Self-Guided Geologic Tour of the Skyline Trail in the Middlesex Fells Reservation (Part 3)

Prepared by Jack Ridge, Professor, Dept. of Earth and Climate Sciences at Tufts University, Medford, MA

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

1. 1. The Skyline Trail has been broken into seven parts. You should not try to do the whole tour in one day (~7 miles or 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 3: Sheepfold to Bear Hill via Winthrop Hill

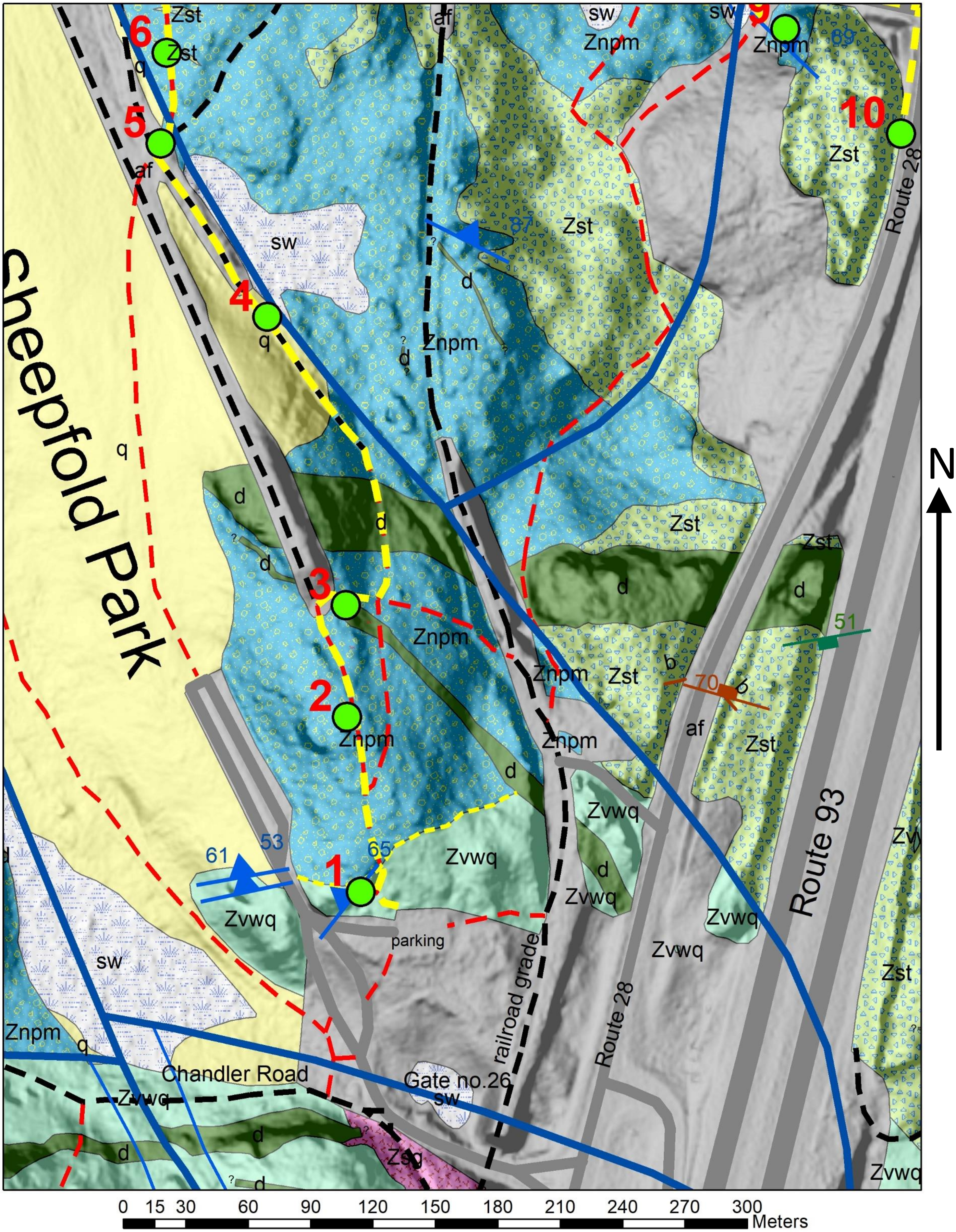
Total distance: 2 miles (3.2 km) to last stop of tour + 0.9-mile (1.45 km) return hike = 2.9 miles (4.65 km)

Prepared by Jack Ridge, Professor, Dept. of Earth and Climate Sciences, Tufts University

Starting point: The lower (southern) Sheepfold parking lot (DCR Gate no. 26) on Rt. 28 west of Spot Pond in Stoneham. Part 3 begins at the northwest corner of the parking lot (left side of entrance, Stop 1) and heads north. Stop 1 is also Stop 24 (last stop) of Part 2 of the tour. Note that Part 3 begins with stops renumbered starting with 1 on Map SKY-3A. Follow the trail on the geologic maps as you go. Stops on the tour are shown with green circles and red numbers. Follow the white trail markers of the Skyline Trail in the park 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. **You can start Part 3 of the tour as a continuation of Part 2,** which has the same starting point, but it will be a lot of walking and time for one trip. Having a hand lens or magnifying glass can be helpful. Have fun!! Hope you enjoy the geology!

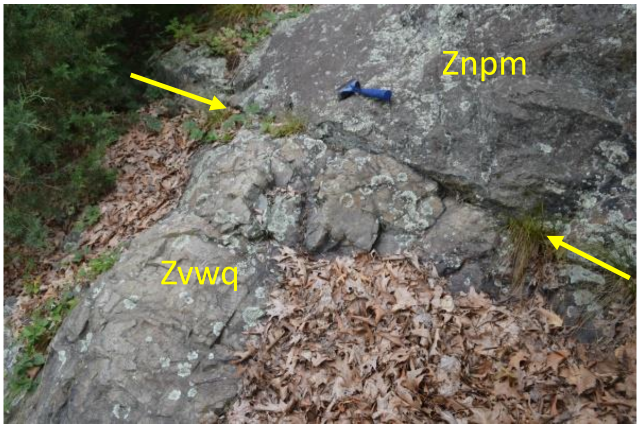
Part 3 focuses on the Neoproterozoic Westboro Formation, Nanepashemet Formation, and Stoneham Granodiorite. The Neoproterozoic was 1000 – 541 million years ago. You will also see younger dolerite dikes, faults, and some glacial features.

