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](https://www.mass.gov/doc/middlesex-fells-reservation-trail-map) 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/.

**Rock Circuit Trail in the Middlesex Fells Reservation**  version: August 30, 2021

**Part 3: Hemlock Pool area to Fellsway East**

Total distance for just Part 3: approximately 2.6 winding miles (4-4.5 km) from Fellsway East parking area and back.

**Starting point:** Part 3 starts at junction E4-8, where the Rock Circuit Trail crosses Woodland Path (Cross Fells Trail) east of the Flynn Ice Rink parking area.

**Follow the trail on the geologic maps as you go starting with Map RC-3A.** 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, trail junction numbers are given from the DCR trail map and are marked with signs in the park.

**Just doing Part 3:** I suggest starting at the Fellsway East at Gate no. 53 and walking west to the start. From the parking area, head south to Gate no. 53 and head west (right) on Jerry Jingle Road. Pass by junction F5-7 to F5-6 and turn northwest (right). Pass through junction F5-4 to F5-1 at Hemlock Pool Road. At F5-1, turn northwest (left) onto Hemlock Pool Road and follow it to Hemlock Pool Path at junction E4-15. Turn west (left) on Hemlock Pool Path and pass by Hemlock Pool on the right to junction E4-13. At E4-13, turn north (right) onto Woodland Path and follow it past junction E4-12 and continue to E4-8, where the Rock Circuit Trail crosses Woodland Path. Take the Rock Circuit Trail south (left) to start Part 3. Stop 1 is at junction E4-8.

**Combining Parts 2 and 3:** This is a relatively long but more efficient hike. Start at the parking area on the Fellsway East near Gate no. 53, cross the Fellsway East to Gate no. 52, and follow the Cross Fells Trail (blue trail marks). Pass two roads at junctions F5-10 and G5-4. Start Part 2 at G5-5, where the Cross Fells Trail crosses the Rock Circuit Trail (white trail marks). Part 2 ends at the start of Part 3, and Part 3 ends at the Fellsway East parking area.
This trip focuses on the Neoproterozoic volcanic rocks of the Pine Hill Felsite and Black Rock Tuff, which underlie much of the southeastern Fells. The Neoproterozoic Era was 1000-542 million years ago. The trip will also point out dolerite dikes of different ages, how the rock units were deformed by faults and fractures, and some glacial features. There are some great views on the way.

NOTE: Polished rock images below 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.

Follow Map RC-3A. From the Cross Fells Trail (Woodland Path) follow the Rock Circuit Trail (white markers) up the hillslope to the south toward the Boojum Rock area.

STOP 1: A meter or two from junction E4-8 is a glacially striated and grooved rock surface on an outcrop of the Pine Hill Felsite (image to right). We will investigate these volcanic rocks in more detail in a few stops. The striations and grooves, which are common in the Fells, were created by the last glacier moving across the land surface. As the glacier slid, the underlying rock was scratched, gouged, and polished by rock fragments and sand being dragged at the base of the glacier. The orientation of the grooves at S21°E (red arrow) indicates the flow direction of the generally south-southeast moving ice sheet. The last glacier receded from the southern Fells about 17,000 yr ago.

STOP 2: In about 80 m, the trail crosses a wide, E-W trending dolerite dike. Note the smooth and rounded forms of dolerite outcrops (image below left) as compared to the heavily fractured and angular outcrops of adjacent volcanic rocks. A dike is an intrusion of magma that fills a fracture, in this case producing dolerite. Dolerite is an igneous rock of intermediate fine grain size made of mafic (dark-colored) minerals and plagioclase feldspar. These dikes usually contain the minerals pyroxene, that may be partly altered to chlorite and amphibole, and magnetite. The high iron content of the rock gives it a dark color, as is easily seen on the cut rock sample (image below right). The faintly purplish-green grains are pyroxene and the gray grains are plagioclase. The rusty surface of dolerite outcrops is due to the weathering (oxidation) of the iron-bearing minerals.

The trail continues along the dike after bending to the west (right) in another 50 m. The trail crosses to the south side of the dolerite dike and crosses a road at junction E4-16.

