# Self-Guided Geologic Tour of the Skyline Trail in the Middlesex Fells Reservation (Part 2)

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Some general information before starting a tour in the Middlesex Fells:

1. The tour of the Skyline Trail has been broken into seven parts. You should not try to do the whole tour in one day (~7 miles, 11 km). It is a lot of hiking and a lot to comprehend in one dose. It's recommended that you do parts of the tour in order, moving counterclockwise around the park. Each tour and its stops are marked on the geologic maps with each part. PLEASE FOLLOW the maps as you go. ***It will be handy to have a sense of direction from the sun, remembering that at noon the sun is due South, in the morning it is to the southeast, and by late afternoon it is to the southwest.***

2. At many times of the year and on weekends, parking areas fill, especially at Sheepfold, so start early.

3. The tours require hiking over some steep and rocky trails, so plan ahead. It is recommended that you have sturdy hiking or trail shoes. I don't recommend sandals or heeled shoes.

4. Make sure you have enough food and water with you. In the Fells, there is nowhere to get water and the spring water is NOT drinkable.

5. In compliance with DCR rules, please stay on official marked trails as indicated on DCR maps. This is also a way of avoiding poison ivy and ticks. In making the geologic map, special permission was obtained from the DCR to go off the trails. See the DCR's official Middlesex Fells Reservation Trail Map (last updated in March 2020). This map accurately shows trails, except where they have been refurbished, and it has the numbered intersection designations indicated in the guide. The DCR map is online at: https://www.mass.gov/doc/middlesex-fells-reservation-trail-map/download and it is sometimes available at kiosks at Fells parking areas.

6. In wet or winter weather, some rock surfaces are slippery. DO NOT venture out onto frozen ponds and reservoirs. The ice may be too thin to support your weight and it is unpredictable!

7. Do not collect rocks on the tour or deface outcrops by writing on them. It is against DCR regulations. Please remove your own trash and follow other DCR rules. Leave no trace!

Some Fundamental Geology to Get Started:

1. The self-guided tours of the Fells focus primarily on **bedrock geology**. This is a characterization of the solid rock that occurs beneath our feet as viewed from above. Exposures of the **bedrock** surface are called **outcrops**. Loose rock debris (or **float**), sediment, and soils on top of the bedrock comprise the **surficial geology**.

2. **Rocks** are naturally occurring solids made of minerals and non-mineral materials. **Minerals** are naturally-occurring, inorganic, crystalline solids that have a specific chemical formula and unique properties that allow us to tell them apart. A **crystalline material** is one in which atoms have a repeated regular pattern (i.e., crystals or crystal structure). Minerals have names in addition to their chemical formulas. For example, sodium chloride ($NaCl$), which is the main ingredient of table salt, is known as the mineral **halite**, while silicon dioxide ($SiO_2$) is **quartz**. The most common mineral at Earth's surface is **feldspar**, an aluminosilicate containing sodium, potassium, and calcium. Non-mineral materials in rocks include organically-produced materials and **natural glass**, which is non-crystalline.

3. Rocks are divided into three main types:

**Igneous rocks** – rocks formed by the solidification of molten rock, or **magma**. Magmas can invade older rock units in the subsurface and then crystallize to form **intrusions** or **intrusive igneous rocks**, which may later be exposed by erosion at Earth's surface. Magma can also escape to Earth's surface before hardening to form **extrusive** or **volcanic igneous rocks**. Examples of these are **lava flows** or magma explosively ejected into the air that later settles to produce **pyroclastic rocks**.

**Sedimentary rocks** – rocks formed by the accumulation or deposition of particles produced by the breakdown and erosion of older rocks. This often happens in oceans and lakes or on river flood plains. Sedimentary rocks also include the accumulation of organically-produced sediment, such as clam shells and coral reefs (limestone) and plant material (coal), or chemical precipitates such as salt beds. **Fossils** occur in sedimentary rocks.

**Metamorphic rocks** – rocks resulting from exposure of existing rocks to increased temperatures or pressures that change the mineral composition and arrangement of mineral grains. We say these rocks are **metamorphosed**.

4. Solid materials (rocks and minerals) have been in existence on Earth for at least 4 billion years. This time in Earth's history defines the expanse of **geologic time**. Geologic time (**geologic time scale**) is subdivided based on past events represented by changes preserved in the rock record. Radiometric dating techniques are then used to place precise numerical ages on rock units and time unit boundaries. A geologic time scale can be found at: https://www.geosociety.org/documents/gsa/timescale/timescl.pdf.

5. On a geologic map, bedrock is classified into units known as **formations**, characterized by rock types and age. Formations have proper names from a place where they are well exposed or first defined. Sometimes, single formations are split into a sequence of mappable units called **members**. The boundaries between geologic units are known as **contacts**. On geologic maps, formations and members are given their own colors and patterns so they can be distinguished from each other. They also have abbreviations that consist of a capital letter for the unit's geologic time period (when it was formed) and lower-case letters that abbreviate for the unit's name. For example, "Zsg" = the Late Proterozoic (Z) Spot Pond Granodiorite (sg). Time period abbreviations in the Fells are Z (Late Proterozoic), P (Pennsylvanian), and Q (Quaternary). If a rock unit does not have a known age or formal name, only lower-case letters are used as an abbreviation. (For example: "d" stands for dolerite). Also shown on maps of the Fells are areas where the geology is concealed by human-made deposits, defined as **artificial fill** (af).

6. On the geologic maps in this guide, geographic north is shown with an arrow. **Compass directions** are given in the guide as degrees W or E of either N or S. For example, N50°E is 50 degrees east of north.

7. **Geologic symbols** on the maps are used to convey information; for example, on the maps here, the blue lines are faults. Symbols at stops on the tour are explained, but a complete description of all rock units and a listing of symbols on the map are given in map explanations at: https://sites.tufts.edu/fellsgeology/

8. The maps in the guide present detailed mapping of the Fells and introduce new formation names. It is an ongoing research project. Things will likely change with more field work and age determinations. Updates of the bedrock map, its explanation, and associated surficial geologic map and tours will be posted as they occur. We welcome feedback at: https://sites.tufts.edu/fellsgeology/.

## Skyline Trail in the Middlesex Fells Reservation version: January 10, 2024

Tufts UNIVERSITY

**Part 2:** Red Cross Path to Sheepfold via Wenepoykin and Silver Mine Hills

Total distance: 1.2 miles (2 km) to first stop + 1.4 miles (2.2 km) tour hike = 2.6 miles or 4.2 km.

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Starting point: Lower (southern) Sheepfold parking lot (DCR Gate no. 26) on Rt. 28 west of Spot Pond in Stoneham. Follow the trail on the geologic maps as you go. Stops on the tour are shown with blue circles and red numbers on the geologic maps. Follow the white trail markers in the field and dashed yellow path on the maps. In the guide, trail junction numbers are given that appear on the official DCR trail map and are marked with signs in the field. The tour begins on Red Cross Path, a little less than 2 km south of the Sheepfold parking lot and works its way back to the parking lot from Stop 1. To get to Stop 1 from Sheepfold, follow the route described below from Sheepfold on Maps SKY-2C, 2B and then 2A. Having a hand lens or magnifying glass can be helpful. Have fun!! Hope you enjoy the geology!