Map SKY-3A


Sheepfold Park
Chandler Road
Gate no.26
parking
railroad grade
Route 28
Route 93
Znpm
Zst
Zvwq
Zsg
sw
af
q
d
b
1
2
3
4
5
6
9
10
61
53
65
87
69
70
51
N
0 15 30 60 90 120 150 180 210 240 270 300
Meters

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.

STOP 1: On the north (left) side of the entrance to the parking lot (image to right, taken in fall), is the contact of the Westboro Formation (Qvwq) and Nanepashemet Formation (Znpm). The Westboro is metasandstone (metamorphosed sandstone), which here is rich in quartz. The original sandy sediment, with its high quartz content, represents a continental shelf environment, far from volcanic or tectonic activity. The metasandstone was later stretched and deformed by burial and mountain building processes (plate tectonics). This is known as regional metamorphism, and it can deform or obscure original bedding in the metasandstone.



The top of the Westboro Formation (Zvwq) at Sheepfold is defined as the top of the last thick metasandstone layer (image to right below, yellow arrows). The rock above is basaltic rock of the Nanepashemet Formation. The irregular surface between the two formations is an unconformity, or a boundary between two rock formations that represents significant missing time in the rock record and is overlain by a sedimentary or volcanic unit. We don't know exactly how much missing time in years, but enough for the Westboro to be metamorphosed and eroded before a basaltic lava flow buried the erosion surface. For more on unconformities see: Unconformities. Other processes have also made the Sheepfold outcrop more complicated. East of the major faults on the west side of Sheepfold, the metasandstone and basalt are heavily contact metamorphosed, or changed by exposure to heat next to an intrusion. The intrusion is the Stoneham Granodiorite (Zst), which is exposed to the east and will be seen later during the tour. Baking of the rocks has changed them to a very brittle, fine-grained rock known as hornfels, in which layering has been largely obliterated by high temperature recrystallization.

From Stop 1 get on the Skyline Trail at the north side of the parking lot and head north onto the flat hilltop.

The Age of the Westboro Formation:

The original shale, siltstone, and sandstone that formed the Westboro Formation prior to metamorphism represent an ancient, stable continental shelf environment. Analyses 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 yr ago). Zircon (zirconium silicate) is a mineral that stores trace amounts of radioactive uranium from the time it crystallized in an igneous rock. This uranium is lost only through radioactive decay to lead. 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 Westboro have various ages from the 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, so the youngest zircon grains give the maximum (oldest possible) age of the Westboro (909 Ma). The youngest possible age for the Westboro Formation is 609 Ma, which is the age of the Spot Pond Granodiorite, the oldest igneous rock that intrudes it. This igneous rock is not metamorphosed and post-dates the metamorphism of the Westboro. Thus, the Westboro is likely much older than 609 Ma. The age constraints for the Westboro Formation (909-609 Ma) place it in the Neoproterozoic Era. For more on how ages are determined for rocks see: RockAges.

STOP 2: This stop refers to the outcrops on the west (left) side of the trail 50-100 m north of Stop 1. Here, basalt of the Nanepashemet Formation (Znpm) has been intensely baked (contact metamorphosed) next to a large intrusion, the Stoneham Granodiorite (Zst). (This rock unit will be fully described later.) An intrusion is a magma body that forced its way into older rocks and cooled to form igneous rock. The Stoneham Granodiorite is well exposed to the east and northeast around Spot Pond. It is a large and irregularly shaped intrusion that we call a pluton. For more on how plutons form see: Plutons. The baking of the basalt at Sheepfold changed it to hornfels, which is a hard, brittle rock formed from the baking of fine-grained minerals in the original rock. Most structures in the original basaltic lava have been destroyed by high temperature recrystallization. In this area, you will see evidence of the granodiorite intrusion in the form of small granodiorite dikes and veins (centimeter-scale dikes) that invade the hornfels and areas where the hornfels fell apart, resulting in many inclusions in the granodiorite (image to right above). Inclusions are pieces of older rock that broke off into a magma and were trapped when the magma crystallized. The inclusions and granodiorite intrusion together make a plutonic breccia. Breccia is a rock made of angular pieces of an older rock. The abundant small dikes and breccias indicate that the main body of the granodiorite pluton is not far away in the subsurface. Look at the outcrops west of the trail for small granodiorite dikes and plutonic breccia.

Continue north across the top of the hill to a paved area where the trail takes a turn to the east (right).

STOP 3: At the right turn, the trail crosses a NW-SE trending dolerite dike (d) (image to right above). The dolerite has a smoother surface than surrounding rock units and resembles the back of a whale. A dike is an intrusion that forced its way into a crack and separated the sides, giving the intrusion a slab-like shape. Over short distances, dikes take the form of planar slabs, but their thickness can change, and they can pinch out. There are no light-colored granodiorite dikes or breccia in the dolerite because it is an intrusion that is younger than the granodiorite. Dolerite is a mafic igneous rock with mineral grains that are sand-sized. It is halfway between a fine-grained rock like basalt and a coarse-grained rock like gabbro. Mafic means dark-colored and on the smooth surface of a piece of dolerite cut on a rock saw (image to right above) you can see the minerals in the rock. The faintly purplish- to greenish-gray grains are pyroxene, while the white to gray blade-like crystals are plagioclase feldspar. If you look at the map, you will see that this is a relatively small dike, as compared to others in the area. For example, the E-W trending dolerite dike that underlies the mound-like hill to the north is much larger. This hill used to be the starting point for soapbox derby races down the paved road on the north side of the hill. Note on the map that the large dolerite dike is offset by the major faults east and west of Stop 3.

