Self-Guided Geologic Tour of the Crystal Springs Trail in the Middlesex Fells Reservation

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

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

1. Tours of the Crystal Spring and Virginia Wood areas have been broken into two parts (north and south of Pond Street). You can do the whole tour in one day, but it is a lot of hiking (~4 twisting miles, ~6 km) and a lot to comprehend in one dose. It's recommended that you do parts of the tour in order: Crystal Springs and then Virginia Wood. Both tours start at the same spot. Each 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. At many times of the year and on weekends, parking areas fill, especially along Pond Street, 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 <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/.

Crystal Springs Trail in the Middlesex Fells Reservation version: May28, 2025
Part 1: Crystal Springs, Whip Hill and Saddleback Hill (north of Pond Street)

(Total distance: about 2 miles (~3 km) round trip.)

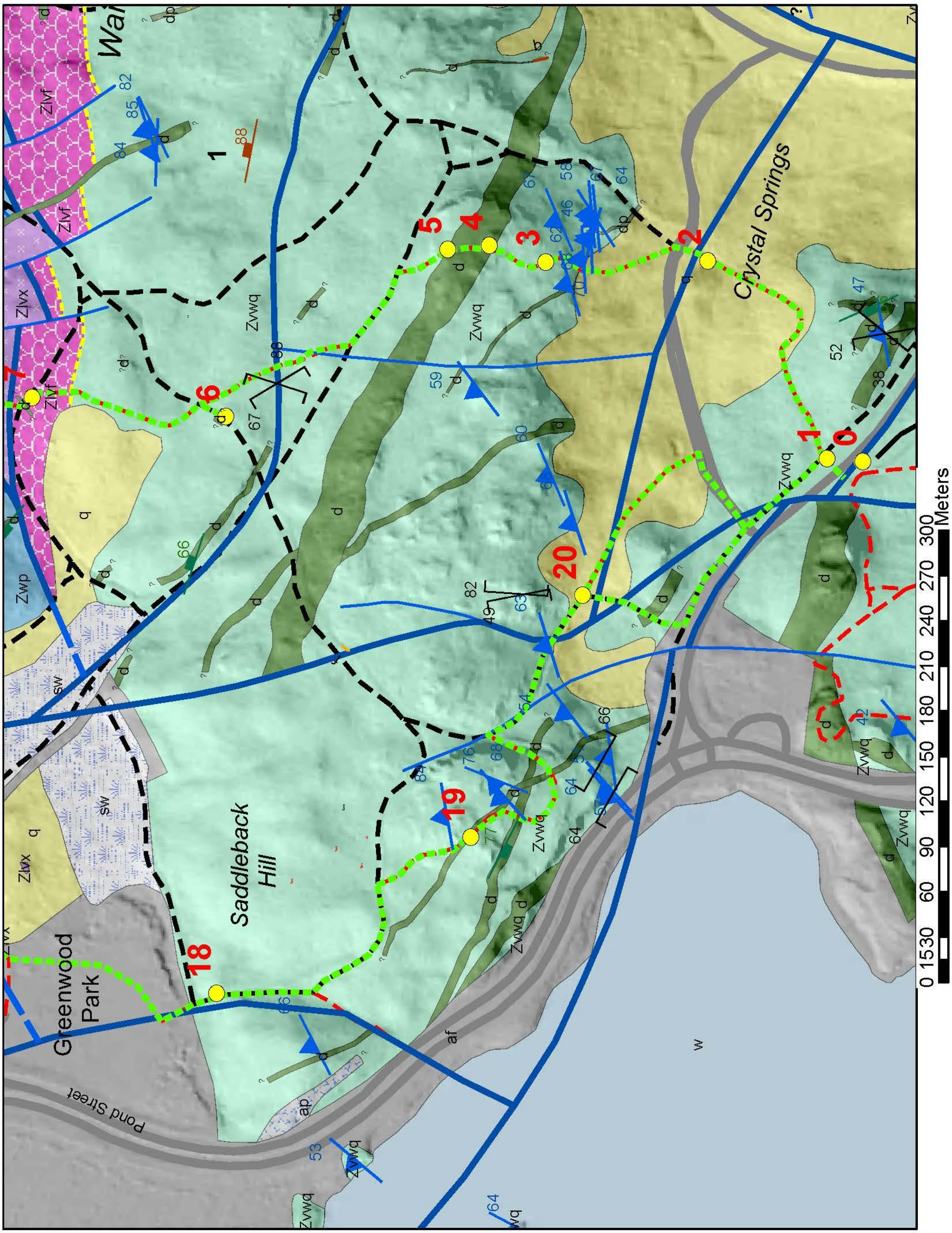
Prepared by Jack Ridge, Prof. Emeritus, Dept. of Earth & Climate Sciences, Tufts University

Starting point: Parking Area at Gate no. 42 on the section of Pond Street heading east away from Spot Pond (see Map CS-1, Stop 0). Head north (across Pond Street) from the parking area. Follow the trail on the geologic maps as you go. Follow the red trail markers in the field and dashed lime green path on the maps. On the geologic maps, stops on the tour are marked by yellow circles with red numbers. In the guide below, trail junction numbers are given that are on the official DCR trail map and are marked with signs in the park. Alternate parking can be found at Greenwood Park on Pond Street at Stop 17. It can be helpful to have a hand lens or magnifying glass. Hope you enjoy the geology! Have fun!!

