GEOLOGIC HISTORY AND VIRTUAL FIELD TRIP OF THE NEW JERSEY HIGHLANDS

by

Rich Volkert and Ron Witte

Words highlighted in blue represent hyperlinks to other pages in the Virtual Field Trip. Use these and Adobe Acrobat navigation buttons to page through this electronic document.

Upper Pohatcong Mountain and Musconetcong Valley viewed from Point Mountain, New Jersey Highlands.

Key to locations.

Red circles (Introduction)
1. Norvin Green State Forest, Passaic Co.
2. Heaters Pond, Ogdensburg, Sussex Co.
3. Waterfall, Electric Brook, Morris Co.
4. Waterfall, Wanaque River, Passaic Co.

Blue circles (Origin)
1. Dike, Route 15.
2. Dike, Jenny Jump Mountain, Warren Co.
3. Sandstone, Marble Mountain, Warren Co.
4. Paleozoic unconformity.
5. Dolomite, Vernon, Sussex Co.
6. Shale, Route 57, Warren Co.
7. Conglomerate, Bearfort Mountain.
8. Musconetcong Valley.
9. Physical weathering, Bernardsville.
10. Chemical weathering, Sterling Hill.

Gold circles (Precambrian Rock Types)
1. Metamorphic foliation.
2. Byram Granite.
3. Lake Hopatcong Granite.
4. Mount Eve Granite.
5. Pegmatite.
6. Gneiss.
7. Interlayered gneisses.
8. Sedimentary gneisses.
9. Quartzite.
10. Marble.

Green circles (Faults and Folds)
1. Small fault in gneiss, Kinnelon, Morris Co.
2. Vertical fault in gneiss along Rt. 287, Passaic Co.
3. Deformed gneiss along Ramapo Fault, Morris Co.
4. Polished fault surface, Ramapo Fault, Morris Co.
5. Folded gneiss, Sussex Co.
6. Small-scale folds, Kinnelon, Morris Co.
7. Folded quartzite and sandstone, Passaic Co.

See page 3 for index map of photo locations found in economic geology, Precambrian fossils, and ice age sections.

Index map showing the location of geologic features photographed for the virtual field trip.

Key to locations.

Gold circles (Economic Geology)
1. Magnetite.
2. Magnetite, Allamuchy State Park, Sussex Co.
3. Iron ore furnace, Wawayanda State Park, Sussex Co.
4. Centennial mine, Passaic Co.
5. Franklinite, Sterling Hill mine, Sussex Co.
6. Willemite, Sterling Hill mine, Sussex Co.
7. Zincite, Sterling Hill mine, Sussex Co.
8. Franklin zinc mine, Sussex Co.
9. Sterling Hill zinc mine, Sussex Co.
10. Willimite and calcite fluorescing.
11. Graphite, Bloomington graphite mine, Morris Co.
12. Graphite, Bloomington graphite mine, Morris Co.
13. Graphite mill, Annandale, Hunterdon Co.
14. Allanite, Allamuchy State Park, Sussex Co.
15. Mica, Warren Co.
16. Serpentine, Montville, Morris Co.
17. Serpentine, Montville, Morris Co.
18. Quarry, Lake Hopatcong, Morris Co.
19. Pompton granite.
20. Sand and gravel, Morris Co.
21. Black soil, Great Meadows, Warren Co.
22. Pequest Valley, Great Meadows, Warren Co.

Purple circles (Precambrian fossils)
1. Stromatolite in Precambrian marble, Sussex, Co.
2. Graphite, Annandale graphite mine, Hunterdon Co.

Blue circles (Ice Age)
1. Weathered till, Port Murray, Warren Co.
2. Striated marble, McAfee, Sussex Co.
3. Glacially polished gneiss, McAfee, Sussex Co.
4. Tripod Rock, Pyramid Mtn., Morris Co.
5. Till on Precambrian gneiss, Oakland, Passaic Co.
6. Glacial meltwater sand and gravel, Sussex Co.
7. Talus, Fox Hill Range, Morris Co.
8. Swamp, Hamburg Mountain, Sussex Co.

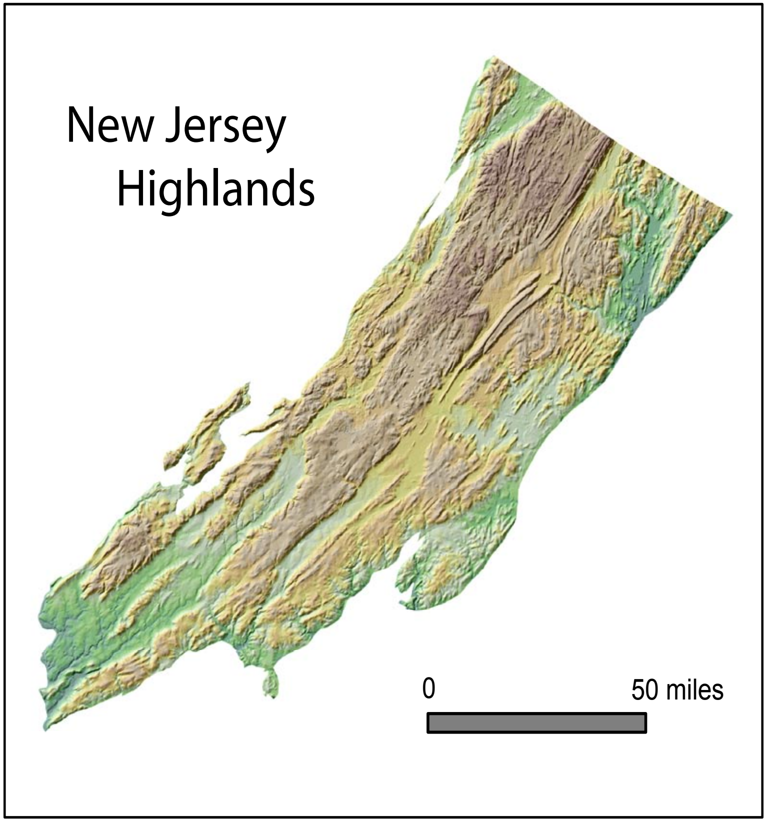
Index map showing the location of geologic features photographed for the virtual field trip.

INTRODUCTION

The New Jersey Highlands are a physiographic province of approximately 1000 square miles of scenic and rugged terrain in northern New Jersey. The Highlands owes its distinctive character of mountainous uplands, rocky northeast-trending ridges, extensive woodlands, numerous lakes , and waterfalls to geologic processes that began shaping the region as long ago as 1 billion years. These same geologic processes make the Highlands an important source of drinking water (its regional watershed areas contain some of the most productive aquifers in the state), and have created habitat for a wide variety of floral and faunal species, as well as wide ranging recreational opportunities.

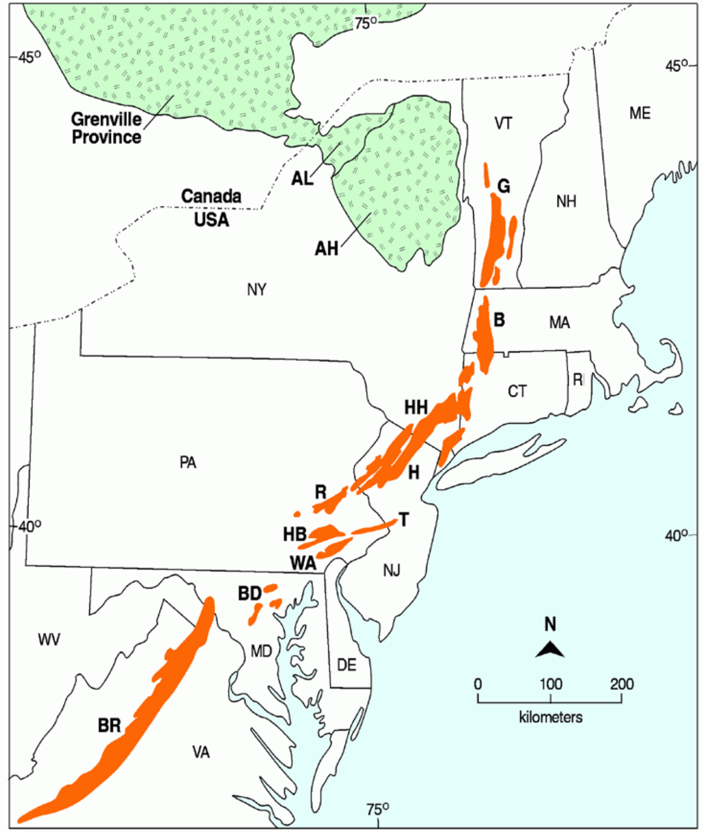
Some of the highest elevations in the state occur in the Highlands because the rocks resist erosion so well. The highest point in the Highlands is on Wawayanda Mountain in Passaic County that reaches an elevation of about 1,496 feet above sea level.

Part of the of the New Jersey Highlands uniqueness is the fact that it is the most ancient part of the state. The region contains rocks that are more than 1 billion years old, making them the oldest rocks in New Jersey. Rocks of similar age and origin as those in the Highlands



Color shaded relief map of the New Jersey Highlands.

form the Adirondack Mountains in northern New York, Green Mountains in Vermont, Berkshire Mountains in Massachusetts, Hudson Highlands in southern New York, Blue Ridge Mountains in Virginia, and Great Smoky Mountains in North Carolina and Tennessee. These ancient mountain belts are the exposed roots of the Appalachian Mountains that stretch from Alabama to Newfoundland, Canada. In eastern North America, rocks of Precambrian age also occur in the Grenville Province in Ontario and Quebec in southeastern Canada.



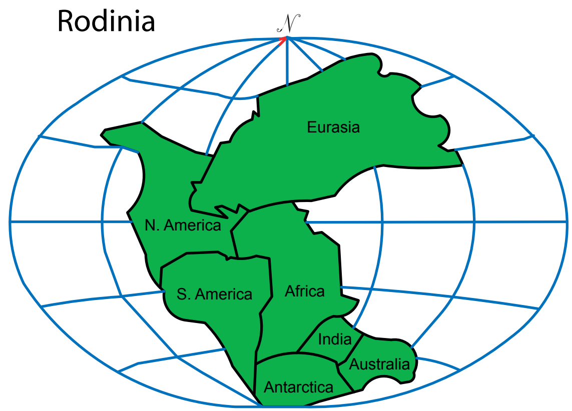
Exposed roots of the Appalachian Mountains (orange-shaded areas) in northeastern, U.S.

HIGHLANDS ORIGIN

Proterozoic Eon

Northern New Jersey has endured a long and complex geologic history that is recorded in the rocks and landforms of the region. The Highlands formed during the Middle Proterozoic Era (also known as the Precambrian) about 1 billion years ago as a result of a collision between the eastern margin of the continent of Laurentia (ancestral eastern North America) and the continent of Amazonia (ancestral South America). Collision of these two continental plates, known as the Grenville Orogeny (orogeny means the process of mountain formation), produced a double thickening of the Earth's crust along the plate boundaries and uplifted the Appalachian Mountains to heights rivaling the present day Rocky Mountains. As a result of this mountain building event, the rocks in the Highlands presently exposed at the surface were buried to depths of as much as 13 miles within the Earth's crust. There they were metamorphosed (metamorphism means to change form) at high temperature and pressure and deformed by faulting and folding. The Precambrian rocks were slowly uplifted and are exposed at the surface today because of erosion of the overlying rocks.

Collision of the Laurentian and Amazonian continents, and their joining with other landmasses about 1 billion years ago, produced a supercontinent known as Rodinia that remained intact for nearly 200 million years. During the Late Proterozoic Era about 800 million years ago, Rodinia began to break up resulting in the splitting and drifting apart of eastern North America and Amazonia. Stretching and extension of the crust associated with this

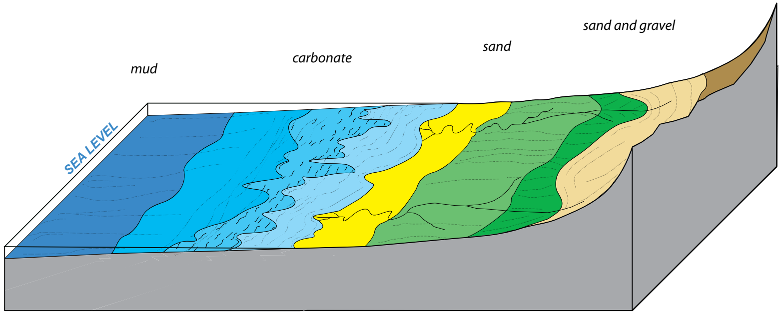


Late Proterozoic rifting occurred in the Highlands about 600 million years ago. This produced an upwelling of magma from the mantle that was emplaced as dikes into the older Precambrian rocks. Extensional stresses in the Highlands also resulted in the down-dropping of crustal blocks along faults and the deposition on land of gravel, sand and silt by streams. The sediments were compacted and cemented into sedimentary rocks that are now conglomerate, sandstone and siltstone, respectively. These rocks are unmetamorphosed because they were not buried deeply within the crust as the Middle Proterozoic rocks were. Sedimentary rocks of Late Proterozoic age are rare in the Highlands, but where present they rest directly on the older Middle Proterozoic rocks, the contact between them separated by more than 400 million years of geologic time.

