

# Self-Guided Geologic Tour: Rock Circuit Trail in the Middlesex Fells Reservation (Part 1)

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

1. The Rock Circuit tour has been broken into three parts. You can do the whole tour in one day, but it is a lot of hiking (~5 twisting miles, ~8 km) and a lot to comprehend in one dose. It's recommended that you do parts of the tour in order, Part 1 to Part 3. The beginning of each part is at the end of another part. 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 along the Fellsway East, 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<sub>2</sub>) 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/>.

**Rock Circuit Trail in the Middlesex Fells Reservation** version: January 16, 2024



## **Part 1: Fellsway East to Pinnacle Rock and back to the Cross Fells Trail**

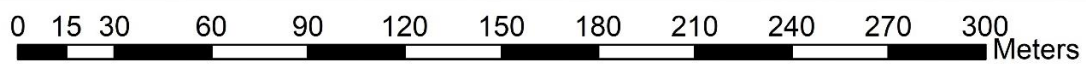
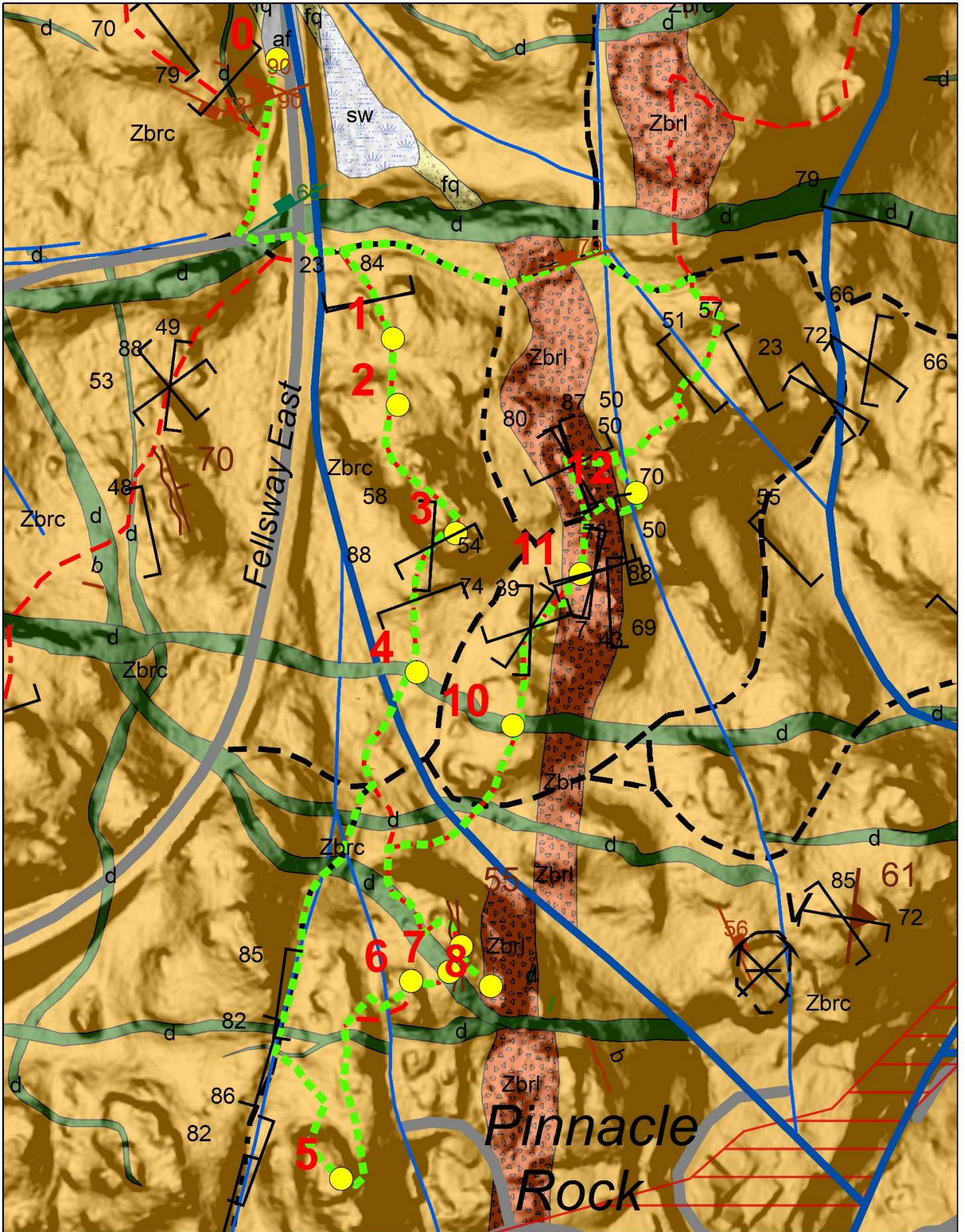
Total distance: about 2 km round trip. This part of the Rock Circuit Trail tour is relatively short, but it involves some steep slopes.) Prepared by Jack Ridge, Professor, Dept. of Earth and Climate Sciences, Tufts University

