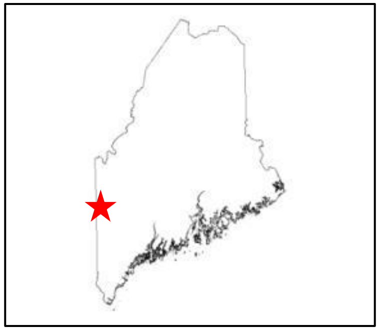
Geologic Site of the Month

November, 2001

Glacial and Postglacial Geology of Grafton Notch State Park

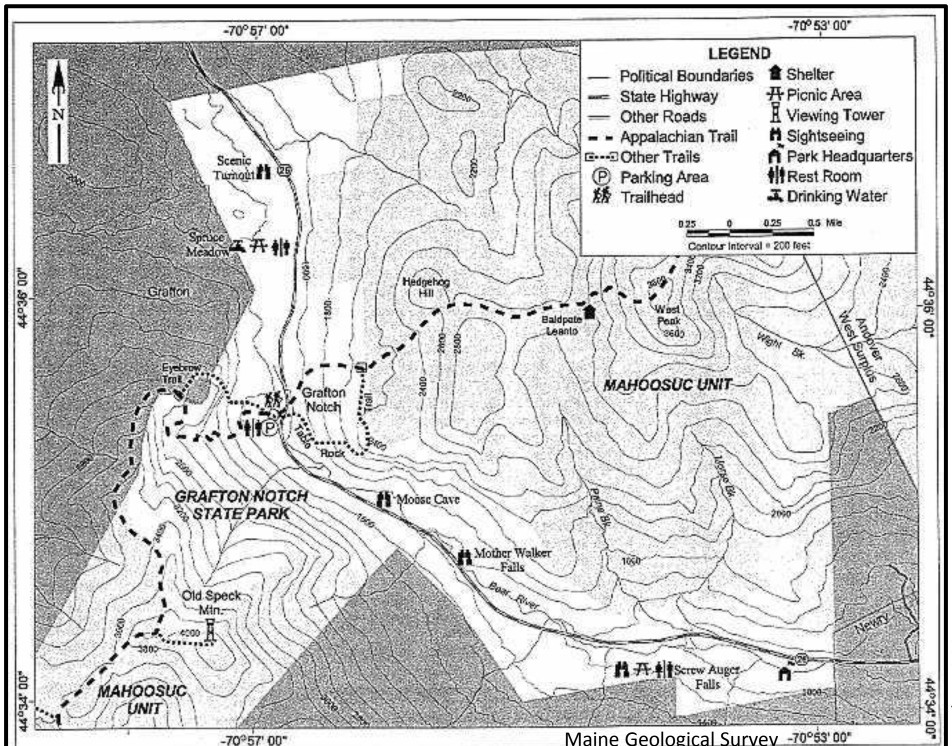


44^{o} 35‘ 36.21“ N, 70^{o} 56‘ 52.27“ W

Text by
Woodrow B. Thompson

Introduction

Grafton Notch State Park (Figure 1) has a spectacular combination of scenery and geology, with landforms illustrating the power of glacial ice and running water in shaping Maine's landscape. Deeply eroded glacial valleys, high cliffs, narrow stream gorges, and potholes are among the striking features that can be seen within the park. These sites are easily accessible along Route 26, with parking and trails conveniently located for group field trips.



Map by USGS

Figure 1. Map of Grafton Notch State Park.

Logistics

The geology of the park also raises some challenging questions concerning the age and origin of Screw Auger Falls and the other waterfalls and gorges seen on this trip. These features are not well understood (even by geologists working in Maine!), so they lend themselves to thought-provoking discussions among teachers and students.

Permission: The park is maintained by the Bureau of Parks and Lands, Maine Department of Agriculture, Conservation and Forestry. No permission is required to visit. Further information is available from the park headquarters (207-824-2912, May 15 - October 15) or the regional office (207-624-6080, year-round).

