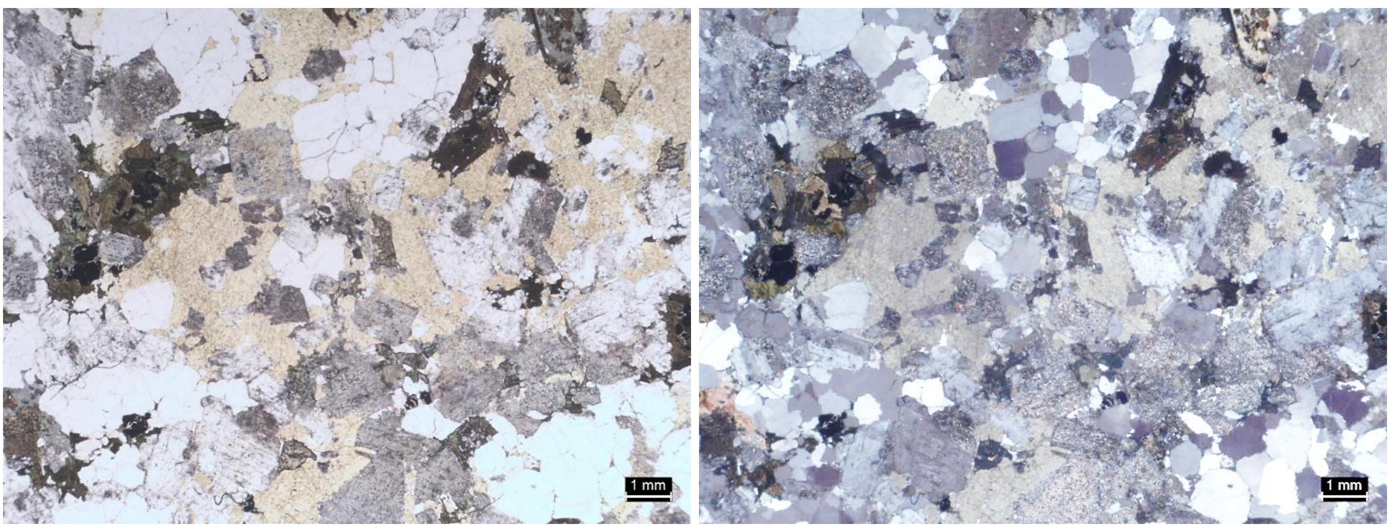
Zwg8: Area of northeast shore of North Reservoir where diorite-gabbro is assimilated into the Winchester Granite giving the granite a high mafic mineral content and porphyritic appearance (site 11471).



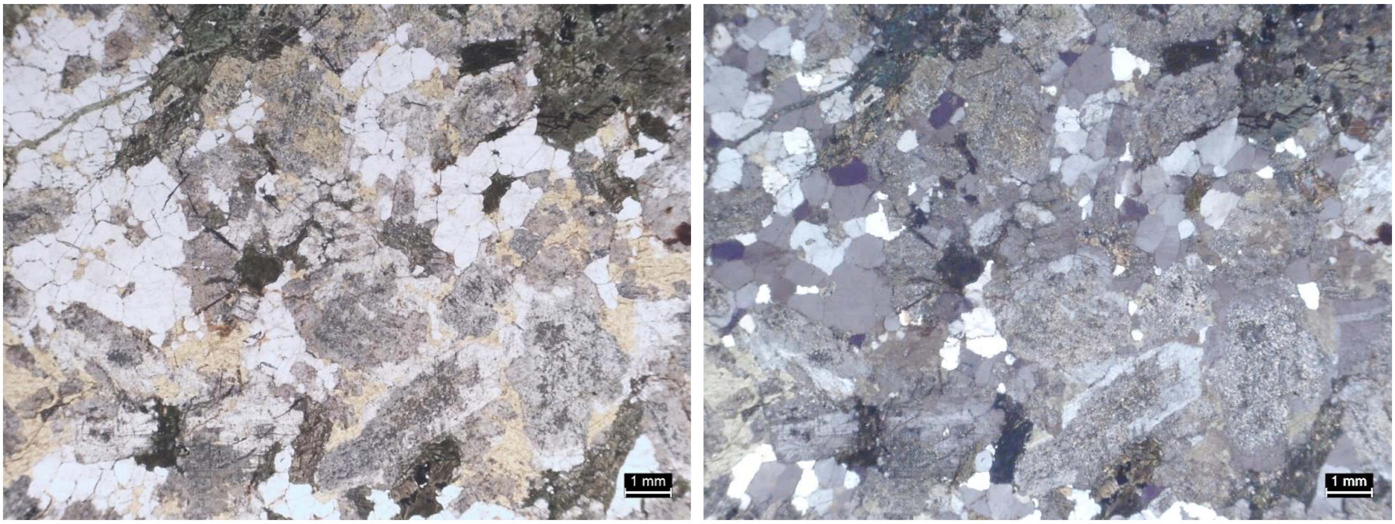
Zwg9: Leucocratic syenogranite (xenolith?) from alkaline area (Zsgk) in the Winchester Granite. West of Bear Hill in Stoneham (site 11221). Mapped as part of Zsgk that is associated with the Spot Pond Granodiorite (see Zsgk description above).

Winchester Granite (cont.)

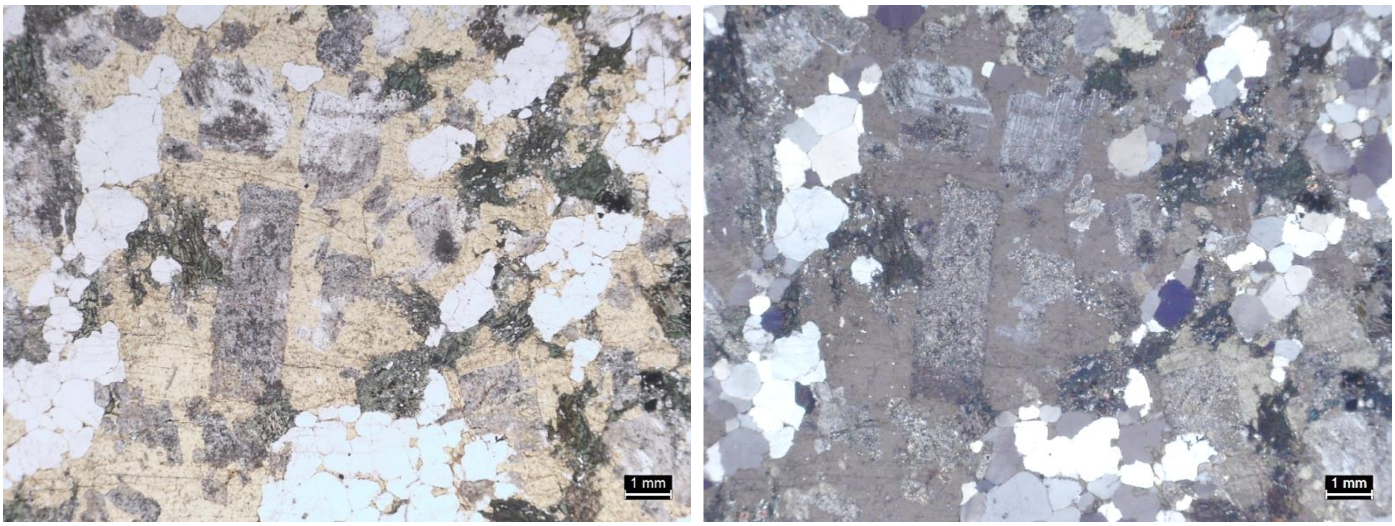
Thin section description: The Winchester Granite is mostly monzogranite to granodiorite, with smaller areas of tonalite, possibly where it has assimilated more dioritic to gabbroic rocks (see Figs. Zwg1 and 7-8 and quartz diorite xenolith described below, Zwgd). Plagioclase generally dominates alkali feldspar with quartz being about 25-30%, plagioclase 40-60% and alkali feldspar mostly 15-30% of felsic minerals (Fig. Zwg1). Quartz tends to occur as rounded to polygonal, equigranular, polycrystalline grains (Figs. Zwg10-12). Quartz in this formation does not have pronounced undulatory extinction like the Spot Pond Granodiorite (Zsg). Quartz can also occur as round grains that are partly assimilated inclusions (Fig. Zwg13) along the contact with the Westboro Formation (Zvwq). Alkali feldspar tends to be less altered than plagioclase and occurs in mostly interstitial pockets (Fig. Zwg11). In larger interstitial areas it encloses euhedral plagioclase and occasional individual quartz grains forming a poikilitic texture (Figs. Zwg10, 12 and 14). The larger interstitial areas show up as being very orange in hand specimens (Fig. Zwg6) and are common adjacent to the Nanepashemet Formation (Znpm). At the north end of Middle Reservoir, the chill zone against the Nanepashemet Formation has small interstitial alkali feldspar areas with crosshatch twinning and plagioclase is absent giving outcrops a very orange appearance. This is the only area where crosshatch twinning was identified. In one location west of the major fault at Bear Hill, and near the northern border of the Fells, alkali feldspar forms what may be an inclusion (Fig. Zwg9 and 15; mapped as Zsgk). In general, plagioclase is mostly euhedral (Figs. Zwg10, 12, 14 and 16) and partly altered to fine sericite (all thin section images), sometimes with scattered fine epidote or faint grain centers of epidote (Figs. Zwg10-11 and 16). Some plagioclase crystals have unaltered rims (Fig. Zwg16), especially where crystals are small. Mafic minerals are mostly hornblende with lesser biotite (Fig. Zwg17). Hornblende can occur as large euhedral or partly euhedral crystals that are often partly altered to chlorite and epidote (Figs. Zwg12, 17 and 18). Biotite is usually heavily altered to chlorite and magnetite (Fig. Zwg14). In some cases, biotite alters to chlorite with hexagonal lamellar networks of magnetite (Fig. Zwg19). The granite has appreciable amounts of titanium as is evident by scattered sphene (titanite) crystals (Fig. Zwg20) and rarer rutile (Fig. Zwg21). Opaque minerals are either titanomagnetite or ilmenite. Magnetite can occur as euhedral 6-sided crystals (Fig. Zwg22) in interstitial areas or is an alteration product (Figs. Zwg14 and 19).



Zwg10: (left in plane polarized light, right with crossed polarizers) Typical Winchester Granite (monzogranite to granodiorite) south of Molly's Spring Road (site 11065). See Fig. Zwg2 for cut rock view. Quartz is clear and polycrystalline, alkali feldspar is stained yellow and encloses euhedral plagioclase, which is gray due to alteration to sericite and scattered epidote. Mafic minerals are hornblende and biotite that are mostly altered to chlorite epidote, and magnetite.

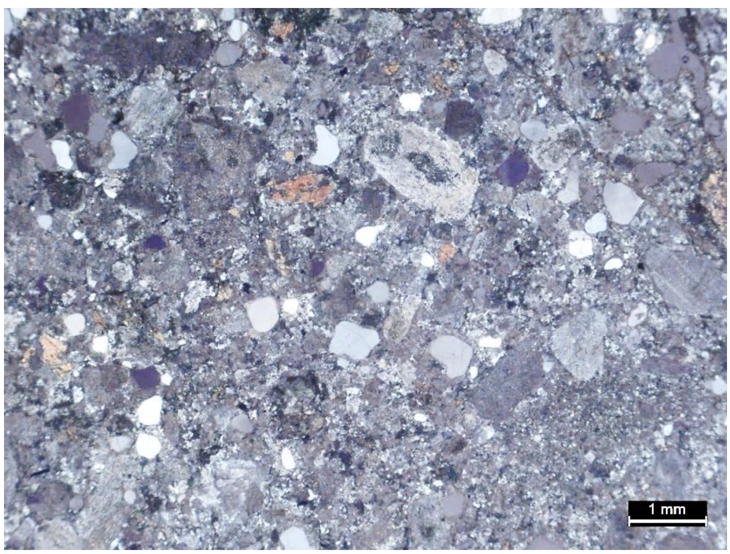


Zwg11: (left in plane polarized light, right with crossed polarizers) Granodiorite north of Long Pond (site 11095). Quartz is polycrystalline, alkali feldspar (stained yellow) is interstitial, and plagioclase is gray due to alteration to sericite and scattered fine epidote. Mafic minerals are hornblende mostly altered to chlorite.

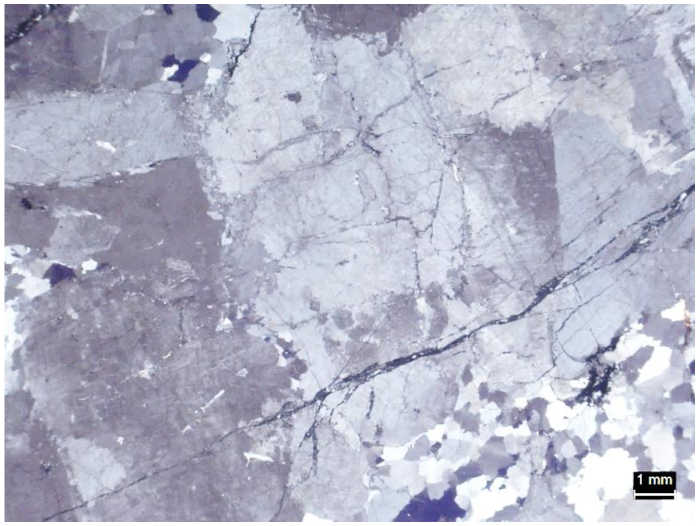


Zwg12: (left in plane polarized light, right with crossed polarizers) Monzogranite along Hillcrest Parkway (site 11097). See Fig. Zwg5 for a cut rock view. Quartz is polycrystalline, alkali feldspar (stained yellow) encloses euhedral plagioclase that is gray due to alteration to sericite. Mafic minerals are hornblende and biotite altered to chlorite and magnetite.

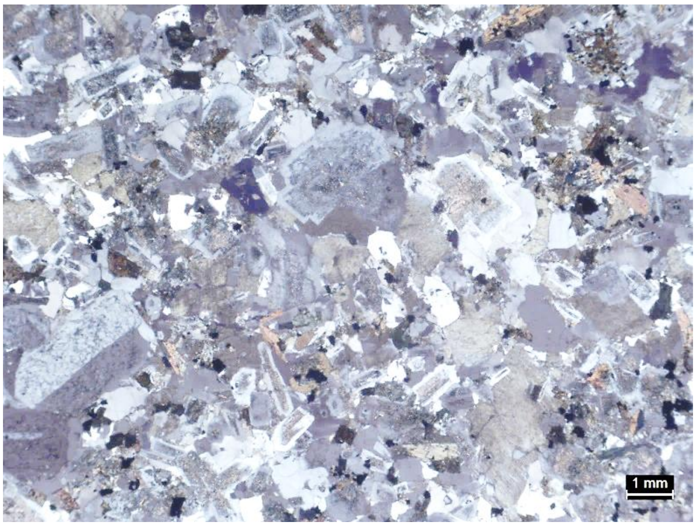
Zwg13: Chill zone of unit in contact with Westboro Formation east of South Border Road (site 11053). Round quartz grains are partly melted xenocrysts from the quartzite. Mafic minerals are hornblende.



Zwg14: Monzogranite north of Middle Reservoir (site 10838). See Fig. Zwg6 for cut rock view. Quartz is polycrystalline and alkali feldspar (stained yellow) encloses euhedral plagioclase that is gray due to alteration to sericite. Mafic minerals are mostly biotite altered to chlorite (green) and magnetite.

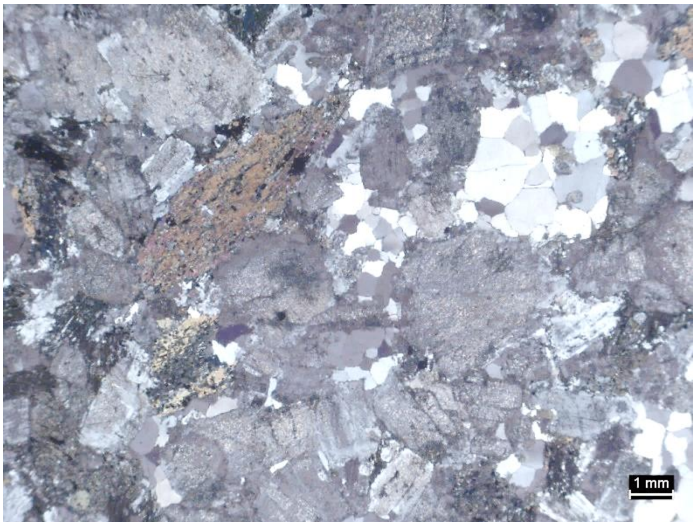


Zwg15: Leucocratic alkali feldspar granite (inclusion?; mapped as Zsgk) east of Money Hill near northern border of Fells (site 11221). Quartz is polycrystalline (lower right), while large alkali feldspar crystals make up most of the remaining rock with very scarce plagioclase and mafic minerals. See Fig. Zwg9 for cut rock view.

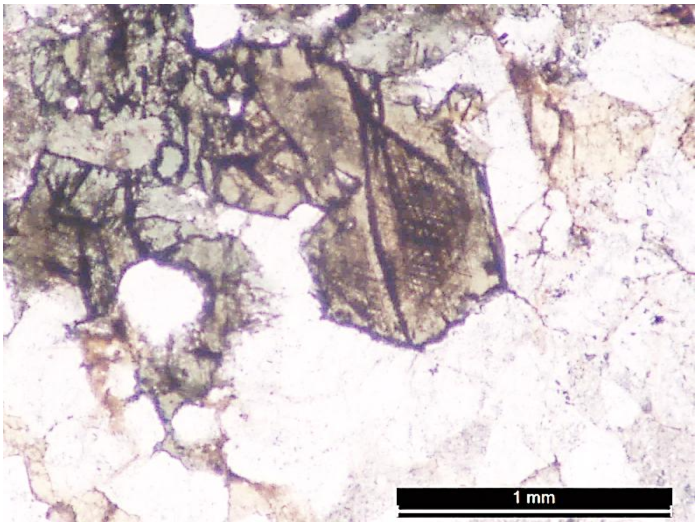


Zwg16: Granodiorite south of Molly's Spring Road (site 11067). Quartz is polycrystalline and interstitial, alkali feldspar (stained yellow) is interstitial, and euhedral plagioclase has gray interiors due to alteration to sericite and epidote but unaltered rims. Mafic minerals are hornblende with minor alteration.

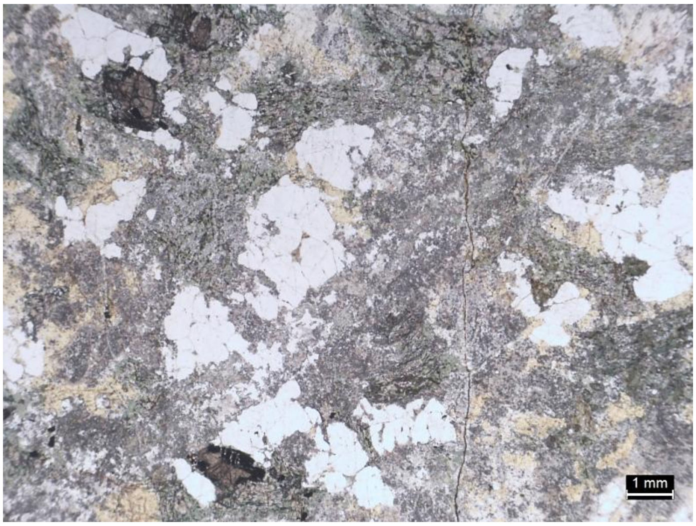
Zwg17: Granodiorite near North Reservoir Dam (site 11230). Quartz is polycrystalline and alkali feldspar (stained yellow) encloses euhedral plagioclase that is gray due to alteration to sericite. Mafic minerals are biotite (dark brown) and hornblende (green) with minor alteration to chlorite.



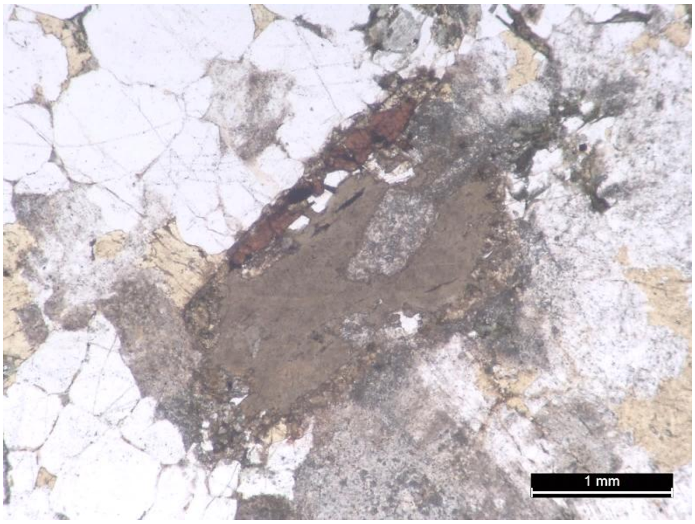
Zwg18: Tonalite west of Middle Reservoir (site 11119). Quartz is polycrystalline, alkali feldspar is scarce, and plagioclase is gray due to alteration to sericite. Mafic minerals are mostly hornblende (brown, euhedral here) partly altered to pseudomorphic epidote and chlorite.



Zwg19: Granodiorite on Grinding Rock Hill near Hillcrest Drive (site 11264). Close up view of biotite altered to chlorite with exsolved hexagonal lamellar magnetite.



Zwg20: Granodiorite near west end of Hillcrest Parkway (site 11097). Quartz is polycrystalline, alkali feldspar is interstitial, and plagioclase (gray) is heavily altered to sericite. Most mafics are altered to chlorite. Dark high relief mafic grains are sphene (titanite). (See Fig. Zwg5.)



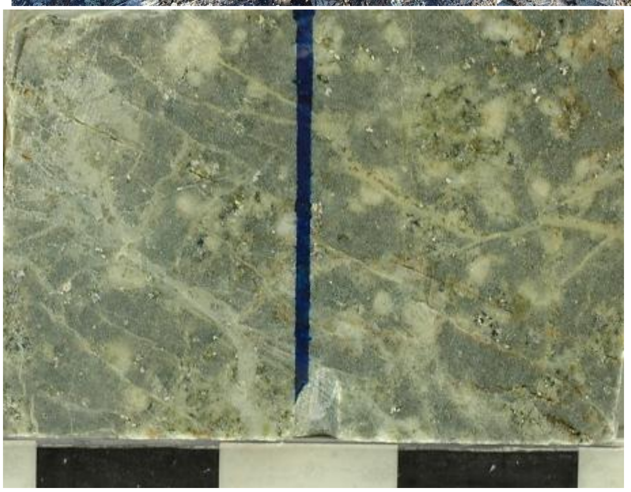
Zwg21: Granodiorite east of North Reservoir (site 11220). Quartz is polycrystalline, alkali feldspar is interstitial, and plagioclase (gray) is altered to sericite. Mafics here are an unidentified drab brown grain (possibly altered sphene) and rare reddish-brown rutile.

Zwg22: Granodiorite near contact with Westboro Formation on west shore of South Reservoir (site 11273). Quartz is polycrystalline, alkali feldspar is interstitial, and plagioclase (gray) is altered to sericite. Small opaque grains are euhedral 6-sided magnetite. Veins are epidote.

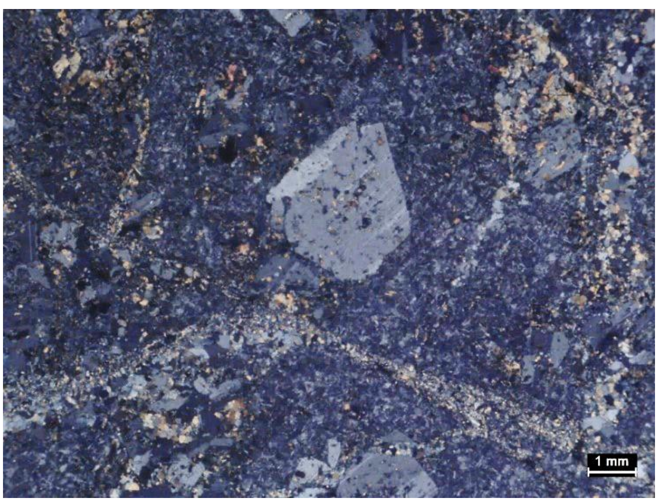
Zfi

Baked Xenoliths of Felsic Volcanic Rock in the 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 felsic volcanic xenoliths that are sparsely porphyritic. Except for minor color differences and alteration by contact metamorphism, all occurrences have the same overall appearance. Occurrences are: 1) the east side of Woodland Avenue across from Quarter Mile Pond, 2) the southwest side of the swamp along Rt. 28 west of Wrights Pond, and 3) west of Red Cross Path and the northern extension of Middle Hill (Figs. Zfi1-3). The sources (or source) of the sialic xenoliths are not known.

Zfi1: Outcrop view of felsic xenolith in Spot Pond Granodiorite west of Red Cross Path and north of Middle Hill in Medford (site 10706).



Zfi2: Felsic xenolith in Spot Pond Granodiorite west of Red Cross Path and north of Middle Hill in Medford (site 10706). Outcrop shown in Fig. Zfi1.

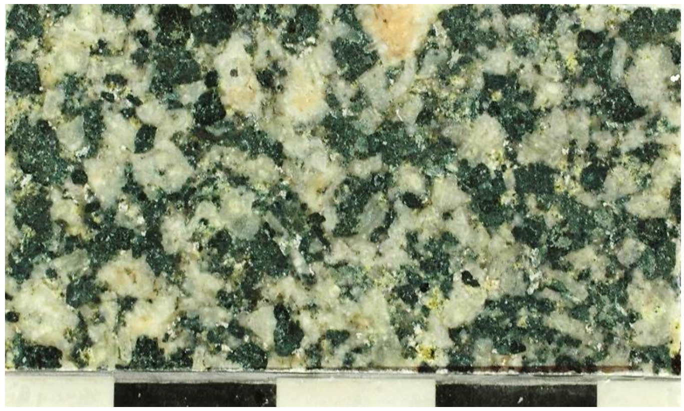


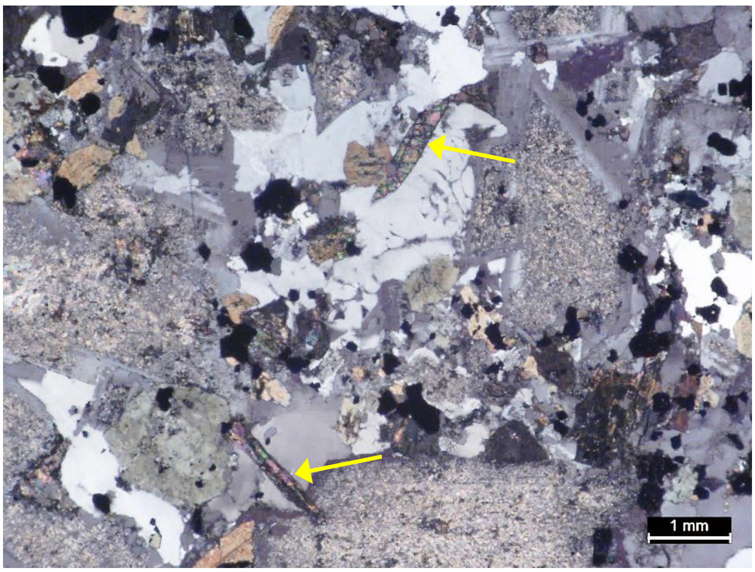
Zfi3: Felsic xenolith in Spot Pond Granodiorite west of Red Cross Path and north of Middle Hill in Medford (site 10706). Thin section view shows plagioclase crystal, fine ground mass of feldspar and quartz, and epidote (bright colors) in veins and as mineral alteration. The matrix of this rock has likely been recrystallized from an original volcanic rock.

Zwgd

Quartz Diorite Xenolith in Winchester Granite (Neoproterozoic?) – Gray, medium-grained, equigranular to faintly porphyritic, quartz diorite xenolith on east side of Money Hill (Fig. Zwgd1). See Fig. Zwg1 for QAP plot with Winchester Granite. Plagioclase in this unit is heavily altered. The xenolith has a higher mafic content than other felsic plutonic bodies (Figs. Zwgd1-3) and a composition distinct from the Winchester Granite (see Fig. Zwg1). The quartz diorite xenolith on Money Hill appears to have a source in a rock unit not exposed at the land surface. This lithology may be assimilated into the granite in several places, most notably in shore exposures at the north to northeast end of North Reservoir (see Figs. Zwg7-8).

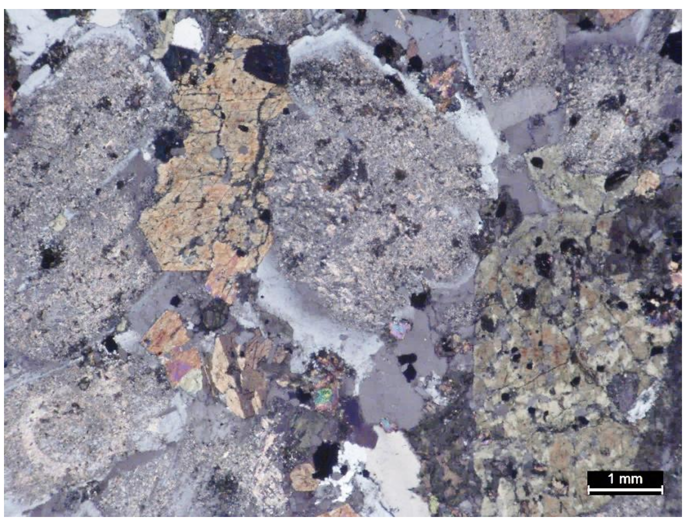
Zwgd1: Quartz diorite xenolith (Zwgd) in Winchester Granite on east side of Money Hill in Winchester (site 11228). Note the near absence of alkali feldspar as compared to the granite.





Zwgd2: Quartz diorite xenolith in Winchester Granite on east side of Money Hill in Winchester (site 11228; Zwgd). Plagioclase is heavily altered to sericite and scattered epidote. Note the scarcity of alkali feldspar as compared to other areas in the granite and slender euhedral sphene (titanite) crystals (arrows).

Zwgd3: Quartz diorite xenolith (Zwgd) in Winchester Granite on east side of Money Hill in Winchester (site 11228). Large tannish-brown crystals are partly altered hornblende. Note the unaltered rim on the altered plagioclase.



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) altered basalt (Fig. Znpm1), mafic breccias and conglomerates (Figs. Znpm2-3), basaltic tuff, and argillite to sandstone derived from basalt debris. The breccia, conglomerate and tuff units can have a lumpy outcrop surface but are often difficult to recognize in the field and are likely more widespread than where they were identified and sampled. Some breccias may be auto-brecciated basalt flows, and their matrices may have been either very fine basalt, basaltic glass, or palagonite prior to hydrothermal recrystallization and precipitation of epidote. The overall dark greenish-gray color of the formation results from various combinations of chlorite, actinolite, hornblende, and epidote (Fig. Znpm4). Although the formation has abundant altered basalt (keratophyre of Kaye, 1980), no lava flow or pillow structures have been found in this unit, and relict amygdaloidal or vesicular rocks have only been seen in breccia and conglomerate pebbles. Some of the basaltic rocks may be altered dikes with contacts that blend with the surrounding basaltic rocks. Recognition of primary structures and contacts between separate lithologies is difficult because: 1) shearing along faults imparts a wavy chlorite/actinolite foliation with epidote veins (Figs. Znpm5-7); 2) original bedding may have been obscured by mass flow in volcaniclastic units; 3) hydrothermal alteration has created epidote, oxides, quartz, and opal veins (Fig. Znpm4 and most other images have epidote); and 4) the unit occurs near plutons and dikes where contact metamorphism altered the rock's composition and sometimes imparted a foliation (Figs. Znpm8-10). This last situation is true throughout most of the unit, and especially from Sheepfold northward to Taylor Mountain where the Nanepashemet is in contact with the Stoneham Granodiorite (Zst), and across much of the northwest Fells where the unit contacts the Winchester Granite (Zwg).

In addition to massive altered basalt, basalt breccia, tuff and argillaceous hornfels, the unit has three unique lithologies among rocks in the Fells including: 1) a basal red to gray sandstone to mudstone with matrix- to clast-supported sandy breccia and conglomerate units with quartzite clasts (see below); 2) scattered clast-supported conglomerate and breccia beds with mafic volcanic pebbles (Figs. Znpm2-3). A notable location is at the northeast corner of Middle Reservoir beneath an unconformity with a younger volcanic flow in the Lynn Volcanic Complex (Zlvf) where baked conglomerate beds contain pebbles of basalt, vesicular basalt, dolerite, gabbro, and sparse felsic volcanic lithologies (Fig. Znpm11); and 3) a thin seam of marble (skarn) at the north end of Middle Reservoir (just west of baked conglomerate) that is interlayered with greenish-black hornfels (Fig. Znpm12) near a contact with the Winchester Granite (Zwg).

