Self-Guided Geologic Tour of Lawrence Woods in the Middlesex Fells Reservation

Prepared by Jack Ridge, Professor, Dept. of Earth and Climate Sciences at Tufts University, Medford, MA with assistance from summer research students Rose Malanga and Lara Williams.

<u>Some general information before starting a tour in the Middlesex Fells</u>:

1. The tour of Lawrence Woods follows a clockwise loop from Medford High School to the north and back. The tour and its stops are marked on the geologic maps. 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. Parking in the Medford High School parking lot should not be an issue as there are plenty of spaces.

3. The tour requires 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 <u>NOT</u> 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!

<u>Some Fundamental Geology to Get Started:</u>

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/.

Lawrence Woods in the Middlesex Fells Reservation version: January 12, 2024

Tufts UNIVERSITY

Loop from Medford High School Parking Lot at start of Mustang Trail

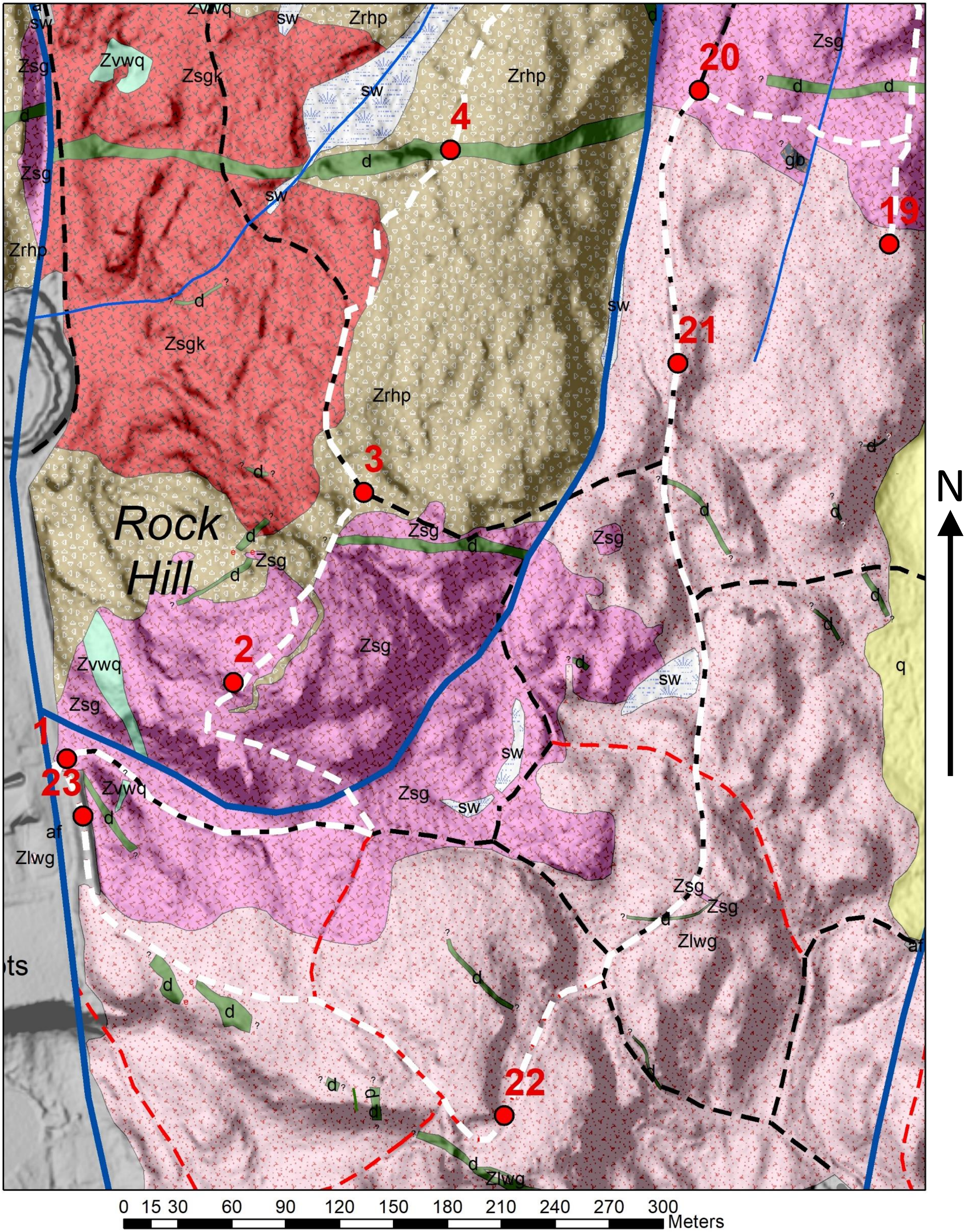
Total distance: about 2 miles (3.0 km) for complete loop. Prepared by Jack Ridge, Professor, Dept. of Earth and Climate Sciences, Tufts University with assistance from summer research students Rose Malanga and Lara Williams in 2021.

Starting point: Parking is available in the large parking lot on the south side (main entrance) of Medford High School. The trip starts at the southeast corner of the high school (near the northeast corner of the parking lot) at the beginning of the Mustang Loop trail (**see Map LW-1A, Stop 1**). The Mustang Loop is a short trail maintained by students at Medford HS. Follow the trail on the geologic maps as you go. Stops on the tour are red circles with red numbers. In the guide, trail junction numbers from the official DCR trail map are given and are marked with signs in the park. Follow the dashed white path on the maps. Having a hand lens or magnifying glass is helpful. Hope you enjoy the geology! Have fun!!

This trip focuses on Neoproterozoic (1000 to 541 Ma or million years ago) plutonic rocks (formed in magma chambers) including the Spot Pond Granodiorite (609 Ma), and the Rams Head Porphyry and Lawrence Woods Granophyre (both ~596 Ma), that intruded the Westboro Formation (909-609 Ma). You will also see younger dolerite dikes and a few glacial features from the last ice age.

NOTE: Cut rock slabs were photographed under water to make them appear polished. Scale bars are in centimeters. In pictures of rock surfaces, there is a rock hammer or pen for scale.

