

Geology of Norvin Green State Forest,
Passaic County, New Jersey,
and Geologic Self-Guided Tour



by Richard A. Volkert and Scott D. Stanford

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New Jersey Geological and Water Survey



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Cover photo: Scenic view of Norvin Green State Forest from Wyanokie High Point (Photo by R. Volkert)

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INTRODUCTION

Norvin Green State Forest is located in a sparsely developed area of northern New Jersey in Passaic County, in the eastern part of the New Jersey Highlands physiographic province (fig. 1). The scenic and rugged area of Norvin Green State Forest is characterized by a series of generally north-trending ridges separated by broad to narrow valleys. Most of the ridges have rounded tops, many of which are open and devoid of vegetation, and slopes that are commonly steep and locally form cliffs. Ridgetop elevations range from about 900 to 1,100 feet above sea level, and are somewhat lower than the highest elevation in the Highlands of 1,496 feet on Wawayanda Mountain in Sussex County. Large areas of natural woodlands and wetlands and numerous streams further characterize the area. This pattern of landforms has been naturally shaped by geologic processes that have operated over the past one billion years.

GEOLOGIC HISTORY OF THE NEW JERSEY HIGHLANDS

Northern New Jersey, including the area of Norvin Green State Forest, has undergone a long and complex geologic evolution, resulting in the formation of a variety of rock types of varying age that are overlain by varying thicknesses of glacial and modern sediment. A geologic time scale is shown on page 4 to aid in visualizing this history.

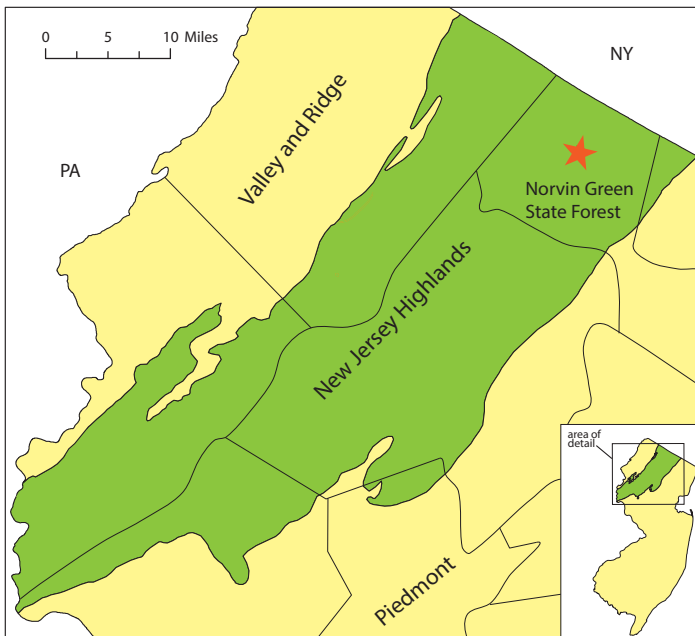


Figure 1. Map showing the location of the New Jersey Highlands (green) and Norvin Green State Forest.

Mesoproterozoic Era

The most ancient part of New Jersey, represented by the New Jersey Highlands Province, formed between about 1,300 and 1,000

million years ago during the Mesoproterozoic Era. Rocks of the Highlands consist mainly of granite, gneiss (pronounced 'nice'), quartzite and marble. Most of the gneisses were formed from sedimentary rocks such as sandstone and less abundant shale, or volcanic rocks. Quartzite formed from quartz-rich sandstone and marble was originally limestone. Some of the gneisses, quartzite and marble were deposited in an ocean basin located off of the ancestral eastern North American continent sometime between 1,300 and 1,250 million years ago. A chain of volcanic islands underlain mainly by various igneous rocks similar to the present-day Aleutian Islands in Alaska was located further off shore.

Between about 1,180 and 1,000 million years ago various gneisses, quartzite and marble were intruded by several different types of granite that had formed from molten magma pooled in large magma chambers within the Earth's crust. Today these granitic rocks underlie roughly 50 percent of the Highlands.

A little over 1 billion years ago, nearly all of the rocks of the Highlands were metamorphosed (metamorphism means to change form) under conditions of high temperature at about 770 °C (1,300 °F) and pressure of 5,500 atmospheres (80,000 pound/square inch) and at a depth of about 13 miles within the Earth's crust. This was the earliest event in the formation of the Appalachian Mountains which, during the collision of the ancestral eastern North American and South American continents, were uplifted in the Highlands to heights possibly rivaling the present-day Rocky Mountains. Rocks of the Highlands form the roots of the ancestral Appalachian Mountains and are exposed today because of erosion of the younger rocks that once covered them. Even today, most of the highest elevations in the state are in the Highlands because the rocks are fairly resistant to erosion.

Neoproterozoic Era

During the Neoproterozoic Era, from 950 until about 542 million years ago, the Highlands were uplifted and subsequently slowly cooled following their deep burial, and then underwent erosion upon reaching the Earth's surface. Sometime around 700 million years ago the ancestral North American and South American continents began to split and drift apart, creating deep fractures in eastern North America. About 600 million years ago magma from the mantle rose filling the fractures that had formed in the Highlands. Upon cooling, the magma produced diabase dikes that are common in the area of Norvin Green State Forest. As the Highlands continued to erode, some sediment was deposited in small basins that formed on land and the rest was transported to the ocean.