Follow the trail east (right) about halfway down the hill, where the trail again heads to the north (left) at junction D3-6. The trail crosses the wide dolerite dike, but it is not well exposed here. You may see loose dolerite debris.

STOP 4: The trail becomes a dirt road and runs along the west side of a wetland to your right. To the west (left) is a hillslope that does not have rock outcrops. The bedrock surface is covered by glacial sediment, known as till, that was dragged across the land surface at the base of a glacier and deposited here. It is shown by the yellow pattern (q) on the map. The 'q' is an abbreviation for undifferentiated sediment from the Quaternary Period (2.6 Ma to present). The swamp to the east (right) is underlain by the Nanepashemet Formation (Znpm). The valley was eroded in the Nanepashemet Formation because the lowland does not have dolerite dikes like the adjacent hill, which tend to be more resistant to erosion.

Continue to the north end of the swamp to junction C3-2.

STOP 5: From junction C3-2, look due northeast (right) along a road and you will see a small upland south of the road. The high ground here is permeated with thin dikes of Stoneham Granodiorite (Zst) that baked the Nanepashemet Formation (Znpm) to hornfels, making it harder and more resistant to erosion. It is the southern edge of a small upland that has many larger granodiorite dikes. East and south of the swamp, the rocks have less granodiorite, and they are more eroded. The relationship between contact metamorphism (hornfels formation) and resistance to erosion plays out in many parts of the Fells, where igneous activity and glaciation worked together to produce the current topography.

From this point, follow the tour on Map SKY-3B.

Continue north on the Skyline Trail.

STOP 6: Not too far into the wooded area, you will see some E-W trending dikes branching off the Stoneham Granodiorite (Zst). The small mounds (image to right) are granodiorite dikes that intruded the Nanepashemet Formation (Znpm). Again, this area is part of a hornfels upland that is more resistant to erosion.

Continue about 50 m beyond the granodiorite dikes at Stop 6. The next stop is just before a right and then quick left bend in the trail.

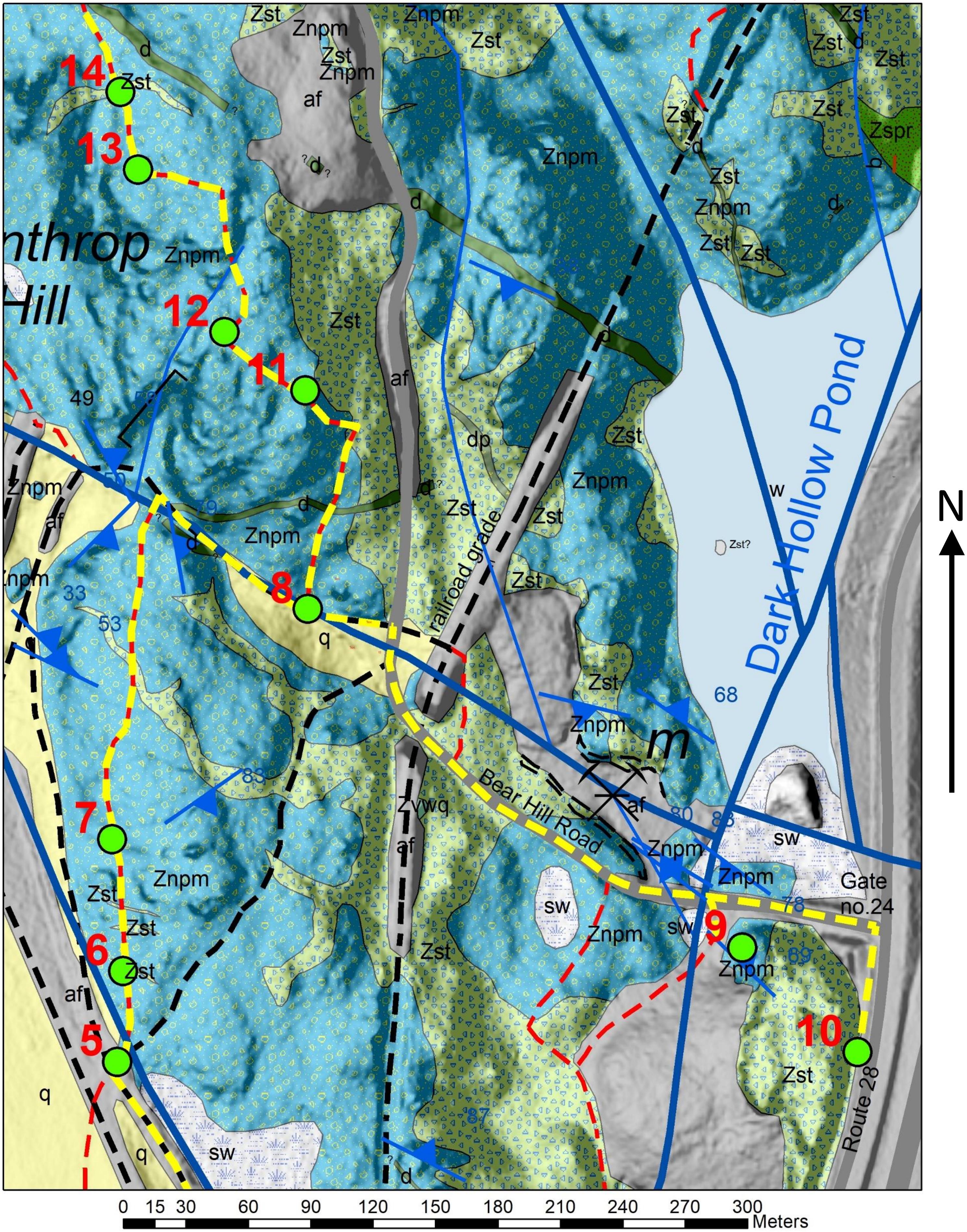
STOP 7: Watch carefully for the dark gray hornfels of the Nanepashemet Formation (Znpm) that is exposed in the trail. This is one of the few places on the trail where you can see faint traces of layering in the hornfels (parallel to pencil in image on right). In this case, the layering was produced either by deformation of the original basalt when it was baked or is a result of partly altered original layering. On the map, there are several places to the north, just west of the trail, where the foliation was preserved well enough to make measurements of its orientation (look for blue symbols that are bars with triangles). You'll learn more about foliation in the hornfels at Stop 9.

