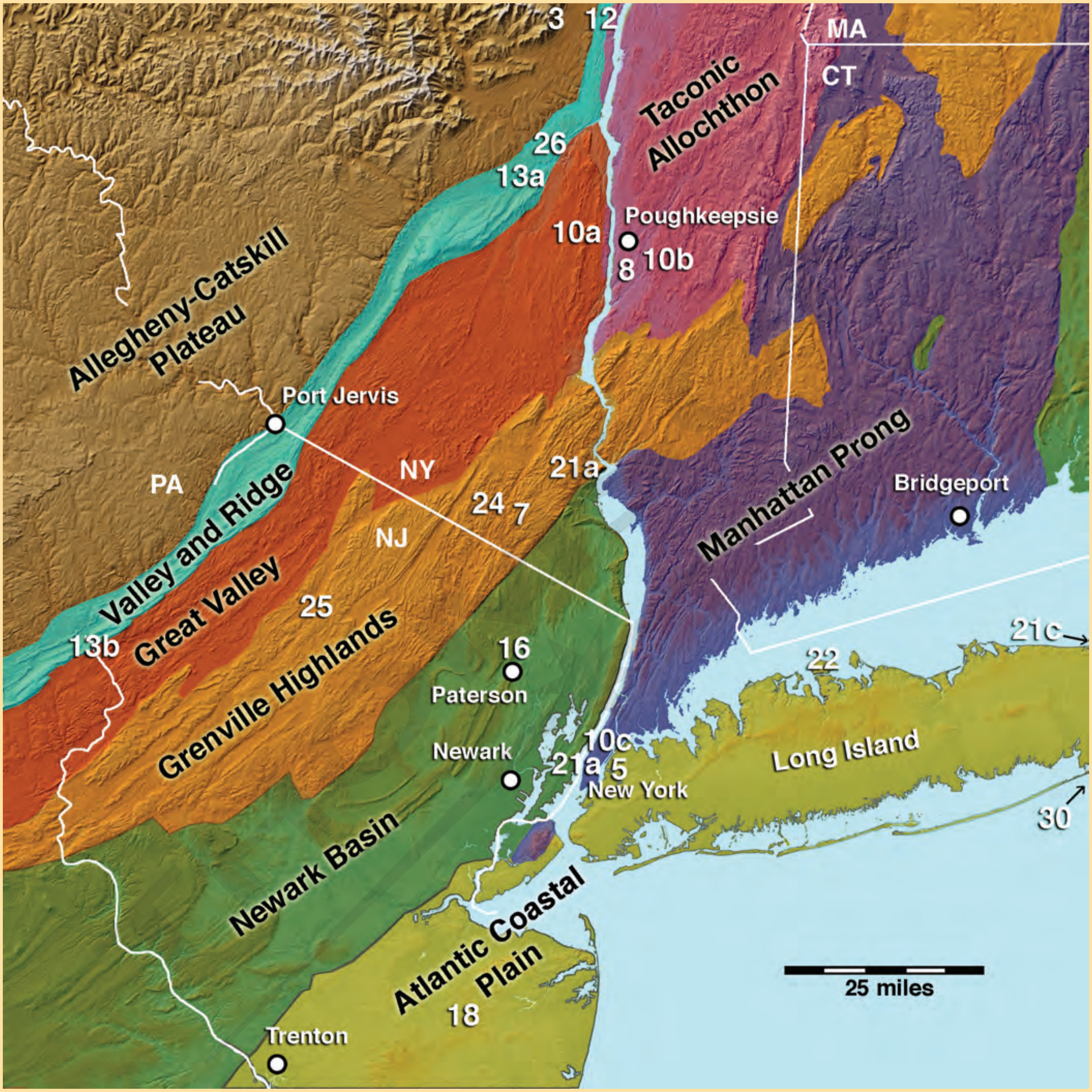
New York–New Jersey

Geology of New York and New Jersey

J Bret Bennington and Charles Merguerian

Hofstra University

View of the tilted and eroded edge of the Palisades intrusive sheet in New Jersey as seen from Inwood Hill Park on the east bank of the Hudson River, New York City.



Physiographic diagram showing the major geological provinces in southeastern New York, northern New Jersey, and adjoining states. Numbers correspond to figure numbers in the text and show approximate geographic locations of photos.

ESSENTIAL QUESTIONS TO ASK

New York–New Jersey.1 Introduction

- *What duration of time and what geological eras are recorded in rocks of the New York–New Jersey region?*
- *What are the names of convergent orogenic events that took place during this time interval?*

New York–New Jersey.2 Ancient Roots of the Grenville Orogeny

- *The Grenville Orogeny was part of the assembly of a Proterozoic supercontinent. What is the name of the supercontinent?*
- *Name five places within 100 miles of New York City where geologists and students can study rocks of the Grenville Orogeny.*

New York–New Jersey.3 Carbonate Seas and the Taconic Orogeny

- *What types of sedimentary layers were deposited during the opening of the Iapetus Ocean, before the start of the Taconic Orogeny?*
- *Identify at least five rock types formed during the Taconic Orogeny.*
- *Which geological province contains the metamorphic roots of the ancient Taconic Mountains? Which geological province preserves the sediments eroded off of the rising Taconic Mountains?*

New York–New Jersey.4 Assembly of a Supercontinent

- *The assembly of supercontinent Pangaea took roughly 250 million years and involved a collision between North America and what two other landmasses?*
- *What tectonic environment and what life-forms existed during deposition of the Helderberg Group of formations in the Early Devonian Period?*
- *After the deposition of the Helderberg limestones, what change took place in the sediments being deposited in the New York–New Jersey region and to what tectonic event can they be attributed?*

New York–New Jersey.5 Breakup of Pangaea

- *During early Mesozoic time, the split up of Pangaea resulted in the formation of elongate rift basins along the eastern margin of North America. Name a place on Earth today where modern rift valleys are forming.*
- *In the New York–New Jersey–Connecticut region, name three Mesozoic basins and the typical rock types you might find in them.*

New York–New Jersey.6 Creation of the Atlantic Coastal Plain

- *Creation of the Atlantic Coastal Plain mirrors conditions that existed in eastern North America at other times in the past. Name at least two earlier intervals of time when passive margin conditions existed along the coast of North America.*
- *What ages and types of sediments are common in coastal plain strata, and what kinds of fossils are found in them?*

New York–New Jersey.7 Ice Age Landscapes

- *Global cooling and the formation of glaciers took place during the Pleistocene Epoch. Name three features each of glacial erosion and glacial deposition found in the New York–New Jersey region.*
- *Glacial deposits have produced major landforms and topographic features in the New York–New Jersey area. Name at least three examples of these.*

New York–New Jersey.8 Economic Mineral Resources

- *Name a dozen economic mineral resources that have been mined for hundreds of years in the New York–New Jersey–Connecticut region.*
- *The Franklin Furnace District of northwestern New Jersey has been a rich source of metals. Name the main ore minerals from this area and the metals that are extracted from them.*

New York–New Jersey.9 Geological Hazards of the Region

- *Name three types of geological hazards associated with the New York–New Jersey area.*
- *Why are moderate earthquakes, which cause little damage in West Coast cities such as Los Angeles, such a potential danger for East Coast cities such as New York and Newark?*

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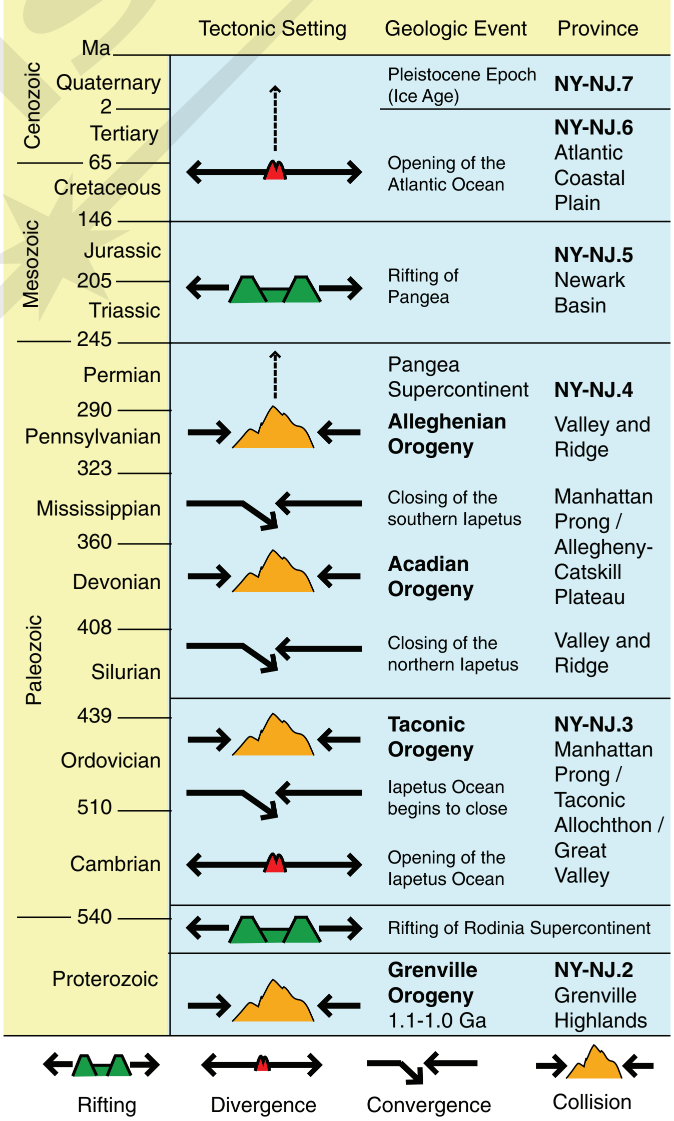
New York–New Jersey.1
Introduction

Volcanoes, high mountains, earthquakes, and other indicators of active geological upheaval are currently associated with the western United States. By contrast, the eastern margin of the continent seems relatively quiet, but this was not always the case. The New York–New Jersey metropolitan region lies on the edge of the North American continent and has experienced a long history of geological activity as eastern North America collided with other tectonic plates and then rifted apart again. The products of these tectonic interactions—geological structures and rock formations—are exposed in the landscape beneath our feet. Geologists reconstruct the history of the Earth by mapping, collecting, and analyzing the rocks, minerals, fossils, and geological structures preserved in different **geological provinces**. What is remarkable about New York and New Jersey is that, within a 100-kilometer (60-mile) radius of New York City, eight major geological provinces are present (Figure NY-NJ.1) that display more than 1 billion years of geological history (Figure NY-NJ.2). The remnants of tropical seas, volcanic eruptions, deep magma intrusion, rising mountains, shifting faults, and advancing glaciers are all on display and ready to be appreciated by anyone with a basic knowledge of geology and a little imagination. This chapter reviews the geological features that are found in the New York–New Jersey metropolitan region and relates the geological features of the present landscape to the events that formed them in the past. We also discuss the economic benefits, as well as the hazards, afforded by the geology of this region.