STOP 3: Across the road is an excellent exposure of the contact of the south (left) side of the dike and the Pine Hill Felsite (image to right, arrows point to contact). Note the smoother surface and rusty color of the dike. It also has a finer grain size along the contact than towards the center because the magma cooled more quickly along its margin with the volcanic rock, forming a chill zone. Glacial grooves on the dike are oriented at S22°E.
The trail drops into a hollow that is a fault zone. A fault is nothing more than a fracture that separates rocks that have moved relative to each other. The trail then climbs a bench.

**STOP 4:** On the bench is volcanic breccia in the Pine Hill Felsite (Zbjc). Felsite is a generic name for any light-colored, fine-grained igneous rock. A breccia is any rock containing coarse angular fragments. The breccia here is a pyroclastic or sedimentary unit made almost entirely of large blocks of volcanic rock in finer olive-gray (light-colored) fine sediment (the matrix), which is rusty when weathered (images below). The origin of the unit remains uncertain because it has not been possible to tell whether the fragments were deposited as airborne material. The unit may be landslide deposit formed from already deposited volcanic debris. This is the bottom unit of the Pine Hill Felsite in the Boojum Rock area and, like at Pine Hill across Rt. 93, the bottom of the unit is breccia and conglomerate (coarse-grained sedimentary rock). The image below on the left shows a volcanic boulder in the breccia surrounded by an the olive-gray matrix weathered to a rusty color. In addition to volcanic fragments, there are also occasional blocks of granite in the breccia (image below on right, red arrow). Some granite boulders are rich in pink feldspar and are pieces of the Spot Pond Granodiorite in the Fells. This relationship proves that the Pine Hill Felsite is younger than the Spot Pond. The breccia ends on a bench below (Stop 5), where it is in contact with an intrusive igneous rock unit.

Scramble down the incline at Stop 4 and out to the flat bench below (left image below, viewed from above in early spring). Note the roof of the ice rink in the distance, which may be concealed when there are leaves on the trees.

**STOP 5:** On the bench is the contact of volcanic breccia (dark unit) in the Pine Hill Felsite (Zbjc) and the Lawrence Woods Granophyre (Zlwg, light tannish pink unit). The images below show the sharp contact (dashed line) between the two units at various scales. A granophyre is a fine-grained granite (quartz with roughly equal amounts of plagioclase and alkali feldspars) with a granophyric texture. A granophyric texture occurs when feldspar, in this case alkali feldspar, and quartz crystallize rapidly and simultaneously to produce irregular, intermingling growths of the two minerals. This texture is only visible in a microscope, but it occurs throughout the unit and over a wide area from Lynn, across North Medford, and all the way to Medford High School. The granophyre represents a magma chamber close to the land surface, referred to as a subvolcanic intrusion. The granophyre intrusion appears to be closely related to the Pine Hill Felsite, which would be its surface (volcanic) equivalent.

Climb back up the steep face of the breccia, keeping an eye out for granite boulders and faint layering or banding within volcanic blocks, which represent layers of ash and glass fragments. Continue south (right) on the Rock Circuit Trail. After about 40 m, a side trail joins from the dirt road to the east (left, from junction E4-18) and the trail climbs onto another bench.
**STOP 6:** The bench is an exposure of volcanic breccia (Zbjc) and on its south (far) end is welded crystal tuff (Zbjb) all in the Pine Hill Felsite. The north (near) end of the bench is part of the volcanic breccia (Zbjc) seen at Stops 4-5 with a few large volcanic blocks. The crystal tuff is a pyroclastic volcanic rock, meaning it was ejected into the air prior to accumulating upon landing. 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 are 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. 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 and this material gives the rock its light to purplish-gray color. The tuff here has crystals of quartz and plagioclase feldspar that are often broken and not easy to see because of their fine grain size. At the south end of the bench, right where the trail drops down off of it, are black flattened pumice fragments (image below left). The flattening was due to the weight of accumulating material squeezing the soft, still-molten pumice. The rock also has zones of volcanic lithic fragments, some which are very large (up to 0.5 m). 3 m east (left when looking ahead on trail) of the flattened pumice fragments are angular, pink volcanic lithic fragments along the small cliff (image below center). Some of the lithic fragments have faint pyroclastic banding, which is layering produced by deposition of ash layers. Moving about 5-6 m back to the north on the trail is an area of tan rocks with dark lithic fragments (image below right). This is volcanic breccia with volcanic fragments in fine ash. 2-3 m south (beyond) of the end of the bench is a large purple boulder that is crystal tuff with faint banding.