Paleozoic Era

During the Paleozoic Era, from 542 million to about 359 million years ago (Cambrian, Ordovician, Silurian, and Devonian Periods), most of the mountainous area of the Highlands had been eroded to relatively flat lowland that was slowly covered by a shallow ocean. Ancestral eastern North America had begun to

drift apart from South America, creating an ocean basin between them. The region remained geologically stable until part of this ocean basin was destroyed during a continental collision about 450 million years ago, and the remainder was destroyed about 290 million years ago when ancestral Africa and Europe collided with the North American continent. These collisions produced renewed uplifting and mountain building in the Highlands.

During the Paleozoic Era the Valley and Ridge Province was formed in New Jersey. Rocks of Paleozoic age do not outcrop in the area of Norvin Green State Forest, but they are present to the west and north where they underlie Bearfort Mountain and Greenwood Lake.

Mesozoic Era

The Mesozoic Era, from about 251 million to 66 million years ago, saw a new cycle of erosion from renewed uplift of the Highlands following continental collision. During the Triassic and Jurassic Periods the continents again began to split and drift apart, forming the modern Atlantic Ocean and creating deep fractures in eastern North America. In the Highlands, the Ramapo fault southeast of Norvin Green is one of these fractures. As the Earth's crust slowly dropped down along the Ramapo fault, a deep basin was created on land east of the Highlands in which large amounts of sediment were deposited from the eroding Highlands. In addition, magma from the mantle was intruded into these sediments forming diabase bodies such as the Palisades, and lava poured out onto the surface as three separate basalt flows creating the Watchung Mountains. Fish swam in lakes, dinosaurs roamed the lowland floodplains, and plants flourished. During this time the Piedmont Province was formed in New Jersey. Sedimentary and igneous rocks of Mesozoic age do not crop out in the area of Norvin Green, but some of the faults in the Highlands were possibly created, or at least reactivated, during that geologic era.

Between about 146 and 66 million years ago (Cretaceous Period), the ocean once again covered the continental margin of southern and central New Jersey depositing a thick accumulation of unconsolidated sediment that today forms the Coastal Plain Province in New Jersey. The Highlands and most of the Piedmont remained above sea level during this time.

Cenozoic Era

Throughout the Cenozoic Era (Tertiary and Quaternary Periods), continental collisions and mountain building processes had ended and the region remained relatively stable. The predominant process in the Highlands was erosion and by about 10 million years ago most of the region was once again reduced to a nearly flat surface. The present landscape has been slowly evolving due largely to stream erosion within the past 10 million years. As global sea level lowered during this period as a result of the growth of polar ice sheets, streams deepened their valleys in the less resistant Paleozoic shale and limestone sedimentary rocks and left the Precambrian rocks and Paleozoic quartzites and conglomerate rising above them as ridges. Valley deepening increased topographic relief (the vertical distance between ridgetops and valley bottoms) in the Highlands by about 500 to 800 feet between 10 and 2.5 million years ago.

Between about 2.6 million years and 21,000 years ago, during the Pliocene and Pleistocene Epochs, as the climate in New Jersey became much colder, the northern part of the state was covered by ice sheets on at least three separate occasions. During the Pleistocene, the climate alternated several times between cold and warm periods. Ice sheets advanced during the colder glacial stages, which were frigid enough to permanently freeze the ground and create a tundra type environment in New Jersey resembling that in northern Canada. Glacial ice sheets melted and receded during the warmer interglacial stages. The glaciers eroded soil and bedrock on ridges and uplands and deposited sediment in valleys, creating the final details of the landforms we see today.

The landscape continues to undergo gradual change even today as sediment is eroded from rocks and glacial deposits of the Highlands and is carried away and transported southward by local tributary streams that drain into the Wanaque River.

GEOLOGY OF NORVIN GREEN STATE FOREST

Bedrock Geology

Rocks of Mesoproterozoic age that range in age from about 1,300 to 1,000 million years underlie all of Norvin Green State Forest and the surrounding areas of the Highlands. These include various types of gneiss, granite and minor amounts of quartzite and marble. Because granite is more resistant to erosion than most of the gneiss, it forms the steep, prominent ridges that characterize the landforms of Norvin Green, such as Wyanokie High Point. Less resistant gneiss underlies the remainder of the area; therefore, steep cliffs are absent and the ridges have less elevation and slope more gently. Thin layers of quartzite and marble are exposed along the east side of Blue Mine Brook and continue south beneath the southwest corner of Wanaque Reservoir. The oldest rocks recognized in the Highlands are 1,370 million years old and they crop out in the Wanaque valley, just east of the Wanaque Reservoir.

Neoproterozoic rocks in the area of Norvin Green State Forest consist of diabase dikes that intrude the granite, gneiss, quartzite, and marble. The dikes are as much as 30 feet wide and extend for distances of as much as two miles. Some of the dikes contain pieces of the rock they have intruded. Diabase dikes are well exposed along the base of the ridge west and east of Blue Mine Brook, and in the upland areas north, east, and south of the Wanaque Reservoir.