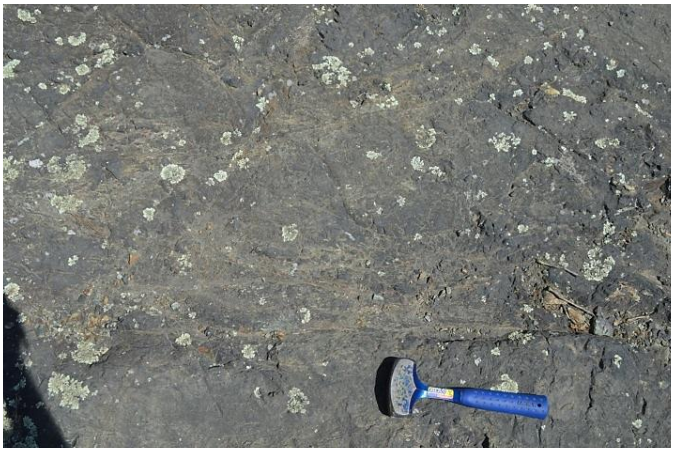
The Nanepashemet Formation is contact metamorphosed (Figs. Znpm4 and 8-10) near dolerite dikes and near its contacts with the Winchester Granite (Zwg) and Stoneham Granodiorite (Zst). It appears to form a thin roof over these plutonic bodies in many places. The unit has a generally low erosional resistance where it has not been baked but contact metamorphism increases its resistant. Later felsic intrusions have created plutonic breccias and numerous irregular felsic dikes in the formation (Fig. Znpm10; see also description of Stoneham Granodiorite, Zst). The alteration of large phenocrysts/ xenocrysts of pyroxene and tuff by contact metamorphism can cause the rock to weather with a honeycomb (alveolar) texture (Figs. Znpm13-14) that mimics coarse vesicles. Dark gray to black hornfels derived from dark basaltic argillite and fine basalt are difficult to distinguish in the field and mapping younger dolerite and basalt dikes is challenging, especially where dikes have melted the adjacent hornfels creating diffuse contacts.

Contact metamorphism next to the Stoneham Granodiorite in the Sheepfold and Winthrop Hill areas causes complete recrystallization to a rock with coarse hornblende and actinolite and formation of a contact parallel foliation produced by the stretching of the heated Nanepashemet Formation. This foliation can mimic sedimentary bedding (Znpm15).

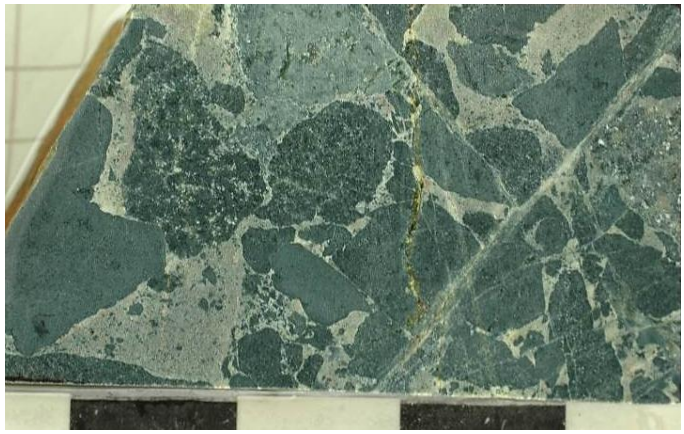
Bounding time relationships with surrounding units have been difficult to discern because major east-west trending faults and large intrusions alter, deform, and interrupt the formation. West of South and Middle Reservoirs and north of a fault along Molly's Spring Road, the Nanepashemet Formation unconformably truncates the regional metamorphic foliation of the Westboro Formation (Zvwq). The base of the Nanepashemet has gray to red sandstone to mudstone and breccia/conglomerate units with angular chunks of quartzite from the Westboro (Figs. Znpm16-18). Nearby are also partly melted and recrystallized inclusions of quartzite with opal veins (Fig. Znpm19) in altered basalt along its contact with a younger dolerite dike. Along Molly's Spring Road, well bedded red mudstone to reddish fine sandstone layers have been found in float boulders associated with the quartzite-bearing breccia and conglomerate beds (Fig. Znpm20).

Exposures of the top of the formation are also elusive because the unit is mostly terminated at east-west trending faults or interrupted by large intrusions (Stoneham Granodiorite and Winchester Granite). At the north end of Middle Reservoir, steeply foliated hornfels, altered basalt, and bedding of laminated fine hornfels layers in conglomerate beds (Fig. Znpm11) are truncated by gently dipping, banded rhyolite (Zlvf) in the Wakefield Formation of the Lynn Volcanic Complex, indicating an angular unconformity. Local float boulders of bedded siliceous mudstone hornfels are associated with the conglomerate (Fig. Znpm21).

The Nanepashemet Formation was defined as part of the Middlesex Fells Volcanic Complex (Bell and Alvord, 1976), which is here split into different formations (Wakefield Formation of Lynn Volcanic Complex and Nanepashemet Formation) that have an unconformable contact at the north end of Middle Reservoir. New radiometric ages support this new subdivision (see Reformulating the "Middlesex Fells Volcanic Complex" on p. 14-15). The Nanepashemet Formation is intruded by the Winchester Granite (Zwg) that has an age of 609-610 Ma (see Winchester Granite description), and it is unconformably overlain by banded rhyolite in the Wakefield Formation (Zlvf) that has a radiometric age of 594-595 Ma. Geochemical differences also suggest that basalt in the Lynn Volcanic Complex is separate from the Nanepashemet Formation, but this distinction is complicated by hydrothermal and contact metamorphic changes to the Nanepashemet (see the Wakefield Formation description on p. 112 and the previously mentioned text on p. 14-15).



Znpm1: Dark gray massive, altered basalt with epidote veins (steeply dipping, trending across image) on Nanepashemet Hill in Winchester (site 11078).

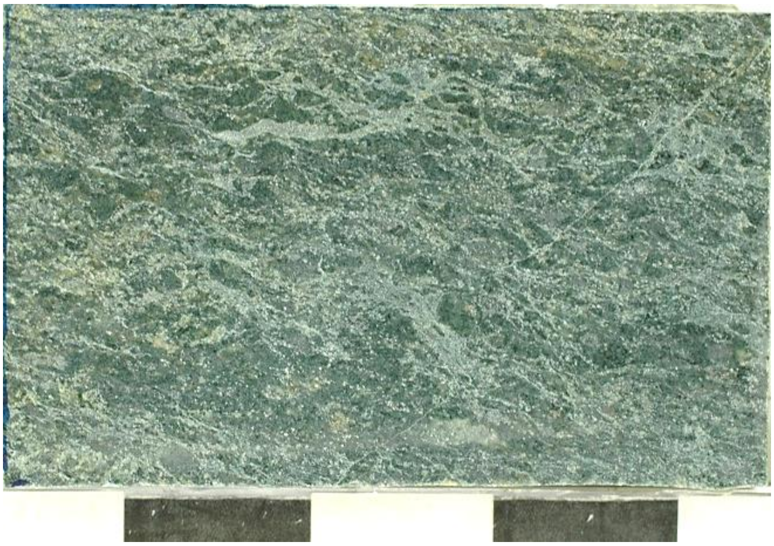


Znpm2: Breccia/conglomerate composed of altered basalt to gabbro pebbles near northeast corner of Middle Reservoir in Stoneham (site 11134).

Znpm3: Outcrop surface of breccia composed of altered basalt pebbles west of South Reservoir in Winchester (site 11110). This unit has epidote veins.

Znpm4: Epidote veins and pockets in highly altered basalt southeast of Quigley Hill in Winchester (site 11072).

Znpm5: Foliated and epidote-rich, chloritic basalt on east shore of Middle Reservoir in Stoneham (site 10881) north of the bounding fault at the upper surface of the Westboro Formation on the east side of Middle Reservoir. The rock here is also baked adjacent to an intrusion hidden beneath the reservoir.



Znpm6: Foliated (heavily sheared) chloritic basalt east of Middle Reservoir in Stoneham near a fault (site 10819, near outcrop in Fig. Znpm5).

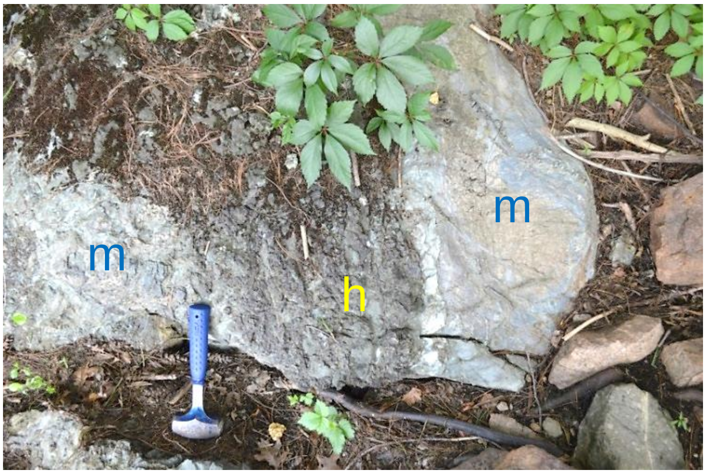
Znpm7: Foliated and baked basalt along a fault on west side of Bear Hill in Stoneham (site 11215).

Znpm8: Altered basalt (a) and more coarsely recrystallized basalt with porphyroblasts (b) on Winthrop Hill in Stoneham (site 11195).

Znpm9: Amphibolite formed by contact metamorphism of basalt adjacent to the Winchester Granite (Zwg) along the west shore of Middle Reservoir in Stoneham (site 11271).

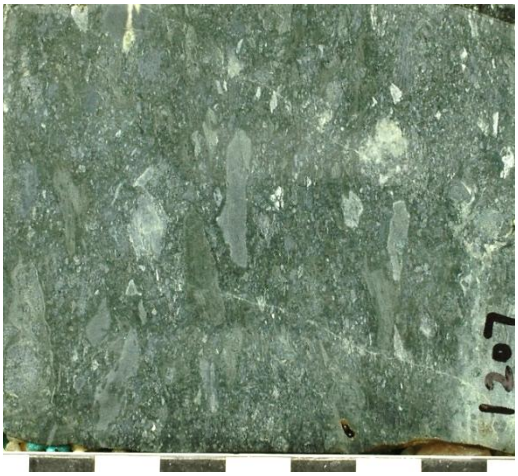
Znpm10: Tonalite dikelets and plutonic breccia in the Stoneham Granodiorite (Zst) truncating fractures in altered basalt on Winthrop Hill in Stoneham (site 11190). See also Stoneham Granodiorite description.

Znpm11: Conglomerate composed of mostly basalt to gabbro pebbles but also a few felsic volcanic pebbles (arrows) at north end of Middle Reservoir in Stoneham (site 11263). The matrix has abundant epidote.



Znpm12: Baked marble (m, skarn) interlayered with dark hornfels (h) at north end of Middle Reservoir in Stoneham (site 11140). This unit is near a contact with the Winchester Granite (Zwg).

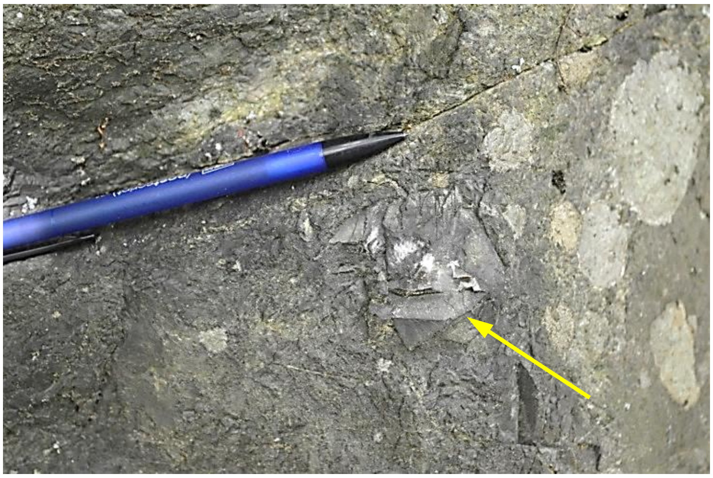
Znpm13: Altered basalt with alveolar weathering (not vesicles) on Nanepashemet Hill in Winchester (site 11114). Alteration is due to contact metamorphism.



Znpm14: Cut rock sample of altered basaltic tuff with aligned fragments that has alveolar weathering and altered pyroxene crystals on Taylor Mountain in Stoneham (site 11207).

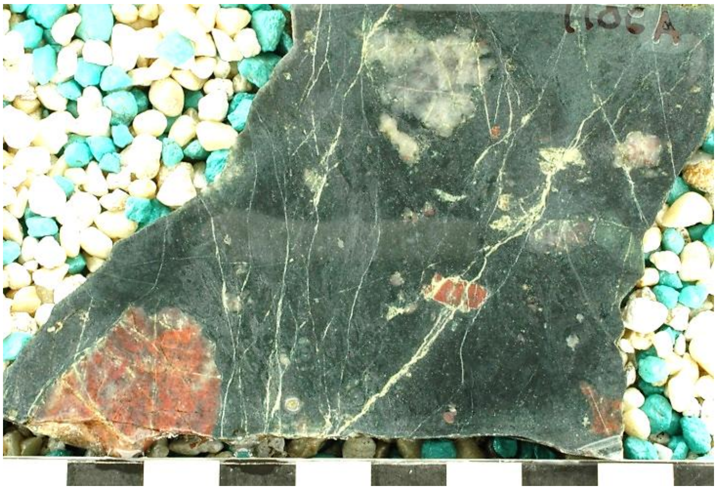
Znpm15: Foliated chlorite- and actinolite-rich altered basalt north of Sheepfold in Stoneham (site 11185). The basalt is heavily baked adjacent to the Stoneham Granodiorite (Zst). The foliation mimics sedimentary bedding.

Znpm16: Quartzite pebbles (arrows) from the Westboro Formation in the base of the Nanepashemet Formation west of South Reservoir in Medford (site 11271).

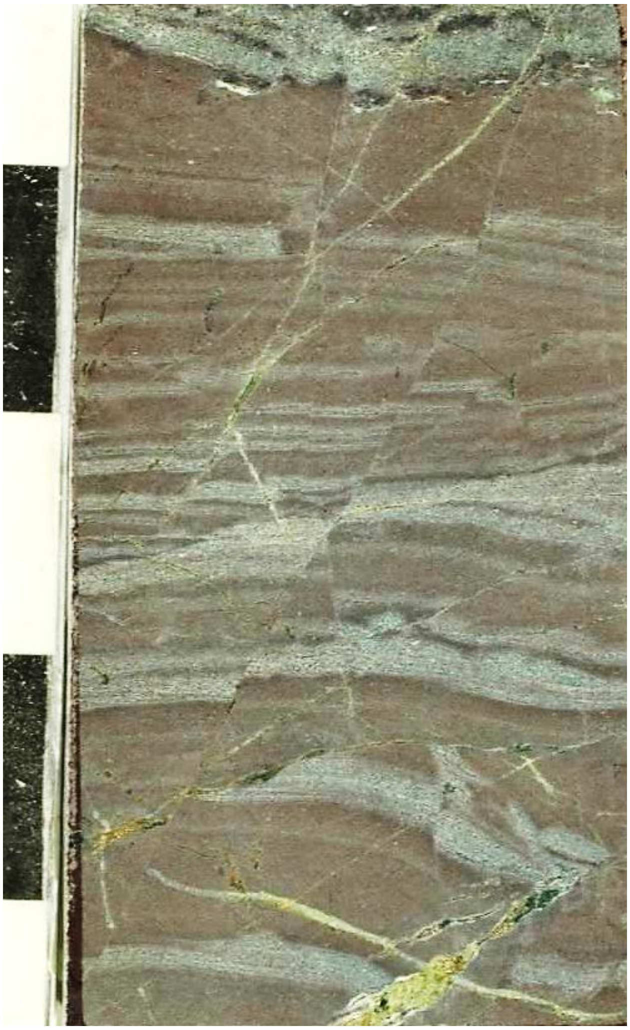


Znpm17: Angular quartzite pebble (arrow) from the Westboro Formation in reddish-gray coarse sandstone in the base of the Nanepashemet Fm. west of South Reservoir and north of Molly's Spring Road in Medford (site 11275).

Znpm18: Angular quartzite (from the Westboro Formation) and basalt clasts in breccia with reddish-gray sandy matrix in the base of the Nanepashemet Formation west of South Reservoir (site 11275).



Znpm19: Fragments of white and red jasper-like quartzite in altered basalt flow in the base of the Nanepashemet Formation north of Molly's Spring Road in Winchester (site 11106). The quartzite is recrystallized, and the rock has opal veins.



Znpm20: Laminated fine sandstone and red mudstone in float boulder from the base of the Nanepashemet Formation north of Molly's Spring Road in Medford (site 11068). At bottom is an epidote vein.

Znpm21: Weathered surface of bedded siliceous sandstone to shale hornfels in float boulder from the Nanepashemet Formation at the north end of Wanapanaquin Hill in Stoneham (site 11146). Dashed line indicates trace of bedding.

Nanepashemet Formation (cont.)

Thin section descriptions: Three things make it difficult to diagnose rock types in the Nanepashemet Formation: 1) the similarity of fine altered basalt and dark gray to black mudstone units, not only in the field but in thin section, 2) alteration and recrystallization along baked contacts with large plutonic bodies and dolerite dikes, and 3) shearing of the unit adjacent to faults. Alteration of the basaltic rocks by baking and hydrothermal fluids leads to the formation of amphibole, epidote and chlorite. Unless remnant detrital quartz grains (argillite/sandstone) or tabular plagioclase crystals and microlites (basalt) occur in the altered units, protoliths are difficult to discern. Distinction of basalt and sediment remains uncertain in some outcrops mapped in the Nanepashemet Formation.

The Nanepashemet has a few common lithologies that are described below.

Sandstone/mudstone and breccia/conglomerate at Molly's Spring Road and at the north end Middle Reservoir: Laminated red to gray sandstone (Fig. Znpm22) to dark to light gray siliceous mudstone that may have actinolite crystals when baked (Fig. Znpm23). Within these sedimentary units are breccia and conglomerate beds with mostly altered basalt to dolerite pebbles (Figs. Znpm24-25). The sandy conglomerate/breccia units near the base of the unit also have quartzite/metasiltstone pebbles from the Westboro Formation (Fig. Znpm26). In one place along Molly's Spring Road recrystallized and partly melted quartzite fragments occur as inclusions in very fine altered basalt (Fig. Znpm27) and the unit is crossed by quartz and opal veins (Fig. Znpm28).

Argillite: Argillite or mudstone hornfels that are not associated with coarser sedimentary rocks are securely identified when they have detrital quartz grains (Figs. Znpm29-31). Preserved bedding is rare when the rock is fine-grained and only occurs where it has not been deformed near faults or baked during contact metamorphism (Fig. Znpm32). Argillite has a dark green appearance in the field from abundant chlorite and actinolite.

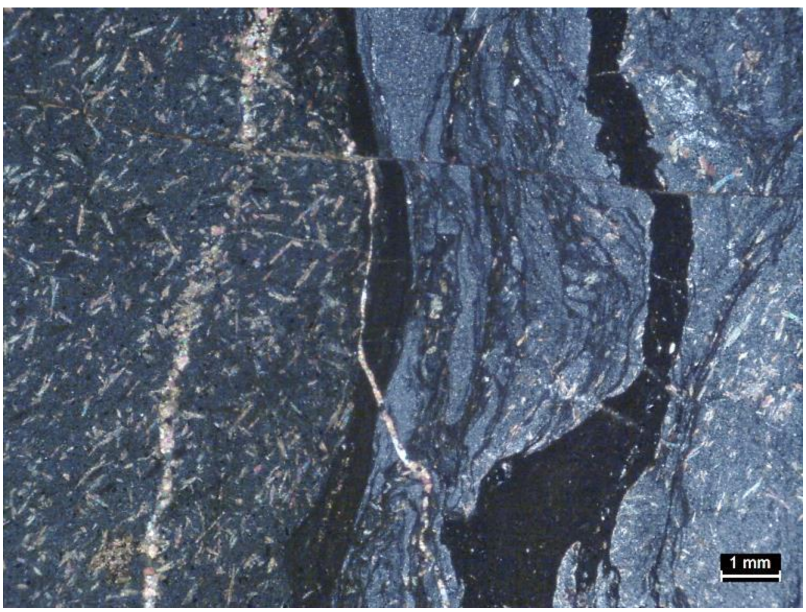
Altered basalt/dolerite: Basalt is safely identified by remnant euhedral plagioclase crystals, microlites, and phenocrysts (Fig. Znpm33-37). So far only one outcrop is known to have relict pyroxene, which is generally altered to actinolite and chlorite (Figs. Znpm33-39). Basalt usually has conspicuous epidote when altered (Fig. Znpm33). In one place on Nanepashemet Hill (Fig. Znpm13) the basalt has altered, but partly preserved, coarse clinopyroxene crystals (Fig. Znpm40) that cause the rock to weather with holes that resemble vesicles. Away from faults these units have not experienced shearing as might occur during regional metamorphism.

Basalt breccia and conglomerate units: Scattered through the Nanepashemet Formation within basaltic units are clast-supported to matrix-supported basalt breccia and conglomerate units. Pebbles in these units are altered basalt with microlites (Figs. Znpm41-42), amygdaloidal basalt with amygdules mostly filled by epidote (Fig. Znpm43), porphyritic basalt (Fig. Znpm44), and altered dolerite with actinolite and chlorite replacing clinopyroxene (Fig. Znpm42). The matrices in these rocks are rich in epidote and chlorite and may have been basaltic glass or palagonite before hydrothermal alteration and recrystallization.

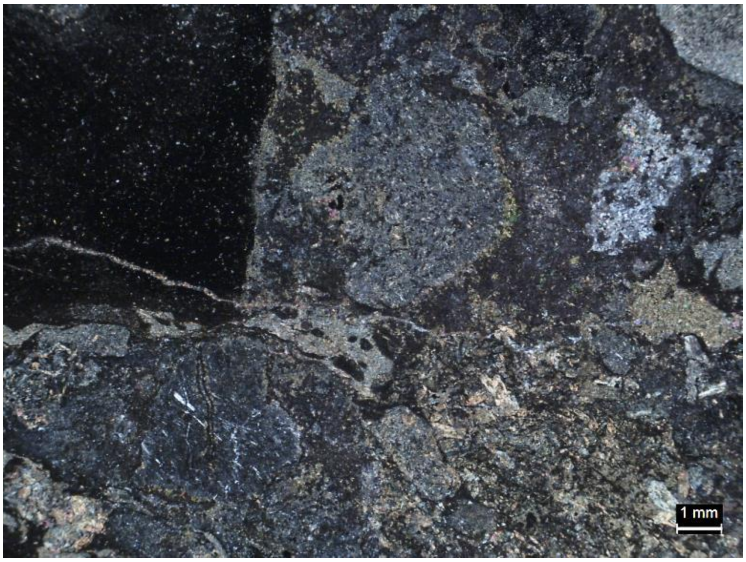
Contact metamorphism: As mentioned above, contact metamorphism alters all the lithologies above and can make them hard to distinguish. They all have a chemistry that leads to the formation of chlorite, actinolite, and hornblende depending on how extreme the alteration. Alteration of chloritic siltstone and fine sandstone often does not destroy all detrital grains, especially quartz, but at the same time there is recrystallization of matrix components to hornblende and actinolite (Figs. Znpm45-46). Contact metamorphism near the Stoneham Granodiorite often results in a foliation parallel to the contact (Figs. Znpm45 and 47), apparently formed as the injecting magma stretches the soft, heated country rock. Contact metamorphism of basalt leads to extreme alteration of plagioclase (Figs. Znpm36-39) and formation of actinolite and hornblende from original mafic minerals (clinopyroxene). In some cases, contact metamorphism of basalt leads to development of fine garnets and epidote in a rock dominated by actinolite and plagioclase (Fig. Znpm33) and a foliation that can resemble bedding in outcrops (Fig. Znpm48).

Shearing near faults: Shearing along faults at elevated temperatures, caused the development of foliation associated with recrystallization and segregation of epidote, actinolite and chlorite (Fig. Znpm49). Shear of breccia/conglomerate may result in a situation where pebble domains are deformed but still discernable (Figs. Znpm50-51).

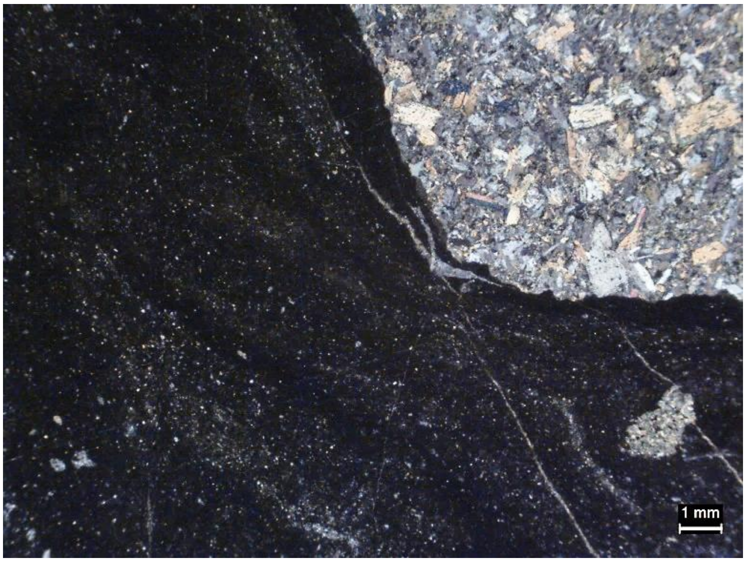
Znpm22: Laminated red sandstone to siltstone in the base of the Nanepashemet Formation along Molly's Spring Road in Medford (site 11068). See Fig. Znpm20 for hand sample view. Thin section in plane polarized light.



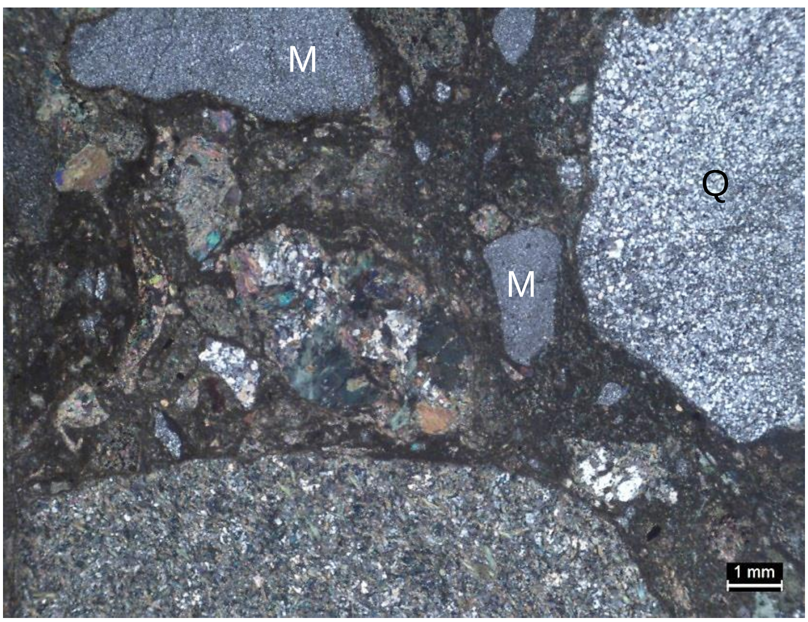
Znpm23: Baked laminated mudstone with actinolite crystals in the base of the Nanepashemet Formation at the northwest corner of South Reservoir (site 11330). Thin section in crossed polarizers.



Znpm24: Conglomerate with mafic pebbles in the base of the Nanepashemet Formation along Molly's Spring Road in Medford (site 11275). Mudstone matrix is dark area in upper left with fine detrital grains. Outcrop views are on Figs. Znpm17-18. Thin section in crossed polarizers.



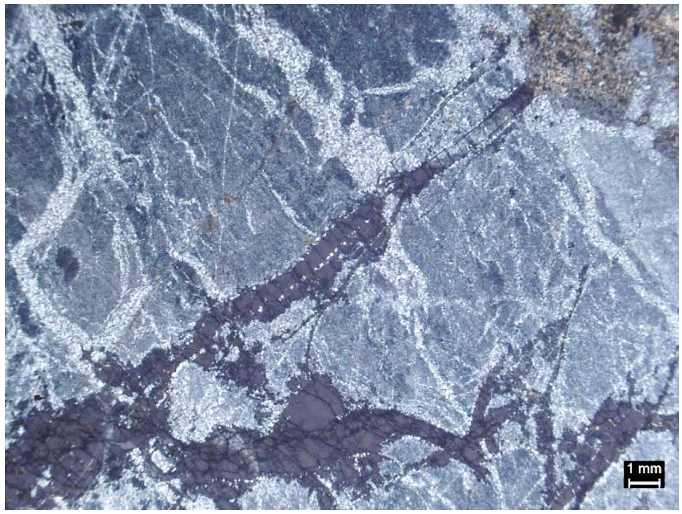
Znpm25: Mudstone (lower and left parts of image) with altered dolerite pebble (upper right) in the base of the Nanepashemet Formation along Molly's Spring Road in Medford (site 11277). Outcrop views are on Figs. Znpm17-18. Thin section in crossed polarizers.

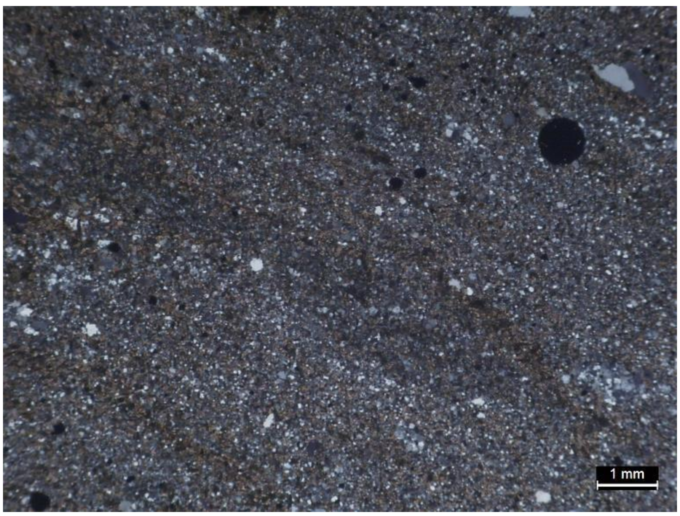


Znpm26: Conglomerate with mostly mafic pebbles (dolerite and basalt) but also quartzite (Q) and metasiltstone (M) pebbles from the Westboro Formation at the north end of Middle Reservoir in Stoneham (site 11263). See Fig. Znpm11 for outcrop view. Thin section in crossed polarizers.

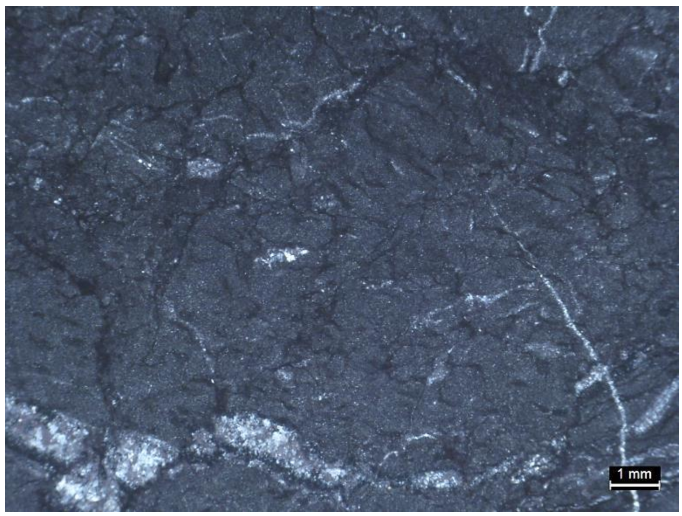
Znpm27: Very fine basalt enclosing recrystallized quartzite inclusions along Molly's Spring Road (site 11106). Colorful veins are epidote. See Fig. Znpm19 for hand sample view. Thin section in crossed polarizers.

Znpm28 (left below): Thin section in plane polarized light. (right below): Same view with crossed polarizers. Fractured metasiltstone crossed by opal vein (tan in plane light, very dark gray in crossed polarizers with crossing fractures) along Molly's Spring Road in Winchester (site 11106). Opal has high negative relief and crosses other veins. It was generated by contact metamorphism adjacent to a large dolerite dike. In upper right corner is epidote-rich matrix of the brecciated rock.

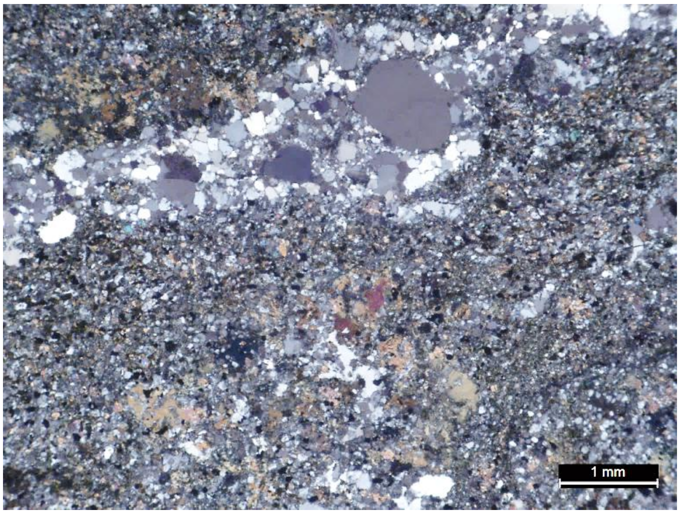




Znpm29: Fine sandstone to siltstone with clear detrital grains of quartz and mica alignment (biotite and chlorite, darker bands) west of Sheepfold in Stoneham (site 10884). Dark spot is pyrite framboid. Thin section in crossed polarizers.