Beyond the boulder, the trail climbs over another knob of crystal tuff with a vernal pool on its east side. A vernal pool is a seasonal, or ephemeral, body of water. In the Northeast, these pools are usually at their fullest in the spring, when snowmelt and a seasonally high water table fill them. In the Fells, some of these pools last through the summer because of upward seepage of groundwater through fractures. After descending from the last knob and passing the vernal pool, you will be directly above the Elm Street/Woodland Road rotary to the west.

**STOP 7:** Along the trail is a collection of 5 large glacial boulders (image to right in early spring). Boulders no. 1 and 5 on the image are glacial erratics of the Stoneham Tonalite from the northern Spot Pond area. Tonalite is an intrusive, coarse-grained igneous rock almost entirely made of plagioclase feldspar and quartz with scattered to sometimes abundant mafic (dark) minerals. To be a glacial erratic, a boulder must be glacially transported and different than the underlying rock, which here is the Pine Hill Felsite. Boulders no. 2-4 are purplish-gray pieces of the underlying Pine Hill Felsite (Zbjb), so while they have been glacially transported, they are not erratics. Continue south on the trail to two more large purplish-gray tuff (Zbjb) boulders.
**STOP 8:** At the boulders (lower left on image to right, view in early spring), the trail comes to a knob underlain by an E-W trending dolerite dike (d) like at Stops 2 and 3. At the base of the knob is the contact between the Pine Hill Felsite (Zbjb) to the north and the dolerite to the south. The trail bends to the east (left) and crosses a second double knob, which is also part of the dolerite dike. The dike is cut into separate blocks by several small faults. After passing the second set of knobs, the trail bends to the left and crosses a third knob underlain by the crystal tuff of the Pine Hill Felsite (Zbjb). **After passing a trail on the left (junction E5-1, same trail crossed at Stop 3), the Rock Circuit Trail steeply descends into a deep valley.**

**STOP 9:** While descending the hill there are large angular blocks of rock along the trail to the left from upslope, which are crystal tuff (Zbjb) and vitric tuff (Zbjv) in the Pine Hill Felsite. Vitric tuff is tuff made of ash with very few crystals or lithic fragments. Along the trail, boulders of the vitric tuff are light gray with no apparent crystals. You will also see boulders of the breccia from Stops 4, 5 and 6. About halfway down the trail to the valley below, look for boulders of a peculiar mixture of orangish-pink crystal tuff in a light gray vitric tuff (image to right). **The trail crosses a road in the valley bottom at junction E5-2.**

**STOP 10:** Just beyond the road and along the flank of the hill across the valley is where a fault runs through volcanic breccia in the Pine Hill Felsite (Zbjc). This valley (no image) has a series of faults with associated fractures as is evident from all the angular fractured boulders lying in the valley. The hill continues over the next ridge, which is underlain by the easternmost occurrence of volcanic breccia in the Pine Hill Felsite. Be on the lookout for not only boulders of breccia but also less frequent conglomerate with rounded granite, sandstone, and volcanic pebbles. The conglomerate is well exposed on the southern end (to right) of the ridge that is crossed by the trail and is mapped as part of the volcanic breccia in the Pine Hill Felsite. **Continue east on the trail.**

**STOP 11:** After crossing the ridge described at Stop 10, the trail crosses another fault valley with some wetlands and a small stream (image on right, pink line is fault). The fault brings the volcanic breccia of the Pine Hill Felsite (Zbjc) on the west (near) side in contact with crystal tuff of the Black Rock Tuff (Zbrc) on the east side. The Pine Hill Felsite is highly fractured, while the Black Rock Tuff occurs as large, bold outcrops east of the fault with a lower fracture density. Also, the Pine Hill has abundant quartz crystals and lithic fragments while the Black Rock has abundant 2-3 mm plagioclase crystals, sparse lithic fragments, and no quartz crystals. If you look at map RC-3A, you will also see that, north of here, the volcanic breccia in the Pine Hill rests on an unconformity (yellow dashed line on map) on the older Black Rock Tuff. An unconformity is a surface that represents a gap in the geologic record and is also overlain by a sedimentary or volcanic unit. Here the unconformity is an erosion surface cut into the Black Rock Tuff that was later covered by breccia of the Pine Hill Felsite. **For more on unconformities see: Unconformities.**
After crossing the small stream and heading uphill the trail cuts across a road at junction E4-17.