This trip focuses on Neoproterozoic metasedimentary and sedimentary rocks of the Westboro Formation and volcanic rocks of the Lynn Volcanic Complex as well as younger dolerite dikes. The Neoproterozoic Era is 1000-541 million years ago. The trip will also point out where rocks were deformed by major faults and fractures and will highlight 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.

Map CS-1


N
Crystal Springs
Saddleback Hill
Greenwood Park
Pond Street
Meters
0 15 30 60 90 120 150 180 210 240 270 300
Zvwq
Zlvf
Zlvx
Zwp

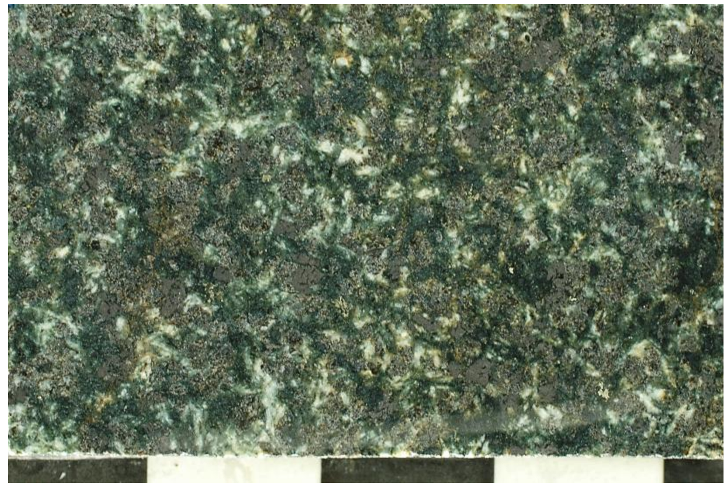
STOP 1: While crossing Pond Street from the parking area at Gate no. 42, you are crossing a major E-W trending fault. A fault is nothing more than a fracture separating rocks that have moved relative to each other. The fault runs through the Westboro Formation (Zvwq), which will be discussed later in more detail where we can see outcrops (surface exposures) of this unit. The valleys in this area are governed by the positions of faults. The faults are very complex, with major E-W trending faults cut and offset by major N-S trending faults. This pattern occurs across the Fells. On Map CS-1, you will see this situation just west of the parking area, where a large dolerite dike (d) and the E-W trending fault along Pond Street are both offset by a N-S trending fault. N-S trending faults give an apparent offset of areas west of the faults moving south relative to areas east of the fault. This is called left-lateral displacement, but we must also account for vertical displacements, which has not been possible in any precise way. There are also minor faults associated with the major faults. Heavy fracturing occurs along faults, allowing for easier erosion, especially during glaciation. Groundwater seeps through the fractures, leading to the formation of springs and small streams. In some areas, outcrops are scarce due to heavy fracturing, erosion, and a cover of glacial sediment. **Continue north on the trail across an area where glacial sediment conceals the rock surface and descend a slope.**

STOP 2: In the valley you will arrive at Crystal Spring (image to right). The slope does not have many outcrops, but instead scattered boulders of many different rock formations and a cover of glacial sediment. 30 m before the spring is a large block (or possibly an outcrop?) of the Westboro Formation (Zvwq). The spring lies along an E-W trending fault that has been mapped out based on local topography, particularly the steep escarpment to the north. Discharge of groundwater, or baseflow, forms Crystal Spring and a small stream, which is active during most seasons. The water at this spring looks clear, but as far as I know, you should not drink it.

After leaving Crystal Spring the trail heads upslope and crosses a paved road at junction F2-6. Across the road to the right, the trail ascends the escarpment to the north (image below).

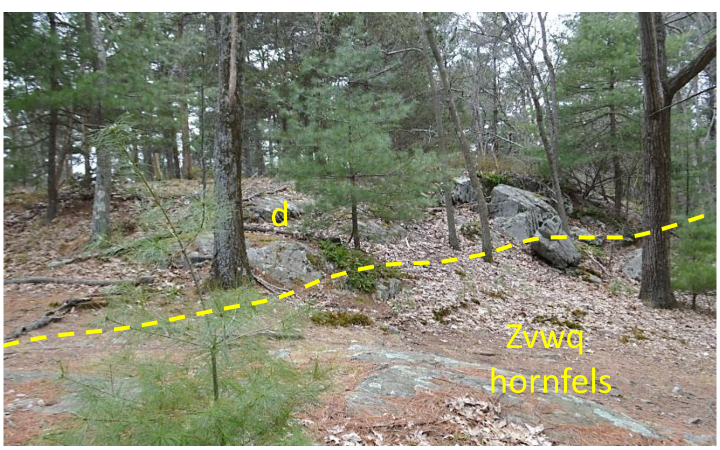
STOP 3: The escarpment is littered with angular fragments of the Westboro Formation (Zvwq) which is exposed high in the escarpment (ahead, image to right in early spring). Here, the Westboro Formation is composed of two interlayered rock types. One is light gray metasandstone, a hard rock composed of metamorphosed sandstone and siltstone (sometimes called quartzite, q on image below to right). The metasandstone units are fine-grained and have vertical fractures as well as layer-parallel break planes that may be cleavage (planes formed by shearing and recrystallization of fine minerals) parallel to what was original bedding. Interlayered with the metasandstone is dark gray argillite and slate (a on image below to right). The argillite and slate have cleavage planes resulting from shearing and recrystallization of fine-grained minerals at low pressures and temperatures during metamorphism. Argillite is shale, or muddy sedimentary rock, that was hardened by light pressure and is brittle while slate is the same rock with cleavage planes. The cleavage shows up as subtle, closely-spaced, parallel break planes. The surfaces of fracture and cleavage planes are green because of a soft, mica-like mineral called chlorite. This rock has undergone regional metamorphism, which occurs over a large area due to compression by tectonic forces and heating by burial. The metamorphism here is relatively light since we can still easily determine the original rock type from prior to metamorphism, and there has been relatively little change in mineral types, although the mineral grains have changed shape. **Continue to the top of the hill.**