**Starting point:** Parking Area on Fellsway East near Gate no. 53 (see Map RC-1, Stop 0). Head south from the parking area kiosk to Gate no. 53 at Jerry Jingle Road (crossing fractured outcrops of the Boojum Rock Tuff). Cross over Fellsway East to Gate no. 52, where the tour begins at the Rock Circuit/Cross Fells trail junction.

**Follow the trail on the geologic maps as you go.** Stops on the tour are yellow circles with red numbers on the geologic maps. Follow the white trail markers in the field and dashed green path on the map. In the guide, DCR trail junction numbers are given that are marked with signs in the park. This is the shortest of the three segments of the tour of the Rock Circuit Trail. Having a hand lens or magnifying glass can be helpful. Enjoy the geology! Have fun!!

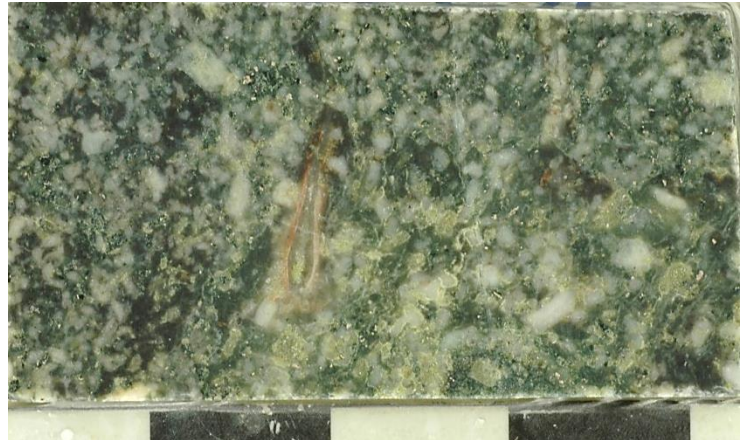
This trip focuses on Neoproterozoic volcanic rocks of the Boojum Rock Tuff of the Lynn Volcanic Complex and younger dolerite dikes, which underlie the southeastern Fells. The Neoproterozoic Era was 1000 to 541 million years ago. The trip will also point out how the rocks were deformed by faults and fractures, and you will see some glacial features.