**STOP 12:** At the road, the trail crosses the south side of a large, E-W trending dolerite dike (image to right). This is the same dike seen at Stops 2 and 3, but here it is in contact with the Black Rock Tuff (Zbrc). The trail begins to follow the dike, which is also exposed in the road. Note the relatively smooth surfaces, low fracture density, and rusty color of the dike as compared to the adjacent volcanic rock.

In a short distance the trail bends to the south-southeast (right) and enters an open area.

**STOP 13:** In the open area, the large, E-W trending dolerite dike cuts across a large, N-S trending dolerite dike, which forms a west-facing ledge, and a smaller, N-S trending basalt dike (image to right). Basalt is compositionally similar to dolerite, but fine-grained. This site is important because it helps establish the age relationships between dikes of different trends. For much of the Rock Circuit tour, we have encountered large, E-W trending dolerite dikes that are parallel to each other (Stops 2, 3 and 8). Wherever we see dikes of a N-S trend, they are crosscut by the large E-W trending dikes. Thus, the E-W dikes are younger.

**Continue the tour on Map RC-3B.**

The trail continues south following the N-S trending dikes to a prominent point formed by the larger N-S trending dike.

**STOP 14:** At the point underlain by the large N-S dolerite dike is a platform with preserved glacial grooves (image to right, parallel to hammer). The grooves are oriented at S36°E. If you look closely at this surface, you will also see some subtle, streamlined (smoothed) knobs that were more resistant to glacial erosion (X’s on image below to right). South of the knobs (to left on image), the less resistant rock was protected from glacial erosion and formed broad tails. These features are called rattails, and they indicate the absolute flow direction of the ice (e.g., N to S vs. S to N), not just the trend of flow indicated by striations and grooves.

The trail continues south. After crossing the outlet of a vernal pool, it cuts sharply to the east (left) where it climbs to the top of a N-S trending ridge.
**STOP 15**: The N-S trending ridge is underlain by welded crystal tuff of the Black Rock Tuff (Zbrc). Like the Pine Hill Felsite, this is a pyroclastic volcanic rock, meaning it was ejected into the air prior to accumulating upon landing. The term *welded* refers to the fact that the ash and glass/pumice fragments were at least partly molten, and they adhered to each other when they landed. The unit is composed of fine ash particles surrounding abundant, mostly broken, white crystals of plagioclase feldspar (image below left). There are also glass and pumice (bubbly glass) fragments that were soft when they landed and were subsequently flattened beneath the weight of accumulating material. The fragments are small (up to 5 mm) and hard to see in outcrop. Both the glassy ash and glass fragments were devitrified to very fine intergrown quartz and feldspar. You may also see occasional small lithic fragments, but they are not common. Across the top of this ridge are scattered orange (iron)-stained and polished remnant patches of glacial striations (image below right). The striations here are oriented S28°E. To see the very fine scratches, it helps to wet the rock surface. Moving past a small cluster of trees at the center of the ridge, there is a thin, E-W trending basalt dike (image at bottom right). Basalt is fine-grained dolerite. Because of fractures in the dike, it eroded more rapidly than the tuff that it intruded, and this has left a channel across the ridge. The road that you can see below to the east (left) is Hemlock Pool Road.

The trail continues south, heading down a steep slope to a low area, and crosses an area that is usually wet.

**Stop 16**: After the wet area is a large E-W trending dolerite dike ridge. The E-W trending dike cuts across a N-S trending dolerite dike (image above on left, view from top of knob of tuff on east side of trail in early spring). This represents the same relative age relationship that was seen at Stop 13 with the E-W trending dike being younger than the N-S trending dike. This area is also where the surrounding rock changes from the Black Rock Tuff (Zbrc) to the north to the Pine Hill Felsite (Zbjc) to the south of the E-W trending dike. The Pine Hill rests on the Black Rock in this area on an unconformity (yellow dashed line on map). For more on unconformities see: [Unconformities](#). After the dike, the trail slowly ascends to the Boojum Rock area through the Pine Hill Felsite and arrives at a steep face.
**STOP 17:** The steep face (image below left) is the north side of a wide, E-W trending dolerite dike. This is the same dike seen at Stop 8 of this tour, at Gate no. 53 at the beginning of Part 1, and at Stop 1 on Part 2. It is also like the dikes seen at Stops 2, 3, and 12 on this tour. The steep ledge here is a product of differential glacial erosion, where the heavily fractured volcanic rocks to the north are less resistant to erosion by southward flowing glacial ice than the dolerite dike. Glacial striations and grooves are found at the top of the ledge (image below right) and are oriented at S13°E, defining the local flow direction of the last ice sheet that covered this area. The ice was deflected slightly to the south as it tried to slide across a low spot in the dike ridge.