Location: Grafton township, in the Old Speck Mountain 1:24,000-scale quadrangle. Route 26 is the only highway through the park. Topographic map coverage for approaches to the park is provided by the Bethel, Puzzle Mountain, and B Pond quadrangles. The latter maps also are useful for interpreting glacial and postglacial landforms in the region.

Access: There is ample parking for cars and buses in designated parking lots at the sites described here. If the lots are not crowded, it is usually possible for buses to park and continue without having to turn around. Trails lead to the specific points of interest. Picnic and toilet facilities are available at Screw Auger Falls and Spruce Meadow Picnic Area.

Group size: Large.

Logistics

Exposure: Several sites described here are waterfalls and gorges along the Bear River. Caution is necessary in these places! Wear shoes with good traction, stay behind guardrails, and avoid steep or slippery places on ledges next to cliffs and fast-moving streams. Leaders should scout the stops prior to their field trips. Most of the park is wooded, and gorges are in deep shade for much of the day (fast film recommended for cameras).

Sampling: Not allowed in State Parks. Use notebooks and cameras to record scenery and geological features.

Directions: Take Route 26 directly to the park from points in southwestern Maine or northernmost New Hampshire. From the east or west, take U. S. Route 2 to Route 26 and go north on this road to the park. See map and road log for specific locations of sites described here.

Geologic History

The bedrock in Grafton Notch State Park consists of metamorphic rocks of Silurian age that were intruded by granitic igneous rocks. To see much of the metamorphic rocks, it is necessary to hike up onto Old Speck Mountain and other peaks of the Mahoosuc range to the southwest. Since the present trip is mainly concerned with glacial features, these rock formations will not be discussed in detail here.

The gorges and waterfalls along Route 26 are developed mainly on granite, though there may be local inclusions of metamorphic rocks. This granite was mapped as part of the New Hampshire Plutonic Series by Milton (1961). More recently it was assigned to the Mooselookmeguntic batholith, a large rock body formed during the Devonian Period (Moench and others, 1995). Some of the granite is very coarse grained - a variety known as pegmatite - with large masses of quartz, feldspar, and mica.

Grafton Notch is located on the drainage divide between the Bear River to the south and Swift Cambridge River to the north. At its highest point, the floor of the notch is about 1550 feet above sea level. The notch is a classic example of a U-shaped valley carved by glacial ice. The most recent glaciation in this area began about 25,000 years ago, when the Laurentide Ice Sheet advanced from Canada into Maine (Marvinney and Thompson, 2000). This glacier became thick enough to cover Maine's highest mountains as it flowed slowly across the state for thousands of years.

Geologic History

It is possible that at one or more times prior to the invasion of the Laurentide Ice Sheet, small alpine glaciers may have existed high on the side of Old Speck Mountain and other nearby peaks, as proposed by Caldwell (1974, 1975). This author has identified several basins that he interprets as cirques carved on the mountainsides by local glaciers. There is no other published information relating to cirques on these mountains, though larger and better-known examples may be seen on other Maine peaks such as Mt. Katahdin and the Bigelow Range (Borns and Calkin, 1977; Davis, 1999).

Abrasion at the base of the Laurentide Ice Sheet, together with the freeze-thaw action of glacial meltwater, eroded the bedrock in Grafton Notch and carved the general form of the valley seen today. Removal of large blocks of rock was facilitated by intersecting networks of cracks (joints) that already existed in the bedrock. Water seeped into these cracks and froze, exerting great pressure that helped loosen the rock to the point where the moving ice could detach it and carry it away. This process most likely formed the impressive overhanging cliff called "The Eyebrow" on the west side of Grafton Notch.

Geologic History

In addition to sculpting the broad features of the park landscape, glacial erosion smoothed the surfaces of individual bedrock ledges in exposed locations such as mountain tops. Sand particles and rock fragments were dragged over the ledges under great pressure at the base of the glacier, "sand papering" the rock surface until it was flat and smooth. Individual rocks dragged across the ledges produced parallel scratches. The narrow ones are called striations, while the deeper and broader furrows are called grooves. Weathering has destroyed these glacial marks on most rock surfaces near Route 26, but hikers can still see remnants of grooves on the high mountain ledges (Figure 2).

