Self-Guided Geologic Tour of the Skyline Trail in the Middlesex Fells Reservation (Part 4)

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. 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 may fill, 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
Part 4: Bear Hill to Grinding Rock Hill via Money Hill and Middle Reservoir

Tufts UNIVERSITY

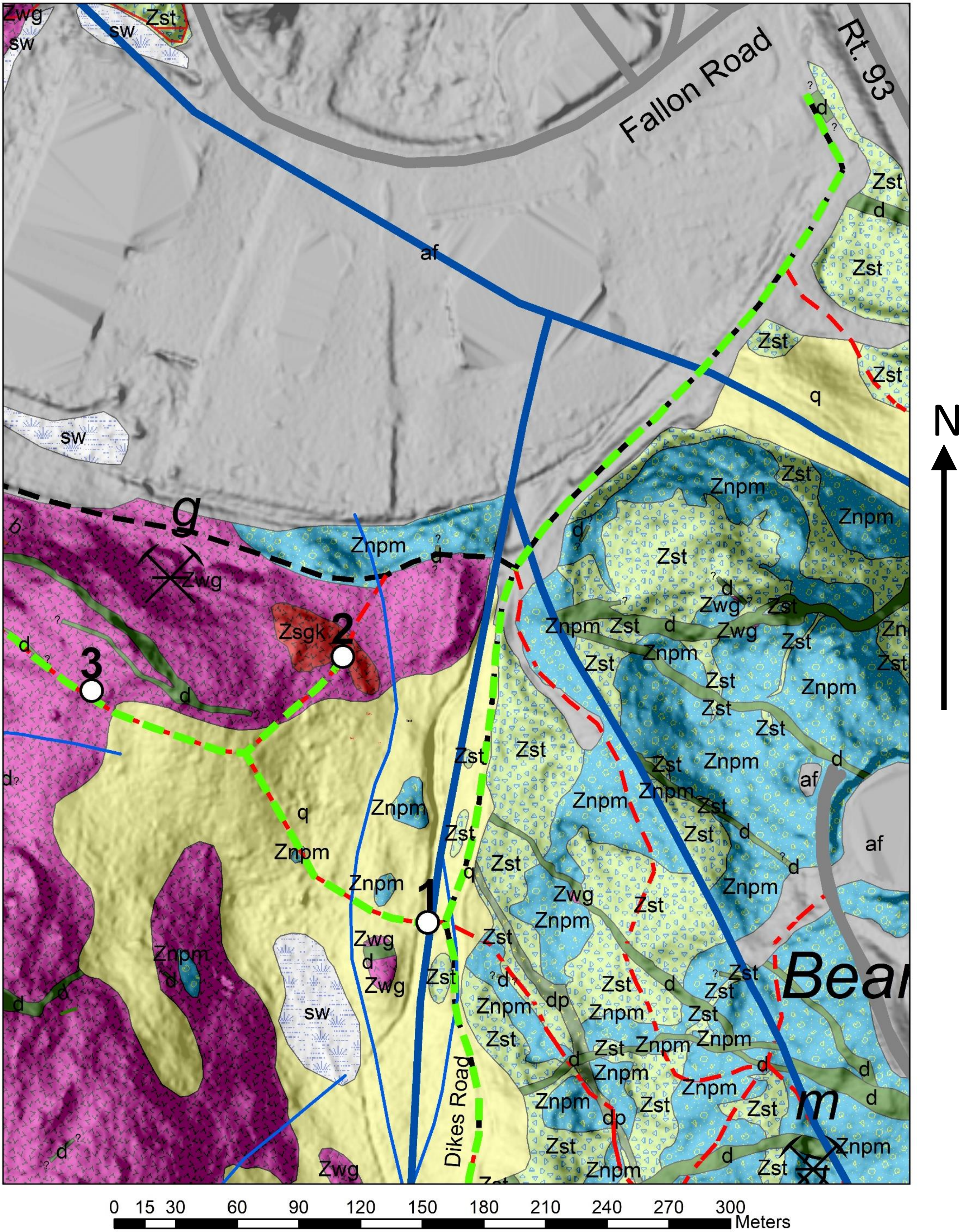
Total distance: 1.8 miles (2.8 km) to last stop of tour + 1.4 miles (2.3 km) return hike = 3.2 miles (5.1 km).

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

Starting point: The parking lot off Fallon Road in Stoneham (DCR gate no. 21, listed as gate no. 20 on DCR map) near Exit 35 of Rt. 93 South (shown on Map SKY-4A). The lot is right next to Rt. 93. Follow the trail on the geologic maps as you go. Stops on the tour are shown with white circles and black numbers. Follow the white trail markers in the field and dashed green path on the maps. The guide provides trail junction numbers, which appear on the official DCR trail map and are marked with signs in the park. Having a hand lens or magnifying glass can be helpful. Hope you enjoy the geology. Have fun!!

Please be aware that this is a relatively long hike as compared to the others because it must negotiate the Middle and North reservoirs. You should plan on at least an extra half hour of hiking as compared to other parts of the tour. I would estimate 3-3.5 hours with time to look at the geology.

Part 4 focuses on the Neoproterozoic Nanepashemet Formation, Winchester Granite, and a small area of the Straw Point Volcanic Complex. The Neoproterozoic was 1000–541 million years ago. You will also see younger dolerite dikes, faults, and some glacial features.


Fallon Road
Rt. 93
Dikes Road
Bear
af
q
sw
Zwg
Zst
Znpm
Zsgk
d
dp
g
m
1
2
3
N
0 15 30 60 90 120 150 180 210 240 270 300
Meters

To get to Stop 1: Follow Map SKY-4A to start the trip. Head south out of the Fallon Road parking lot (DCR Gate no. 21, listed as no. 20 on DCR map) and follow the dirt road along the northern border of the Fells to junction C1-6. From this junction, follow Dikes Road south (left) into the valley to junction C2-1. This route passes by the north and west sides of Bear Hill where the Nanepashemet Formation (Znpm) is intruded by the Stoneham Granodiorite (Zst). For more on this area, refer to Part 3 of the Skyline tour.
There are also some alternative starting points for this tour (Distances are calculated for the route above, not the alternative routes):

1. You can begin the tour from DCR Gate no. 17 on Hillcrest Parkway in Winchester. Start at Stop 17 of this hike and follow the guide from that stop. Directions are given in the text for this variation of the tour.
2. You can start the tour as a continuation of Part 3 that started at Sheepfold. Stop 1 of Part 4 is the last stop of Part 3. Note that if you pause to look at the geology of each stop, the hike will take a lot of time and walking, possibly too much for one trip. Directions are given at the end of the tour for a return to Sheepfold.

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 or rock hammer for scale.