Map LW-1A



Rock Hill
Zsgk
Zrhp
Zsg
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1
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19
20
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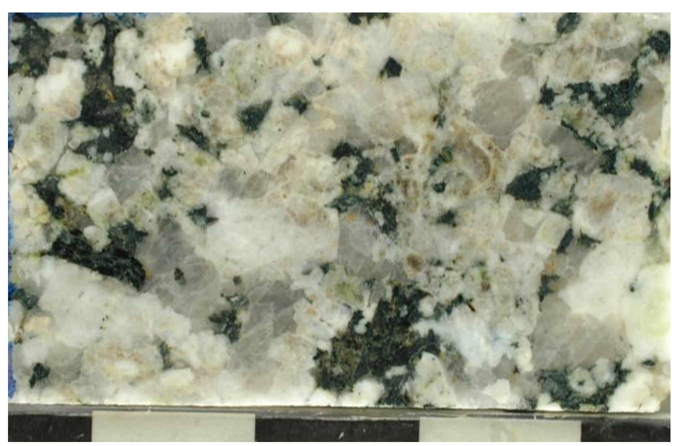
0 15 30 60 90 120 150 180 210 240 270 300
Meters

STOP 1: (On Map LW-1A) - At the start of the Mustang Loop, the trail surface (image to right) is heavily fractured Spot Pond Granodiorite (Zsg). We will learn about this rock formation at Stop 2. Referring to the map, you will see that this area is at the junction of two major faults, shown as heavy blue lines. Faults are simply large fractures along which opposite sides have moved relative to each other or been displaced. High stresses associated with the faults fractured the surrounding rock formations, which is typical of large faults. Faults are often actually a fault zone of crushed rock instead of a single plane. One fault runs north-south along the east side of the high school beneath the parking spaces (see map). A second, older fault runs E-W along the base of Rock Hill and is crosscut by (and older than) the N-S high school fault. Both faults have been inactive for 100s of millions of years. You will notice that the E-W fault follows a valley on the north side of the trail. During wet periods, water seeps out of fractures to form springs and wetlands in the valley. This seepage also occurs along the trail just ahead. The fractured rock allows the seepage of groundwater from higher surrounding areas. Many fracture surfaces have a dark green color, which is due to the mineral chlorite. Chlorite commonly grows along fractures in circulating hydrothermal (hot water) groundwater solutions, when the faults were active, and the area was deeper in the crust prior to erosion.

Continue east (uphill) on the trail for about 150 m along the south side of the fault zone. At junction B6-15 (marked on left side of trail) turn north (sharp left) onto the Mustang Loop. Cross the fault and head up the slope toward Rock Hill. At the top of the slope take the trail to the east (sharp right) up some ledges and leave the Mustang Loop behind.

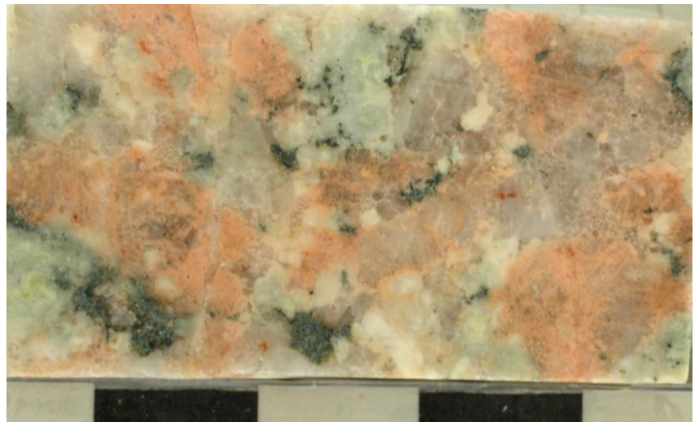
STOP 2: Near the top of the hill are outcrops of the Spot Pond Granodiorite (Zsg). It is sometimes difficult to see a fresh surface on this rock unit because it can be covered by lichens (image to right). The rock unit generally has an irregular, knobby surface where it is weathered. This is sometimes referred to as a hobnailed texture, named after the soles of boots with metal studs nailed into them to form a tread. Granodiorite is a coarse-grained igneous rock with 0.5-1 cm crystals. The light-colored mineral grains are 20-60% quartz and two feldspars, with white plagioclase feldspar dominating over pinkish-orange alkali (potassium-rich) feldspar. This tends to give the rock a gray appearance, and on Rock Hill the granodiorite has very little of the pink feldspar. On a cut rock surface (image below to right), the creamy white grains are plagioclase, and the light gray areas are quartz. Pink alkali feldspar grains are sparse and fill the small spaces between the larger mineral grains. Quartz grains, that are resistant to weathering, are what form the hobnailed texture. The dark mineral grains are black mica (or biotite) that is mostly altered to chlorite (dark green). Later (Stop 18) you will learn about the age of the granodiorite and how ages are determined in igneous rocks. The Spot Pond Granodiorite is the coarsest igneous rock unit in the Fells. In general, the slower a magma cools, the larger the crystals or mineral grains. The Spot Pond formed in a magma chamber (body of subsurface molten rock) deep in the crust where the magma could cool very Slowly. Rocks of this type, formed by magmas that invade other rocks, are called intrusions. ***Intrusions are always younger than the things they intrude.*** Specifically, the intrusion here is called a pluton, which is a large, irregularly-shaped magma body. For more on how plutons form see: Plutons.



Continue uphill and north across the top of Rock Hill. You'll notice on the map that the trail will eventually straddle the contact between the Spot Pond Granodiorite (Zsg) and the Rams Head Porphyry (Zrhp) before reaching a dirt road (Stop 3) where the tour enters the Rams Head. Unfortunately, there are only poor outcrops in this area.