**To start from Sheepfold:** (See below if you are starting Part 2 as a continuation of Part 1.)

Take the Mountain Bike Loop (green markers and red plastic signs with bikes) south from just west of the old railroad grade (trolley line) bridge that crosses over the car entrance road to Sheepfold on Map SKY-2C. **Do not follow the old railway path. The bike loop is the trail west (right) and above the old railway!** You will cross through trail junctions D4-1 and D4-3 before arriving at Brooks Road at junction D4-4 (on Map SKY-2B). Cross the road and stay on the bike loop past junction C4-11 to the next junction (D4-9) and head south (left) a short distance on the Cross Fells Trail (blue markers) to junction C4-12. Take Silver Mine Road east (left, Mountain Bike Loop again) past trail junctions C4-13, D5-2, D5-3, and D5-4, cutting across the Skyline Trail three times on Map SKY-2A. Just south of road junction C5-20 (East Dam Road), you will arrive at the Skyline Trail again at junction C5-21, where the tour starts. This is also the end point of Part 1 (near Stop 26 of that tour).

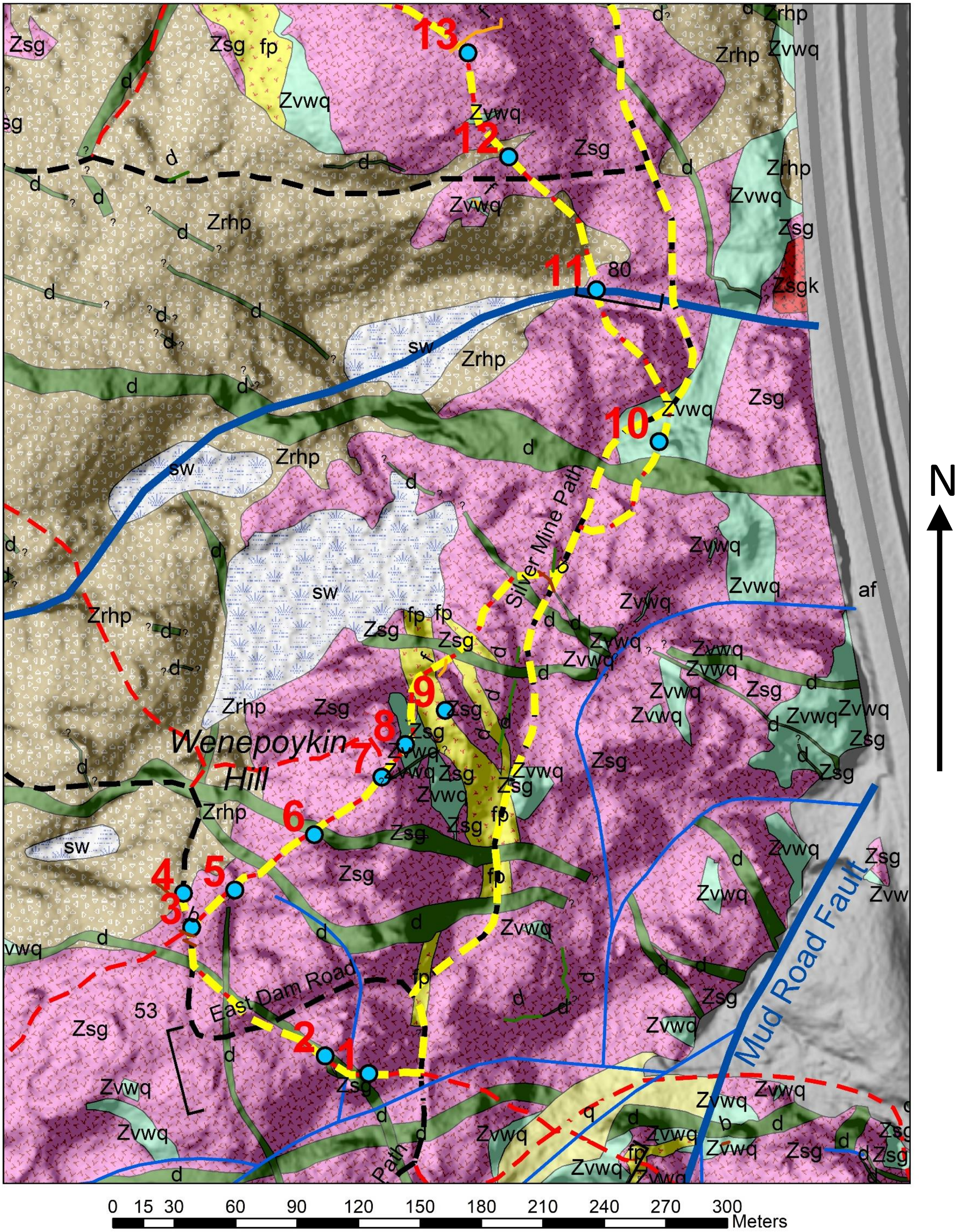
**If you are starting Part 2 of the tour as a continuation of Part 1**:

Please note that Part 2 will begin with stops renumbered, starting with Stop 1 on Map SKY-2A. When you finish, use the directions above to return to Stop 1 from Sheepfold, and then follow the directions at the end of Part 1 to return to the Bellevue Pond parking area: Head south on Red Cross Path and then southeast on Mud Road to Quarry Road, which will take you to the Bellevue Pond parking area.

This trip focuses on the Neoproterozoic metasedimentary rocks of the Westboro Formation (<910 Ma, Ma = millions of yr ago) and the intrusive igneous rocks of the Spot Pond Granodiorite (609 Ma) and Rams Head Porphyry (596 Ma). The Neoproterozoic Era was 1000 to 541 Ma. You will also see younger rhyolite and dolerite dikes as well as some glacial features from the last ice age.

***NOTE: Polished rock images are cut rock slabs photographed under water. Scale bars are in centimeters. In pictures of rock surfaces, there is often a camera lens cap, pencil, or rock hammer for scale.***