**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.**



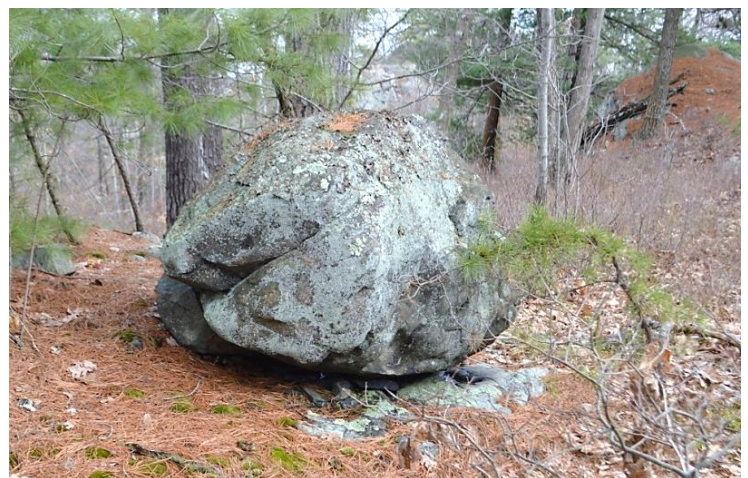
**Follow map RC-1.** Proceed to Gate no. 53 and cross the Fellsway East. You are crossing two geologic features: 1) a major fault running N-S along the Fellsway East, and 2) a large, E-W trending dolerite dike, which on the west side of the Fellsway forms a linear hill and runs along the south side of Jerry Jingle Road (more on these dikes later). After crossing the Fellsway East, the dike is on the north (left) side of the Cross Fells Trail. After crossing through Gate no. 52 follow the Rock Circuit Trail (white markers) up the hillslope to the south (right) toward Pinnacle Rock.

**STOP 1:** On the left at the first bench in the hillslope are outcrops of the Boojum Rock Tuff in the Lynn Volcanic Complex (Zbrc on map), which covers the southeastern corner of the Fells. Part 1 of the tour is entirely in the Boojum Rock Tuff! It has a huge outcrop area on the geologic map and extends into Malden and Melrose. This unit is a pyroclastic volcanic rock, meaning it was ejected into the air prior to accumulating on the land surface. Pyroclastic rocks can have 4 components in them: 1) ash, or fine, broken glass shards that may have still been molten when they landed; 2) crystals which were mineral grains that had started to crystallize in the magma prior to eruption; 3) large pieces of glass and pumice (bubbly glass), which may still have been molten when they landed; and 4) lithic fragments, which are fragments of pre-existing rock, either from prior volcanic eruptions or any older rocks through which the magma passed in the subsurface. The rocks exposed here are welded crystal tuff. Tuff is any pyroclastic rock with ash in it. The term welded refers to the fact that the ash and glass/pumice fragments were at least partly molten (liquid), allowing them to adhere to each other when they landed. The tuff here has abundant crystals in it, which occur as small (up to 2 mm) white plagioclase feldspar grains that are often broken (image below to right). This unit is noteworthy among volcanic rock units in the Fells because it lacks quartz crystals and has a very consistent composition over its large outcrop area. In an outcrop, you may see occasional small lithic fragments, but you will not see glassy materials for two reasons: the glassy ash particles are too small to see without a microscope, and glass that remains at high temperatures after it solidifies will slowly convert to a crystalline solid composed of very fine-grained quartz and feldspar. This change of hardened glass to a crystalline material is called devitrification. The devitrified glass gives the rock its overall greenish-gray color on fresh surfaces. The larger glass and pumice fragments are up to 5 mm and were soft when they landed. As a result, they were flattened under the weight of accumulating material before they hardened and devitrified. The flattened fragments, best seen in a microscope, blend in with surrounding devitrified ash.



**Continue toward the top of the hill.**

**STOP 2:** On the left, you will pass a glacially transported boulder resting on the Boojum Rock Tuff. The boulder is a piece of the Stoneham Granodiorite (Zst), transported from the northern Spot Pond area and left here when the last glacier receded or melted away about 17,000 yr ago. Granodiorite is an intrusive, coarse-grained igneous rock almost entirely made of plagioclase feldspar and quartz with lesser alkali feldspar and scattered to sometimes abundant mafic (dark) minerals. An intrusion is a body of magma that invaded other rocks in the subsurface and then crystallized. The boulder is a glacial erratic. To be a glacial erratic a rock must be glacially transported and end up resting on a different bedrock unit than the one it came from. Boulders like this are common throughout the Fells.