Continue north on the trail to the road at junction C2-8 and turn southeast (right) toward junction D3-1 (Stop 8).

STOP 8: Almost immediately after junction C2-8, you will walk through a thin offset dolerite dike (d, see map SKY-3B). The road follows a valley that is the course of a major E-W fault that runs through the Nanepashemet Formation (Znpm) as you head to junction D3-1. You will hear more about the Nanepashemet Formation later. Like the E-W faults south of Sheepfold, this fault is crosscut by major N-S faults that also define valleys, such as the valleys underlying Dark Hollow Pond to the east near Rt. 28.

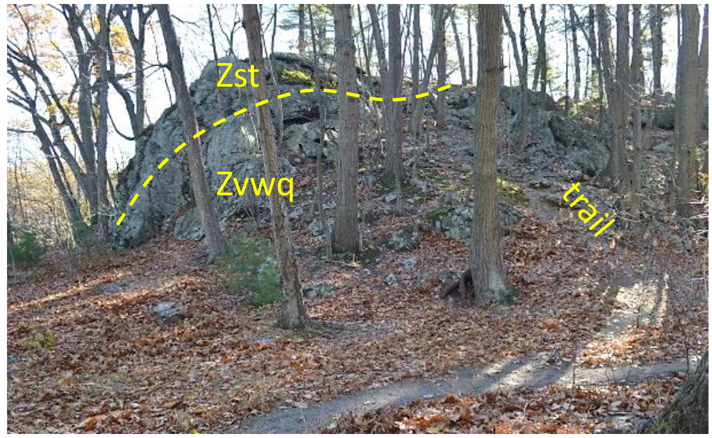
At junction D3-1 the trail heads north again, but first the tour will take a side trip, continuing southeast (straight) to Bear Hill Road. Turn south (right) on Bear Hill Road and follow it under the old concrete railroad bridge on an abandoned trolley line that once went between Medford and Stoneham. Continue east-southeast past trail junctions D3-3 and D3-4 (Mountain Bike Loop) to the next trail on the south (right) side of the road. Dark Hollow Pond will be on your left to the north.

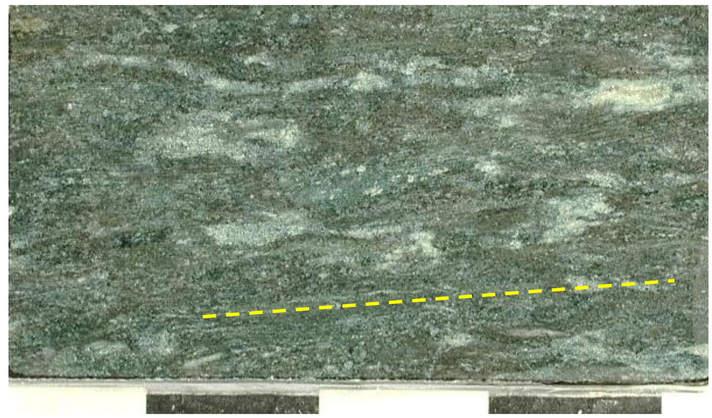
Map SKY-3B



Winthrop Hill
Dark Hollow Pond
railroad grade
Bear Hill Road
Route 28
Gate no.24
Znpm
Zst
Zspr
Zvwq
af
dp
d
q
sw
w
m
N
0 15 30 60 90 120 150 180 210 240 270 300 Meters

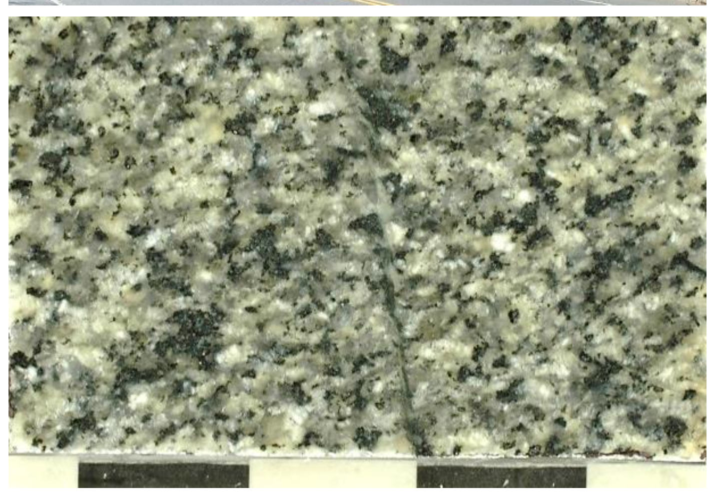
STOP 9: The hill south (to right) of the road (image on right) has the contact of the Nanepashemet Formation (Znpm) and the Stoneham Granodiorite (Zst). The granodiorite makes up the top of the hill, and it is relatively fine-grained along the contact. This is the chill zone of the granodiorite pluton, where heat loss and cooling of the magma occurred relatively fast and prevented coarse crystal development. For more on how plutons form see: Plutons. A zone of deformed basaltic rock, about 20 m or so wide along the contact (on trail), has been turned to hornfels from contact metamorphism. This is also the rock type at Stops 2 and 6, but the hornfels here has a prominent foliation from simultaneous baking and stretching of the hot basaltic rock as it was intruded by the granodiorite. The metamorphic foliation (image on right, line parallel to foliation) is the result of intense squeezing and shearing, that has realigned and torn apart layers in the recrystallized basalt. Fine-grained black mica, dark green chlorite, and amphibole (actinolite) have grown in the rock. Alteration of the basalt is especially intense near the contact.