▶ **Figure NY-NJ.1** Physiographic diagram showing the major geological provinces in southern New York, northern New Jersey, and adjoining states.

All rocks have a story to tell. One of the greatest scientific achievements of the twentieth century was the discovery that there is a unifying theme to the stories found in rocks—the theory of plate tectonics. The **lithosphere** of the Earth is broken up into discrete plates that are created at mid-ocean ridges and move across the surface of the planet until they are consumed along deep ocean trenches. Because of plate tectonics, continents and ocean basins are not static features of the Earth; rather, they are constantly moving and changing through time. As tectonic plates separate, a continent may be rifted apart and a new ocean basin can grow between the diverging plates. Where plates converge, ocean basins shrink as seafloor is subducted and recycled back into Earth's mantle. Plate convergence eventually brings continental landmasses into collision, resulting in **orogeny**—the uplift and formation of a mountain range. This sequence of

▶ **Figure NY-NJ.2** Geological timescale showing the sequence of tectonic settings and geological events that can be interpreted from the rocks found in different geological provinces in New York and New Jersey.



tectonic events—**rifting**, divergence, convergence, and orogeny—forms a repeating **geotectonic cycle** of the breakup and re-formation of **supercontinents** (this makes sense: on a finite Earth, continents can only diverge so much before they begin to converge on the opposite side of the globe). In New York and New Jersey, rocks preserve evidence for four major tectonic collisions and resulting orogenies, as well as one major rifting event (see Figure NY-NJ.2). The oldest of these collisions, the Grenville Orogeny, was part of an older geotectonic cycle that culminated in the assembly of an ancient supercontinent named **Rodinia** during the Proterozoic Eon (see Figure NY-NJ.2). Later, after Rodinia rifted apart, an ocean basin called the Iapetus formed adjacent to eastern North America as tectonic plates diverged. Eventually, this ocean basin began to close as plate convergence commenced during the Appalachian geotectonic cycle. The three younger collisions (the Taconic, Acadian, and Alleghenian Orogenies) were part of the closing of the Iapetus Ocean basin and the formation of the most recent supercontinent, called **Pangaea**, during the Paleozoic Era (see Figure NY-NJ.2). During the Mesozoic Era (the so-called Age of Reptiles), Pangaea rifted apart and a new ocean basin, the Atlantic, formed along the eastern margin of North America. The Atlantic Ocean basin continued to widen through the rest of the Mesozoic and Cenozoic Eras as seafloor spreading along the mid-Atlantic Ridge moved Africa and Europe progressively farther away from the Americas.

The high mountains pushed up during past orogenies are now long gone, worn down to their roots by tens to hundreds of millions of years of uplift, weathering, and erosion. The modern mountains of the region, such as the Ramapo-Hudson Highlands, the Taconic Range, the Adirondack Mountains, and the Catskill Mountains, have been carved by erosion into the ancient rock (Figure NY-NJ.3). Many of the modern topographic features of northern New Jersey and New York were created during the last ice age, less than 100,000 years ago, as kilometer-thick continental ice sheets flowed over the region, sculpting the bedrock and depositing massive quantities of gravel, sand, and mud. The rock formations in New York and New Jersey produced by ancient tectonic events include historically important mineral deposits of iron, zinc, and copper. Also present are thousands of faults that crisscross the bedrock of the region, some of which remain active and capable of generating the occasional moderate earthquake. Finally, as a coastal region, metropolitan New York–New Jersey is vulnerable to the destructive effects of wind, waves, and storm surge generated by hurricanes and nor'easters.

► **Figure NY-NJ.3** High up in the Catskill Mountains, rock layers are horizontal, showing that the Catskill Mountains have been carved into the bedrock, which is relatively undisturbed. Road cut along NY Route 23A, near Palenville, New York.

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Section New York–New Jersey.1 Summary

- A long record of geological events impacting the eastern margin of North America, from the Proterozoic to the last Pleistocene ice age, is preserved in the rock formations of the New York–New Jersey metropolitan region.
- Four discrete episodes of tectonic collision resulting in orogeny and one episode of tectonic rifting are preserved in the rocks of this region.

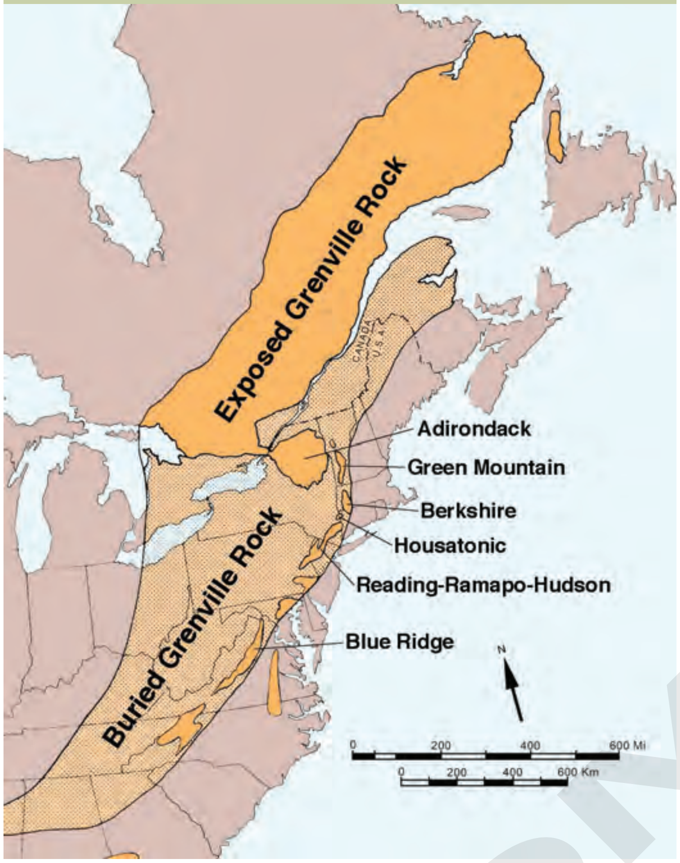
New York–New Jersey.2

Ancient Roots of the Grenville Orogeny

The oldest bedrock found in New York and New Jersey is part of an elongate belt of high-grade metamorphic rock called the Grenville Province buried beneath the eastern margin of North America (Figure NY-NJ.4). Radiometric dating of minerals within these rocks yields an age of metamorphism of around 1.1 billion years ago (Ga) and source material ages that reach back to greater than 1.8 Ga. Large regions of high-grade metamorphic rock, such as schist, gneiss, marble, and amphibolite, are produced when tectonic plates converge, bringing continental crust into collision to produce a high mountain range. As the crust compresses and thickens in the collision zone, rock beneath the rising peaks subsides to great depth and is subjected to intense heat and directed pressure (stress) over millions of years. The Grenville Province represents the roots of a high mountain range that formed along the eastern margin of North America as an older geotectonic cycle drew to a close, bringing another continent into collision with North America. The identity of the other continent is uncertain, but recent geological research suggests that a fragment of South America called **Amazonia** is the most likely candidate.

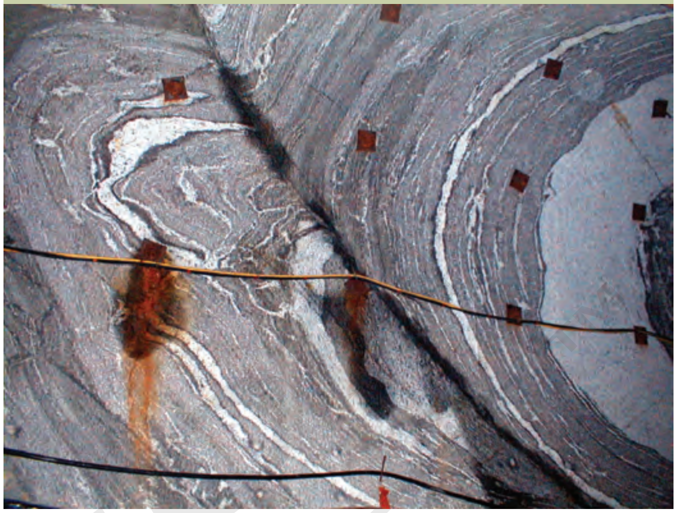
Although buried beneath much younger rock and sediment in most places, Grenville rock can be studied because younger plate tectonic collisions have folded and faulted the older bedrock, bringing it to the surface in several regions.

▶ Figure NY-NJ.4 Map showing the extent of both buried and exposed Grenville metamorphic rock in eastern North America, including named Grenville massifs.