Photo by Tim Stone

Figure 2. Glacial grooves on ledge along the Appalachian Trail north of Mahoosuc Arm. The grooves run top-to-bottom across the photo. The intersecting diagonal lines were produced by uneven weathering of harder and softer rock layers.

Geologic History

Eventual climatic warming caused the ice sheet to become thinner, and in western Maine the edge of the glacier retreated back toward Quebec. The earliest drainage of meltwater from the ice occurred in tunnels in the bottom part of the glacier. This tunnel drainage may have existed even when the ice was still very thick over the state. The paths of the tunnels are now indicated by ridges of sand and gravel (eskers) that were deposited in them by subglacial streams. One such esker system trends up the Swift Cambridge River almost to Grafton Notch. It is absent along the steep upper portion of the Bear River valley, and then reappears farther down the valley near Route 2. Part of this esker ridge can be seen east of Route 26, just after turning north from Route 2 (Figure 3).

Photo by Woodrow B. Thompson

Figure 3. Esker ridge in Bear River valley.

Geologic History

The Surficial Geologic Map of Maine (Thompson and Borns, 1985) shows that the eskers form large branching networks, each of which converges toward the coast (Borns, 1981). This pattern suggests that an integrated and simultaneous subglacial drainage network may have extended from central to coastal Maine (Ashley and others, 1991). The esker system that passes through Grafton Notch can be traced discontinuously southeast through the South Paris area to large sandy deltas that formed where the glacial stream poured into the ocean in Gray. (The sea extended much farther inland in late-glacial time, due to lingering depression of the land by the weight of the ice sheet.) The courses of the eskers were determined largely by a pressure gradient that decreased in the direction of thinner ice. This pressurized "plumbing system" was so influential that in places the subglacial streams departed from valleys and flowed uphill through gaps in the mountains in order to take a more direct route to the south edge of the ice sheet!

Geologic History

As the margin of the Laurentide Ice Sheet receded toward Grafton Notch, a torrent of meltwater rushed out of the glacier and down the Bear River valley (Figure 4). The meltwater stream carried much sediment that washed out of the ice. Some of it was deposited along the valley bottom as sand and gravel outwash.

Photo by Woodrow B. Thompson

Figure 4. View looking up the Bear River valley from Puzzle Mtn. Old Speck Mtn. and Grafton Notch are in the distance.

Geologic History

Gravel pits excavated in this material often show nice layering and variations in coarseness due to the sorting action of running water (Figure 5). Outwash deposits have flat upper surfaces at elevations higher than the modern river flood plain. Intermediate levels, known as stream terraces, are preserved in some places. These formed in postglacial time as the Bear River progressively cut down through the outwash, ultimately reaching its present position.

Photo by Woodrow B. Thompson

Figure 5. Well-stratified glacial outwash exposed in gravel pit in the Bear River valley.

Geologic History

Southeast of Grafton Notch, the Bear River has cut deep gorges and potholes into bedrock at Screw Auger Falls, Mother Walker Falls, and Moose Cave. Many interesting geologic features (described in the itinerary) can be seen at these localities. The fundamental questions are how and when were the gorges eroded? Did they form mainly during glacial retreat, when a torrential meltwater stream poured down the valley, or has a substantial amount of downcutting occurred in postglacial time? These questions are considered below in the interpretive section.

As the glacier margin retreated north from the highest part of the notch floor, it was now in the valley of the Swift Cambridge River. The normal northward drainage in this valley was blocked by the ice, so water exiting the glacier was trapped between the ice margin and Grafton Notch. It rose to the level of the notch, through which it spilled out to the south and down the Bear River. The existence of this ancient ice-dammed glacial lake, known as Lake Cambridge, was recognized by geologists in the 1930's (Leavitt and Perkins, 1935). Continuing ice retreat opened later outlets for Lake Cambridge at lower elevations, causing the lake to drain east into the Ellis River basin and finally west into the headwaters of the Androscoggin River (Thompson and Fowler, 1989).