**Continue south on the trail to the highest point on the hill.**

**STOP 3:** On the hilltop just before the steep slope to the valley below is an outcrop of the Boojum Rock Tuff (Zbrc) with closely-spaced, parallel fractures (cracks). Fractures like this are common throughout the rock unit and are formed due to compression of the rocks. Fracture orientations in the Boojum Rock Tuff have been measured at hundreds of places. On the map you will see a black bracket symbol ([]), which shows fracture orientations. The small bars on the bracket point in the direction in which a fracture dips downward. The nearby number indicates the dip in degrees away from horizontal. Two fracture sets were measured at the top of this hill. The fracture data from the southeast Fells shows a clustering in specific orientations. This demonstrates that the fractures aren't just cracks with random directions, but instead were created by well-organized stresses exerted on the rocks in a particular orientation. **Descend the steep hill to a lowland.**



**STOP 4:** About 30-40 m after the lowest spot in the lowland is a bump and rock rubble on the trail, which is a 5-10 m wide, E-W trending dolerite dike (d on the map, no image). We will discuss the dark minerals that occur in dolerite dikes in more detail at Stop 7. A dike is an intrusion of magma that filled a fracture in the subsurface. Later, on our return from Pinnacle Rock, you will see this dike again at Stop 10.

**Continue south to a wide path at junction F5-11. Recently, the Rock Circuit Trail south of here was reconfigured, so it does not match the current DCR map. Follow the Rock Circuit Trail as it shifts to the right before heading up the hill southward (left) on Pinnacle Path. Do not turn to the left, or go straight ahead from junction F5-11, which is close to the return trail from Pinnacle Rock.**

**STOP 5:** Pinnacle Path follows a fault, which cuts across a low spot in the crest of the hill. A fault is nothing more than a crack that separates two bodies of rock that moved relative to each other. Beyond the crest of the hill, the trail then turns off to the east (left) and climbs the first pinnacle in this area. Looking to the south from this spot is a great view of Boston. Shortly, we will see some even better views. Note that the Boojum Rock Tuff is heavily fractured in this area, and, on the map, you will see small faults (blue lines) nearby. After leaving the pinnacle and heading north (reversing direction), the trail goes by two abandoned concrete radio tower platforms. If you look adjacent to the first platform, you will see broken rock debris of crystal tuff in the Boojum Rock Tuff (Zbrc). This debris has relatively fresh surfaces that show its greenish-gray interior color and small white to gray plagioclase feldspar crystals.