STOP 4: At the top of the escarpment, you will notice a change in the shape of outcrops where the trail crosses a wide, E-W trending dolerite dike (d). The dolerite is smoother and more rounded (image below left, east or right side of trail) than the Westboro Formation (Zvwq) on the slope below. A dike is an intrusion of magma that filled a fracture. Dolerite is an igneous rock of intermediate (sand size) grains made of mafic (dark-colored) minerals and plagioclase feldspar. Usually, dolerite dikes contain the mafic minerals pyroxene and magnetite. Pyroxene may be partly altered to chlorite and amphibole, which are both green. In the cut rock sample (image below right), the faintly purple grains are pyroxene, and the light grains are plagioclase. High iron content gives the rock a dark color on fresh surfaces and a rusty weathered appearance due to oxidation of iron. Dolerite dikes are common throughout the Fells.



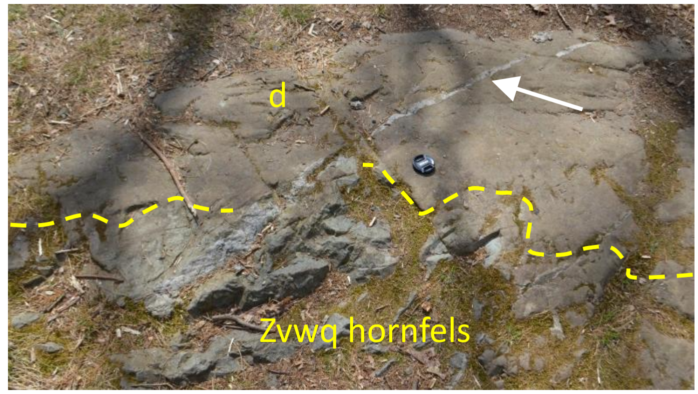
Continue to the far side of the hilltop to where the trail starts to descend.

STOP 5: There is more of the dolerite dike (d) on the hilltop. The north side of the dike is well marked to the west (left) by a steep face (image below on left). The trail descends into the Westboro Formation (Zvwq), which is much harder and less fractured here than in most places (image below on right with light-colored metasandstone near the hammer), for example at Stop 3. Near the edge of the dike, the Westboro Formation was exposed to very high temperatures, or baked, when the dike intruded. Baking caused some of the fine clay and mica particles in the argillite to recrystallize, like what happens when clay is fired in a furnace, producing a dense and hard rock called hornfels. Quartz grains have also fused together. These processes constitute a type of metamorphism called contact metamorphism. It occurs on a very local scale and results from high temperature exposure near an intrusion, whereas regional metamorphism, which we discussed earlier, was due to compression and heating on a much larger scale that changed the whole rock formation. Here, the zone of contact metamorphism is not more than 20 m wide on both sides of the dike. Contact metamorphism can produce different metamorphic effects in different rocks.



Continue north on the trail. After joining Cross Path at junction F2-7, the trail heads west (left), and in about 75 m heads northwest (right) into the woods again. Outcrops along this section of the trail are small and scare. In a little more than 100 m, the trail crosses Saddleback Path (also the Heart Healthy Trail) at junction F2-11. From junction F2-11, take a sharp left and head southwest about 20 m to a mound on Saddleback Trail.

STOP 6: The mound in the trail is hornfels in the Westboro Formation (Zvwq) along an irregular contact with a thin NW-SE trending dolerite dike (image to right). The hornfels is hard and the dolerite has few fractures, so the mound is more resistant to erosion. A large quartz vein crosses the contact (arrow on image); look for the 2-cm-wide, light band that trends E-W across the outcrop. The quartz vein formed after both surrounding rock formations and was precipitated from hydrothermal (hot water) solutions that circulated along a fracture that crossed the contact. The dike was already solid when the vein formed. Note also, the quartz vein is offset along a small fault (upper right corner of image).