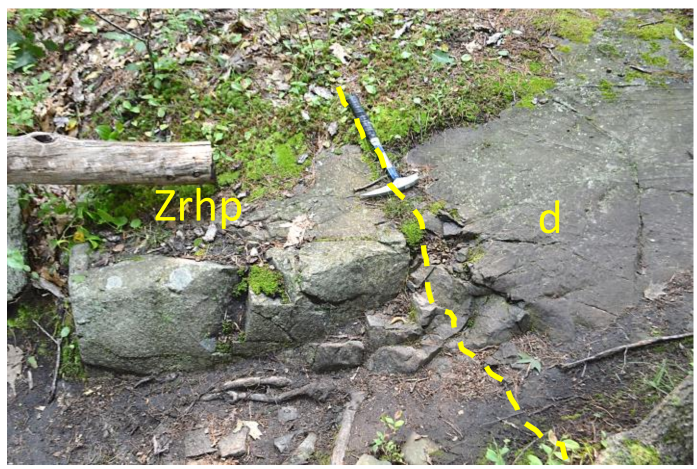
STOP 3: A lower, relatively flat area is visible north of the road. This low topography is typical of areas underlain by the Rams Head Porphyry (Zrhp), which will be described at Stop 5. There are generally fewer outcrops of the Rams Head than of the other plutonic rock units. This unit is heavily fractured, which aids in the erosion of the land surface and creates scattered, angular blocks. Near this stop, and as you head northwest (left) on the road for the next 30 m, you may see some scattered outcrops of the Rams Head, which has finer crystals than the Spot Pond Granodiorite (Zsg). Note on the map the occasional slender invasions of the Rams Head into the Spot Pond (near Stop 2) and the pieces of the Spot Pond in the Rams Head (60-100 m west-southwest of Stop 3). The pieces are fragments of the Spot Pond that broke off into the Rams Head magma and were later trapped. These fragments are called inclusions or xenoliths, and along with the invasions of Rams Head into the Spot Pond, give us the relative ages of the two units. ***Inclusions are always older than the unit that surrounds them.*** Thus, the Spot Pond is older than the Rams Head.

As you head northwest on the road, another odd feature occurs near Stop 3. On Map LW-1A you will see an orange unit labeled Zsgk, which is an alkali granite, dominated by alkali feldspar (rich in potassium) rather than plagioclase. In the cut rock image (right), quartz is gray, plagioclase feldspar is white to pale greenish gray, and alkali feldspar is pinkish orange. Like in the Spot Pond, the dark minerals are biotite altered to chlorite. Unfortunately, no good outcrops of this unit occur along the trails. The unit has sharp contacts may be a variation of the Spot Pond Granodiorite, but this remains uncertain.

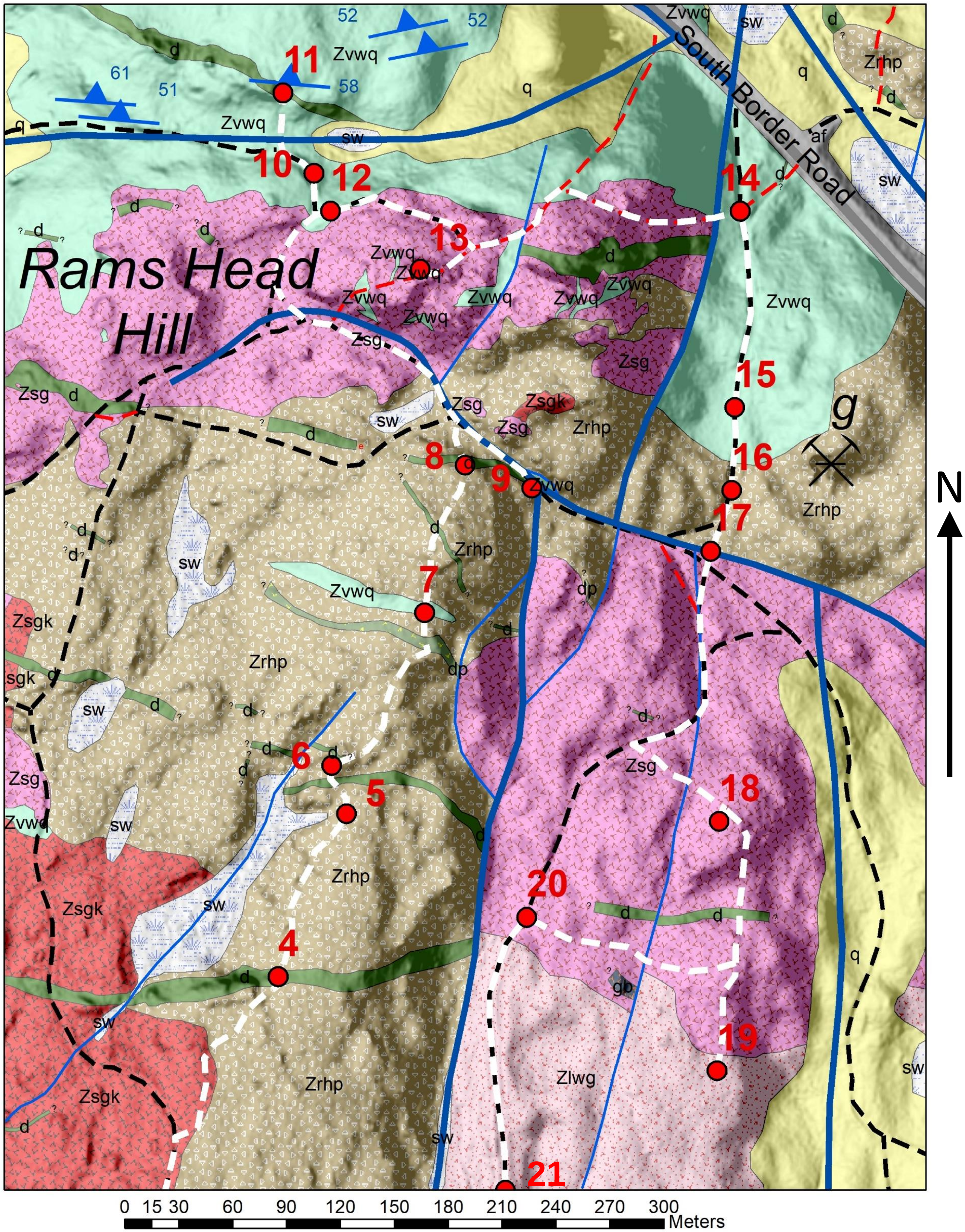


From Stop 3 continue north (to left from previous trail). Just before the road starts to bend to the west (left) take either of the two small trails to the northeast (right). The two trails join and cross a relatively flat, open, wooded area for about 80 m before arriving at a small ridge with a steeper northern slope on the left side of the trail (Stop 4).

STOP 4: The east-west trending ridge here is supported by a nearly vertical slab-like intrusion, or dike, of dolerite (d) in the Rams Head Porphyry (Zrhp). Dikes form where magma invades a fracture, forcing the sides apart. East-west trending dolerite dikes occur across the entire Fells and appear to be the youngest set of dolerite dikes in the Fells. Visible on the trail (image to right) is the contact (dashed line) of the north (far) side of the dolerite dike (d) with the Rams Head Porphyry (Zrhp). The contact on the south side of the dike is not exposed.