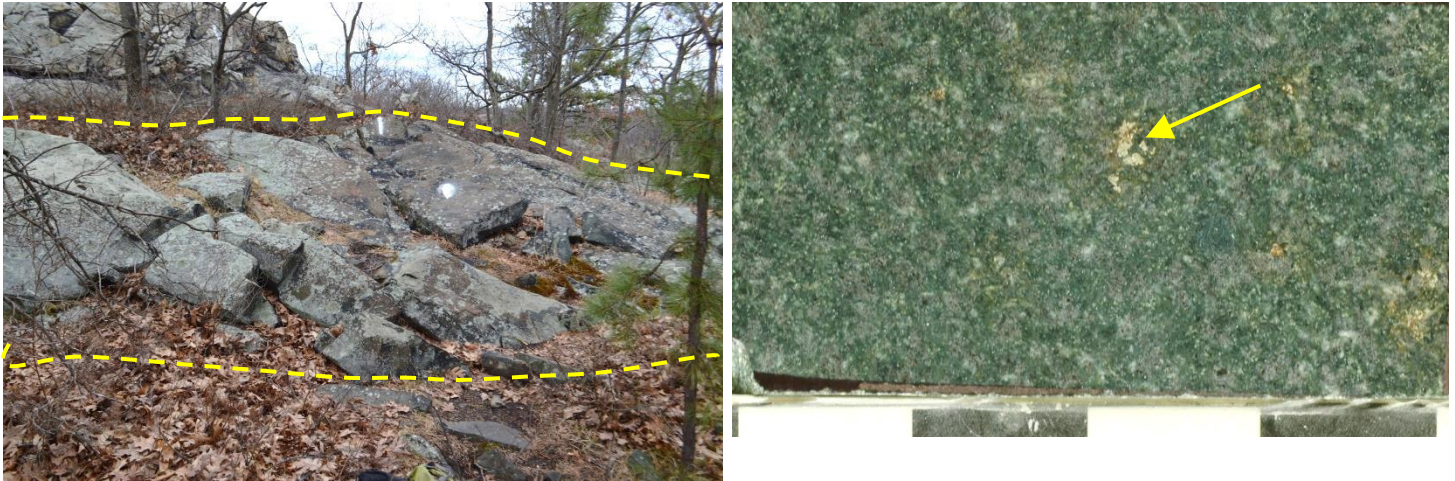
**A short ways after the abandoned concrete platforms, the trail crosses a small valley and then ascends a steep slope to a ridge crest.**

**STOP 6:** Where the trail makes a sharp turn east (right) and a few meters south you can see a cluster of boulders perched on the Boojum Rock Tuff (image to right). These boulders are pieces of the underlying tuff, so they are not glacial erratics, though they were glacially transported. The boulders seem to have been a single boulder that fell apart after it came to rest on the hilltop. The far boulder has blackish-gray, specular hematite veins exposed on its northern face (red arrow). The veins were fractures in which hematite (iron oxide,  $Fe_2O_3$ ) precipitated from hydrothermal (hot water) solutions passing through the fractures. Just below the boulder at the sharp turn in the trail (yellow arrow) is a polished and striated rock surface with striations oriented  $S23^\circ E$ . Striations are scratches produced by a glacier sliding across the rock surface, recording the direction in which the last glacier was moving. These were created during the last ice age, when glacial ice covered this area about 35,000-17,000 years ago.



**After making the sharp right turn (east), you will cross a small valley toward Pinnacle Rock.**

**STOP 7:** As you cross the far end of the small valley, the trail crosses a N-S trending dolerite dike that runs along the flank of Pinnacle Rock (image below on left, view east). Dolerite is an igneous rock of intermediate (sand size) grains made of mafic (dark-colored) minerals and plagioclase feldspar. Usually, these dikes contain the minerals pyroxene and magnetite. The pyroxene may be partly altered to chlorite and amphibole. This is a good opportunity to see the rusty surface produced by the weathering of iron-bearing minerals in the rock. The high iron content of the rock gives it a dark color on fresh surfaces, which is easily seen on a cut rock sample (image below on right). The faintly purplish-green grains are pyroxene while the plagioclase is gray. This dike also contains pyrite, an iron sulfide mineral, sometimes called fool's gold, with a metallic brassy color (arrow on image). This dike has the same chemistry as lava flows in Hawaii and Iceland, but it was formed as an intrusion that filled a fracture.