Interpretation

It is uncertain why the glacial erosion became so intense in Grafton Notch. Perhaps the flow of the ice was focused here by preexisting topography, or maybe a weakness in the bedrock favored erosion in this area. Once the ice stream was established through the notch, glacial flow would have continued to be concentrated in the valley, like water going through a funnel. The carving of the notch may have begun during earlier episodes of glaciation, prior to coverage by the Laurentide Ice Sheet.

To estimate the time of glacial retreat, the ages of organic material from the bottoms of ponds in western Maine have been determined by the radiocarbon dating method. This technique is based on the known rate of decay of radioactive carbon-14 in fossil plant and animal remains. Laboratory measurement yields ages in "radiocarbon years", which can then be converted into actual calendar years. The ages of plant and insect debris in lowermost pond muds (deposited soon after the glacier departed) suggest that the ice sheet retreated from Grafton Notch about 12,800 radiocarbon years ago, or about 15,000 actual years ago. Given the small number of sample sites across the region, this age should be regarded as very approximate!

Interpretation

A problem in understanding the recent geology of Grafton Notch State Park is to determine how and when the gorges and potholes formed along the Bear River. The processes by which rivers erode bedrock are complex and difficult to model numerically. Studies of modern streams indicate that river incision may occur by plucking along joints, bashing by the sediment load tumbling along the stream bed, abrasion by the suspended sediment load, and through a poorly documented process called cavitation (Whipple and others, 2000). Cavitation occurs when air dissolved in the stream water spontaneously forms bubbles in zones of lower water pressure. If the water then enters a higher-pressure zone, the collapse of these bubbles may explosively impact the rock surface on the stream bed.

It seems likely that cutting of the gorges would have occurred mostly when glacial ice remained in the valley. Subglacial streams carrying a heavy sediment load under great pressure could have started cutting into the bedrock, especially if the rock was fractured or otherwise weak. This process would have been intense when the esker tunnel passed through Grafton Notch, but erosion by meltwater streams discharging from the front of the ice would have continued as the glacier receded through the notch. In other parts of New England, some large potholes occur in places where they must have been cut entirely by glacial streams. One example is the series of potholes up to 42 ft deep at Pulpit Rock Conservation Area in Bedford, New Hampshire (Hildreth and Moore, 1996).

Interpretation

Except during floods, the modern Bear River probably does not have a volume of water or sediment nearly as large as the glacial stream. However, well-rounded stones are found in river potholes today, where they swirl around during floods and contribute to further erosion of the potholes. Brewer (1978) inventoried the gorges in Grafton Notch State Park and elsewhere in Maine. He concluded that Screw Auger Falls resulted from glacial stream incision, while the gorges at Moose Cave and Mother Walker Falls may have formed by both glacial and postglacial stream erosion exploiting faults or other structural weaknesses in the rock. However, the rates at which these gorges are continuing to deepen remains unknown.

Suggested itinerary, activities, and discussion questions

The following itinerary gives cumulative mileages starting at the junction of U. S. Route 2 and Route 26. Mileages are given to nearest 0.05 (1/20) mile.

0.00 From jct. of Rtes. 2 and 26, go north on Rte. 26.

0.10 Note the Bear River flood plain on the left and a slightly higher river terrace on the right. The coarse gravely sediment comprising the terrace is exposed in a low bank next to the road. An esker ridge can be seen several hundred feet to the east (Figure 3).

8.55 Park entrance marked by road sign. The road is on the Bear River flood plain here. When leaves are off the trees, a slope covered by bouldery till appears in the woods north of the road. Till is pulverized rock debris deposited directly from glacial ice, with little or no subsequent reworking by meltwater. It is very commonly seen on hill slopes in Maine and often expressed by surface boulders (except where they have been gathered into stone walls!).