Map SKY-2A


Wenepoykin Hill
Silver Mine Path
East Dam Road
Mud Road Fault
Path
N
1
2
3
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9
10
11
12
13
80
53
Zsg
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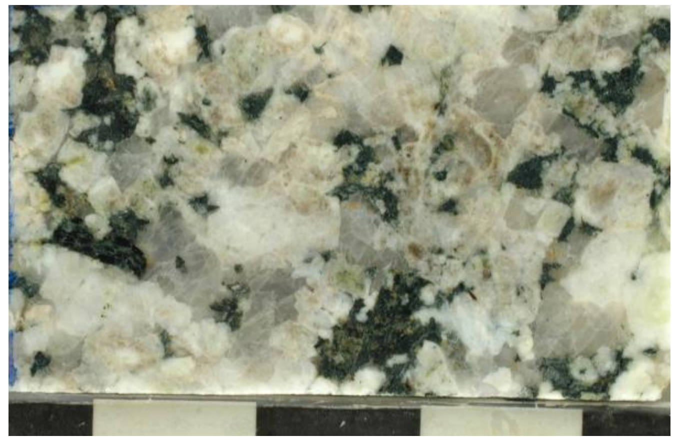
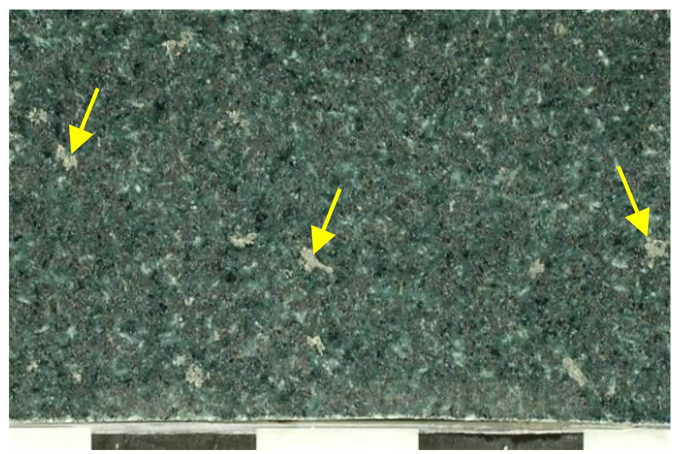
0 15 30 60 90 120 150 180 210 240 270 300
Meters

**STOP 1: From junction C5-21, head up the steep slope (west, image to right). (Part way up slope, stay to the left and do not follow the unmarked trail to the right.)** The trail and bench are underlain by the Spot Pond Granodiorite (Zsg). Granodiorite (image below to right) is a coarse-grained igneous rock, in which 20-60% of the light-colored minerals are quartz (light gray areas) and the remainder are feldspar: plagioclase (white) and less abundant alkali feldspar (small tannish areas). You are in the middle of a large area of the granodiorite that has varying amounts of the two feldspars, sometimes with more alkali feldspar than is shown here. The rock also has mafic (dark) minerals that are mostly chlorite (dark green), which formed by alteration of biotite (black mica). This is the coarsest igneous rock unit in the Fells. Slow cooling of the magma allowed the easily visible, coarse grains to form. This rock formed as a large intrusion of magma that invaded older rocks and crystallized as a pluton, which is a large irregularly shaped intrusion. Intrusions are useful for determining relative ages since ***intrusions are always younger than the rocks they intrude.*** For more on how plutons form: Plutons.

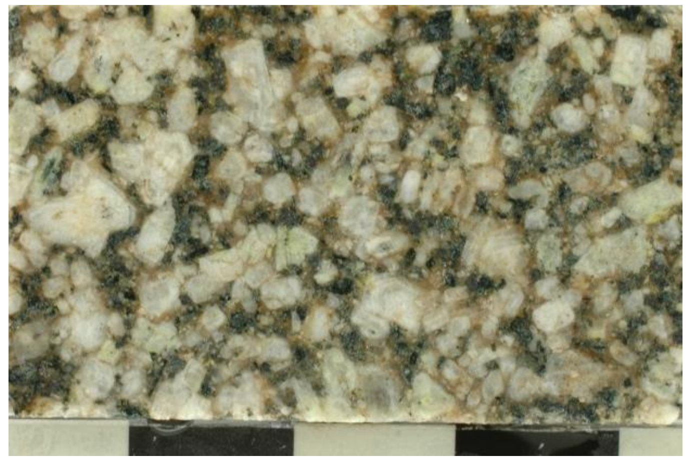


**STOP 2:** Before crossing East Dam Road for the first time at junction C5-19, the trail follows a dolerite dike (d, see Map SKY-2A). Look for the fine, dark green to rusty rock surface in the trail. A dike is an intrusion that forced its way into existing rocks along a fracture and then crystallized. Note the shape of the dike on the map; it is a slab-like body with parallel sides. ***Like plutons, dikes are always younger than the rocks they intrude.*** The image to the right is dolerite cut on a rock saw to expose a flat, non-weathered surface. Dolerite is composed of mostly sand-sized mafic (dark) minerals. This is finer than the granodiorite at Stop 1. The faintly purple mineral grains are pyroxene, which are partly altered to amphibole and chlorite, both of which are green. The tiny, light gray, blade-like mineral grains are plagioclase. The brassy yellow mineral grains (at arrows) are an iron sulfide mineral called pyrite, also known as fool's gold. When this rock weathers, oxidation of pyrite and iron in the mafic minerals can form a rusty surface. After crossing East Dam Rd at granodiorite outcrops, the trail parallels the dike before coming back to the road. **The trail follows East Dam Road north a short distance to junction C5-18.**



**STOP 3:** You will see up to seven thin dolerite (d) and basalt (b) dikes in the Spot Pond Granodiorite (Zsg) exposed on the west side of the road near the trail junction (image to right, dikes outlined). Basalt has the same composition as dolerite but has finer grains that are too small to see with the naked eye. The dikes are too thin (<1 m) to show with map units, so instead the map shows their location with thin brown lines.

**From Stop 3 the tour takes a side trip north (straight ahead) on East Dam Road but will return to junction C5-18.**



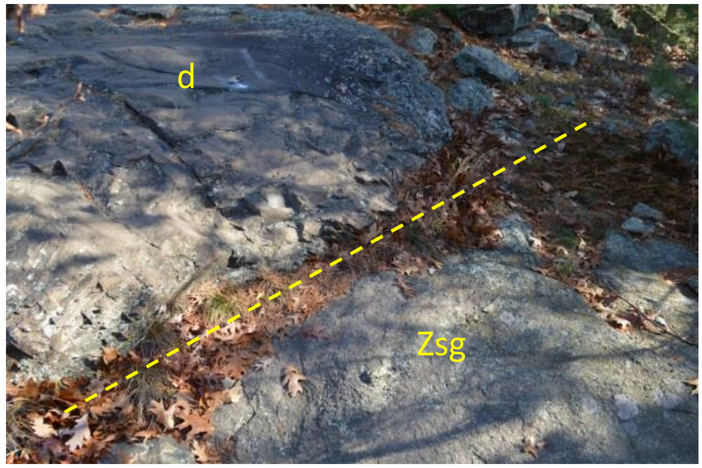
**STOP 4:** Beyond the trail junction, the first outcrops encountered in the middle of East Dam Road (image to right) show the contact of the Spot Pond Granodiorite (Zsg) and Rams Head Porphyry (Zrhp). The porphyry is recognized by its speckled appearance, lighter color, and more rectangular feldspar crystal shapes than in the granodiorite (cut rock image below to right). The white speckles are plagioclase crystals, which dominate the rock. This rock unit is a quartz diorite porphyry. A porphyry is a rock with two different grain sizes: a coarse set of crystals forming phenocrysts (here, its the white mineral, which is plagioclase), and finer minerals that make up the surrounding ground mass (pink/tan and greenish-gray areas). Quartz diorite is an igneous rock in which the light-colored minerals are <20% quartz and <10% alkali feldspar, with the rest being plagioclase. The pinkish-tan areas are fine-grained quartz and alkali feldspar. Mafic minerals in the rock are more abundant than in the Spot Pond Granodiorite and are primarily amphibole (hornblende) that has been mostly altered to chlorite (green color). A distinctive feature of this rock is the very well-formed, rectangular plagioclase crystal shapes. A close look also reveals that these crystals have concentric growth patterns called zoning. This happens when a crystal grows in successive concentric layers that have slightly changing compositions during crystallization. On East Dam Road, the porphyry is very fine-grained along its contact with the Spot Pond Granodiorite, where the diorite cooled quickly. This area represents the rapidly-cooled or chilled margin (chill zone) of the quartz diorite pluton. This provides evidence that the Rams Head Porphyry intruded the Spot Pond. For more on how plutons form: Plutons. The Rams Head has been dated at 596 Ma with uranium-lead isotope ratios from zircon crystals while the Spot Pond has been dated to 609 Ma, which is consistent with their field relationship. For more on how ages are determined for rocks: RockAges.