Paleozoic Era

The youngest rocks in the New Jersey Highlands are sedimentary and were formed during the Paleozoic Era between 550 million and 365 million years ago. By about 550 million years ago, the Precambrian mountains of the ancestral Highlands were partially eroded and covered by a vast sea into which sediments transported by streams were deposited. The oldest Paleozoic sediments include gravel and sand that were deposited by streams along an ancient seacoast during the Cambrian Period. Eventually these sediments became conglomerate and sandstone and they now lie in most instances directly on the eroded Middle Proterozoic rocks separated by an unconformity, or erosional gap, of more than 500 million years. During the early part of the Ordovician Period**,** calcium carbonate deposits formed into limestone and dolomite (magnesium limestone) in the shallow part of this sea. Later, during the Ordovician Period, sand, silt and clay formed sandstone, siltstone, and shale respectively, in deeper water further offshore.

Over the course of geologic time, further collisions between ancestral eastern North America and other landmasses rejuvenated mountain formation in the Highlands. These occurred at about 450 million years ago during the Taconian Orogeny and about 270 million years ago during the Alleghanian Orogeny, the latter collision



Generalized block diagram showing the distribution of sediment along a passive contiental margin.

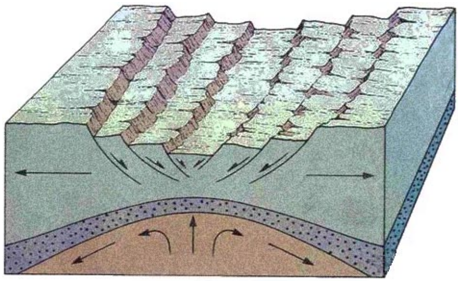
eventually closing the sea completely. The assembly of ancestral eastern North America and Africa to other landmasses at about 270 million years ago produced a supercontinent known as Pangea.

Although Paleozoic rocks were originally deposited on top of the older Precambrian rocks, some are preserved today in the Highlands because they dropped down along faults during periods that the earth's crust moved. The Green Pond Mountain Region that extends from Greenwood Lake in Passaic County southwest to Califon in Hunterdon County is an example of a down-dropped belt of Paleozoic rocks. Ridges in this belt are underlain by less easily eroded sedimentary rock called conglomerate that is known informally as puddingstone.

Other examples of down-dropped belts of Paleozoic rocks include some of the major river valleys in the Highlands, such as the Pequest, Musconetcong, South Branch Raritan, and Lamington that are underlain by more easily eroded Paleozoic limestone, dolomite and shale.

Mesozoic Era

At about 230 million years ago during the Mesozoic Era, breakup of the supercontinent of Pangea had begun, resulting in the splitting up and drifting apart of eastern North America and Africa. Extensional stresses from this rifting event resulted in the down-dropping of crustal blocks in the Highlands along faults. The boundary between the Highlands and Piedmont Province was developed at this time along the Ramapo fault, with the crustal block on the east side of the Ramapo fault beneath the Piedmont Province dropping downward more than 20,000 feet. Although no rocks of Mesozoic age occur in the Highlands, down-dropped blocks of Precambrian rocks occur well east of the Ramapo fault where they occur beneath rocks of Mesozoic age and form the floor of the Piedmont Province.


Initial period of rifting along divergent crustal plates.

By about 100 million years ago the continued splitting and drifting apart of landmasses from eastern North America led to the development of the modern Atlantic Ocean basin, and once more the sea covered the continental margin of New Jersey.

Cenozoic Era

The present landscape of the Highlands is largely the result of weathering and erosion during the Tertiary and Quaternary Periods. The Tertiary Period was a time of relative quiescence geologically, marked by cycles of weathering and erosion. During this time the topography of the Highlands was shaped by streams that cut deeply into less resistant rocks, leaving the more resistant rocks standing as high ridges.

Over the last two million years, continental glaciers originating in the subarctic regions of Canada, reached the Highlands at least three times. During each glaciation, bedrock ridges, hills and slopes were worn down by the action of moving glacial ice, and valley floors were deeply scoured. In places some older valleys were buried by glacial drift, and new ones cut by meltwater streams.

The rugged topography of the New Jersey Highlands is mainly the result of its many rock types having varying resistance to weathering and erosion. In most places harder rocks form higher areas, whereas softer rocks typically underlie lowlands. Highly faulted and jointed rocks are also more susceptable to erosion.

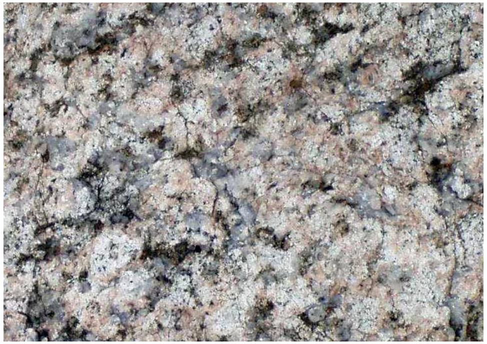
Since the last glacier receded from New Jersey about 17,000 years ago the climate has become increasingly warmer. In many places, swamps and bogs have formed where shallow lakes and ponds have become filled with decayed vegetation and detritus. Rock outcrops have been fractured by the effects of freeze and thaw, their dislodged pieces forming aprons of rocky debris at their bases. Postglacial streams have further cut down in glacial valley-fill materials, widening their valley floors and depositing flood plains.

Precambrian rock types and ages

The Middle Proterozoic (Precambrian) rocks that underlie the New Jersey Highlands are the oldest rocks in the state. They are as old as 1.3 billion years and are as young as 960 million years. Over 30 different types of Precambrian rocks are recognized in the Highlands, but they can be grouped into four main types, granite, gneiss (pronounced "nice"), quartzite, and marble. All except the youngest granites were metamorphosed at about 1 billion years ago under conditions of high temperature and pressure. This metamorphism altered the original minerals in the rocks into new minerals, and then compressive stresses during metamorphism aligned the new minerals into parallel layers that give the rock a banded appearance. This banding, known as foliation, defines the rock structure, or the direction that the bedrock trends.


Foliation (light and dark layering) in gneiss.

Granite is a widespread and common rock type that underlies about 50 percent of the Highlands. It is a massive-textured, medium-grained igneous rock that crystallized from magma and is composed of the common minerals quartz and feldspar. Granite in the Highlands consists of three main types that include the 1.1 billion-year-old Byram granite, named for its abundance in Byram Township in Sussex County, the 1.095 billion-year-old Lake Hopatcong granite, named for Lake Hopatcong in Morris and Sussex Counties, and the 1.02 billion-year-old Mount Eve Granite, named for Mount Eve in Orange County, New York. Also common in the Highlands, is a very coarse-grained type of granite known as pegmatite that formed as thin bodies from magma similar to granite. Pegmatites range in age from about 1 billion to 960 million years.


Granitic texture consisting of medium-grained crystalline quartz and feldspar.

Gneiss, a general term for a metamorphosed rock that has a banded texture, is widespread and common and underlies about 45 percent of the Highlands. Prior to metamorphism, some gneiss was originally igneous rock that formed from ancient volcanic eruptions or from magma. These alternating light- and dark-colored gneisses are the oldest Precambrian rocks in the Highlands and they form the 1.3 billion-year-old Losee Suite, named for Losee Pond (now Beaver Lake) in Sussex County.

Other gneisses that are younger than the Losee Suite originally were sedimentary rocks formed mainly from different types of sandstone. Some of the sedimentary gneisses were deposited in a terrestrial environment but most were deposited in a Precambrian sea. Metamorphosed sedimentary gneisses (Fig. 8) and volcanic gneisses range in age from about 1.3 to 1.15 million years.

Also part of the 1.3 million-year-old sedimentary gneisses is quartzite, a relatively rare metamorphosed sedimentary rock in the Highlands that originally was pure, quartz-rich sandstone deposited in the Precambrian sea.

Quartzite (granular metamorphozed quartz sandstone).

Marble (Fig. 8), is 1.3 million-years-old and occurs throughout the Highlands, but is most abundant in the west where it underlies about 5 percent of the region. Marble is a metamorphosed sedimentary rock that was originally limestone (calcium carbonate) or dolomite (calcium-magnesium carbonate) deposited in a shallow part of the Precambrian sea. The Franklin Marble in the western Highlands, named for Franklin in Sussex County, hosts the famous zinc ore deposits at Franklin and Sterling Hill.

Faults and Folds

Faults

Fractures or fracture zones along which rocks on adjacent sides have broken and moved upward, downward, or horizontally are termed faults. Faults are a common feature in the Precambrian rocks of the Highlands. They range in width from a few tenths of an inch to hundreds of feet and in length from a few feet to as much as tens of miles. Some of the larger faults, such as the Ramapo fault that forms the boundary between the Highlands and Piedmont provinces and the Reservoir fault, that borders the Green Pond Mountain Region, were formed during the Precambrian and have undergone renewed movement over the course of geologic time. Other faults in the Highlands were formed later in geologic time during the Paleozoic and Mesozoic Eras. Compressive forces due to continental collision during the Middle Proterozoic and Paleozoic Eras produced thrusting in the Highlands in which rocks on the east side of faults were moved upward and over rocks on the west side. Extensional forces due to breakup of continental landmasses during the Late Proterozoic and Mesozoic Eras produced normal faults in the Highlands in which rocks on the east side of faults were dropped downward relative to rocks on the west side.

Small faults in Gneiss.

Historically New Jersey has not experienced a major earthquake, although it occurs within a seismically active region that is currently undergoing some compressional stress. This has produced a number of earthquakes of relatively low intensity, and up until 1990 82 documented earthquakes of magnitude 3 or less had occurred in the Highlands. The majority of these earthquakes occurred along faults in the central and eastern Highlands, with the Ramapo fault being the most seismically active fault in the region.

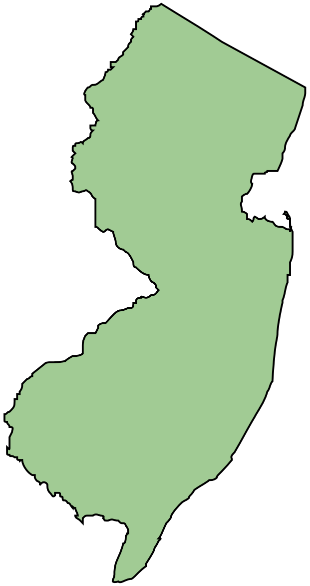
Folds

Folds are a common feature in Middle Proterozoic rocks of the Highlands. Most folds were formed about 1 billion years ago, at roughly the same time that the rocks were metamorphosed, as a result of compression and squeezing of the crust during collision of ancestral eastern North America and the continent of Amazonia. Folds in the Precambrian rocks in the Highlands are variable in dimension and have widths that range from a few inches to several thousand feet. Folds that are arched upward are known as anticlines and those that are arched downward are known as synclines.

Small-scale folds in Precambrian marble accentuated by bands of dark green pyroxene near Hamburg, Sussex County.

Folds are also a common feature in Paleozoic rocks of the Highlands. Paleozoic folds were formed as a result of compression and squeezing of the crust from continental collision during the Paleozoic Era. However, Paleozoic rocks are unmetamorphosed because they were not deeply buried, and so the folding occurred at much lower temperature than folding in the Precambrian rocks.

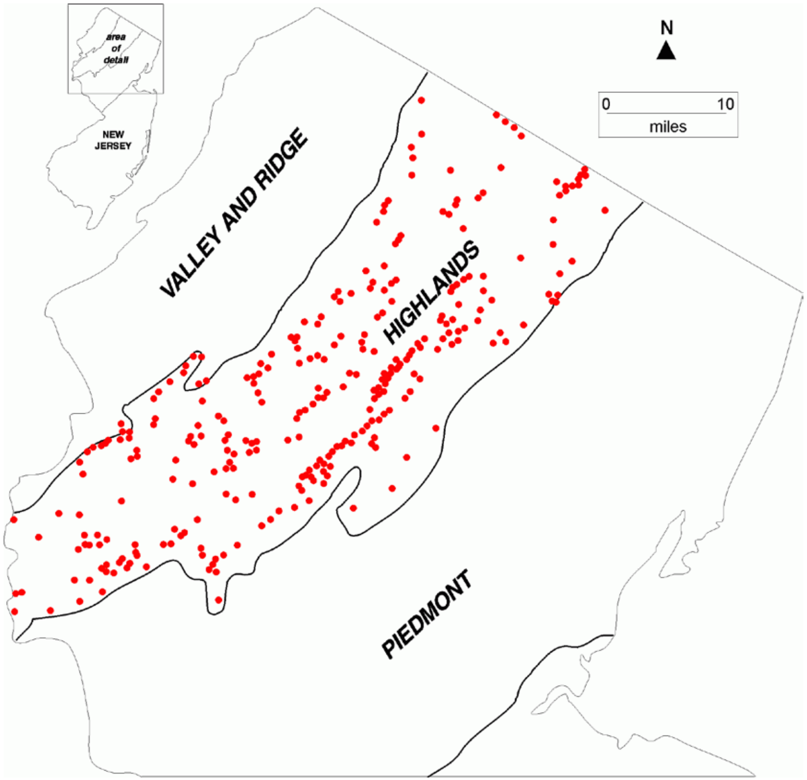
Possibly the most visible and well-known Paleozoic folds in the Highlands are on Route 23, near Newfoundland in Passaic County in the Green Pond Mountain Region.