Suggested itinerary, activities, and discussion questions

9.55 Turn left into parking lot for Screw Auger Falls (Figure 6). Caution: it is not recommended to venture downstream past the guardrail. The area around the lower end of the falls is steep and uneven. Safety concerns vary with the time of year. The falls are spectacular during periods of snowmelt or following heavy rain, but this is also when greatest caution is needed!

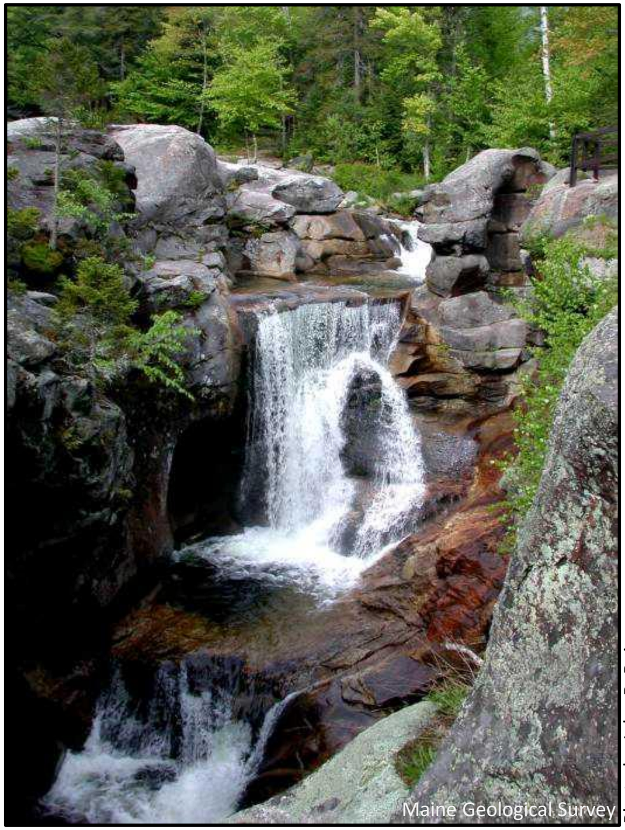


Photo by John B. Poisson

Figure 6. Screw Auger Falls

Suggested itinerary, activities, and discussion questions

The ledges above the falls are nicely waterworn and show pegmatite veins cutting the granite bedrock. This is a good place to discuss bedrock geology and try to determine age relationships between multiple cross-cutting pegmatites and other features. *What minerals can be identified in the coarse pegmatite?*

During periods of low water, it may be possible to investigate the rock basins more closely. Look for well-rounded stones that have been worn smooth by swirling around in the stream. *Is sand or gravel dominant in the stream bed? Can you find types of rock in the stream that differ from the local bedrock in the ledges? How might these stones have gotten here?*

Suggested itinerary, activities, and discussion questions

Where the guardrail starts at the head of the falls, note the round potholes worn into the rock (Figure 7). There is also a natural bridge where the side of a deep pothole has been breached. Although there are two such bridges in the park (the other being at Mother Walker Falls), this is a very rare feature in Maine. Some very deep potholes occur in the main gorge. Discuss the origin of the potholes and natural bridge. *When and how might they have formed?*