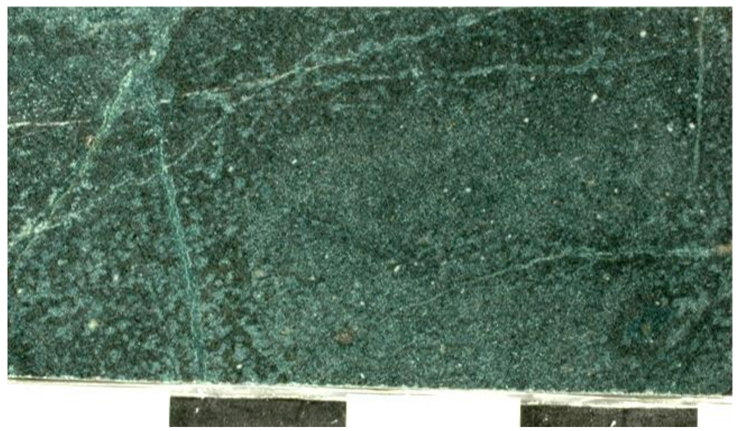
Return to Bear Hill Road and continue east (right) out to Rt. 28. Follow the sidewalk south (right) about 60 m to the road cut. Although there is a paved sidewalk, be aware of the high-speed traffic on Rt. 28.

STOP 10: OK, finally! This outcrop is the Stoneham Granodiorite (Zst; image to right, west side of Rt. 28). Granodiorite is a light-colored, coarse-grained igneous rock in which 20-60% of the light-colored minerals are quartz, with plagioclase dominating alkali feldspar, which gives the rock its overall gray appearance. Here, the rock has a considerable component of mafic minerals, in this case biotite (black mica) and amphibole (hornblende). The flat surface on the cut rock sample (image below to right) shows the quartz (gray areas) and plagioclase (white areas), while the black crystals are biotite and hornblende. No alkali feldspar is discernable on the image because these grains are very fine. As compared to other rock units in the Fells, it is relatively free of alteration, with only minor green chlorite that formed from the alteration of original mafic minerals. A green chlorite vein crosses the center of the image from top to bottom. Intrusion of the granodiorite pluton fractured rocks produced many inclusions (xenoliths) of white metasandstone, argillite, and basaltic hornfels. If you look closely at the rock face on a fresh surface, you are likely to see some dark spots, which are the inclusions. For more on how plutons form see: Plutons. The age of the Stoneham Granodiorite at the north end of Spot Pond is ~595 Ma. For more on how ages are determined for rocks see: RockAges.



From Rt. 28, head back to Bear Hill Road, head back west, go under the railroad bridge, and return to Stop 8 at junction D3-1. At Stop 8 head north (right) on the Skyline Trail up Winthrop Hill.

STOP 11: At the sharp bend that is 80-100 m up the trail from junction D3-1 there is a steep slope at the contact between the Stoneham Granodiorite (Zst) to the east (right) and the Nanepashemet Formation (Znpm) to the west (image to right). The rock type of the Nanepashemet Formation is hard to determine because of contact metamorphism, but it was originally basalt, a fine-grained mafic igneous rock that often occurs as lava flows (think Hawaii!), with a few conglomerate and breccia beds with basalt pebbles. A conglomerate is a sedimentary rock made of particles larger than 2 mm and sedimentary breccia is a conglomerate with angular particles. Today, the basalt and basalt pebbles are basalt hornfels due to contact metamorphism that has altered the rock unit, making it difficult to see original basalt structures. On the image (below to right) is a piece of the hornfels cut on a rock saw. The hornfels is very fine-grained with small crystal clusters, known as porphyroblasts (light spots on image), that grew during contact metamorphism. The Nanepashemet Formation is not regionally metamorphosed like the Westboro Formation (Zvwq), but rather intensely contact metamorphosed. The Nanepashemet is better exposed with less alteration west of Middle and North Reservoirs (Nanepashemet Hill area) and is currently under investigation with chemical and microscope analyses to determine more about its origin, which, again, is hard to determine from outcrops of hornfels.