Economic Mineral Deposits

Unquestionably, the geology of the New Jersey Highlands played a significant role in the early cultural development of the region. As mines were being developed to recover various economic minerals, towns sprung up nearby. Mining in the Highlands began as early as the 1700's, or possibly even the late 1600's and lasted until 1987. Currently there are no operating underground mines in the state. The earliest miners were Dutch or English and as the mining industry developed, immigrants mainly from Europe were drawn to New Jersey to work in the mines. While gold and silver discoveries were historically reported from time to time in the Highlands, neither is present in more than very trace amounts. The following list includes most of the economic materials that were mined or quarried from the Highlands.

Iron



Generalized distribution of iron mines in the New Jersey Highlands. In some instances, multiple mines are shown as a single dot because of the scale of the map.

Between about 1710 and 1966 iron ore ([magnetite]) was extensively mined in the Highlands and created a once-thriving industry that was responsible for much of the early settlement in the region. By the time of the Revolutionary War, 8 [furnaces] and 79 forges were in operation to process iron ore for use by the Continental Army. During the late 1800's and early 1900's New Jersey led the nation in iron ore production until the discovery of the Lake Superior deposits in Michigan.

In all, more than 300 mines and prospects were worked throughout the Highlands that produced an estimated 50 million tons of ore by the close of the industry. Most of the ore occurred as the mineral magnetite, although less abundant deposits of hematite were also locally mined. Mine workings ranged in depth from small surface prospect pits to the Mount Hope mine that had a total depth of slightly over 2,690 feet, and the Scrub Oaks mine of about 3,200 feet below the ground surface. The Mount Hope mine also has the distinction of being the oldest iron mine in the nation, possibly being worked as early as 1665. In 1996, the Scrub Oaks mine was the last iron mine to close in the Highlands. The Mount Hope and Scrub Oaks mines were also the state's largest producers, yielding in excess of 6 million and 7 million tons of ore, respectively.

Zinc

The zinc ore (franklinite, willemite, zincite) of the Franklin and Sterling Hill mines in Sussex County were of considerable historical and scientific significance because no other deposits like them exist anywhere in the world. The Franklin mine was worked from about 1770 until 1954 and the Sterling Hill mine from 1772 until 1987. These deposits are unique because of their metamorphosed ore mineral assemblages, and remarkable in the fact they have produced more than 360 different mineral species, 33 of which occur only in New Jersey. Many of the minerals found at these two zinc deposits fluoresce under ultraviolet light, but probably the best known are calcite that fluoresces

Part of the mineral and mining display at the Franklin Mineral Museum, Franklin, Sussex County.

Assortment of rock drills used to mine ore, Sterling Hill Mining Museum, Ogdensburg, Sussex County.

red and willemite that fluoresces green. During the early 1900's New Jersey ranked second in the nation in zinc ore production from the Franklin and Sterling Hill mines, both of which had produced a combined total of more than 36 million tons of ore by the time of their closure.

Graphite

Graphite was mined from about 1848 until 1931 at 13 locations in the Highlands in Passaic, Morris, and Hunterdon Counties. During the peak of mining activity, four separate mills operated to process the ore. The largest graphite mines were at Bloomingdale in Passaic County and Annandale in Hunterdon County. They had workings extending to depths of 60 feet and 50 feet, respectively. Total production figures for the graphite mines are unavailable, but apparently they could not compete financially with other domestic (especially New York Adirondack) mines or imported sources of graphite.

Radioactive ore

Radioactive ore was mined underground during the mid 1900's mainly from the Bemco (also known as the Charlotte) mine near Cranberry Lake in Sussex County and the Scrub Oaks mine in Morris County. Both of these mines were developed initially for their magnetite (iron ore) deposits. The radioactive ore included various uranium, thorium, and rare-earth element-bearing minerals.

Mica

Mica was mined sometime prior to 1869 from surface workings at sites in Franklin and Harmony Townships, Warren County and Mendham Township, Morris County. The workings were relatively small and confined mainly to surface pits.

Serpentine

Serpentine was quarried from about 1848 until the early 1900's from the Klein quarry near Phillipsburg, Warren

County, Gordon quarry near Montville, Morris County, and Sanders quarry near Mendham. The Phillipsburg and Mendham occurrences were extensive enough for the rock to be used as a decorative building stone. Some of the serpentine was also ground into mineral pulp for a variety of uses.

Crushed stone

Although not a mineral deposit, some of the Precambrian rocks of the Highlands have been quarried for crushed stone since the 1800's. The Pompton Pink Granite, unique to the Riverdale area in Passaic County, was used during construction of the approach to the Smithsonian Institution in Washington D.C. in the early 1900's. Some granites and gneisses in the Highlands are currently quarried for use as aggregate. Marble was quarried in the past for use as a flux during roasting of iron ore in furnaces, in the portland cement industry, and as a decorative building stone.

Sand and gravel

Deposits of unconsolidated sand and gravel left by glacial-meltwater streams have been mined from surface pits since the 1800's at numerous locations in the northern and central Highlands.

Peat and black soil

Small deposits of peat formed from partially decomposed vegetative material in glacial lakes and bogs were mined during the late 1800's and early 1900's from a few locations in the Highlands in Sussex and Warren Counties. Extensive deposits of organic-rich black soil associated with peat underlie agriculturally important areas of the Pequest River valley at Great Meadows in Warren County and the Wallkill River valley in Sussex County and Orange County, New York.

Peat formed in shallow lakes and ponds where over time decayed plant material accumulated on the floor of the watery basin. Eventually the basin becomes filled with decayed vegetation and a swamp or bog is formed.

Precambrian Fossils

Until recently, fossils were thought to be absent, or at least unrecognizable, in Precambrian rocks of the Highlands. This is because of the ancient age of the rocks that date to a time when only primitive microorganisms lived in marine environments, and the fact the Precambrian rocks were metamorphosed under conditions of high temperature and pressure sufficient to obliterate any fossil remains. However, this thinking changed in 1999 when a fossil stromatolite was discovered in marble in Sussex County. Stromatolites are the fossilized remains of colonies of microbial organisms formed in a shallow sea that have a characteristic laminated and domed structure. The laminations are mats constructed by the microorganism as they trapped fine grains of calcium carbonate sediment on the sticky surface of their filaments. A new organic mat was then constructed over the layer of fine sediment, trapping another layer of sediment and producing the next lamination.

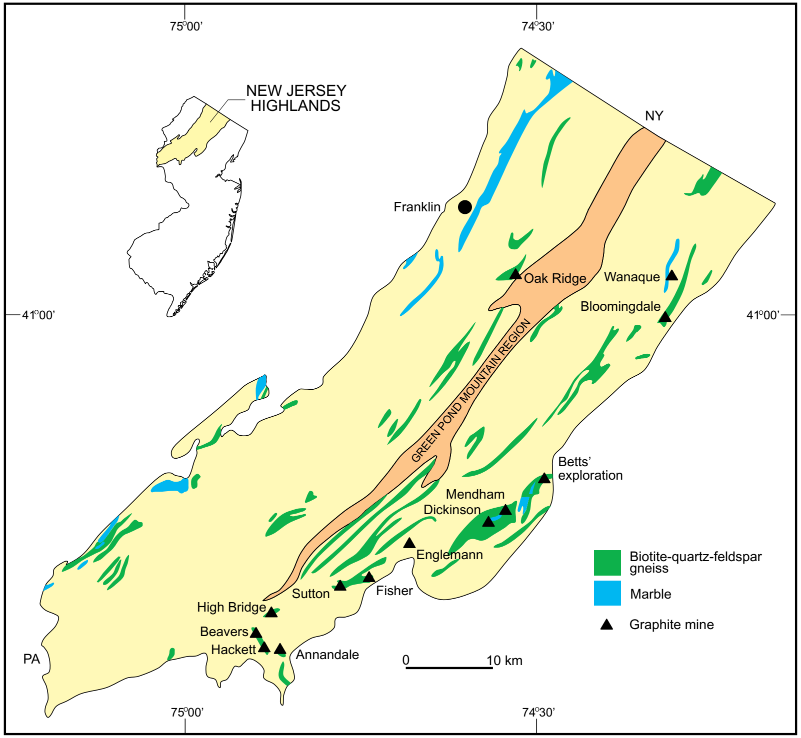
Stromatolites in the Allentown Formation near Hamburg, New Jersey.

Modern stromatolites in western Australia (from Jochem, Frank J., Stromatolites, Australia, FIU course no. OCB 3043, 5 May 2006, <http://www.jochemnet.de/fiu/OCB3043_31.html>

Stromatolites are among the oldest known fossils and are found in 3.3 billion-year-old marble in Australia and in 3 billion-year-old marble in South Africa. Stromatolites are still forming today, notably in warm water marine environments such as the Bahamas and Australia and this setting may provide a modern analog for the marine environment in which the New Jersey stromatolites formed.

The age of the stromatolite in the Highlands is about 1.3 billion years and is the same as that of the enclosing marble. It remains the oldest fossil discovered in New Jersey. Fossils in Precambrian rocks in the Highlands older than marble would not be expected because these granites and gneisses crystallized from magma or lava and, therefore, would not have contained fossils.

Indirect evidence for fossil remains in the Highlands also comes from the geochemical composition of graphite. Graphite is composed of carbon that may have a number of geologic sources, but only carbon from organic matter preferentially concentrates the light isotope of carbon. Carbon isotope analysis shows that the Highlands graphite formed from the metamorphism of organic carbon and, therefore, likely represents the remains of algae that had accumulated in an oxygen deficient part of the Precambrian marine environment. The host rocks of the stromatolite and graphite fossil occurrences in the Highlands are roughly the same age and were formed in the same marine environment, supporting the presence of 1.3 billion-year-old life in an ancient Precambrian sea in the ancestral Highlands.

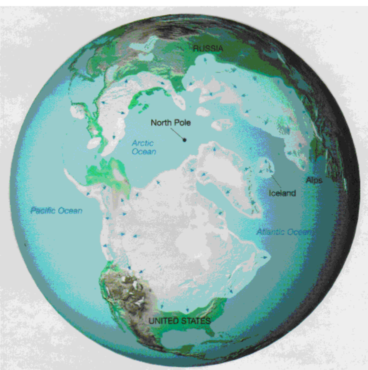


Simplified geologic map of the New Jersey Highlands showing the locations of grahite mines.

Ice Age

Greenhouse to Icehouse

During the latter part of the Pliocene Epoch, about 2.5 million years ago (Ma), a large buildup of ice began in the Northern Hemisphere. In North America, great ice sheets centered in the continent's subarctic regions gradually grew from compacted and recrystallized snow. Eventually, the ice became thick enough to flow and move outward under its own weight. At their maximum size, these continental glaciers covered a large part of North America and were as much as 10,000 feet thick at their centers. In New Jersey, they may have been as much as 2,000 feet thick.

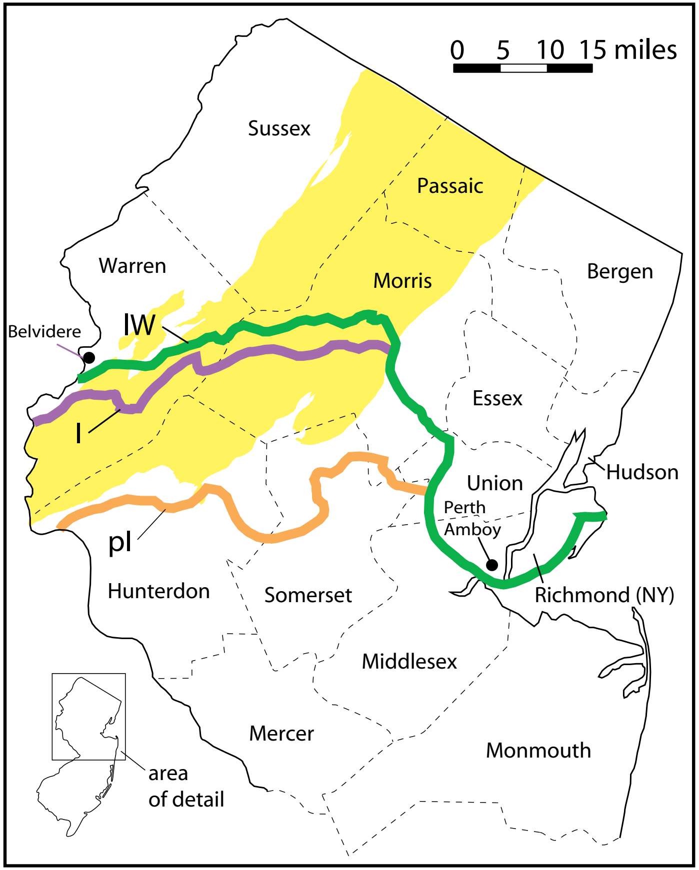


Maximum extent of ice in the northern hemisphere

The buildup of ice in the Northern Hemisphere marks the beginning of a major climatic shift in the Northern Hemisphere. The last 2.5 (Ma) have been a time of overall global cooling, but this period was also marked by wide fluctuations in temperature. The New Jersey Highlands not only experienced the cold climate of glaciations, but also subtropical climate during some of the interglacial periods. Current scientific theory suggests that continental glaciations were triggered by eccentricities in the Earth's orbit and tilt of its axis, which altered the amount of solar radiation (also called insolation) striking the northern hemisphere. During periods of reduced insolation glaciers grew and conversely they shrank during periods of increased insolation. This meant the climate in New Jersey varied from arctic in glacial periods to temperate or subtropical during interglacial periods. Based on the marine oxygen isotope record, the growth and decay of ice sheets in the northern hemisphere was cyclic. It also shows that New Jersey may have experienced at least 10 major glaciations during the ice age.