After about 15-20 m, the trail crosses the south side of the E-W trending dolerite dike and heads across a bare, lichen-covered surface.

**STOP 18:** The bare surface is an exposure of the volcanic breccia of the Pine Hill Felsite (Zbjc). This exposure is the same unit seen at Stops 4-5. Although it is a struggle to see features in some parts of the outcrop because of lichen growth, the unit consists of mostly purplish-gray lithic tuff containing large angular blocks of light gray to pink volcanic lithic fragments (image to right). This unit makes up the bottom of the Pine Hill Felsite in this area and rests on the same unconformity that occurs to the north near Stop 11. Thus far, only volcanic lithic fragments have been found here.

After about 30-40 m, the trail leaves the Pine Hill Felsite (Zbjc) and climbs a ledge.

**STOP 19:** The ledge here is welded crystal tuff of the Black Rock Tuff (Zbrc) that underlies most of the Boojum Hill area (image to right, view to south). The contact with the volcanic breccia in the Pine Hill Felsite (Zbjb) is a small E-W trending fault (dashed line on image). The ledge at this stop is a scarp, or sudden break in slope, formed along the fault. Areas to the south have moved upward to expose the Black Rock Tuff, but the scarp is not a result of fault displacement. Rather, it is the result of different erosion rates across the fault. The Pine Hill was less resistant to glacial erosion than the Black Rock. Many hundreds of meters have been eroded from both sides of the fault since it was last active. On Map RC-3B, you will notice that, if you follow the fault further east, a small branch of the large dolerite dike we saw at Stop 17 crosscuts the fault, indicating that the dike is younger than the fault. Further east, the large dike also crosscuts the fault and intruded the fault plane. Just north of the current stop, the dolerite dike from Stop 17 also crosscuts a N-S trending dolerite dike.
After leaving the fault, the trail heads east across a small valley and then up on a ridge where you will see a sign board.

**STOP 20:** The ridge is composed of crystal tuff in the Black Rock Tuff (Zbrc). The preceding small valley has the N-S trending dolerite dike that is crosscut by the dike at Stop 17 (see map RC-3B), but the N-S dike is poorly exposed in the trail area. On top of the ridge, you will see the ruins of the MIT Observatory, which was an early geodetic survey station set up in 1899 by what is now the Dept. of Earth, Atmospheric, and Planetary Sciences at MIT (image to upper right). Geodesy is the study of Earth's shape as it relates to gravity. The observatory was set up with very accurate telescopic surveying devices used to locate markers on hilltops, miles away. When the observatory was active, primarily as a teaching facility, there was far less tree cover. Measurements allowed the early geodesists to teach and refine surveying methods and to determine very subtle differences in land surface movements (tilt). This was state-of-the-art in the late 1800's and today is replaced by laser and satellite technology.

Leaving the observatory, the trail heads down a rocky surface in the crystal tuff in which fractures are coated with the pistachio green mineral epidote (image to right). This mineral is common in fractures in all rock units across the Fells and is the result of precipitation by hydrothermal (hot water) solutions that traveled along the fractures.

**Continue the tour on Map RC-3C.**

Continue on the Rock Circuit Trail to junction F5-8 where it intersects the Rock Circuit Connector (orange trail markers).

**STOP 21:** At junction F5-8 is a knob of crystal tuff in the Black Rock Tuff (Zbrc) that has slickensides with hematite mineralization (image to right). Slickensides are polished, striated, and grooved surfaces created by displacement along faults. In this case, hematite, an iron oxide with a metallic, steely gray color, grew along the fault planes. It grew as a result of hydrothermal fluid circulation when the faults were active and is striated. There is also minor epidote on this outcrop. The striations and grooves indicate the displacement direction of the faults. They are different than glacial striations because they extend into the rock along a fracture rather than just existing on the rock surface and are generated by different processes. The fault surfaces here are wavy, but on average they dip gently to the west and the slickenside striations are oriented NNW (arrow). Displacement on the slickenside surface is indicated by minor steps that face north showing that the rock above the slickensides moved north relative to rock below. A blue symbol on the map shows the orientation of the slickensided surface and orientation of the striations on this surface. At the very top of the knob at this stop, look for the bronze geodetic survey marker mounted in the rock surface.