Mesoproterozoic and Neoproterozoic faults in the Norvin Green State Forest area have formed in response to ruptures in the Earth's crust during ancestral eastern North America's intermittent collisions and separations with other continents. Because the North American continent is currently moving westward, faults in the Highlands are currently not significantly active or prone to major earthquakes.

Glacial Geology

The glacial features in the area of Norvin Green State Forest are almost entirely the product of the most recent glacier to enter New Jersey, which reached its maximum extent about 21,000 radiocarbon years ago and retreated from the state by about 18,000 radiocarbon years ago. Although the major valleys and mountains in the area were shaped primarily by river erosion during the several million years before the arrival of glaciers, nearly all of the landform details of the area are the result of glacial action. The rocky ridges and knobs formed when soil and sediment that formerly mantled the land surface were frozen onto the bottom of the glacier and then stripped away as the ice moved, exposing the underlying bedrock. Between the ridges, basins were scoured out by the glacier in bedrock that was soft or easily broken due to pre-glacial weathering. Some of these basins were created when sediment deposited by the retreating glacier formed dams across valleys. The many swamps, marshes, and natural ponds in the area now fill these basins.

The shape and form of the rock outcrops and ridges reflect the direction of movement of the glacial ice. On slopes that faced north, into the advancing ice, the glacier's base was under more pressure than on slopes that faced south, away from the advancing ice. Thus, rock on the north facing slopes was abraded and scoured by rock fragments frozen into the ice. The southerly movement of the glacier dragged the embedded fragments, which were under high pressure, against the rock. This abrasive action formed broad, sloping ledges. Rock on south and southeast facing slopes was broken into large blocks when water at the bottom of the glacier was squeezed into fractures in the rock. When this water froze, it cracked the rock into blocks and then locked them onto the bottom of the glacier. As the ice moved, it eventually removed many of the blocks, leaving behind cliffs in more resistant types of bedrock such as granite. This process provided the many boulders scattered across the area, most of which consist of granite and gneiss from local rock outcrops.

The ice dragged rock fragments across the bedrock surface, cutting grooves known as striations. Most striations have been weathered away since retreat of the glacier, but on very hard, or freshly exposed rock, they are still visible. Striations can be seen in bedrock outcrops on some ridge crests and also on some outcrop surfaces along the trails of Norvin Green State Forest. These striations indicate that ice moved to the south, or slightly east of south, as it advanced over this region.

As it moved, the glacier eroded soil and rock in some places, while depositing it in others. This material, a mixture of boulders, gravel, sand, silt, and clay, is known as till. Till can form several types of landforms, all of which are represented in, or near, the area. Drumlins are streamlined, ice molded hills composed mostly of till. They are elongated in the direction of glacier flow. Moraines are belts of ridges and swales formed where till accumulated at the glacier's margin. They mark locations where the retreating ice margin paused. Most of the area, except for rock outcrops, is covered with a thin layer of till. Soils in these areas are thin and rocky and are generally unsuitable for agriculture. Some north facing slopes have a thicker, more continuous layer of till than elsewhere because

ice was under more pressure on those slopes and melted to release more sediment. These areas of thicker till were easier to clear and farm and were commonly used for pastures and orchards.

As the glacier melted, it generated large volumes of meltwater. This water flowed in channels beneath, or along, the edge of the glacier, and down valleys leading away from the front of the glacier. The meltwater washed away sand and silt from newly exposed till, leaving concentrations of boulders in the channels as evidence of the drainage. Meltwater also carried sand, gravel, silt, and clay released from the melting ice and deposited the sediment in glacial lakes and river plains. Glacial lakes formed in valleys that sloped toward the retreating glacier, and so were dammed by the ice front, like the valley of Blue Mine Brook in the area of Norvin Green. Small hills and terraces of sand and gravel mark deltas and fans built into these lakes at the former edge of the ice. Other glacial lakes formed in valleys that were dammed by ridges of till or sand and gravel laid down along earlier ice margins, like the Wanaque valley east of Wanaque Reservoir. The lakes filled with sediment or drained as the ice retreated from the valley. On ridges and uplands, ponds filled small basins eroded into the bedrock by the glacier. Most of these ponds are now wetlands. After glacier retreated, the slow action of water and ice on cliffs and steep rock slopes pried away loose rock, which accumulated in aprons of debris known as talus at the base of the slope. These processes continue to slowly alter the present landscape of the area.

ECONOMIC RESOURCES

The local geology has played an interesting role in the development of the areas surrounding Norvin Green State Forest. For example, between 1710 and 1966, a thriving industry based on mining the iron ore mineral magnetite flourished in northern New Jersey which, during the early 19th century, led the nation in iron ore production. During the Revolutionary War, some of this ore was forged into cannonballs and other weaponry for use by the Continental Army. More than 400 mines and prospects throughout northern New Jersey were worked, producing an estimated total of 50 million tons of iron ore by the close of the industry.

The remains of two abandoned iron mines are in Norvin Green State Forest. These include the Blue mine, known also at different times as the London or Iron Hill mine, and the Red mine, known also as the Laurel, Laurel Hill, or Roomy mine lying about a half mile to the north of the Blue mine.