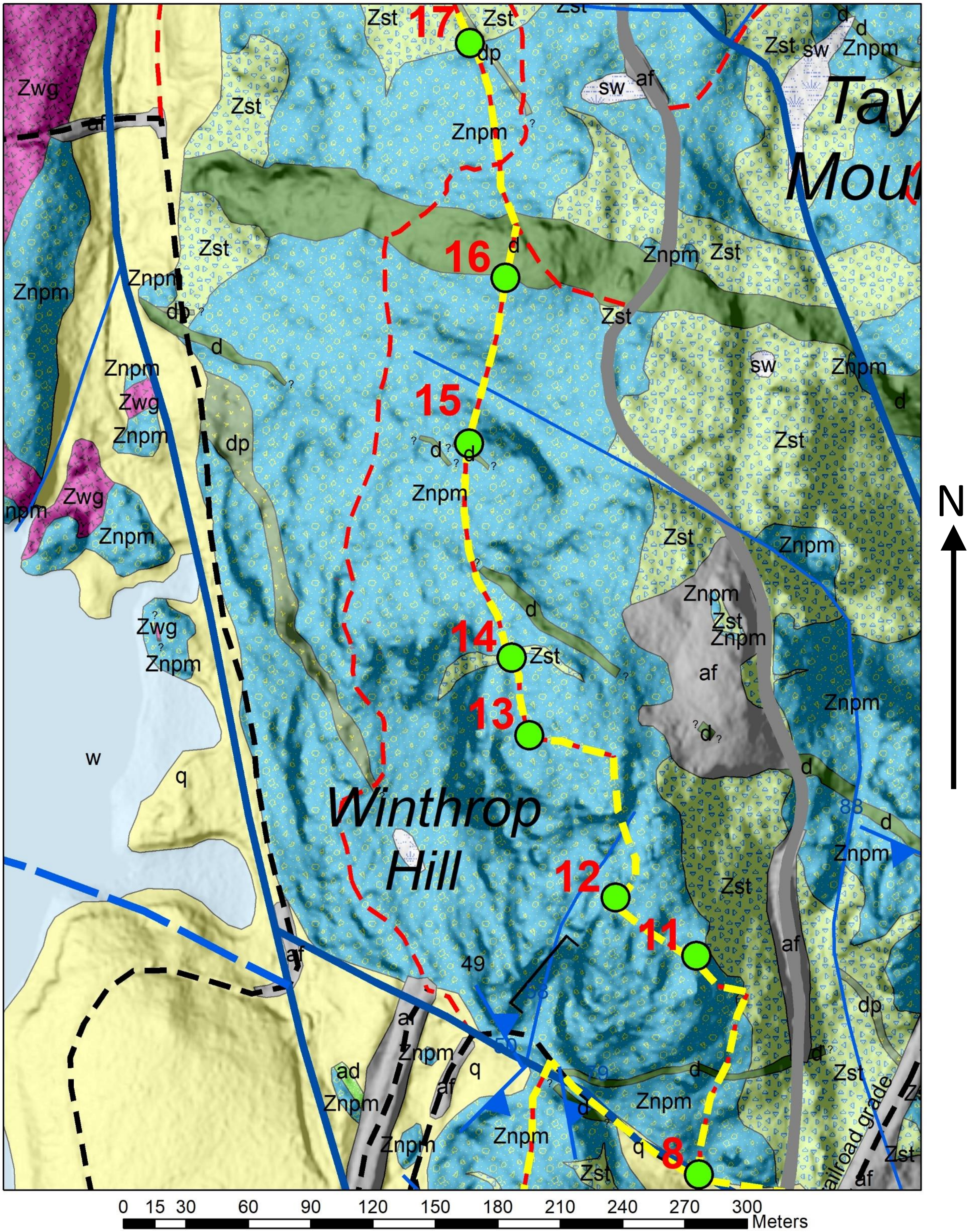


Continue to follow the tour on Map SKY-3C.

Continue up the trail as it winds to the top of Winthrop Hill.

STOP 12: Adjacent to the trail, as you approach the top of Winthrop Hill (image on right), is basaltic hornfels of the Nanepashemet Formation (Znpm) with dikes and plutonic breccia formed by intrusion of the Stoneham Granodiorite (Zst). In these thin dikes (arrow on image) the granodiorite has a pink or orange color due to iron oxide in the rock. This is like the exposures of hornfels seen at Stop 2 back at Sheepfold.

Follow the trail across the top of Winthrop Hill to its western side where the trail makes a sharp bend to the north (right).


17
16
15
14
13
12
11
8
Winthrop
Hill
Tay
Mou
N
Zwg
Znpm
Zst
dp
d
af
sw
w
q
ad
49
88
railroad grade
0 15 30 60 90 120 150 180 210 240 270 300
Meters

STOP 13: At the sharp bend (image below to left) are more examples of basaltic hornfels in the Nanepashemet Formation (Znpm) that is invaded by dikes and plutonic breccia of the Stoneham Granodiorite (Zst). The whole top of the hill is the Nanepashemet invaded by the Stoneham, making it very resistant to erosion.

The western summit of Winthrop Hill also has a great view to the west and northwest (image below to right). Clearly visible from the flat area that lies a few meters west of the sharp bend in the trail are North Reservoir and the dam at its north end. Beyond this is an old quarry in Woburn near the Winchester line. On a clear day, you can also see Mount Wachusett on the horizon, above the west shore of the reservoir to the left of the view shown here.

Follow the trail north as it starts to slowly descend the northwest side of Winthrop Hill.

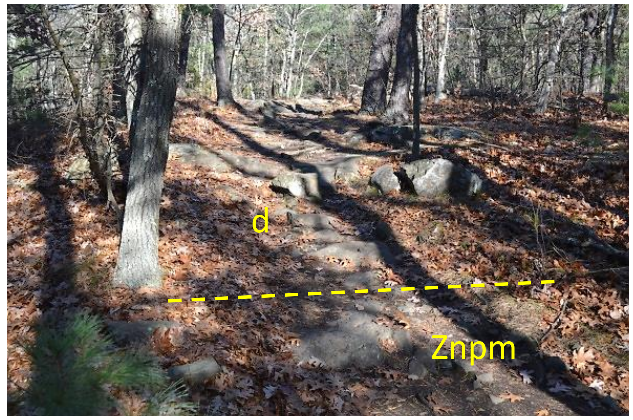
STOP 14: In about 30 m the trail crosses a large dike of the Stoneham Granodiorite (Zst) with inclusions of hornfels from the Nanepashemet Formation (Znpm). The inclusions (arrows on image) are less than 1m across, are angular in shape, and have surfaces with holes in them where material has weathered out of the rock. When the Nanepashemet Formation is heavily baked, it is not unusual for it to weather in this pattern, making it look like Swiss cheese. The holes are called alveolar weathering and should not be confused with air bubbles (vesicles) that occur in lava flows. Despite intense heating of the inclusions, they still have sharp boundaries and did not completely melt and mix with the granodiorite.

Continue down Winthrop Hill for about 100 m.

STOP 15: Near the base of the hill on the east (right) side of the trail, a dolerite dike (d, image to right) cuts through the Nanepashemet Formation (Znpm). The dike has the form of a long lens and is not very extensive. Dolerite dikes that cross the Nanepashemet Formation are difficult to trace. Not only do the dikes have about the same grain size, color, and overall chemistry as the Nanepashemet Formation, but they also have irregular shapes and diffuse or gradational contacts, where the hornfels was partly assimilated by the dolerite dikes. The dikes have smoother and often rusty-colored, weathered surfaces. Along sharp contacts, there is usually a thin (1-3 cm) chilled margin of fine basalt in the dikes.

Continue downhill and cross a shallow valley that is a minor fault.