The Fordham Gneiss is folded within younger, Early Paleozoic age metamorphic rock of the Manhattan Prong Province and can be seen exposed in the Bronx in New York City and along I-287 in Westchester County. Tunneling for New York City's water supply has also revealed the Fordham Gneiss in the subsurface of Brooklyn and Queens, beneath western Long Island (Figure NY-NJ.5). The largest region of Grenville rock in the Tri-State area (northern New Jersey, southern New York, and western Connecticut) forms a northeast trending terrain called the Reading-Ramapo-Hudson **massif**, or simply the Grenville Highlands. This province is an extension of the Blue Ridge province to the south and the Berkshire and Green Mountain provinces to the north (see Figure NY-NJ.4). Isolated regions of Grenville Highlands called the Housatonic massif and the Athens and Chester domes can be found in northwestern Connecticut and Vermont. In New York State, the Adirondack Mountains are etched into a roughly circular region of Grenville-age bedrock that is currently being pushed upward by tectonic forces. Erosion has stripped away the younger layers of sedimentary rock to reveal the older metamorphic rock in the Adirondack region. Some of the rock of the high peaks region of the Adirondack Mountains is composed of metamorphosed **anorthosite**, a peculiar igneous rock formed almost exclusively of plagioclase feldspar (Figure NY-NJ.6).

▶ Figure NY-NJ.5 Folded and faulted Fordham Gneiss exposed in the wall of the excavation for the Queens Water Tunnel, New York City Water Tunnel #3. Note the folded gneissic layers and the distinct brittle fault running diagonally across the center of the image.



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The geology within the Grenville Highlands is a complex mixture of metasedimentary and metaigneous rock types, all highly deformed and cut by numerous faults. These rocks record a 300-million-year history of plate convergence and collision associated with the Grenville Orogeny (see Figure NY-NJ.2). The high grade of metamorphism and extreme structural complexity of the rocks, combined with a relative lack of exposure in the humid northeast (indeed, rocks are easier to study in arid environments where soils are thin and plants are scarce), have

▶ Figure NY-NJ.6 Outcrop of anorthosite in the Adirondack Mountains, NY Route 3 near Saranac Lake, New York. Note the large, elongate crystals of bluish gray twinned plagioclase feldspar.

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▶ **Figure NY–NJ.7** Strike-slip fault valley, Harriman State Park, Hudson Highlands, New York. The ridge in the foreground on the right is the same as the ridge in the background on the left, but both ridge segments have been displaced by horizontal movement along a fault. Grenville rocks are typically glacially sculpted, as shown by the rounded ridge profiles in this view.

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presented a challenge to geologists trying to decipher the details of the Grenville orogenic event. Recent geological mapping in the Hudson Highlands has found evidence for the development of a **subduction zone** off the east coast of North America at about 1.2 Ga, leading to collisions with a **volcanic island arc** and another continent by 1.02 Ga. This was followed by episodes of igneous intrusion, and finally by strike-slip faulting (Figure NY-NJ.7) and rapid erosion to produce the Grenville Province, the ancestral roots of the Appalachian Mountains.

Section New York–New Jersey.2 Summary

- The metamorphic bedrock of the Grenville Highlands Province in New York, New Jersey, and New England was formed during a plate tectonic collision between North America and Amazonia, more than 1 Ga ago. Grenville-age rock underlies much of eastern North America.
- The Grenville Orogeny took place during the assembly of supercontinent Rodinia, near the end of the Proterozoic Eon.

New York–New Jersey.3
Carbonate Seas and the Taconic Orogeny

Although recognized only locally in the New York–New Jersey area, geological evidence for rifting and the breakup of Rodinia hundreds of millions of years after the uplift of the Grenville Mountains can be seen in the Blue Ridge region of Maryland, Virginia, and North Carolina. In the Northeastern United States the eroded roots of the Grenville Mountains are directly overlain by formations such as the Potsdam Sandstone and the Lowerre and Poughquag Quartzite, composed of layers of shoreline sands and gravels deposited as sea level rose and flooded eastern North America near the beginning of the Paleozoic Era. Five hundred million years of time go unrecorded, marked only by a **nonconformity** between the older metamorphic rock and the younger strata. During the Cambrian Period, shallow seas covered much of the North American continent, then situated astride the equator. Initially, as plate tectonic motions opened up the Iapetus Ocean basin, uplift and tectonic activity were absent from eastern North America, resulting in a **passive continental margin.** A warm, tropical climate and the absence of eroding mountains created ideal conditions for the growth of the marine organisms that produce limestone, allowing an enormous thickness of carbonate rock (Figure NY-NJ.8) to accumulate in a broad carbonate platform (a modern example would be the Great Barrier Reef in Australia). Farther offshore, away from the carbonate platform, terrigenous muds accumulated in the deeper water away from the margin of the continent. By the end of the Cambrian Period, a dislocation in the seafloor off the coast of North America created a subduction zone. The Iapetus Ocean basin stopped widening and began to close as the continent and the oceanic plate began to converge by the process of subduction. Volcanism associated with the subduction zone formed a volcanic island archipelago, similar to modern-day Indonesia. As subduction continued, this volcanic landmass was brought into collision with North America beginning in the Middle Ordovician, causing the Taconic Orogeny (Figure NY-NJ.9).

▶ **Figure NY-NJ.8** Shallow-water platform carbonates exposed in the Cambro-Ordovician Wappinger limestone, Wappinger Falls, New York.

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Evidence for the Taconic Orogeny can be seen in the rocks exposed in the Manhattan Prong, Great Valley, and Taconic Allochthon geological provinces (see Figure NY-NJ.1). In fact, the Taconic Orogeny is more completely represented than any other in the Tri-State region. In the vicinity of New York City and western Connecticut, much of the bedrock is medium- to high-grade metamorphic rock, produced in the crustal roots of the Taconic Range, where sedimentary layers deposited earlier were caught between the colliding landmasses. Sandstones and limestones of the carbonate platform were metamorphosed into quartzite and marble (for example, the Lowerre Quartzite and Inwood Marble of New York City, the Woodville Marble of Connecticut, and the Stockbridge Marble of Massachusetts), whereas offshore mudstones were transformed into schist (the Manhattan Formation exposed in parts of New York City) and the sedimentary layers of mudstone and graywacke associated with the volcanic island arc were changed into schist, granofels, and amphibolite of the Hartland Formation of Manhattan, the Bronx, and western Connecticut (Figure NY-NJ.10). A major geological boundary called **Cameron's Line**, mapped through the middle of the Manhattan Prong, separates metamorphic rocks associated with the North American continent from those associated with the colliding volcanic island arc. Cameron's Line is a ductile shear fault within an accreted subduction zone (suture)—an illustration of how continents grow over time as tectonic collisions weld new segments of crust to their margins.

In addition to metamorphism, convergent orogenies have other important geological effects. Adjacent to the axis of mountain building, sedimentary layers are shoved, causing them to fold and move along **thrust faults**. In some cases, large regions of existing rock may be displaced by many kilometers, forming an **allochthon**. During the Taconic Orogeny, offshore shales deposited adjacent to North America were pushed westward on top of the rocks of the carbonate platform, resulting in the Taconic Allochthon. The modern Taconic Mountains along the east side of the Hudson River in New York are composed of slates, phyllites, and schists that were displaced as much as 100 kilometers and metamorphosed in a former subduction zone (see Figure NY-NJ.10). The crustal thickening associated with the formation of a mountain range can also cause the formation of a foreland basin on the continent as the weight of the orogen (mountain belt) depresses the adjacent crust. (A useful analogy is to imagine a bowling ball placed on a mattress—the bowling ball protrudes above the mattress while at the same time depressing the mattress around it.) As the rising mountains weather and erode, the gravel, sand, and mud produced become deposited in the adjacent foreland basin. During the early stages of the Taconic Orogeny, enormous quantities of sediment were transported westward, accumulating as thick deposits of sandstone, siltstone, graywacke, and shale, now

▶ **Figure NY-NJ.9** Diagram illustrating the change in the continental margin of eastern North America from a passive margin to a converging plate boundary, leading to a collision with a volcanic island arc during the Taconic Orogeny.

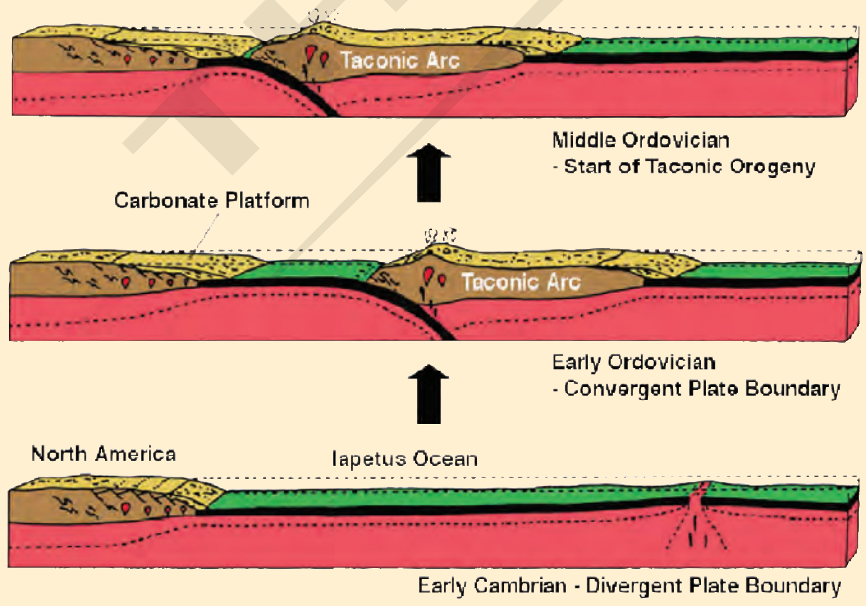

Figure NY-NJ.10 Three examples of Ordovician rocks deformed during the Taconic Orogeny.

ⓐ Inclined blackish gray shale and graywacke of the Normanskill Formation exposed in Johnson-Iorio Park, Highland, New York.