**Reverse direction back to junction C5-18 and continue northeast (left) on the combined Skyline (white markers) and Cross Fells (blue markers) Trails. Continue 25 m northeast on the combined trails.**

**STOP 5: S**outh (to right) of the trail is a steep-sided, closed depression in the Spot Pond Granodiorite (Zsg) that has a vernal pool. A vernal pool is a wetland that has ephemeral standing water, often in the spring (thus the name "vernal") but is dry for much of the year. (The image above to the right was taken in the Fall of 2017, when the pool was dry). They are important places for breeding frogs, toads and salamanders in the spring. Depressions like this occur in the granodiorite in several parts of the Fells. They may have been scoured out by glacial ice, where there is fractured rock associated with faults or fractured dikes crossing these basins. Glacial deposits often fill the basins and cover the rock surface, making it hard to diagnose their origin. Unfortunately, this has happened here. Since they are closed depressions (no outlet on their rims), they probably represent areas of infiltration and groundwater recharge during snowmelt and wet periods. Evaporation in the summer lowers water levels or causes them to dry up entirely. The vernal pool at this stop has a very small area from which it can receive runoff, and it appears to be spring fed from below at times of the year when the water table is high.

**Continue northeast on the trail to where it starts to climb Wenepoykin Hill.**

**STOP 6:** About halfway up the southwest side of Wenepoykin Hill, the Spot Pond Granodiorite (Zsg) is crossed by an E-W trending dolerite dike (d) that is about 10 m wide. The southern (downhill side) contact of the dike has a chilled margin (image to right). As you cross the dike you will find a large piece of granodiorite surrounded by the dolerite. The granodiorite is an inclusion or xenolith, which is a piece of pre-existing rock that broke off into the dolerite magma and was trapped when the magma crystallized. This is a useful observation, along with the chilled dike margin and shape of the dike, for determining relative ages, since ***inclusions are always older than surrounding igneous rock.***




**Continue up Wenepoykin Hill to where the Cross Fells Trail splits away from the Skyline Trail at junction C5-11.**

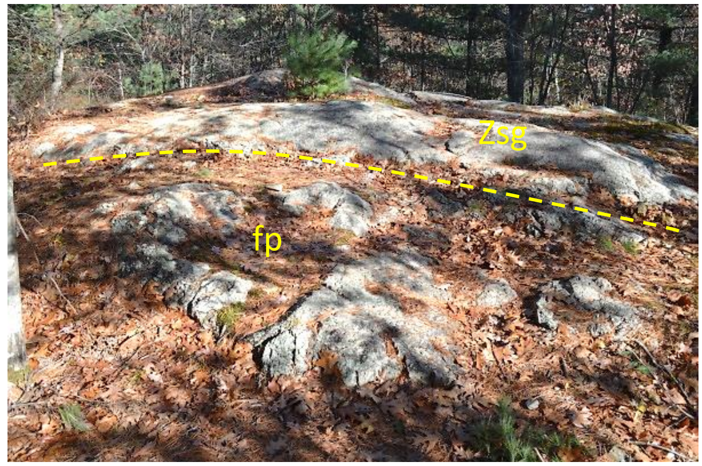
**STOP 7:** Near the trail junction are glacially rounded outcrops typical of the Spot Pond Granodiorite (Zsg). It is a good place to see the mineral make-up of the granodiorite on clean surfaces that are not covered by lichens (image to right). The light gray areas are quartz and the white grains are plagioclase. The orangish-pink mineral is alkali feldspar, which is more abundant here than in most areas of the granodiorite. As a result, the rock is very close to being granite (approximately equal amounts of plagioclase and alkali feldspar), rather than granodiorite. Areas with higher alkali feldspar content tend to have much lower, or almost non-existent, mafic minerals. The Spot Pond Granodiorite is 609 million years old. This age was determined from the ratios of isotopes of uranium and lead in tiny zircon (zirconium silicate) crystals in the rock. As uranium decays to lead, the ratios of these isotopes change with age. At the top of Wenepoykin Hill in the late fall and winter is a view across North Medford to the east, and you can see the ocean north of Boston. For more on how rock ages are determined see: RockAges.

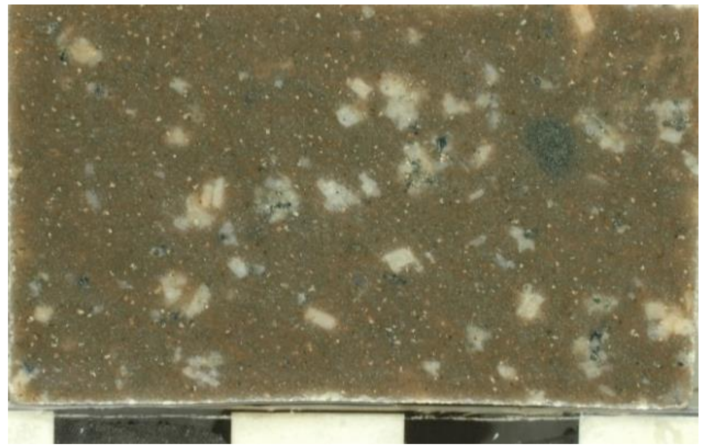
**Head across the top of the hill and down the steep northeast slope (be careful!). It can be icy in winter.**

**STOP 8:** On the steep slope is a large inclusion of the Westboro Formation (Zvwq) in the Spot Pond Granodiorite (Zsg). This formation is made of alternating layers of quartz-rich metasandstone and argillite (image to right). Metasandstone is metamorphosed sandstone and argillite hardened by light metamorphism of siltstone and shale. In addition to the Westboro Formation being metamorphosed by deformation of Earth's crust over a large area (regional metamorphism), the inclusion was also heated to a high temperature, or baked, when it broke off into the granodiorite magma (contact metamorphism). Contact metamorphism caused many of the minerals in the inclusion to recrystallize at high temperature, making the rock hard and brittle. This is especially true of clay minerals in the argillite that were baked, like when clay is fired in a kiln to make pottery. The resulting rock is called hornfels. Regional and contact metamorphism were not extreme enough to completely wipe out the original layering in the inclusion, which is still visible in some places (image above).