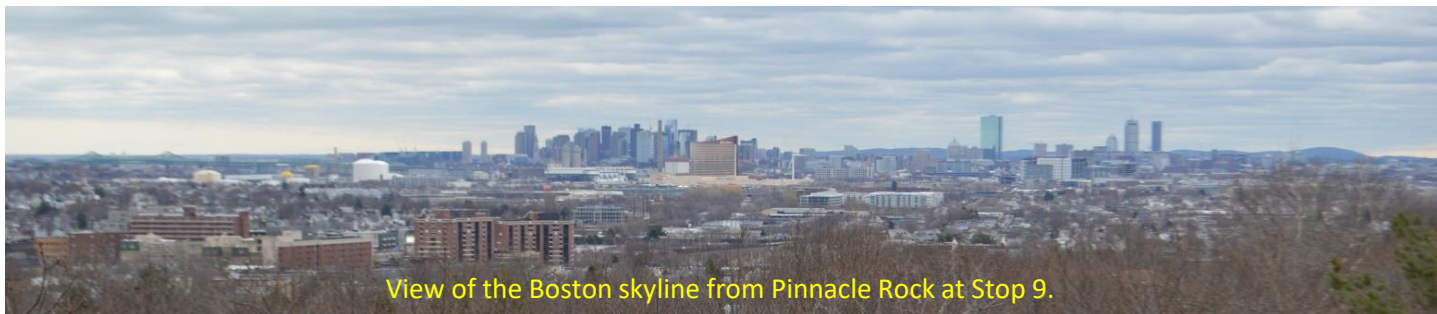


**STOP 8:** Before climbing up the steep face of Pinnacle Rock, look at the rock surface about 15 m to the south (image below left, arrow shows position of image on right). Exposed here is welded lithic crystal tuff (Zbrl), which forms a N-S trending and eastward dipping layer within the Boojum Rock Tuff. This is the same volcanic rock we have seen so far, welded crystal tuff, but with the addition of many lithic fragments (image below right). Almost all of the lithic fragments are gray, angular volcanic rock types. There are also occasional metasandstone lithic fragments from a much older metamorphic rock formation exposed north of here, called the Westboro Formation (Zvwq). This exposure tells us that the magma erupted through volcanic rocks from earlier eruptions associated with the Boojum Rock Tuff, and that deeper in the crust the magma encountered older metamorphic rocks. The unit is steeply dipping to the east; this appears to be the orientation of an ancient volcanic land surface that was later tilted.



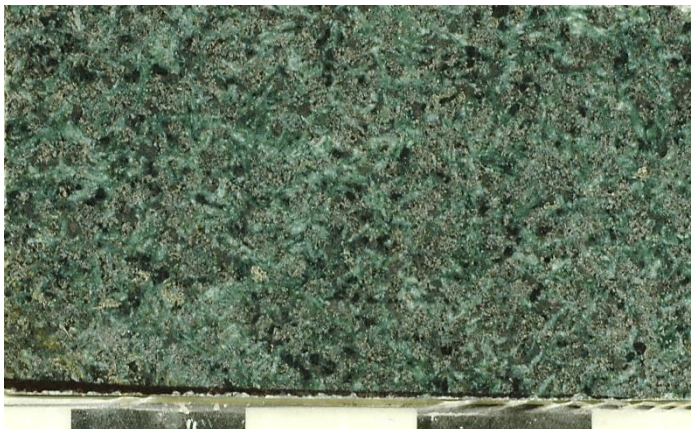
**STOP 9:** At the top of Pinnacle Rock is an excellent view of the Boston skyline (panorama at top of next page). Visible from east to west (left to right) are the Mystic Tobin Bridge, downtown Boston, and the Back Bay skyline. The top of Pinnacle Rock is crystal tuff (Zbrc) and is just west of the contact with the lithic crystal tuff (Zbrl) seen at Stop 8. Where the trail heads down from the ridge crest, you may see small orange (iron)-stained patches of smooth, highly polished rock, which is what remains of a glacially striated surface.

**From here the trail heads downhill to where it crosses East Path in the valley below. Before reaching East Path, the trail bends to the east (right) and crosses a wet area on wooden planks. East Path is marked as a fire road (bike symbol). Cross East Path and head upslope a short distance.**



View of the Boston skyline from Pinnacle Rock at Stop 9.