Number of Ice Invasions

The position and difference in weathering characteristics of glacial sediments in New Jersey show that continental ice sheets reached New Jersey at least three times. This number is far lower than that indicated by the oxygen isotope record. However, this difference may be explained by the following. Not all glaciations may have reached New Jersey and younger glaciations, especially in



Limits of glaciations in New Jersey. The trace of the late Wisconsinan limit (lW) generally marks the position of the Terminal Moraine. Key: lW - late Wisconsinan, I - Illinoian, and pI - pre-Illinoian.

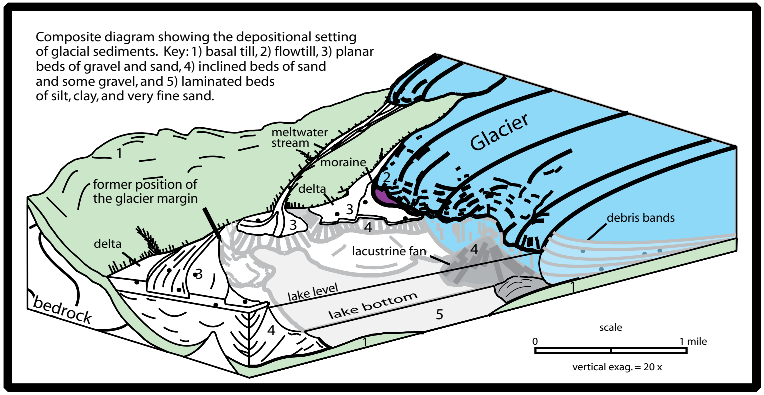
areas underlain by hard rock with moderate relief such as New Jersey, typically remove evidence of older glaciations by erosion. Weathering and erosion related to nonglacial processes have also obscured the glacial record.

The oldest glaciation in New Jersey, named the pre-Illinoian, nearly covered all of the Highlands. The age of this glaciation is uncertain due to its antiquity and extensive and complex weathering history of its deposits. It may represent one or several glaciations during the early to middle part of the Pleistocene (1.8 to 0.8 Ma) or Late Pliocene (2.5 to 1.8 Ma). A second ice sheet reached the Highlands during the late Illinoian glaciation about 130,000 thousand years ago (Ka) and it covered the northern half of the Highlands. In a few places its terminus is represented by an end moraine (low ridge of soil and rock laid down at the edge of the ice sheet). The youngest glacial deposits in New Jersey were laid down during the late Wisconsinan glaciation (21 Ka) and they provide the clearest record of glaciation. Its furthest advance is generally marked by an end moraine called the Terminal Moraine, which lies just northward of the Illinoian terminal position. Most of the glacial features observed today in the Highlands were produced during the late Wisconsinan glaciation.

The Work of a Glacier

The action of each ice sheet modified the shape of the land by deeply scouring valleys, wearing down and streamlining rock ridges, hills, and slopes, and by eroding most of the loose, unconsolidated surface materials and weathered bedrock. Features carved in bedrock by moving glacial ice are numerous in the Highlands. They include striations, crescentic marks, polished bedrock, and plucked outcrops. Striations are linear scratches and grooves cut in bedrock by overriding ice and they show the direction the glacier flowed. They formed in places where hard stones, frozen to the bottom of the glacier, scraped across softer underlying bedrock. Striations are also found on stones that have been glacially transported. Crescentic marks, which include gouges, fractures, and chatter marks, are cracks and chips in the rock surface made when stones at the glacier's base exerted great pressure on the underlying rock. Other forms of glacial erosion include polishing and plucking. Polishing occurred where sand and silt, frozen on the glacier's base, slides over rock. Like sandpaper smoothing a piece of rough wood, the rock surface becomes highly smoothed. Plucking occurred where rock fragments, fractured and loosened from pressure exerted by the weight of the overriding glacier, were broken off. Generally, the fragments, some as big as boulders, are removed from the downstream side of the outcrop. In extreme cases, the processes of abrasion and plucking can impart to an outcrop a whaleback shape called a roche moutonee. In another testament to the power of moving ice, boulders were carried by glaciers many miles from their source. These relic stones are called erratics and several are larger than automobiles. Many have been carried a great distance and some now rest on mountaintops.

Glacially-eroded gneiss outcrop in Jenny Jump State Forest. Ice flow was from left to right.



Composite diagram showing the depositional setting of glacial sediments. Key: 1) basal till, 2) flowtill, 3) planar beds of gravel and sand, 4) inclined beds of sand and some gravel, and 5) laminated beds of silt, clay, and very fine sand.

Glacial Deposits

Deposits of at least three glaciations record major cold periods during the ice age. Glacial deposits are characterized as having been deposited directly by or from glacial ice or having been deposited by glacial meltwater streams. Rocks, sand, silt, and clay entrained in the ice sheets were deposited as till, an unsorted mixture of clay-to boulder-sized material. This material was laid down from the glacier on the bedrock surface in sheets, in streamlined hills called drumlins, and in ridges laid down along the former edge of the ice sheet called moraines. Stratified sediment consisting of sorted and layered gravel, sand, and silt was deposited by glacial meltwater streams in valleys that drained away from the glacier and in glacial lakes.

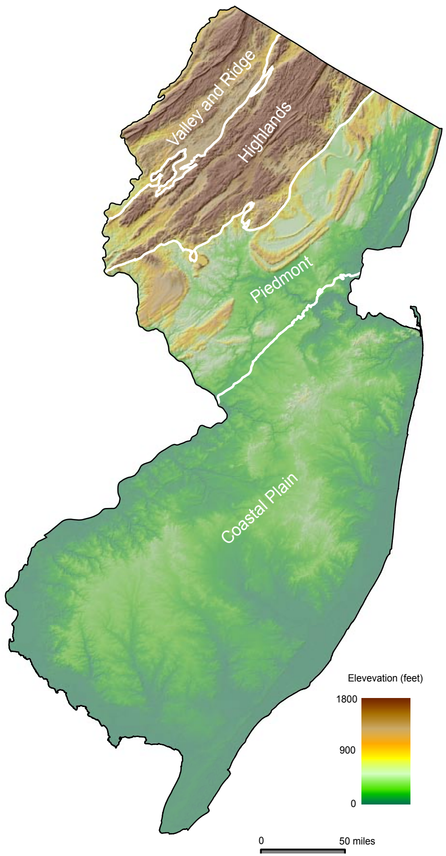
Postglacial Time

Following retreat of the last ice sheet from New Jersey about 17,000 years ago, cold and wet conditions, and sparse vegetative cover enhanced erosion of slope material by earth flows, soil creep, and slope wash. Gradually as climatic conditions warmed, vegetation spread and was succeeded by types that further limited erosion. The mechanical disintegration of rock outcrops by freeze and thaw provided additional sediment, some of which forms small aprons of talus at the base of larger outcrops and cliffs in Highlands. In other places areas of outcrop were reduced to joint-block rubble. A few small boulder fields were formed where boulders; transported downslope by creep, accumulated at the base of hillslopes and in first-order drainage basins. These fields, and other concentrations of boulders formed by glacial transport and meltwater erosion, were further modified by freeze and thaw, their stones reoriented to form crudely-shaped stone circles. The many swamps and poorly drained areas in the Highlands are also typical of glaciated landscapes. Upon deglaciation, surface water, which flowed in a well-defined network of streams prior to glaciation, became trapped in the many depressions, glacial lakes and ponds, and poorly drained areas that formed in areas covered by the ice sheet.

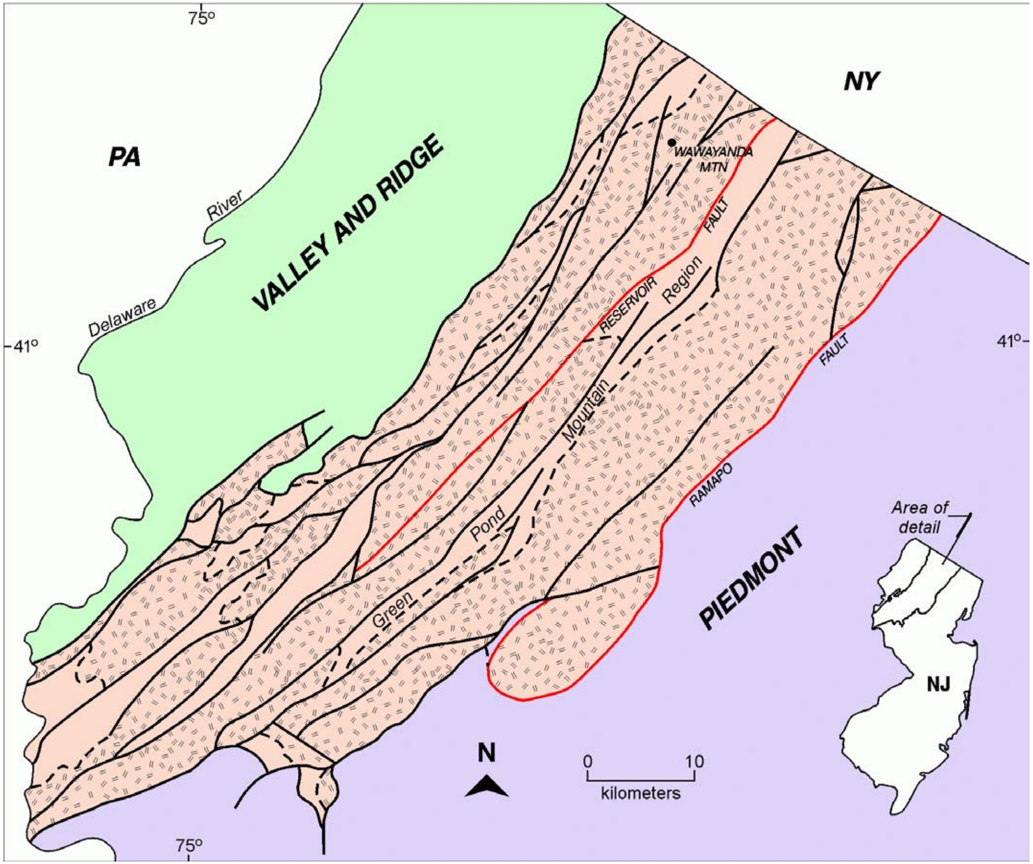
By 14,000 years ago, relatively barren lake and pond sediments, which largely consisted of weathered rock and soil washed in from surrounding higher ground, became enriched in organic material. This change represents a warming of the climate where it became possible for aquatic vegetation to thrive. Additionally, the landscape changed from tundra to a mix of small expanses of spruce and hemlock and open land populated by shrubs and grasses. Eventually a closed boreal forest of conifers covered the highlands. About 10,000 years ago at the start of the Holocene Epoch oak and other hardwoods began to populate the Highlands, eventually displacing the conifers. The many shallow lakes and ponds left over from the ice age slowly filled with decayed vegetation eventually forming bogs and swamps. Presently, we are in the midst of an interglacial period. Based on the geologic record, ice will cover the Highlands sometime during the next 40,000 to 100,000 years.

Precambrian gneiss reduced to a series of detached blocks by physical weathering of the original outcrop along joints and fractures, NJ Audobon Scherman-Hoffman Wildlife Sanctuary, Somerset County.

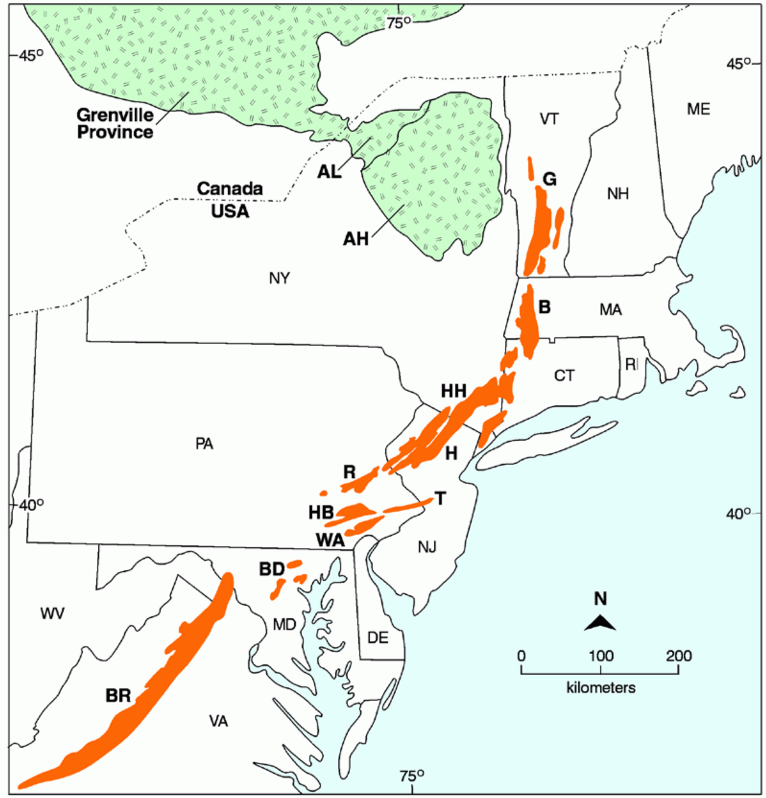
Color-shaded relief map of New Jersey. New Jersey has distinctive landforms that may be divided into four regions known as physiographic provinces. These regions are called the Valley and Ridge, Highlands, Piedmont, and Coastal Plain Provinces. The Highlands Province occupies an area of approximately 980 square miles. Its topography is rugged, consisting of discontinuous ridges and hills that are separtated by narrow, deep valleys.