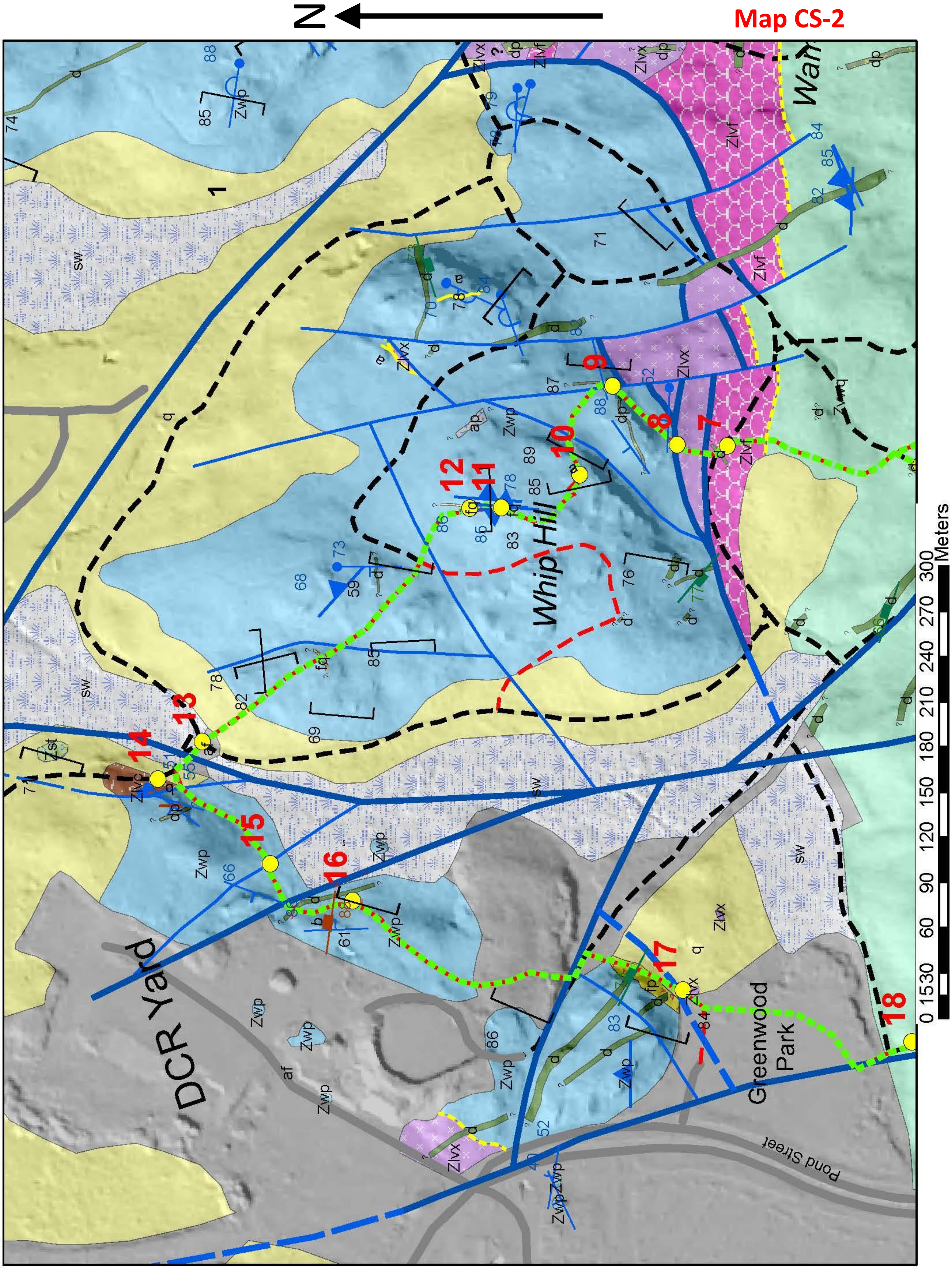


Return to the Crystal Spring Trail at junction F2-11 and continue north (left) to junction F2-12 where the trail crosses a road.

Continue the Tour on Map CS-2

STOP 7: At junction F2-12 the trail enters a lava flow in the Wakefield Formation of the Lynn Volcanic Complex (Zlvf). The rock here is called felsite, a generic name for any light-colored (non-mafic) fine-grained igneous rock. The felsite is exposed at the SW corner (left side) of the trail junction alongside a small NE-SW trending dolerite dike (image below left, view to SW). The dike is deeply weathered along fractures. Exposures of the felsite over most of its outcrop belt are sparse. The unit is torn apart by faults, heavily fractured, and can be eroded and covered by glacial sediment. The dike is likely responsible for protecting it from glacial erosion at this site. The felsite in the Wakefield Formation is mostly made of rhyolitic pyroclastic rocks. Rhyolite is a fine-grained igneous rock with the same chemical composition as granite (a coarse-grained igneous rock composed of quartz with two types of feldspar, plagioclase and alkali). Pyroclastic rocks are made of volcanic materials that were airborne before accumulating on the land surface. This may include four components: 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. Most of the pyroclastic units in the Lynn Volcanic Complex are welded tuffs with flattened pumice fragments, abundant plagioclase and quartz crystals, and lithic fragments. Tuff is any pyroclastic rock partly composed of ash. Welded means that the ash and pumice fragments were still partly molten when they landed, so they adhered to each other. Molten pumice fragments became flattened as material accumulated on top of them. Unlike most of the Wakefield in this area (tuff) the rock at Stop 7 is a rhyolitic lava flow. Close examination of the east (uphill) end of the outcrop (image below right) reveals flow banding and cumulophyric plagioclase crystals. Flow banding was produced by the flow of lava that had slight differences in composition, oxidation, or crystal sizes and has swirls of parallel layers, like marble cake. Cumulophyric crystals are delicate clusters of intergrown crystals, in this case plagioclase, with well formed crystal shapes within finer material (white specks, image below right). The lava would have been very viscous (sticky), molten rhyolitic glass (also called obsidian) with a few crystals. Glass in lava and welded tuff is not stable over geologic time and, after solidification, the glass crystallizes, or devitrifies, to very fine quartz and feldspar. The lava flow has a radiometric age of 596 million yr (obtained by Francis Macdonald at UC Berkeley). The age of the lava was determined by the measurement of uranium and lead isotope ratios in tiny zircon (zirconium silicate) crystals. With time, uranium decays to lead and the ratios change, allowing for an age calculation. - For more on how rock ages are determined see: RockAges.