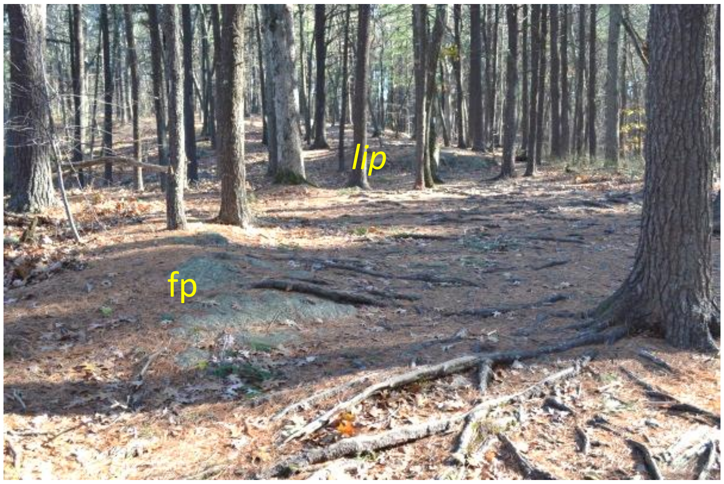
STOP 1: At junction C2-1 the Skyline Trail crosses Dikes Road. Paralleling Dikes Road in the valley is a major N-S trending fault (no image), which has displaced rocks on the west side to the south and downward, relative to rocks on the east side. However, the amount of vertical displacement remains uncertain. The fault zone is heavily sheared and separates areas with different intrusions. To the east is the Stoneham Granodiorite (Zst) and to the west is the Winchester Granite (Zwg), both of which intruded the Nanepashemet Formation (Znpm). The two intrusions are of different ages. The Winchester Granite has been radiometrically dated at 609 Ma, the same age as the Spot Pond Granodiorite, while the Stoneham Granodiorite has an age of 595 Ma and intrudes a volcanic unit at the north end of Spot Pond (Straw Point), which is nearly the same age. (Ma = mega-annum or millions of years ago). For more on how rock ages are determined see: RockAges. Shattered rock along the Dikes Road fault allowed more erosion, especially during glaciation, which is why there is a valley and wetlands along Dikes Brook. Follow the trail west (right) away from Dikes Road and across Dikes Brook. The bedrock surface on the west side of the valley is mostly concealed by glacial sediment except for a small outcrop of the Nanepashemet Formation on the trail). The glacial sediment is till that was dragged across the land surface to this position and deposited by the glacier. It is shown by the yellow color on the map. The 'q' on this unit is an abbreviation for sediment from the Quaternary Period (2.6 Ma to present).
Head uphill and take the side trail northeast (right) at trail junction (C1-4).

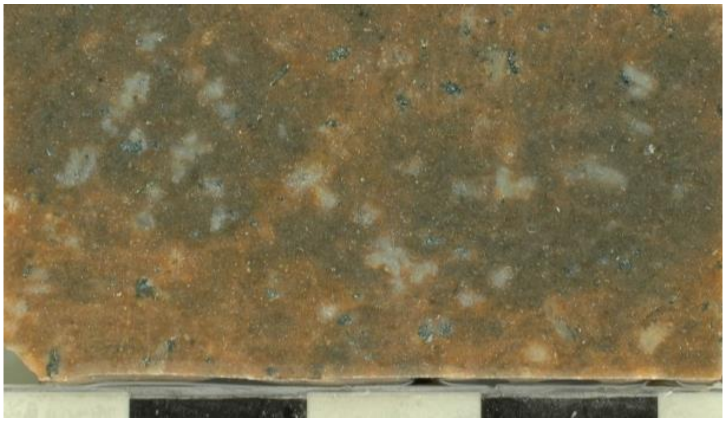
STOP 2: About 70 m from junction C1-4, the side trail crosses a poorly exposed area of alkali granite (Zsgk) in the Winchester Granite (Zwg). The Winchester Granite will be discussed at Stop 3. Alkali granite is a coarse igneous rock in which 20-60% of the light-colored minerals are quartz and the rest are almost entirely alkali feldspar. The sample shown here (image to right) has no plagioclase. You'll recognize the alkali granite by its vivid orange color imparted by alkali feldspar in loose boulders and in a poor exposure further up the slope. The alkali granite area is like some seen in the Spot Pond Granodiorite (Zsg), but this is the only known alkali granite body in the the Winchester Granite. The alkali granite has an uncertain origin. It may be an inclusion, or it could be a piece of the main body of the Winchester Granite which was transported by magma flow from another part of the magma chamber that had a different crystallization history. An inclusion is a piece of another rock formation that broke off into magma and was trapped when the magma crystallized. The inclusion origin theory for the alkali granite is supported by the fact that: 1) it has a coarser grain size than the Winchester Granite, 2) it has sharp contacts with surrounding units, and 3) similar bodies of alkali granite occur in intrusions that have different rock types (Winchester and Spot Pond).
Return to trail junction C1-4 and continue west (right). Pass by a trail heading south (left) that is not marked on DCR maps. Continue northwest (straight ahead) on the Skyline Trail.

STOP 3: The first outcrop encountered on the trail, about 75 m northwest of junction C1-4, is a typical exposure of Winchester Granite (Zwg). Granite is a coarse-grained igneous rock in which 20-60% of the light-colored mineral grains are quartz and the remaining are about half plagioclase and half alkali feldspar (image to right). On the image, quartz is gray, plagioclase is white, and alkali feldspar is pinkish-orange. The mafic (dark) minerals are biotite (black) mica that has been partly altered to chlorite. The Winchester Granite varies from place to place in its ratio of plagioclase to alkali feldspar, the color of the alkali feldspar (creamy pink to brownish-red), and the abundance of mafic minerals, which can comprise up to half of the rock. The Winchester Granite is an intrusion or body of magma that invaded other rocks in the subsurface before crystallizing. The granite is a large irregularly shaped intrusion, also known as a pluton. For more on how plutons form see: Plutons. The granite has an age of about 609 Ma (mega-annum, or millions of years ago), which is the same as the Spot Pond Granodiorite seen on other parts of the Skyline tour. This places the rock in the Neoproterozoic Era. This age was determined through measurements of naturally-occurring trace amounts of radioactive isotopes of uranium and the lead isotopes to which they decay within tiny zircon crystals. Zircon (zirconium silicate) is a mineral used for determining radiometric ages of rocks because it is impervious to all except the most extreme heating and deformation and provides accurate results on a rock's age. For more on determining rock ages see: RockAges.