STOP 16: After the valley, the trail approaches the crest of a flat-topped hill (image to right). This is the southern (near) side of a very wide, E-W trending dolerite dike (d) that cuts through the Nanepashemet Formation (Znpm). This dike is about 40 m wide, making it one of the widest dolerite dikes in the Fells. Segments of the dike, which have been displaced by faults, can be traced across the entire Fells. The flat center of the dike is relatively coarse-grained as compared to most dolerite dikes because it took longer to cool. This dike is also noticeably less altered than most other dikes in the Fells, probably indicating that it is part of a young set of dikes, but it is still displaced by N-S trending faults. However, it is not as young as the Medford Dike to the south (see Part 1), which is not offset by N-S trending faults.

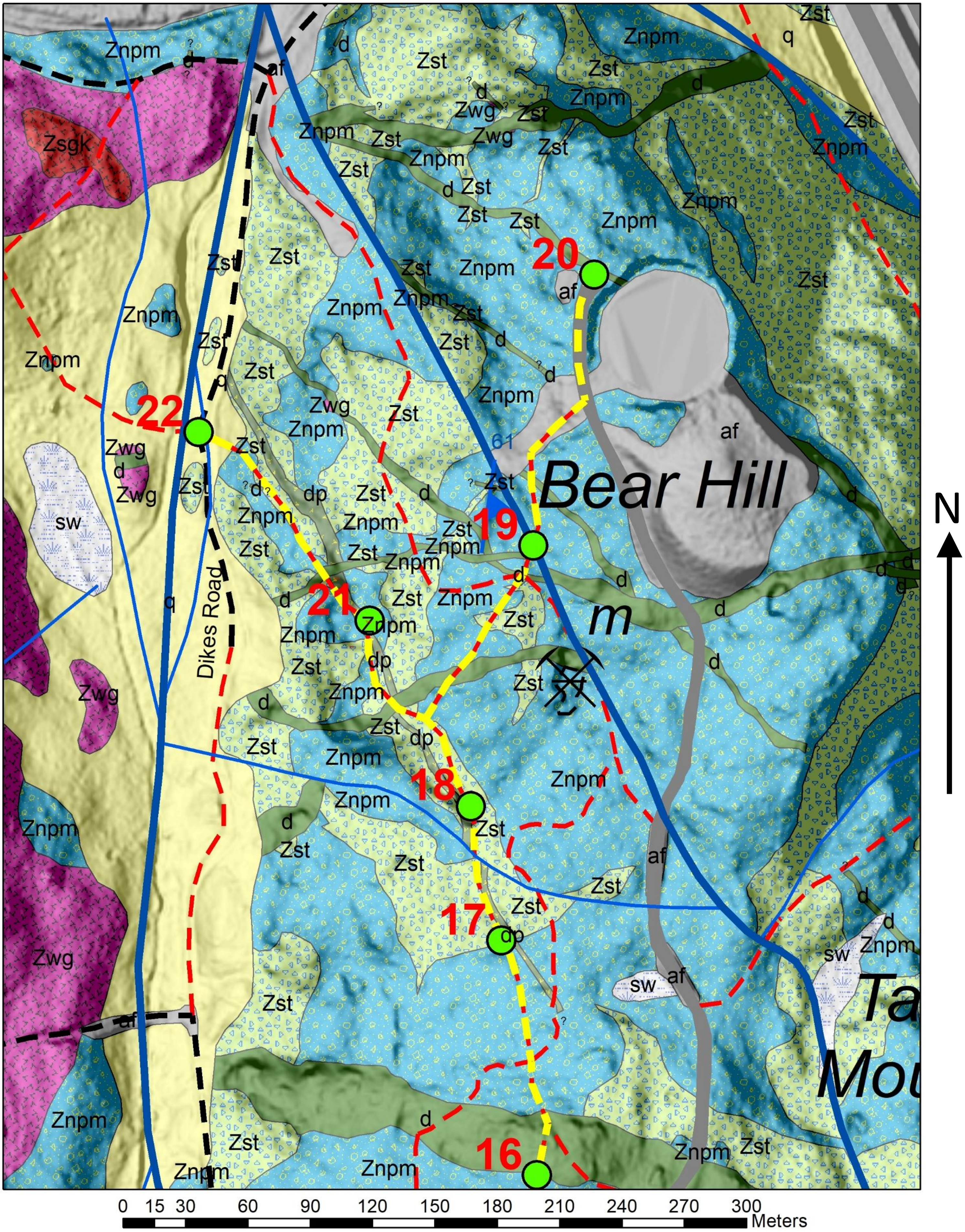


Continue to follow the tour on Map SKY-3D. Continue north and cross over the Reservoir Trail (orange markers).

STOP 17: The trail comes to a relatively large area of Stoneham Granodiorite (Zst) in basaltic hornfels of the Nanepashemet Formation (Znpm). The trail crosses a bench underlain by the granodiorite (image on right). East (to the right) of the bench is a porphyritic dolerite dike (dp) that will be seen in more detail at the next stop. At the north end of the bench, if you look closely, you can see the contact of the granodiorite and dike in the trail as you leave the bench. Look for rectangular, white crystals in the dike. The granodiorite occurs here over a large area, and it may be the top of a pluton covered by thin patches of hornfels. On the map, you will see this patchwork arrangement, which is what makes up Bear Hill to the north, while the east side of Bear Hill is a wall of granodiorite. **Continue north on the trail.**

STOP 18: Look for the steppingstones where a small fault crosses the trail (image to right, dashed line) and offsets the NW-SE trending porphyritic dolerite dike (dp) at the last stop. Beyond the fault, the dike and Stoneham Granodiorite (Zst) form a ridge that drops off sharply on its west (left) side. A porphyritic dolerite dike is the same as a regular dolerite dike but with a porphyritic texture. Porphyritic texture is when the rock has two different grain sizes, with large crystals known as phenocrysts (which here are white plagioclase) sitting in finer material known as the ground mass (which here is dolerite). The image below on the right shows a close-up view of the porphyritic dike surface at the arrow on the image above. The white mineral grains that stick out of the weathered rock surface are the plagioclase phenocrysts. Note that the crystal shapes of the phenocrysts often have parallel sides. The gray surrounding material is the dolerite ground mass. Look for fragments of the dike rock about 15 m beyond the steppingstones and 2-3 m to the west (left) of the trail. On the map, you can see that the porphyritic dolerite dike is crosscut by the E-W trending dolerite dikes (d) in this area, which are younger. Additional supporting evidence for this is that the porphyritic dike is more altered than the E-W trending dikes.