**Continue to the base of the steep slope.**

**STOP 9:** At the base of the slope is a narrow low spot crossed by a porphyritic rhyolite dike (fp) that intruded the Spot Pond Granodiorite (Zsg). There are small exposures of the pinkish-gray-weathering dike on its east side (opposite steep slope) where it contacts the granodiorite (image to right), but also look for broken blocks of this rock at the base of the steep slope. Rhyolite (cut rock image, below right) is a fine-grained igneous rock with the same chemical composition as granite. Rhyolite formed from granitic magma that cooled quickly, which prevented coarse crystals from developing. This is one of several reddish-gray rhyolite dikes that intruded the Spot Pond Granodiorite in this area. The dike is porphyritic with well-formed white plagioclase phenocrysts, which, with some diligence, can be seen in the field in the much finer surrounding ground mass. As you leave this area and climb down the dike, you can see a second rhyolite dike. Both dikes are crosscut and displaced by a dolerite dike (d).



**Continue on the trail through an area of Spot Pond Granodiorite (Zsg) and dolerite dikes (d) before crossing over Silver Mine Path at junction D5-4.**

**STOP 10:** East of Silver Mine Path, the trail crosses over a dolerite dike (d) and a hornfels inclusion of baked Westboro Formation (Zvwq), both in the Spot Pond Granodiorite (Zsg). The image on the right shows a view looking south (back along trail), with the dike in the distance and the trail descending the inclusion in the foreground. The dike and inclusion are not easy to tell apart, since both are fine-grained and dark gray. However, the dike has a smoother surface. Note on the map how the dike displaces the inclusion, suggesting that the dike followed a small fault. Faults are often the pathways for dike intrusion, as magma can more easily invade a fracture opening.

**The trail crosses back over Silver Mine Path at junction D5-3 and continues up and across a hill.**

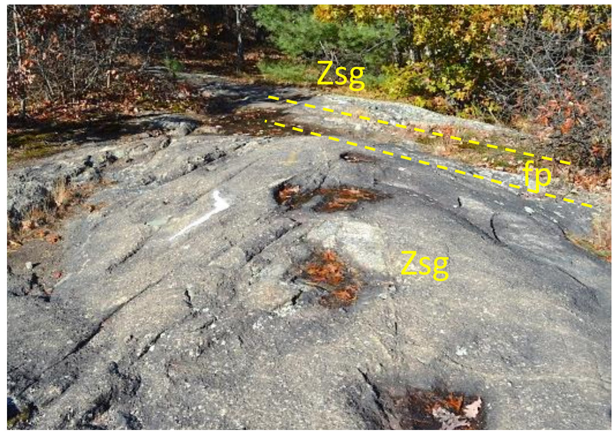

**STOP 11:** After crossing a small hill of Spot Pond Granodiorite (Zsg), the trail descends to the stream outlet (footbridge) for a wetland to the west (left). The wetland is underlain by the Rams Head Porphyry (Zrhp), which forms lowlands along its contact with the granodiorite. The valley is a major E-W fault. A fault is a fracture separating two rock bodies that have moved relative to each other. Faults have displacement, while fractures don't. East of the footbridge is a large, flat face (image on right), which is a fracture (joint) plane in the granodiorite. It was created by stresses associated with the fault, and it parallels the fault. The bracket symbol ( **]** ) on the map indicates that the joint plane dips to the north (direction of tic marks or small bars) at 80°. On the hillslope north of the stream (ahead) is the granodiorite/porphyry contact.

**After crossing a dirt road at junction D5-1 the trail ascends Silver Mine Hill.**

**STOP 12:** Silver Mine Hill gets its name from an old mine shaft about 250 m northwest of here in a fault valley. The old mining operation was reported in the *Medford Mercury* in 1881 as having silver, gold and copper. There is no significant (if any) precious metal in this area, and the mining operation may have been a hoax perpetrated to sell property or swindle investors. The first outcrop on the trail up the hill (image on right) is a finger-like projection of the Rams Head Porphyry (Zrhp) into the Spot Pond Granodiorite (Zsg). Look for the porphyry's tightly packed white plagioclase crystals that give the rock a speckled appearance (see Stop 4). A little further up the trail is the contact of granodiorite with the north side of the porphyry projection.

**Continue to the top of Silver Mine Hill.**


**STOP 13:** At the top of Silver Mine Hill, the trail levels off on a rounded flat surface of Spot Pond Granodiorite (Zsg). The far side of this flat area (image to right) has a 1.5-2 m-wide rhyolite dike (fp) that crosses the hilltop (see orange line on map). Note on the map that, just to the west, the Rams Head Porphyry (Zrhp) crosscuts the contacts of a Westboro Formation (Zvwq) inclusion and porphyritic rhyolite dike (fp) that are both in the granodiorite, which clearly shows the younger age of the porphyry.




**The trail continues northwest (downhill) across granodiorite and descends to the base of the hill at Silver Mine Path. Continue the tour on Map 2B. Cross Silver Mine Path at junction C4-13 and climb another small hill.**