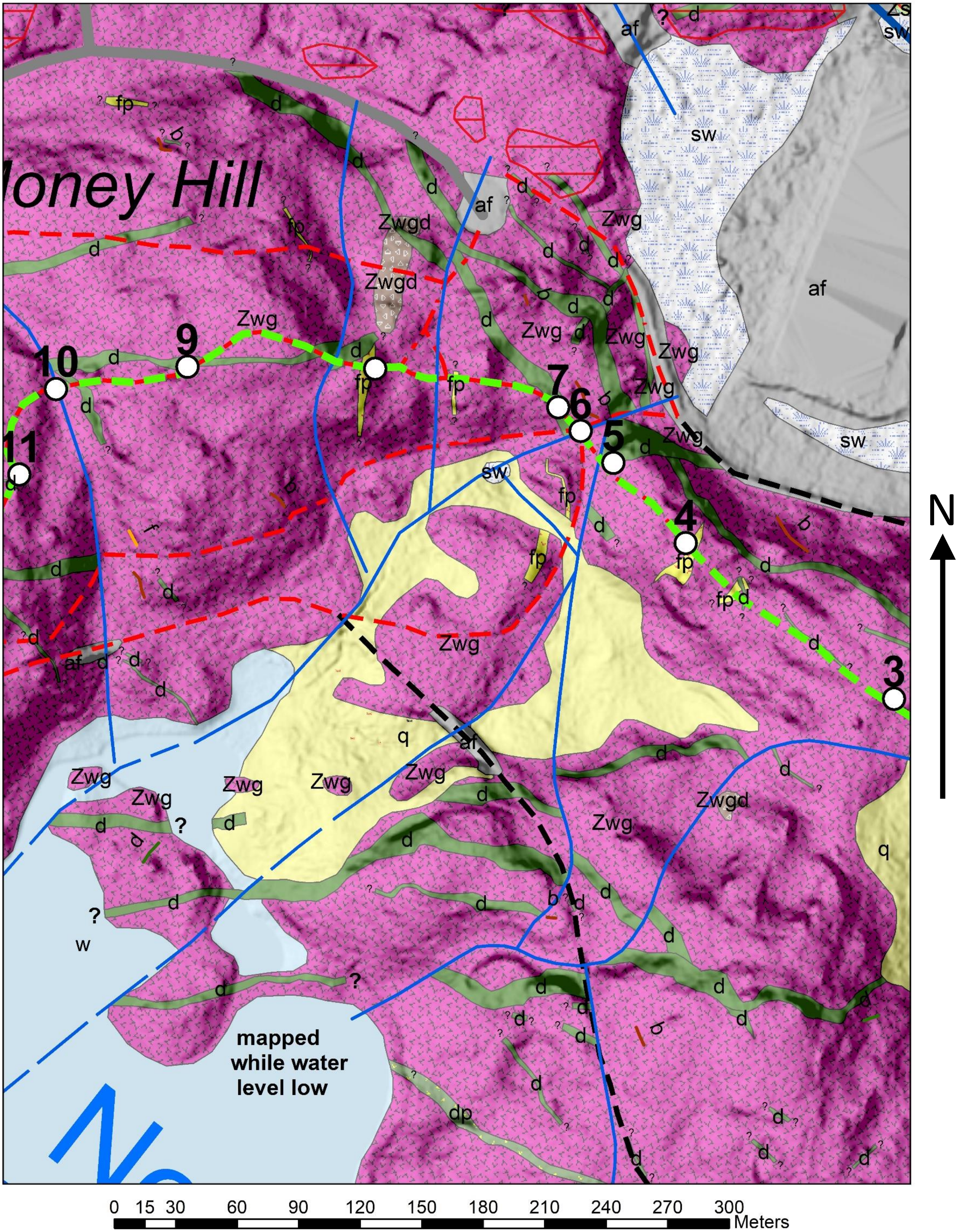
Continue to follow the tour on Map Sky-4B. Follow the trail west for another 150 m.

STOP 4: After crossing an intermittently exposed dolerite dike (d) and after the trail descends a small lip of Winchester Granite (image on right, view back to east), an irregularly-shaped porphyritic rhyolite dike (fp), which weathers to a tan color, cuts through the Winchester Granite (Zwg). Rhyolite (image below on right) is a fine-grained, light-colored, igneous rock with the chemical composition of granite. Rhyolite formed from granitic magma that cooled quickly, which prevented coarse crystals from developing. A dike is a type of intrusion that forced its way into pre-existing rocks along a fracture. The magma separated the sides of the fracture and then crystallized, forming a slab-like rock body. This dike is one of several discontinuous rhyolite dikes that intruded the Winchester Granite. The dike is porphyritic, meaning that it has two grain sizes: large crystals, or phenocrysts, here made of white plagioclase, floating in much finer (microscopic) crystals known as the ground mass (image to right). The rock is heavily fractured, and on weathered surfaces the phenocrysts can blend in with the ground mass, which makes it difficult to see the rock's texture in the field. Rhyolite dikes are common in granites and are often related to late stages of magma crystallization, but it remains uncertain how they are related to the granite here.





Continue west to junction C1-3.


Money Hill
mapped
while water
level low
N
0 15 30 60 90 120 150 180 210 240 270 300
Meters
Zwgd
Zwg
af
sw
fp
d
b
q
w
dp
1
3
4
5
6
7
9
10
11

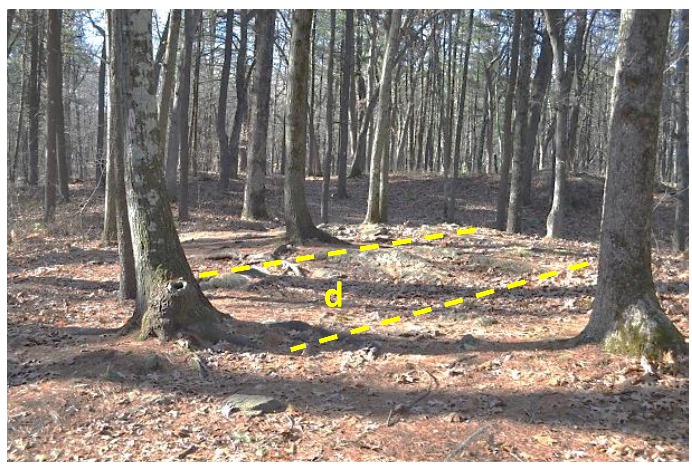
STOP 5: As you descend into a small valley to junction C1-3 (image below on left, view back to northeast), you are crossing over a wide dolerite dike (d) that intruded the Winchester Granite (Zwg). The dike is exposed north of the trail (arrow on image). Dolerite is a mafic (dark-colored), igneous rock with sand-sized mineral grains. Rocks made up of grains this size are considered intermediate, in between coarse- (gabbro) and fine-grained (basalt) rocks of this composition. The dike has a sandpaper–like surface, unlike the adjacent granite. A close-up view of dolerite is shown below on the right. The dark, faintly purplish-gray and greenish-black (mafic) mineral grains are mostly pyroxene, and the small, light gray, blade-like mineral grains are plagioclase. Some of the pyroxene is partly altered to dark green chlorite and amphibole. Oxidation of iron in the mafic minerals often gives the rock's surface a rusty appearance.