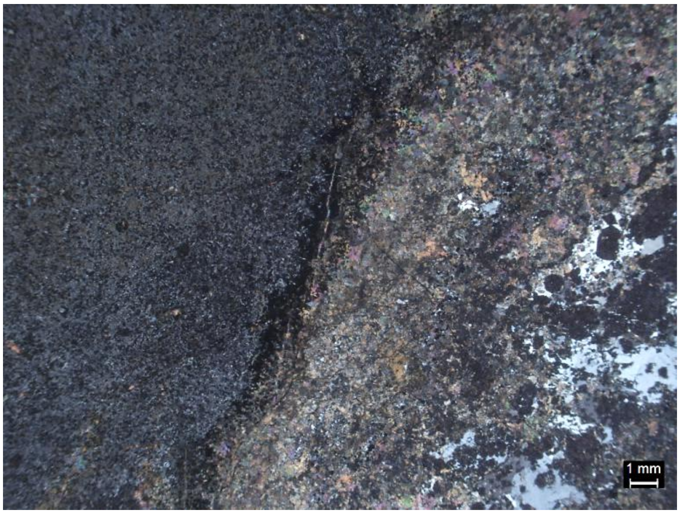


Znpm30: Argillite with occasional fine detrital grains along east side of South Border Road in Winchester (site 11051). Bedding is disrupted and rock is crossed by quartz veins. Thin section in crossed polarizers.

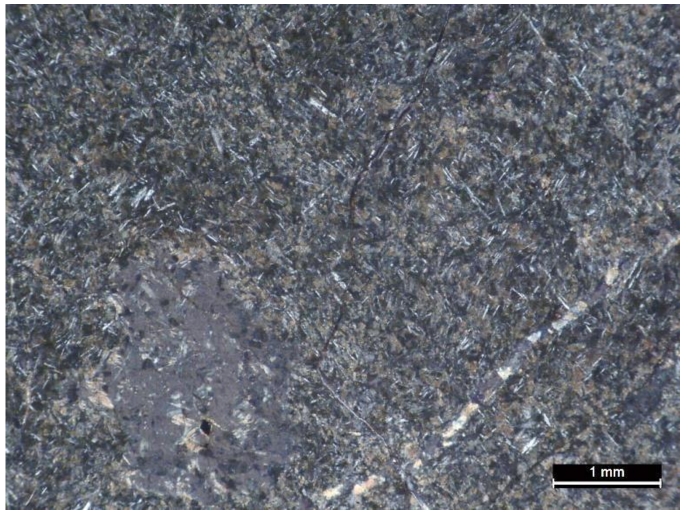


Znpm31: Fine sandstone with abundant detrital grains but also recrystallization of matrix minerals to actinolite and hornblende along west side of Rt. 28 north of Sheepfold in Stoneham (site 11164). Quartz has recrystallized to form a band across the upper image. Crossed polarizers.

Znpm32: Preservation of faint laminated bedding in argillite along South Border Road in Winchester (site 11054). Thin section in crossed polarizers.

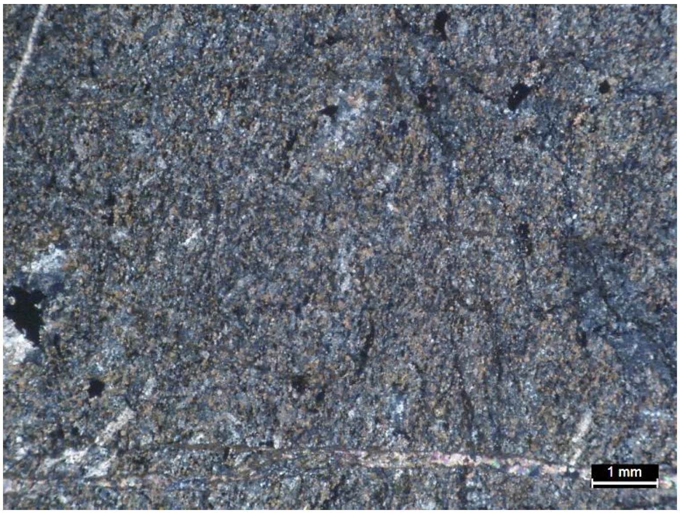


Znpm33: Altered contact zone of basalt near dolerite dike southeast of Quigley Hill in Winchester (site 11072). Basalt (left) has heavily altered plagioclase and pyroxene altered to actinolite while contact zone (right) has coarser actinolite, epidote, and garnets (black crystals) in quartz. See Fig. Znpm4 for outcrop view. Thin section in crossed polarizers.

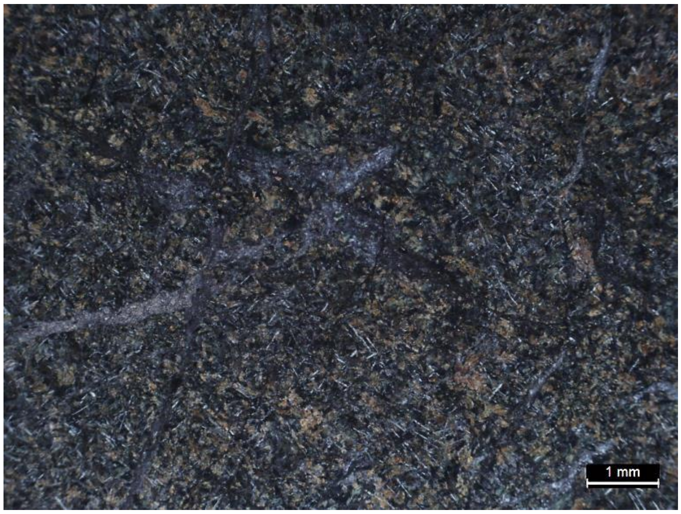


Znpm34 (above): Altered basalt with mostly pilotaxitic plagioclase and mafic minerals altered to actinolite and chlorite north of western arm of South Reservoir in Medford (site 11108). In lower left, coarse grain is altered plagioclase phenocryst. Thin section in crossed polarizers.

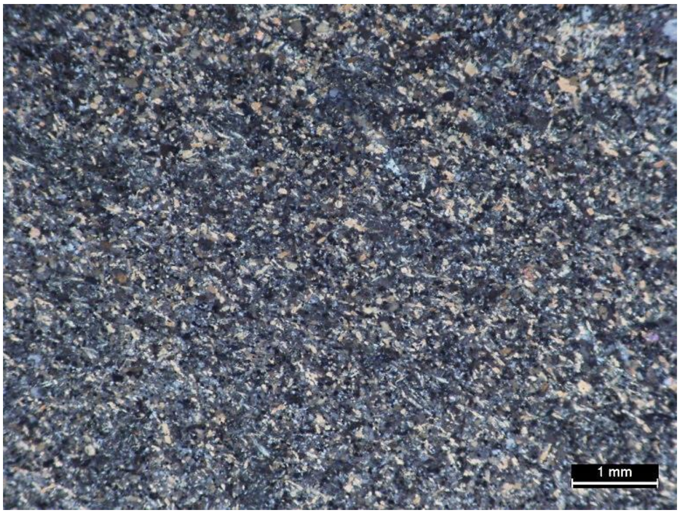
Znpm35: Basalt with microlites and cumulophyric plagioclase and mafic matrix minerals altered to actinolite on Nanepashemet Hill in Winchester (site 11109). Thin section in crossed polarizers.



Znpm36: Highly altered basalt with altered plagioclase blades and mafic matrix minerals altered to actinolite and chlorite just above contact with Westboro Formation at Sheepfold in Stoneham (site 11326). Thin section in crossed polarizers.



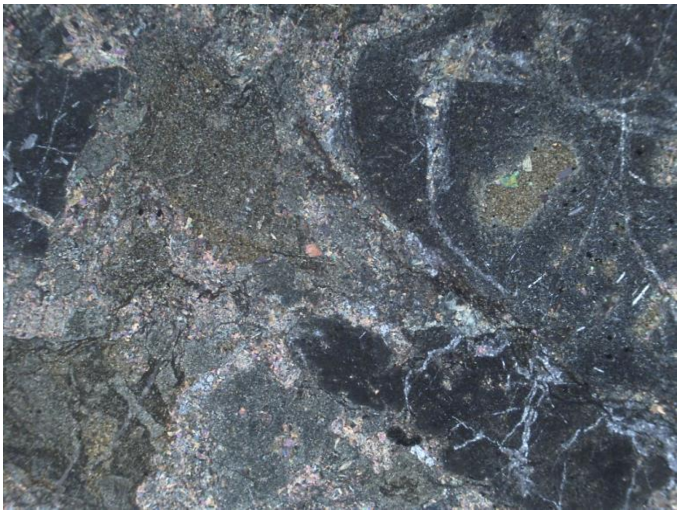
Znpm37: Highly altered basalt with pilotaxitic plagioclase microlites and mafic minerals altered to actinolite and chlorite north of Middle Reservoir in Stoneham (site 11135). Thin section in crossed polarizers.



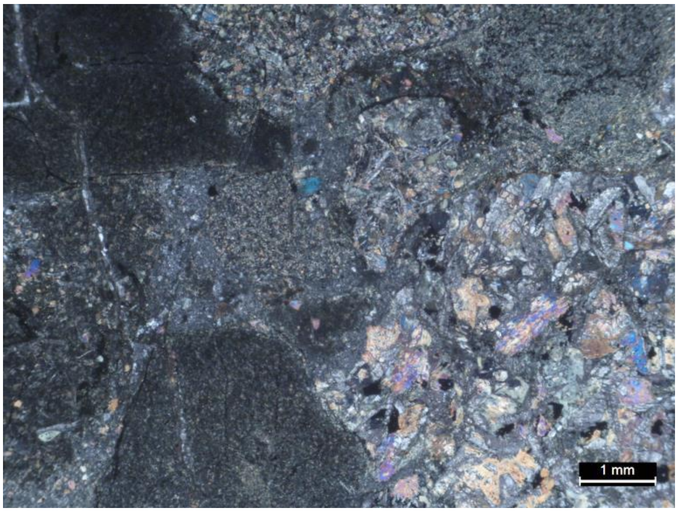
Znpm38: Basalt with fine plagioclase blades that are almost completely altered and mafic minerals altered to actinolite and chlorite on Winthrop Hill in Stoneham (site 11302). Thin section in crossed polarizers.

Znpm39: Basalt with recrystallized plagioclase and mafic minerals altered to mostly actinolite west of Sheepfold in Stoneham (site 11324). Thin section with crossed polarizers.

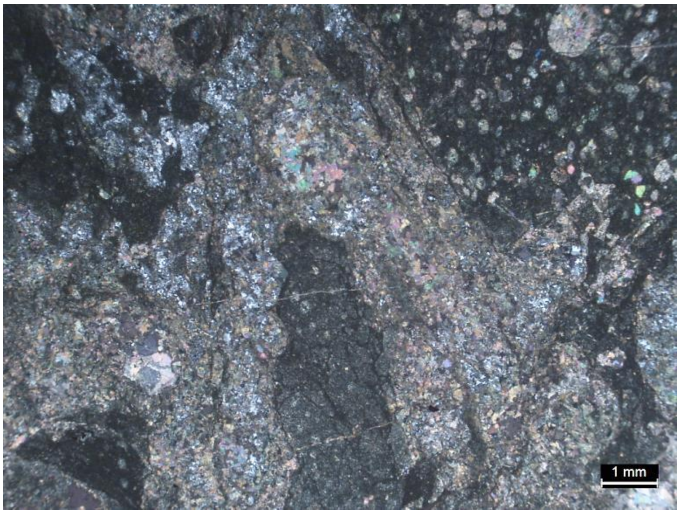
Znpm40: Basalt with groundmass mafic minerals altered to mostly actinolite on Taylor Mountain north of Dark Hollow pond in Stoneham (site 11207). Coarse crystals are partly altered clinopyroxene. See Fig. Znpm14 for cut rock view.



Znpm41: Volcaniclastic breccia with basalt fragments on Nanepashemet Hill in Winchester (site 11114). Clasts have plagioclase microlites and the matrix is mostly epidote and chlorite. See Fig. Znpm13 for outcrop view. Crossed polarizers.

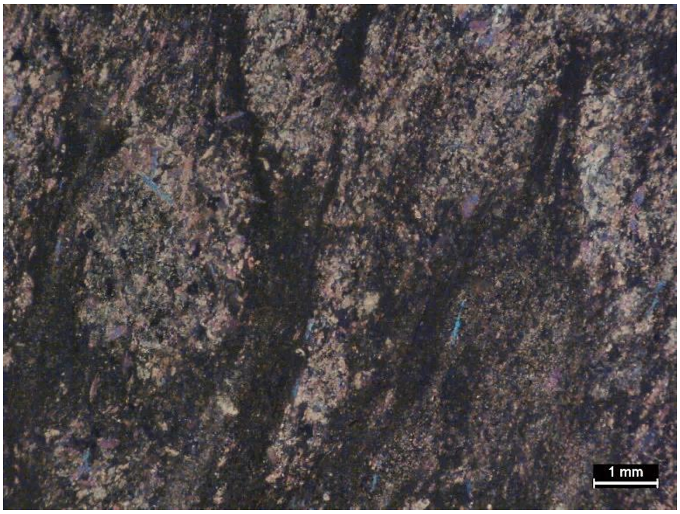


Znpm42: Volcaniclastic conglomerate with altered basalt and dolerite clasts near northeast corner of Middle Reservoir in Stoneham (site 11131). Dolerite clast in lower right has clinopyroxene replaced by actinolite. Fig. Znpm2 is a hand sample view of a similar rock.

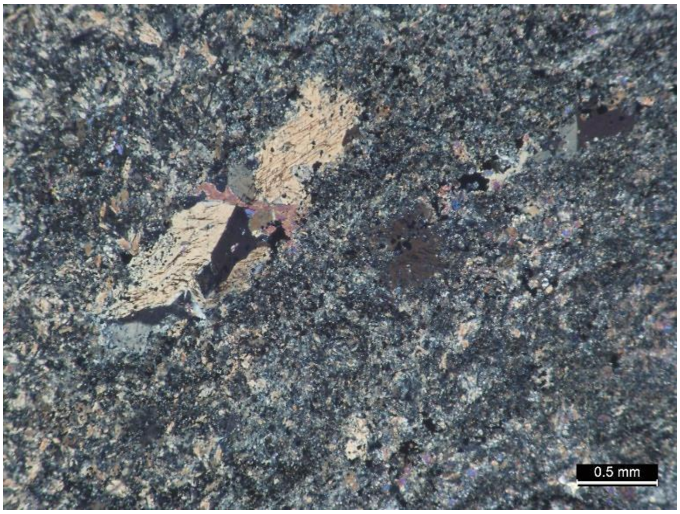


Znpm43: Highly altered volcanic conglomerate/breccia with amygdaloidal basalt clast (upper right) on Nanepashemet Hill in Winchester (site 11115). Amygdule filling is mostly epidote. The matrix is also rich in epidote. Crossed polarizers.

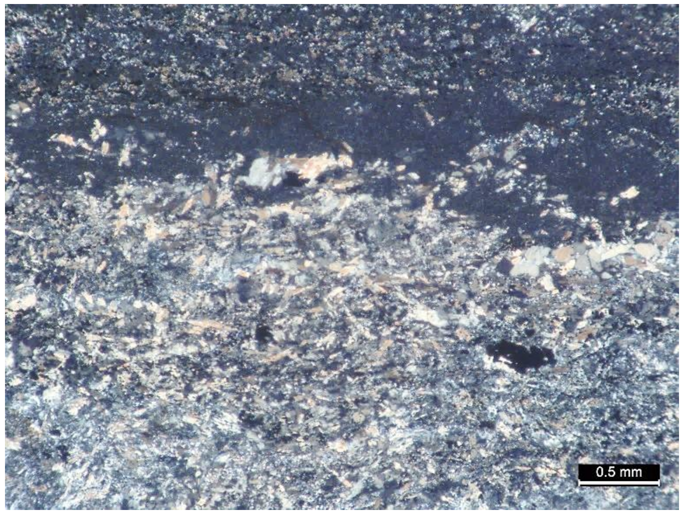
Znpm44: Highly altered volcaniclastic conglomerate/ breccia with porphyritic basalt clasts on Nanepashemet Hill in Winchester (site 11311). The matrix is rich in epidote and may have been palagonite prior to recrystallization. A similar rock is shown in outcrop in Fig. Znpm3. Thin section in crossed polarizers.



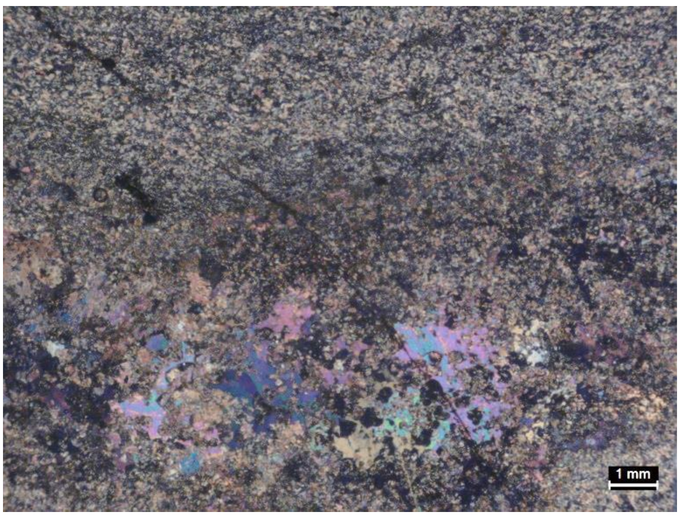
Znpm45: Highly altered argillite along contact with Stoneham Granodiorite (Zst) east of Sheepfold in Stoneham (site 11182). This rock has been recrystallized with bands rich in actinolite and chlorite. Thin section in crossed polarizers.



Znpm46: Argillite along contact with Stoneham Granodiorite (Zst) east of Sheepfold in Stoneham (site 11182). This rock has been recrystallized with hornblende (large crystals) and finer actinolite but still carries detrital quartz in fine areas. Thin section in crossed polarizers.



Znpm47: Foliated, highly contact metamorphosed argillite along contact with Stoneham Granodiorite (Zst) east of Sheepfold in Stoneham (site 11182). This rock has been recrystallized with segregation of hornblende, actinolite, chlorite and garnet (dark band) but still carries detrital quartz in fine areas. Thin section in crossed polarizers.



Znpm48: Foliated, highly contact metamorphosed basalt along contact with Stoneham Granodiorite (Zst) northeast of Sheepfold in Stoneham (site 11185). This rock has been recrystallized with segregation of actinolite, chlorite, and garnet (dark crystals) in epidote (colorful areas). For outcrop view with foliation resembling bedding see Fig. Znpm15. Thin section in crossed polarizers.

Znpm49: Foliated chloritic altered basalt with bands of varying concentrations of epidote (colorful grains), actinolite, chlorite and oxides (dark bands) west of Sheepfold near Middle Reservoir in Stoneham (site 10881). For outcrop view see Fig. Znpm5. Thin section in crossed polarizers.

Znpm50: Sheared volcaniclastic rock with flattened domains that were once pebbles. Rock occurs along a fault west of Middle Reservoir in Stoneham (site 11120). Matrix areas have fine actinolite and epidote. A hand specimen view is in Fig. Znpm51 below. Thin section in crossed polarizers.

Znpm51: Sheared volcaniclastic rock with domains that were once pebbles. Rock occurs along a fault west of Middle Reservoir in Stoneham (site 11120). Thin section view is in Fig. Znpm50 above.

Westboro Formation (for splitting of the Westboro Fm. see p. 19)

Zwp

Non-metamorphosed Westboro Formation at Whip Hill (Neoproterozoic) – Dark gray (7.5YR 3/0), well cemented, sometimes siliceous, laminated to thinly bedded, fine sandy mudstone and massive to faintly layered, muddy to sandy mass flow units. Mudstone units exhibit rusty yellowish-brown weathering (10YR 5/6; Fig. Zwp1-7). Muddy mass flow deposits (olistostromes) dominate the unit and range in thickness from a few centimeters to at least 20 m with massive mudstone, sheared laminated mudstone, mudstone breccia (Fig. Zwp5-6), and medium to light gray sandstone olistoliths. The olistoliths are dismembered and contorted with cusped edges from soft sediment deformation (Fig. Zwp7). Bailey (1984) and Bailey and others (1989) documented preserved bedding and sedimentary structures in this part of the Westboro Formation and identified it as an olistostrome.

When not rotated by mass movement, laminated bedding dips very steeply to the north to west and in some cases is slightly overturned. The unit has crosscutting beds (Fig. Zwp3-4), crosscut ripple crossbeds (Fig. Zwp5), and graded beds (Fig. Zwp2) indicating the orientation of the unit. Laminated mudstone and siltstone units have a well-defined anisotropy of magnetic susceptibility (AMS) foliation at a low angle to the plane of bedding (imbricated) but a weak lineation, consistent with a sedimentary fabric (Figs. Zwp8-9). In the Whip Hill area there is no evidence of penetrative regional metamorphism, but the units can be locally sheared near faults and are altered to hornfels near dolerite dikes and other intrusions (Fig. Zwp10). The Westboro at Whip Hill lacks calcium-magnesium silicate units seen in the regionally metamorphosed Westboro of Virginia Wood and west of Rt. 93.

The non-metamorphosed Westboro at Whip Hill is unconformably overlain by volcaniclastic conglomerate (Zlvc) in the Wakefield Formation of the Lynn Volcanic Complex at the northeast corner of Spot Pond next to the Stone Zoo. A tiny area of the unconformity is exposed in a fault slice on northern Whip Hill (see "*Enigmatic Westboro Fm./Lynn Volcanic Complex contact"* on p. 158) where the Westboro is overlain by crystal tuff in the Wakefield. Further south near Wamoset Hill the non-metamorphosed Westboro is bounded on the south by a fault separating it from the Lynn Volcanic Complex (Zlvx) in another fault block. Mapping of the unit described above as part of the Westboro by previous workers (LaForge, 1932; Bell and Alvord, 1976; Kaye, 1980; Bailey, 1984; Bailey and others, 1989) did not recognize the extent of the east-west trending section of Lynn (Wakefield) volcanic rocks that separate areas of the Westboro at Whip Hill from the Westboro in Virginia Wood. The description of the Westboro by Bell and Alvord (1976) does not include units like described above and implies regional metamorphism throughout the Westboro.

U-Pb ages (LA-ICPMS) were determined for 210 zircon grains from a quartz sandstone olistolith on Whip Hill (site 11355). The zircon ages for the formation indicate a maximum age of about 910 Ma (Fig. Zwp11). One zircon crystal younger than this in the sample (813 Ma) appears to be anomalous with very high uranium (1650 ppm) and is thought to have experienced lead loss that invalidates its age. This zircon age distribution is identical to the distribution for zircon crystals in other parts of the Westboro Formation near Breakheart Reservation in Saugus (Thompson and others, 2012) and along Pond Street south of the Stone Zoo (Francis MacDonald, pers. comm.).

Zwp1: Laminated tannish-gray weathering fine sandstone and siltstone to gray mudstone at the north end of Whip Hill in Stoneham (site 10386).

Zwp2: View of cut rock with laminated mudstone to fine sandstone southeast of Whip Hill in Stoneham (site 10359). Micro-graded beds indicate up is to the right. Fractures are lighter in color due to weathering.

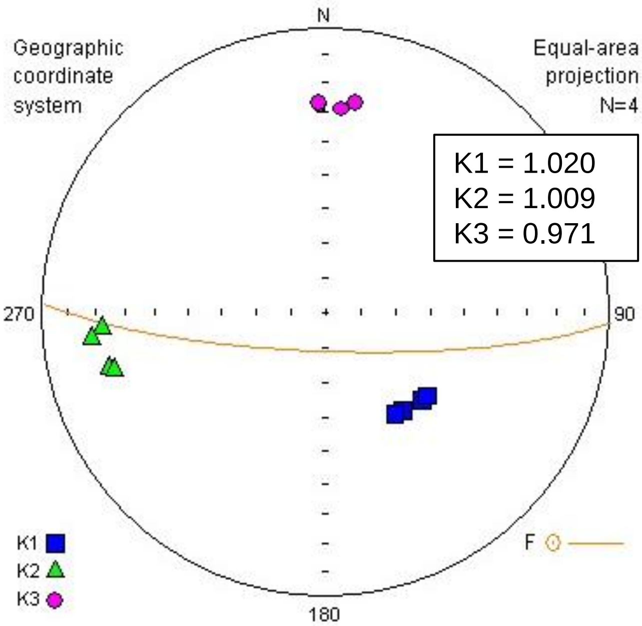
Zwp3: Laminated fine sandstone to siltstone with crosscutting layers (site 11312) in Whip Hill Park. Up is toward top of image and to north. Pencils and lines indicate bedding.

Zwp4: Rusty weathering, laminated fine sandstone on the north end of Whip Hill in Stoneham (site 10583). In the center of this view one set of laminated beds is truncating a second set (arrow points to surface) and the beds are being viewed upside down with the bottom of the image (up) to the north.

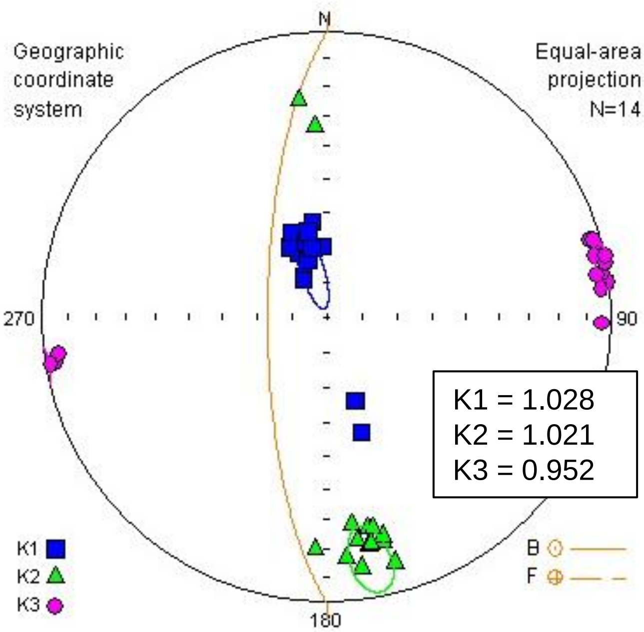
Zwp5: Ripple crossbeds with tangential bottoms and truncation above by laminated flat beds (center of image) in muddy fine sandstone west of Whip Hill in Stoneham (site 10762). Crossbeds are shown right side up. Northwest is toward top of image (up). Pen sits at top of thin mass flow unit. Note mudstone breccia (b).

Zwp6: Mudstone breccia in mass flow unit on western hilltop in Whip Hill Park in Stoneham (site 11314).

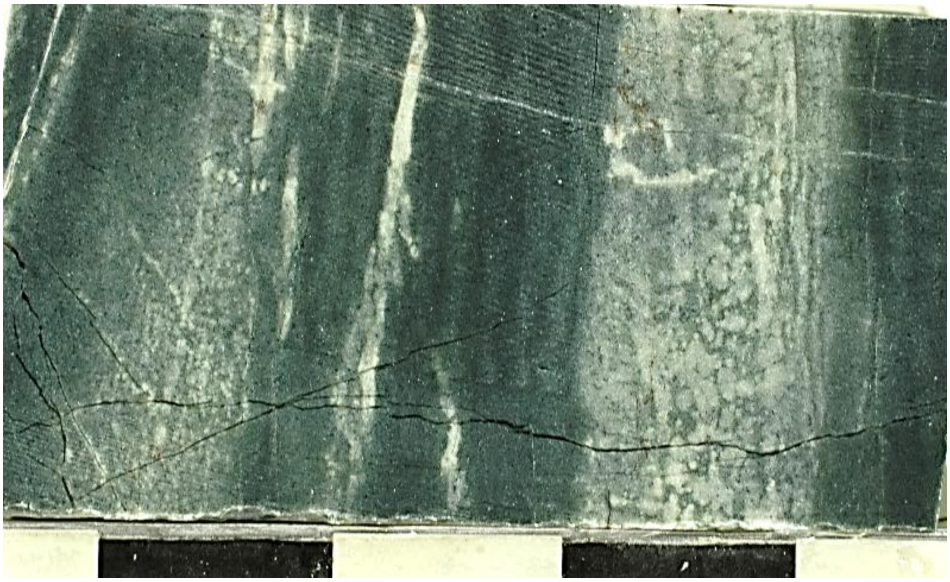
Zwp7: Dismembered light gray quartz sandstone olistoliths in massive muddy fine sandstone to mudstone on Whip Hill in Stoneham (site 10381). Whole view is within a single mass flow unit. Above arrow sandstone mass has pinched ends and cusps indicating that it was soft when emplaced in the flow unit. West is toward bottom of image.



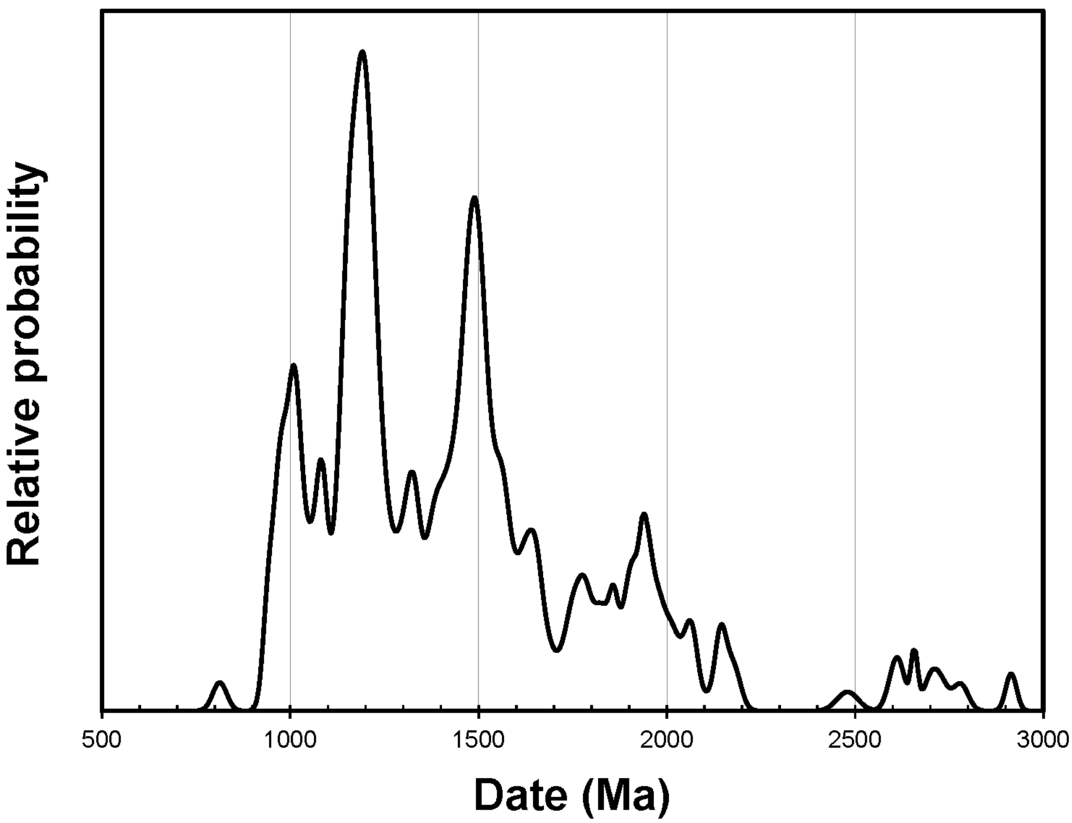
Zwp8: Anisotropy of magnetic susceptibility (AMS) measurements (n=4) for laminated siltstone and mudstone southeast of Whip Hill in Stoneham (site 10359, see Figs. Zwp2 and 12). Points are axes of susceptibility ellipsoid: K1 = maximum , K2 = intermediate, and K3 = minimum. Also plotted is a field measurement of bedding as a brown great circle oriented with a strike of S86°E and dip of 80° SW. Bedding is slightly overturned and up is to the north. The magnetic foliation (plane of K1 and K2; strike S87°E, dip 61°S) falls near the bedding plane. The stereo plot shows a lineation (K1) that is dipping SE at 54° and is imbricated slightly from bedding suggesting a sedimentary origin for the magnetic fabric. Note also that the K axes are tightly clustered and not dispersed on the magnetic foliation plane but the K1 and K2 magnitudes are similar and depict a weak lineation. From unpublished senior thesis by Katherine Lowe at Tufts University (2014).



Zwp9: Anisotropy of magnetic susceptibility (AMS) measurements (n=14) for laminated siltstone and mudstone at the north end of Whip Hill in Stoneham (site 10386, see Fig. Zwp1). Units here dip to west. Points are axes of susceptibility ellipsoid: K1 = maximum , K2 = intermediate, and K3 = minimum. Also plotted is a field measurement of bedding as a brown great circle oriented with a strike due S and dip of 73°W. Top is to the west on the plot. The magnetic foliation (plane of K1 and K2; strike S11°E, dip 83°SW) falls near the bedding plane. The stereo plot shows a magnetic lineation dipping NNW at 75° and slightly imbricated to bedding suggesting a sedimentary origin for the magnetic fabric. Note also that K axes are tightly clustered and not dispersed on the magnetic foliation but the K1 and K2 magnitudes are similar and indicate a weak lineation. From unpublished senior thesis by Katherine Lowe at Tufts University (2014).