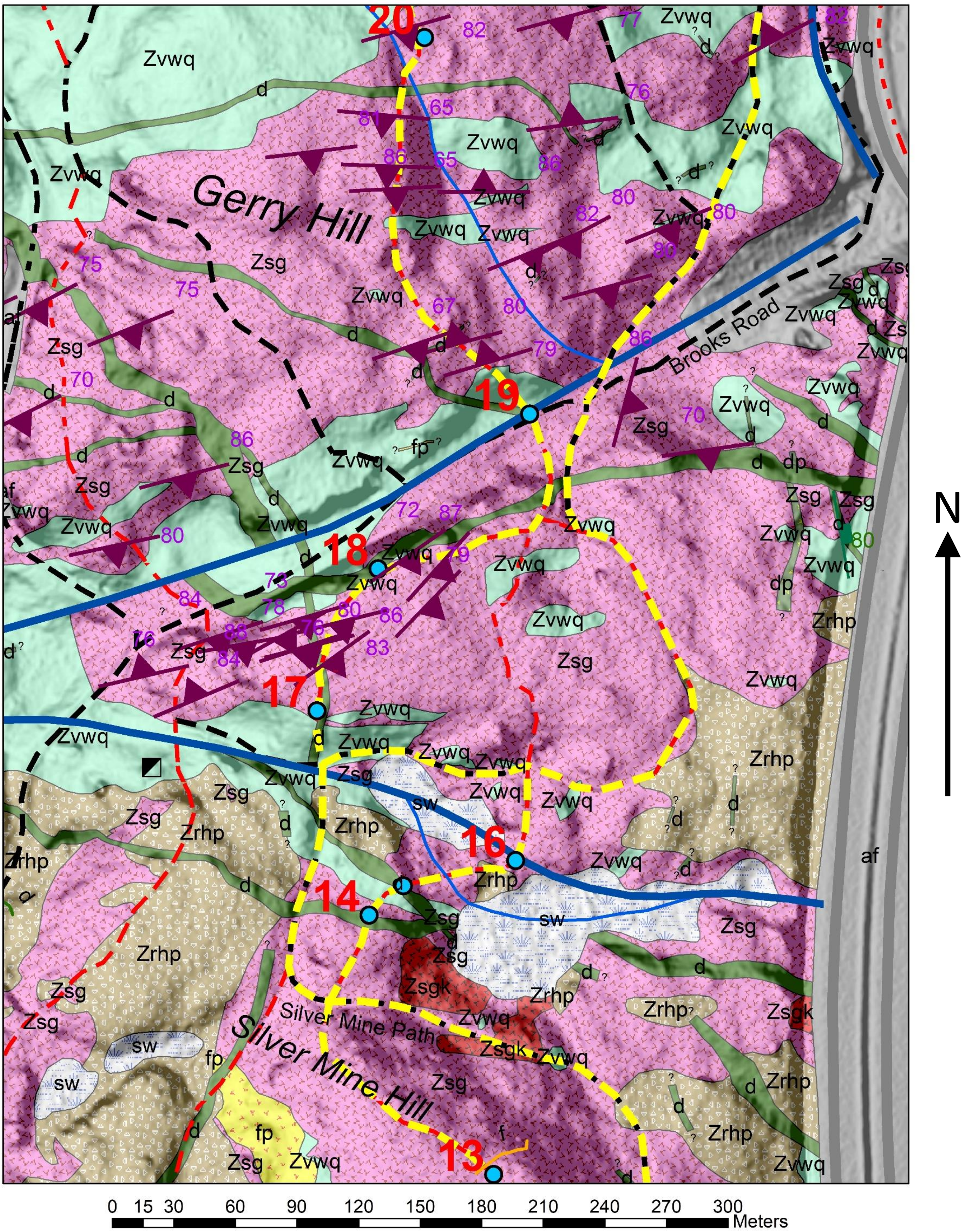
**STOP 14:** The trail climbs through the Spot Pond Granodiorite (Zsg), then crosses an E-W trending dolerite dike (d) at the top of the hill. The dike is about 10 m wide and has glacial grooves and striations preserved on its surface (image to right, grooves parallel to hammer). The grooves were produced by glacial ice sliding across the rock surface during the last glaciation at about 17-35 ka (ka = kilo-annum or 1000's of years ago). The striations are oriented S26°E, which is the direction the glacial ice was sliding. Very little weathering has occurred on the grooved surface since that time. Until recently a thin layer of soil may have covered the surface but was eroded to expose the glacial features. If you look closely, you are likely to see other areas with grooves and striations on dolerite dikes.

**Continue across the hilltop and head downslope to the right.**

**STOP 15:** A second dolerite dike (d) crosses the trail, forming a bench (image to right). This dike is oriented WNW-ESE and is crosscut by the dike at Stop 14. This demonstrates at least two different ages of dolerite dikes. Like the dike at Stop 14 the dike here intruded the Spot Pond Granodiorite (Zsg). It also cuts across an inclusion of the Westboro Formation (Zvwq) in the low spot just west of the dike and about 10 m south (to right) of the trail.


**Continue beyond the dike to a low area between two wetlands.**

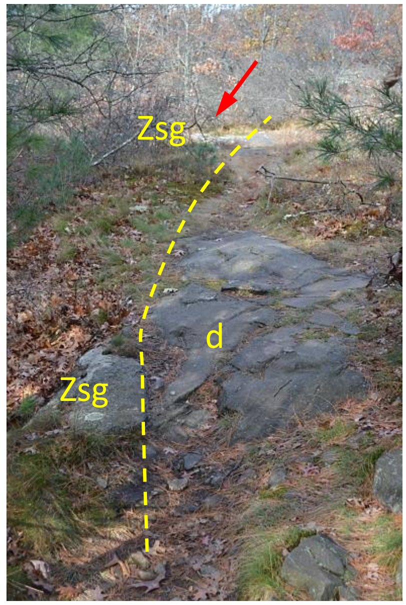
Map SKY-2B


Gerry Hill
Silver Mine Hill
Silver Mine Path
Brooks Road
20
19
18
17
16
14
13
Zvwq
Zsg
Zrhp
Zsgk
d
dp
fp
sw
af
f
N
0 15 30 60 90 120 150 180 210 240 270 300
Meters

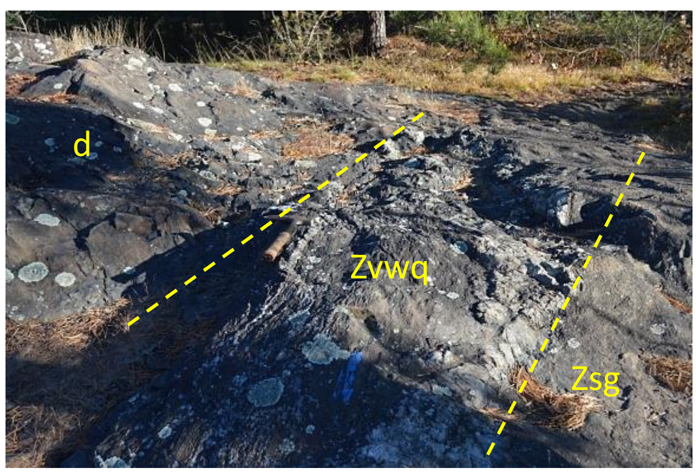
**STOP 16:** At the east end of the lowland, a major fault runs through the wetland area. The fault is just beyond the last knob of granodiorite in the lowland (image to right). The lowland is underlain by the Spot Pond Granodiorite (Zsg) and Rams Head Porphyry (Zrhp). Between the two wetlands, there is a bend in the fault. A minor fault branches off the main fault closer to the last stop (see Map SKY-2B), and rocks in the lowland area are heavily fractured.

**Continue to road junction (C4-11). The tour will follow a detour to show more interesting rocks. At junction C4-11, follow the dirt road west (left) to the Cross Fells Trail (blue markers, junction C4-9) and turn north (right). This will eventually bring you back to the Skyline Trail.**

**STOP 17:** The Cross Fells Trail climbs over a hornfels inclusion of the Westboro Formation (Zvwq) and then follows a dolerite dike (d), crossing through the Spot Pond Granodiorite (Zsg) at the crest of the slope (image on right). Continue to the flat outcrop of granodiorite on the west (left) side of the trail (arrow on image to right). This outcrop has an excellent example of the fabric that exists in the granodiorite in a zone that extends from here to the north. Fabric is the alignment of mineral grains in a rock, in this case due to the rotation, recrystallization and bending of quartz crystals and mafic minerals by stress acting on the granodiorite. The more brittle surrounding plagioclase crystals were rotated between the deforming quartz grains. This sets up a plate-like, planar structure in the rock, or foliation. A special symbol is used on the map (purple bar with triangle) to indicate the orientation of the foliation. The triangle shows the dip direction of the foliation, and a nearby number indicates the angle of dip away from horizontal in degrees. The dip here is very steep and nearly vertical. There is also probably an elongation of quartz grains that then line up linearly, but the direction of this lineation cannot be determined with field observations. The deformation of the granodiorite is parallel to the trend of nearby metasandstone inclusions and appears to be due to either: 1) stretching of the granodiorite shortly after it formed but while it was still hot, or 2) stretching of hot granodiorite associated with nearby E-W trending faults. In either case, the deformation is localized to an E-W zone about 400 m wide. This deformation is a part of regional metamorphism that occurred in this area, and this is the only area of igneous rock in the Fells that has a well-oriented metamorphic fabric. **Continue north about 75 m.**




**STOP 18:** The trail runs near the south (near) side contact of an 8-10 m wide, E-W trending dolerite dike (d, image on right). The contact is with a Westboro Formation (Zvwq) inclusion that is sandwiched between the dike and the Spot Pond Granodiorite (Zsg). Look for the alternating layers of metasandstone (white layers) and argillite (dark gray) in the trail. The north (far) side of the dike forms a steep cliff along the valley below along Brooks Road, where most of the rock north of the dike has been peeled away by glacial erosion. Look for glacial grooves on the top surface of the dike that trend S29°E.