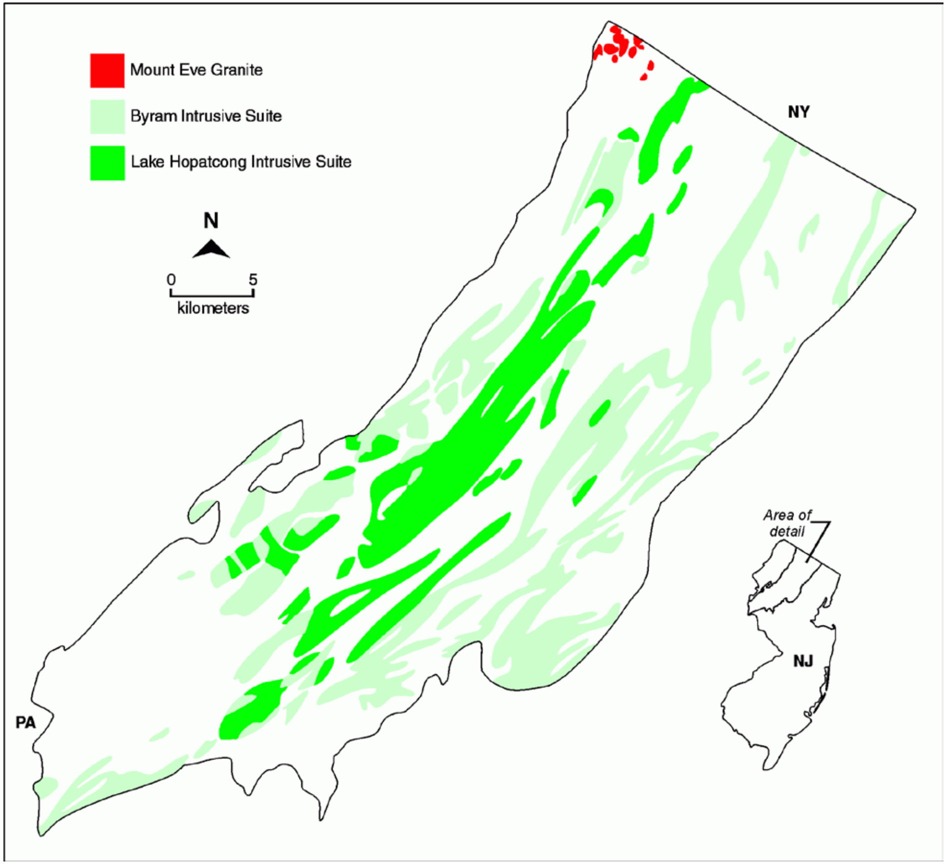
Simplified geologic map of northern New Jersey showing the location of the Highlands (colored tan). Solid black lines are faults and red lines mark faults discussed. Short- dashed lines mark contacts between older Precambrian rocks and younger Paleozoic rocks.



Distribution of Precambrian age rocks in eastern North America. BR, Blue Ridge; BD, Baltimore domes; WA, West Chester-Avondale; HB, Honey Rokk upland; R, Reading prong; T, Trenton prong; H, New Jersey Highlands; HH, New York Hudson Highlands; B, Berkshire Mountains; G, Green Mountains; AL, AH, Adirondack Mountains; and Grenville Province in southeastern Canada. The orange-shaded ares represent the exposed roots of the Appalachian Mountains.

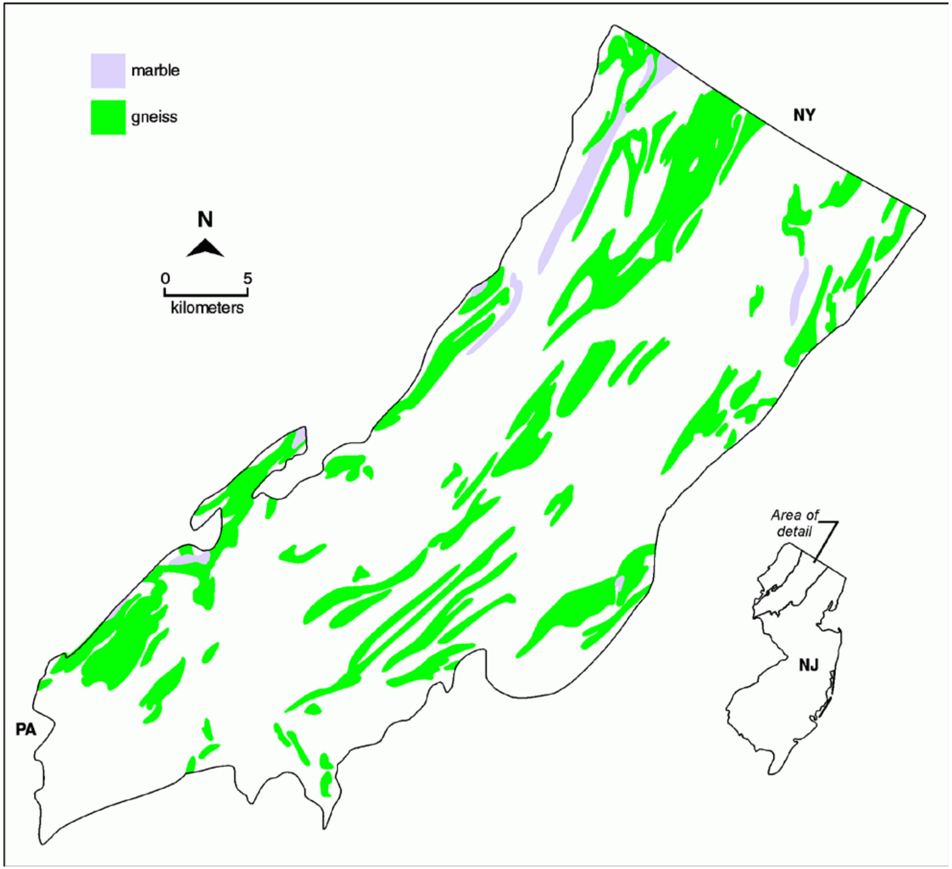


Distribution of granite in the New Jersey Highlands.

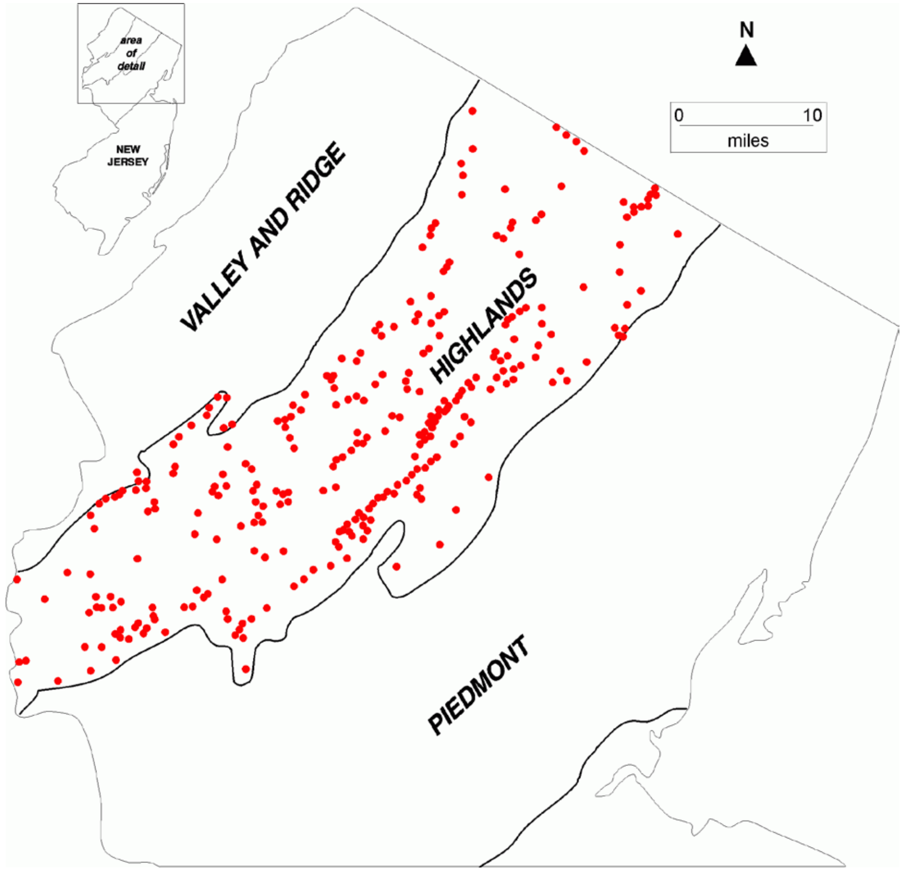


Distribution of rocks of the Losee Suite (blue-shaded area) in the New Jersey Highlands.

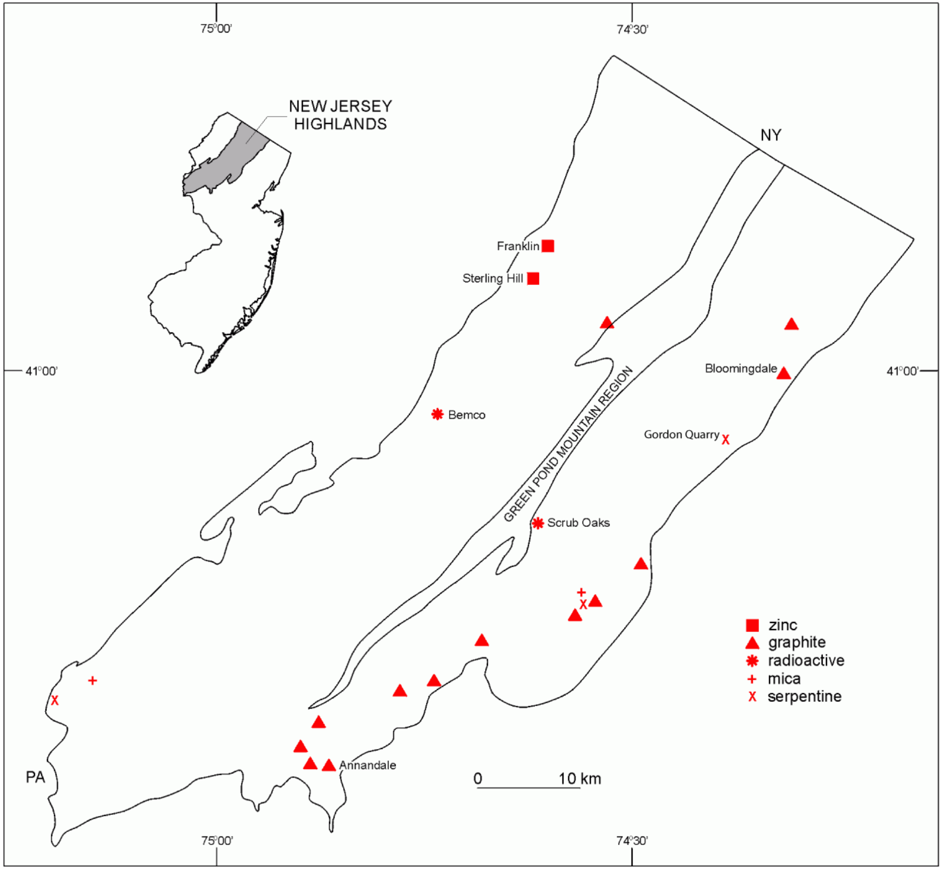
Distribution of sedimentary gneisses and marble in the New Jersey Highlands.