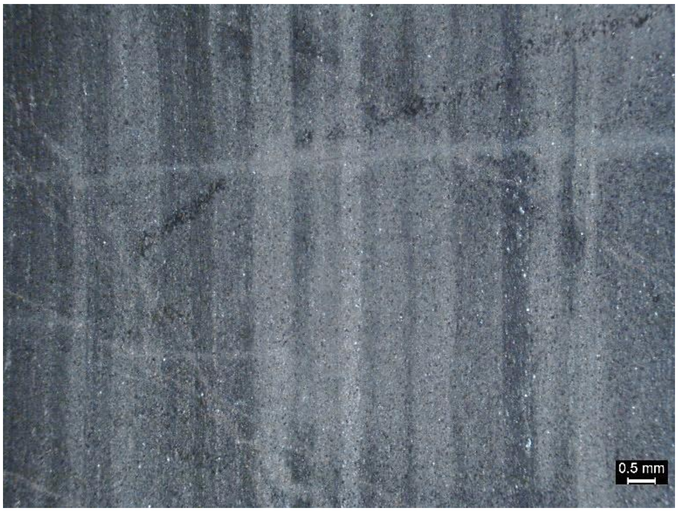
Zwp10: Fine sandstone to mudstone hornfels adjacent to dolerite dikes and Stoneham Granodiorite west of the Stone Zoo and along the east side of Spot Pond in Stoneham (site 11242).



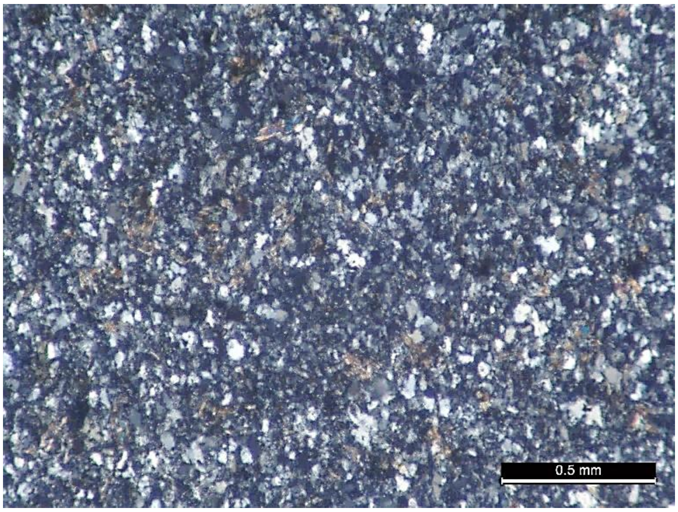
Zwp11: Probability distribution for U-Pb ages of 210 zircon grains (LA-ICPMS) on Whip Hill in Stoneham (site 11355). The grain at 813 Ma is anomalous due to a very high uranium content (1650 ppb).

Westboro Formation – Whip Hill area (cont.)

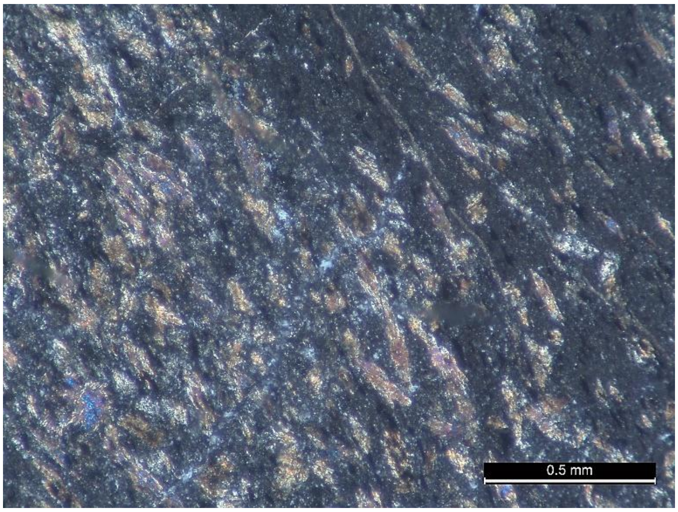
Thin section description (All images are thin sections with crossed polarizers) – Lithologies vary in this formation from fine mudstone to medium quartz-rich sandstone. Mudstone to siltstone units are often laminated and have very fine quartz grains (Fig. Zwp2, 12-13). Matrices are easily altered along faults and adjacent to dikes with the growth of chlorite, actinolite blades, epidote, and veins of zoisite (Figs. Zwp14-15) and silicification (Fig. Zwp10). Sandstone units are generally poorly to moderately sorted with very round grains and minor suturing (Figs. Zwp16-17). Only occasionally are sandstone beds well sorted Fig. Zwp18). The lack of sutured, flattened, and polycrystalline grains separates it from the Westboro Formation in Virginia Wood where the unit is regionally metamorphosed. The Whip Hill section of the Westboro is only sheared along faults. Occasionally there are detrital zircon grains visible in thin sections of sandstone (Fig. Zwp17).



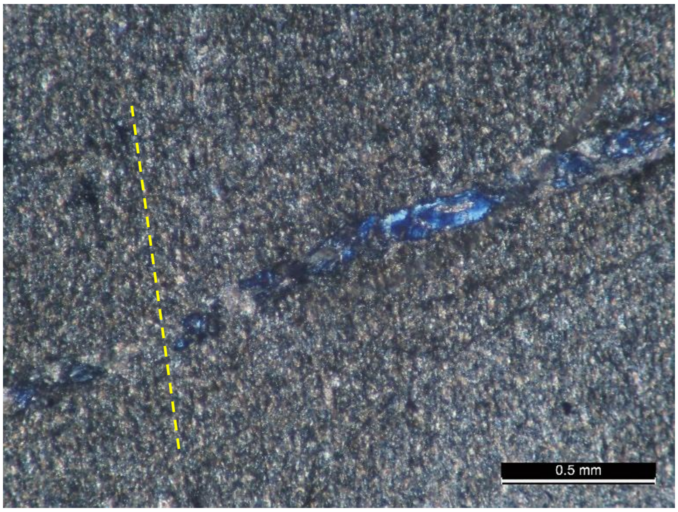
Zwp12 (left): Laminated siltstone to fine sandstone with isolated fine quartz grains (tiny white specks) southeast of Whip Hill in Stoneham (see Fig. Zwp2 for cut rock view; site 10359). Dark areas are richer in chlorite. Bedding is vertical in image and up to left.



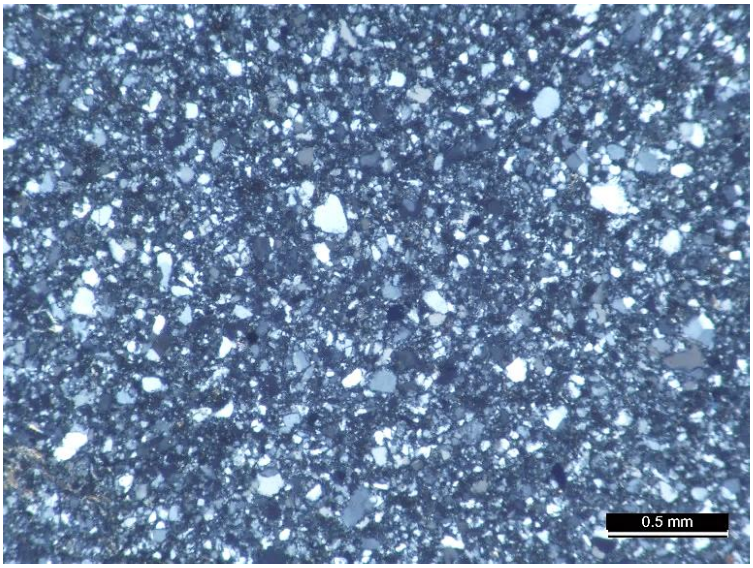
Zwp13 (right): Laminated siltstone to fine sandstone with dominantly quartz grains in a matrix of actinolite, chlorite, and minor sericite at the southern end of Whip Hill in Stoneham (site 597BN). Dark areas are richer in chlorite.



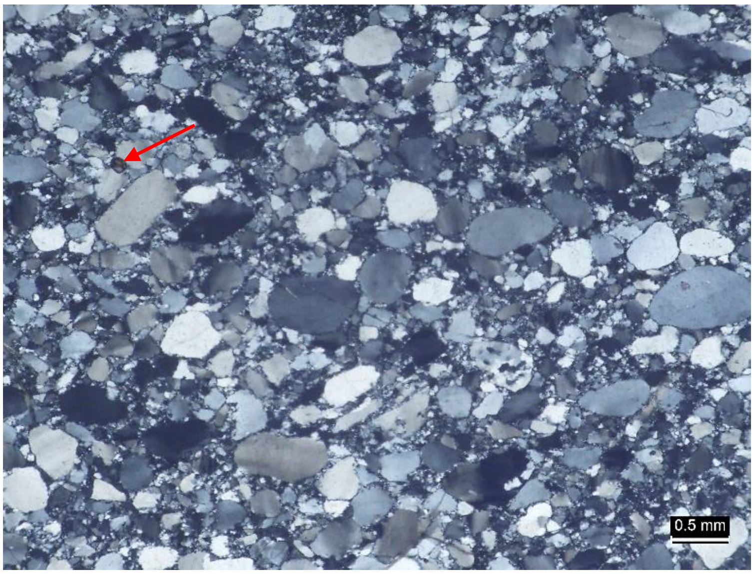
Zwp14 (left): Mudstone to siltstone with actinolite blades and chlorite next to dolerite dike west of Whip Hill in Stoneham (site 10763). Dark area to right is richer in chlorite. Bedding runs from upper left to lower right following alignment of actinolite blades that are a product of contact metamorphism.



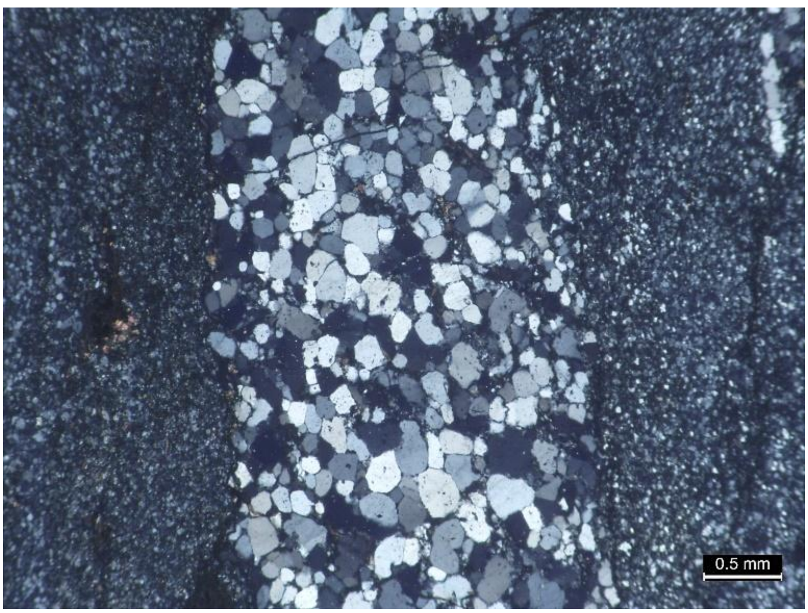
Zwp15 (right): Heavily baked siltstone (hornfels) with quartz grains and fine matrix altered to actinolite west of Stone Zoo along Spot Pond in Stoneham (site 11242). Original bedding is vertical on image (dashed line). Blue colored vein is zoisite. See Fig. Zwp10 for view of cut rock.



Zwp16: Poorly sorted fine sandstone east of Greenwood Park in Stoneham (site 10569). This lithology is dominated by quartz grains that can be highly rounded and are barely sutured at grain contacts. Between the sand grains is a small amount of sericite and chlorite but mostly fine particulate quartz.



Zwp17: Moderately sorted medium sandstone in the DCR maintenance yard west of Whip Hill in Stoneham (site 10764). Sandstone has dominantly rounded quartz grains. The quartz grains are barely sutured and have faint undulatory extinction but are not flattened or polycrystalline. The arrow points to a detrital zircon grain.



Zwp18: Well sorted and rounded quartz sandstone bed (bedding vertical in image) just above fault contact with the Lynn Volcanic Complex (Zlvx) at the south end of Whip Hill in Stoneham (site 10573). Surrounding the sandstone bed is fine sandstone to siltstone. The quartz grains are rounded and lightly sutured but not polycrystalline. Between the sand grains are silt grains and minor chlorite and sericite.

Zvwq

Westboro Formation in Virginia Wood (Neoproterozoic, Tonian?) – Dark gray (7.5YR 4-5/0), rusty weathering argillite to metasiltstone, and white to light gray (7.5 YR 8-7/0), thinly bedded to massive, fine to medium quartzite (Fig. Zvw1-5). Quartzite appears to dominate outcrops in many places, but argillaceous units are not as well exposed and overall make up most of the formation. The argillaceous units have a layer-parallel cleavage (Fig. Zvw2). Traces of the remnants of sedimentary layering appear in many places especially west of Rt. 93. Recrystallized and deformed calcium/magnesium-silicate layers with tremolite, diopside, and zoisite plus lesser calcite occur on Pond Street, in Virginia Wood, and west of the southern arm of South Reservoir (Figs. Zvw4-8). In Virginia Wood, thick and massive, very light gray to white layers are composed of mostly tremolite with quartz grains (Figs. Zvw9-10). The Ca/Mg units were likely dolomitic sandstone to mudstone prior to regional metamorphism. The best continuous outcrop of the Westboro in the Fells occurs along Pond Street on the west shore of Spot Pond (Fig. Zvw11) and has all the lithologies described above.

Abundant slab-like quartzite/argillite hornfels xenoliths of the Westboro up to 150 m long are mapped in the Spot Pond Granodiorite (Zsg) and smaller xenoliths occur in the Winchester Granite (Zwg), Rams Head Porphyry (Zrhp), and Stoneham Granodiorite (Zst). The Stoneham Granodiorite has very abundant small xenoliths from the Westboro along the southeast shore of Deer Hill and along Rt. 93 (see Stoneham Granodiorite description, Figs. Zst11-12). Argillite in the Westboro is baked to hornfels in xenoliths and adjacent to plutonic bodies. The argillite hornfels generally has actinolite and chlorite, while baked quartzite has biotite and chlorite (see thin section descriptions).

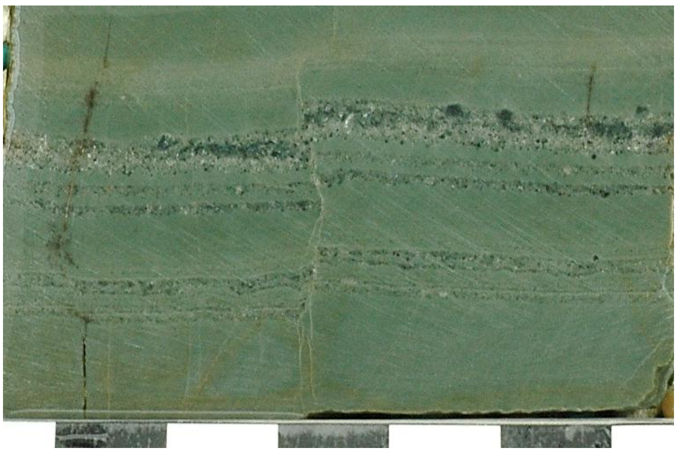
Overall, the Westboro Formation in the Virginia Wood area has low-grade regional metamorphism not seen in any other unit in the Fells. There is a consistent W to SW striking foliation that dips to the N to NW except where this trend is reoriented along faults or slightly overturned. Metamorphic foliation is generally parallel to layering, which is relict bedding preserved to varying degrees. Thick quartzite layers maybe massive and brittley dismembered (Fig. Zvw1) while thinner beds within argillaceous units are flattened and folded with cleavage development. Some units were ductile and formed boudins of quartzite or Ca/Mg-silicate minerals (Figs. Zvw4-5, 8, and 12-13). Quartzite units have stretched/flattened, polycrystalline, and heavily sutured and serrated quartz grains (Fig. Zvw14; see also thin sections below) with minor mica tails and shadows. The unit can be mylonitic in places, especially near faults and in Ca/Mg units in Virginia Wood, which gives the rock a banded or streaked appearance (Fig. Zvw4-8,15-19). White bands formed in the unit are rich in tremolite (Figs. Zw4-10, 13, 15 and 17-19). Small drag folds occur along Pond Street and in Virginia Wood (Figs. Zvw5 and 17-18), west and south of South Reservoir (Fig. Zvw19), in Winchester (Fig. Zvw20), and in quartzite xenoliths (Fig. Zvw21). They may be more abundant than were observed but are hard to recognize in the field. The sense of shear indicated by folds is for SE translation of layers upward over layers below on the NW dipping plane of foliation on Pond Street (Fig. Zvw5 and 18). Anisotropy of magnetic susceptibility measurements (Fig. Zvw22-23) define a consistent magnetic foliation in agreement with field foliation measurements and a weak magnetic lineation indicating only minor stretching associated with flattening, but the lineation is consistent with the direction of overturning of drag folds.

The lowest parts of the Westboro south of Ravine Road are either hidden beneath an unconformity or are in fault contact with the Boojum Rock Tuff that carries quartzite lithic fragments. The contact in this area is mostly concealed by glacial sediment. From Spot Pond to the area east of Medford High School the unit is truncated by plutonic intrusions. East of Spot Pond at Wamoset Hill the Lynn Volcanic Complex (Zlvc) unconformably overlies the Westboro. West of Spot Pond the unit is truncated above at an unconformity cutting across a thick (2-3 m) quartzite layer beneath the Nanepashemet Formation (Znpm). The unconformity is exposed on the north side of the southern parking lot at Sheepfold (Fig. Zvw24). West of Sheepfold and east of Middle Reservoir the unit is truncated along a fault overlain to the north by bluish-green (5G-BG 4/1-2), chloritic, altered basalt of the Nanepashemet Formation (see Figs. Znpm5-6). West of South Reservoir at Molly's Spring Road, sedimentary units in the base of the Nanepashemet Formation (see Znpm description) truncate foliation in the Westboro along an unconformity. In Malden and Melrose at Pine Banks Park the Westboro is unconformably overlain by the Boojum Rock Tuff of the Lynn Volcanic Complex (see description of Boojum Rock Tuff) and is unconformably overlain by the Wakefield Formation on Wamoset Hill. The top of the unit is also truncated in some areas by major faults and intrusions (Winchester Granite, Zwg and Stoneham Granodiorite, Zst).

The Westboro Formation in the Fells was previously mapped with the Whip Hill and Virginia Wood areas combined as the Westboro Quartzite by LaForge (1932) as originally defined by Emerson (1917) without recognition of the intervening Lynn Volcanic Complex (Wakefield Formation) in the Whip and Wamoset Hill areas. Kaye (1980) also did not recognize the full separation of the Whip Hill and Virginia Wood areas of the Westboro by the intervening volcanic units. 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 Ca-Mg silicate zones and a lower metamorphic grade. The metamorphic grade in the Fells is still above that of any other unit in the Fells. U-Pb ages for detrital zircon crystals in this unit have yielded a youngest age of 909 +/-24 Ma (LA-ICPMS; F. MacDonald, pers. comm.) that matches the Westboro Fm. further east at 912.2 +/-0.6 Ma (CA-ID-TIMS; F. MacDonald, pers. comm.) and the results of Thompson and others (2012). The zircon age probability distribution is also consistent with the new probability distribution for the Westboro in the Whip Hill area (see previous unit above). These ages constrain the age of the Westboro to younger than about ~910 Ma, likely making it from the Tonian (first period of the Neoproterozoic).

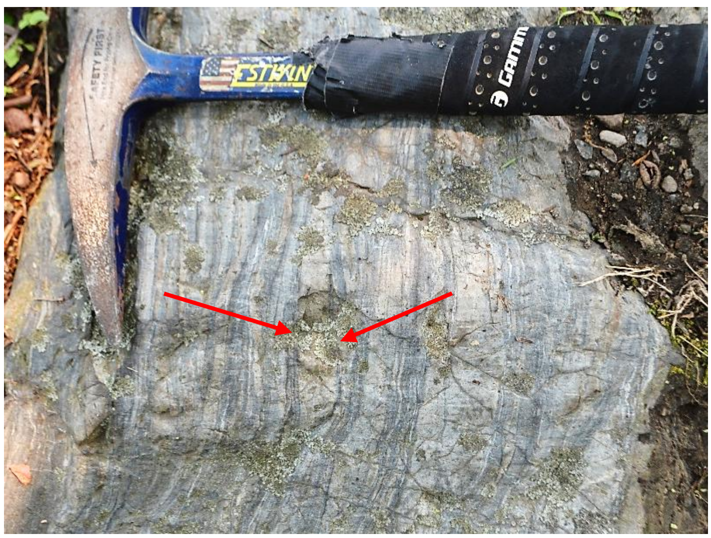
Zvw1: Interlayered argillite and white quartzite layers with stretched original bedding, bedding parallel foliation, and dismembered quartzite units on Gerry Hill in Medford (site 10812).

Zvw2: Interlayered thin argillite and white quartzite layers with stretched original bedding, bedding parallel foliation, and dismembered quartzite units on Gerry Hill in Medford (site 11379). Pencil for scale. See later discussion of magnetic susceptibility results.



Zvw3: Interlayered argillite and thin sandstone beds with little stretching of original bedding where the unit is highly silicified in Pine Banks Park in Melrose (site 11452). This rock is also unusual because of its very angular grains (see later thin section image). The green color is from chlorite. Silicification is also discussed with the Boojum Rock Tuff at this site.

Zvw4: Interlayered and highly deformed argillite and quartzite with Ca-Mg silicate layers at corner of Alden Rd. and Standish Lane in Winchester (site 11582). Note quartzite-rich boudin within CA-Mg silicate layers (between arrows).



Zvw5: Interlayered and highly deformed argillite, calcium-magnesium silicate, and white quartzite boudin layers with folds (arrow) along Pond Street in Virginia Wood in Stoneham (site 10316).

Zvw6: Interlayered argillite and quartzite layers with tannish-white layers rich in tremolite. These layers are discontinuous and deformed in Virginia Wood along Spot Pond Brook in Stoneham (site 10298).

Zvw7: Crosscutting joints forming a blocky outcrop in layered and sheared argillite and quartzite with tremolite-rich layers in Virginia Wood along Spot Pond Brook in Stoneham (site 10298). At same outcrop as shown in Fig. Zvw6.

Zvw8: Interlayered, gray fine tremolite-rich quartzite layers with Ca/Mg-silicate zones (white areas with calcite, diopside, and tremolite) that are sheared into small boudins along Pond Street at Spot Pond in Stoneham (site 10316; see Fig. Zvw5 above).

Zvw9: Massive appearing creamy white quartzite with abundant tremolite in gray argillaceous layers along Spot Pond Brook in Virginia Wood in Stoneham (site 11285). See closeup view in Fig. Zvw10.

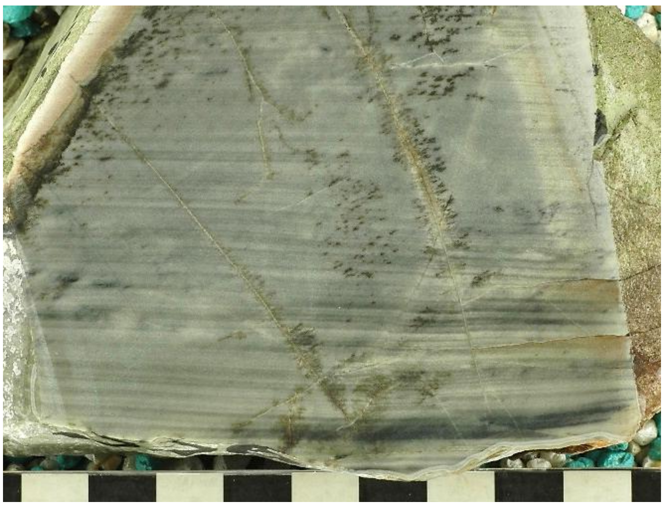
Zvw10: (left) Creamy white quartzite with abundant tremolite along Spot Pond Brook in Virginia Wood in Stoneham (site 11285). Base of unit has light and dark banding controlled by tremolite and chlorite abundance. Same outcrop as in Fig. Zvw9.

Zvw11: (above) The “Pond Street Outcrop” of the Westboro Formation along the west shore of Spot Pond in Stoneham (site 11286). Interlayered and deformed quartzite, argillite, and Ca/Mg-silicate units. See Figs. Zvw5 and 8 for detailed images. Telephone pole and traffic cone for scale.

Zvw12: (left) White quartzite layers that have been flattened and form boudins in cleaved argillite in Virginia Wood north of Pond Street in Stoneham (site 10327).

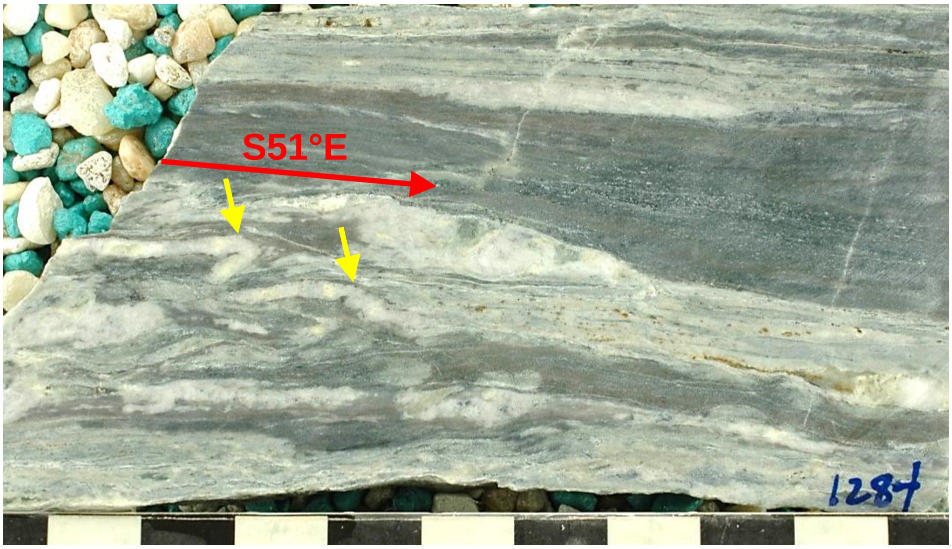
Zvw13: Interlayered and highly deformed argillite, Ca/Mg-silicate, and quartzite layers forming boudins in Virginia Wood east of Pond Street in Stoneham (site 10319). White mineral grains are Ca/Mg-silicates (diopside, tremolite, and calcite). In this sample is also zoisite.

Zvw14: Quartzite layers of varying grain size in Virginia Wood along Spot Pond Brook in Stoneham (site 10297). Quartz grains in the units on the right and far left are flattened and stretched.

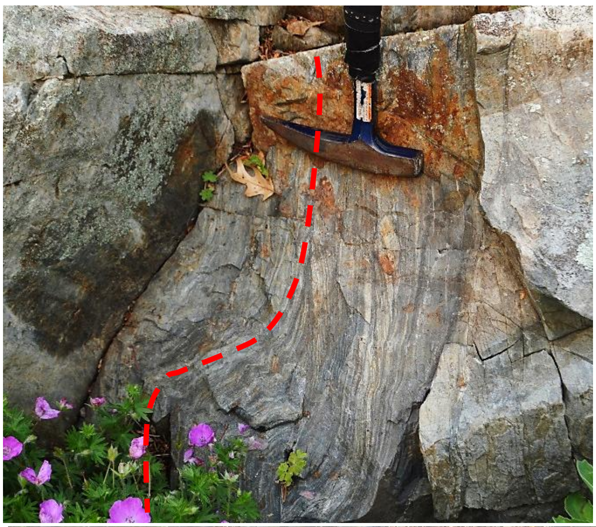


Zvw15: Siliceous laminated quartzite layers (mylonitic?) with abundant tremolite south of Ravine Road in Stoneham (site 10556).

Zvw16: Mylonitic quartzite layers that have been sheared into streaks surrounded by mica west of South Reservoir in Medford (site 11032) along the north side of an E-W trending fault.



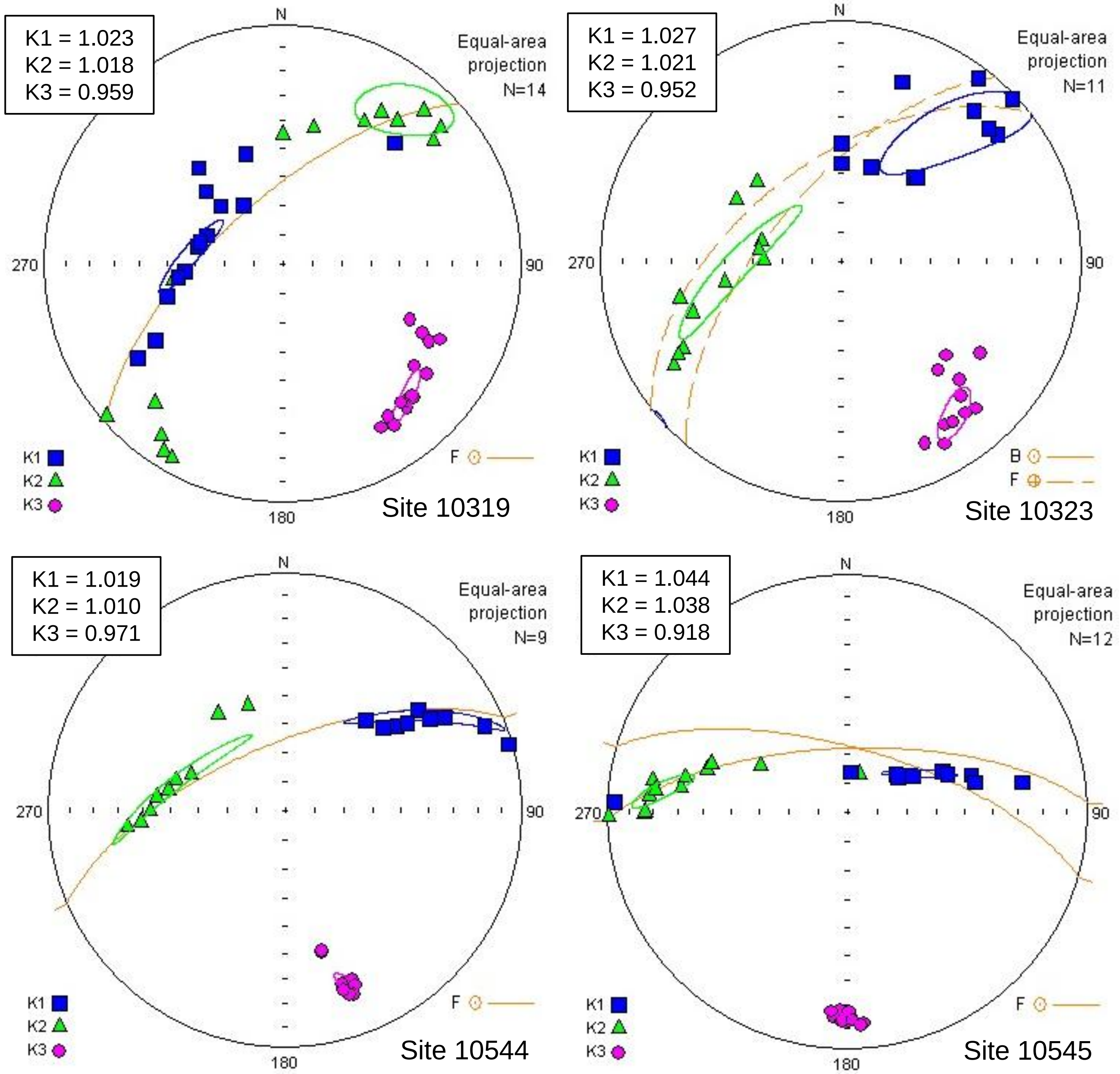
Zvw17: (left) Drag fold along the north side of Pond Street near the Fellsway East intersection (site 10302).
Zvw18: (above right) Drag fold in Ca/Mg-silicate units in Pond Street outcrop along Spot Pond (site 11284; see Figs. Zvw5, 8 and 11 for additional images from the Pond Street outcrop).