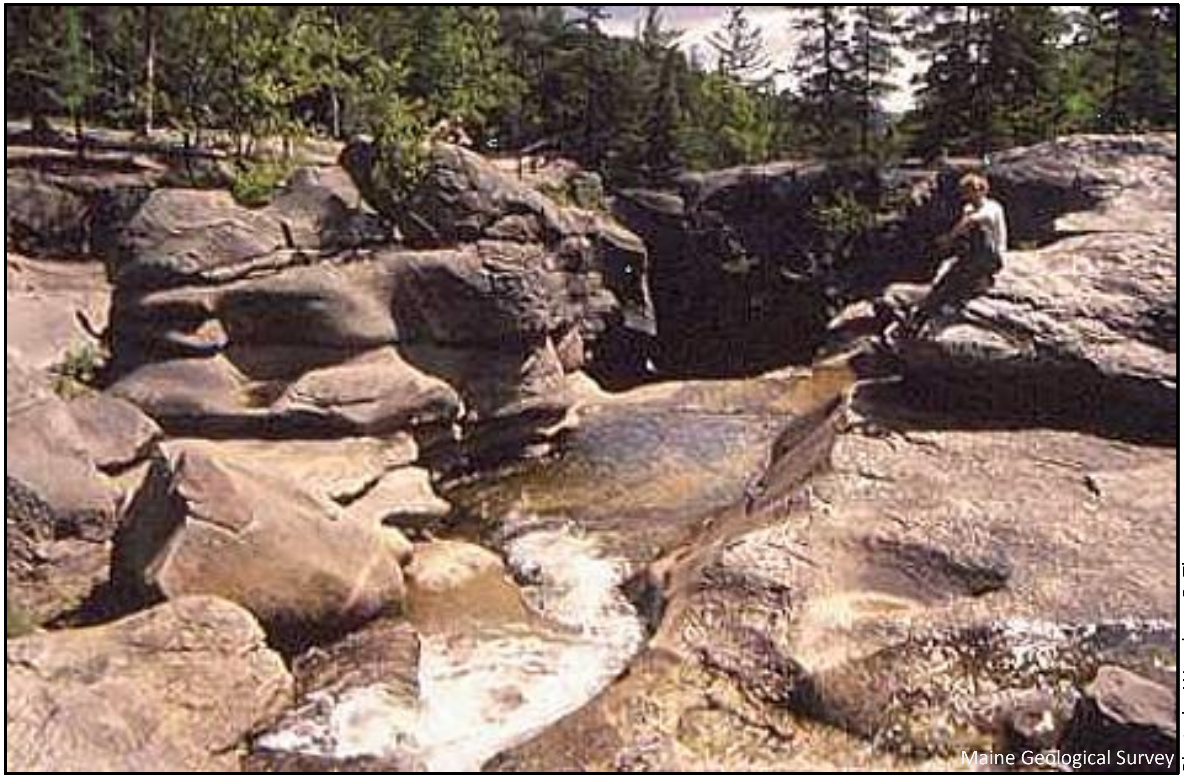


Photo by Woodrow B. Thompson

Figure 7. Intersecting potholes at head of Screw Auger Falls.

Suggested itinerary, activities, and discussion questions

9.65 Reenter Rte. 26 at west end of parking area and continue up the valley.

10.75 Parking area on right for Mother Walker Falls. According to Brewer (1978) the gorge at Mother Walker Falls is about 1000 ft long, up to 40 ft deep, and has a series of cascades with a total drop of 100 ft. The parking lot offers a good view of glacially eroded cliffs on the side of the valley northwest of here.

From the parking area, the trail to the left leads to the upper end of the falls, where you can see an abandoned stream channel cut in bedrock and waterworn ledges. There is also a natural bridge at this end of the gorge (Brewer, 1978). You have to be in the stream to see it, so this feature may not be safe to view except during times of low water. The trail to the right goes to an overlook at the lower end of the falls. (Caution: no guardrail here!). Nice exposures of coarse granite pegmatite veins occur in a rock face along the uphill side of this trail. There is also a pegmatite vein in the ledge next to the viewpoint at the end of the trail. You can see good horizontal joints in the cliff face directly across the gorge from the overlook. This is a type of fracturing called sheet jointing, which probably has resulted from stress release in the earth's crust due to erosion of overlying rock. Similar joints are exposed in New England granite quarries, where excavations show that the spacing of the joints increases with depth below the ground surface. *Can you see joints with different orientations in the bedrock at Mother Walker Falls? What other geologic processes might have fractured the bedrock?*

Continue northwest on Rte. 26.

Suggested itinerary, activities, and discussion questions

11.55 Parking area on right for Moose Cave. Note excellent views of glacially eroded cliffs on both sides of the notch. From the parking lot, a trail goes down through the woods to the gorge, passing boulders that probably were left by melting glacial ice. You will soon come to a deep narrow cleft in the bedrock, through which the Bear River passes (Figure 8). (Caution: no guardrail in most areas - don't get too close to the edge!)