In addition to iron ore, minor amounts of graphite ore were mined at two locations southeast of Norvin Green State Forest, one immediately south of Wanaque Reservoir and the other near Bloomingdale. These graphite mines were active between about 1864 and 1885. The Bloomingdale mine consisted of three openings, a shallow open cut and two shafts 20 feet and 60 feet deep that were opened on a vein 16 feet wide. Graphite ore was separated and processed at a mill in Bloomingdale, one of only four mills in the Highlands that processed graphite ore.

A minor industry was also developed near Bloomingdale based on the quarrying of granite and gneiss for use as crushed stone. Small amounts of granite known as Pompton Pink Granite quarried at two

locations near Riverdale was used in 1908 during construction of the Smithsonian National Museum of Natural History in Washington D.C. A small quarry was also developed in marble south of Wanaque Reservoir, possibly for use as a flux in roasting iron ore at local furnaces. Deposits of glacial sand and gravel in the West Brook valley and the Wanaque valley were also mined for use as construction aggregate.

Postglacial geologic conditions provided favorable sites for the location of reservoirs comprising the watershed area of the Wanaque

River. These include Wanaque Reservoir to the east of Norvin Green, created in 1920 with a capacity of 29.6 billion gallons, and Monksville Reservoir to the north, created in 1985 with a capacity of 7 billion gallons. Most of the local granite and gneiss contains enough ground water in fractures to serve as an important source of water for domestic, industrial, and public-supply wells in the region. However, glacial sand and gravel deposits are even more productive sources of ground water in the valleys of the region.

Geologic Time Scale

Years Ago ¹	Eon	Era	Period	Epoch	Geology, Life, and Environment	
0 to 10,000	CEANOZOIC	QUATERNARY	QUATERNARY	Holocene	Climate change from boreal (cold)	Modern humans evolve.
10,000 to 2.6 million				Pleistocene	Northern New Jersey glaciated at least 3 times.	
1.8 to 66 million			TERTIARY	TERTIARY	Pliocene	First large mammals appear. Abundant mammals; first hominids. Grasses and modern birds appear.
					Miocene	
					Oligocene	
	Eocene					
	Paleocene					
66 to 146 million	MESOZOIC	CRETACEOUS	Late	Heyday of dinosaurs, pterosaurs and marine reptiles until their extinction at end of period. First flowering plants.		
			Early			
146 to 200 million	MESOZOIC	JURASSIC	Late	Earliest birds appear. Giant dinosaurs (sauropods) flourish. Plants: ferns, cycads and ginkos.		
			Middle			
			Early			
200 to 251 million	MESOZOIC	TRIASSIC	Late	Age of dinosaurs begins. First mammals. Mollusks are dominant invertebrate.		
			Middle			
			Early			
251 to 299 million	PHANEROZOIC	PERMIAN	Late	Age of Amphibians. Pangea forms. Greatest mass extinction ever. Trilobites go extinct.		
			Early			
299 to 359 million	PHANEROZOIC	PENNSYLVANIAN ²	Late	Widespread coal swamps. First winged insects and reptiles.		
			Middle			
			Early			
359 to 416 million	PHANEROZOIC	MISSISSIPPIAN ²	Late	Many ferns and amphibians.		
			Early			
416 to 444 million	PALEOZOIC	DEVONIAN	Late	Age of Fishes. First shark. Many diverse land plants. Earliest amphibians, ferns and mosses.		
			Middle			
			Early			
444 to 488 million	PALEOZOIC	SILURIAN	Late	Bloomsburg Red Beds Shawangunk Formation	First insects, jawed fish, vascular land plants.	
			Middle			
			Early			
488 to 542 million	PALEOZOIC	ORDOVICIAN	Late	Martinsburg Formation • High Point Member • Ramseyburg Member • Bushkill Member	First corals, moss. Primitive fish, fungi and seaweed.	
			Middle			
			Early			
542 to 2500 million	PROTEROZOIC ³	CAMBRIAN	Late	Age of Trilobites. Cambrian explosion of life occurs. First vertebrates. Earliest fish. First shells appear.		
			Middle			
			Early			
542 to 2500 million	PROTEROZOIC ³	PROTEROZOIC ³	PROTEROZOIC ³	Cold climate with three episodes of glaciation in late Proterozoic. First soft-bodied invertebrates build-up and colonial algae. Oxygen build up in atmosphere during Mesoproterozoic.		
					Neoproterozoic	
					Mesoproterozoic	
					Paleoproterozoic	
					Lower limit of Eoarchean is not currently defined. Estimated to be 4600 million years.	
2500 to 4600 million	ARCHEAN ³	ARCHEAN ³	ARCHEAN ³	Life appears. First bacteria and blue-green algae begin freeing oxygen to Earth's atmosphere. Earth molten. Sun and planets form.		
					Neoaarchean	
					Mesoarchean	
					Paleoaarchean	