So, what is dolerite? Dolerite is a medium-grained, dark-colored (mafic) igneous rock (image to left) that is common in dikes. If it were fine-grained, it would be basalt, and if it were coarse-grained, it would be gabbro. Minerals in dolerite are mostly pyroxene (faintly purplish-green on image) and plagioclase feldspar (gray). The right side of the image has more plagioclase than the left side. Much of the pyroxene in this sample has been altered to green amphibole and chlorite. Tiny black grains are magnetite.


Rams Head Hill
South Border Road
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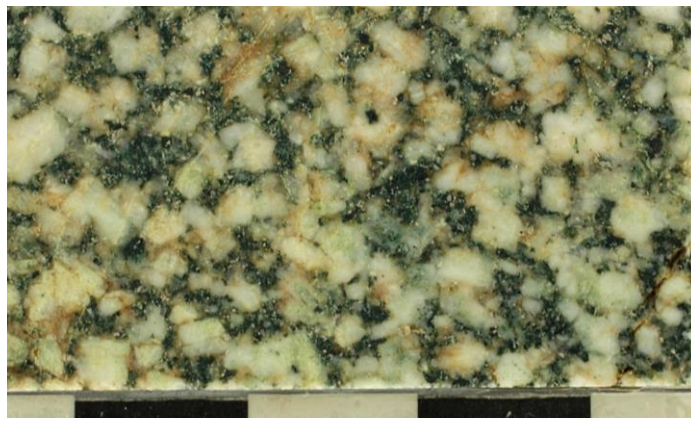
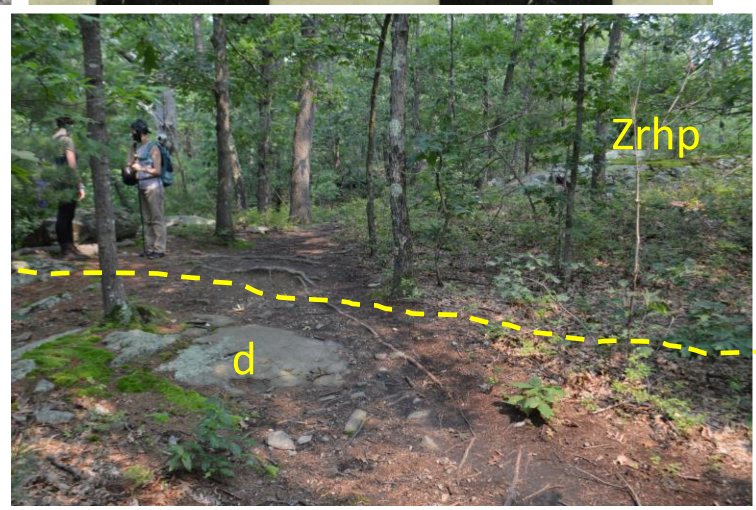
Refer to Map LW 1-B for the next part of the tour. Continue north on the trail across an area with rock rubble for about 50 m to an outcrop area that continues for another 30 m.

STOP 5: This is the first area where there are some lichen-free surfaces that show the minerals and texture of the Rams Head Porphyry (Zrhp, image below to left taken on far side of outcrop ridges). On clean, non-lichen covered surfaces, you can easily see many small, white crystals within finer, darker mineral grains, giving the rock a salt-and-pepper appearance. A rock of this texture, with coarse crystals surrounded by fine crystals, is called a porphyry. The coarse crystals are called phenocrysts. In a cut rock slab (image below to right), you can see the rectangular crystal forms of the white plagioclase phenocrysts that dominate the rock. The spaces between them are mostly filled by the dark-colored (mafic) minerals amphibole (hornblende) and black mica (biotite) that have been partly altered to chlorite. Other spaces are occupied by fine-grained quartz and very small amounts of alkali feldspar. Comparing this image with the image of the Spot Pond Granodiorite (Zsg) at Stop 2, you will see less and finer-grained quartz and more mafic minerals in the Rams Head. Like the Spot Pond, the Rams Head is a large pluton. For more on how plutons form see: Plutons. The Rams Head has been radiometrically dated at 596 Ma (mega-annum or millions of years ago). For more on how rock ages are determined see: RockAges.

From the north (far) end of the area of Stop 5 continue north another 30 m.



STOP 6: At this stop, there is another east-west trending dolerite dike (d) in the Rams Head Porphyry (Zrhp). The image to the right shows a view of the stop from the south (looking ahead). The students in the image are standing just beyond the dike, where the stop location is shown on the map. The porphyry forms a low ridge behind the dike (at Zrhp label). On the ridge, you may see small exposures of a thin dolerite dike that crosses the trail. On the map, the main dike is offset by a fault in the low area to the west (left) that is mostly occupied by a swamp.



Continue north on the trail about 70 m and climb over a ledge. In another 30 m is Stop 7.

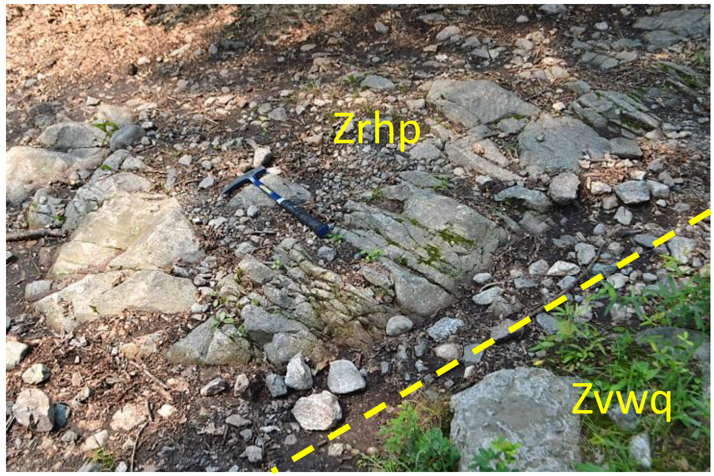
STOP 7: The trail is crossed by a thin gray inclusion of the Westboro Formation (Zvwq) in the Rams Head Porphyry (Zrhp). The Westboro Formation is a metamorphic rock unit composed of alternating layers of quartz-rich metasandstone (metamorphosed sandstone) and heavily sheared argillite. Argillite is very hardened muddy sedimentary rock. The exposure here (image to right, along west (left) side of trail) has conspicuous light gray to white quartz. It is metamorphosed not only due to ancient tectonic activity (regional metamorphism) but was also baked at high temperature but low pressure in the surrounding magma (contact metamorphism). The fact that the Westboro forms an inclusion demonstrates that it is older than the Rams Head.