**STOP 10:** The trail crosses the E-W trending dolerite dike we saw earlier at Stop 4, but here, it is much better exposed. The dike forms an E-W trending ridge (image to right taken in winter) because of its resistance to weathering and erosion relative to the surrounding highly fractured crystal tuff (Zbrc). The dike is not as fractured and crosscuts fractures in the tuff, which means that the dike intruded after the tuff was fractured. Also note the rusty color and fine grain size of the dike (image below right). On this image, the faintly purplish-green areas are pyroxene, and the less conspicuous gray grains are plagioclase feldspar. In another 40-50 m, the trail ascends a steep slope onto a small hill of fractured crystal tuff, which has several orange (iron)-stained, polished glacial striation and groove remnants that trend S24°E. The trail then descends into a small valley before ascending another hill to Stop 11. The contact between crystal tuff (Zbrc) and lithic crystal tuff (Zbri) within the Boojum Rock Tuff is in the small valley.



**Continue across the small valley onto the next steep-sided pinnacle.**

**STOP 11:** This pinnacle is one of the best places to see lithic crystal tuff of the Boojum Rock Tuff (Zbri). Like at Pinnacle Rock, the lithic fragments are almost entirely gray, angular volcanic rocks with very sparse metasandstone fragments (image to right). On the map, this unit continues north from Pinnacle Rock. About halfway up to the top of this pinnacle is a highly polished, tan platform that has striations oriented S17°E. Ice flow here was about 10 degrees more southerly than at nearby sites because it was deflected by the western steep face of the hill.



**After this stop, the trail descends into a valley to trail junction G5-8. There are two options here as the trail splits and later rejoins, to provide an alternative to the very steep slope directly ahead.**

**STOP 12: Option 1 (up steep face):** From junction G5-8, climb up the steep face directly ahead onto the hill composed of lithic crystal tuff (Zbrl). On the hill's north (far) side, the trail heads down into a ravine and then sharply turns east (right) down a steep face to a trail junction in the valley below. This valley is a N-S trending fault. The Rock Circuit Trail continues straight to the east, but if you want to explore the fault valley, head south (right) at the trail junction. The fault is described in Option 2.

**STOP 12: Option 2 (into valley to east):** From junction G5-8, head down the slope to the east (right) into a hollow bounded by steep faces. The hollow runs along a N-S trending fault. From the valley bottom, follow the trail north (left) up the rubbly slope. This is fractured rock along the fault (along dashed line on image to right) that continues north through a small valley.



When you arrive at the junction with the trail from Option 1, head east (right) to continue on the Rock Circuit Trail. Continue east (right) on the trail across a wetland, where the rock is heavily fractured in the fault zone. Upward seepage of groundwater along fractures is the source of the wetland. The trail heads up onto a steep knob that is back in the crystal tuff (Zbrc) of the Boojum Rock Tuff. Follow the trail north (left) to the Cross Fells Trail (blue markers) at junction G5-5. This spot is the beginning of Part 2 of the tour.

You can continue with Part 2 of the Rock Circuit Tour or head back to the parking area on the Fellsway East by heading west (left) on the Cross Fells Trail. Part 2 is a longer hike than Part 1 and ends on Woodland Path close to the Flynn Ice Rink parking lot on Woodland Road. Part 2 gives directions back to the Fellsway East.

### **END of Part 1.**

To head back to the Fellsway East parking area at the end of Part 1, turn left (west) at junction G5-5 and follow the Cross Fells Trail back to the Fellsway East. You will pass two roads joining the Cross Fells Trail at junctions G5-4 (Black Rock Path) on the north (right) side and then F5-10 on the south (left) side. After the second junction, the Cross Fells Trail is almost always wet or icy, except in the middle of dry summers, due to seepage of groundwater. There is a spring along the road as you approach the base of the hill, likely fed by groundwater from the wetland to the east. You will arrive at the starting point of Part 1 of the tour at the base of the hill. Cross the Fellsway East from Gate no. 52 to 53 and turn right (north), following the Cross Fells Trail (blue markers) toward the parking area.