STOP 6: At trail junction C1-3 is an intersection of dikes and faults that makes the geology very complex (see Map SKY-4B, no image). There appear to be two relatively large, intersecting dolerite dikes (d) cutting through the Winchester Granite (Zwg) south of the faults that meet in the valley. However, it remains uncertain how they correspond to dikes north of the faults, even though horizontal displacements do not appear to be large. Making matters more complicated are displaced porphyritic rhyolite dikes (fp) to the south, like at Stop 4.

Continue across the valley at junction C1-3 for about 15 m.

STOP 7: The trail (image on right) crosses a NW-SE trending greenish-gray dolerite dike (d) in the Winchester Granite (Zwg). The dike is heavily fractured and appears to be altered. This is likely the same dike as the older of the two dikes across the valley at the last stop. Look for the contact of granite and dolerite on the west (far) side of the dike and note the very knobby surface of the granite where quartz grains have resisted weathering.

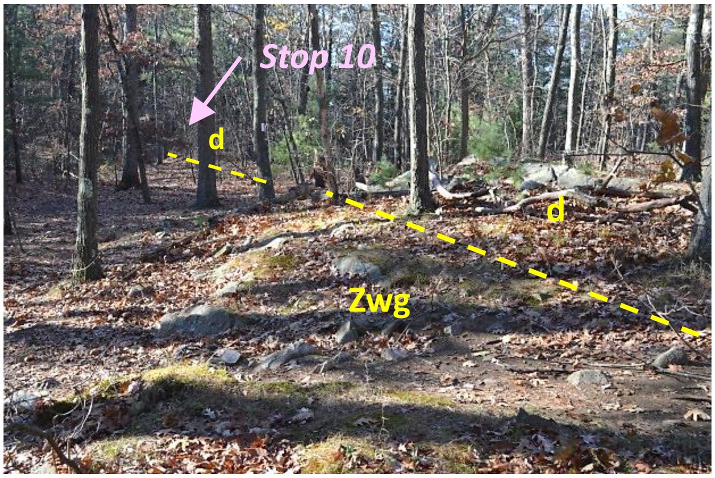
Continue west through junction C1-2 and ascend an upland.



STOP 8: Near the top of the slope the trail crosses a porphyritic rhyolite dike (fp) followed by a dolerite dike (d), which is displaced by a fault along the escarpment to the north (image on right). All these units cut through the Winchester Granite (Zwg). The rhyolite dike, which weathers to a tan color, is highly fractured and has been largely reduced to a pile of rubble. The dolerite dike is also fractured, but it is more traceable, and we will follow it to the next two stops as the trail winds through it. The dolerite dike also seems to become thinner and disappear in the valley to the east (right) near an inclusion of diorite (Zwgd on map Sky-4B, rock with plagioclase and mafic minerals only) in the Winchester Granite.

Continue across the flat top of Money Hill for about 70 m.

STOP 9: After traversing the flat top of Money Hill, the trail again crosses the dolerite dike (d) from Stop 8 that cuts through the Winchester Granite (Zwg, image on right). Shown on the image (dashed line) is the southern contact of the dike with the granite, and further ahead is the position of Stop 10. This dike follows the north side of the trail and will become important at the next stop.

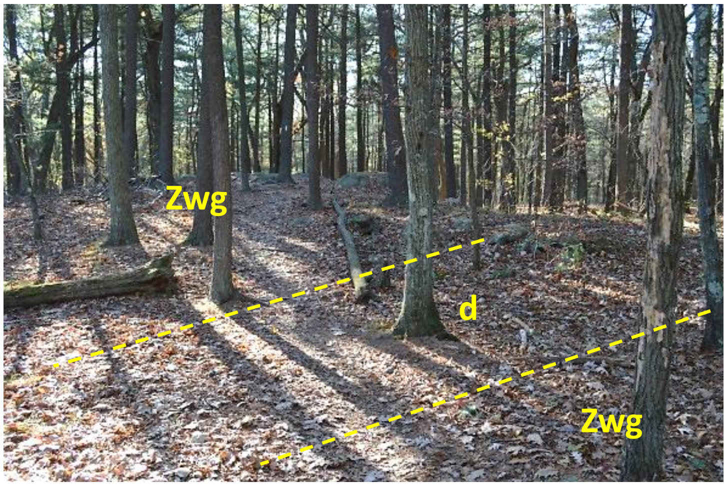


Continue the tour on Map SKY-4C. Follow the trail to where it drops into a valley.

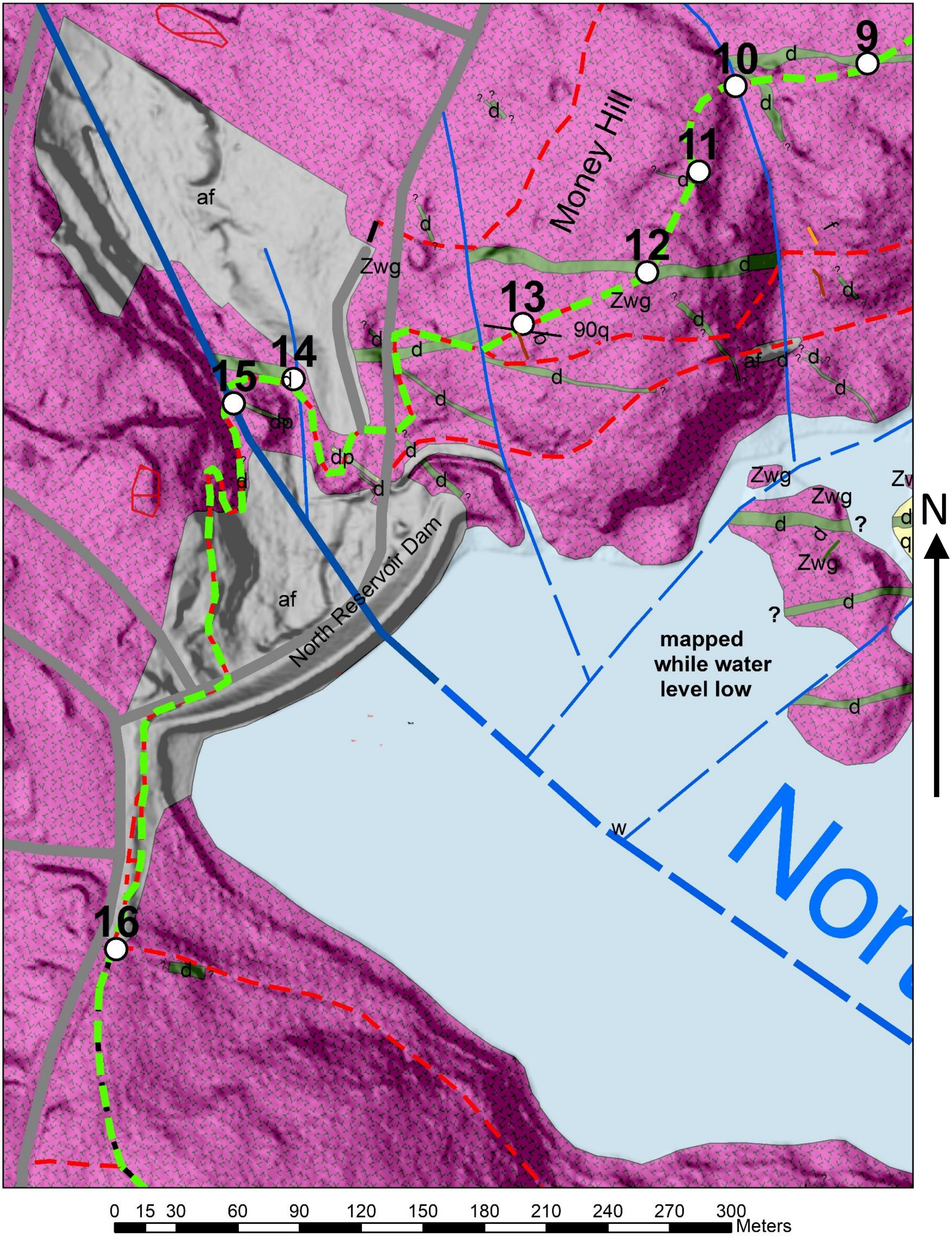
STOP 10: At the valley, the dike from the last stop is exposed on the north (right) side of the trail (see image above, view from Stop 9). The valley is the site of a fault, that cuts through the Winchester Granite (Zwg). Look at map SKY-4C and note that the fault crosscuts the E-W trending dike at this stop with 10s of meters of displacement. Across the fault and on the west side of the valley is a dike to the south (Stop 12), which may be the same dike as seen at Stop 10. It is also worth noting that the fault appears to bend across Money Hill and is not flat.
Cross over the fault and valley and follow the trail for about 40 m as it bends to the south (left).