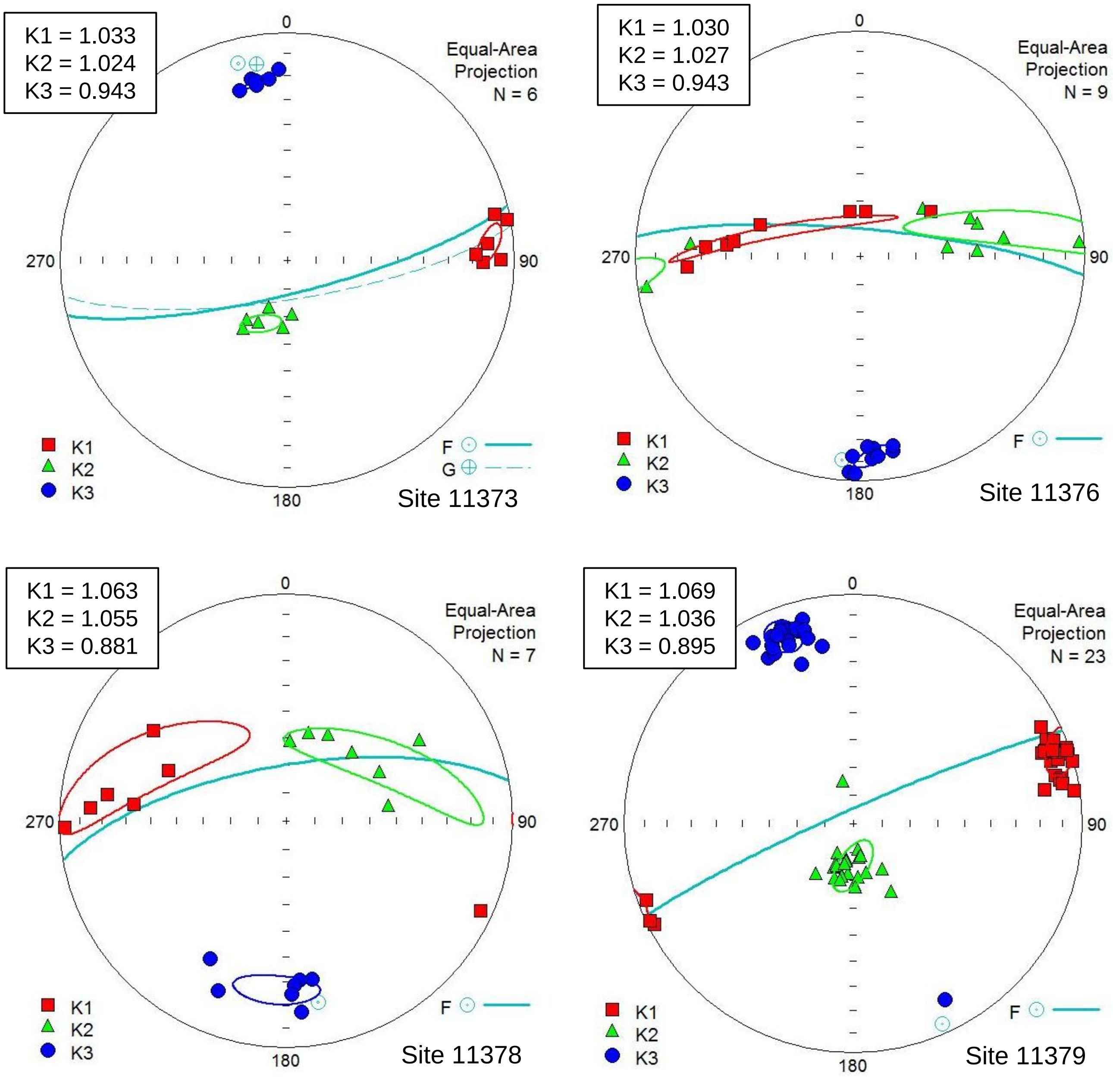
Zvw19: (left) Drag fold in Ca/Mg-silicate units along Hollywood Road in Winchester (site 11581). Line shows fold pattern.

Zvw20: Interlayered and deformed argillite and rusty quartzite layers east of South Border Road in Medford (site 11049). Arrows indicate hinges of fold with an S-pattern indicating left-lateral displacement in this view.

Zvw21: Fold structures in intensely folded argillaceous and chloritic quartzite in xenolith in the Spot Pond Granodiorite in Lawrence Woods in Medford (site 10996).



Zvw22: Anisotropy of magnetic susceptibility in the Westboro Formation from north of Pond Street from Spot Pond to the Crystal Spring area in Stoneham. Sites 10319 and 10323 are in Ca/Mg-silicate and quartzite units near Spot Pond while sites 10544 and 10545 are in argillaceous quartzite units near Crystal Spring. Points in the lower hemisphere are the directions of axes of a susceptibility ellipsoid. Axes are: K1 = maximum, K2 = intermediate, and K3 = minimum. Ellipses are 95% confidence intervals about axis measurements. The plane of K1 and K2 defines a great circle that is the magnetic foliation, while K1 is the magnetic lineation. The brown lines are field measurements of foliation planes. Lineation was not discernable in the field. Magnetic susceptibility has a well-defined foliation that dips steeply to the northwest to north and matches outcrop foliation measurements, while lineation on the foliation plane is dispersed on the foliation plane and weakly defined since K1 and K2 have similar magnitudes. However, magnetic lineation is consistent between sites and with the overturning direction of drag folds (see Figs. Zvw5, 17-19). Data from unpublished senior thesis (2014) by Katherine Lowe at Tufts University.



Zvw23: Anisotropy of magnetic susceptibility (AMS) in the Westboro Formation from west of South Reservoir in Winchester (sites 11373, 11376, 11378) and on Gerry Hill in Medford (site 11379, see Fig. Zvw1-2 for outcrop view). Points in the lower hemisphere are the directions of axes of the susceptibility ellipsoid. Axes are: K1 = maximum, K2 = intermediate, and K3 = minimum. Ellipses are 95% confidence intervals about axis measurements. The blue lines are field measurements of foliation planes. A lineation was not discernable in the field. The plane of K1 and K2 defines a great circle that is the magnetic foliation, while K1 is the magnetic lineation. The susceptibility has a well-defined foliation at all sites that dips steeply, strikes east-west, and is close to foliation measurements in the field. There is a weakly defined lineation that is relatively consistent between sample sites. On Gerry Hill (site 11379), lineation is better defined and is horizontal with distinguishable K1 and K2 magnitudes. This is better defined than for any other Westboro sample in the Fells. Note the tight clustering of susceptibility axes as compared to most other samples. Data from unpublished independent study project by Lara Williams (2022) at Tufts University.

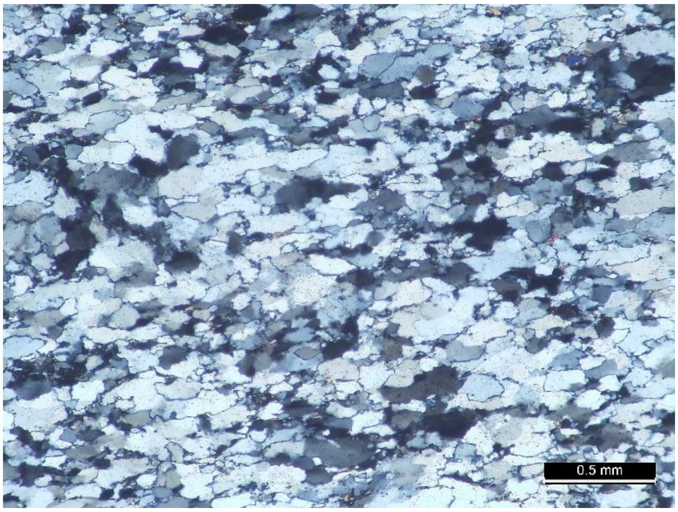
Zvw24: Unconformity at top of the Westboro Formation (arrow) at entrance to the southern Sheepfold parking lot in Stoneham (site 11160). The dark unit above is altered basaltic rock of the Nanepashemet Formation, which sits on the unconformity. Below is quartzite. Both units were baked by nearby intrusion of the Stoneham Granodiorite (Zst).

Thin section descriptions – The Westboro Formation in Virginia Wood and west of Rt. 93 is composed of three types of metamorphic lithologies that include quartzite, slatey argillite to metasiltstone, and units with Ca/Mg-silicate minerals. These units are sometimes mixed and can be altered by contact metamorphism. The different lithologies are described below.

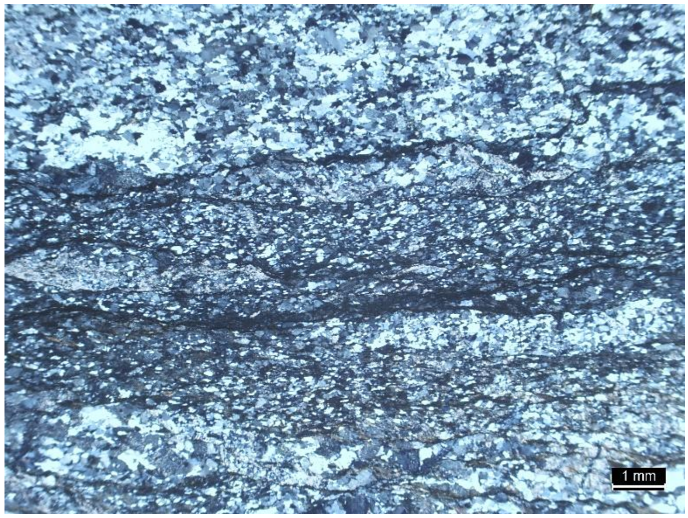
Quartzite: Quartzite can range from rocks that are entirely fine to medium sand-sized quartz and feldspar grains to rocks with fine sand-sized grains floating in a fine-grained matrix of argillite and siltstone and that may have Ca/Mg-silicate minerals, especially tremolite. Rocks that are composed almost entirely of sand-sized grains are quartz with up to 1/3 feldspar (plagioclase and alkali feldspar) that is altered to sericite (Figs. Zvw25-27). Grains are heavily sutured and serrated, and quartz is polycrystalline with undulatory extinction (Figs. 25-32). These characteristics make the sandy units of the Westboro in the Virginia Wood area distinct from sandstone units in the Whip Hill area, which are almost entirely quartz and show only very light suturing of grains. There are places where original sand grains are less deformed and sutured because grains are not touching and are protected by a fine matrix (Fig. Zvw28-29). Between grains in the Virginia Wood area are tiny pockets of muscovite and amphibole (mostly tremolite), with minor chlorite (Fig. Zvw30) and occasionally diopside (Fig. Zvw31). When quartz grains are isolated in finer matrix material, as commonly occurs in units with Ca/Mg-silicate minerals or where units are interbedded with argillite, they can still be polycrystalline with undulatory extinction, lightly to heavily serrated, and flattened, while still showing some of their original roundness (Fig. Zvw32). Matrix materials have finer clastic grains of very fine sand and silt as well as a combination of fine chlorite and amphibole (mostly tremolite; Fig. Zvw33-34) with minor sericite. High amounts of tremolite imparts a creamy white color and chert-like texture to the quartzite units (Figs. Zvw33-36; see Figs. Zvw6-10 for outcrop and cut rock views). Quartzite units often show evidence of compression and pressure solution, in addition to the suturing mentioned above (Zvw36-37), in the form of stylolites (Fig. Zvw38). Some quartzite units composed of medium sand-sized grains have noticeable detrital zircon crystals in thin section (Fig. Zvw38). Contact metamorphism seen along the edges of large plutonic bodies and in xenoliths did not seem to destroy the original outlines of quartz and feldspar grains. However, matrix materials reacted to form biotite and chlorite, and feldspar was altered. Individual samples show separate bands of biotite and chlorite and there is a suggestion that chlorite is more common when feldspar abundance is higher (Fig. Zvw39). One quartzite xenolith in the Spot Pond Granodiorite near Medford High School had conspicuous alkali feldspar grains (Fig. Zvw40).

Argillite and metasiltstone: Fine-grained units are composed of very fine sand to silt-sized particles with surrounding amphibole, chlorite, and sericite (Fig. Zvw41). Argillite can have cleavage development with alignment of very fine chlorite and muscovite and flattening of clastic silt and fine sand particles (Figs. Zvw42-43). Tremolite appears to be the dominant amphibole in argillaceous units (Fig. Zvw44) that had an original mudstone protolith containing Ca/Mg carbonate. Shearing in these units is easily recognized. Sand to silt units are often separated into micro-boudins surrounded by chlorite and tremolite (Figs. Zvw45-46).

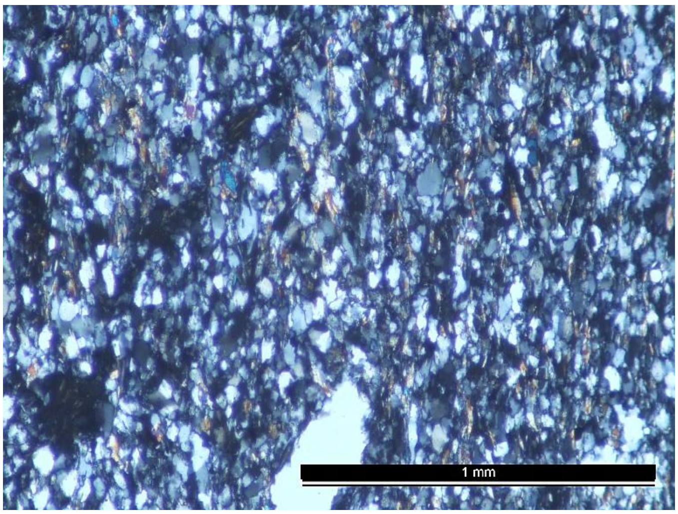
Calcium/magnesium silicate units: Units with calcium/magnesium silicate minerals as well as minor calcite result from the regional metamorphism of original dolomitic sedimentary units. The minerals found in these units in addition to quartz and feldspar in order of abundance are tremolite, diopside, calcite, zoisite, and possibly minor amounts of orthopyroxene (Figs. 47-49). These units appear to be more easily deformed and small-scale boudins and folds are not uncommon (see Figs. Zvw4-5, 8, 13 and 17-19 for outcrop and cut rock views).



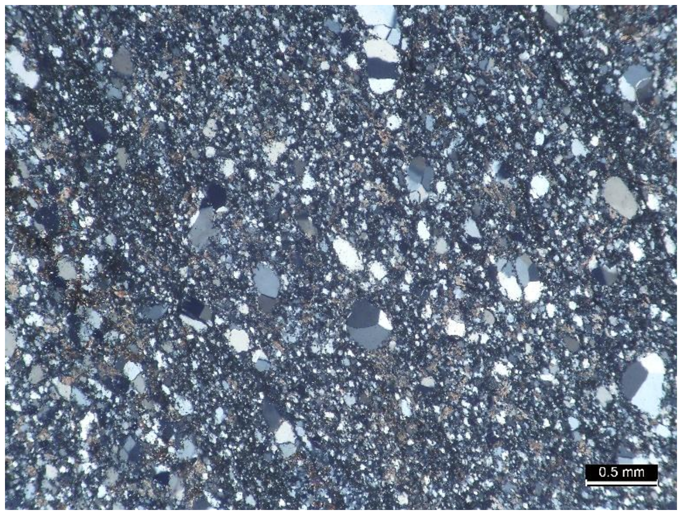
Zvw25: Fine to medium quartzite with mostly quartz and secondary feldspar on northern peninsula in South Reservoir in Medford (site 10852). Grains are heavily sutured, serrated, and polycrystalline with sparse matrix material.



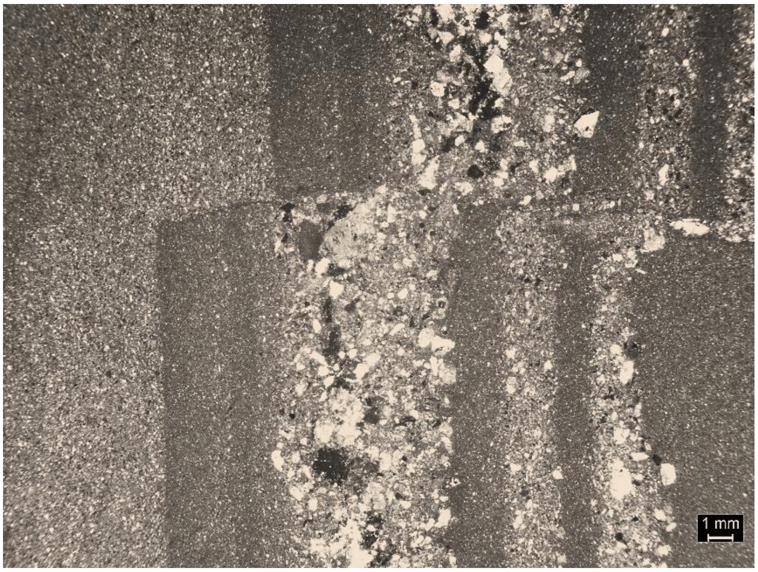
Zvw26: Mixture of shear-bounded fine to medium quartzite lenses south of Sheepfold along Rt. 28 in Stoneham (site 114BN). Grains are heavily sutured, serrated, and polycrystalline with very fine matrix material that includes sericite and chlorite.



Zvw27: Fine to medium quartzite with mostly quartz and some feldspar on Gerry Hill in Medford (site 162BN). Grains are heavily sutured, serrated, and polycrystalline with a matrix that includes sericite, tremolite, and chlorite. Foliation is vertical in this image.

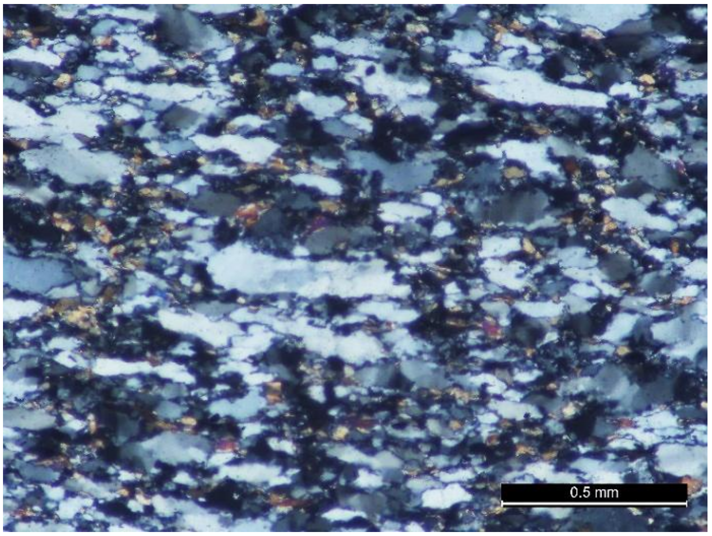


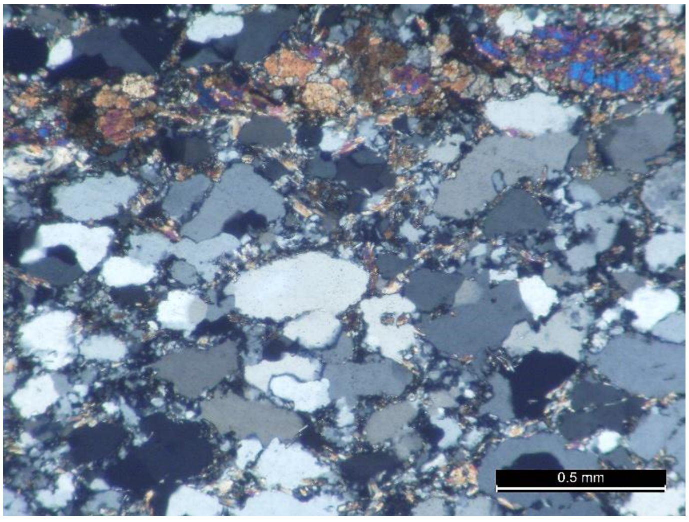
Zvw28: Very fine to medium quartzite with mostly quartz and some feldspar on Gerry Hill in Medford (site 10323). Grains are lightly serrated and polycrystalline with a matrix that includes many silt grains, tremolite, and chlorite. Grains are not as sutured and rounder than grains in better sorted quartzite samples, possibly because larger grains have fewer points of contact and stress. Foliation trends from upper left to lower right in this image.



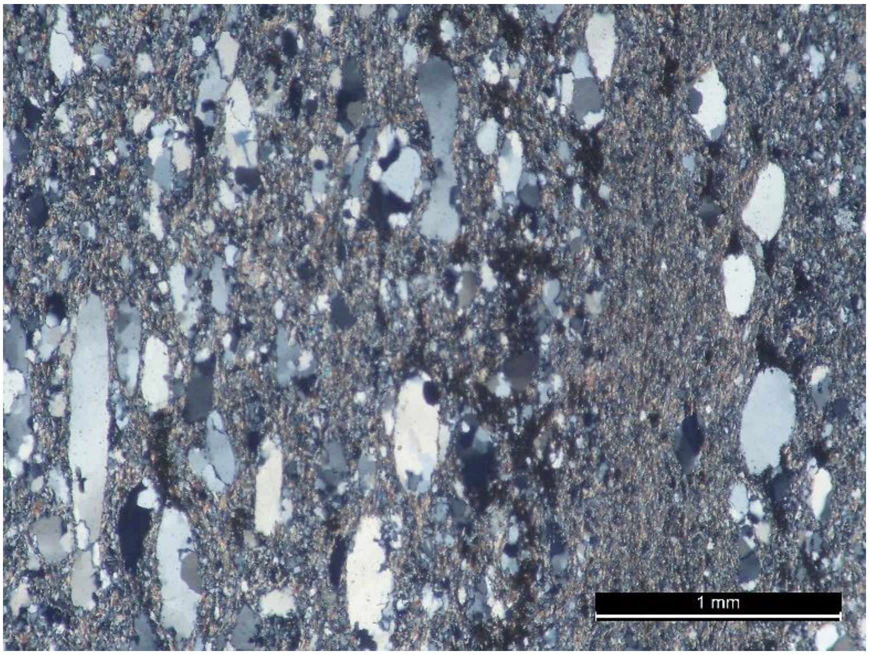
Zvw29: Interlayered argillite and thin sandstone beds with little stretching of original bedding in Pine Banks Park in Melrose (site 11452). Fine-grained matrix material surrounds most larger grains. This site is unusual because it also has many very angular grains. Up is to the left. Silicification at this site is discussed with the Boojum Rock Tuff and unconformity on the Westboro at this site.

Zvw30: Medium quartzite with severely flattened grains on west side of Gerry Hill in Medford (site 10777). Grains are heavily sutured, serrated, and polycrystalline with a matrix that includes tremolite and minor sericite.

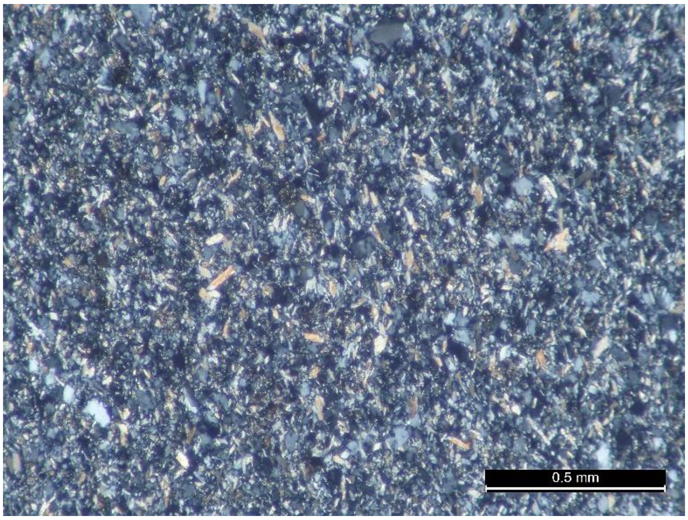




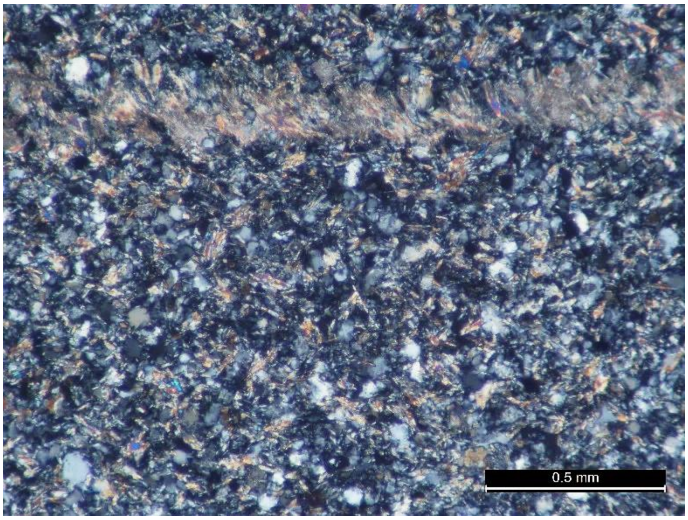
Zvw31: Medium quartzite with mostly quartz and a diopside band (top of image) north of the Pond Street ravine near Crystal Spring in Stoneham (site 10322). Grains are heavily sutured, serrated, and polycrystalline.



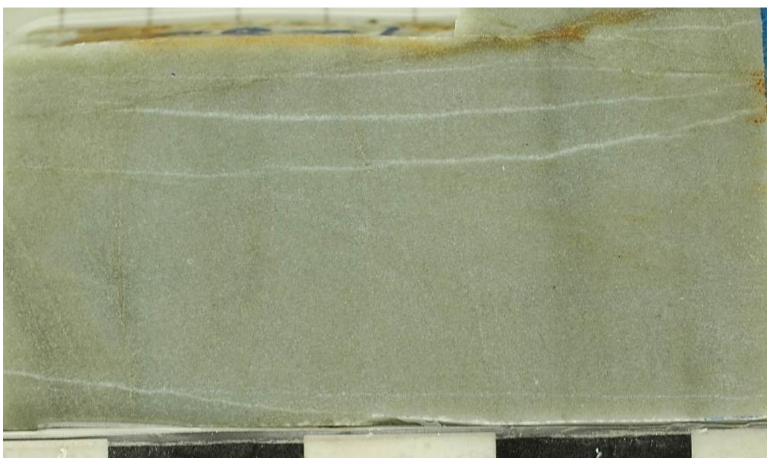
Zvw32: Quartzite with isolated quartz grains along Spot Pond Brook in Virginia Wood in Stoneham (site 10297). Grains are flattened, lightly serrated, and polycrystalline with a fine matrix of mostly tremolite and chlorite. See Fig. Zvw14 for cut rock view.



Zvw33: Fine quartzite in Virginia Wood south of Ravine Road (site 10556). The matrix of this rock is dominantly tremolite, which gives the rock a creamy white appearance in outcrop. See Fig. Zvw15 for cut rock view.

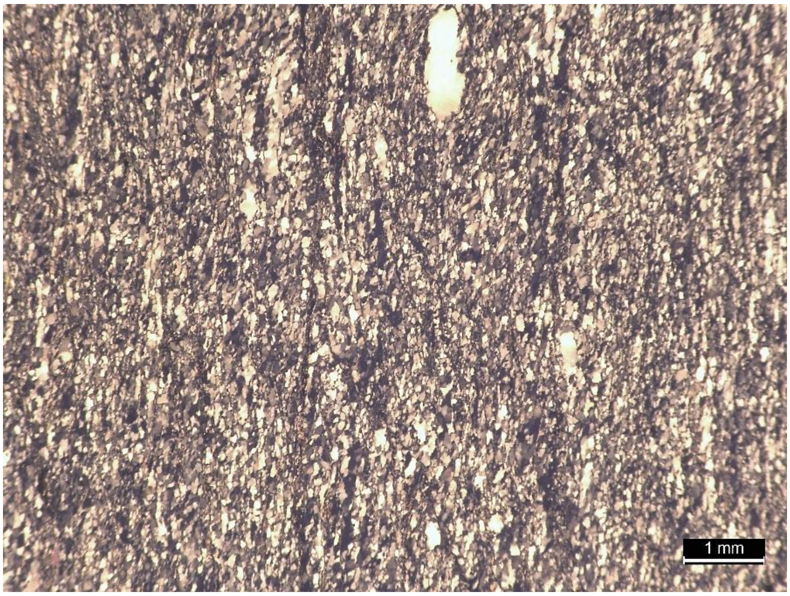


Zvw34: Fine quartzite in Virginia Wood along Spot Pond Brook (site 11285) with bands of dominantly tremolite that give the rock a creamy white color and a banded appearance. See Fig. Zvw35 for a cut rock view and Figs. Zvw6-7 for outcrop views.

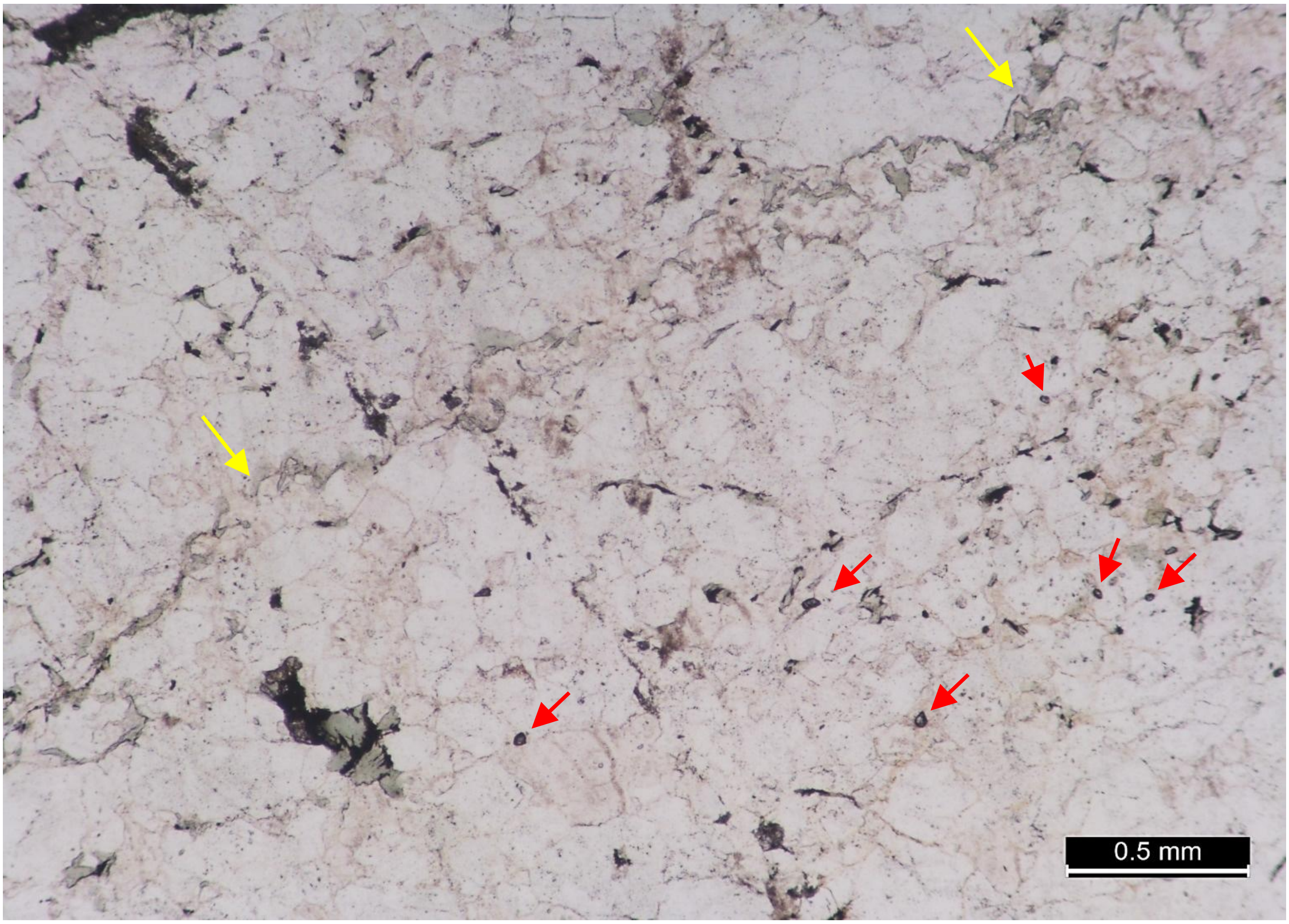


Zvw35: Cut rock view of fine quartzite with tremolite that gives the rock a creamy white color in Virginia Wood along Spot Pond Brook (site 11285). Banding in rock is faint and vertical in view while veins cross the slide from left to right. See Fig. Zvw34 for thin section view and Figs. Zvw9-10 for outcrop views.

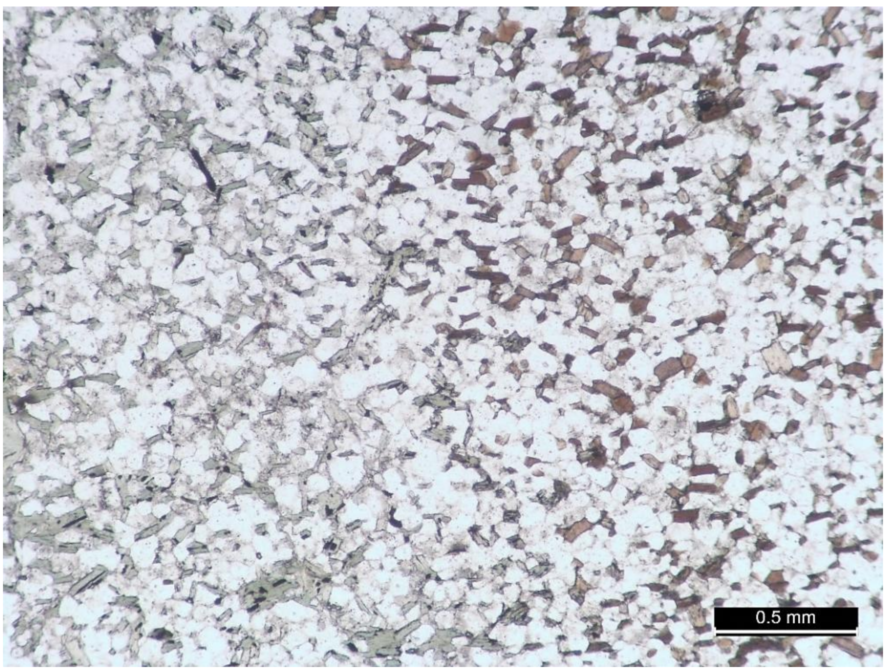
Zvw36 (above): Fine quartzite beds with varying amounts of chlorite and Ca-Mg silicate minerals (mostly tremolite) along Main Street on northwest corner of Wyoming Hill in Melrose (site 11504). Although this sample appears to have well preserved laminated bedding, sand grains in this rock are highly deformed (see Fig. Zvw37).