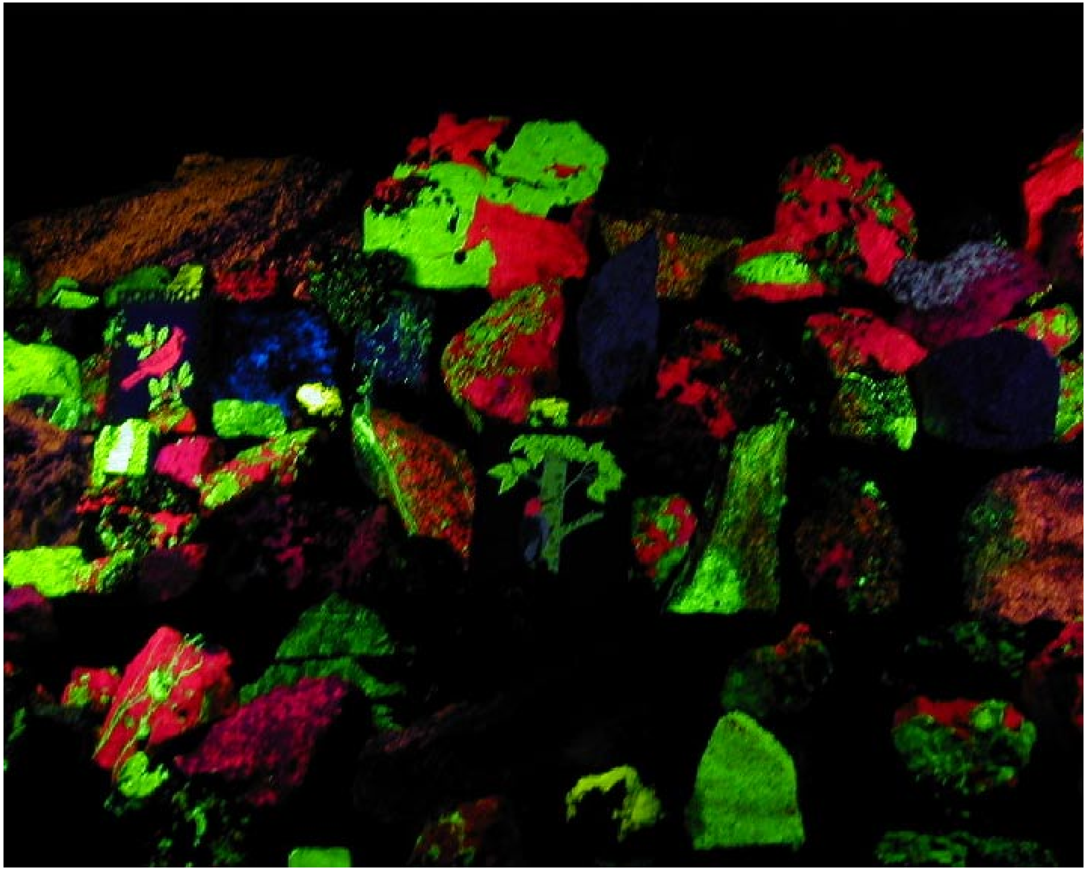
Generalized distribution of iron mines in the New Jersey Highlands. In some instances, multiple mines are shown as a single dot because of the scale of the map.



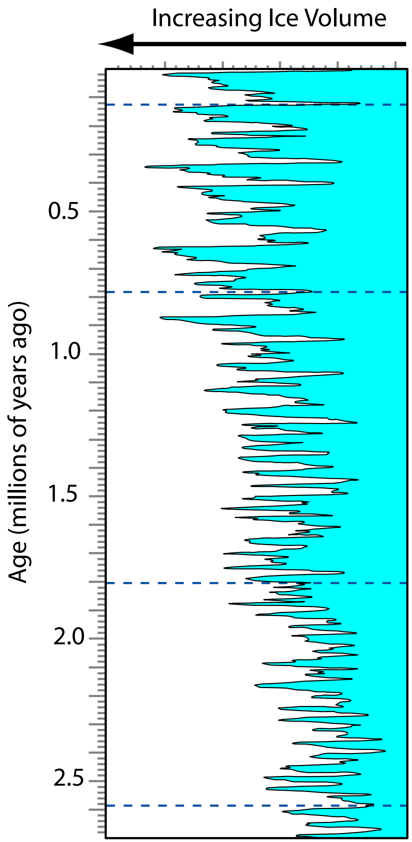
Distribution and locations of the principal economic mineral deposits, exclusive of iron, in the New Jersey Highlands.



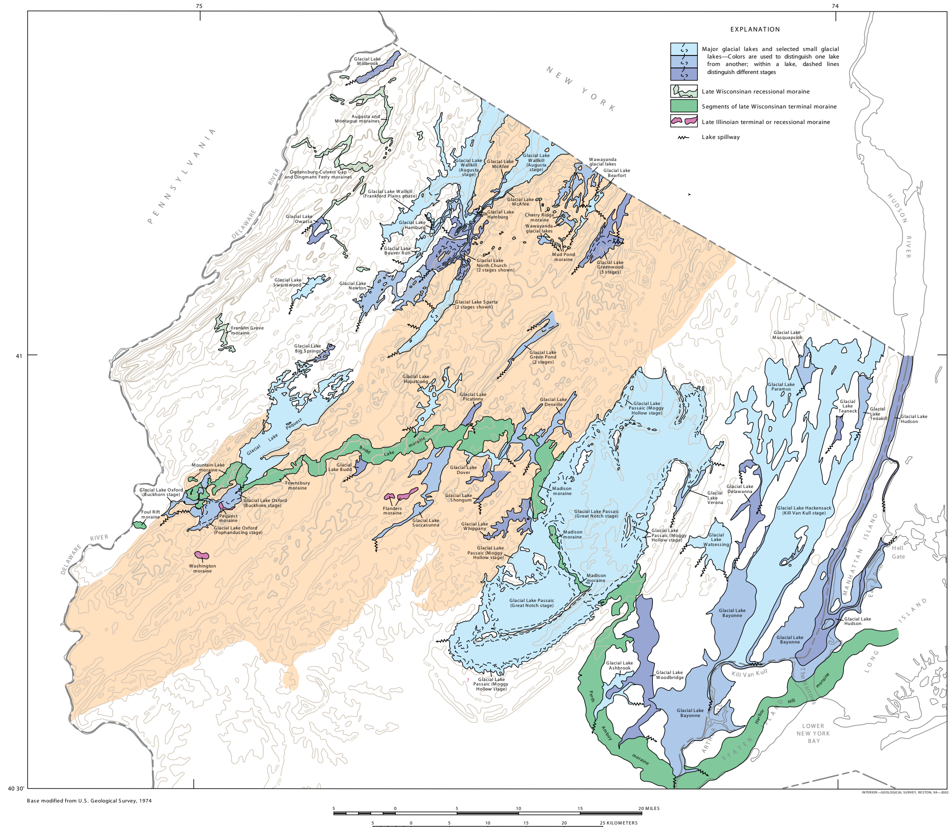
Willemite (green) and calcite (red) fluorescing under ultra-violet light.



Changes in global ice volume over the last 2.7 million years. Blue peaks represent periods of glaciation with nine major glaciations occuring during the last one million years. *Diagram modified from the composite Marine Isotope Stage curve , Global chronostratigrahic correlation table for the last 2.7 million years v. 2004 b, University of Cambridge.*

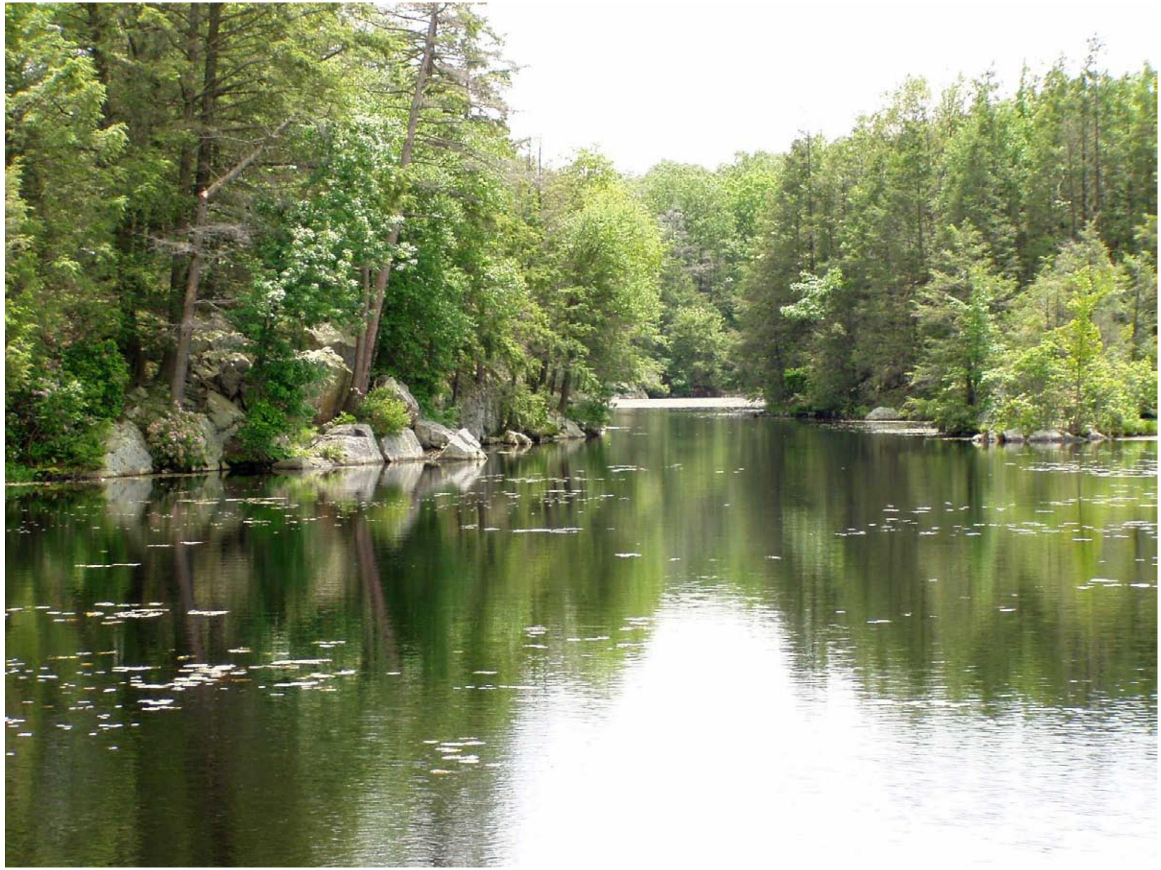


Extent of selected glacial lakes, lake spillways, and moraines in northern New Jersey. Topographic contour interval is 200 ft. *Map modified from Stone, B. D., Stanford, S. D., and Witte, R. W., 2002, Surficial geologic map of northern New Jersey: U.S. Geological Survey Misc. Geol. Inv. Map I-2540-C, scale 1:100,000.*



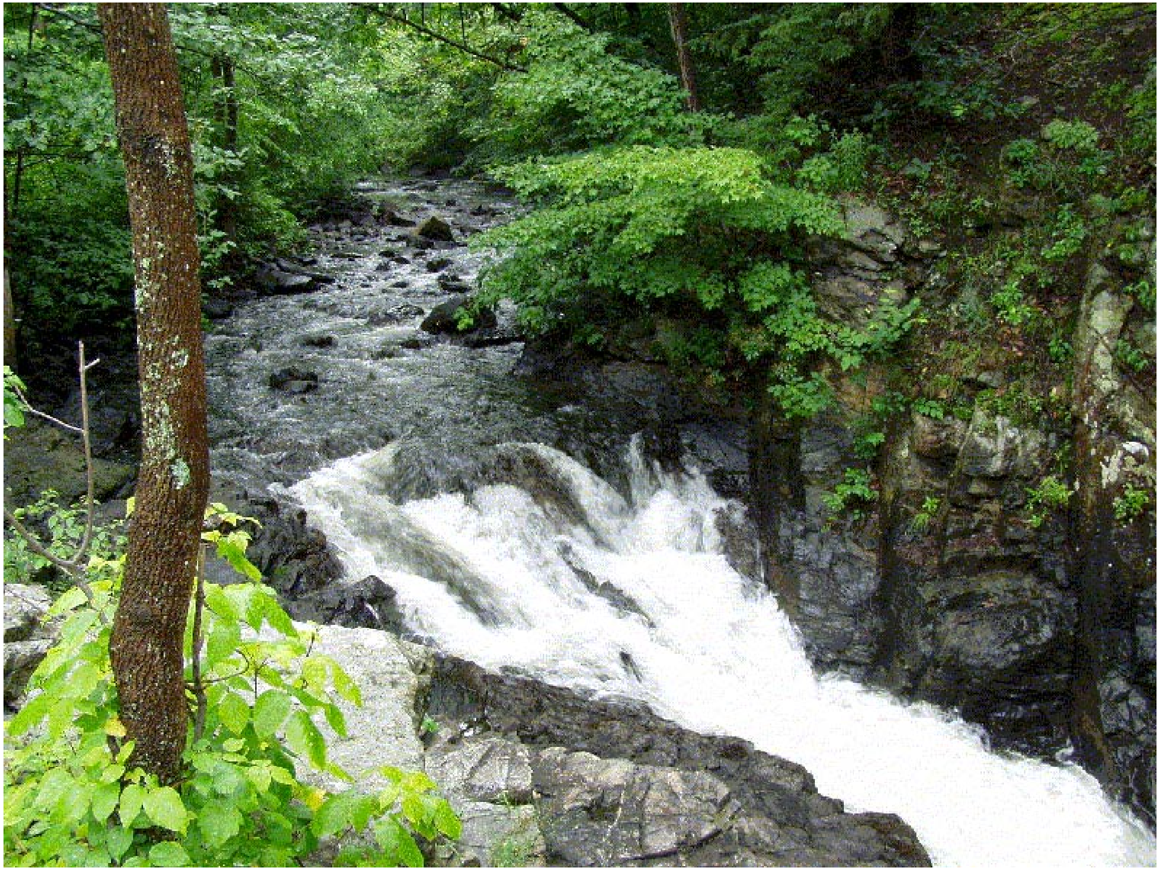
Characteristic mountainous upland landforms of the New Jersey Highlands, Norvin Green State Forest, Passaic County. The high elevations of the Highlands are due to the resistance of the Precambrian rocks to erosion.