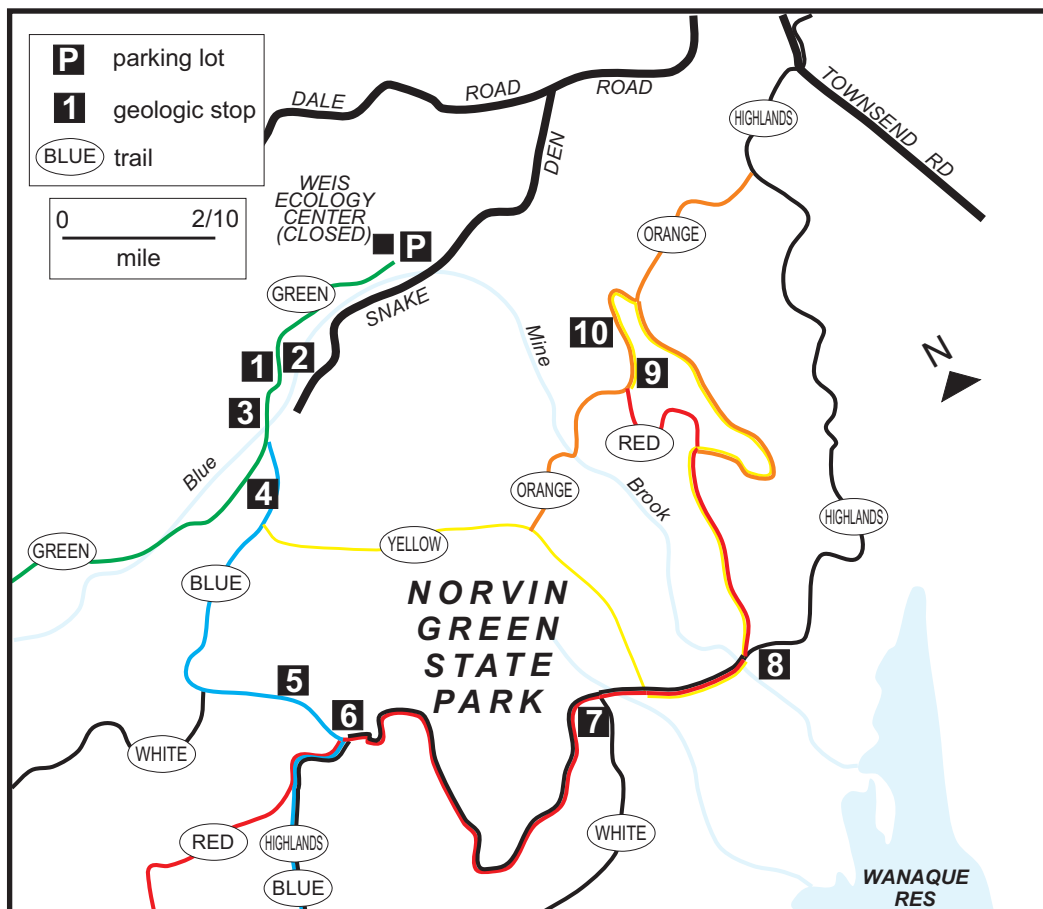
¹Gradstein, F.M. and others, 2004, A Geologic Time Scale: Cambridge University Press, 589 p.

²Pennsylvanian and Mississippian comprise the Carboniferous System.

³Also called Precambrian, a non-specific time term.

Geologic time scale (T. Seckler, New Jersey Geological Survey, 2010)

GEOLOGIC SELF-GUIDED TOUR



Map showing the distribution of trails in Norvin Green State Forest and the location of self-guided geologic stops along the trails. Numbers are keyed to stop descriptions in the text. Parking lot at the Weis Ecology Center is shown on the map by “P”.

The following stops permit a self-guided tour of locations where a particular bedrock feature, glacial deposit, or other geologic feature is best observed. The tour begins and ends at the Weis Ecology Center, where parking is available. The round trip distance of the entire tour, covering all 10 stops, is about 4 miles.

Stop 1. Glacial delta deposit (41° 04.1167’N, 74° 19.6333’W)

This hill along the orange L trail, just off the green trail, is a deposit of sand and gravel laid down in a glacial lake. The gravel, which consists of gray, white, and purple-red pebbles, is visible in the trail bed on the slopes and top of the hill (fig. 2). The gray and purple-red pebbles are known as erratics because they are not derived from erosion of the local granite and gneiss bedrock (which are the whitish pebbles), but instead were carried by the glacier from areas where Paleozoic sandstone (the gray pebbles) and quartzite (the purple pebbles) crop out north of Greenwood Lake. Meltwater washed the pebbles, and finer sand particles, from the glacier and deposited them along the front of the ice in a lake. The sand and gravel were gradually built up to the surface of the lake to form a deposit known as a delta. The flat top of the hill marks the level of the lake. When it was deposited, the east side of the hill (looking back towards the Weis Ecology Center) was banked against the front of the glacier, which filled the valley to the east and covered the adjoining hills. The glacier in this position acted as a dam across the Blue Mine Brook valley, holding in a lake that filled the valley to the west and rose to the level of a gap on the south side of the valley that served as the



Figure 2. View from top of gravel hill. Ice stood against this slope while the gravel was deposited in a glacial lake, which filled the valley up to the level of the hilltop. Photo by S. Stanford.

spillway for the lake. Lake water drained southward from this spillway into the Wanaque valley. As the glacier front retreated, lower gaps were uncovered and the lake lowered. It drained completely when the West Brook valley (along the present West Brook Road) was deglaciated.