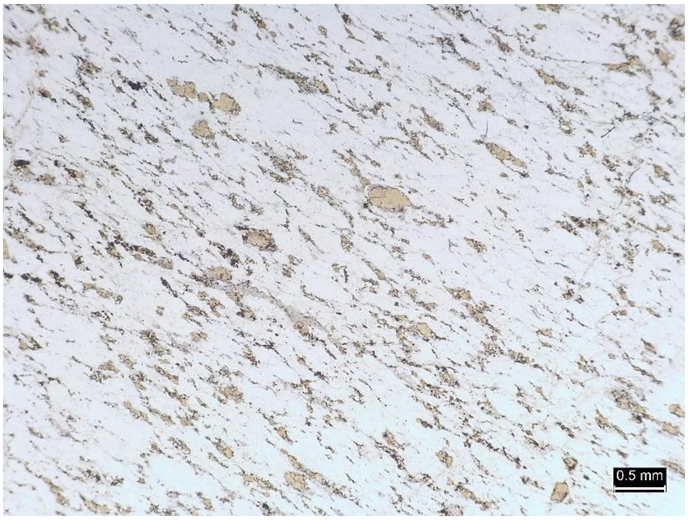
Zvw37 (right): Fine sandstone beds with varying amounts of chlorite and Ca-Mg silicate minerals (mostly tremolite) along Main Street on northwest corner of Wyoming Hill in Melrose (site 11504). Sand grains are highly flattened and sutured (see cut rock in Fig. Zvw36 above).



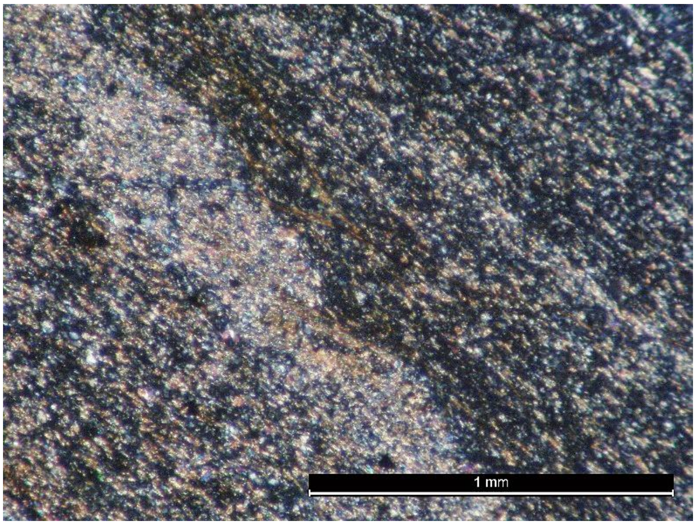
Zvw38: Fine to medium quartzite with mostly quartz and secondary feldspar (dusty altered areas) at southern parking lot at Sheepfold (site 11160). See Fig. Zvw24 for outcrop view. Grains are heavily sutured, serrated, and polycrystalline. Yellow arrows indicate stylolite with chlorite mineralization and red arrows identify detrital zircon crystals. Pale green areas are chlorite.



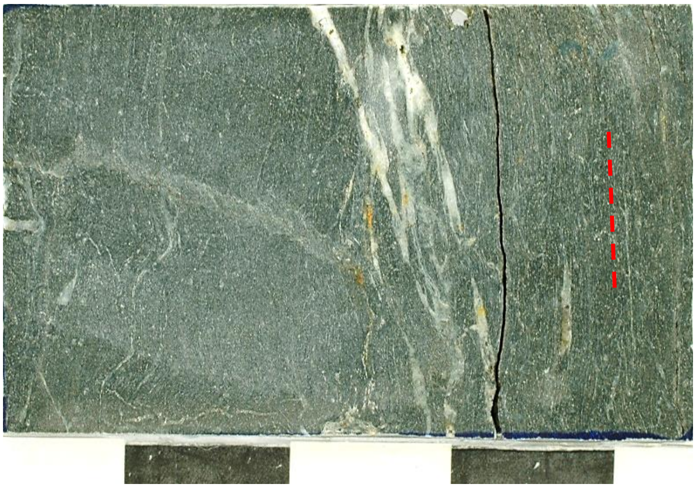
Zvw39: Fine quartzite xenolith in Spot Pond Granodiorite east of Wenepoykin Hill near Rt. 93 in Medford (site 10724). Rock is mostly quartz with some feldspar that shows up as dusty altered areas. Feldspar is more abundant on the left side of the image. On the right side, matrix minerals are brown biotite, while on the left is pale green chlorite.



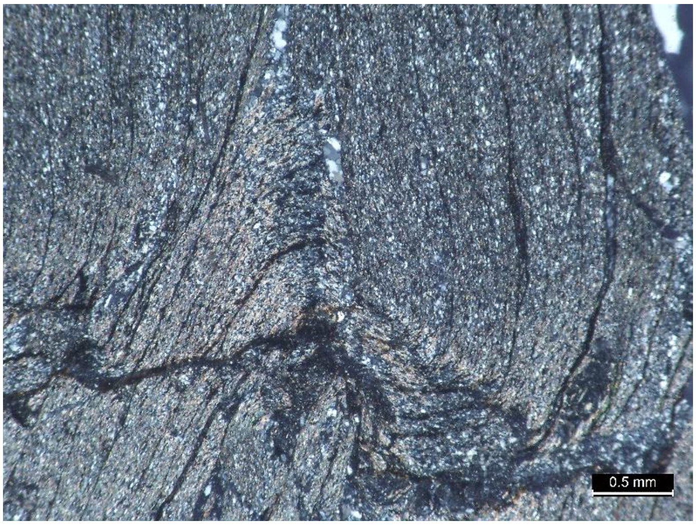
Zvw40: Medium quartzite with alkali feldspar (stained yellow) in xenolith in the Spot Pond Granodiorite near Medford High School in Medford (site 10998).



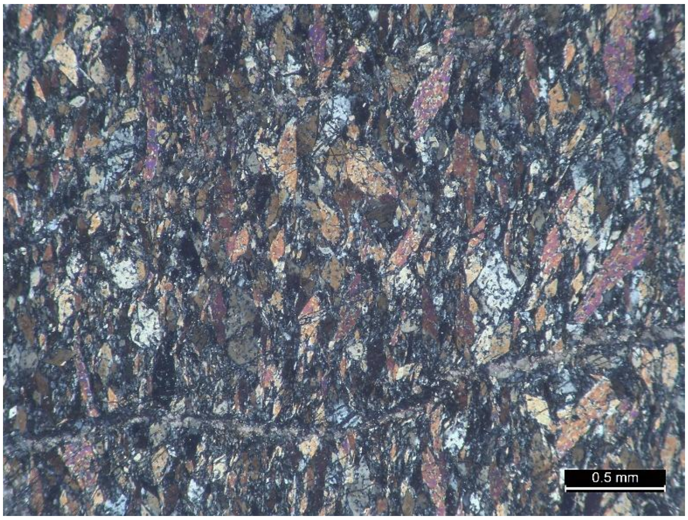
Zvw41: Argillite with layers with varying amounts of detrital grains and tremolite that tends to make layers light in color. Dark layers have more chlorite. South of Spot Pond Brook in Virginia Wood in Stoneham (site 10295).



Zvw42 (above): Cut rock view of dark gray argillite with cleavage development (trace parallel to red line) north of Gerry Hill in Medford (site 10859). See Fig. Zvw43 for thin section view.



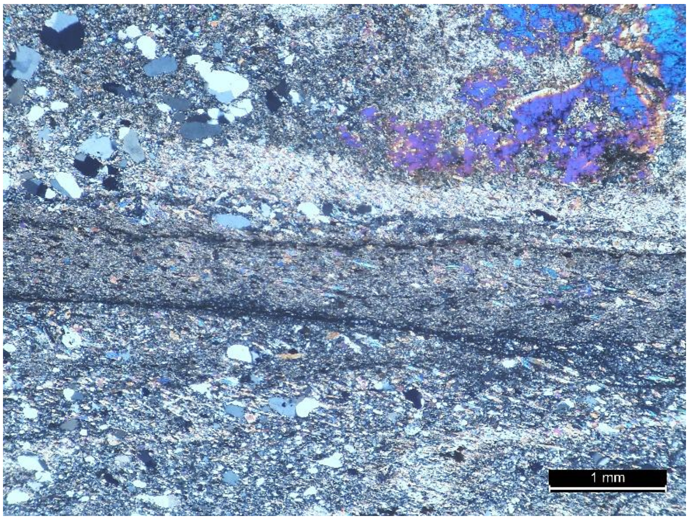
Zvw43: (above) Thin section view of argillite with cleavage development and fold north of Gerry Hill in Medford (site 10859). See Fig. Zvw42 for cut rock view. Matrix of rock has muscovite and chlorite aligned to cleavage and some opaque oxide on cleavage planes. Darker areas where cleavage is nearly vertical or horizontal on image is where micas are near extinction with crossed polarizers.



Zvw44: (left) Argillite with well oriented tremolite blades, chlorite, and scattered relict detrital quartz and feldspar on the west shore of the northern peninsula in South Reservoir in Medford (site 10828).

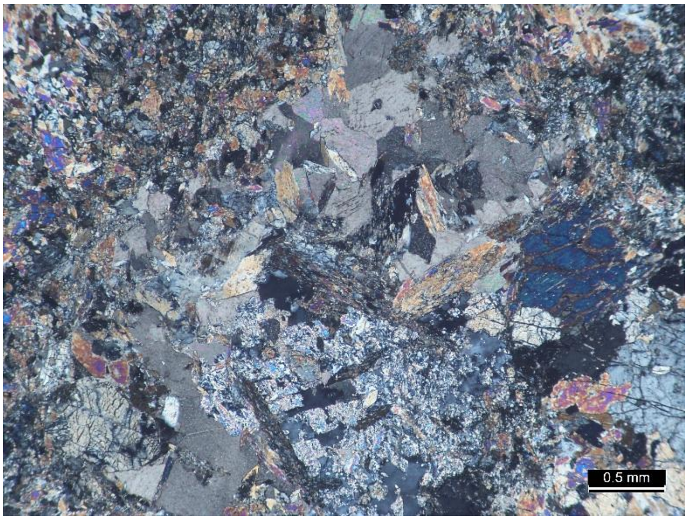
Zvw45 (above): Highly sheared argillite with fine quartzite boudins on Deer Hill west of Spot Pond in Stoneham (site 217BN). The matrix here is mostly chlorite.

Zvw46 (above): Highly sheared argillite with fine quartzite boudins west of southern South Reservoir in Medford (site 11032). This site sits adjacent to an east-west trending fault that likely contributed to deformation. See Fig. Zvw16 for cut rock view.



Zvw47 (above): Sheared quartzite and argillite with abundant tremolite and diopside (bright colors) east of Pond Street (site 10319). Note also rounded polycrystalline quartz grains in upper left. See Fig. Zvw13 for cut rock view.

Zvw48 (above): Quartzite and argillite with abundant tremolite, diopside (bright colors in right center) and zoisite (grayish-blue and zoned) on Pond Street in Stoneham (site 11284). See Figs. Zvw11 and 18 for outcrop and cut rock views. Dark line across center of view is an open crack.



Zvw49: Area of Ca-Mg silicate minerals with calcite (gray to faintly pinkish-gray) and abundant tremolite and diopside (bright colors) west of lower South Reservoir in Medford (site 11020).

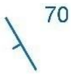
EXPLANATION OF MAP SYMBOLS

ORIENTATION DATA

Strike and dip of foliation and lineation features in sedimentary and metamorphic rocks.

Orientation of bedding for which top is known. At these locations bedding has not been significantly altered by structural deformation. Tic points to younger beds.

Orientation of overturned bedding for which top is known. At these locations bedding has not been significantly altered by structural deformation. Tic points to older beds.

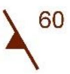


Orientation of bedding/layering for which a top is not known from field information. At these locations bedding has not been significantly altered by structural deformation.

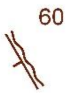
Orientation of foliation. Represents orientation of compositional layering and in most cases is a strong foliation parallel to significantly deformed bedding.

Bearing and plunge of lineation on a foliation plane including fold axes.

Strike and dip of planar features in volcanic rocks



Orientation of foliation represented by banding in felsite.

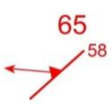


Foliation of flattened and stretched glass or pumice fragments (fiammé).

Strike and dip of planar foliation in deformed plutonic igneous rocks

Foliation in coarse-grained igneous rocks expressed as elongated quartz grains and the alignment of other minerals. Found in the Spot Pond Granodiorite (Zsg) near its intrusive contact with quartzite west of Rt. 93 in the Gerry Hill area.

Orientation of magnetic susceptibility measurement



Anisotropy of magnetic susceptibility (AMS): strike and dip of magnetic foliation - plane of maximum (K1) and intermediate (K2) susceptibility axes (foliation symbol and large number) and plunge of lineation (maximum susceptibility axis - K1) on foliation plane (arrow and small number)

Strike and dip of dikes

basalt

dolerite

porphyritic basalt/dolerite

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

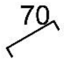
basalt


dolerite


porphyritic basalt/dolerite

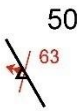

andesite, dacite or rhyolite

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



Strike and dip of continuous planar fractures and joints - only shown where fractures are flat and continuous over a distance of at least 5 m. Associated with these prominent joints are many other local fractures not indicated on the map that are sometimes a part of Riedel fracture systems. Density of measurements is dependent on host rock units, some of which have a massive and homogeneous character that allows the development of consistent long flat fractures while other units have fractures with many directions that are not traceable over more than a few meters.

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.



Tension gashes along shear or joint surfaces – strike and dip of shear or major joint surface (black) and average strike and dip of tension gash surfaces (red)

FAULTS

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

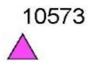
Major faults (dashed where inferred) - major faults with large lateral extent (often over 1 km) and apparent displacement (usually >50 m) as determined by the offset of dikes, unit contacts of major rock units, and other continuous features such as other fractures and faults. These faults are generally associated with highly sheared rock that forms larger valleys or ravines than along minor faults or adjacent rocks have associated shear fabrics. Major faults are in mostly two sets, an older generally E-W trending set and a younger generally N-S trending set. The E-W set was intruded by the youngest E-W set of dolerite dikes, as is suggested by the large displacement of rock units on opposite sides of these dikes. The E-W dikes were later displaced by the N-S trending set of major faults.

Major faults separating large sections of the Avalon terrane (dashed where inferred) – major faults separating sections of the Avalon Terrane with different groups of rock formations not just the offset of one group of rocks. Sometimes associated with wide mylonitic shear zones. Most notable is the Walden Pond Fault of Kaye (1980) in the northern Boston North Quadrangle and extending down the Mystic Valley further west in the Lexington Quadrangle.

UNCONFORMITIES

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

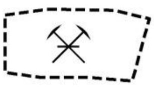
OTHER FEATURES



Bedrock sample site with sample number. Sites are hyper-linked to digital images in the original GIS map. 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 later bedrock mapping. Samples marked Pf, DG, X, and MR are approximate locations of sites of Zarrow (1978).

Locations where bedrock displays noteworthy properties described in field notes. Sites are hyper-linked to digital images in the original GIS map.

Bedrock quarry, mine, or excavation for fill. Dashed line only used in areas of large excavations. Abbreviations for rock types: f - felsite, g - granite, G – gabbro, m – metasedimentary rock, d - dolerite. Excavations or "pits" in Quaternary deposits (q) are not given a unit symbol.



Abandoned bedrock quarry, mine, or excavation for fill. Dashed line only used in areas of large excavations. Abbreviations for rock types: f - felsite, g - granite, G – gabbro, m – metasedimentary rock, d - dolerite. Excavations or "pits" in Quaternary deposits (q) are not given a unit symbol.

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 (T_Rm).

Site of radiometric age with age listed in millions of years before present (Ma). See unit descriptions and Appendix 3 for details.

CONVERSION TABLE

Meters	Feet	Meters	Feet
1	3.2808	9	29.527
2	6.5617	10	32.808
3	9.8425	20	65.616
4	13.123	30	98.424
5	16.404	40	131.23
6	19.685	50	164.04
7	22.965	100	328.08
8	26.246		

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Geologic mapping, the processing of samples, and financial support for thin sections were all furnished by the Dept. of Earth and Climate Sciences at Tufts University (formerly the Dept. of Earth and Ocean Sciences). Thin sections were made at Burnham Petrographics of Rathdrum, Idaho and Spectrum Petrographics in Vancouver, Washington.

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REFERENCES

Bailey, R.H., 1984, A Precambrian continent margin sequence (slope deposits and olistostromes): Boston North Quadrangle, *in* L.S. Hanson, ed., Geology of the Coastal Lowlands, Boston, MA to Kennebunk, ME: Guidebook of 76th Annual Meeting of the New England Intercollegiate Geologic Conference, p. 145-164.

Bailey, R.H., Skehan, J.W., Dreier, R.B., and Webster, M.J., 1989, Olistostromes of the Avalonian terrane of southeastern New England, *in* J.W. Horton, Jr. and N. Rast, eds., Mélanges and olistostromes of the U.S. Appalachians: Geological Society of America Special Publication no. 228, p. 93-112.

Bell, K.G., 1948, Geology of the Boston Metropolitan Area: PhD thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 390 p.

Bell, K.G. and Alvord, D.C., 1976, Pre-Silurian stratigraphy of northeastern Massachusetts, *in* Page, L.R. (ed.), Contributions to the Stratigraphy of New England: Geological Society of America Memoir 48, p. 179-216.

Billings, M.P., 1925, On the mechanics of dike intrusion: Journal of Geology, v. 33, no. 2, p. 140-150.

Billings, M.P. and Roy, C.J., 1933, Weathering of the Medford Diabase, pre- or postglacial?: Journal of Geology, v. 41, no. 6, p. 654-661.

Cardoza, K.D., 1987, Geochemistry of the Middlesex Fells Volcanic Complex (Mafic Member) and Brighton Volcanics, Boston-Avalon Zone, eastern Massachusetts: M.S. thesis, Boston College, Chestnut Hill, Massachusetts, 76 p.

Cardoza, K.D., Hepburn, J.C., and Hon, R., 1990, Geochemical constraints on the paleotectonic setting of two late Proterozoic mafic volcanic suites, Boston-Avalon zone, eastern Massachusetts, in A.D. Socci, J.W. Skehan, and G.W. Smith (eds.), Geology of the Composite Avalon terrane of Southern New England: Geological Society of America, Special Paper no. 245, p. 113-131.

Castle, R.O., Hepburn, J.C. and Kopera, J.P., 2005, Bedrock geologic map of the Reading Quadrangle, Massachusetts v 1.0: Massachusetts Geological Survey (4th), in review April 2005.

Clapp, C.H., 1921, Geology of the igneous rocks of Essex County, Massachusetts: U.S. Geological Survey Bulletin no. 704. 132 p.

Emerson, B.K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geological Survey Bulletin 597, 289 p.

Hampton, R., 2017, The Middlesex Fells Volcanic Complex: A revised tectonic model based on geochronology, geochemistry, and field data: Undergraduate senior thesis, Harvard University, Cambridge, Massachusetts, 115 p.

Hepburn, J.C., Hon, R., Dunning, G.R., Bailey, R.H., and Galli, K., 1993, The Avalon and Nashoba terranes (eastern margin of the Appalachian Orogen in southeastern New England), *in* J.T. Cheney and J.C. Hepburn, eds., Field Trip Guidebook for the Northeastern United States: 1993 Boston GSA, Volume 2, Geological Society of America Annual meeting and 85th Annual New England Intercollegiate Geological Conference, Boston, Massachusetts: Department of Geology and Geography, University of Massachusetts, Amherst, Massachusetts, contribution no. 67, p. X-1 to X-31.

Hermes, O.D. and Murray, D.P., 1990, Geochemical distinctions of late Proterozoic and Paleozoic volcanism in the Avalon zone of New England, *in* Socci, A.D., Skehan, J.W., and Smith, G.W., eds., Geology of the composite Avalon terrane of southern New England: Boulder, Colorado, Geological Society of America Special Paper 245, p. 97-112.

Kaye, C.A., 1980, Bedrock geologic map of the Boston North, Boston South, and Newton Quadrangles: U.S. Geological Survey Miscellaneous Field Investigation Map MF-1241, scale 1:24,000.

Kaye, C.A., 1984, Boston Basin restudied, *in* L.S. Hanson, ed., Geology of the Coastal Lowlands, Boston, MA to Kennebunk, ME: Guidebook of 76th Annual Meeting of the New England Intercollegiate Geologic Conference, p. 124-144.

Kaye, C.A. and Zartman, R.E., 1980, A Late Proterozoic Z to Cambrian age for the stratified rocks of the Boston Basin, Massachusetts, U.S.A., *in* Wones, D.R., ed., The Caledonides in the USA: Blacksburg, Virginia Polytechnic Institute and State University Memoir 2, p. 257-261.

Klein, B.Z. and Eddy, M.P., 2023, What's in an age? Calculation and interpretation of ages and durations from U-Pb zircon geochronology of igneous rocks: Geological Society of America Bulletin, DOI: https://doi.org/10.1130/B36686.1

LaForge, L., 1932, Geology of the Boston area, Massachusetts: U.S. Geological Survey Bulletin 839, 105 p.

Lane, A.C. and Wolf, A., 1932, Weathering of the Medford Diabase – pre- or postglacial?: Journal of Geology, v. 40, no. 5, p. 459-465.

Lane, A.C. and Wolf, A., 1933, Reply to Billings and Roy (1933): Journal of Geology, v. 41, no. 6, p. 661-666.

Le Bas, M.J. and Streckeisen, A.L., 1991, The IUGS systematics of igneous rocks: Journal of the Geological Society of London, v. 148, p. 825-833.

Naylor, R.S., 1981, Felsic volcanic units in the Boston area, Massachusetts, *in* Boothroyd, J.C. and Hermes, O.D., eds., Geological field trips in Rhode Island and adjacent areas: 73rd Annual New England Intercollegiate Geologic Conference Guidebook, Kingston, Univ. of Rhode Island, p. 303-314.

Ross, M.E., 1981, Mafic dikes of northeastern Massachusetts, *in* Boothroyd, J.C. and Hermes, O.D., eds., Geological field trips in Rhode Island and adjacent areas: 73rd Annual New England Intercollegiate Geologic Conference Guidebook: Kingston, University of Rhode Island, p. 285-302.

Ross, M.E., 1984, Mafic dikes from Boston to Cape Ann, *in* L.S. Hanson, ed., Geology of the Coastal Lowlands, Boston, MA to Kennebunk, ME: Guidebook of 76th Annual Meeting of the New England Intercollegiate Geologic Conference, p. 81-102.

Ross, M.E., 1990, Mafic dikes of the Avalon Boston terrane, Massachusetts, *in* Socci, A.D., Skehan, J.W., and Smith, G.W., eds., Geology of the composite Avalon terrane of southern New England: Boulder, Colorado, Geological Society of America Special Paper 245, p. 133-153.

Ross, M.E., 1992, Petrology and tectonic significance of Mesozoic mafic dikes of the coastal New England igneous province, Massachusetts, in Puffer, J.H. and Ragland, P.C., eds., Eastern North American Mesozoic Magmatism: Geological Society of America Special Paper, no. 268, p. 63-74.

Ross, M.E., 2001, Igneous petrology of the Pine Hill area, Medford, Massachusetts, in West, D.P., Jr. and Bailey, R.H., eds., Guidebook for Geological Field trips in New England: 2001 Annual Meeting of the Geological Society of America, Boston, Massachusetts, p. M-1 to M-25.

Ross, M.E., 2001, Igneous petrology of the Pine Hill area, Medford, Massachusetts, in West, D.P., Jr. and Bailey, R.H., eds., Guidebook for Geological Field trips in New England: 2001 Annual Meeting of the Geological Society of America, Boston, Massachusetts, p. M-1 to M-25.

Ross, M.E., 2010, An early Triassic $^{40}Ar/^{39}Ar$ age for a camptonite dyke in Cambridge, Massachusetts: Atlantic Geology, v. 46, p. 127-135.

Ross, M.E., 2020, The petrology and age of the Medford dolerite dike, Medford, Massachusetts: Dept. of Marine and Environmental Sciences, Northeastern University, Open File Report no. 3, 55 p. https://doi:10.13140/RG.2.2.21253.99041

Ross, M.E., 2021, Mafic dikes of the Boston metropolitan area, Massachusetts: Northeastern University, Boston, Massachusetts, Open File Report no. 4, 94 p. https://doi: 10.13140/RG.2.2.29116.16000

Smith, C.J., 1985, Late Proterozoic Avalonian magmatism north of Boston, eastern Massachusetts: Unpub. Master of Science thesis, Boston College, Chestnut Hill, Massachusetts, 156 p.

Smith, C.J. and Hon, R., 1984, Geology, petrology and origin of the Precambrian igneous rocks located in the area north of Boston, *in* L.S. Hanson, ed., Geology of the Coastal Lowlands, Boston, MA to Kennebunk, ME: Guidebook of 76th Annual Meeting of the New England Intercollegiate Geologic Conference, p. 292-309.

Thompson, M.D., 1985, Evidence for a late Precambrian caldera in Boston, Massachusetts: Geology, v. 13. P. 641-643.

Thompson, M.D., 2017, Bedrock Geologic Map of the Newton 7.5' Quadrangle, Middlesex, Norfolk and Suffolk Counties, Massachusetts: Massachusetts Geological Survey Geologic Map GM-17-01. 1:24,000. 1 map sheet and explanatory text.

Thompson, M.D. and Hermes, O.D., 1990, Ash-flow stratigraphy in the Mattapan Volcanic Complex, greater Boston, Massachusetts, *in* Socci, A.D., Skehan, J.W., and Smith, G.W., eds., Geology of the composite Avalon terrane of southern New England: Boulder, Colorado, Geological Society of America Special Paper 245, p. 85-95.

Thompson, M.D., Barr, S.M., and Grunow, A.M., 2012, Avalonian perspectives on Neoproterozoic paleogeography: evidence from Sm-Nd isotope geochemistry and detrital zircon geochronology in SE New England, USA: Geological Society of America Bulletin, v. 124, p. 517-531. https://doi:10.1130/B30529.1

Toulmin 3d, P., 1964, Bedrock geology of the Salem Quadrangle and vicinity Massachusetts: Geology of Selected Quadrangles in Massachusetts, U.S. Geological Survey Bulletin 1163-A, 79 p.

Wilson, A.W.G., 1901, The Medford dike area: Boston Society of Natural History Proceedings, v. 30, p. 353-374.

Winter, J.D., 2010, Principles of Igneous and metamorphic Petrology: Prentice Hall, New York, 702 p.

Wones, D.R. and Goldsmith, R., 1991, Intrusive rocks of eastern Massachusetts, in N.L. Hatch (ed.), The Bedrock Geology of Massachusetts: U.S. Geological Survey Paper 1366-I, p. I1-I61.

Zarrow, L., 1978, Structural relationships and geochemical investigation of the Lynn Volcanic Complex, Pine Hill, Boston North Quadrangle, Massachusetts: MS thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 182 p.

Zartman, R.E., Hurley, P.M., Krueger, H.W. and Giletti, B.J., 1970, A Permian disturbance of K-Ar ages in New England: its occurrence and cause: Geological Society of America Bulletin, v. 81, p. 3359-3374.

Zen, E-an, ed., 1983, Bedrock geologic map of Massachusetts: U.S. Geological Survey, scale 1:250,000.

Appendix 1 - A. Point Count data for the Stoneham Granodiorite (Zst).

Zst Sample	Zst IUGS rock name	Count Total	Percentages: Q	A	P	Gran	Chl+Op	Ep/Zo	Hb	Bt	Sp	Oth	Notes	Normalized percentages: QAP tot	Qnorm	Anorm	Pnorm
672BN	tonalite	406	26.1	3.2	48.0	0.0	14.3	7.9	0.0	0.0	0.5	0.0	Chill zone, Rut seen	77.3	33.8	4.1	62.1
10408	tonalite	386	27.7	1.0	67.9	0.0	2.8	0.3	0.0	0.0	0.3	0.0	Chill zone	96.6	28.7	1.1	70.2
10422s	granodiorite	355	22.0	13.0	52.4	0.0	9.3	2.5	0.0	0.0	0.8	0.0	Chill zone, assim. rhyolite	87.3	25.2	14.8	60.0
10428	granodiorite	422	17.8	6.9	54.5	0.0	5.2	1.4	13.5	0.0	0.7	0.0		79.1	22.5	8.7	68.9
10441	qtz monzodiorite	419	12.2	7.4	54.7	0.7	5.5	2.9	16.2	0.0	0.5	0.0	Basalt inclusion w Act	74.9	16.7	10.4	72.9
10459s	granodiorite	377	27.1	17.0	43.2	0.0	5.8	1.1	2.7	1.9	1.3	0.0		87.3	31.0	19.5	49.5
10461	granodiorite	391	21.5	10.0	53.5	0.0	4.6	3.8	5.1	0.0	1.5	0.0		84.9	25.3	11.7	63.0
10549	granodiorite	356	16.6	17.4	47.8	0.0	4.5	5.3	7.9	0.0	0.6	0.0		81.7	20.3	21.3	58.4
10586	granodiorite	309	12.3	3.2	57.6	18.8	6.1	1.3	0.0	0.0	0.6	0.0	Chill zone	91.9	23.6	13.7	62.7
10588	qtz monzodiorite	384	11.2	13.5	54.9	4.7	10.4	3.4	0.0	0.0	1.8	0.0		84.4	16.0	18.8	65.1
10870	monzogranite	360	31.9	25.6	32.2	0.0	3.6	3.6	0.0	2.8	0.3	0.0		89.7	35.6	28.5	35.9
10957	monzogranite	356	30.9	21.9	36.5	0.0	1.7	0.3	0.8	7.9	0.0	0.0	Has quartzite inclusion	89.3	34.6	24.5	40.9
10958A	granodiorite	364	14.3	6.6	48.6	10.7	7.7	3.0	8.2	0.0	0.8	0.0		80.2	24.5	14.9	60.6
10958B	granodiorite	358	12.3	5.9	46.6	10.3	8.7	5.6	9.2	0.3	0.8	0.3	Oth: Ap	75.1	23.2	14.7	62.1
11163	granodiorite	393	34.4	14.2	41.2	0.0	8.9	1.0	0.0	0.0	0.3	0.0		89.8	38.2	15.9	45.9
11165	granodiorite	381	35.2	13.1	41.7	0.0	6.6	0.3	0.0	3.1	0.0	0.0		90.0	39.1	14.6	46.4
11166	qtz diorite	387	11.9	4.4	67.4	0.0	6.5	1.0	5.4	3.4	0.0	0.0		83.7	14.2	5.2	80.6
11176	granodiorite	364	28.0	17.3	44.2	0.0	6.3	1.6	1.1	0.3	1.1	0.0		89.6	31.3	19.3	49.4
11199	granodiorite	359	29.2	18.1	39.6	0.0	7.8	2.8	0.0	1.1	1.4	0.0		86.9	33.7	20.8	45.5
11200	granodiorite	348	24.7	9.5	44.3	6.6	7.2	5.7	0.0	1.1	0.9	0.0		85.1	32.9	15.0	52.0
11202C	tonalite	319	21.0	6.0	55.8	0.0	7.8	0.0	6.0	3.4	0.0	0.0	Has basalt inclusion	82.8	25.4	7.2	67.4
11202F	qtz monzodiorite	396	13.6	9.1	49.2	1.8	13.4	2.0	10.1	0.8	0.0	0.0		73.7	19.7	13.5	66.8
11205	granodiorite	358	18.7	6.7	47.2	1.7	8.7	3.9	11.2	1.4	0.6	0.0		74.3	26.3	10.2	63.5
11208	granodiorite	358	22.6	15.4	46.1	0.0	6.4	1.4	5.3	0.3	2.5	0.0	Some Act	84.1	26.9	18.3	54.8
11209	granodiorite	354	20.6	8.8	46.9	0.0	5.4	3.1	12.7	1.7	0.8	0.0		76.3	27.0	11.5	61.5
11210	qtz monzodiorite	350	12.9	6.6	49.1	1.1	6.6	4.9	16.3	0.3	2.3	0.0		69.7	19.3	10.2	70.5
11211	qtz monzodiorite	380	15.5	20.5	47.9	0.8	6.3	1.6	6.8	0.0	0.5	0.0	Basalt, rhyolite inclusions	84.7	18.8	24.7	56.5
11212	qtz monzodiorite	357	14.0	5.9	51.0	0.0	7.6	6.2	12.9	0.0	2.5	0.0		70.9	19.8	8.3	71.9
11213	granodiorite	364	23.1	6.9	50.8	0.0	7.4	2.2	8.0	1.1	0.5	0.0	Has basalt inclusion	80.8	28.6	8.5	62.9
11239	tonalite	363	20.9	2.5	50.1	0.0	11.0	5.2	9.9	0.0	0.3	0.0		73.6	28.5	3.4	68.2
11240	tonalite	355	25.6	2.5	49.3	0.0	7.6	13.2	1.1	0.0	0.3	0.3	Oth: hematite	77.5	33.1	3.3	63.6
11241	granodiorite	377	12.7	6.9	48.0	7.2	7.4	2.9	13.5	0.0	1.3	0.0		74.8	21.8	14.0	64.2
11259	granodiorite	375	29.1	13.3	53.9	0.0	3.5	0.0	0.0	0.3	0.0	0.0	Chill zone	96.3	30.2	13.9	56.0

Key to abbreviations: *A = alkali feldspar, Act = actinolite, Bt = biotite, Chl = chlorite, Ep/Zo = epidote and zoisite, Hb = horneblende, Gran = granophyric and myrmekitic grains, Op = opaque grains, Oth = others, P = plagioclase, Q = quartz, Rut = rutile, Sp = sphene (titanite).*

Note: *Gran grains were tabulated as 1/2 Q and 1/2 A.*

Appendix 1 - B. Point count data for granodiorite correlative to the Stoneham Granodiorite from Smith (1985) and point count data from the Wanapanaquin Hill Porphyry (Zwap)

Zst - Calculation from point count data of Smith (1985, Table 8).