STOP 11: The trail heads uphill as it crosses through good examples of glacially streamlined surfaces (image on right) of the Winchester Granite (Zwg). You may also see a small dolerite dike at the base of the slope at this exposure. The rounded and smoothed surfaces of the granite are the result of abrasion by glacial ice that slid across the area during the last ice age about 35-17 ka (kilo-annum or thousand years ago). Unfortunately, the granite has weathered just enough since glaciation to remove glacial striations and grooves. This is typical of granite surfaces across the Fells, except where recent removal of soil and glacial sediment uncovers a striated surface that has not yet been weathered.
Continue another 50 m on the flat granite plateau.

STOP 12: On the western end of the Money Hill upland (image on right), a dolerite dike (d) cuts through the Winchester Granite (Zwg). This may be the continuation of the dike at Stop 10, where it has been displaced to the south by the fault. The dashed lines on the image show the approximate location of the contacts on both sides of the dike where it crosses the trail.



Follow the trail as it descends the plateau. The trail joins the Reservoir Trail (orange markers, from north) at junction B1-1.

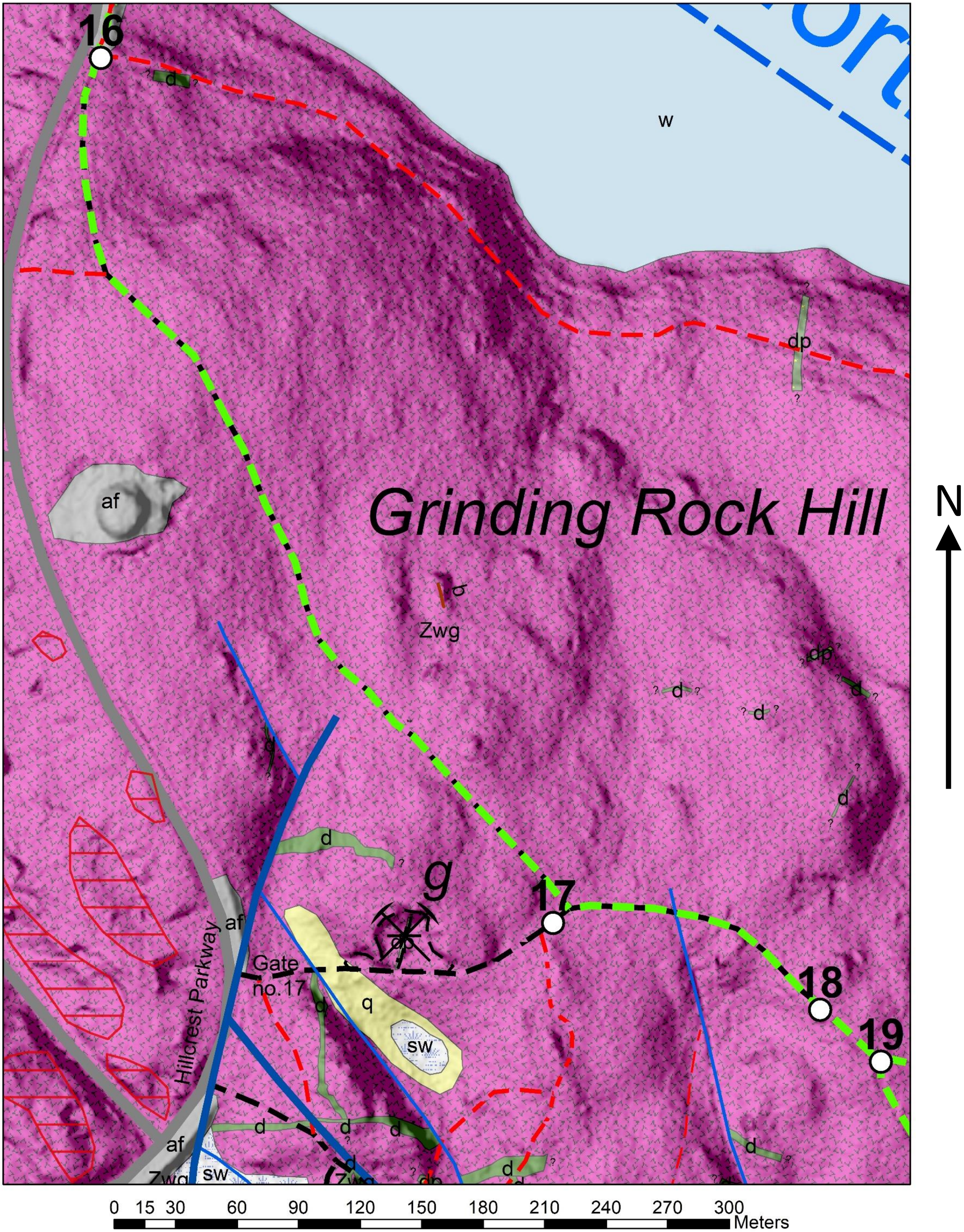

9
10
11
12
13
14
15
16
Money Hill
af
Zwg
90q
dp
North Reservoir Dam
mapped
while water
level low
w
N
0 15 30 60 90 120 150 180 210 240 270 300
Meters

STOP 13: Just after junction B1-1, the smooth surface of the Winchester Granite (Zwg) is exposed in the trail. There are two features that are of interest here. The first is a vertical quartz vein that runs through the granite, trending S82°E (arrow on image to right). Quartz veins are produced by the precipitation of quartz from hot water (hydrothermal) solutions in fractures in the granite. Note that this trend is parallel to the two nearest dolerite dikes. Therefore, the quartz vein probably formed long after the granite was solid. The vein sticks up above the granite surface because of quartz's resistance to weathering, and the height of the vein gives a minimum estimate of postglacial erosion of the granite surface. The second interesting feature is a small red aplite dike that occurs on the eastern end of the outcrop (image below). Aplite dikes are thin, very fine-grained dikes rich in alkali feldspar, intruded into earlier-formed granite, and may represent the rapid crystallization of the last bit of magma in a granitic pluton. These dikes are often red or pink and are very common in granitic rocks. The cracks in which the aplite dikes form may be the result of contraction of the granite as it crystallized and cooled. Surprisingly, aplite dikes are relatively scarce in the Fells.