Stop 2. Joints in gneiss (41° 04. 1000' N, 74° 19.5833' W)

Two interesting geologic features along the green trail are the structural control of Blue Mine Brook and presence of a small waterfall. Looking upstream toward the footbridge, the stream displays a slow meandering course as it flows over unconsolidated glacial sediments. As the stream encounters the outcrops of Mesoproterozoic gneiss near the cement weir, its course is strongly channeled along naturally-occurring fractures in the bedrock known as joints (fig. 3). Note the slight change in the stream's course just above the cement weir as it follows several different sets of joints. Below the weir the stream follows yet a different joint.



Figure 3. Channeling of stream along joint surface formed in bedrock. Photo by R. Volkert.

Why is there a waterfall here? Upstream from the cement weir the stream flows along a gentle gradient, but as it exits from the weir the gradient becomes much steeper because the bedrock outcrops are more resistant to erosion than the glacial sediments upstream, forming a topographic slope. The sharp change in gradient causes the water to cascade down the slope, forming a waterfall. Further downstream, near the pool, the gradient is again gentle and the falls disappear.

Stop 3. Boulder field (41° 04.0500' N, 74° 19.6333' W)

The bouldery flat that you walked across from this point near the trail sign board back to the bridge across the stream is a glacial boulder field (fig. 4). It was formed when water draining from glacial lakes, and, later, regular stream flow of Blue Mine Brook, washed sand and silt particles from till covering the valley floor. As the flowing water washes sand and silt particles away, the boulders and cobbles, which are too large for the water to move, are left behind forming a stony lag on the valley's floor. Note that the boulders are rounded in shape. This reflects the abrasion and shaping action that occurred when they were transported in the moving sand-laden ice of the glacier. The glacial waters here were sourced by lake outflows from valleys to the northwest that drained into the Blue Brook valley after lowering of the glacial lake described at Stop 1.



Figure 4. Boulder field along Blue Mine Brook. Photo by S. Stanford.

Stop 4. Talus slope (41° 04.0000' N, 74° 19.6333' W)

Climbing the combined blue and yellow trails, the abundance of angular blocks of Mesoproterozoic bedrock that drape the hillslope are a conspicuous feature (fig. 5). These blocks represent an early stage in the destruction of bedrock outcrops, such as the one here, through the process of physical weathering. Note the extent to which joints are developed in the bedrock. During colder weather, water that collects in the joints freezes and acts like a wedge to pry the joints apart. With repeated cycles of freezing and thawing, the blocks of rock detach and are transported downhill aided by gravity. They collect along the base of the slope forming an apron of talus. Note the sharp edges of the blocks and their rectangular shapes where they have become detached from the bedrock outcrop along joint surfaces. Compare their shape to the rounded shape of the rock debris at Stop 3, which has been rounded by tumbling action and abrasion during transport by flowing ice or water.



Figure 5. Talus slope downslope from bedrock outcrop. Photo by R. Volkert.

Stop 5. Balanced rock (41° 03.7833' N, 74° 19.8500' W)

The large boulder sitting on the bedrock ridge's crest (fig. 6) is a balanced rock. It rests on two small stones, with a knob of the boulder providing the third leg of support. This unusual configuration was probably created during final melting of the ice. The boulder, which is hornblende granite that was picked up by the glacier from farther down the hillslope to the north, was lowered onto the small stones as the ice melted. Similar melting processes were widespread as the glacier retreated but in most places the enclosing ice was laden with sand and silt and the boulders were let down onto till or sloping ground. Thus, boulders melting out from the ice were buried in sediment or toppled downhill. The flat bedrock ledge here, and absence of sediment in the glacier, permitted the boulder to settle into an exposed, stable balanced position.