Map CS-2


N
DCR Yard
Whip Hill
Greenwood Park
Pond Street
0 15 30 60 90 120 150 180 210 240 270 300
Meters
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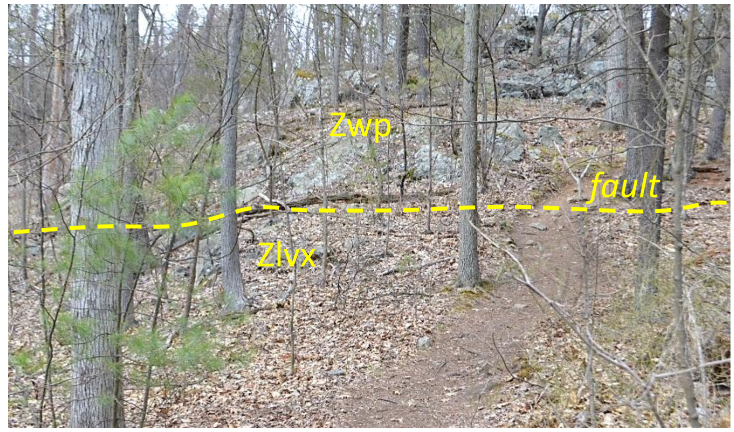
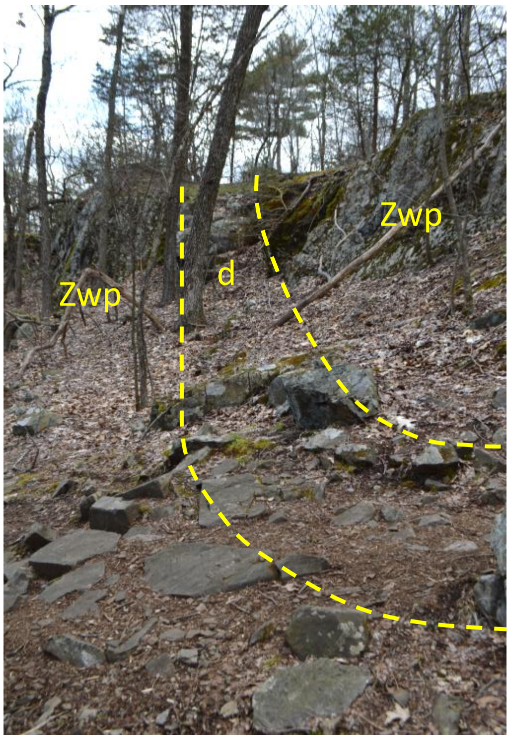
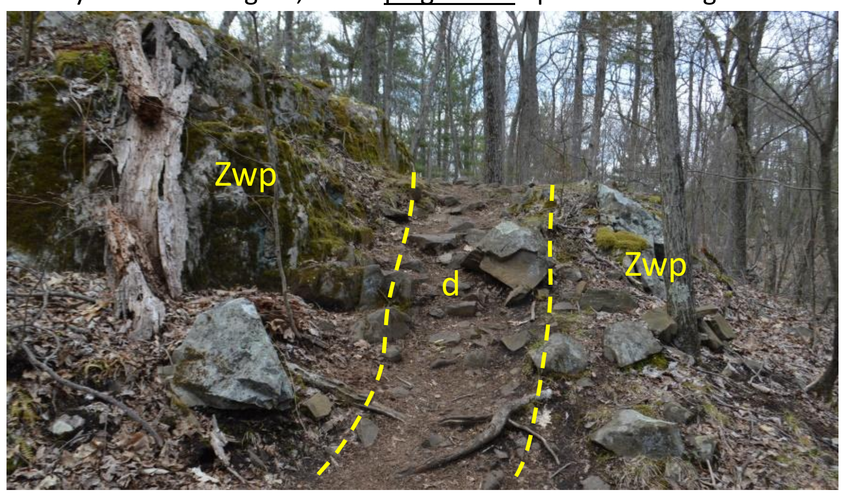
After a brief turn to the west (left) along the road, the trail continues north (right) toward Whip Hill.



STOP 8: After crossing a small fault valley, the base of the far hill has the contact of the Wakefield Fm. (Zlvx) and a new section of the Westboro Formation in the Whip Hill area (Zwp). At this location, the contact occurs along a minor fault. The Westboro Formation on Whip Hill is described more fully a few stops from here. The Wakefield at this location is a welded crystal tuff and is highly fractured in the valley along the fault. The low, irregular terrain to the east (to right in low area adjacent to road) has more exposures of the volcanic rocks.



STOP 9: A short distance up the hill, the trail passes a bending dolerite dike (dp). The dike is about 1.5-2 m wide, starts as E-W trending on the west (left) side of the trail (image to left) and then bends to follow the trail north (image below, view north). The dike is porphyritic in places, meaning that the fine-grained dolerite has a set of distinctively coarser crystals in it. The crystals are elongate, white plagioclase up to 5 mm long.