After crossing a road and descending to the floor of the valley below the North Reservoir Dam, the trail crosses a wooden footbridge over a small stream.

STOP 14: Before crossing the bridge, you will see a dolerite dike (d) with glacial grooves (image to right above) cutting through the Winchester Granite (Zwg). The grooves are oriented S28°E, showing the flow direction of glacial ice through this valley during the last glaciation. The valley is the location of a small fault that splinters away from a major fault that crosses through the valley on the other side of a knob of Winchester Granite (Zwg) that is across the stream. The small fault causes a minor southward displacement of the dike on its west side relative to the dike segment east of the fault at Stop 14. This is known as left lateral displacement, which means that when you view rocks on the far side of the fault, they seem to be displaced to the left. **Cross over the stream to the far side of the valley.**

STOP 15: The trail turns south (left) at the far side of the valley. Here it follows the major fault in the valley, which is inferred to go along the floor of North Reservoir to the west side of Sheepfold (see Map SKY-4C and Part 2 of the Skyline tour). It has a much larger apparent displacement than the minor fault at the last stop. On the west side of the fault, the dike you saw at the footbridge has been displaced south to beneath the dam at North Reservoir. Yes, the fault crosses beneath the dam, but luckily the fault has not been active for hundreds of millions of years! After the trail turns south, the top of the knob on the east (left) side of the trail has a NW-SE trending porphyritic dolerite dike (dp) with conspicuous phenocrysts (image to right). (**cont.**)


16
w
Grinding Rock Hill
N
af
dp
d
Zwg
g
17
18
19
Gate
no.17
q
sw
Hillcrest Parkway
0 15 30 60 90 120 150 180 210 240 270 300
Meters

The dike is well exposed on the far side of the top of the knob, and there are scattered boulders from the dike on the west side of the knob along the trail. The phenocrysts in the dike are rectangular, white plagioclase crystals.
The trail continues south toward North Reservoir and then weaves its way around the west end of the North Reservoir Dam to the west side of the reservoir. Keep your eyes open for orangish-red alkali granite boulders that are glacial erratics from a rock formation to the north in Woburn. A glacial erratic is a stone transported by a glacier and now resting on a different rock formation than the one from which it is derived. **Continuing on the Skyline Trail, you will eventually come to Hillcrest Parkway and then to junction B2-2, where the Willow Spring Path branches away (left) to the west shore of North Reservoir. Stay on the Skyline Trail.**
Continue the tour on Map Sky-4D.

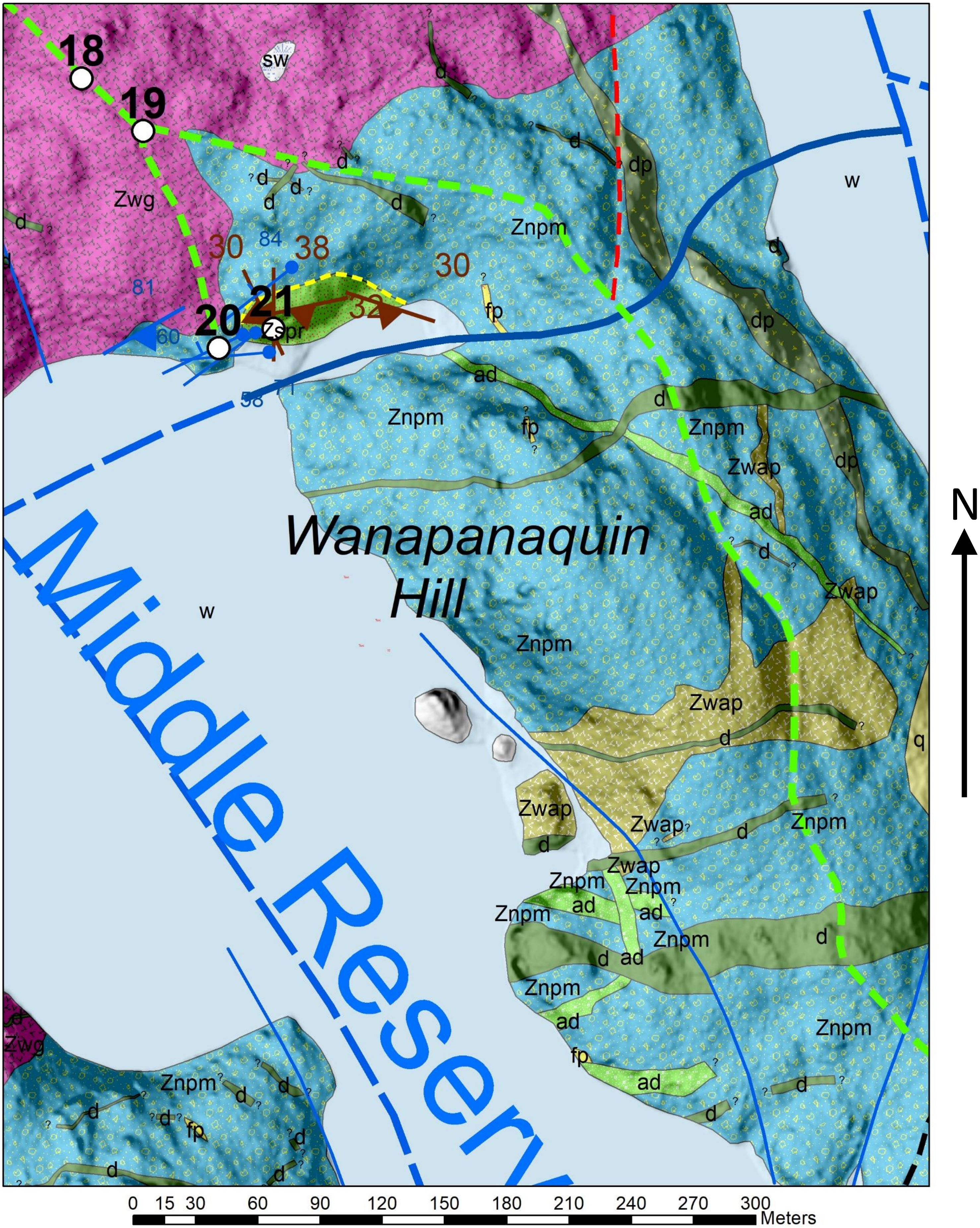
STOP 16: At junction B2-2, the Skyline Trail climbs the north side of Grinding Rock Hill. This hill is underlain by the Winchester Granite (Zwg). The granite is exposed along Hillcrest Parkway but there are only a few small exposures along the trail on the north flank of the hill. This is partly due to a thin cover of glacial sediment (till) that was deposited during the last glaciation, but also because the very smooth surface of the granite does not leave many outcrops (no small cliffs and ledges). You will not see many bedrock outcrops until you cross the far side of the hilltop and approach the next road junction (B2-3). Stop 17 is just to the west (right) of this junction as the Skyline Trail makes a slight bend to the west (right).