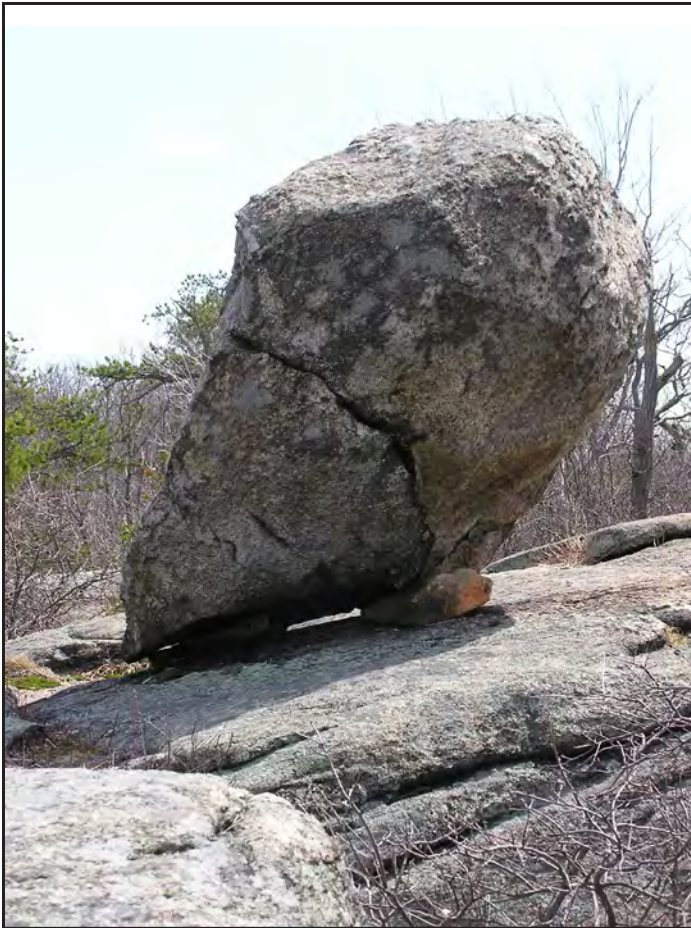


Figure 6. Balanced rock. Photo by S. Stanford.

The supporting stones are also hornblende granite and are angular and somewhat flat in shape. This suggests that they were not transported by the glacier but may have flaked off the boulder shortly before final melting of the ice, perhaps when the top of the boulder was exposed but the base was still embedded in ice. The boulder itself is pitted, cracked, and flaked by postglacial weathering. A slab of granite resting on the bedrock near the back (north) side of the boulder looks as though it can be refitted to the main boulder and may have broken off along one of these postglacial cracks.

Stop 6. Granite at Wyanokie High Point (41° 03.6667' N, 74° 19.8500' W)

At an elevation of 960 ft. above sea level, the crest of Wyanokie High Point along the combined red and Highlands trail affords an exceptional 360° geologic perspective of the surrounding region. Looking east and south in the foreground are Wanaque Reservoir and Wanaque valley; Ramapo Mountain is in the background (fig. 7a). The New York City skyline is visible to the southeast in the background and to the left of that is the crest of the Second Watchung Mountain underlain by 200 million-year-old basalt.



Figure 7a. Crest of Wyanokie High Point. Wanaque Reservoir is in distance. Photo by R. Volkert.

Wyanokie High Point is underlain by Mesoproterozoic-age medium- to coarse-grained, massive, pinkish-white Byram granite (Fig. 7b), named for the location in Byram Township where it is best exposed. Note the tight, interlocking texture formed by the mineral grains that include quartz (light gray), feldspar (white to pink) and hornblende (black) that help create a rock that is fairly resistant to erosion. Byram granite has been dated at 1.185 billion years using uranium-lead isotopes and is one of the oldest granites in the Highlands.



Figure 7b. Byram granite at Wyanokie High Point. Photo by R. Volkert.

Granite outcrops here and elsewhere in Norvin Green State Forest display smooth, polished surfaces and streamlined shapes resulting from the abrasive action of rock and sediment frozen into the base of glacial ice as it moved over the bedrock. The same erosional features have been visible since Stop 4 on exposed bedrock along the ridge to the west. The smooth surface of the rock on Wyanokie High Point is shaped into elongate ridges known as *roche moutonnées* (a French term roughly translated as “sheep-back rock”). These erosional forms have smooth surfaces formed by abrasive erosion on their upglacier side (here, to the north), and broken, cliffed faces on their downglacier side (here, to the south, towards the New York City skyline) (fig. 7c), formed by an erosional process known as quarrying or plucking. These features occur both on the small scale of individual outcrops and on the larger scale of entire hills and mountain ridges. For example, the entire ridge since Stop 4 consists of smooth, abraded ledges on its northeast side, which faced advancing ice, and quarried cliffs on its southwest side, which faced downglacier. This pattern repeats on prominent hills and ridges throughout the glaciated Highlands, and is a distinctive element of the intricate landscape of this region.

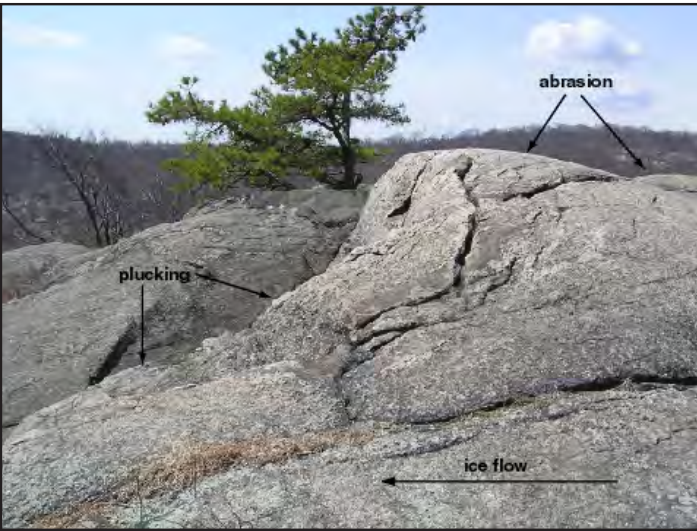


Figure 7c. Roche moutonnée on Wyanokie High Point. Photo by S. Stanford.