Continue north about 90 m across another ledge to Stop 8 in view of a road .

STOP 8: Another east-west trending dolerite dike (d) in the Rams Head Porphyry (Zrhp) crosses the trail, forming a relatively smooth surface (no image). The dike continues down slope to the east (right) to the road below. This dike will play an important role at Stop 9.

Follow the trail down to the road near junction B6-6. Follow the road east (hard right) for about 50 m.

STOP 9: The road follows the course of a major fault. The Rams Head Porphyry (Zrhp) is heavily fractured along the fault (image to right of road surface, view to west). The image shows the fault location (dashed line). Look for the Westboro Formation (Zvwq) exposed along the north side of the road (to right of the image). This is a small slice of the Westboro that is interpreted to have been displaced along the major fault and also bounded by a minor fault on its north side. On the south side of the road, you can see a section of the dolerite dike (d) from Stop 8, but it cannot be found to the north side because it has been cut off and displaced by the fault.

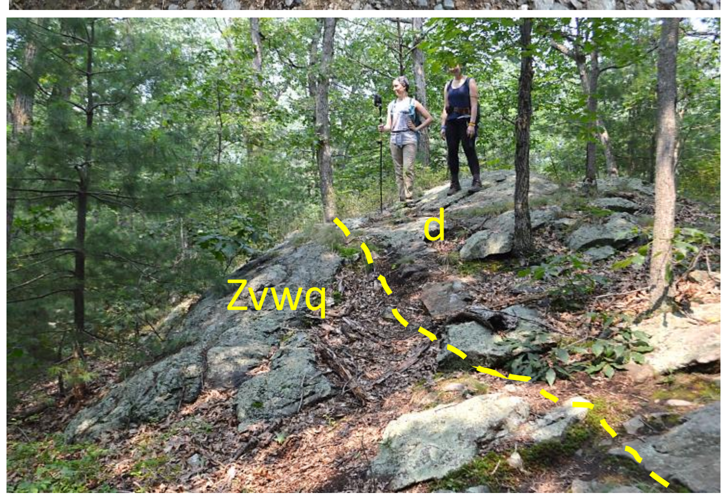


Return to road junction B6-6 and take the road to the northwest (bear right) and follow the fault and road along the base of Rams Head Hill. Spot Pond Granodiorite (Zsg) occurs on both sides of the road. The road briefly joins the Cross Fells Trail (blue markers). Where the road splits take the branch to the north (right) and follow it over the hilltop. Outcrops of Spot Pond Granodiorite occur on both sides of the road. At the top of the hill at junction B5-12, take the branch to the left. After about 20 m is Stop 10.

STOP 10: On the east (right) side of the road is an outcrop of baked Westboro Formation (Zvwq, image to right) composed of recrystallized quartz-rich metasandstone. The Westboro is no older than about 909 Ma but older than the Spot Pond (609 Ma) that intrudes it. For more on how rock ages are determined see: RockAges. The outcrop is very smooth, with faint glacial grooves and striations indicating glacial ice flow (sliding) in a S22°E direction, which closely matches striation directions from the last ice age across the Fells and the entire Boston area. On the image, the striations are parallel to the handle of the rock hammer.

Follow the road northwest (downhill) for another ~15 m and turn north (right) on the small trail for 30 m to the top of a steep slope.

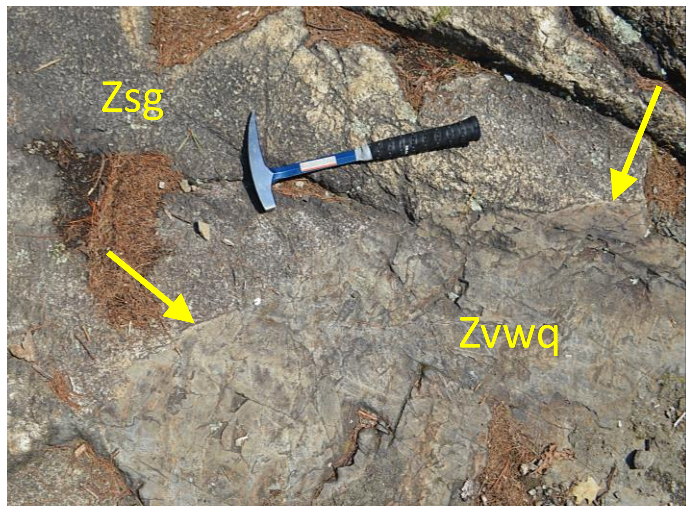
STOP 11: At the top of the slope is yet another east-west trending dolerite dike (d), this time in the Westboro Formation (Zvwq). On the west side of the trail (image to right), the dashed line delineates the contact on the south side of the dike. The students in the image are standing on the dike. On Map LW-1B you will notice a blue symbol on the Westboro Formation. The small triangle on this symbol points in the direction in which the layers dip downward into the ground, and the blue number indicates how steep the dip is away from horizontal. Near Stop 11 this is 58°.



Return to junction B5-12 and turn east (left) to the first outcrop in the road.

STOP 12: In the road (image to right) is the heavily baked Westboro Formation (Zvwq). On the south (right) side of the road in the woods are outcrops of the Spot Pond Granodiorite (Zsg), and the contact between the two is at the edge of the road. The Westboro has been recrystallized by contact metamorphism that has obscured the original layering in the unit. Baked, dense, fine-grained units like this are called hornfels. Further up the road on the south (right) side of the road (just to the right of students in the image) is an outcrop of the Spot Pond with its hobnailed texture. At the base of this outcrop, look for the contact with the Westboro Formation.

Continue up the road 75 m to junction B5-13 and turn south (right) for another 15 m. Turn west on the Cross Fells Trail (blue markers, hard right) to the remnants of a concrete foundation at the summit of Rams Head Hill. This was the old Lawrence Observatory.