If you started the tour at Hillcrest Parkway, Stop 17 is the last stop and you should follow the trail to Stop 17 and then head west (right) on the road to DCR Gate no. 17.

To start Part 4 of the tour from DCR Gate no. 17 on Hillcrest Avenue: Follow the entrance road east on Map SKY-4D past the small abandoned quarry (very small excavated pit) on the north (left) side of the road to the first trail junction (Stop 17 at junction B2-3) and continue east from that point. DO NOT continue on the Skyline Trail.

STOP 17: At junction B2-3 (on Map SKY-4D; image to right) are knobby outcrops of the Winchester Granite (Zwg) at the continuation of the Skyline Trail. Note the many veins that occur in the granite here. Stops 3 and 18 of this tour and Part 5 of the Skyline tour give you more information about the Winchester Granite. The Winchester Granite has been radiometrically dated to 609 Ma (mega-annum or millions of years ago). For more on how rock ages are determined see: RockAges.
NOTE: From junction B2-3, the tour leaves the Skyline Trail, which continues south. From here, the tour takes you back (east) to Stop 1 and the parking area off Fallon Road in Stoneham or back to Sheepfold if you are combining Parts 3 and 4. Follow the road east (left). DO NOT stay on the Skyline Trail.

STOP 18: From junction B2-3, follow the road 170 m east past a small valley on the south (right) to outcrops on both sides of the road. This is the Winchester Granite (Zwg) near its contact with the Nanepashemet Formation (Znpm) that is to the east (ahead). Here, the granite (cut rock image on right) has a reddish-orange color on fresh surfaces and a high mafic mineral content. The Winchester Granite here displays some of the variations discussed at Stop 3. The mafic minerals are heavily altered to green chlorite. Compare the image here with the image for Stop 3. The variations at Stop 18 are related to its proximity to basalt in the Nanepashemet Formation. These variations occur in other contact areas as well, perhaps because of iron absorbed from the Nanepashemet Formation. Plagioclase and alkali feldspar have about the same abundance here, but the conspicuously orange alkali feldspar steals the show. **Continue east (straight) on the dirt road for 30-40 m.**
Continue the tour on Map Sky-4E.


18
19
20
21
sw
Zwg
Znpm
Zwap
Zspr
d
dp
ad
fp
q
w
30
84
38
81
60
32
58
Wanapanaquin Hill
Middle Reserv
N
0 15 30 60 90 120 150 180 210 240 270 300
Meters

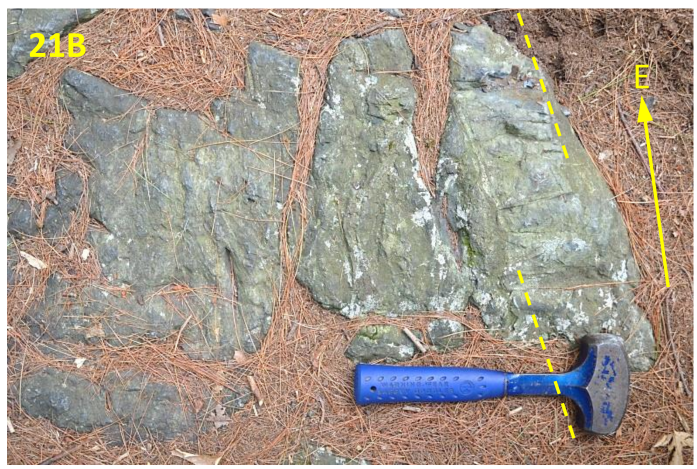
STOP 19: Follow a small path that heads south (right) down to Middle Reservoir (no image). About 20 m east (left) of the path is the contact of the Winchester Granite (Zwg) and Nanepashemet Formation (Znpm). Outcrops visible to the east are dark greenish-gray exposures of basaltic rocks in the Nanepashemet Formation. The Nanepashemet is mostly basaltic (mafic) lava flows with a few intervening sedimentary units. At the bottom of the trail (Stop 20) is a small knob that projects into the reservoir and has an exposure of conglomerate and mudstone beds with mafic (dark-colored) volcanic pebbles. Conglomerate is a sedimentary rock made of particles greater than 2 mm. Here the unit was heavily baked by contact metamorphism and the basalt and sedimentary layers were altered to hornfels. Contact metamorphism is the alteration of rocks adjacent to a magma chamber or intrusion by heating. In this case, the magma formed the Winchester Granite pluton. For more on how plutons form see: Plutons. Hornfels is a hard, brittle rock formed by the heating of fine mineral grains, especially clay, that fuse the rock together, much like firing clay in a kiln to produce pottery. Hornfels usually has its original bedding and structures altered, sometimes even obliterated, as the rock recrystallizes at high temperatures. A full discussion of hornfels is in Part 3 of the Skyline tour at Sheepfold and on Winthrop and Bear Hills, but it is a little easier to see the original materials that were baked at this stop. Part 5 of the Skyline tour also focuses on the Nanepashemet Formation.

STOP 20: **Continue down to the reservoir.** Projecting into Middle Reservoir is a small knob of heavily baked basalt, volcanic conglomerate, and inconspicuous layered units all in the Nanepashemet Formation (Znpm). The north (near) side of the outcrop is basalt, which is fine-grained mafic igneous rock. The south side of the outcrop, along the water, has conglomerate made of both mafic and non-mafic volcanic pebbles (image 20A) with some severely altered original mudstone beds that are still visible and steeply dipping in the hornfels (image 20B, trending across image at arrows). Throughout this outcrop is evidence of contact metamorphism. On the north side of the outcrop and back up the trail slightly on the left side, you can see rusty-brown to orange outcrops of fine-grained granite (image 20C, at arrows) in the chill zone of the Winchester Granite (Zwg). The chill zone is the part of an intrusion along its contact where the rock cooled rapidly, preventing the formation of coarse crystals. Along the shore of the reservoir at water level and about 20 m west of the conglomerate outcrop is an outcrop of light gray marble in the Nanepashemet Formation (image 20D). This will be wave-washed if the reservoir is high. Marble is metamorphosed limestone, a sedimentary rock made mostly of calcium carbonate (the mineral calcite). Here the marble is formed by contact metamorphism and has interlayers of dark gray hornfels as well as streaks that may be poorly preserved bedding.