Heaters Pond in Ogdensburg, Sussex County. The Highlands are dotted with an abundance of lakes and ponds, many of which owe their origin to glacial processes during the ice age (for example, Wawayanda Lake, Budd Lake, and Lake Hopatcong).



Waterfall along Electric Brook, Schooleys Mountain, Schooleys Mountain Park, Morris County.

Waterfall along the Wanaque River, Wanaque Wildlife Management Area, Passaic County. Waterfalls are common in the Highlands. They form over resistant bedrock or form in response to an abrupt change in stream gradient downstream.



Dark gray diabase dike of Late Proterozoic age (center) intruding older light-colored Middle Proterozoic gneiss, Sparta area, Sussex County. More than 60 such dikes in the Highlands were the result of magma that rose from the mantle during rifting of ancestral eastern North America from the supercontinent Rodinia approximately 600 million years ago.

Close-up of Late Proterozoic diabase dike, Jenny Jump Mountain, Warren County.

Sedimentary sandstone of Late Proterozoic age, Phillipsburg area, Warren County. Although relatively rare in the Highlands, rocks of Late Proterozoic age are locally preserved in the western Highlands.

Contact between Middle Proterozoic gneiss (below) and sandstone of Paleozoic (Cambrian) age (above), Hamburg area, Sussex County. The contact, known as an unconformity, represents an erosional gap of more than 500 million years of geologic time. The older gneiss dips steeply toward the left of the photo, whereas the sandstone beds dip gently toward the right.

Outcrop of light gray dolomite of Paleozoic (Ordovician and Cambrian) age, Vernon Valley near the Walkill River, Sussex County.

Outcrop of gray shale of Paleozoic (Ordovician) age, Route 57 in the Musconetcong River Valley, Warren County.

Stromatolites were discovered in the 1.2 billion-year-old Franklin Marble from the New Jersey Highlands during routine fieldwork by Rich Volkert of the New Jersey Geological Survey. Stromatolites are the fossilized remains of colonies of cyanobacteria that often have a characteristic dome-shaped laminated structure. The Franklin Marble was formed from limestone deposited in a marine (ocean) environment during the Precambrian Era. Stromatolites in the marble provide tangible evidence for the occurrence of ancient biological activity in this environment in New Jersey.

Mill of the Annandale Graphite Cooperation, Clinton Township, Hunterdon County, New Jersey. Nothing remains of the original building.

Purple conglomerate of Paleozoic (Devonian) age, Bearfort Mountain, Passaic County. White pebbles, called clasts, are quartz set in a matrix of sand coated and stained purple by the iron mineral hematite. This sedimentary rock is often referred to informally as puddingstone, a nickname given to it by English settlers because of its resemblance to pudding containing pieces of fruit.

View looking northwest from Musconetcong Mountain across the Musconetcong Valley. Upper Pohatcong Mountain is in the distance. These two ridges are underlain by Precambrian rocks that are more resistant to erosion, whereas the valley is underlain by Paleozoic limestone, dolomite and shale that are less resistant and weather more readily.

An example of physical weathering of a once continuous outcrop of Precambrian bedrock, NJ Audubon Hoffman Sanctuary at Bernardsville, Somerset County. The outcrop was slowly broken apart by water that froze in its natural fractures and by the action of tree roots. Once an outcrop breaks up into smaller blocks it becomes even more susceptible to weathering.

Advanced state of weathering of Precambrian rock, Sterling Hill mine at Ogdensburg, Sussex County. This rock has disintegrated in place, forming rock fragments and coarse sand (called grus by geologists).

Metamorphic banding (also known as foliation) in Precambrian gneiss, Silas Condict Park in Kinnelon, Morris County. The alternating light and dark bands formed during high temperature metamorphism of the original rock as the minerals recrystallize and separate because of differences in their density. The parallel alignment of the minerals is due to compressional stresses during metamorphism that squeezed and flattened the layers.

Medium-grained, pink Byram granite, Echo Lake area, Passaic County. The granite is composed of the minerals hornblende (black), feldspar (pink) and quartz (light gray). The age of the Byram granite is about 1.1 billion years.

Medium-grained, greenish-gray Lake Hopatcong granite, Woodport, Sussex County. The granite is composed of the minerals pyroxene (dark green), feldspar (greenish-gray) and quartz (light gray). The age of the Lake Hopatcong granite is about 1.095 billion years.

Medium-grained, pink Mount Eve Granite, Pochuck Mountain, Sussex County. The granite is composed of the minerals hornblende and biotite (black), feldspar (pink and white) and quartz (light gray). The age of the Mount Eve Granite is about 1.02 billion years.

Very-coarse-grained granite pegmatite, Wawayanda State Park, Sussex County. The pegmatite is composed of the minerals hornblende (black), feldspar (pink) and quartz (light gray). While identical in composition to finer-grained granite, pegmatites owe their coarse grain size to the water-rich nature of the magma that enhances mineral growth. Pegmatites in the Highlands range in age from 1 billion to about 960 million years.

Outcrop of typical Highlands Precambrian gneiss (pro-nounced nice). Gneiss formed in a wide variety of geologic environments; some originated from sedimentary and some from igneous rock. Consequently, the composition, mineralogy, texture, color, and age of gneiss is highly variable. Regardless of origin, gneiss in the Highlands was metamorphosed about 1 billion years ago.

Medium-grained, interlayered light and dark Losee gneiss, near Hamburg, Sussex County. The light layers are composed of the minerals plagioclase feldspar (white) and quartz (light gray) and the dark layers of hornblende and biotite (black). The age of the Losee Suite is about 1.2 billion years, making them among the oldest rocks in the Highlands. Losee gneiss formed from the metamorphism of sodium-rich volcanic and magmatic rocks.

Well-layered, medium-grained Precambrian sedimentary gneiss, near Belvidere, Warren County. Prior to metamorphism the rock was sandstone. The alternating thick and thin layers may reflect differences in thickness of the original sedimentary beds. Metamorphosed sedimentary gneisses in the Highlands are about 1.15 to 1.2 billion years old and formed in a variety of environments on land and in the ocean.

Precambrian quartzite, Bloomingdale Township, Passaic County. This light-gray, glassy rock, composed almost entirely of the mineral quartz, was originally quartz-rich sandstone prior to metamorphism. Quartzite in the Highlands is about 1.15 to 1.2 billion years old and formed at the same time as the rest of the sedimentary gneisses.

Precambrian marble, Ogdensburg, Sussex County. Prior to metamorphism, marble in the Highlands was limestone or dolomite that formed in a shallow ocean. Marble in the western Highlands hosts the world famous zinc ore deposits at Franklin and Sterling Hill.

Multiple thin, closely spaced faults cutting an outcrop of Precambrian gneiss, near Kinnelon, Morris County. Note the offset of the dark bands on opposite sides of the faults.

Click here for another fault photograph.

Near vertical fault zone approximately 50 feet wide in Precambrian gneiss, Route 287, Passaic County. Note the close spacing of the fractures in the center of the fault zone compared to the wider spacing in the less deformed gneiss at the right and left of the photograph.

Outcrop of highly deformed gneiss along the Ramapo fault, Riverdale, Morris County.
The Ramapo fault is a major structural feature in the Highlands, having a width of at least several hundred feet and stretching for a length of 50 miles from Somerset County northeast to New York State. Instead of the fracturing that characterizes most Highlands faults, the Ramapo fault displays stretching and flattening of the rock layers (analogous to pulling on soft taffy) known as mylonite. This type of faulting occurs under conditions of higher temperature and deeper in the Earth's crust then brittle fracturing such as that shown in the previous photographs.

Click here for another photo of the Ramapo Fault.

Smooth polished fault surface,
Ramapo Fault,

Typical style of Precambrian-age folds in a block of gneiss from Sussex County. This type of fold is known as "isoclinal" because the limbs are nearly parallel and dip in roughly the same direction. Most of the folds seen in Precambrian rocks in the Highlands formed about a billion years ago deep in the crust during the heat and pressure of metamorphism. This caused the rocks to become "softer" and more flexible and then fold as the Earth's crust was buckled and compressed by collision of tectonic plates, much like the ends of a small rug pushed toward the middle.

Click here for another fold photograph.

Small-scale folds developed on the limbs of larger folds in Precambrian gneiss, near Kinnelon, Passaic County. This type of fold is known as "upright" because the limbs dip in opposite directions. Buckling of the layers in the center of upright folds in the Precambrian rocks sometimes forms a pattern like the letter "W" or "M", as seen here. Note the absence of this pattern in the isoclinal folds pictured.

Folds of Paleozoic age developed in unmetamorphosed sedimentary quartzite and sandstone, Route 23, near Newfoundland, Passaic County. The convex fold on the left is known as an anticline and the concave fold on the right is a syncline. This type of folding is known as "upright" because the limbs of the folds are not parallel and dip in opposite directions. These folds formed due to buckling of the Earth's crust along ancestral eastern North America during its collision with ancestral Africa about 270 million years ago. Some Paleozoic folds, however, formed during an earlier collision about 450 million years ago. Paleozoic rocks were not metamorphosed or buried as deeply as the Precambrian rocks, and because of this folds formed at much lower temperature.

Most of the iron ore mined in the Highlands was magnetite, an iron oxide mineral. Note the attraction of the pencil magnet to the block of ore. The width of ore layers in Highlands iron deposits ranges from a few inches to as much as 50 feet.

Click here for another magnitite photo.

Thin magnetite ore layer enclosed within dark colored volcanic gneiss, Franklin, Sussex County. Note the attraction of the pencil magnet to the block of ore.

Disseminated grains of magnetite in granite pegmatite, Allamuchy State Park, Sussex County.

Furnace at Wawayanda State Park, Sussex County. Constructed in 1845, it was typical of the charcoal-fired furnaces that sprang up throughout the Highlands to roast magnetite ore.

Typical Highlands abandoned iron mine workings at the Centennial mine, Passaic County. This mine operated from about 1875 until 1880 and produced about 2,200 tons of iron ore.

Black franklinite (zinc manganese iron oxide) crystals in Precambrian marble (white) from the Sterling Hill mine at Ogdensburg, Sussex County. Franklinite was named in 1819 for Franklin in Sussex County where the mineral was first described.

Flesh-colored willemite (zinc silicate) and franklinite (black) in Precambrian marble (white) from the Sterling Hill mine at Ogdensburg, Sussex County. Willemite fluoresces bright green and some marble fluoresces red in ultraviolet light.

Dark red zincite (zinc manganese oxide) and franklinite (black) in Precambrian marble (white) from the Sterling Hill mine at Ogdesnburg, Sussex County.

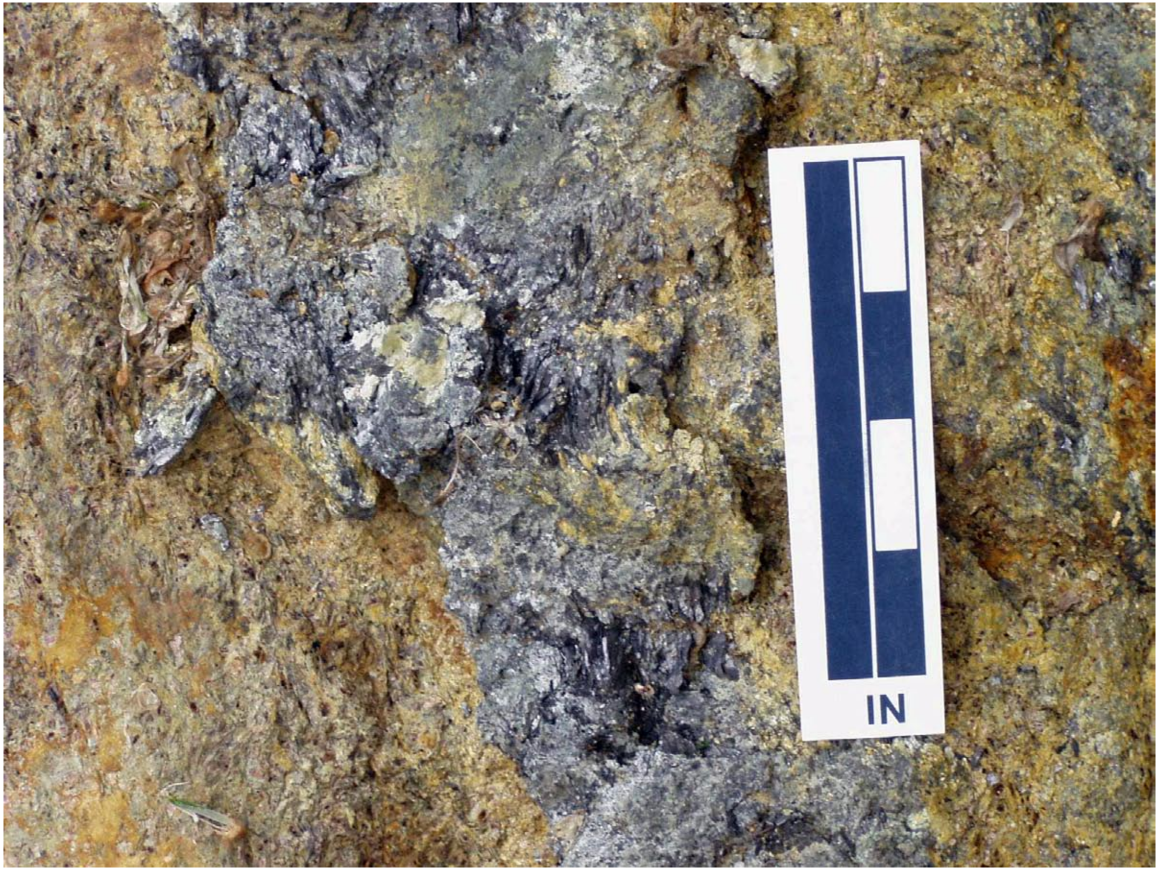
Water-filled Franklin zinc mine at Franklin, Sussex County (view looking north). The Franklin mine was worked from about 1770 until 1954.