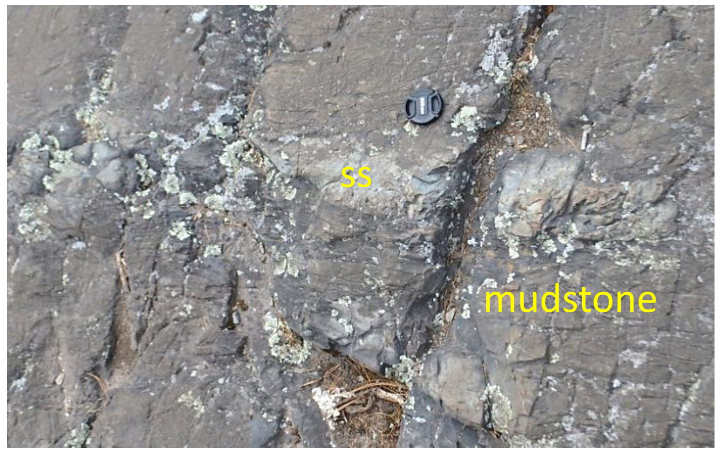


After following the dike, the trail bends to the west (left), leaves the dike, and heads toward the top of Whip Hill. The trail then crosses a small N-S trending fault that follows a ravine to the south (left). Continue to the top of Whip Hill.

STOP 10: Just where the trail arrives at the top of Whip Hill and begins to pass through some cedar trees, the Westboro Formation (Zwp) is intruded by a thin (~5 cm wide) rhyolite dike. This dike is difficult to see because of lichen cover (image to right, arrow). Dikes of this type, which are mostly wider than this one, are common across the top of Whip Hill. The top surface of the dike is higher than the surrounding Westboro Formation, which has weathered more rapidly. The top surface of the dike is highly polished and has fine glacial striations oriented at S30°E. The striations indicate the direction in which ice slid across the top of the hill during the last glaciation when ice covered the land surface here about 35,000-17,000 years ago.

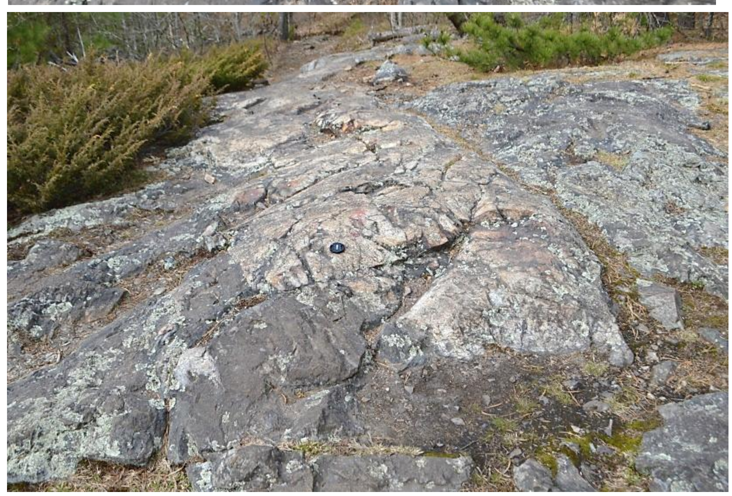
Follow the trail north for another 40-50 m to the highest point of Whip Hill.

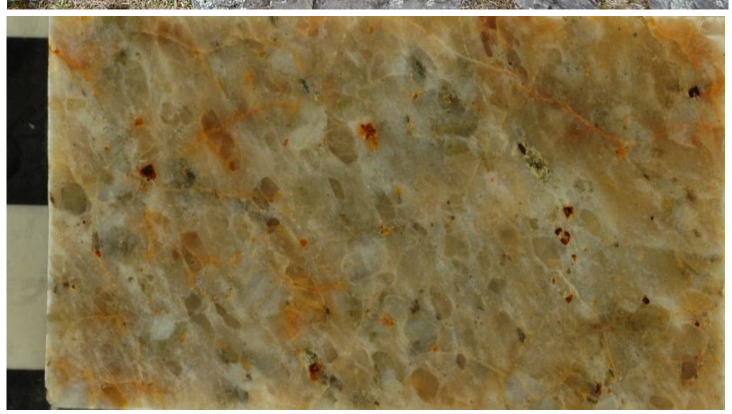
STOP 11: The high point is a good place to see some of the internal structures of this sedimentary part of the Westboro Formation (Zwp). Within the Westboro here are large blocks of light gray quartz sandstone (ss) surrounded by rusty, dark gray mudstone (image below left). The sandstone blocks do not have sharp or flat boundaries and sometimes display pinched ends, indicating that they were soft when they were deposited in the mudstone (image below right). The sandstone masses are sometimes very large, up to many meters across. The mudstone either has no distinct bedding or it has well preserved thin bedding (lamination) that may contain sandy layers. The Westboro is mostly made of what were originally poorly or non-cemented sandstone blocks in muddy debris flows formed along an ancient continental slope where they slid into deeper water. A key thing to observe here is that, although the unit has deformed sediment, it was sediment that was deformed when it was soft and not solid rock yet. It was not solid rock that was deformed by regional metamorphism. Unlike the Westboro Formation south of the Lynn Volcanic Complex seen earlier and in Virginia Wood, it is not regionally metamorphosed with cleavage, except where it is deformed near faults, and is generally only altered where it is baked next to dikes.