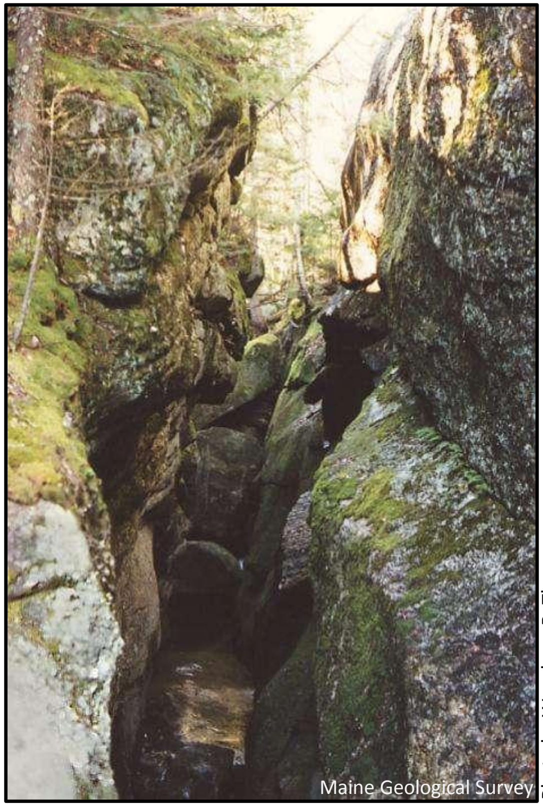


Photo by Woodrow B. Thompson

Figure 8. The gorge at Moose Cave.

Suggested itinerary, activities, and discussion questions

A park sign informs us that the Moose Cave gorge is 600 ft long and 50 ft deep. Huge slabs of rock have detached from the hillside and fallen into the gorge, and in places the brook disappears under them. Brewer (1978) speculated that the gorge may have developed along a fault in the granitic bedrock, but this origin has not been confirmed. Major faults in Maine are sometimes marked by prominent quartz veins or zones in which the rock is greatly broken and contorted (shear zones). *Do you see any evidence of faults in the vicinity of the gorge?*

The questions concerning the age and origin of the gorge at Screw Auger Falls likewise apply to Moose Cave. *Geologists would also like to know whether past stream erosion at this site was limited to the narrow confines of the gorge, or did it affect a broader part of the valley floor?*

Suggested itinerary, activities, and discussion questions

These mysteries become more intriguing when we examine some quartz veins near the gorge. Starting at the stairway landing that looks down on the park sign at the "cave", walk back up the trail (west) about 20 ft. At this point, there are pods of white quartz in the ledge near the trail (on the side toward the gorge; Figure 9).

Photo by Woodrow B. Thompson

Figure 9. Pods of white quartz in ledge next to Moose Cave gorge. See Figure 10 for close-up of quartz pod in front of person.

Suggested itinerary, activities, and discussion questions

Figure 10 shows one of the best examples. Look closely at the quartz and rub your fingers across it to feel how smooth it is. If you get the light at certain angles, you'll see a shiny reflection from the polished surface. This resembles the polish that often results from abrasion of rock surfaces beneath glacial ice. The similarity is even greater when you look very closely and see fine parallel grooves that appear to be glacial striations (Figure 10). These grooves trend eastward, parallel to the river. *Why do you suppose the smooth surfaces are nicely preserved on quartz, but not on the surrounding ledge surface?*

Photo by Woodrow B. Thompson

Figure 10. Close-up of polished quartz surface at Moose Cave. Pencil rubbing has highlighted dozens of narrow grooves that are parallel to the pencil.