STOP 21: This stop backtracks uphill from the reservoir. A few meters along the path uphill from the shore is the first of two small trails heading east (right). About 15 m down the first trail is a ledge of banded porphyritic rhyolite (image 21A below) in the Straw Point Volcanic Complex (Zspr), radiometrically dated here at 594.7 Ma. For more on how ages are determined for rocks see: RockAges. Rhyolite is a fine-grained, light-colored igneous rock with the same chemical composition as granite. This is a small bit of the Straw Point Volcanic Complex, like is found at the northwest corner of Spot Pond in Stoneham. Not much of this formation is exposed here because of the reservoir, and to the south it is cut off by a fault that parallels the shore and crosses through the small cove of the reservoir to the east. We have seen rhyolite dikes earlier on this trip on Money Hill, but here the rhyolite is a lava flow with some plagioclase phenocrysts. This is a light-colored lava flow as opposed to the dark basaltic lava that occurs in the Nanepashemet Formation and in Hawaii. Banding (layering) in the lava (image 21A below), which is not easy to see without some searching, is the result of the flow of the lava and is interpreted to approximately represent horizontal when the lava flow was formed. The bands now have a low dip angle (20-40°) across outcrops for almost 50 m. It is important to note that, unlike the Nanepashemet Formation (Znpm), the rhyolite flows show no evidence of contact metamorphism, meaning that they formed after intrusion of the Winchester Granite (Zwg) pluton. For more on how plutons form see: Plutons.

The second small trail heading east (right), about 25 m up from the reservoir and above the last trail, climbs to the top of the banded rhyolite outcrop. On this trail and extending beneath the banded rhyolite is hornfels of the Nanepashemet Formation (Znpm). This unit has altered bedding that is dipping close to vertical (dip of 84° on image 21B, parallel to lines, arrow points east). The contact here (rhyolite over hornfels) represents an erosional unconformity. An unconformity is a boundary at the top of a unit that represents missing time in the rock record and is overlain by a sedimentary layer, ash deposit, or lava flow. Beds in the Nanepashemet Formation are truncated by erosion that occurred prior to the flow of the rhyolitic lava. For more on unconformities see: Unconformities.

So here is the interpreted order of events: First, the Nanepashemet Formation was formed (basalt lava flows and sedimentary deposits). Next, the Winchester Granite intruded the Nanepashemet Formation at 609 Ma. The granite formed a chill zone next to the Nanepashemet Formation and the Nanepashemet was altered to hornfels through contact metamorphism. Then, the Nanepashemet Formation was eroded. Finally, the rhyolitic lava flow in the Straw Point Volcanic Complex spread across the erosion surface at 595 Ma.



From this stop, head back up the path to the road at the top of the hill and head east (right).

THIS WAS THE LAST STOP IF YOU STARTED AT FALLON ROAD OR SHEEPFOLD. If you started at Fallon Road or Hillcrest Parkway the remaining part of this tour will take you back to Stop 1. Directions to Sheepfold are given below.

To get to Stop 1: Follow the road east (right) on Map Sky-4E as it follows the granite contact. You will cross some outcrops of hornfels in the Nanepashemet Formation (Znpm), as well as a dolerite dike (d). The Nanepashemet outcrops will appear dark greenish- to bluish-gray in the road surface because of their chlorite content. At the first road intersection, where Willow Path joins from the north (left), head south (right). The road crosses a fault and then Wanapanaquin Hill on the right, which is in the Nanepashemet Formation and crossed by several dolerite dikes. At the south end of Wanapanaquin Hill is a small porphyritic intrusion, the Wanapanaquin Porphyry (Zwap, see map SKY-4E), which may be part of the Stoneham Granodiorite (see Part 3 of the Skyline tour). After about 0.3 miles (0.5 km) is the first major road junction (just south of SKY-Map 4E, no trail junction number). Head east (left) on this road. It will cross a major fault at a stream valley where the road goes over a culvert.

If you are heading back to Sheepfold: look for the path leading off to the east (right) 50-100 m after the stream valley. This will take you to the open field at Sheepfold. The path through the field will take you up to the parking areas.

To continue to Stop 1 and Fallon Road: After crossing the stream valley, continue to follow the road after it bends to the north (left) and then begins to parallel the shore of North Reservoir for about 0.22 miles (0.35 km). Stay on the road as it bends east (right) around an embayment of the reservoir and then sharply turns north (left) again onto the southern extension of Dikes Road. Continue on Dikes Road, along the east shore of the reservoir, about 0.5 miles (0.8 km) to junction C2-1, where the Skyline Trail crosses Dikes Road (Stop 1, also Stop 22 of Part 3).

When you arrive at the Skyline Trail:
If you started at Hillcrest Parkway: Head west (left) on the Skyline Trail (Map SKY-4A) and continue the tour at Stop 1.
If you started at the Fallon Road parking area: Continue on Dikes Road (north) and then northeast (right) at the first road junction (C1-6) to the parking lot at DCR Gate no. 21 (marked as no. 20 on DCR map).

Below is a listing of all the rock units you have seen on Part 4 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)
porphyritic rhyolite dikes (fp)
Nanepashemet Formation (Znpm)
Stoneham Granodiorite (Zst)
Straw Point Volcanic Complex – Rhyolite Member (Zspr)
Winchester Granite (Zwg)

Here is a summary of the features and vocabulary for Part 4 of the Skyline Trail tour:

minerals:
- quartz
- plagioclase feldspar
- alkali feldspar
- mafic rocks and minerals
- pyroxene
- amphibole – hornblende
- biotite (black) mica
- chlorite
- zircon
- calcite (calcium carbonate)

igneous rocks:
- coarse-grained vs. fine-grained
- aplite (dike)
- basalt (as dikes)
- basaltic lava
- dolerite
- granite
- granodiorite
- porphyry, porphyritic
  - (phenocrysts + ground mass)
- dacite
- rhyolite – dikes and banded rhyolite lava flow
- magma – molten rock, magma chamber
- extrusion – lava flow
- intrusion
- dike
- pluton - For more on how plutons form see: Plutons.
- plutonic breccia
- inclusion (xenolith)

chill zone or chilled margin
- assimilation
- crosscutting

sedimentary rocks:
- conglomerate, mudstone, limestone

metamorphic rocks:
- contact metamorphism
- argillite - hardened shale/siltstone
- hornfels – baked, brittle rocks
- marble – metamorphosed limestone

time abbreviations:
- 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.
angular unconformity
contacts

fracture planes or joints
fault, fault displacement
left lateral displacement

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