Sample	IUGS rock name	Q	A	P	Hb	Sp	Oth		QAP tot	Qnrm	Anrm	Pnrm	Location
DG-4	tonalite	21.2	2.1	61.2	8.7	0	0		93.2	22.7	2.3	65.7	0.4 km W of BM106, Wakefield, Boston North Quad.
BN-18C	granodiorite	42.6	8.7	44.4	4.2	0	0		95.7	44.5	9.1	46.4	0.68 km WNW BM 106, Wakefield, Boston North Quad.
BN-21	granodiorite	33.4	7.8	48.2	10.4	0.2	0		89.4	37.4	8.7	53.9	1.85 km NE BM 133 Oakland Vale, Boston North Quad.
BN-21A	tonalite	33.4	3.0	50.8	6.0	1.3	0		94.5	35.3	3.2	53.8	1.6 km NE BM 133 Oakland Vale, Boston North Quad.

Zwap Sample	IUGS rock name	Count Total	Percentages: Q	A	P	Gran	Chl+Op	Ep/Zo	Hb	Bt	Sp	Oth	Notes		Normalized percentages: QAP tot	Qnorm	Anorm	Pnorm
11149	granodiorite	368	15.5	0.8	60.9	12.2	9.0	0.5	0.0	0.0	0.8	0.3	Oth: Zir		89.4	24.2	7.8	68.1
11156	granodiorite	371	13.7	0.5	56.3	18.3	10.8	0.0	0.0	0.0	0.3	0.0	Fine, rut seen		88.9	25.8	10.9	63.3

Key to abbreviations: *A = alkali feldspar, Act = actinolite, Bt = biotite, Chl = chlorite, Ep/Zo = epidote and zoisite, Hb = horneblende, Gran = granophyric and myrmekitic grains, Op = opaque grains, Oth = others, P = plagioclase, Q = quartz, Rut = rutile, Sp = sphene (titanite), Zir = zircon.*

Note: *Gran grains were tabulated as 1/2 Q and 1/2 A.*

Appendix 1 - C. CIPW Norm % data for volcanic units from the Wakefield Formation in the Lynn Volcanic Complex in the northern and southern Fells, Stoneham, Melrose, and Wakefield from tuff units (normalized XRF data of Smith, 1985) and flow units (normalized LA-ICPMS data of Hampton, 2017).

Sample	*IUGS rock*	*Q*	*A*	*P*	*QAP tot*	*Qnorm*	*Anorm*	*Pnorm*	*Location*
Wakefield Fm. at Wamoset Hill and Sewall Woods area									
MLY-57	rhyolite	33.1	21.5	42.3	96.9	34.2	22.2	43.7	0.25 km NNW BM66, Melrose, Boston N Quad., crystal tuff from Smith (1985, Table 10)
RH1635	dacite	30.1	27.3	39.6	97.0	31.0	28.1	40.8	S of Whip Hill, Stoneham, Boston North Quad., flow
Wakefield Fm. In Stoneham and Wakefield									
MLY-52	dacite	34.2	19.0	41.1	94.3	36.3	20.1	43.6	blasting site, 0.85 km W Castle Hill BM, Wakefield, Boston N Quad., lithic tuff from Smith (1985, Table 10)
MLY-53	dacite	21.3	18.0	53.1	92.4	23.1	19.5	57.5	0.45 km SW Castle Hill BM, Wakefield, Boston N Quad., tuff from Smith (1985, Table 10)
BN-20	rhyolite	33.1	27.1	36.7	96.9	34.2	28.0	37.9	0.2 km W Castle Hill BM, Wakefield, Boston N Quad., tuff from Smith (1985, Table 10)
BN-20A	dacite	25.2	21.1	49.5	95.8	26.3	22.0	51.7	0.2 km W Castle Hill BM, Wakefield, Boston N Quad., tuff from Smith (1985, Table 10)
BN-15A	rhyolite	27.2	24.6	43.6	95.4	28.5	25.8	45.7	tennis courts Stoneham HS, 1.11 km WNW High Rock BM, Boston N Quad., tuff from Smith (1985, Table 10)
BN-19	rhyolite	35.4	25.0	36.8	97.2	36.4	25.7	37.9	W end playground, 0.7 km E BM106, Wakefield, Boston N Quad., tuff from Smith (1985, Table 10)
RH1625	rhyolite	33.3	26.6	37.1	97.0	34.3	27.4	38.2	N end of Middle Reservoir, flow

Appendix 1: D. Point Count data for the Lawrence Woods Granophyre (Zlwg) along with Rams Head inclusion (Zrhp) in Zlwg (site 10979)

Zlwg		Count	Percentages:												Normalized percentages:			
Sample	**IUGS rock name**	**Total**	**Q**	**A**	**P**	**Gran**	**Op**	**Chl**	**Ep/Zo**	**Hb**	**Bt**	**Sp**	**Oth**	**Notes**	**QAP tot**	**Qnorm**	**Anorm**	**Pnorm**
864BN	monzogranite	361	6.1	1.1	37.1	46.8	1.9	5.3	1.4	0.0	0.0	0.3	0.0		91.1	32.4	26.9	40.7
10234	monzogranite	364	30.5	19.2	34.3	9.1	1.1	5.8	0.0	0.0	0.0	0.0	0.0		93.1	37.6	25.5	36.9
10253	monzogranite	384	16.4	23.7	34.6	16.7	2.1	5.7	0.8	0.0	0.0	0.0	0.0		91.4	27.1	35.0	37.9
10478B	monzogranite	411	5.8	2.4	29.0	57.9	1.7	1.0	0.7	1.5	0.0	0.0	0.0		95.1	36.6	33.0	30.4
10491	monzogranite	406	17.7	1.5	24.9	51.7	1.0	2.2	0.2	0.2	0.2	0.2	0.0		95.8	45.5	28.5	26.0
10510	syenogranite	393	13.7	5.6	19.8	57.0	1.5	2.0	0.3	0.0	0.0	0.0	0.0		96.2	43.9	35.4	20.6
10511	syenogranite	406	4.2	2.7	20.2	65.5	0.5	3.2	1.0	0.0	0.0	2.7	0.0		92.6	39.9	38.3	21.8
10516	monzogranite	383	28.2	27.2	33.4	2.1	3.7	4.7	0.8	0.0	0.0	0.0	0.0		90.9	32.2	31.0	36.8
10520	monzogranite	404	25.7	28.7	26.5	15.3	1.7	0.7	1.0	0.0	0.0	0.2	0.0		96.3	34.7	37.8	27.5
10532	monzogranite	381	17.3	24.9	37.0	9.4	1.6	5.5	3.4	0.0	0.0	0.8	0.0		88.7	24.9	33.4	41.7
10624	syenogranite	416	7.0	4.6	16.6	68.8	0.5	0.7	0.7	1.0	0.0	0.2	0.0		96.9	42.7	40.2	17.1
10625	monzogranite	365	10.1	6.0	37.3	37.0	3.0	1.6	1.9	2.2	0.0	0.3	0.5	Oth: 2-Mx	91.0	31.5	27.0	41.0
10638	syenogranite	359	10.9	12.3	21.2	49.6	0.0	1.9	4.2	0.0	0.0	0.0	0.0		93.9	38.0	39.5	22.6
10642	syenogranite	354	27.1	20.1	19.2	26.3	2.0	1.4	3.4	0.3	0.0	0.3	0.0		92.7	43.4	35.8	20.7
10660B	granodiorite	390	8.2	3.1	40.8	36.7	3.8	5.9	1.5	0.0	0.0	0.0	0.0		88.7	29.9	24.1	46.0
10751	monzogranite	396	27.5	17.9	30.3	17.7	3.3	3.0	0.3	0.0	0.0	0.0	0.0		93.4	38.9	28.6	32.4
10760	syenogranite	391	8.7	1.5	17.6	63.4	2.3	3.3	2.8	0.0	0.0	0.3	0.0		91.3	44.3	36.4	19.3
10886	monzogranite	366	20.8	15.8	30.9	18.0	1.4	5.5	7.7	0.0	0.0	0.0	0.0		85.5	34.8	29.1	36.1
10929	monzogranite	362	21.0	16.9	36.5	16.3	2.2	5.8	1.1	0.0	0.0	0.3	0.0		90.6	32.2	27.6	40.2
10981	monzogranite	363	19.3	17.4	37.7	12.9	0.6	4.7	7.4	0.0	0.0	0.0	0.0		87.3	29.5	27.3	43.2
10983	monzogranite	362	23.8	26.2	30.4	0.0	5.2	8.3	6.1	0.0	0.0	0.0	0.0		80.4	29.6	32.6	37.8
10989	monzogranite	383	29.0	24.3	37.3	0.0	2.6	3.9	1.3	0.0	0.0	0.3	0.0		90.6	32.0	26.8	41.2
10990	monzogranite	361	22.4	21.1	38.8	8.0	1.7	5.3	1.1	0.0	0.0	0.0	0.0		90.3	29.3	27.8	42.9
10999	granodiorite	375	25.6	14.1	44.0	6.1	2.4	4.5	2.4	0.0	0.0	0.3	0.0		89.9	31.9	19.1	49.0
11002	monzogranite	363	27.0	31.4	34.4	0.3	2.2	2.8	1.4	0.3	0.0	0.3	0.0		93.1	29.1	33.9	37.0
11060	monzogranite	345	22.9	31.9	31.9	0.0	2.0	4.9	4.9	0.0	0.0	1.4	0.0		86.7	26.4	36.8	36.8
10979*	qtz monzodiorite	369	14.9	11.4	57.2	0.0	2.4	6.2	3.3	4.6	0.0	0.0	0.0		83.5	17.9	13.6	68.5

*sample 10979 is inclusion of Zrhp

Key to abbreviations: *A = alkali feldspar, Bt = biotite, Chl = chlorite, Ep/Zo = epidote and zoisite, Hb = horneblende, Gran = granophyric and myrmekitic grains, Mx = fine matrix, Op = opaque grains, Oth = others, P = plagioclase, Q = quartz, Sp = sphene (titanite).*

Note: *Gran grains were tabulated as 1/2 Q and 1/2 A.*

Appendix 1: D. (cont.). Point count data for the Lawrence Woods Granophyre (Zlwg) from Smith (1985, Table 8).

Norm calculation of XRF data from Smith (1985).

Sample	*IUGS rock name*	*Q*	*A*	*P*	*Gran*		*QAP tot*	*Qnorm*	*Anorm*	*Pnorm*	*Location*
G-1	qtz monzo diorite	14.6	23.3	54.9	0		92.8	15.7	25.1	59.2	Parking lot behind Lawrence Memorial Hospital, Smith (1985), Table 17 (XRF CIPW Norm)
LY-36	granodiorite	20.39	21.69	48.18	0		90.3	22.6	24.0	53.4	0.8 km WSW Windy BM, Malden, Boston North Quad., Smith (1985), Table 17 (XRF CIPW Norm)
LY-41	qtz monzo diorite	17.68	19.44	53.0	0		90.1	19.6	21.6	58.8	1.3 km ENE BM45, Malden, Boston North Quad., Smith (1985), Table 17 (XRF CIPW Norm)
LY-45	granodiorite	20.84	18.4	51.7	0		90.9	22.9	20.2	56.9	0.35 km W BM 93, Medford, Boston North Quad., Smith (1985), Table 17 (XRF CIPW Norm)

Appendix 1 - E. Point Count data for the Rams Head Porphyry (Zrhp) and separate diorite/gabbro (Zdg).

Zrhp	*IUGS rock*	*Count*	*Percentages:*											*Normalized percentages:*			
Sample	***name***	***total***	***Q***	***A***	***P***	***Op***	***Chl***	***Ep/Zo***	***Hb***	***Bt***	***Sp***	***Oth***	***Notes***	***QAP tot***	***Qnorm***	***Anorm***	***Pnorm***
192	tonalite	392	24.2	3.3	59.2	1.3	6.4	1.0	2.8	0.0	0.8	1.0	Oth: 4-Cc	86.7	27.9	3.8	68.2
818	tonalite	342	15.5	1.2	58.5	0.9	6.7	7.0	7.6	1.2	1.5	0.0		75.1	20.6	1.6	77.8
10725B	granodiorite	398	20.4	7.5	56.5	2.8	0.8	3.0	6.5	1.8	0.8	0.0		84.4	24.1	8.9	67.0
10730	granodiorite	390	18.5	7.4	58.2	2.3	2.1	1.8	5.9	2.8	1.0	0.0		84.1	22.0	8.8	69.2
10733B	qtz diorite	381	15.2	5.8	64.6	1.0	0.8	2.9	6.0	2.6	0.8	0.3	Oth: Rut	85.6	17.8	6.7	75.5
10963	tonalite	394	21.1	1.5	53.8	1.3	0.0	4.1	9.1	7.4	1.0	0.8	Oth: 3-Rut	76.4	27.6	2.0	70.4
10966	granodiorite	367	25.1	6.5	53.1	1.1	3.0	3.0	1.4	6.0	0.8	0.0		84.7	29.6	7.7	62.7
10969	qtz diorite	382	16.5	3.7	66.5	1.0	0.8	0.0	5.2	3.9	1.8	0.5	Oth: 1 - Rut, 1 - Ap	86.6	19.0	4.2	76.7
10992	qtz diorite	385	16.4	3.1	66.2	2.1	7.0	3.6	0.0	0.5	0.8	0.3	Oth: Ap	85.7	19.1	3.6	77.3
10997	tonalite	349	16.9	4.0	59.6	2.0	0.9	0.3	6.6	7.4	2.0	0.3	Oth: Ap	80.5	21.0	5.0	74.0
11004	qtz diorite	396	17.2	7.1	64.6	1.3	6.3	0.8	0.0	1.0	0.8	1.0	Oth: 1-Ap, 3-Rut	88.9	19.3	8.0	72.7
11016	tonalite	383	20.4	5.0	54.3	3.1	9.1	3.7	0.0	3.9	0.5	0.0		79.6	25.6	6.2	68.2
11017	tonalite	352	19.9	2.8	58.8	3.7	11.4	0.9	0.0	2.3	0.3	0.0		81.5	24.4	3.5	72.1
11267*	diorite	370	0.8	0.3	40.5	3.8	0.0	4.3	49.2	0.0	0.3	0.8	Oth: 3-Ap	41.6	1.9	0.6	97.4

*sample 11267 is an isolated outcrop along an E-W trending fault west of South Reservoir that appears to be a separate diorite unit (Zdg).

Key to abbreviations: *A = alkali feldspar, Ap = apatite, Bt = biotite, Cc = calcite, Chl = chlorite, Ep = epidote, Hb = horneblende, Op = opaque grains, Oth = others, Q = quartz, P = plagioclase, Rut = rutile, Ser = sericite, Sp = sphene (titanite), Zo = zoisite.*

Appendix 1 - F. CIDW Norm% XRF data for the Boojum Rock Tuff (Zbrc) in the Lynn Volcanic Complex. Data from Smith (1985).

CIPW Norm% of XRF analysis from Smith (1985)

Sample	*IUGS rock*	*Q*	*A*	*P*		*QAP tot*	*Qnrm*	*Anrm*	*Pnrm*	
MLY-44	andesite	17.1	18.4	53.6		89.1	19.2	20.7	60.2	Smith (1985), Table 15
MLY-45	andesite	13.2	15.1	60.0		88.3	14.9	17.1	68.0	Smith (1985), Table 12

Appendix 1 - G. Point Count data for the Spot Pond Granodiorite (Zsg) and its alkaline areas (Zsgk) (cont. on next page).

Zsg		Count	Percentages:										Normalized percentages:			
Sample	**IUGS rock name**	**total**	**Q**	**A**	**P**	**Chl+Op**	**Ser**	**Ep**	**Bt**	**Sp**	**Oth**	**Notes**	**QAP tot**	**Qnorm**	**Anorm**	**Pnorm**
165	myl granodiorite	300	50.0	8.0	34.0	8.0	0.0	0.0	0.0	0.0	0.0	polycrystalline Q	92.0	54.3	8.7	37.0
326	granodiorite	900	34.9	15.0	40.2	4.4	0.0	4.6	0.0	0.7	0.2	3 sections counted	90.1	38.7	16.6	44.6
10283	monzogranite	298	44.0	18.1	16.8	3.0	10.7	7.0	0.0	0.3	0.0		78.9	55.7	23.0	21.3
10288	tonalite	290	44.8	0.7	42.1	3.4	0.0	8.6	0.0	0.3	0.0	Cataclastic areas	87.6	51.2	0.8	48.0
10477	granodiorite	300	31.3	17.0	42.7	4.7	0.0	4.0	0.0	0.3	0.0		91.0	34.4	18.7	46.9
10490	granodiorite	300	39.3	9.0	37.0	6.0	0.0	8.3	0.0	0.3	0.0	Brecciated	85.3	46.1	10.5	43.4
10518	granodiorite	300	38.7	10.0	41.3	8.0	0.0	0.0	0.0	2.0	0.0		90.0	43.0	11.1	45.9
10562	granodiorite	300	39.7	5.3	47.3	6.0	0.0	1.7	0.0	0.0	0.0	Cataclastic areas	92.3	43.0	5.8	51.3
10621	granodiorite	300	31.7	7.3	44.0	7.3	0.3	9.3	0.0	0.0	0.0	Fractured	83.0	38.2	8.8	53.0
10675	granodiorite	300	35.0	6.7	46.7	5.0	0.0	5.7	0.0	1.0	0.0		88.3	39.6	7.5	52.8
10700	tonalite	301	26.2	5.3	54.5	10.0	0.0	2.3	0.3	1.0	0.3		86.0	30.5	6.2	63.3
10732	monzogranite	300	41.3	17.7	30.7	0.3	0.0	9.7	0.0	0.3	0.0		89.7	46.1	19.7	34.2
10736	granodiorite	300	40.3	8.7	44.7	4.7	0.3	1.3	0.0	0.0	0.0	polycrystalline Q	93.7	43.1	9.3	47.7
10740	myl tonalite	300	24.7	3.0	58.3	7.3	6.3	0.3	0.0	0.0	0.0	polycrystalline Q	86.0	28.7	3.5	67.8
10817	myl granodiorite	300	40.0	9.0	44.3	3.7	0.0	0.0	2.3	0.3	0.3	polycrystalline Q	93.3	42.9	9.6	47.5
10890	granodiorite	300	36.0	5.3	41.3	9.7	0.0	6.7	0.0	1.0	0.0	ophitic P in A	82.7	43.5	6.5	50.0
10941	granodiorite	600	33.7	9.0	44.8	10.7	0.0	1.8	0.0	0.0	0.0	2 sections counted	87.5	38.5	10.3	51.2
10964	granodiorite	300	28.7	19.7	48.0	3.0	0.0	0.3	0.0	0.3	0.0		96.3	29.8	20.4	49.8
10973	tonalite	300	46.0	0.7	42.0	10.7	0.0	0.3	0.0	0.3	0.0		88.7	51.9	0.8	47.4
10986	tonalite	910	25.4	5.5	55.7	9.6	0.1	3.1	0.0	0.5	0.1	3 sections counted	86.6	29.3	6.3	64.3
11000	granodiorite	300	43.7	5.7	38.0	12.0	0.0	0.0	0.0	0.7	0.0		87.3	50.0	6.5	43.5
11001	granodiorite	600	40.0	12.0	38.8	7.5	0.0	1.0	0.0	0.7	0.0	2 sections counted	90.8	44.0	13.2	42.8
11261	granodiorite	300	30.0	15.3	47.3	5.0	0.0	1.7	0.0	0.7	0.0		92.7	32.4	16.5	51.1
11291	myl tonalite	900	32.6	0.0	45.6	20.8	0.6	0.1	0.0	0.3	0.1	3 sections counted	78.1	41.7	0.0	58.3

Key to abbreviations: *A = alkali feldspar, Bt = biotite, Chl = chlorite, Ep = epidote, myl = mylonitic, Op = opaque grains, Oth = others, P = plagioclase, Q = quartz, Ser = sericite, Sp = sphene (titanite).*

Zsgk		Percentages:							Normalized percentages:			
Sample	**IUGS rock name**	**Q**	**A**	**P**	**Chl+Op**	**Ep**	**Oth**	**Notes**	**QAP Tot**	**Q norm**	**A norm**	**P norm**
10261	monzogranite	31.0	42.0	24.7	1.0	1.3	0.0	very clean	97.7	31.7	43.0	25.3
10469	syenogranite	35.3	56.3	7.3	1.0	0.0	0.0	very altered	99.0	35.7	56.9	7.4
10634	syenogranite	31.3	49.0	9.3	2.0	0.0	8.3	Oth: cataclastite	89.7	34.9	54.6	10.4
10993A	monzogranite	20.0	32.3	42.3	4.3	1.0	0.0	Cc veins, altered Bt	94.7	21.1	34.2	44.7
11008	syenogranite	25.7	55.7	18.0	0.7	0.0	0.0		99.3	25.8	56.0	18.1
11121	alkali granite	28.7	69.3	2.0	0.0	0.0	0.0		100.0	28.7	69.3	2.0

Key to abbreviations: *A = alkali feldspar, Bt = biotite, Cc = calcite, Chl = chlorite, Ep = epidote, Op = opaque grains, Oth = others, Q = quartz, P = plagioclase.*

Appendix 1 - G. (cont.) Point count data from Smith (1985) and CIDW Norm% data from Hampton (2017, LA-ICPMS analysis) for the Spot Pond Granodiorite (Zsg).

Point count/CIPW Norm analyses from Smith (1985) and RH1629 from Hampton (2019).

Sample	Rock name	Q	A	P	QAP tot	Qnorm	Anorm	Pnorm	
BN-8	granodiorite	34.5	10.0	51.5	96.0	35.9	10.4	53.6	NW side Rts. 129 & 1, 2.2 km E Castle Hill BM, Saugus, Boston North Quad. From Smith (1985, Table 8)
BN-2K	granodiorite	29.7	11.4	44.5	85.6	34.7	13.3	52.0	Rear Kmart, Rt. 1 W, 1.1 km N Felton BM, Saugus, Boston North Quad. From Smith (1985, Table 8)
DG-3	granodiorite	31.5	11.8	47.3	90.6	34.8	13.0	52.2	Ethan Allen pkg lot, Rt. 1 E, 1.8 km NW BM21 Oakland Vale, Boston N. Quad. From Smith (1985, Table 8)
BN-7	granodiorite	28.6	17.8	45.5	91.9	31.1	19.4	49.5	1.85 km NW BM21, Oakland Vale, Boston North Quad. From Smith (1985, Table 8)
BN-1	granodiorite	39.5	14.0	43.5	97.0	40.7	14.4	44.8	0.85 km NE BM21, Saugus, Boston North Quad. From Smith (1985, Table 8
RH1629	granodiorite	26.8	15.8	47.9	90.5	29.6	17.5	52.9	CIDW Norm% from La-ICPMS analysis in Fells

Appendix 1 - H. Point Count data for the Winchester Granite (Zwg) and diorite inclusion (Zwgd) – (cont. on next page)

Zwg	IUGS rock	Count	Percentages:													
Sample	**name**	**Total**	**Q**	**A**	**P**	**Chl-Op**	**Ep/Zo**	**Hb**	**Bt**	**Sp**	**Mx**	**Notes**	**QAP tot**	**Qnorm**	**Anorm**	**Pnorm**
10838	monzogranite	375	26.4	21.6	33.6	13.1	5.1	0.0	0.3	0.0	0.0	Near Znpm, very orange	81.6	32.4	26.5	41.2
11053	granodiorite	376	16.5	9.9	30.3	8.5	2.2	6.1	0.0	0.0	26.4	Chill zone <u>w</u> Zvw.	83.2	30.5	22.5	47.0
11058	monzogranite	377	27.0	19.8	32.8	11.9	3.5	4.1	0.0	0.9	0.0	A ophitic host of P	79.7	33.9	24.8	41.2
11065	monzogranite	378	27.3	19.9	36.7	6.9	3.1	3.1	2.6	0.5	0.0	A ophitic host of P	83.9	32.5	23.7	43.8
11067	monzogranite	379	20.5	24.1	39.6	8.4	1.8	2.9	2.6	0.0	0.0	A ophitic host of P	84.3	24.3	28.7	47.0
11071	monzogranite	380	22.6	20.7	34.0	19.7	1.3	0.8	0.3	0.5	0.0	A ophitic host of P	77.4	29.2	26.8	44.0
11077	granodiorite	381	29.6	10.4	42.0	14.6	1.4	1.1	0.8	0.0	0.0		82.0	36.1	12.7	51.2
11095	granodiorite	382	26.5	10.9	43.7	4.2	0.8	9.2	4.5	0.3	0.0		81.1	32.6	13.4	54.0
11097	monzogranite	383	25.8	20.2	29.6	13.2	5.0	5.3	0.6	0.3	0.0		75.7	34.1	26.7	39.1
11119	tonalite	384	28.0	2.6	51.1	14.0	0.3	3.7	0.3	0.0	0.0		81.7	34.3	3.1	62.6
11122	granodiorite	385	19.1	16.6	44.3	14.6	0.3	3.1	2.0	0.0	0.0		80.0	23.9	20.7	55.4
11123	granodiorite	386	23.9	10.8	43.9	11.1	2.2	4.4	3.6	0.0	0.0		78.6	30.4	13.8	55.8
11130	granodiorite	387	24.3	15.5	42.4	13.9	2.7	0.8	0.5	0.0	0.0		82.1	29.5	18.8	51.6
11193	granodiorite	388	27.8	16.3	42.0	13.3	0.3	0.3	0.0	0.0	0.0		86.1	32.3	18.9	48.8
11220	granodiorite	390	27.9	14.6	38.3	3.7	0.6	5.4	9.6	0.0	0.0		80.8	34.5	18.1	47.4
11222	granodiorite	391	27.2	18.6	41.3	9.2	2.5	0.5	0.0	0.7	0.0		87.1	31.3	21.3	47.4
11225	granodiorite	392	24.0	6.9	47.0	20.4	0.3	0.8	0.0	0.6	0.0	Highly altered	77.9	30.9	8.9	60.3
11229	tonalite	394	29.4	4.0	52.6	2.9	0.0	2.6	8.6	0.0	0.0		86.0	34.2	4.7	61.1
11230	granodiorite	395	26.9	15.0	40.7	2.7	0.0	2.7	12.0	0.0	0.0		82.6	32.6	18.1	49.3
11231	monzogranite	396	25.1	23.7	37.3	7.9	0.8	3.7	1.1	0.3	0.0	Op clusters	86.2	29.2	27.5	43.3
11237	tonolite	397	30.4	5.1	50.4	13.8	0.3	0.0	0.0	0.0	0.0		85.9	35.4	5.9	58.7
11238	granodiorite	398	18.7	17.6	48.8	13.5	0.0	0.0	0.3	1.1	0.0		85.1	22.0	20.7	57.3
11262	granodiorite	399	25.6	12.2	45.8	13.6	2.8	0.0	0.0	0.0	0.0		83.6	30.6	14.6	54.8
11264	granodiorite	400	18.0	16.6	47.5	11.8	4.2	0.0	1.1	0.8	0.0	Rut seen	82.0	21.9	20.2	57.9
11273	granodiorite	401	26.7	10.0	38.6	10.8	13.9	0.0	0.0	0.0	0.0	Part cataclastic	75.3	35.4	13.3	51.3
11308#	syenogranite	402	42.6	36.7	18.4	2.1	0.3	0.0	0.0	0.0	0.0	Cataclastic, chill zone	97.6	43.6	37.6	18.8
11219*	qtz diorite	389	12.4	5.3	49.7	12.6	2.5	14.6	2.2	0.6	0.0	qtz diorite inclusion	67.4	18.3	7.9	73.8
11228*	qtz diorite	393	11.0	2.6	49.9	4.2	1.6	29.0	0.0	1.8	0.0	qtz diorite inclusion	63.4	17.3	4.1	78.6

** samples 11219 and 11228 are inclusions of mafic-rich quartz diorite (Zwgd).*

 # sample11308 is alkaline chill zone next to Nanepashemet Formation (Znpm).

***Key to abbreviations:** A = alkali feldspar, Bt = biotite, Chl = chlorite, Ep/Zo = epidote and zoisite, Hb = horneblende, Mx = very fine matrix area, Op = opaque grains, P = plagioclase, Q = quartz, Rut = rutile, Sp = sphene (titanite).*

***Note:** Mx areas were tabulated as 1/3 Q, 1/3 A and 1/3 P.*

Appendix 1 - H. (cont.) CIDW Norm% data for the Winchester Granite (Zwg) from Hampton (2017; LA-ICPMS data).

CIPW Norm% of LA-ICPMS analysis from Hampton (2019)

Sample	*IUGS rock*	*Q*	*A*	*P*		*QAP tot*	*Qnrm*	*Anrm*	*Pnrm*
RH1631-1	granodiorite	25.8	17.4	48.2		91.4	28.2	19.0	52.7
RH1631-2	granodiorite	25.5	17.7	47.9		91.1	28.0	19.4	52.6

Appendix 2 - A. Point count data for crystal tuff in the Wakefield Formation (Zlvx) of the Lynn Volcanic Complex. Every count is at least 300 points with the exception of a few samples at Straw Point. Points are on a 1.5 mm grid. Categories are defined at end of appendix.

Wakefield Formation		Crystals:					Lithic Fragments:				Matrx	Minerals/Veins:			Total	Percentages: Whole Rock (minus Mn/Vn)				Percentages: Crystal types (Minus Op)			
Crystal tuff - Zvlx		Q	P	A	H-B	Op	volc	bas	qt/arg	ign		Chl	Epid	Qt/Ox	**Count**	Total	Xals	Frag	Matrx	Total	P	Q+A	HB
10554B1	Straw Pt	6.3	38.7	0.3	0.0	2.6	11.4	7.6	25.0	0.0	192	0	0	1	285	284	16.9	15.5	67.6	45.4	85.4	14.6	0.0
10554B2	Straw Pt	4.6	32.8	0.8	1.0	2.9	7.7	2.6	26.8	0.0	203	0	0	0	282	282	14.9	13.1	72.0	39.1	83.7	13.8	2.5
10611	Straw Pt	2.0	46.4	1.1	1.1	5.4	23.3	2.5	17.2	0.0	222	3	1	1	326	321	17.4	13.4	69.2	50.6	91.6	6.1	2.2
10615	Straw Pt	4.0	33.3	0.0	0.7	5.0	3.9	6.1	32.1	0.0	116	1	0	0	202	201	21.4	20.9	57.7	38.0	87.7	10.6	1.7
10616	Straw Pt	8	109	3	0	3	11	0	4	0	199	0	1	1	339	337	36.5	4.5	59.1	120	90.8	9.2	0.0
11254	Straw Pt	7	51	3	6	2	1	0	73	1	225	1	0	0	370	369	18.7	20.3	61.0	67	76.1	14.9	9.0
669BN	Spot Pd	19	144	5	5	1	2	0	1	1	198	0	0	0	376	376	46.3	1.1	52.7	173	83.2	13.9	2.9
10418	Spot Pd	20	122	11	2	4	27	0	1	3	194	0	0	1	385	384	41.4	8.1	50.5	155	78.7	20.0	1.3
11245	Spot Pd	24	141	14	1	3	19	1	0	2	173	0	0	2	380	378	48.4	5.8	45.8	180	78.3	21.1	0.6
10600	Stone Zoo	9	52	2	0	1	48	0	0	0	220	0	1	8	341	332	19.3	14.5	66.3	63	82.5	17.5	0.0
10345B	Wamoset	8	48	7	4	1	80	0	0	11	216	0	0	1	376	375	18.1	24.3	57.6	67	71.6	22.4	6.0
10362	Wamoset	29	140	6	4	6	30	0	0	0	168	0	0	2	385	383	48.3	7.8	43.9	179	78.2	19.6	2.2
595BN	Whip Hill	10	60	2	1	6	124	0	1	0	176	6	0	7	393	380	20.8	32.9	46.3	73	82.2	16.4	1.4
10376	Whip Hill	12	49	3	1	4	128	0	28	2	192	1	0	0	420	419	16.5	37.7	45.8	65	75.4	23.1	1.5
11389B	Whip Hill	7	94	3	2	4	50	0	1	0	241	3	3	3	411	402	27.4	12.7	60.0	106	88.7	9.4	1.9
10368A	Whip Hill	9	61	2	4	5	52	0	13	0	259	0	0	0	405	405	20.0	16.0	64.0	76	80.3	14.5	5.3
10368B	Whip Hill	7	54	0	3	2	74	0	3	0	223	0	0	0	366	366	18.0	21.0	60.9	64	84.4	10.9	4.7
10371B	Whip Hill	3	53	0	0	2	62	0	0	0	280	0	0	0	400	400	14.5	15.5	70.0	56	94.6	5.4	0.0
10572	Whip Hill	4	35	0	3	4	19	0	0	0	227	2	0	1	295	292	15.8	6.5	77.7	42	83.3	9.5	7.1
10407C	Doleful Pd	20	155	11	4	1	34	0	0	1	188	0	0	0	414	414	46.1	8.5	45.4	190	81.6	16.3	2.1
10411	Doleful Pd	24	126	4	10	4	0	0	0	0	245	0	0	0	413	413	40.7	0.0	59.3	164	76.8	17.1	6.1
10593	Doleful Pd	6	49	0	1	1	31	0	0	0	239	0	5	2	334	327	17.4	9.5	73.1	56	87.5	10.7	1.8

Appendix 2 – A (cont.). Point count data for crystal tuff in the Wakefield Formation (Zlvx) of the Lynn Volcanic Complex.