ⓑ Refolded slaty cleavage in greenish slate and siltstone of the Taconic sequence exposed along Dutchess County Road 21, Noxon, New York.

ⓒ Refolded folds of foliation in schist and granofels of the Hartland Formation, Central Park, New York City.

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exposed as the Martinsburg (Pennsylvania and New Jersey) and Normanskill Formations (New York) in the Great Valley Province (see Figure NY-NJ.10). Toward the end of the Taconic Orogeny, these strata were also shoved by tectonic forces, causing folding, uplift, and erosion of the layers to the east and even metamorphism of some of the strata closer to the orogen.

Section New York–New Jersey.3 Summary

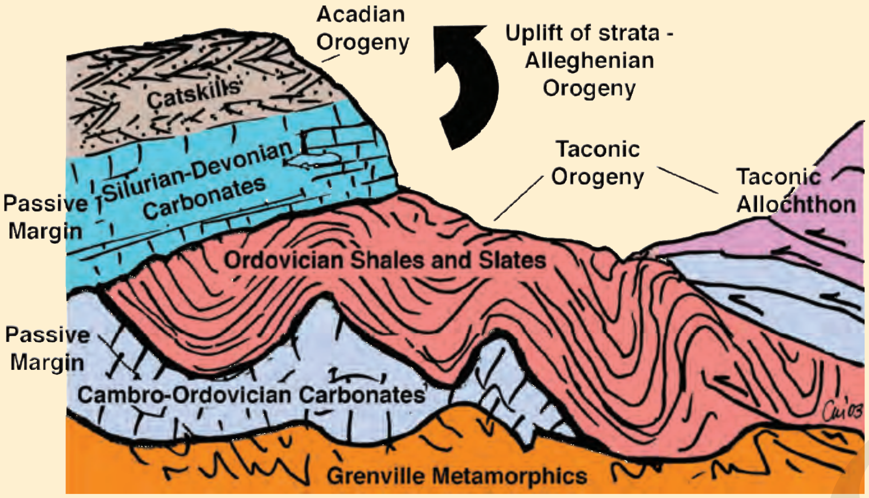
- Passive margin conditions at the beginning of the Paleozoic Era led to the deposition of nearshore sands and gravels and shallow-water carbonates in New York and New Jersey. Deposition of carbonates ended with the initiation of the Taconic Orogeny, a collision between eastern North America and a volcanic island arc.
- Evidence for the Taconic Orogeny can be found in the metamorphic rock of the Manhattan Prong and Taconic Allochthon, and in the sedimentary rock of the Great Valley Province.

New York–New Jersey.4

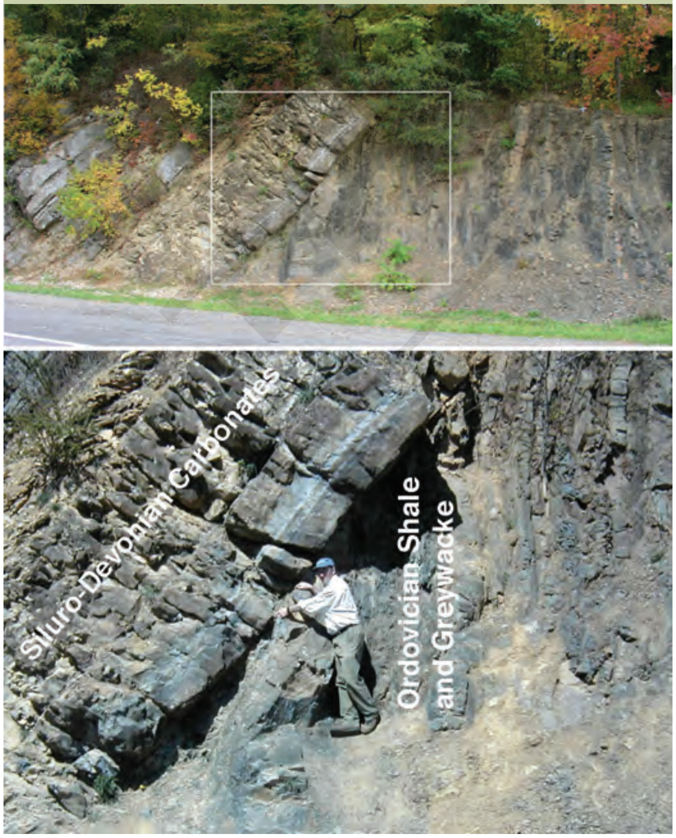
Assembly of a Supercontinent

The Taconic Orogeny marks the first of three collisions that impacted eastern North America during the closing of the Iapetus Ocean basin, culminating in the assembly of supercontinent Pangaea. Evidence for the later two orogenies in the Tri-State region can be seen in the rocks of the Manhattan Prong, Valley and Ridge, and Allegheny-Catskill Plateau provinces (Figure NY-NJ.11). Following the Taconic Orogeny, weathering and erosion leveled the mountains, creating a surface of unconformity across the region (Figure NY-NJ.12). In the Late Silurian Period, rising sea level again flooded the eroded eastern margin of North America. Coastal river systems draining now-vanished uplands to the east carried vast quantities of quartz gravel and sand, depositing them along the shoreline to form the extensive conglomerate and sandstone layers of the Shawangunk-Kittatinny Formation. Today, these formations underlie a prominent ridge (Figure NY-NJ.13) marking the eastern edge of the Valley and Ridge Province that extends from southeastern New York (the Shawangunk Ridge) south through New Jersey (Kittatinny Mountain) and Pennsylvania (Blue Mountain). By the Late Silurian Period and into the Early Devonian Period, deposition of sand gave way to limestone formation as tropical marine waters covered much of North America. This temporary return to passive margin conditions allowed the development of another carbonate platform across eastern North America, leading to the deposition of the Helderberg Group of carbonate formations. Helderberg limestones outcrop along the western edge of the Valley and

▶ **Figure NY-NJ.11** Illustration showing the rock types and record of tectonic events preserved in a cross section of the Hudson Valley region. Compare with Figure NY-NJ.12.



▶ **Figure NY-NJ.12** Taconic angular unconformity exposed at New York State Thruway approach road, NY Route 23, Leeds, New York. Note the vertically inclined Ordovician shale and greywacke truncated by dipping Silurian and Devonian carbonate strata. Late in the Taconic Orogeny, sediments shed from the Taconic Mountains were uplifted and eroded down to a flat surface. After submergence during the Late Silurian and Early Devonian Periods, carbonate sediments were deposited above the Taconic erosion surface. Eventually, during the Alleghenian Orogeny, the entire sequence was uplifted and tilted to the west. Compare with Figure NY-NJ.11.



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Ridge and along the margin of the Allegheny-Catskill Plateau. Fossils of brachiopods, crinoids, **stromatoporoids**, and corals are abundant in these Devonian limestones. An abrupt shift from passive margin to collisional tectonics in the Middle Devonian is shown by a change from shallow-water carbonate rocks to deep-water shales, marking the onset of the Acadian Orogeny. Closure of the northern Iapetus Ocean in the Devonian brought northern Europe, Greenland, and North America into collision. In the New England region, a small continental landmass named Avalonia collided, pushing up high mountains. As the Acadian mountains weathered and eroded, vast quantities of **terrigenous sediments** were transported southwestward by rivers and deposited into a foreland basin across New York, New Jersey, and Pennsylvania. Today, the thick sequence of layers of conglomerate, sandstone, and mudstone produced from these sediments is exposed in the Allegheny-Catskill Plateau. Middle Devonian marine strata changed over to Late Devonian terrestrial **red beds** (see Figure NY-NJ.3) as the foreland basin filled to sea level with sediment. Even if geologists had no evidence of Acadian metamorphism from New England, they would still recognize the Acadian Orogeny from the enormous pile of eroded sediment shed from these ancient mountains. Tectonic activity associated with the Acadian Orogeny continued into the Mississippian Period. Although there are few Mississippian-age strata present in the New York–New Jersey region (they are present in Pennsylvania and farther south), Devonian- to Permian-age igneous intrusives are found in the Manhattan Prong.

The final closure of the southern Iapetus Ocean occurred during the Pennsylvanian and Permian Periods, when western Africa and eastern North America collided during the Alleghenian Orogeny. This is primarily a southern event, shown by metamorphism, folding, thrust faulting, and the deposition of enormous quantities of eroded terrigenous sediment in Pennsylvania, Maryland, Virginia, West Virginia, and farther south. In the New York–New Jersey region, the only apparent evidence for the Alleghenian Orogeny is the folding of the older rock layers seen in the Valley and Ridge and evidence for deep burial of the Devonian strata in the Appalachian-Catskill Plateau. Although Pennsylvanian-age sediments shed from the rising Alleghenian Mountains probably did once cover New York State, they subsequently eroded away. Also missing from the Tri-State region are any rocks deposited during the Permian Period. By this time, supercontinent Pangaea was formed and seafloor spreading slowed, which led to a drop in global sea level and emergence and erosion across much of eastern North America.

Figure NY-NJ.13 Prominent topographic ridge formed by Silurian Shawangunk Conglomerate.

View of Shawangunk Ridge looking south from Lake Mohonk, New York.

View south across the Delaware Water Gap, New Jersey.

J Bret Bennington

Section New York–New Jersey.4 Summary

- After the Taconic Orogeny, passive margin conditions returned to eastern North America, resulting in renewed deposition of limestone. Subsequently, two other tectonic collisions occurred as the Iapetus Ocean fully closed during the assembly of supercontinent Pangaea.

- Evidence for the Acadian Orogeny is seen in the thick pile of eroded terrigenous sediments preserved in the rocks of the Appalachian-Catskill Plateau. Evidence for the Alleghenian Orogeny is found in the folding of older rock layers seen in the Valley and Ridge Province.