STOP 13: At the base of the old foundation is an inclusion of the Westboro Formation (Zvwq) in the Spot Pond Granodiorite (Zsg). Across the center of the image to the right is the contact (at arrows) on the north side of the inclusion. The hammer rests on the Spot Pond. Inclusions are abundant along the contact between the two units. The largest Westboro inclusion found so far in the Spot Pond is about 100 m long south of Sheepfold. If you look closely at the inclusion at Stop 13, you will see light-colored areas that are quartz-rich metasandstone and darker gray layers of baked argillite hornfels. Argillite is hard, brittle shale and siltstone that was originally a muddy sedimentary rock. The rock was lightly metamorphosed and then baked to a hornfels.

Retrace your steps to junction B5-13 and turn east (right), following the Cross Fells Trail (blue markers). The trail crosses through the Spot Pond Granodiorite (Zsg). Stay on this trail to the bottom of the steep hill at Rams Head Road (junction B5-14). To the north, you will see and hear traffic on South Border Road.

STOP 14: At the base of the steep hill where the land flattens out, and just before reaching Rams Head Road (Map LW-1B), is a major north-south trending fault. West of the fault are the Spot Pond Granodiorite (Zsg), the Rams Head Porphyry (Zrhp), and an east-west trending dolerite dike (d), all cut by the fault (see map LW-1B). East of the fault is an area of highly fractured Westboro Formation (Zvwq) with limited outcrops. The lowland in this area is where glacial erosion easily removed the fractured Westboro. As we move south on Rams Head Road to the next stop, you will be able to follow the fault at the base of the steep slope to the west (right).

Continue about 120 m south (uphill) on Rams Head Road.

STOP 15: Where Rams Head Road goes over a gentle rise are scattered blocks of the Westboro Formation (Zvwq), especially on the east (left) side of the road (image to right). These blocks have a mostly medium to light gray color and are made of fine, quartz-rich metasandstone. The angular/sharp corners on these boulders show that they have not been eroded by transport over any large distance. Some of the boulders may have been glacially transported during the last ice age, but technically they are not glacial erratics because they occur on the same rock formation from which they were derived.

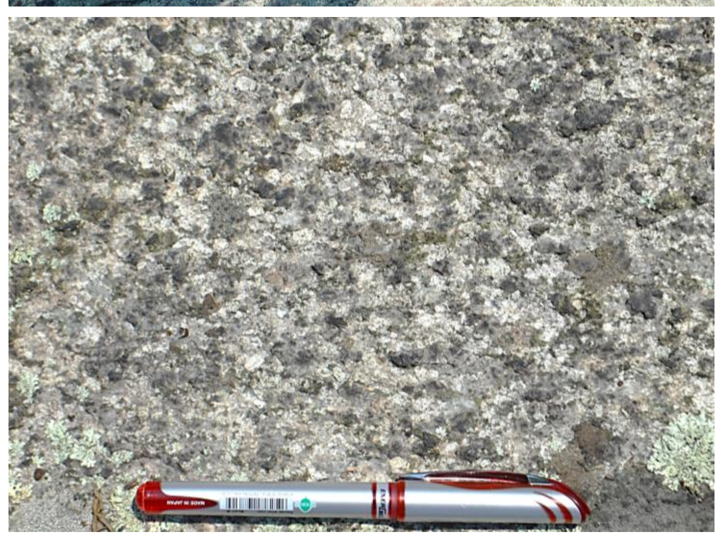
Continue south on Rams Head Road for about 50 m to an outcrop on the west (right) side of the road.

STOP 16: On the right (west) side of the road (image to right, view to south) is an outcrop of the Rams Head Porphyry (Zrhp). Rams Head Road has crossed over the intrusive contact between the Westboro Formation (Zvwq) and the Rams Head into an area where the Rams Head occurs on both sides of the north-south trending fault. Small inclusions of the Westboro are common in the Rams Head in this area.

Continue south to the second of two spurs heading to the west (right) at junction B6-7.

STOP 17: Just before junction B6-7, the major east-west trending fault we saw at Stop 9 crosses Rams Head Road (no image, see Map LW-1B) and separates the Rams Head Porphyry (Zrhp) to the north from the Spot Pond Granodiorite (Zsg) to the south. This fault also displaces the north-south trending fault that paralleled Rams Head Road up to this point. Rams Head Road continues south, following a minor fault with a small displacement. Erosion along this fault formed a small valley.

Continue to follow Rams Head Road south (straight) in the Spot Pond Granodiorite (Zsg). Note the knobby, rounded hills that appear in this area typical of the Spot Pond. After the road bends to the west (right), take the small trail to the east (left) as it heads over a small hill. The trail then crosses a north-south trending low spot that is the same minor fault followed by Rams Head Road leading away from Stop 17. Follow the trail onto the next knob. At the top of this knob and a few meters to the south (right) is an open area with an exposed rock surface.