Continue to the north end of the hilltop where the slope starts to descend.

STOP 12: At this point is one of the strangest rock units in the Fells (image on right). At first this looks like a slightly rusty sandstone unit with rounded grains up to 3 mm in diameter. However, viewed in a microscope the rock has a puzzling texture, but it is clearly igneous. It is a rhyolite dike with rounded crystals of quartz and feldspar in surrounding finely intergrown quartz and feldspar (image below right). The rounded grains are crystals picked up by the magma from a coarse, granitic igneous rock unit. After the crystals were incorporated into the magma, they started to get absorbed by melting, leading to their very round shapes. The dike presents a second puzzle as to how it was emplaced in that it appears to have pinched ends. It appears to have squeezed between layers in the sedimentary units of the Westboro. A third surprise is the presence of small fluorite (calcium fluoride, CaF_2) crystals in the dike. These are clearly seen in a microscope, but you may be able to see them on the outcrop as small (1 mm or less) square crystals with red to brown oxide coatings (image to right).



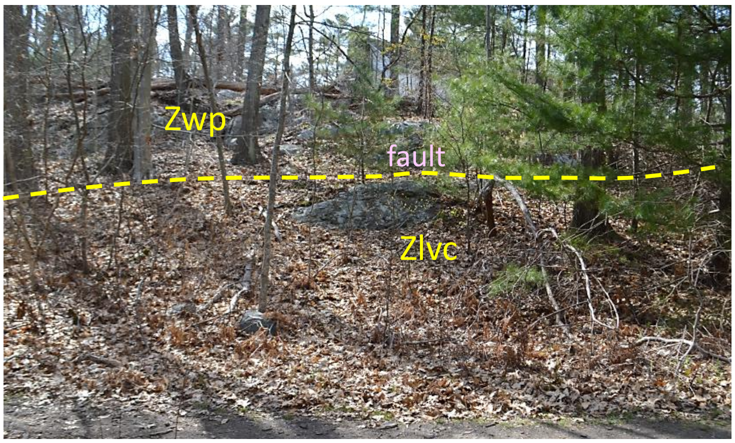


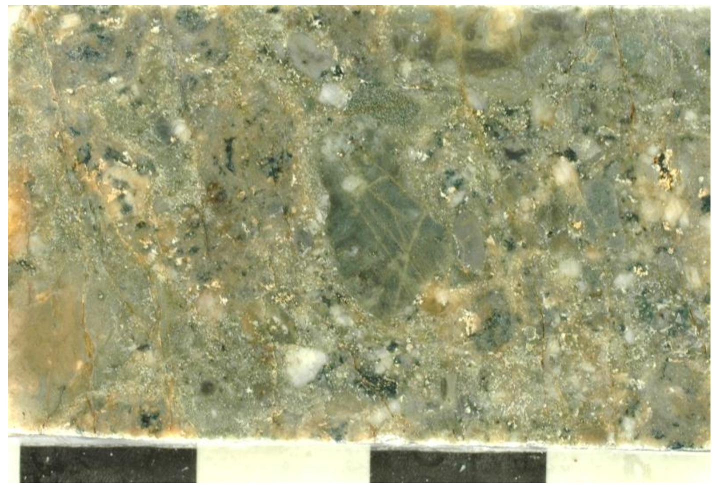
The exact age of the Westboro Formation is not known but by measuring uranium and lead isotope ratios in zircon crystals we can calculate the ages of sand grains in the unit. These grains are from older igneous rocks, so the age of the youngest sand grain (~910 Ma) represents the oldest possible (maximum) age for the Westboro. In the western Fells the intrusion of the Westboro by the Spot Pond Granodiorite (609 Ma) represents the youngest possible age for the Westboro.

Follow the trail down hill and cross a trail at junction F2-1. Continuing northwest the trail descends Whip Hill through some knobs of quartz sandstone and arrives at Whip Hill Path at junction E2-10. The trail then crosses a wetland.

STOP 13: The wetland sits on a major fault zone that displaces rocks on opposite sides of the valley (no image). Rocks in the valley are heavily fractured and were eroded faster than adjacent rocks. The true displacement direction on the fault zone remains uncertain because there is no way to gage vertical movement that may have occurred.

STOP 14: When the trail reaches the far side of the fault valley at junction E1-2 it faces a hill slope (image below left is a little bit south of the junction) that has a fault contact of the Westboro Formation (Zwp) and the Wakefield Formation in the Lynn Volcanic Complex (Zlvc). The volcanic rock here is a volcanic breccia or conglomerate which is pebble-sized pieces of volcanic rock in a finer matrix of mostly sand-sized particles (image below right). This appears to be a sedimentary rock (conglomerate) composed of mostly reworked volcanic but also other materials including sandstone and granite. The Westboro across (west of) the fault has bedding that dips to the west-northwest. It also has small crossbeds (beds within a thicker bed that dip from the top to bottom of the thicker bed) that indicate that the rock formation is right side up (center of image below on right at arrow). The fault between the two units appears to be splinter off the main valley fault and nearly vertical.





After heading south (left) at junction E1-2 the trail comes to a wooden walkway over a wet area.

STOP 15: On the map you will see that at the wet area the trail crosses two slots. The first slot is a minor fault and the second is a major fault, both displacing the Westboro Formation (Zwp). The second slot has a fault with very significant displacement but just how much is unknown because it has not been possible to assess vertical movement on this fault. It splits away from the fault zone beneath the large wetland to the east.