New York–New Jersey.5
Breakup of Pangaea

At the close of the Paleozoic Era, the Earth's continents were assembled into a single supercontinent called Pangaea. Starting early in the Mesozoic Era, Pangaea began to fragment as upwelling mantle heat initiated rifting along the sutures formed between the original continents. By the Late Triassic Period, Africa was in the process of rifting away from eastern North America and the opening of the modern Atlantic Ocean basin had begun. Extension of the crust near and along the suture between the two continents caused the formation of a series of elongate rift valleys (Figure NY-NJ.14) similar to those that are forming in East Africa today. These rift valleys filled with sediment distributed by vast river systems and with basaltic lava flows. At depth, mantle-derived mafic intrusives were invading the rift basin fill. As the basins formed, they spread away from the active (mid-Atlantic) ridge and are now preserved as discrete geological regions along the margin of eastern North America from South Carolina to Newfoundland. Mesozoic rift basins in the Tri-State region include the Newark Basin in northern New Jersey and the Hartford Basin extending through central Connecticut and

Figure NY-NJ.14 Map showing locations of Triassic-Jurassic rift basins along the eastern margin of North America.

Adapted From: Figure 2.17a from Monroe-Wicander-Hazlet, Physical Geology, Sixth Ed. (2007).

Figure NY-NJ.15 Geological cross section of the Newark Basin from the Ramapo fault bordering the Ramapo Highlands eastward to the nonconformity above metamorphic rocks of the Manhattan Prong.

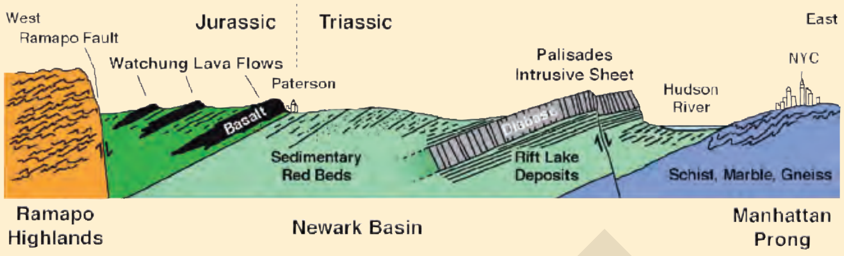

Figure NY-NJ.16 Stacked Early Jurassic lava flows of the Orange Mountain Basalt exposed at the Great Falls of Paterson, New Jersey. Here, at the Paterson Gap, the Passaic River has exploited a fault in the basalt to erode a short canyon, creating the waterfall. Locate the position of this photo on the diagram in Figure NY-NJ.20.

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Massachusetts. These two basins have similar geological features and may once have been continuous across the Manhattan Prong, an idea supported by the presence of the small Pomperaug Basin in western Connecticut. The Ramapo-Hudson Highlands border the Newark Basin to the east along the Ramapo border fault (Figure NY-NJ.15). During the Triassic and Jurassic Periods, the metamorphic bedrock beneath the Newark Basin tilted downward along this fault, creating an elongate rift valley to the east. Rivers draining the bordering highlands fed into the basin, depositing conglomerates and sandstones as huge fans and as landslide deposits. Because the basin was a closed depression, large rift lakes filled the center of the basin during times of wet climate, only to dry up during intervals of arid climate. Sediments deposited in the rift lakes included shoreline siltstones and deep-lake black shales. Dinosaurs roamed the lakeshores, leaving behind a copious fossil record of footprints and trackways. Fossils of freshwater fish and aquatic reptiles are also found in Mesozoic basin shales. Deposition of sedimentary rock in both the Newark and Hartford Basins continued well into the Early Jurassic Period, when both basins also experienced protracted volcanic and intrusive igneous activity. Mantle-derived magma rising within the rift zone intruded the previously deposited sedimentary layers, cooling within the strata to form sheets of **diabase** rock. The Palisades Cliffs bordering the east side of the Newark Basin along the Hudson River (see cover photo) are formed from the eroding edge of a large intrusive sheet of diabase (the West Rock diabase in Connecticut is a similar feature). Some magma also reached the surface of the basin to erupt, forming extensive **flood basalt** flows. The prominent Watchung Hills in northern New Jersey are elongate ridges formed of tilted, erosion-resistant basaltic lava (Figure NY-NJ.16). Three time-separated episodes of eruption produced the three Watchung lava flows within the Newark Basin. The cooled flows were subsequently buried beneath younger sedimentary layers, and the entire sequence of rock was gradually tilted to the west by continued subsidence along the Ramapo fault. (Except for the fact that the rocks dip eastward, a mirror image of this sequence of sedimentary and volcanic strata exists within the Hartford Basin.)

Section New York–New Jersey.5 Summary

- Rifting and separation of Africa from eastern North America began in the Triassic Period as the supercontinent of Pangaea began to break up. Rift basins preserved from this event are exposed along the margin of North America, including the Newark Basin in New Jersey and the Hartford Basin in Connecticut.

- Rift basin geology includes sedimentary rocks deposited by rivers and lakes, fossil dinosaur trackways, and diabase intrusive sheets and basalt lava flows.

New York–New Jersey.6
Creation of the Atlantic Coastal Plain

Continued rifting of North America from Africa in the Jurassic Period culminated in the development of a new mid-ocean ridge system and the eruption of new seafloor crust between the previously joined continents. Deep in the subsurface of the eastern continental margin are buried rift valleys, evaporite deposits, and marine reefs that record the gradual opening of the modern Atlantic Ocean basin. As it was at the beginning of the Paleozoic, eastern North America became a deeply eroded, tectonically quiescent passive margin. As the Atlantic Ocean basin grew wider, the seafloor lithosphere attached to the edge of the continent cooled and contracted into the mantle, which induced down-warping of the margin of North America to form a broad continental shelf. The modern coastal plain is essentially the inner region of the continental shelf that is currently exposed above sea level. The history of the Atlantic Coastal Plain is one of deposition and the accumulation of sediment during times of high global sea level and exposure and erosion during times of low global sea level. As sediments are carried by rivers to the coast, gravels, sands, and muds are deposited in nearshore to offshore environments on the continental shelf. Continuing tectonic subsidence lowers the surface of the shelf, creating space for new sedimentary layers. Thus, over the past 150 million years, a thick pile of sedimentary strata has accumulated along the margin of eastern North America. These strata are tilted seaward because subsidence of the outer continental shelf occurs at a higher rate than the inner continental shelf. During times of low global sea level, such as the present, the coastal plain is exposed to erosion, with older Cretaceous deposits exposed along the northwest side of the coastal plain and progressively younger Tertiary deposits exposed to the southeast side (Figure NY-NJ.17). The topography of the coastal plain is generally flat, and most exposures of strata are found along stream banks and coastal cliffs. Also, because the sediments of the coastal plain were never deeply buried beneath overlying layers, they are compacted, but they have not been cemented into solid rock (Figure NY-NJ.18).

▶ **Figure NY-NJ.17** Geological map and cross section showing the age and succession of offshore-dipping sedimentary deposits of the Atlantic Coastal Plain. The younger strata rest above the Fall Zone planation surface, a nonconformity above crystalline bedrock.

▶ **Figure NY-NJ.18** Late Cretaceous glauconite sands of the Navesink Formation exposed in the stream bank of Big Brook, near Marlboro, New Jersey. Note the compacted but unlithified nature of these 70-million-year-old sediments; shelly fossils, such as the ammonite in the center of the photo, can easily be excavated with a trowel.


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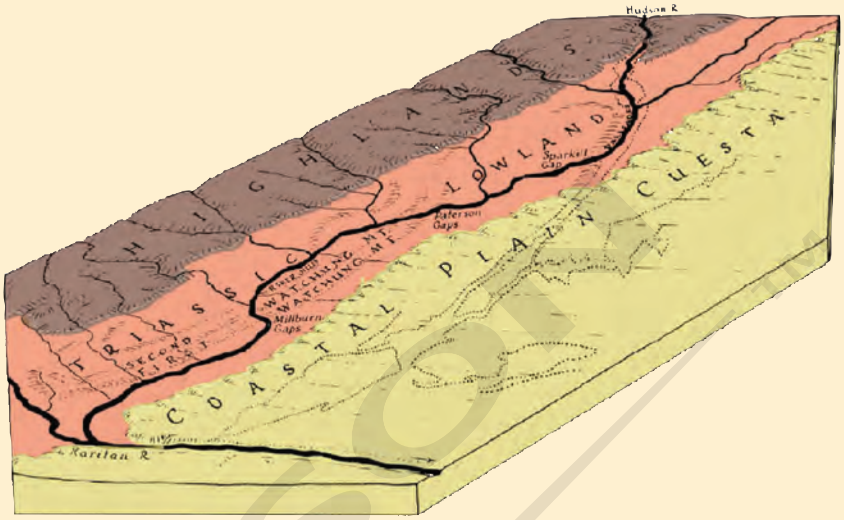
During the Late Cretaceous Period, global sea level was unusually high and eastern North America was flooded by the Atlantic Ocean well inland of the present shoreline. A lack of red-colored minerals in dominantly light-colored Cretaceous strata indicates no derivation from the erosion of Newark Basin rocks and suggests that the shoreline during the Late Cretaceous Period was located at least as far westward as the Ramapo Fault. Cretaceous and Early Tertiary deposits of the modern inner coastal plain, such as the Navesink and Hornerstown Formations, contain marine fossils (Figure NY-NJ.19) and abundant **glauconite**, a mineral that is currently found forming in deep-water outer continental shelf environments. This also implies a Cretaceous shoreline many kilometers inland of its present position. As global sea level dropped after the Miocene Epoch, the coastal plain was exposed above sea level and began to erode. Moderately

Figure NY-NJ.20 Block diagram showing blockage of the ancestral Hudson River by the inner coastal plain cuesta and the former path of the river through the Sparkill, Paterson, and Millburn Gaps across the Newark Basin to Raritan Bay. (Figure has been colorized from an original drawing of Johnson, 1931.) Johnson, D. W., 1931, Stream sculpture on the Atlantic slope, a study in the evolution of Appalachian Rivers: New York, NY, Columbia University Press, 142 p.



erosion-resistant Cretaceous strata formed a low, tilted ridge called a **cuesta** along the inner coastal plain. This cuesta controlled the drainage pattern of rivers flowing toward the coast. For example, the present course of the Hudson River was blocked by the coastal plain cuesta, causing the Hudson to flow inland across the Newark Basin and to empty into Raritan Bay south of Staten Island (Figure NY-NJ.20). During the Pliocene Epoch, uplift and erosion removed much of the coastal plain strata north of New Jersey, allowing the Hudson River to shift to its modern drainage path along the nonconformity between the Newark Basin fill and the Manhattan Prong (see Figure NY-NJ.1). The Sparkill Gap, a prominent **wind gap** that follows a fault through the northern part of the Palisades sheet, marks the place where the Hudson once flowed before the shift took place. Although covered by Quaternary glacial deposits, coastal plain strata extend northward beneath Long Island, where the thick Cretaceous sands of the Magothy and Raritan Formations hold trillions of gallons of fresh groundwater, providing irreplaceable drinking water **aquifers** for a large urban and suburban population.