Sterling Hill zinc mine at Ogdensburg, Sussex County (view looking west across the Wallkill Valley). The Sterling Hill mine was worked from about 1772 until 1987.

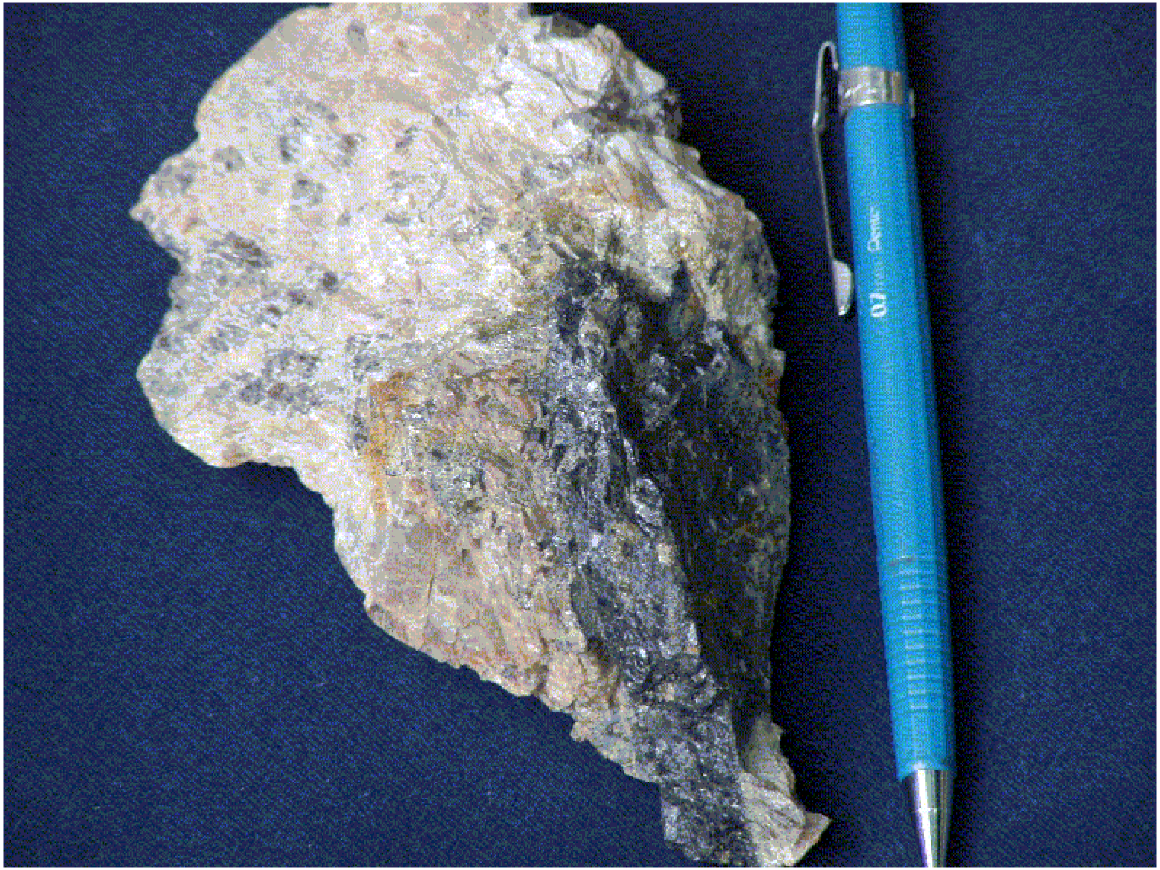
Graphite ore (gray layer left of hammer) from the Bloomingdale graphite mine near Bloomingdale, Morris County. Note the characteristic rusty coloration of the host gneiss caused by oxidation of iron sulfide minerals.

Click here for another graphite photo.

Graphite (gray platy mineral) from the Bloomingdale graphite mine near Bloomingdale, Morris County.



Large black crystal of allanite (rare-earth silicate) in granite pegmatite, Allamuchy State Park, Sussex County.



Large crystals of dark brown phlogopite mica (hydrous potassium magnesium aluminum silicate) from mica mine in Warren County.

Light green serpentine (hydrous magnesium iron silicate) in Precambrian marble (light gray), near Montville, Morris County.

Click here for another serpentine photo.

Dark green serpentine (magnesium iron silicate), near Montville, Morris County.

McNear crushed-stone quarry, Lake Hopatcong, Morris County.

Pompton Pink Granite known only from Pompton Junction, Passaic County and contiguous Riverdale, Morris County. Prized as a building stone, this granite was used in construction of the annex at the Smithsonian Institution in Washington D.C. during the early 1900's.

Sand and gravel mined from a pit in Morris County. These deposits and similar deposits in the Highlands were laid down by glacial-meltwater streams during the last ice age about 17,000 to 20,000 years ago.

Organic-rich black soil underlying the Pequest Valley at Great Meadows, Warren County. Jenny Jump Mountain is in the distance.

Flat-bottomed Pequest Valley (a former glacial-lake basin) at Great Meadows, Warren County viewed from Jenny Jump Mountain.

Massive graphite from the Annandale mine, Hunterdon County. Graphite in the Highlands formed during the metamorphism of carbon from the remains of organic matter that had accumulated in the same Precambrian ocean environment as the stromatolites found in Sussex County.

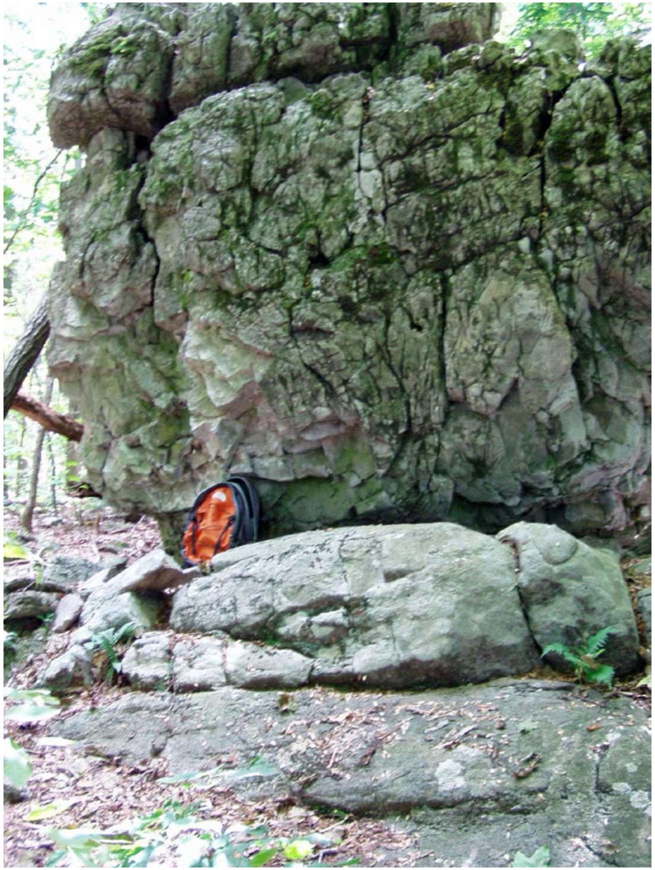
Deeply weathered older till of pre-Illinoian age near Port Murray, Warren County, New Jersey.

Glacially scoured and polished outcrop of Precambrian gneiss, McAfee, Sussex County. The smoothed and streamlined outcrop was formed by the glacier sliding across the outcrop. Rock fragments and sand frozen to the moving glacier's base gradually wore down the rocky substrate.

Tripod rock, Pyramid Mountain Natural Historical Area, Montville Township, Morris County. This is a classic example of a glacial erratic, a bedrock boulder transported by glacial ice and deposited when the ice melted. Tripod rock is a balanced rock, a relatively uncommon feature that forms when a larger erratic settles on top of smaller boulders that create a supporting base.

Click here for another erratic photo.

Large erratic of Paleozoic-age dolomite resting on an outcrop of Precambrian gneiss, near the crest of Wawayanda Mountain, Sussex County.



Glacially polished and grooved surface of Precambrian marble, McAfee, Sussex County. The grooves, known as striations (parallel to pencil), were carved into the bedrock by rock fragments and sediments frozen into the base of the moving glacial ice. The trend of the striations points in the direction that the ice was moving, in this case toward the southwest.

Glacial till deposited directly on Precambrian bedrock, Oakland, Passaic County. Note the absence of soil or weathered rock along the contact. This weathered material was removed by the glacier before the till was deposited. The till pictured here is an unsorted mix of silt, sand, and cobble- to pebble-size gravel, although elsewhere in the Highlands it may also contain boulders and clay.

Stratified layers of gently inclined silt, sand and minor gravel, Sparta, Sussex County. These sediments were deposited in a delta formed by a meltywater stream flowing into a glacial lake.

Apron of talus below weathered ridge of gneiss on Fox Hill Range, near Chester, Morris County.

Small swamp formed in glacially-scoured rock basin, Hamburg Mountain, Sussex County. Prior to glaciation streams flowed off the Highlands in a well-defined network of channels. During glaciation erosion of the rock surface and covering by glacial deposits resulted in the formation of many small lakes, ponds, and wetlands. The warmer climate of the Holocene allowed aquatic vegetation to thrive. Over time decayed vegetation filled in the watery basin to form a swamp or bog.

Geologic Time Scale

Years Ago	Eon	Era	Period	Life and Environment
0 to 2 million	PHANEREOZOIC (Evident Life)	CENOZOIC (Recent Life)	QUATERNARY	*First humans evolve and coexist with mammouths, mastodons and saber-toothed cats, and giant sloths.*
2 to 67 million			TERTIARY	*First large mammals appear and dominate the period. Primitive whales, rodents, primates followed by pigs, cats, horses, dogs, bears and the first hominids. Grasses and modern birds also appear.*
67 to 140 million		MESOZOIC (Medieval Life)	CRETACEOUS	*Heyday of dinosaurs at the start of the Cretaceous followed by their extinction (with many plants and animals) at the end of the period from volcanism and/or asteriod impact. First flowering plants.*
140 to 208 million			JURASSIC	*Earliest birds appear. Giant dinosaurs (Sauropods) flourish. Plants include ferns, cycads and gingkos.*
208 to 250 million			TRIASSIC	*Age of dinosaurs begins. First mammals appear. Mollusks are dominant invertebrate. Many reptiles (turtles and ichthyosaurs).*
250 to 290 million		PALEOZOIC (Ancient Life)	PERMIAN	*Age of amphibians. Supercontinent known as Pangaea forms. Greatest mass extinction ever at end of period. Trilobites go extinct.*
290 to 365 million			PENNSYLVANIAN AND MISSISSIPPIAN (Carboniferous)	*Widespread coal swamps. Large primitive trees. First winged insects and reptiles. Many ferns. Amphibians common.*
365 to 405 million			DEVONIAN	*Age of Fishes. Fish and land plants become abundant and diverse. First shark. Earliest amphibians, ferns and mosses.*
405 to 430 million			SILURIAN	*First insects, jawed fish and vascular plants on land (plants with water-conducting tissue).*
430 to 500 million			ORDOVICIAN	*First corals. Primitive fishes, seaweed and fungi. First non-vascular land plants (like mosses).*
500 to 570 million			CAMBRIAN	*Age of Trilobites. The Cambrian Explosion of life occurs. All Phyla that exist today develop. First vertebrates and earliest primitive fish. First shells appear on shellfish, mollusks, echinoderms, brachiopods, trilobites.*
570 to 2500 million	PROTEROZOIC (Early Life)	PRECAMBRIAN		*First soft-bodied invertebrates and colonial algae. Oxygen build-up: Mid Proterozoic*
2500 to 3800 million	ARCHEAN (Ancient)			*Life appears. First bacteria and blue-green algae begins to free oxygen to atmosphere*
3800 to 4600 million	PRE-ARCHEAN			*Earth molten*