In another 40 m is trail junction C2-2, where the tour takes a short side trip to the top of Bear Hill. To follow the side trip, head northeast (right) from C2-2 on Bear Hill Trail. Almost immediately, Bear Hill Trail crosses a dolerite dike (d). At junction C2-3, Bear Hill Trail crosses the combined Reservoir Trail and Mountain Bike Loop (orange and green markers).


Bear Hill
Dikes Road
Znpm
Zst
Zwg
Zsgk
af
d
dp
q
sw
m
61
16
17
18
19
20
21
22
N
0 15 30 60 90 120 150 180 210 240 270 300
Meters

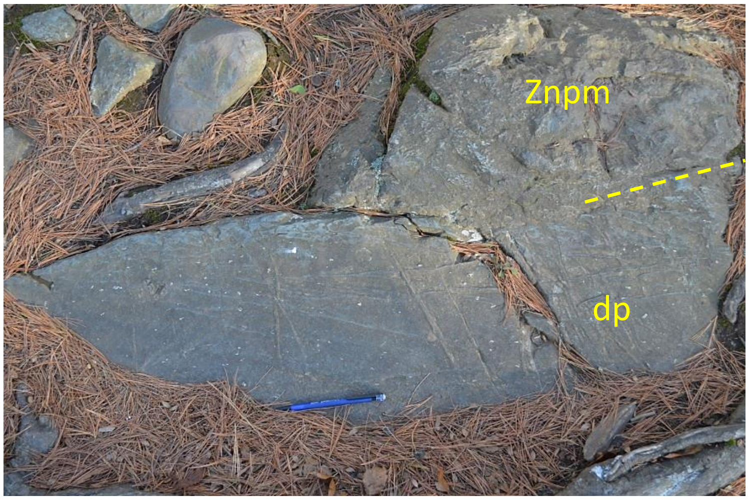
STOP 19: Slightly beyond where Bear Hill Trail crosses the other trails, it crosses two small dolerite dikes (d) and a major fault, which occupies the valley to the northwest (left) and the road to the southeast (right). Look on the map for the offset of the dikes by the fault. The fault shows an apparent displacement of its west side to the south relative to the east side, best shown by the offset of the large dike near the abandoned quarry symbol (crossed pickaxes) on the map.

From here, continue up Bear Hill Trail. A short way up the trail (~20-30 m) look down and to the left for a good view of the fault valley. After arriving at the top of Bear Hill, you will see a large water storage tank and a tower.

STOP 20: If it is open climb to the top of Bear Hill Tower for a view to the west. On most clear days, you can see Mt. Wachusett (very faintly visible at red arrow on image to right). On rare, extremely clear days with no haze, you can see Mt. Monadnock and Mt. Sunapee in New Hampshire. In the foreground is an abandoned quarry in Woburn. In the open lot at the base of the tower is a dolerite dike (d) crossing basaltic hornfels of the Nanepashemet Formation (Znpm).

When you are done with the tower, retrace your steps down Bear Hill Trail to the start of the side trip at junction C2-2. At C2-2 head northwest (right) on Skyline Trail for about 50-60 m.

STOP 21: In the middle of the trail is an exposure of the contact of the NW-SE trending porphyritic dolerite dike (d) and hornfels of the Nanepashemet Formation (Znpm, image to right). The small rectangular white crystals (phenocrysts) in the dolerite dike are plagioclase. From this stop, the trail heads downslope along a vertical face that is the west side of the porphyritic dike.



Continue on the trail to the bottom of the hill at Dikes Road (junction C2-1).

STOP 22: Across Dikes Road and paralleling it on its west side is a major N-S trending fault. This fault represents a major displacement of rocks, with the west side of the fault having moved south relative to the east side. The west side of the fault is also thought to have moved downward a substantial amount, but how much remains uncertain. The fault separates areas of the Winchester Granite (Zwg) to the west from areas of Stoneham Granodiorite (Zst) to the east. The Winchester Granite is discussed on Part 4 of the tour.

END OF PART 3: Stop 22 is the beginning point (Stop 1) for Part 4 of the tour, which explores areas of the northwest Fells. To return to Sheepfold either: 1) go back up the Skyline Trail to the Reservoir Trail (orange markers) and follow it back to Sheepfold, or 2) follow Dikes Road south along the east shore of North Reservoir. After about 0.4 miles (0.6 km), the road makes a sharp bend to the west (right) around a cove in the reservoir and then a gentler turn to the south (left). Continue south about 0.25 miles (0.4 km) and look for a small trail to the east (left) that will take you to the open field at Sheepfold and the parking lot at the far side of the field.

Below is a listing of all the rock units you have seen on Part 3 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 dolerite dike (dp)
Westboro Formation (Zvwq)
Stoneham Granodiorite (Zst)
Nanepashemet Formation (Znpm)

Here is a summary of the features and vocabulary for Part 3 of the Skyline Trail tour:

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

coarse-grained vs. fine-grained

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

sedimentary rocks:
- sandstone, siltstone + shale = mudstone

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

geologic time:
- Ma = mega-annum, millions of years ago
- radiometric dating - For more on how ages are determined for rocks see: RockAges.
- Quaternary Period
- Neoproterozoic Era
- unconformity - For more on unconformities see: Unconformities.

contacts
fracture planes or joints
fault, fault displacement

weathering – surface degradation of rocks
erosion – removal of weathered rock debris
alveolar weathering – formation of holes by weathering
glaciation or ice age
glacial striations and grooves
glacial sediment - till