Figure NY-NJ.19 Fossil mosasaur tooth embedded in jawbone fragment from the Big Brook locality near Boundary Road, New Jersey. Mosasaurs were large marine lizards that hunted fish and other reptiles in the seas of the Late Cretaceous Period. Atlantic Coastal Plain deposits often contain shelly marine fossils and the bones and teeth of both marine and terrestrial animals.

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Section New York–New Jersey.6 Summary

- The Atlantic Coastal Plain developed as the Atlantic Ocean basin began to widen during the Mesozoic and the edge of the North American continent subsided to form a continental shelf.
- During times of high global sea level, marine sands and muds were deposited far inland of the present shoreline during the Cretaceous and Tertiary Periods. These deposits are now being exposed by erosion in stream valleys along the New Jersey Coastal Plain.

New York–New Jersey.7
Ice Age Landscapes

Although the bedrock of the New York–New Jersey region is ancient, the modern features of the topographic landscape are not. The mountains of the Grenville Highlands, the Taconics, the Catskills, and the Adirondacks are Quaternary-age features, etched by streams into landscapes rejuvenated by mild tectonic uplift. In northern New Jersey, New York, and New England, the land has also been extensively modified by glacial ice. During the Pleistocene Epoch of the

Quaternary Period, beginning about 2 million years ago, global cooling fostered a series of glaciations, each of which sent immense continental ice sheets flowing southward from Canada into the United States, only to melt back during warmer interglacial periods. Each glacial advance and retreat sculpted the landscape, modifying or erasing the features left from the previous glaciation. The modern northern landscape is largely a product of the Wisconsinan glaciation, which began about 100,000 years ago, peaked at 20,000 years ago, and ended 10,000 years ago (although glacial deposits and landscape features from at least as many as two older glaciations are preserved in some places). Advancing continental glaciers flowed approximately from north to south and modified the landscape by carving, polishing, and plucking the soil and bedrock they passed over. The thickness of the Wisconsinan ice sheet was likely more than a kilometer over central New York and at least half a kilometer over northern New Jersey, and the great weight of the glacier fractured the rock below as the ice completely covered the region, filling the valleys and completely burying the mountain peaks. Evidence for glaciers overwhelming the Pleistocene topography can be seen on the bedrock surfaces at the top of the Adirondack Mountains in New York and at High Point in northwestern New Jersey. Exposed rock surfaces are smoothed and polished, giving outcrops a rounded look that geologists refer to as **roche moutonée** (French meaning "fleecelike rock"). Linear grooves and **striations** carved by ice-embedded rock fragments being dragged beneath the glacier are common features on outcrop surfaces, as are **chattermarks**, crescentic fractures caused by the weight of the ice on the bedrock (Figure NY-NJ.21). Flowing glacial ice carved deeply into preexisting stream valleys, widening their profiles into a distinctive U-shape. Glacially excavated valleys and land surfaces also contain a multitude of depressions that form natural lakes and ponds. New York and northern New Jersey, which were completely glaciated, have thousands of natural lakes. By comparison, Virginia, which was not glaciated, has only two natural lakes.

Glaciers are also significant agents of deposition. Melting glacial ice releases enormous quantities of sediment excavated from the land, from huge boulders to minute particles of clay and **rock flour**. **Erratics**, large boulders transported by glaciers, are common features of northern landscapes. Glacial deposits (**drift**) can be divided into two main types (Figure NY-NJ.22). **Till** is an unsorted mix of particle sizes combining boulders, sand, and clay that is released directly in contact with melting ice. Stratified drift or outwash is sorted and layered sediment that is transported away from the ice by flowing meltwater. Glaciated landscapes are typically mantled with a combination of till and outwash that often fills glacially carved valleys. The Finger Lakes of central New York are north-south trending, U-shaped, glacial valleys that are dammed at their southern ends by glacial sediments. The lower reach of the Hudson River is a fiord, a glacially carved valley that is flooded by the sea. However, the river itself is only a fraction of the depth of the Hudson Valley, most of which is filled in with glacial drift. Till that accumulated beneath the flowing glacier was sculpted into

▶ Figure NY-NJ.21 Features associated with recently glaciated landscapes.

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ⓐ Bedrock at the top of Bear Mountain, New York, rounded into roche moutonée form. Also visible are chattermarks, faint striations, and a small erratic boulder of Silurian Green Pond Conglomerate, which indicates that the ice flowed from the northwest.

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ⓑ Glacially striated bedrock surface in Central Park, New York City, New York.

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ⓒ Large erratic boulder of igneous bedrock plucked from the floor of Long Island Sound and deposited on the north shore of Long Island near Sound Beach, New York.

▶ Figure NY-NJ.22 Comparison of two major types of glacial drift.

ⓐ Till—an unsorted mixture of boulders, gravel, sand, and mud exposed at the east end of Caumsett State Park, Long Island, New York.

ⓑ Stratified drift (outwash)—poorly to well sorted layered pebbles and sand exposed at the west end of Caumsett State Park, Long Island, New York.

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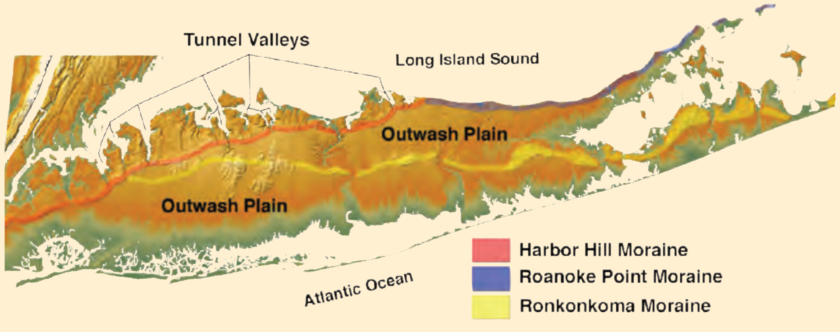
streamlined, tear drop–shaped hills called drumlins. Swarms of north-south–oriented drumlins are present in the Hudson Valley and south of Lake Ontario in western New York.

Glacial sediments accumulated at the southern margin of the ice sheet, where rock and sediment were delivered by flowing ice and then released by melting, piling up to form a linear hill called a moraine. The moraine that marks the farthest extent of ice advance is the terminal moraine, and moraines that form during pauses in the retreat of an ice sheet are recessional moraines. Long Island is a large glacial deposit made up of a combination of till and outwash deposited as a series of moraines resting on top of older coastal plain sediments. The twin forks at the eastern end of Long Island are formed from two of the moraines, the Roanoke Point Moraine and the Ronkonkoma Moraine (Figure NY-NJ.23). A third moraine, the Harbor Hill Moraine, truncates the Ronkonkoma Moraine and extends along the northwestern third of Long Island and may or may not be an extension of the Roanoke Point Moraine to the east. To the west, the Harbor Hill Moraine continues along the southeastern coast of Staten Island and joins with the Bangor Moraine in northern New Jersey. Erosion of the moraines by waves has stranded thousands of erratic boulders along the north shore of Long Island. North of the Harbor Hill Moraine, the landscape is cut by a series of short, steep-sided valleys that terminate along the margin of the moraine. Most of these are **tunnel valleys**, carved beneath the ice sheet by flowing streams of subglacial meltwater. Several large tunnel valleys form harbors between the necks of land on the western north shore of Long Island. South of the moraines on Long Island are flat, gently sloping outwash plains composed of stratified deposits of outwash sand and gravel. The moraines themselves are composed of a combination of till, stratified drift, and in the Harbor Hill Moraine, large blocks of the underlying Cretaceous coastal plain strata that were bulldozed in front of the advancing ice. The landscape of the moraines is an irregular mix of knobby hills and depressions called kame and kettle topography, formed as pockets of rock debris within the glacier were released alongside blocks of ice buried in drift as the ice front wasted away. Kettle ponds are also common features in valleys of northern New Jersey and New York that host deposits of glacial drift. An interesting feature of kettle ponds is that they sometimes contain the bones of extinct ice-age mammals. Skeletons of mammoths and mastodons, two species of extinct North American elephant, continue to be found on occasion in New York and New Jersey. Despite almost a billion years of geological history, the ultimate

▶ Figure NY-NJ.23 Digital elevation model of Long Island showing the three major moraines, outwash plains, and tunnel valleys.



development of our northern landscape is largely the result of glacial erosion, deposition, and the work of running water liberated in the end stages of Pleistocene glaciation.

Section New York–New Jersey.7 Summary

- The landscape of northern New Jersey, New York, and New England was modified extensively by glacial ice during the Wisconsinan glaciation. Glaciers carve and erode the landscape as they advance and also create distinctive landforms by depositing sediment when they melt.
- Glacial striations, roche moutonée, and erratics are common glacial features in the region. Long Island is composed of several glacial moraines and outwash plains.