**Continue on the Cross Fells Trail to where it joins the Skyline Trail at junction C4-10. Follow the Skyline Trail down to Brooks Road at junction C4-7.**

**STOP 19:** Brooks Road follows a wide valley with a major E-W trending fault that displaces several rock units and creates geologic mismatches across the valley. North of the valley, the trail climbs Gerry Hill through an inclusion (image to right) of the Westboro Formation (Zvwq) before again entering the Spot Pond Granodiorite (Zsg). The inclusion here is partly assimilated, which means the inclusion is partly melted and dispersed into the magma that then crystallized to form the granodiorite.
**Continue to the top of Gerry Hill and watch for the foliation in the granodiorite.**

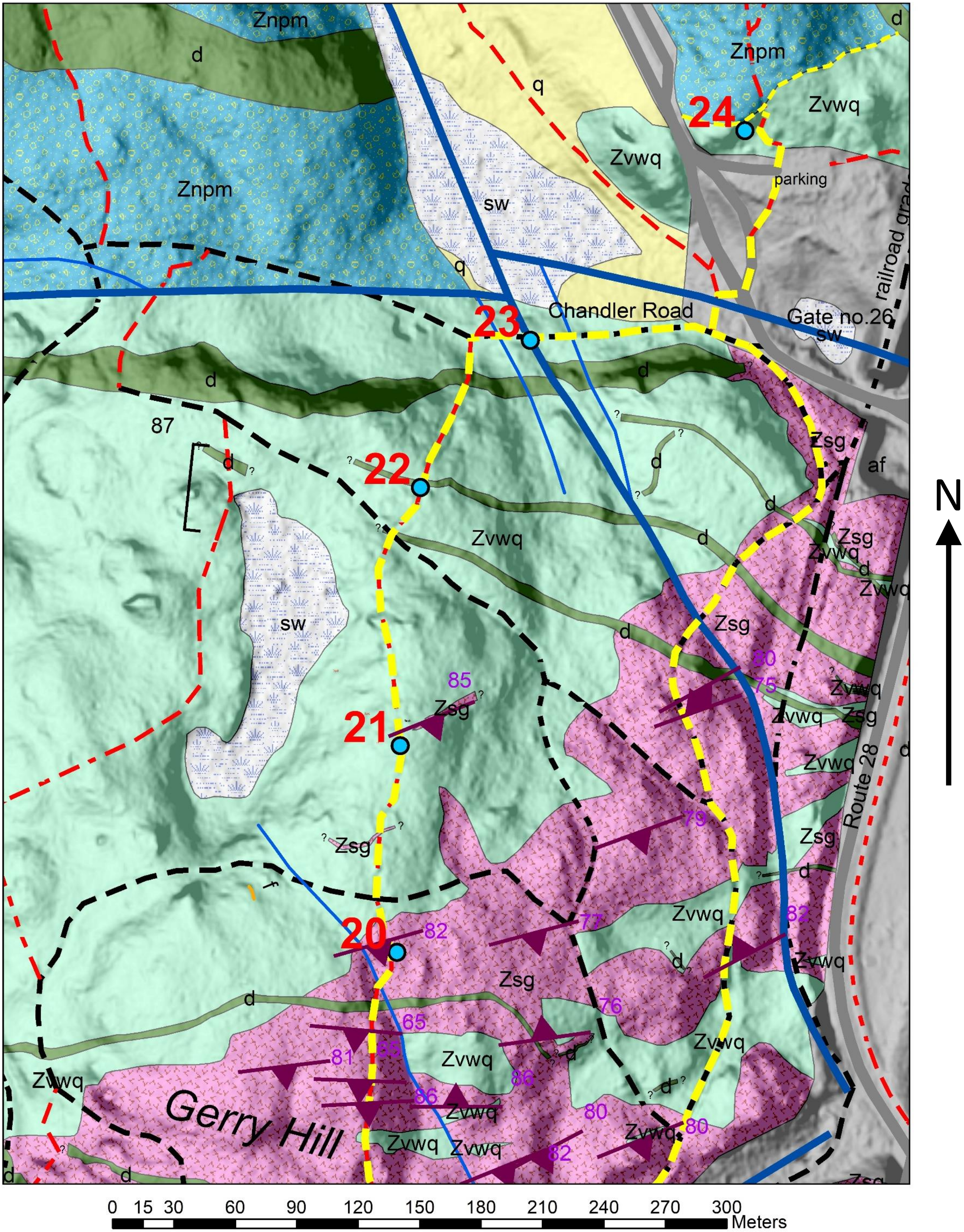
**STOP 20:** At the top of Gerry Hill and just before the junction (C4-2) with Gerry Hill Path, the surface of the Spot Pond Granodiorite (Zsg) has been sculpted and streamlined by glacial erosion (image to right, view south). The image captures the smooth rock surface in late fall sunlight and shadows. Ice flow was ~S25°E across the rock (right to left on image). At the north end of this outcrop in the trail is the contact of the granodiorite and the Westboro Formation (Zvwq).

**Follow the remainder of the tour on Map 2C. After crossing Gerry Hill Path, the trail traverses the Westboro Formation. Occasionally, you may spot small dikes of granodiorite.**

**STOP 21:** Where the trail starts to descend the flat top of Gerry Hill is an open area with one of the most spectacular outcrops in the Fells (image to right). This surface has alternating layers of white, quartz-rich metasandstone and dark gray argillite in the Westboro Formation (Zvwq). What is unusual at this site is its light metamorphism and hints of preserved bedding, with shearing mostly restricted to the weaker argillite beds. The layers are nearly vertical and trend ENE-WSW, as indicated by the blue symbols (lines with looped tic marks) on the map. The tops of the beds are facing north, but they are very slightly overturned, meaning that they were rotated more than 90° away from horizontal. The east end of the outcrop has the contact between the Westboro Formation (Zvwq) and the Spot Pond Granodiorite (Zsg). There are several things to see: 1) look for blocky inclusions of white metasandstone in the granodiorite (image to right), 2) trace out the contact and note that there is no chill zone in the granodiorite, and 3) look closely at the granodiorite, and you will be able make out a subtle foliation that parallels the inclusions. The granodiorite here forms a large dike that pinches out toward the trail. The lack of a chill zone may mean that the granodiorite cooled slowly along its contact and heat was not quickly lost to the surrounding metamorphic rocks, suggesting that it formed at a significant depth in the crust. Near the trail where it re-enters the woods to the north, you can find upright quartzite beds that are glacially polished, with striations trending S24°E.