Stop 7. Glacial erratics
(41° 03.6000' N, 74° 19.2833' W)

As the descent from Wyanokie High Point levels off, the trail crosses from exposed bedrock onto a deposit of till (see Stop 3), which covers the bedrock along the lower slopes of the mountain, down to the stream crossing just past the junction with the white trail. As you descend this stretch of trail, note the abundance of rounded boulders and cobbles indicating glacial transport, and the scattering of white, gray, and purple quartzite and conglomerate erratics. Just before the junction with the white trail there are several rounded erratic boulders of purple to reddish-brown conglomerate along the trail (fig. 8). This conglomerate (sometimes referred to as “puddingstone” because of its resemblance to British fruit pudding) is sedimentary rock about 390 million years old that contains rounded pieces of quartz in a matrix of sand-size quartz grains. The purple color of the rock is due to oxidized iron coating the quartz grains. The conglomerate does not crop out in Norvin Green State

Forest but was plucked from Bellvale Mountain in New York, north of Greenwood Lake, and glacially transported at least 8 miles to the south.



Figure 8. Conglomerate erratic. Photo by S. Stanford.

Stop 8. Blue Mine
(41° 03.5667' N, 74° 19.0167' W)

A water-filled opening into the hillslope is a remnant of historic iron mining at the Blue mine. The host rock for the magnetite deposit is medium-grained, salt-and-pepper weathering gneiss known as amphibolite, formed from the metamorphism of volcanic basalt. Both the host rock and magnetite ore are Mesoproterozoic in age. The Blue mine was worked intermittently from the end of the 18th century until its close in 1905. The magnetite ore body varied in thickness from nine to 16 feet and was explored along three shafts, over a total length of 500 feet and to a depth of 125 feet below the ground. The Blue mine yielded more than 8,000 tons of ore prior to closing.



Figure 9. Entrance to Blue mine. Photo by R. Volkert.

The Red or Roomy mine, located north of the Blue mine, was worked intermittently from about 1840 until 1857 and then reopened briefly about 1890. Magnetite ore was mined from a vein that was four feet thick. The amount of ore removed from the Roomy mine remains unknown. Much of the iron in the magnetite from these mines was probably recovered through

roasting and smelting of the ore at the Freedom Furnace, which operated from 1838 until 1855 in the Wanaque Valley east of the mines.

Stop 9. Quartzite (41° 04.0000' N, 74° 19.0333' W)

Outcrops along the east side of the yellow trail are of Mesoproterozoic quartzite. The rock here is white to light gray, glassy in appearance, well banded, dense, and breaks with an irregular fracture. Except for thin, parallel layers containing a dark green mineral known as pyroxene, the rock is composed almost entirely of quartz. This particular layer of quartzite can be traced several miles to the south where it continues beneath Wanaque Reservoir (exposed during past drought conditions), finally ending south of Lake Ioscoe.



Figure 10. Outcrop of quartzite. Photo by R. Volkert.

Outcrops of quartzite of Mesoproterozoic age are rare in the Highlands and this outcrop is perhaps one of the best examples. The quartzite was formed through metamorphism of quartz-rich sandstone deposited in a shallow sea about 1,250 million years ago. Similar quartzites that crop out at Bloomingdale, Mendham, Clinton, and High Bridge host many of the Mesoproterozoic-age graphite deposits in the Highlands.

Stop 10. Diabase dike (41° 04.0500' N, 74° 19.0333' W)

An exceptional example of a ~600 million-year-old diabase dike may be seen along the crest and western flank of Ball Mountain, on the yellow trail east of Blue Mine Brook (fig. 11). Here the dike intrudes Mesoproterozoic gneiss, quartzite and marble. This dike has a width of as much as 30 feet and extends for a distance of nearly 2.5 miles from Snake Den Road south to Posts Brook. The dike has a dense and massive texture, weathers light gray to brown and is greenish-gray on fresh surfaces. Other characteristics include a sharp, angular contact against gneiss, fine-grained margins in the dike from rapid cooling against the gneiss that grade into a coarser grain size toward the interior of the dike, and pieces of coarse-grained, pink granite ripped loose from surrounding rock and enclosed in the dike during its intrusion.

Diabase dikes similar to this one are common throughout the Highlands. They formed from magma from the mantle that rose

and filled fractures in the Earth's crust as ancestral eastern North America was separating from ancestral South America about 600 million years ago.

Glacial erosion of the dike along the ridge crest formed roche moutonnées like those at Stop 6. The diabase is more finely crystalline and less exposed than the granite at Stop 6 and therefore has experienced less postglacial surface weathering and pitting. Thus, the smooth, abraded surfaces of the roche moutonnées preserve striations,



Figure 11. Outcrop of diabase dike. Photo by R. Volkert.

which can be seen on several outcrops on and to the left (west) of the trail. These striations were carved into the bedrock surface by rock debris at the glacier's base and provide evidence for ice movement to the south. Striations were no doubt common on all abraded bedrock surfaces, but were entirely erased by 0.25- to 0.5-inch thick postglacial weathering on exposed surfaces, particularly on granite and gneiss. Today they are preserved only on rocks that resist weathering, like quartzite, or on freshly exposed rock surfaces.

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