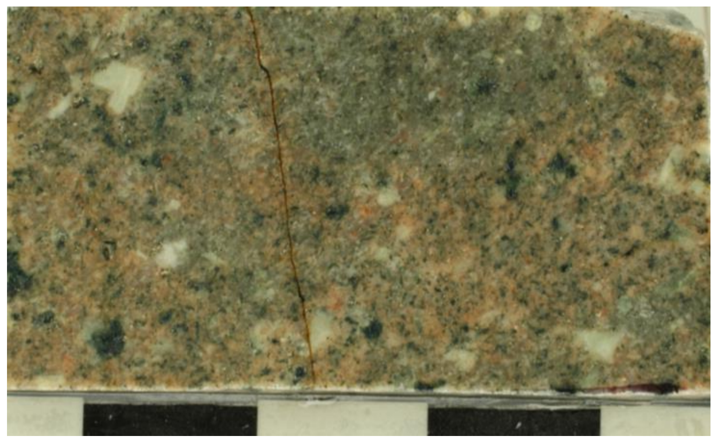


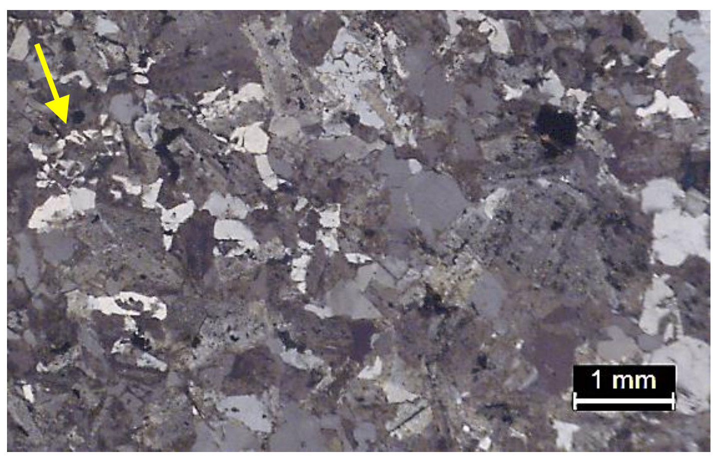
STOP 18: The open area (image to right, view to west) is an exposure of the Spot Pond Granodiorite (Zsg). This is an excellent opportunity to see the hobnailed surface and minerals (image below to right) of the Spot Pond. Like at Stop 2, the granodiorite here is coarse-grained, with 0.5-1 cm crystals and its light-colored minerals are composed of 20-60% quartz and two feldspars, with white plagioclase dominant over pinkish orange alkali feldspar. This gives the rock a gray, rather than pink, appearance. Dark mineral grains are black mica (biotite) that is mostly altered to chlorite (dark green). These dark grains are hard to see on the outcrop. Note also the fractures, or joints, in the rock. The wider spacing of these joints than the fractures in the other rock units in the area makes the Spot Pond Granodiorite more resistant to glacial erosion, and the rock unit tends to form higher rounded hills than the other units.

We have seen the Spot Pond Granodiorite at several places, but what about the numerical age of this rock formation and others in the Fells? The Spot Pond is 609 Ma (mega-annum or millions of years old). To find out how this number was obtained, refer to the link below. This link answers the question that people frequently ask when I see them in the Fells – How old are the rocks? For more on how rock ages are determined see: RockAges.

Return to the trail and continue south across ledges of granodiorite. Avoid taking side trails to the east (left). In 50 m the trail heads up onto a ledge of granodiorite. Pass by the small trail to the west (right), continue straight, and cross over a boulder row in 50 m. In another 10 m is a clearing underlain by a pink, fine-grained rock unit.

STOP 19: The pink rock unit (image below to right) is the Lawrence Woods Granophyre (Zlwg), which is ~596 Ma and has a light gray to pink color on weathered surfaces. For more on how rock ages are determined see: RockAges.

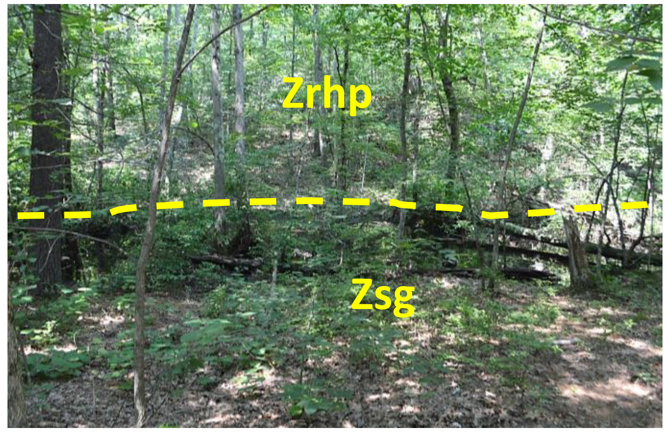




At this location you will have difficulty seeing crystals in the unit. It is almost entirely fine-grained here because this site is in the unit's chill zone where it intruded the Spot Pond Granodiorite (Zsg); the contact is near the boulder row. A chill zone is a very fine-grained area along the margins of an intrusion where it cooled more quickly. In other areas, the granophyre is still relatively fine-grained, but forms a porphyry with visible plagioclase feldspar phenocrysts, like in the Rams Head Porphyry (Zrhp) seen earlier. The Lawrence Woods appears to be a magma chamber formed at shallow depths beneath an area of volcanic eruptions, and it appears to be associated with volcanic rocks of the Lynn Volcanic Complex at Pine Hill (Part 1 of the Skyline Trail Tour). This is called a subvolcanic pluton. For more on how plutons form see: Plutons. If this unit had crystallized into a coarse-grained igneous rock, it would be classified as a granite. On the right is a cut sample of the Lawrence Woods Granophyre at Stop 19. Unfortunately, it is not possible to see the granophyric texture without the aid of a microscope, but it occupies parts of the fine-grained, pink to gray areas of the rock. In the cut rock sample (image to right), you can also see scattered plagioclase and mafic mineral phenocrysts that aren't very easy to see on the weathered surface of the outcrop. In a granophyre, initial phenocrysts of plagioclase started to form, but the remaining magma appears to have cooled so rapidly that coarse crystals of quartz and alkali feldspar could not form. In some places, they are finely intergrown with each other as shown by intermingled very fine crystals of the two minerals (microscope image to right at arrow). They did not get a chance to form coarse crystals despite making up a high percentage of the rock's composition. The granophyric grain here (yellow arrow) is surrounded by many fine quartz and feldspar crystals.

Retrace your steps back across the boulder row and take the small trail west (left) now. Follow the trail to Rams Head Road.

Stop 20: At Rams Head Road, the trail sits on the Spot Pond Granodiorite (Zsg) and is about 15 m north of the contact with the chill zone of the Lawrence Woods Granophyre (Zlwg). Parallel to Rams Head Road to the west (across a low swampy area), is a major fault (image to right). The image shows the position of the fault across a wetland and the steep slope beyond with the Rams Head Porphyry (Zrhp). Rocks near the fault are highly fractured, allowing glacial erosion of a valley during ice ages. The valley has wetlands where water is seeping out of the ground at springs. The fault appears to have considerable offset, bringing the Rams Head Porphyry (Zrhp) on the west side of the fault in contact with the granodiorite and granophyre on the east side. Also, two east-west trending dolerite dikes (d) to the west are terminated by the fault (see Map LW-1B).