New York–New Jersey.8

Economic Mineral Resources

Many types of economic mineral deposits, including iron, zinc, cement, building stone, and **aggregate** (crushed rock, gravel, and sand), have been mined and quarried in the New York–New Jersey region going back to colonial times. On a smaller scale, emery, copper, cobalt, mica, clay, and feldspar were also mined. Except for limestone, trap rock, sand, and gravel, mining has ceased in this region because of the discovery of richer, more economic sources of ore elsewhere, or because of environmental considerations. Iron mining in Connecticut began in 1658 by exploiting deposits associated with igneous rock in the Hartford Basin near East Haven. The large-scale extraction of iron ore in northwestern Connecticut began in 1762. Starting by 1710 in Whippany, New Jersey, iron was mined in the metamorphic rock of the Grenville Highlands, exploiting ores of limonite, magnetite, and hematite. Hundreds of small pits and prospects line the hills of the Ramapo-Hudson Highlands through New York and New Jersey (Figure NY-NJ.24). In the late 1700s, many of these mines supplied iron for the Continental Army. The Colonial forges were situated in valleys underlain by folded Paleozoic carbonate rocks in the highlands or in the Great Valley and Valley and Ridge provinces northwest of the highlands, where access to abundant wood, running water, and limestone (for flux) made it possible to smelt the highland ores into pig iron. During the Revolutionary War, the Americans placed iron chains and booms across the Hudson River to prevent the British Navy from using the river to divide the northern and southern colonies. One of these was the great iron chain strung across the river at Fort Montgomery in New York. The remains of the Fort Montgomery chain can be seen at the Bear Mountain Lodge, located at the base of Bear Mountain in the Hudson Highlands.

▶ **Figure NY-NJ.24** The Black Ash Iron prospect in the Proterozoic Hudson Highlands in New York is typical of the hundreds of small magnetite prospect pits found throughout the Ramapo-Hudson Highlands.

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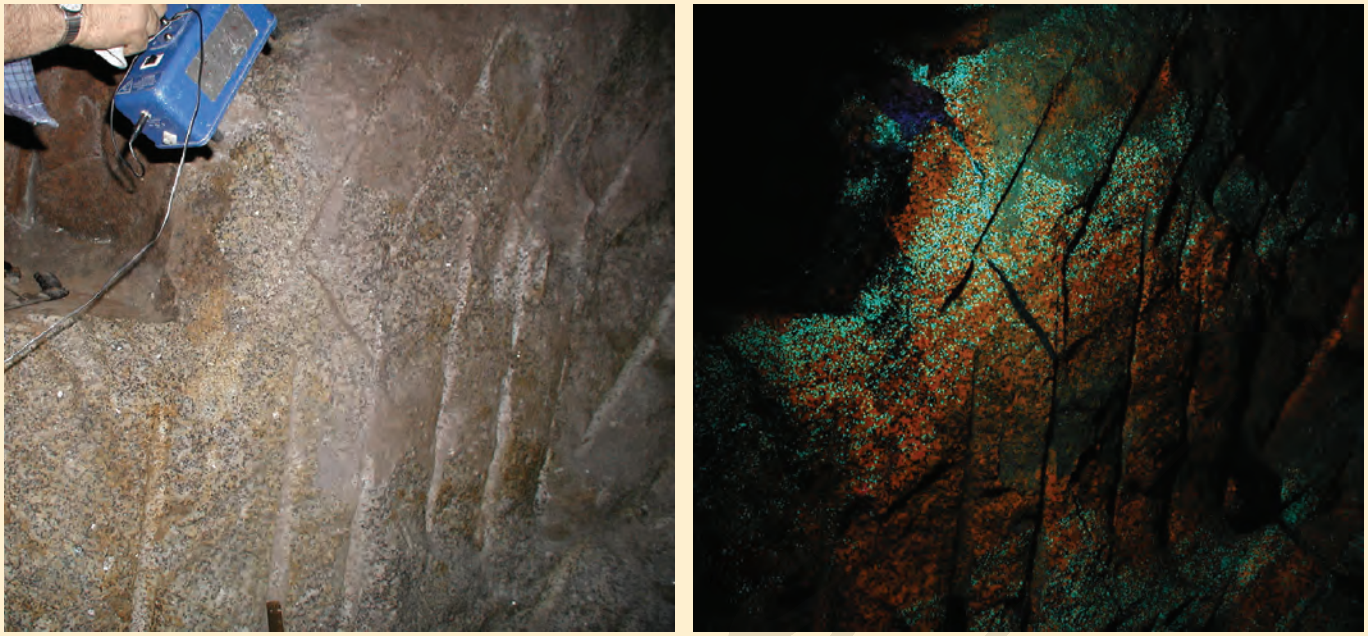
Nestled among the hilly areas of northwest New Jersey are the globally unique Franklin (Mine Hill) and Ogdensburg (Sterling Hill mine) zinc-iron-manganese ore deposits. These deposits have yielded nearly 300 different minerals, roughly 10% of all known minerals and a number vastly greater than from any other single region in the world. Amazingly, more than 60 of these minerals exhibit fluorescence or phosphorescence when illuminated by ultraviolet light (Figure NY-NJ.25). Four minerals constitute the primary ore group: franklinite (a spinel-type oxide mineral of zinc, manganese, and iron), willemite (a zinc silicate), zincite (a zinc-manganese oxide), and calcite, much of which contains manganese. Franklinite and zincite, abundant in the Franklin area, have been found in only trace amounts elsewhere. Both of these famous zinc mines are now closed. The last ore was lifted from the Franklin Mine in 1954 and at Sterling Hill in 1987. Fortunately, the site of the Franklin Mine now hosts the Franklin Mineral Museum, and the nearby Sterling Hill Mine has been preserved as it was when mining ended. At Sterling Hill, in addition to seeing one of the world's largest collections of fluorescent minerals, visitors can tour the mine buildings and walk through the upper level of the mine itself to experience mining an ore body from inside of the Earth.

Concrete is composed of sand and gravel held together by cement. In Rosendale, New York, located in the Valley and Ridge Province north of Poughkeepsie, a cement industry sprang to life in 1825, when deposits of Silurian **dolostone** and limestone were found to offer a source of natural cement (Figure NY-NJ.26). These cement stones were quarried because the dolomitic layers contain just the right amount of quartz silt to make cement when roasted. Rosendale cement provided much of the cement for construction in New York City in the late 1800s and was used in many famous public structures, including the foundations and piers of the Brooklyn Bridge, the base of the Statue of Liberty, the Treasury Building in Washington, DC, and the Kensico and Ashokan Reservoir dams of the New York City water supply system. By 1910, the Rosendale cement industry was made obsolete by the development of the Portland cement process, which can use

▶ **Figure NY-NJ.25** Extraction of the Sterling Hill ore was aided by using ultraviolet light in the mining process to sort the different mineral phases. Manganiferous calcite, one of the associated gangue minerals, fluoresces bright orange. Willemite, a valuable ore mineral, fluoresces bright green.



ⓐ Ore body viewed in white light.

ⓑ Ore body fluorescing in ultraviolet light.

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more common and voluminous Devonian limestones. Even today, barges loaded with Portland cement travel up and down the Hudson River from cement mines near Kingston, Catskill, Hudson, and Ravena, New York.

Although unglamorous, the single most economically valuable type of rock is building stone and aggregate. Quarried rock is used for building stone and decorative facing (for example, polished marble or granite), and crushed rock, gravel, and sand (aggregate) are used for building roads and making concrete. Specific examples of regional sources of building stone and aggregate are as follows:

▶ **Figure NY-NJ.26** Rosendale cement was mined using the room and pillar method wherein the roof of the mine is supported by pillars of unmined rock. Abandoned mines such as the one pictured here are common in the Rosendale-Tillson area of New York. Several mines are now used as underground storage facilities for corporate document archives and for mushroom farms.

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- Pleistocene Glacial Drift: construction fill and sand for concrete
- Mesozoic arkose sandstone (Newark, Pomperaug, and Hartford Basins): building stone ("brownstones") used extensively in Philadelphia, New York, and New Haven
- Mesozoic diabase: crushed aggregate (trap rock) for roads and railway beds
- Paleozoic shales: construction fill and road metal
- Paleozoic marble and limestone: building stone
- Proterozoic and Paleozoic granites: building stone

Section New York–New Jersey.8 Summary

- Although most mining has now ceased in the Tri-State region, historically important deposits of iron, zinc, copper, and manganese were mined beginning in the 1600s.
- Quarrying of rock and sediment for cement, concrete, aggregate, and building stone continues to be an important economic activity in the region.