Suggested itinerary, activities, and discussion questions

It is important to know whether the grooves were formed by glacial ice. If so, then stream erosion (regardless of whether glacial or postglacial) was restricted to the gorge, and the adjacent glacially striated surface was not removed. The trend of the grooves is more easterly than the regional direction of glacial flow (southeast), but this may simply reflect funneling of ice by the local orientation of the valley. However, it is not certain that the grooves have a glacial origin. At the site shown in Figures 9 and 10, they are shorter and less continuous than usually seen on glaciated ledges. Some of them widen slightly in the downvalley direction, having a narrow parabolic outline. These kinds of erosion marks resemble larger-scale erosional features that some geologists attribute to subglacial meltwater floods. If we assume the quartz pods indicate stream erosion, we are left with the question of why this erosion ultimately became focused along the present gorge!

Continue up the valley on Rte. 26.

11.8 Glacial meltwater channel on right side of road (no parking area here, but cars or vans can pull onto road shoulder). The flat swampy floor of this channel is typical of many other channels in Maine that were carved by water flowing out of the Laurentide Ice Sheet. The small brook that presently flows through here is disproportionate to the size of the channel, so we can infer that the channel was cut by the larger volume of glacial meltwater streams, followed by glacial lake drainage, pouring through Grafton Notch. When the glacial source no longer existed, the eroded floors of such channels remained as flat, poorly drained areas that eventually developed into wetlands.

Suggested itinerary, activities, and discussion questions

12.3 Parking area on left for Old Speck Mtn. trail. From here you can hike part way up the mountain to the top of a high cliff called The Eyebrow. This destination can be reached directly via the steep Eyebrow Trail, or by a short detour off the Appalachian Trail leading up Old Speck. At least half a day should be allowed for a hike to The Eyebrow. This vantage point provides a spectacular view to the east, looking down the Bear River valley (Figure 11). The U-shaped cross section of the valley is due to erosion by the continental ice sheet, which scooped out a large trough in the bedrock. Glacial plucking removed rock from the cliff at The Eyebrow, producing the high overhang seen today.

Photo by Woodrow B. Thompson

Figure 11. View from top of cliff at The Eyebrow, looking east down the Bear River valley.

Suggested itinerary, activities, and discussion questions

13.0 Meltwater channel (Figure 12; buses can pull onto road shoulder here, but there is no parking lot; watch for moose in this area). This is the highest part of the floor of Grafton Notch. You are on the divide between the drainage basin of Bear River to the south and Swift Cambridge River to the north. The elongate swampy area on the west side of the road is the headward end of the glacial meltwater channel seen at the previous stop.

Figure 12. Moose in glacial meltwater channel on west side of Route 26.

Suggested itinerary, activities, and discussion questions

13.3 Turn left into parking lot for Spruce Meadow Picnic Area. There is ample parking here for cars and buses, as well as picnic and toilet facilities. Follow trails through the woods for a short distance to the picnic table at the far south end of the site. There is a nice view overlooking the adjacent wetland and distant overhanging cliff of The Eyebrow to the south. (Note: if this picnic site is occupied, the next two sites to the north offer the same view.) *Discuss the origin of The Eyebrow.*

Walk north along the west side of the picnic area, rising onto a low ridge. This may be part of the discontinuous esker system that follows the Swift Cambridge valley and passes through Grafton Notch. An esker ridge is clearly present northwest of here (it appears on the topographic map), and another segment protrudes from the wetland west of the picnic area. The pebbly gravel along the paths here is typical of sedimentary material that might be seen in an esker. However, there is some question as to whether the topography at this locality is totally natural. *Could there have been a former gravel pit near the parking area, with the ridge being just a remnant of the original ground?* Human excavations have altered the landscape in many parts of the world, and old revegetated gravel pits (for example) sometimes can be mistaken as natural landforms! Even if the gravel at Spruce Meadow is not part of the local esker, it certainly was formed in late-glacial time by meltwater discharging from the Laurentide Ice Sheet.

References and Additional Information

Further information on the geology of the Grafton Notch area is available in the references listed below. Some of these are out-of-print, but may be available through interlibrary loan. Most of them can be examined in the resource center at the Maine Geological Survey in Augusta.

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