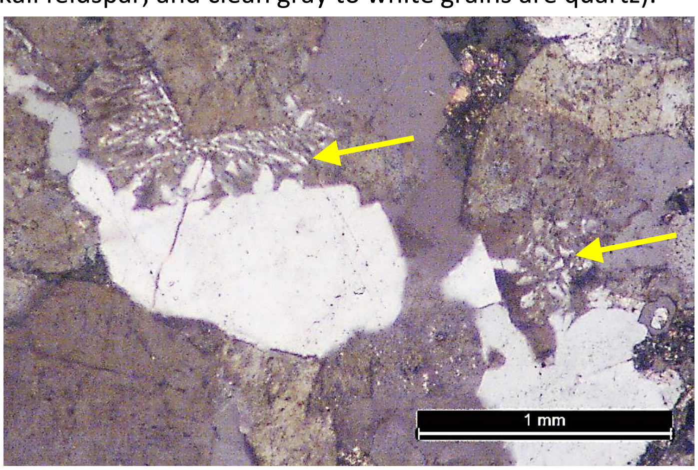


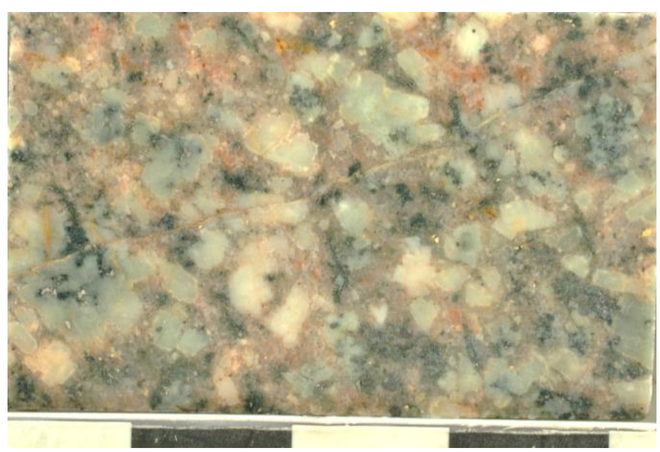
Follow the remainder of the tour on Map LW-1A. Continue south on Rams Head Road for about 150 m where the road descends a slope.

Stop 21: Fractured Lawrence Woods Granophyre (Zlwg) is exposed over about 15-20 m of the surface of Rams Head Road (image to right, view downhill to south). The unit is still fine-grained here, but it may be possible to see a few phenocrysts of plagioclase feldspar in the rock.

Continue south on Rams Head Road, passing by a road on the west (right) at junction B6-11. In another 60 m, pass by a road on the east (left) at junction B6-12. In 90 m, cross over a trail at junction B6-17 and then cross a second smaller trail that is not shown on the map. After this, the road crosses the top of a small hill and bends to the right downhill through outcrops of the Lawrence Woods Granophyre (Zlwg). At road junction B7-3, stay left, and then in 10 m, turn right on a road that crosses a valley and heads west (uphill). In another 100 m is Stop 22.

Stop 22: On the west (right) side of the road is a ledge (image on right) of the Lawrence Woods Granophyre (Zlwg). The rock here is coarser than at Stop 21 and is outside the very fine-grained chill zone of the unit seen at Stop 19. Small plagioclase phenocrysts are visible on the outcrop and are easily seen in cut rock samples (image below on right - white to light gray grains, often with flat crystal faces). The phenocrysts are surrounded by finer quartz and plagioclase grains, as well as granophyric grains. The granophyric grains are conspicuous in microscope views, more so than in the chill zone at Stop 19 (image below, at arrows are granophyric grains, tan grains are alkali feldspar, and clean gray to white grains are quartz).





Continue on the road as it bends to the west (right). In 30 m, cross a trail at junction B7-2. Look for the iron bar embedded in the rock on the south (left) side of the road at this junction. I am not sure what purpose this bar had. In another 100 m, pass a road on the right at junction B7-1. Continue west for about 120 m where the trail bends to the north (right) along a rock wall embankment. Follow the embankment for ~40 m along the Medford HS parking lot on the left.

Stop 23: In the rock rubble at the base of the embankment, look for surfaces covered with shiny, metallic (silvery) flakes of an iron oxide called hematite (Fe_2O_3). Hematite forms along fractures in many parts of the Fells (image to right). When hematite is metallic like this, it is called specular hematite. The rock waste here was likely excavated during construction of the high school from along the N-S trending, major fault zone beneath the school. Hydrothermal (hot water) solutions precipitated the hematite as they circulated along fractures where dissolved iron encountered oxygen. Fractures filled with mineral precipitates like this form veins, which have the appearance of mini-dikes. They are often places where the rock is easily split when excavated.

Follow the trail a short distance to the end of the tour at Stop 1.

END OF TOUR.

Here is a list of the rock units you have seen in Lawrence Woods.

dolerite dikes (d)
Lawrence Woods Granophyre (Zlwg)
Rams Head Porphyry (Zrhp)
Spot Pond Granodiorite (Zsg)
Westboro Formation (Zvwq)

Here is a list of the features and vocabulary discussed on the Lawrence Woods tour:

Vocabulary:
rocks and minerals
minerals: (grains or crystals)
- quartz
- plagioclase feldspar
- alkali feldspar
- pyroxene
- amphibole – hornblende
- black mica (biotite)
- chlorite
- specular hematite

igneous rocks:
- coarse-grained vs. fine-grained
- magma, magma chamber – molten rock
- subsurface igneous rocks:
- dolerite (also sometimes called diabase)
- granodiorite
- granophyre, granophyric grains
- porphyry, porphyritic
  - (phenocrysts + finer ground mass)
- intrusion
- dike
- pluton - For more on how plutons form see: Plutons.
  - subvolcanic pluton
- inclusion (xenolith)
- chill zone or chilled margin

volcanic (surface, extrusive) igneous rocks:
- lava – flow of extruded magma
- pyroclastic rocks – ejected into atmosphere

sedimentary rocks:
- sandstone, siltstone, shale

metamorphic rocks:
- regional metamorphism
- metasandstone
- argillite – hardened shale/siltstone
- contact metamorphism
- hornfels – baked fine-grained rocks
- hydrothermal alteration

geologic time:
- abbreviation: Ma = mega-annum (millions or yr)
- radiometric dating - For more on how rock ages are determined see: RockAges.
- radioactive decay
- half-life
- isotopes (parent and daughter)
- zircon crystals

contacts – boundaries between geologic units

fracture planes or joints
fault, fault displacement
fault zones

weathering – surface degradation of rocks
erosion – removal of weathered rock debris
Springs, groundwater seepage
glaciation or ice age
glacial erosion
glacial striations and grooves
glacial erratic – glacial boulder, unlike bedrock