Follow the Rock Circuit Trail south (right) from junction F5-8 for about 75 m to a sharp turn east (left).
**STOP 22:** At the sharp turn, the trail begins to follow a wide, rusty weathering, E-W trending dolerite dike that is related to the dikes seen at Stops 2, 3, 8, 12, 13, 16 and 17. This is the same dike seen at Stops 4 and 10 of Part 1 of the Rock Circuit tour. On the south side of this dike, look for the contact of the dike with crystal tuff in the Black Rock Tuff (Zbrc, image to right). The grain size along the margin of the dike is finer and does not have the salt and pepper appearance of the coarse-grained center. The fine-grained edge of the dike is its chill zone, where magma cooled more quickly next to the crystal tuff. The trail follows the dolerite dike east for about 30 m before turning southeast (right) and descending into a valley. After the valley, the trail climbs to the summit of Boojum Rock.

**STOP 23:** Boojum Rock has one of the best views of Boston from the Fells (image below). The rock here is again welded crystal tuff in the Black Rock Tuff (Zbrc). Leaving the summit, the trail skirts the east side of Boojum Rock.

Descend southward along the east slope of Boojum Rock to a bench where the trail turns east (left).

**STOP 24:** The bench has a great example of flake weathering exhibited by the Black Rock Tuff (Zbrc). This unit peels or pops off in flakes, giving the rock surface a splotchy coloration pattern. Flake weathering appears to result from initial chemical weathering of the rock surface, producing a light tan-colored outer weathered zone, or weathering rind, that is usually 2-3 mm thick. This likely creates very fine pore spaces, in the otherwise hard, solid rock. The pores may allow lichen growth and water to penetrate the rock, causing expansion when the water freezes. Other mechanisms are likely involved such as periodic fires, but we don’t yet know what role they play. This type of weathering is widespread on the Black Rock Tuff, but it does not occur on any other rock units in the Fells.

The trail continues east and crosses Jerry Jingle Road near its intersection with another road at junction F5-9. Across the road, the trail climbs the steep face of East Boojum Rock.
STOP 25: At the top of East Boojum Rock, the crystal tuff of the Black Rock Tuff (Zbrc) is crossed by several sets of parallel fractures (image to right). Note the bracket symbols ([]) on the map that show the dip direction of the fracture planes and the nearby number indicating the degree of dip away from horizontal. From here you can see areas south to Boston and hawk migration in the fall months.

After leaving the top of East Boojum Rock, the trail descends to the south, bends to the east (left), and then goes north (left again). The trail crosses two steep slopes at prominent scarps.

STOP 26: The second steep slope is where the trail crosses a rusty, E-W trending dolerite dike (image to right). This is the same dike seen at Stop 22 near Boojum Rock and Stops 4 and 10 of Part 1 of the Rock Circuit tour. This is yet another example of differential glacial erosion: the dolerite dike has a steep northern face as a result of being more resistant to erosion than the more heavily fractured volcanic rock to the north. At the bottom of the scarp, the trail heads northeast (right) and crosses two N-S trending dikes, which are not easy to trace in the field, and are crosscut by the larger E-W trending dikes in the area.

Continue into the lowland below where the trail bends east (right). On the way to the next stop, you will see many long, flat fracture surfaces in the Black Rock Tuff. The trail runs next to and then crosses over a ridge of the Black Rock Tuff before crossing a wooden bridge over an outlet stream from a wetland to the west (left). The trail then ascends a slope up to Jerry Jingle Road at near Gate no. 53.

STOP 27: The slope before Jerry Jingle Road is the south side of a large E-W trending dolerite dike (d). This is the same dike seen at Stop 17 near the MIT Observatory. From Jerry Jingle Road is a view to the west (up the road) of the northern flank of the dolerite dike, which parallels the road (image to right, view west). This is another example of glacial differential erosion leaving the dike as a high ridge.

END of Part 3.

The Fellsway East parking area is just to the north of Jerry Jingle Road along the Fellsway East. To reach it, follow the Cross Fells Trail (blue markers, see arrow on image above). Where the Cross Fells Trail cuts away to the west (left) continue straight ahead to the parking area.