Continue on the trail about 100 m.

STOP 16: The trail passes a ledge of light gray deformed sandstone in the Westboro Formation (Zwp, image to right). The Westboro here is sheared and deformed more than in other areas in the Whip Hill area because it sits along the fault seen at Stop 15.

Continue up an incline to the south. Just before entering the large artificial fill deposit (af, see map CS-2) the trail crosses another outcrop of sandstone. After crossing the artificial fill area, the trail descends to Whip Hill Road at junction E2-1. Follow Whip Hill Road southeast (left) for 25 m. At this point turn southwest (right) where the trail cuts away from the road toward Greenwood Park (playground area).

STOP 17: Just before the opening in the stone wall at Greenwood Park there are some highly fractured and scattered outcrops of crystal tuff in the Wakefield Formation (Zlvx, image to right). This formation underlies the low area of the park beneath the artificial fill and the Stone Zoo across Pond Street. Outcrops of this formation are poor because it is highly fractured, and it was easily eroded during glaciation. Fracturing is due to an E-W trending fault that runs along the base of the hill made of the Westboro Fm. just to the north.

At the base of the steep slope to the north (right) with lightly baked Westboro Formation (Zwp) above it (image to right) is a rhyolite dike (fp) that is barely exposed. At the base of this slope is the E-W trending fault discussed above like the fault at Stop 8.

After entering the playground area and at the southern end of the wall, you will see a few large boulders of the Lynn that were cleared to make the park. The wall is made of many boulders from dolerite dikes and coarse rocks from the Spot Pond Granodiorite that do not occur here and were brought in for construction of the wall.

Continue the Tour on Map CS-1

Cross the playing fields (straight across the center) to the forested area south of Greenwood Park and the base of Saddleback Hill at junction E2-2.

STOP 18: At the base of Saddleback Hill is a badly shattered outcrop of metamorphosed Westboro Formation (Zvwq) that is mostly fractured argillite (image to right). Scattered about are boulders from the Wakefield Formation, dropped off by southward moving glacial ice. These boulders are true glacial erratics since they were moved to a different bedrock unit than the one from which they are derived.

The tour continues south up Saddleback Hill and passes junction E2-3 to E2-4. Take a right (west) at E2-4, which takes you to the top of a steep hill overlooking Spot Pond above Pond Street to the west.

STOP 19: At the top of the hill is a view west through the trees to Spot Pond and below is Pond Street. The trail follows the contact of the west side of a 5-m wide dolerite dike (d) and the Westboro Formation (Zvwq, image to the right). The Westboro is <u>baked</u> in this area and does not show fractures and cleavage very well. The N-S trending dike has large (up to 1 cm) <u>vesicles</u> (gas bubbles). The best view of Spot Pond is 10-15 m west (to right) of the hillcrest shown on the image. Beneath this hill on Pond Street is a long exposure of the Westboro Formation that is easily seen driving along Pond Street (panoramic view, top of next page).

The trail follows the dike before descending to the west (right) downslope and eventually circling around to the east side of the hill and rejoining Saddleback Path at junction E2-5.

Panoramic view of the Westboro Formation outcrop along Pond Street below Stop 19. This is a view to the east from the sidewalk along Spot Pond. This exposure has deformed zones with calcium-magnesium silicate minerals including the minerals tremolite, diopside, zoisite, and calcite. The rock units were likely a sedimentary rock sequence of sandstone and mudstone that had an appreciable amount of magnesium and calcium carbonate minerals.

Take a right at junction E2-5 on Saddleback Path heading southeast down Saddleback Hill. At junction F2-4 a small trail branches east (left) and Saddleback Path continues south.

STOP 20: Above on the steep slope of Saddleback Hill the metasandstone and argillite in the Westboro Formation (Zvwq) are sheared and deformed like at Stop 3. Metasandstone layers have been pulled apart into pods and are surrounded by cleaved argillite. The image to the right is from the steep face to the north. (I don't advise going up there). Note the pinched end of the metasandstone pod. The cleavage developed parallel to original bedding in the argillite. Cleavage planes here dip steeply to the north.

To get back to the parking lot where this guide started, either:

1) **continue south on Saddleback Path to the sidewalk on the north side of Pond Street. The sidewalk will take you east (left) past Gate no. 41 to where the Crystal Springs Trail crosses Pond Street, or alternatively,**

2) **follow the small trail at junction F2-4, which heads southeast to Crystal Spring Road at junction F2-5. The mound of glacial sediment that this trail crosses is likely a remnant of a glacial end moraine. End moraines are piles of sediment left behind at the margin of the retreating glacier. At junction F2-5 follow Crystal Spring Road south (to right) to the sidewalk along Pond Street at Gate no. 41 and head east (left) to the Crystal Spring Trail.**

The parking lot at the start of the tour is across Pond Street from the Crystal Spring Trail at Gate no. 42. Part 2 of tours in this area (Virginia Wood Tour), on the combined Virginia Wood and Spot Pond Brook Historic Trails, begins at this parking lot heading southwest as described in the Virginia Wood (Part 2) guide.

Here are more detailed explanations of some things discussed on the Crystal Springs tour:

For more on how plutons form see: Plutons.
For more on how rock ages are determined see: RockAges.
For more on unconformities see: Unconformities.