(cont.) Wakefield Formation		Crystals:					Lithic Fragments:				Matrx	Minerals/Veins:			Total	Percentages: Whole Rock (minus Min/Vns)				Percentages: Crystal types (Minus Op)			
Crystal tuff - Zvlx		*Q*	*P*	*A*	*H-B*	*Op*	*volc*	*bas*	*qt/arg*	*ign*		*Chl*	*Epid*	*Qt/Ox*	***Count***	*Total*	*Xals*	*Frag*	*Matrx*	*Total*	*P*	*Q+A*	*HB*
10745	L. Pine Hill	9	22	0	1	1	5	0	0	0	247	1	15	2	303	285	11.6	1.8	86.7	32	68.8	28.1	3.1
881BNA	Pine Hill	11	32	2	2	2	69	0	9	5	206	0	0	13	351	338	14.5	24.6	60.9	47	68.1	27.7	4.3
881BNC	Pine Hill	7	69	2	1	3	76	1	5	6	218	0	1	2	391	388	21.1	22.7	56.2	79	87.3	11.4	1.3
10493	Pine Hill	11	76	0	2	5	18	0	0	11	240	1	0	3	367	363	25.9	8.0	66.1	89	85.4	12.4	2.2
10497	Pine Hill	4	26	1	1	2	86	0	32	1	201	0	0	2	356	354	9.6	33.6	56.8	32	81.3	15.6	3.1
10498	Pine Hill	5	36	1	1	0	98	6	16	0	218	0	0	3	384	381	11.3	31.5	57.2	43	83.7	14.0	2.3
10502A	Pine Hill	5	53	2	2	3	62	5	3	4	287	0	0	0	426	426	15.3	17.4	67.4	62	85.5	11.3	3.2
10513	Pine Hill	5	40	0	0	1	39	6	4	0	285	0	2	0	382	380	12.1	12.9	75.0	45	88.9	11.1	0.0
11283	Pine Hill	10	66	2	7	3	44	0	0	11	217	3	0	0	363	360	24.4	15.3	60.3	85	77.6	14.1	8.2
10676B	Wrights Pd	7	66	2	0	2	50	0	3	2	243	0	5	0	380	375	20.5	14.7	64.8	75	88.0	12.0	0.0
10953	Wrights Pd	4	41	0	0	0	5	0	0	0	264	0	17	12	343	314	14.3	1.6	84.1	45	91.1	8.9	0.0
10955	Wrights Pd	2	29	3	0	2	22	0	0	1	275	0	3	1	338	334	10.8	6.9	82.3	34	85.3	14.7	0.0
10236A	Boojum	7	28	0	2	2	65	0	1	0	259	0	1	23	388	364	10.7	18.1	71.2	37	75.7	18.9	5.4
10239	Boojum	5	24	0	1	6	33	0	2	0	284	1	11	3	370	355	10.1	9.9	80.0	30	80.0	16.7	3.3
10245	Boojum	3	23	1	1	2	59	2	14	0	263	0	3	5	376	368	8.2	20.4	71.5	28	82.1	14.3	3.6
10246	Boojum	3	36	1	1	4	60	0	0	2	240	0	0	9	356	347	13.0	17.9	69.2	41	87.8	9.8	2.4
10551	Boojum	1	23	0	1	1	46	0	0	0	287	0	3	1	363	359	7.2	12.8	79.9	25	92.0	4.0	4.0
11460	Pine Banks	6	114	1	13	3	41	0	1	1	202	0	2	0	384	382	35.9	11.3	52.9	134	85.1	5.2	9.7
11463	Pine Banks	6	143	1	5	7	34	0	8	0	191	1	2	0	398	395	41.0	10.6	48.4	155	92.3	4.5	3.2
11537	Sewall Wd	29	104	11	7	2	86	0	0	0	146	6	1	8	400	385	39.7	22.3	37.9	151	68.9	26.5	4.6
11541	Sewall Wd	4	90	9	5	1	8	0	0	5	287	0	0	0	409	409	26.7	3.2	70.2	108	83.3	12.0	4.6
11654	Crystal Lk	27	101	2	2	1	2	0	0	0	235	0	8	2	380	370	35.9	0.5	63.5	132	76.5	22.0	1.5
11655	Crystal Lk	4	91	2	0	6	33	0	1	0	277	0	2	0	416	414	24.9	8.2	66.9	97	93.8	6.2	0.0

Abbreviations

Crystals (Xals): Q = quartz; P = plagioclase; A = alkali feldspar; H-B = Hornblende and Biotite, both after alteration; Op = opaque mineral grains. ***NOTE: Some Straw Point samples with low crystal density had crystals counted separately and then were normalized to the whole rock count.***

Lithic Fragments (Frag): volc = felsic volcanic; qt/arg = quartzite, argillite; bas = basalt; ign = cousre igneous rocks, multi-grain fragments.

Matrx: matrix, fine mineral material and intergrown quartz and feldspar bewteen crystals and lithic fragments.

Minerals/Veins (dominant mineral in vein or mineralized spot): Chl = chlorite; Epid = epidote; Qt/Ox = quartz and oxides

Appendix 2 - B. Point count data for facies of the Boojum Rock Tuff (Zbrc, Zbrl, Zbrv, Zbrr) of the Lynn Volcanic Complex. Every count is at least 300 points. Points are on a 1.5 mm grid. Categories are defined at end of appendix.

Zbrc		Crystals:					Lithic Fragments:			Matrix:	Minerals/Veins:				Percentages: Whole Rock (minus Min/Vns)				Percentages: Crystal types (minus A+Op)			
Gray crystal tuff		Q	P	A	Hb	Op	volc	qtz/arg	ign		Chl	Epid	Qt/Ox	Total	Total	Xals	Frag.	Matrix	Total	P	Q+A	Hb
415BN	crystal tuff	1	131	0	12	2	6	0	0	214	6	7	1	380	**366**	39.9	1.6	58.5	**144**	91.0	0.7	8.3
450BN	crystal tuff	2	151	0	22	10	1	0	0	191	6	2	0	385	**377**	49.1	0.3	50.7	**175**	86.3	1.1	12.6
717BN	crystal tuff	0	125	0	16	3	2	0	0	169	4	1	7	327	**315**	45.7	0.6	53.7	**141**	88.7	0.0	11.3
725BN	crystal tuff	0	169	0	14	6	28	0	0	146	6	4	6	379	**363**	52.1	7.7	40.2	**183**	92.3	0.0	7.7
10009	crystal tuff	0	185	0	18	10	15	0	0	158	5	4	0	395	**386**	55.2	3.9	40.9	**203**	91.1	0.0	8.9
10010	crystal tuff	0	165	0	18	7	30	4	0	172	4	2	0	402	**396**	48.0	8.6	43.4	**183**	90.2	0.0	9.8
10011	crystal tuff	0	160	0	24	4	12	1	0	156	3	1	0	361	**357**	52.7	3.6	43.7	**184**	87.0	0.0	13.0
10013	crystal tuff	1	162	0	13	9	27	9	0	153	4	4	0	382	**374**	49.5	9.6	40.9	**176**	92.0	0.6	7.4
10022	crystal tuff	0	133	0	14	5	46	0	0	160	3	2	0	363	**358**	42.5	12.8	44.7	**147**	90.5	0.0	9.5
10023	crystal tuff	0	138	0	18	4	18	1	0	140	7	16	0	342	**319**	50.2	6.0	43.9	**156**	88.5	0.0	11.5
10027	crystal tuff	0	140	0	22	5	3	0	0	166	5	5	3	349	**336**	49.7	0.9	49.4	**162**	86.4	0.0	13.6
10274	crystal tuff	0	160	0	26	5	2	0	0	173	0	9	2	377	**366**	52.2	0.5	47.3	**186**	86.0	0.0	14.0
10275	crystal tuff	0	146	0	16	5	5	0	0	200	0	6	8	386	**372**	44.9	1.3	53.8	**162**	90.1	0.0	9.9
10289	crystal tuff	1	141	0	15	6	16	2	0	170	6	0	3	360	**351**	46.4	5.1	48.4	**157**	89.8	0.6	9.6
10294	crystal tuff	0	150	0	4	4	1	0	0	206	4	8	18	395	**365**	43.3	0.3	56.4	**154**	97.4	0.0	2.6
10349B	crystal tuff	0	160	0	19	4	28	0	0	166	2	0	0	379	**377**	48.5	7.4	44.0	**179**	89.4	0.0	10.6
10350	crystal tuff	0	161	0	15	0	1	0	0	188	5	34	11	415	**365**	48.2	0.3	51.5	**176**	91.5	0.0	8.5
10900	crystal tuff	0	108	0	16	5	14	0	0	191	0	10	0	344	**334**	38.6	4.2	57.2	**124**	87.1	0.0	12.9
10902	crystal tuff	0	111	0	4	6	2	0	0	185	3	14	4	329	**308**	39.3	0.6	60.1	**115**	96.5	0.0	3.5
10903	crystal tuff	0	128	0	12	2	21	0	0	170	1	8	0	342	**333**	42.6	6.3	51.1	**140**	91.4	0.0	8.6
10904	crystal tuff	0	109	0	2	1	1	0	0	213	2	13	0	341	**326**	34.4	0.3	65.3	**111**	98.2	0.0	1.8
10905	crystal tuff	0	147	0	3	7	14	1	0	156	3	6	2	339	**328**	47.9	4.6	47.6	**150**	98.0	0.0	2.0
10908	crystal tuff	0	122	0	22	4	25	2	0	141	0	4	1	321	**316**	46.8	8.5	44.6	**144**	84.7	0.0	15.3
10909	crystal tuff	0	115	0	20	2	2	0	0	172	0	2	2	315	**311**	44.1	0.6	55.3	**135**	85.2	0.0	14.8
10910	crystal tuff	0	127	0	15	1	37	0	0	137	0	18	7	342	**317**	45.1	11.7	43.2	**142**	89.4	0.0	10.6
10911	crystal tuff	0	132	0	13	4	63	0	0	131	2	2	0	347	**343**	43.4	18.4	38.2	**145**	91.0	0.0	9.0
10914	crystal tuff	0	127	0	28	6	57	0	0	135	0	2	0	355	**353**	45.6	16.1	38.2	**155**	81.9	0.0	18.1
10918	crystal tuff	0	163	0	23	5	32	0	0	150	0	0	0	373	**373**	51.2	8.6	40.2	**186**	87.6	0.0	12.4
10919	crystal tuff	0	141	0	17	5	28	0	0	144	1	15	3	354	**335**	48.7	8.4	43.0	**158**	89.2	0.0	10.8
10920	crystal tuff	1	113	0	14	3	79	1	0	100	0	5	3	319	**311**	42.1	25.7	32.2	**128**	88.3	0.8	10.9
10924	crystal tuff	1	144	0	19	3	32	0	0	143	9	2	1	354	**342**	48.8	9.4	41.8	**164**	87.8	0.6	11.6
10925	crystal tuff	0	135	0	15	3	19	0	0	160	11	7	1	351	**332**	46.1	5.7	48.2	**150**	90.0	0.0	10.0

Appendix 2 - B. (cont.) Point count data for facies of the Boojum Rock Tuff (Zbrc, Zbrl, Zbrv, Zbrr) of the Lynn Volcanic Complex.

Zbrc (cont.)		Crystals:					Lithic Fragments:			Matrix:	Minerals/Veins:				Percentages: Whole Rock (minus Min/Vns)				Percentages: Crystal types (minus A+Op)			
Gray crystal tuff		*Q*	*P*	*A*	*Hb*	*Op*	*volc*	*qtz/arg*	*ign*		*Chl*	*Epid*	*Qt/Ox*	**Total**	**Total**	***Xals***	***Frag.***	***Matrix***	**Total**	***P***	***Q+A***	*Hb*
10926	crystal tuff	0	126	0	10	2	40	1	0	130	5	5	7	326	**309**	44.7	13.3	42.1	**136**	92.6	0.0	7.4
10927	crystal tuff	0	139	0	21	7	11	0	0	169	3	0	1	351	**347**	48.1	3.2	48.7	**160**	86.9	0.0	13.1
10928	crystal tuff	0	139	0	21	7	41	0	0	175	2	2	1	388	**383**	43.6	10.7	45.7	**160**	86.9	0.0	13.1
10935	crystal tuff	0	136	0	14	8	45	0	0	105	8	2	1	319	**308**	51.3	14.6	34.1	**150**	90.7	0.0	9.3
10946	crystal tuff	0	94	0	10	4	26	6	0	184	2	3	1	330	**324**	33.3	9.9	56.8	**104**	90.4	0.0	9.6
10947	crystal tuff	0	99	0	6	2	22	0	0	167	3	37	5	341	**296**	36.1	7.4	56.4	**105**	94.3	0.0	5.7
11293A	crystal tuff	0	115	0	1	4	7	0	0	146	22	23	14	332	**273**	44.0	2.6	53.5	**116**	99.1	0.0	0.9
11296	crystal tuff	0	128	0	13	3	32	3	0	145	3	11	8	346	**324**	44.4	10.8	44.8	**141**	90.8	0.0	9.2
11297	crystal tuff	0	40	0	3	2	0	0	0	284	2	13	6	350	**329**	13.7	0.0	86.3	**43**	93.0	0.0	7.0
11334	crystal tuff	0	139	0	21	4	3	1	0	152	8	6	7	341	**320**	51.3	1.3	47.5	**160**	86.9	0.0	13.1
11431	crystal tuff	1	147	1	0	1	17	4	0	149	5	15	1	341	**320**	46.9	6.6	46.6	**149**	98.7	1.3	0.0
11434	crystal tuff	3	117	0	9	4	81	1	0	175	1	1	0	392	**390**	34.1	21.0	44.9	**129**	90.7	2.3	7.0
11436	crystal tuff	1	140	0	19	4	31	1	0	140	1	0	2	339	**336**	48.8	9.5	41.7	**160**	87.5	0.6	11.9
11458	crystal tuff	2	150	2	7	3	8	15	0	188	1	1	4	381	**375**	43.7	6.1	50.1	**161**	93.2	2.5	4.3
11466	crystal tuff	0	144	1	16	1	37	6	0	161	2	1	0	369	**366**	44.3	11.7	44.0	**161**	89.4	0.6	9.9
11476	crystal tuff	0	118	0	6	2	69	10	0	133	0	0	3	341	**338**	37.3	23.4	39.3	**124**	95.2	0.0	4.8
11496	crystal tuff	0	142	0	16	2	20	5	0	190	0	0	1	376	**375**	42.7	6.7	50.7	**158**	89.9	0.0	10.1
11506	crystal tuff	0	125	0	13	4	72	0	0	203	0	1	0	418	**417**	34.1	17.3	48.7	**138**	90.6	0.0	9.4
11521	crystal tuff	0	158	0	18	6	2	1	0	205	0	0	25	415	**390**	46.7	0.8	52.6	**176**	89.8	0.0	10.2

Zbrl		Crystals:					Lithic Fragments:			Matrix:	Minerals/Veins:				Percentages: Whole Rock (minus Min/Vns)				Percentages: Crystal types (minus A+Op)			
Lithic tuff		*Q*	*P*	*A*	*Hb*	*Op*	*volc*	*qtz/arg*	*ign*		*Chl*	*Epid*	*Qt/Ox*	**Total**	**Total**	***Xals***	***Frag.***	***Matrix***	**Total**	***P***	***Q+A***	*Hb*
688BN	lithic tuff	0	140	0	17	3	65	12	1	114	3	0	0	355	**352**	45.5	22.2	32.4	**157**	89.2	0.0	10.8
723BN	lithic tuff	0	122	0	21	4	118	3	0	109	1	1	0	379	**377**	39.0	32.1	28.9	**143**	85.3	0.0	14.7
10020	lithic tuff	0	127	0	23	5	106	2	0	158	0	0	0	421	**421**	36.8	25.7	37.5	**150**	84.7	0.0	15.3
10024	lithic tuff	0	139	1	15	5	57	0	0	160	8	2	0	387	**377**	42.4	15.1	42.4	**155**	89.7	0.6	9.7
10042	lithic tuff	0	116	0	21	2	53	1	0	127	0	8	0	328	**320**	43.4	16.9	39.7	**137**	84.7	0.0	15.3
10352	lithic tuff	0	116	0	20	6	46	1	0	149	1	0	0	339	**338**	42.0	13.9	44.1	**136**	85.3	0.0	14.7
10353	lithic tuff	1	116	0	19	1	120	0	0	122	0	0	0	379	**379**	36.1	31.7	32.2	**136**	85.3	0.7	14.0
10354	lithic tuff	1	113	2	13	5	40	8	75	121	0	4	3	385	**378**	35.4	32.5	32.0	**129**	87.6	2.3	10.1
10355	lithic tuff	0	163	0	24	4	81	0	0	132	2	10	2	418	**404**	47.3	20.0	32.7	**187**	87.2	0.0	12.8

Appendix 2 – B. (cont.) Point count data for facies of the Boojum Rock Tuff (Zbrc, Zbrl, Zbrv, Zbrr) of the Lynn Volcanic Complex.

Zbrv		Crystals:					Lithic Fragments:			Matrix:	Minerals/Veins:				Percentages: Whole Rock (minus Min/Vns)				Percentages: Crystal types (minus A+Op)			
Vitric tuff		*Q*	*P*	*A*	*Hb*	*Op*	*volc*	*qtz/arg*	*ign*		*Chl*	*Epid*	*Qt/Ox*	**Total**	**Total**	*Xals*	*Frag.*	*Matrix*	**Total**	*P*	*Q+A*	*Hb*
11349	vitric tuff	2	70	0	0	2	57	2	0	235	0	0	0	368	**368**	20.1	16.0	63.9	**72**	97.2	2.8	0.0
11350	vitric tuff	1	74	0	1	3	48	0	0	245	2	0	0	374	**372**	21.2	12.9	65.9	**76**	97.4	1.3	1.3

Zbrr		Crystals:					Lithic Fragments:			Matrix:	Minerals/Veins:				Percentages: Whole Rock (minus Min/Vns)				Percentages: Crystal types (minus A+Op)			
Red crystal tuff		*Q*	*P*	*A*	*Hb*	*Op*	*volc*	*qtz/arg*	*ign*		*Chl*	*Epid*	*Qt/Ox*	**Total**	**Total**	*Xals*	*Frag.*	*Matrix*	**Total**	*P*	*Q+A*	*Hb*
11447	red xal tuff	1	175	0	1	2	31	9	0	158	4	1	13	395	**377**	47.5	10.6	41.9	**177**	98.9	0.6	0.6
11469	red xal tuff	0	90	0	5	3	191	2	0	77	0	7	2	377	**368**	26.6	52.4	20.9	**95**	94.7	0.0	5.3

Abbreviations:

Crystals (Xals):
Q = quartz; P = plagioclase; A = alkali feldspar; Hb = Hornblende (some biotite), both after alteration; Op = opaque mineral grains.

Lithic Fragments (Frag):
volc = volcanic; qtz/arg = quartzite, argillite and basaltic rocks; ign = cousre igneous rocks, multi-grain.

Matrix: fine mineral material and intergrown quartz and feldspar bewteen crystals and lithic fragments

Minerals/Veins (dominant mineral in vein or mineralized spot):
Chl = chlorite; Epid = epidote; Qt/Ox = quartz and oxides

Appendix 3 - Radiometric ages in the Middlesex Fells and nearby areas

Table. Listing of all radiometric ages from bedrock units in the Middlesex Fells Reservation - version May 4, 2025

Sample Name	Unit Name	Map Symbol	Rock Type	Location	Method	Age (Ma)	Notes on related units	Reference
	Dikes							
none	dolerite dike	d	dolerite	west side of Bear Hill along Rt. 93 in Stoneham	K-Ar whole rock	290 $\pm$ 15	cuts through Stoneham Granodiorite	Zartman (1970)
dike 40	dolerite dike	d	dolerite	west of Bellevue Pond in Medford	$^{40}Ar/^{39}Ar$ whole rock	226 $\pm$ 3	cuts through Lynn Volcanic Complex	Ross (2021)
dike 33	dolerite dike	d	dolerite	Pine Hill in Medford	$^{40}Ar/^{39}Ar$ whole rock	353 $\pm$ 4	cuts through Lynn Volcanic Complex	Ross (2001, 2021)
dike 37	dolerite dike	d	dolerite	Pine Hill in Medford	$^{40}Ar/^{39}Ar$ whole rock	573 $\pm$ 5	cuts through Lynn Volcanic Complex	Ross (2001, 2021)
dike G	gabbro dike	gb	gabbro	Middle Hill in Medford	$^{40}Ar/^{39}Ar$ whole rock	403 $\pm$ 3	cuts through Lynn Volcanic Complex	Ross (2001, 2021)
none	Medford Dike		gabbro	west side of Pine Hill in Medford	K-Ar biotite	190 $\pm$ 6	cuts through Spot Pond Granodiorite, Lynn Volcanic Complex and Lawrence Woods Granophyre	Ross (1981, 1990, 2001, 2021)
dike 22	Medford Dike	TRm	gabbro	west side of Pine Hill in Medford	$^{40}Ar/^{39}Ar$ biotite	304.4 $\pm$ 0.6	cuts through Lynn Volcanic Complex and Lawrence Woods Granophyre	Ross (2020, 2021)
11559	Medford Dike	TRm	gabbro	west side of Pine Hill in Medford	zircon CA-ID-TIMS U-Pb	238.07 $\pm$ 0.09 (6 zircons)	cuts through Lynn Volcanic Complex and Lawrence Woods Granophyre	NEW
	Volcanic units							
RH1625	Wakefield Fm., Lynn Volcanic Complex	Zlvf	banded rhyolite flow	northeast corner Middle Reservoir in Stoneham	LA-ICPMS U-Pb, 17 zircons	601.2 $\pm$ 5.6	Unconformably overlies Winchester Granite and Nanepashemet Formation	Hamilton (2017)
RH1625	Wakefield Fm., Lynn Volcanic Complex	Zlvf	banded rhyolite flow	northeast corner Middle Reservoir in Stoneham	zircon CA-ID-TIMS U-Pb	594.70 $\pm$ 0.32 (5 zircons), same sample as above	Unconformably overlies Winchester Granite and Nanepashemet Formation	Francis MacDonald (pers. comm.)
10421	Wakefield Fm., Lynn Volcanic Complex	Zlvf	banded rhyolite flow	Straw Point, northwest corner of Spot Pond in Stoneham	zircon CA-ID-TIMS U-Pb	595.27 $\pm$ 0.34 (4 zircons)	Interlayered with basalt, intruded by Stoneham Granodiorite	NEW
F1512	Wakefield Fm., Lynn Volcanic Complex	Zlvf	banded rhyolite flow	South of Whip Hill (Wamoset Hill), Stoneham	zircon CA-ID-TIMS U-Pb	595.82 $\pm$ 0.23 (5 zircons)	Unconformably overlies Westboro Fm.	Francis MacDonald (pers. comm.)

Appendix 3 - Radiometric ages in the Middlesex Fells (cont.)

RH1601	Boojum Rock Tuff of Lynn Volcanic Complex	Zbrc	andesitic crystal tuff	southeastern Fells near Hemlock Pool in Medford	LA-ICPMS U-Pb, 42 zircons	602.1 ± 3.9	Unconformably overlain by Wakefield Fm. in the Lynn Volcanic Complex, unconformably overlies Spot Pond Granodiorite	Hamilton (2017)
725BN	Boojum Rock Tuff of Lynn Volcanic Complex	Zbrc	andesitic crystal tuff	southeastern Fells near Pinnacle Rock in Medford	zircon CA-ID-TIMS U-Pb	596.35 ± 0.21 (6 zircons)	Unconformably overlain by Wakefield Fm. in the Lynn Volcanic Complex, unconformably overlies Spot Pond Granodiorite	NEW

Plutonic units

10958	Stoneham Granodiorite	Zst	tonalite to granodiorite	along Pond Street near Rt. 93 in Stoneham	zircon CA-ID-TIMS U-Pb	595.14 ± 0.17 (6 zircons)	Intrudes Wakefield Fm. of Lynn Volcanic Complex, Nanepashemet Fm., and Westboro Fm., abundant basalt and quartzite xenoliths	NEW
MT95-1	subvolcanic phase of Lynn Volcanic Complex		granophyric porphyry	Castle Hill, Saugus	zircon CA-ID-TIMS U-Pb	595.8 ± 1.2 Ma	In the Middlesex Fells this is similar to the Lawrence Woods Granophyre but younger	Thompson et al., 2007
11555	unamed gabbro	Zdg	hornblende gabbro/ diorite	between South Reservoir and South Border Road in Medford	zircon CA-ID-TIMS U-Pb	596.02 ± 0.32 (5 zircons)	Intrudes Westboro Fm. on its north side and cut by major E-W fault on its south side	NEW
10969	Rams Head Porphyry	Zrhp	tonalite porphyry	between South Reservoir and South Border Road in Medford	zircon CA-ID-TIMS U-Pb	596.24 ± 0.21 (6 zircons)	Intrudes Spot Pond Granodiorite	NEW
10478	Lawrence Woods Granophyre	Zlwg	subvolcanic granophyre	north side of Elm St. south of Wrights Pond in Medford	zircon CA-ID-TIMS U-Pb	2 populations - older inhereted: 3 zircons, 598.13 ± 0.27; younger: 3 zircons, 596.77 ± 0.54	Intrudes Wakefield Fm. of Lynn Volcanic Complex in southern Fells	NEW
10516	Lawrence Woods Granophyre	Zlwg	subvolcanic granophyre	southeast corner of Pine Hill along Rt. 93 exit ramp in Medford	zircon CA-ID-TIMS U-Pb	596.50 + 0.53 (3 zircons), 3 other zircons were much older	Intrudes Wakefield Fm. of Lynn Volcanic Complex in southern Fells	NEW

Appendix 3 - Radiometric ages in the Middlesex Fells (cont.)

10409	Spot Pond Granodiorite of Dedham Complex	Zsg	coarse granite	near east end of Doleful Pond in Stoneham	zircon CA-ID-TIMS U-Pb (5 zircons)	609.08 ± 0.24 (5 zircons)	Intruded by Stoneham Granodiorite, Dedham North Granodiorite of Smith and Hon (1984) and Smith (1985)	NEW
SP700	Spot Pond Granodiorite of Dedham Complex	Zsg	coarse granodiorite	near Red Cross Path/Mud Road intersection in Medford	LA-ICPMS U-Pb, 38 zircons	602.2 ± 4.4	contains large Westboro Fm. inclusions and rare felsic volcanic inclusions, part of Dedham Complex, Dedham North Granodiorite of Smith and Hon (1984) and Smith (1985)	Francis MacDonald (pers. comm.)
SP700	Spot Pond Granodiorite of Dedham Complex	Zsg	coarse granodiorite	near Red Cross Path/Mud Road intersection in Medford	zircon CA-ID-TIMS U-Pb	609.45 ± 0.25 (5 zircons), same sample as above	Contains large Westboro Fm. inclusions and rare felsic volcanic inclusions, part of Dedham Complex, Dedham North Granodiorite of Smith and Hon (1984) and Smith (1985)	Francis MacDonald (pers. comm.)
11368	Spot Pond Granodiorite of Dedham Complex	Zsg	coarse granodiorite	between Spot Pond and Wrights Pond	zircon CA-ID-TIMS U-Pb	609.11 ± 0.22 (6 zircons)	Contains large Westboro Fm. inclusions, part of Dedham Complex, intruded by Rams Head Porphyry and Lawrence Woods Granophyre; Dedham North Granodiorite of Smith and Hon (1984) and Smith (1985)	NEW
RH1627	Winchester Granite	Zwg	medium granite	east of Long Pond in Winchester	LA-ICPMS U-Pb, 40 zircons	605.7 ± 3.3	Intrudes Nanepashemet and Westboro Formations	Hamilton (2017)
RH1627	Winchester Granite	Zwg	medium granite	east of Long Pond in Winchester	zircon CA-ID-TIMS U-Pb	609.72 ± 0.24 (4 zircons), same sample as above	Intrudes Nanepashemet and Westboro Formations	Francis MacDonald (pers. comm.)

Sedimentary and Metasedimentary units

11355	Westboro Fm. on Whip Hill	Zwp	quartz sandstone olistolith	northern Whip Hill in Stoneham	LA-ICPMS U-Pb, 250 zircons	youngest zircon age: <910 Ma	Sample from sandstone olistolith	NEW
MT96-3	Westboro Fm. Near Breakheart Reservation		quartzite	east of Middlesex Fells in Saugus	LA-ICPMS U-Pb, 102 zircons	youngest zircon age: 912 Ma	Intruded by Dedham Complex	Thompson et al., 2012
F1510	Westboro Fm. in Virginia Wood	Zvwq	quartzite	east side of Pond Street north of Woodland Road intersection in Stoneham	LA-ICPMS U-Pb, 40 zircons, youngest zircon CA-ID-TIMS	youngest zircon age: 912 ± 0.6 Ma	Intruded by Spot Pond Granodiorite further south	Francis MacDonald (pers. comm.)

Notes: All new ages and ages reported from MacDonald are U-Pb zircon ages measured at the Isotope Geology Laboratory at Boise State University, Boise, Idaho with 95% confidence interval. Age from Thompson et al., 2007 was done at MIT. When available only the CA-ID-TIMS ages, which have higher accuracy and precision than the LA-ICPMS, K-Ar or Ar/Ar methods are used to infer the ages of units.

References:

Hampton, R., 2017, The Middlesex Fells Volcanic Complex: A revised tectonic model based on geochronology, geochemistry, and field data: Undergraduate senior thesis, Harvard University, Cambridge, Massachusetts, 115 p.

Ross, M.E., 1981, Mafic dikes of northeastern Massachusetts, *in* Boothroyd, J.C. and Hermes, O.D., eds., Geological field trips in Rhode Island and adjacent areas: 73rd Annual New England Intercollegiate Geologic Conference Guidebook: Kingston, University of Rhode Island, p. 285-302.

Ross, M.E., 1990, Mafic dikes of the Avalon Boston terrane, Massachusetts, *in* Socci, A.D., Skehan, J.W., and Smith, G.W., eds., Geology of the composite Avalon terrane of southern New England: Boulder, Colorado, Geological Society of America Special Paper 245, p. 133-153.

Ross, M.E., 2001, Igneous petrology of the Pine Hill area, Medford, Massachusetts, in West, D.P., Jr. and Bailey, R.H., eds., Guidebook for Geological Field trips in New England: 2001 Annual Meeting of the Geological Society of America, Boston, Massachusetts, p. M-1 to M-25

Ross, M.E., 2020, The petrology and age of the Medford dolerite dike, Medford, Massachusetts: Dept. of Marine and Environmental Sciences, Northeastern University, Open File Report no. 3, 55 p. https://doi:10.13140/RG.2.2.21253.99041

Ross, M.E., 2021, Mafic dikes of the Boston metropolitan area, Massachusetts: Northeastern University, Boston, Massachusetts, Open File Report no. 4, 94 p. https://doi: 10.13140/RG.2.2.29116.16000

Smith, C.J., 1985, Late Proterozoic Avalonian magmatism north of Boston, eastern Massachusetts: Unpub. Master of Science thesis, Boston College, Chestnut Hill, Massachusetts, 156 p.

Smith, C.J. and Hon, R., 1984, Geology, petrology and origin of the Precambrian igneous rocks located in the area north of Boston, in L.S. Hanson, ed., Geology of the Coastal Lowlands, Boston, MA to Kennebunk, ME: Guidebook of 76th Annual Meeting of the New England Intercollegiate Geologic Conference, p. 292-309.

Thompson, M.D., Grunow, A.M., and Ramezani, J., 2007, Late Neoproterozoic paleogeography of the southern New England Avalon zone: Insights from U-Pb geochronology and paleomagnetism: Geological Society of America Bulletin, v. 119, no. 5/6, p. 681-696. Doi: 10.11130/B26014.1

Thompson, M.D., Barr, S.M., and Grunow, A.M., 2012, Avalonian perspectives on Neoproterozoic paleogeography: Evidence from Sm-Nd isotope geochemistry and detrital zircon geochronology in SE New England, USA: Geological Society of America Bulletin, v. 119, no. 5/6, p. 681-696. Doi: 10.11130/B26014.1

Zartman, R.E., Hurley, P.M., Krueger, H.W. and Giletti, B.J., 1970, A Permian disturbance of K-Ar ages in New England: its occurrence and cause: Geological Society of America Bulletin, v. 81, p. 3359-3374.