**Follow the trail northward and cross over the dirt road at junction C4-14. The trail then heads downhill.**

Map SKY-2C



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Meters

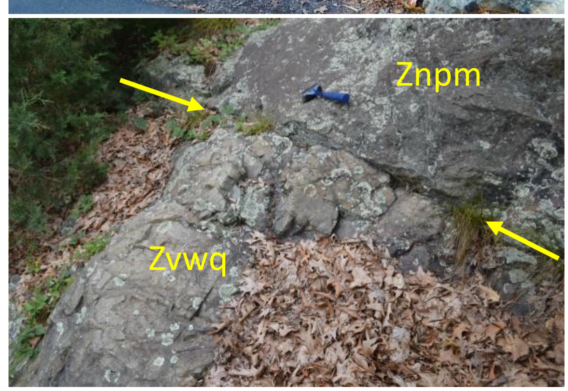
The Age of the Westboro Formation:

One thing we haven't yet discussed is the age of the Westboro Formation. The original shale, siltstone, and sandstone that formed this unit prior to metamorphism represent an ancient, stable continental shelf environment. Analysis of trace amounts of radioactive elements in zircon sand grains in this unit indicate that it cannot be older than 909 Ma (mega-annum or millions of years ago). Zircon (zirconium silicate) is a mineral that stores trace amounts of radioactive uranium, which is lost only by radioactive decay to lead, from the time it crystallized in an igneous rock. Knowing the rate at which uranium decays, and measuring the ratios of uranium and lead isotopes, allows us to calculate the age of the zircon sand grains. The zircon grains in the metasandstone have various ages, coming from many different igneous rocks that were eroded to produce the sand grains. The sand grains all have ages older than the time they were deposited in the sandstone, and the youngest zircon grains give the maximum (oldest possible) age of the Westboro (909 Ma). The youngest possible age for the Westboro Formation is about 609 Ma, which is the age of the oldest igneous rock that intrudes the Westboro. This igneous rock is the Spot Pond Granodiorite. It is not metamorphosed over most of its outcrop area and post-dates the Westboro's metamorphism. Therefore, the Westboro is likely significantly older than 609 Ma. The age constraints for the Westboro Formation (909-609 Ma) place it in the Neoproterozoic Era. For more on how rock ages are determined see: RockAges.

**STOP 22:** Just as the trail starts to descend to Chandler Road, it crosses an E-W trending dolerite dike (d). This dike (image to right) is very closely aligned with the layering in the Westboro Formation (Zvwq) and fracturing parallel to the layering may be partly responsible for the dike's orientation, with planar spaces parallel to the layers opening more easily to fill with magma. Near the stairway at the base of the hill is another, larger dolerite dike (d) with a similar orientation. **At the base of the hill is Chandler Road (also the Reservoir Trail – orange markers) at junction C3-4. Head east on Chandler Road for about 30 m.**

**STOP 23:** A major fault crosses the road from the wetland to the north (left) and enters a narrow valley to the south. North of here the major fault is beneath the wetland and then runs beneath North Reservoir. The rock is heavily fractured near the fault, and as a result was deeply eroded during glaciation. East of the wetland at the north end of Sheepfold is one of the few places in the Fells where thick glacial sediment extensively conceals the bedrock surface. On the map this is indicated with Quaternary deposits (q).
**Continue east on Skyline Trail to where it enters the smaller southern parking lot at Sheepfold.**

**STOP 24:** On the north (far) side of the driveway leading into the southern parking lot is the contact between the Westboro Formation and basaltic rock of the Nanepashemet Formation (Znpm, image to right taken in fall). The top of the Westboro is defined as the top of a thick metasandstone layer (image below to right, yellow arrows). The irregular surface between the two formations is an unconformity, which is a boundary between two rock formations that represents significant missing time in the rock record and is overlain by a sedimentary unit or volcanic unit. We don't know exactly how much missing time in terms of years, but it was enough for the Westboro to be metamorphosed and eroded before the basalt flowed across the erosion surface. Other processes have also made the Sheepfold outcrop more complicated. East of the major fault at the last stop, the rocks at Sheepfold have a different appearance. Both the metasandstone and basalt are contact metamorphosed to hornfels by a large intrusion to the east that also occurs beneath the units here. The intrusion is the Stoneham Granodiorite (Zst), which will be explored on Part 3 of the tour. The hornfels has had its bedding and foliation almost entirely obliterated by contact metamorphism (baking). For more on unconformities see: Unconformities.



**END OF PART 2**

If you started this tour as an extension of Part 1, see the directions at the beginning of Part 2 to return to Stop 1 of Part 2 at Red Cross Path, and then the directions at the end of Part 1 (also at beginning of this document) to return to the Bellevue Pond parking area by way of Red Cross Path, Mud Road, and Quarry Road.

Below is a listing of all the rock units you have seen on Part 2 of the Skyline Trail tour. Can you make a list of the relative order in which the rock units formed?

dolerite (diabase) dikes (d)
porphyritic rhyolite dike (fp)
Quaternary deposits (q)

Spot Pond Granodiorite (Zsg)
Westboro Formation (Zvwq)
Rams Head Porphyry (Zrhp)

**Here is a summary list of the features and vocabulary for Part 2 of the Skyline Trail tour:**

minerals:
- quartz
- plagioclase feldspar
- alkali feldspar
- mafic rocks and minerals
- pyroxene
- amphibole – hornblende
- biotite mica
- chlorite
- zircon

coarse-grained vs. fine-grained
zoning

subsurface igneous rocks:
- basalt (as dikes)
- dolerite
- rhyolite (as dikes)
- granodiorite
- quartz diorite
- porphyry, porphyritic
  - (phenocrysts + ground mass)
- magma – molten rock, magma chamber
- intrusion
- dike
- pluton - For more on how plutons form see: Plutons.
- inclusion (xenolith)
- chill zone or chilled margin
- assimilation
- crosscutting

sedimentary rocks:
- sandstone, siltstone, shale
- bedding

metamorphic rocks:
- metasandstone - metamorphosed sandstone
- argillite – hardened shale/siltstone
- hornfels – baked fine-grained rocks
- contact metamorphism
- regional metamorphism
- foliation
- lineation

time abbreviations:
- Ma = mega-annum, millions of years ago
- ka = kilo-annum, thousands of years ago

Quaternary Period (2.6 Ma – present)
Neoproterozoic Era
radiometric dating - For more on how rock ages are determined see: RockAges.
contacts
unconformity - For more on unconformities see: Unconformities.

fracture planes or joints
fault, fault displacement
fault zone

weathering – surface degradation of rocks
erosion – removal of weathered rock debris
vernal pool - ephemeral wetland
glaciation or ice age
glacial striations and grooves
glacial sediment