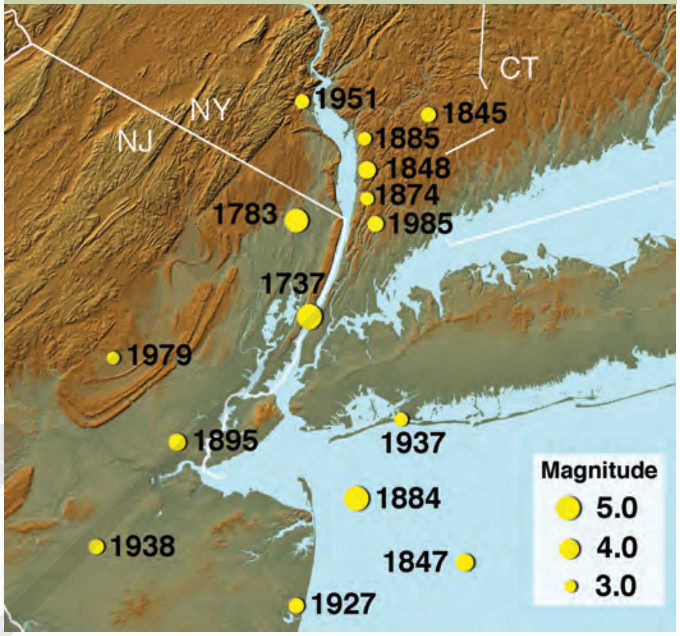
New York–New Jersey.9

Geological Hazards of the Region

The New York–New Jersey metropolitan region is located along a passive continental margin with low mountains and no major forms of active tectonism. Unlike the West Coast, the

East Coast does not experience frequent, large earthquakes or subduction-induced volcanism. But this does not mean that the East Coast is free of geological hazards. The historical record of **seismicity** in the East does show that significant earthquakes do occur, they just do not occur very often relative to the span of human experience. The crystalline bedrock that underlies the eastern margin of North America is cut by numerous brittle faults, most of which are potentially active. Some of these faults have had a discernible impact on the modern topography. For example, New York City is cut by a multitude of steep north-northeast–trending faults of probable Mesozoic age and a set of younger northwest-trending brittle faults. The Manhattanville fault at 125th Street underlies a broad U-shaped valley, and another one of the northwest-trending faults, the 14th Street fault, has lowered the bedrock surface, creating a subsurface valley filled with glacial drift. Because of the expense of anchoring tall buildings in unconsolidated sediments, the average height of the buildings is lower in the area of Manhattan between 23rd and Canal streets, creating the familiar dip in the Manhattan skyline between Midtown and the Financial District (Figure NY-NJ.27). Although earthquakes generated by movement along these faults are rare events, the historical record shows that they do happen. The New York metropolitan region experienced three earthquakes of approximately magnitude 5 on the Richter scale in the 1700s and 1800s (Figure NY-NJ.28). More recently, in 2001, two earthquakes with magnitudes near 2.5 occurred in Midtown and upper Manhattan. Although small relative to seismic events in California, an earthquake of magnitude 5 occurring in present-day Manhattan would have potentially catastrophic effects, particularly for older buildings,

▶ **Figure NY-NJ.28** Map of historical seismicity in the New York City region. All earthquakes greater than 3.0 on the Richter magnitude scale are plotted. Locations for older earthquakes are approximate. The three largest earthquakes recorded are estimated to have been 5.2 (1884), 5.2 (1737), and 4.9 (1783), and all are reported to have generated enough shaking to knock over chimneys and open large cracks in the ground. Equivalent shaking today would likely shatter glass windows in skyscrapers, rupture water mains as soils liquefied, and cause some failure of older masonry walls.



▶ **Figure NY-NJ.27** Aerial view of the Manhattan skyline showing how building height is controlled by the subsurface geology. In the Financial District (left center) and Midtown (right of center), buildings are taller because they can be anchored in bedrock that is nearer the surface. In between, the buildings are shorter because the bedrock surface drops along faults, creating a valley that has been glaciated and filled with unconsolidated glacial sediments, which are not good for supporting tall buildings.

Charles Merguerian

which lack modern reinforcement. Another potential problem during a moderate earthquake is the **liquefaction** of soils and unconsolidated sedimentary fill. Many buildings along the shoreline of Manhattan Island are constructed on fill and may experience amplified shaking during a moderate earthquake. The infrastructure of cities in the Northeast is not engineered to withstand earthquake motion as it is on the West Coast, because most people do not recognize earthquakes as a hazard. However, it is sobering to consider that the Charleston, South Carolina earthquake of 1886 was magnitude 7.2 and completely destroyed that city, which is located in a geological setting (passive continental margin with ancient, deformed crystalline rocks beveled beneath coastal plain strata) very similar to that of New York City.

The same warning given for earthquakes can also be applied to hurricanes. Although the Northeast coast is not impacted by hurricanes as much as the Florida or Gulf coasts, the historical record shows that the New York–New Jersey metropolitan region has experienced significant, destructive hurricanes in the recent past (Figure NY-NJ.29). Hurricanes are notorious for bearing destructive winds, but less appreciated (at least before the impact of Katrina on New Orleans) is the devastating flooding that hurricanes often cause. **Storm surge** generated by winds piling water up against the coastline causes coastal flooding, and high-volume rainfall produces inland flooding. The damage done by coastal flooding is magnified by the fact that the coastlines and barrier islands of the Northeast have experienced a huge surge in population and infrastructure over the past half century. Barrier island communities such as Long Beach in New York and Atlantic City in New Jersey are also particularly vulnerable because of rising sea level. Recent global sea level rise has been estimated to be about 15 cm (6 inches) per 100 years, whereas sea level rise at Atlantic City has been measured to be 38 cm (15 inches) per 100 years. The higher rate of sea level rise in the New York–New Jersey region is likely due to sinking of the coastline caused by tectonic subsidence or the compaction of sediments beneath the coastal plain. In any case, rising sea level makes barrier islands and coastlines more vulnerable to storm waves and coastal

▶ **Figure NY-NJ.29** Map showing tracks of hurricanes that have impacted the coast of New York and New Jersey from 1900 to 2005. The most destructive storm was the so-called Long Island Express, which struck eastern Long Island and New England in 1938. This storm was a Category 3 with 121 mph sustained winds and a northward velocity of 70 mph when it crossed Long Island. Parts of eastern Long Island, western Connecticut, and Rhode Island were devastated, with 700 people killed and more than 8,000 homes destroyed. (Base map courtesy of National Oceanic and Atmospheric Administration)

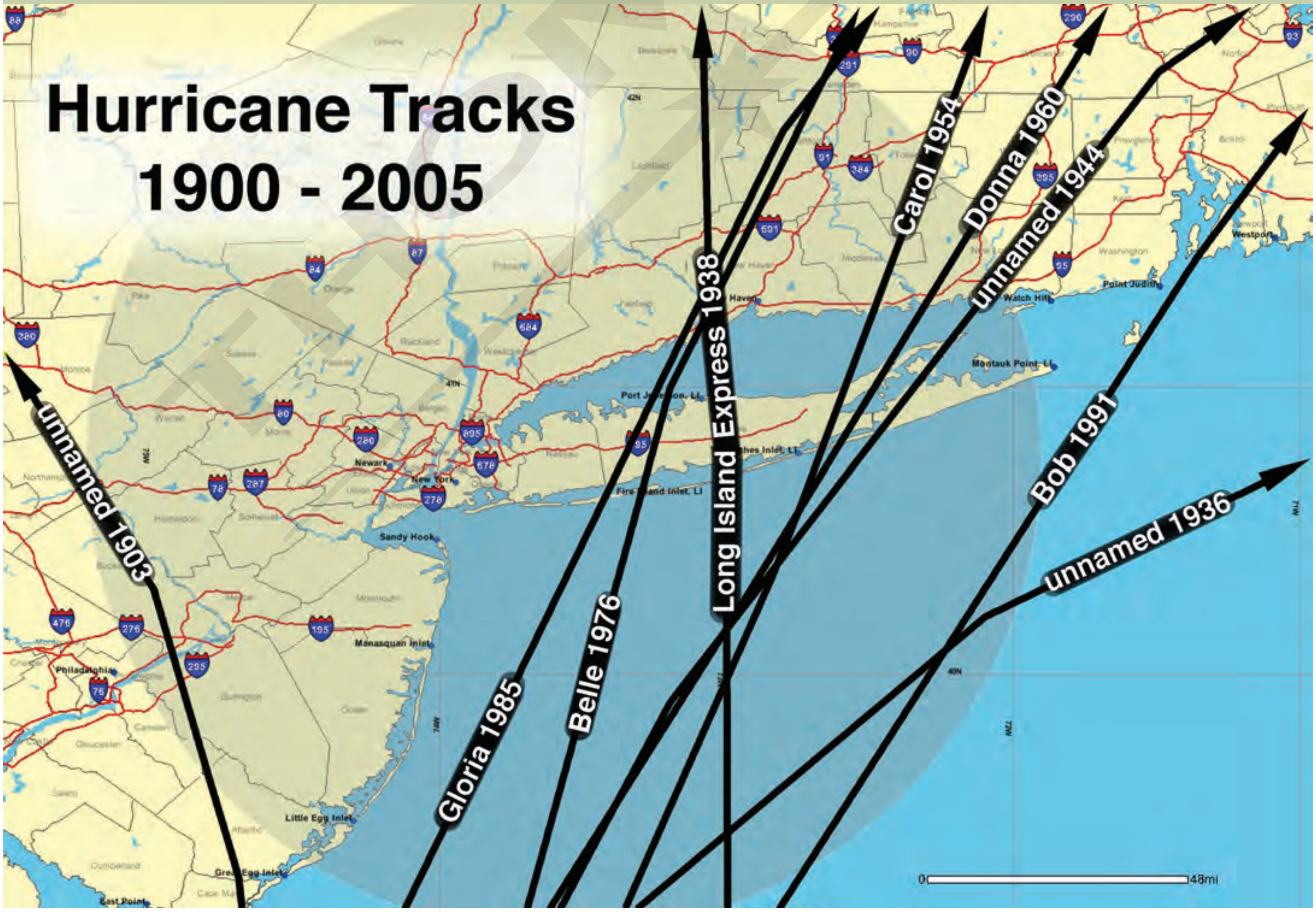


Figure NY-NJ.30 Photos of the breach in the Fire Island barrier beach at Westhampton, New York, caused by winter storms in 1992–1993.

U.S. Army Corps of Engineers

ⓐ Although still standing in the photo, these homes were quickly claimed by the sea as waves eroded the sand supporting them.

ⓑ View of the final quarter-mile breach with Moriches Bay and the south shore of Long Island in the background.

flooding. This was dramatically illustrated on Long Island in 1992–1993, when winter storms caused a quarter-mile breach in the barrier island at Westhampton, opening a channel between Moriches Bay and the Atlantic Ocean and destroying more than 80 homes (Figure NY-NJ.30). Repairing the breach and restoring the sand to allow the homeowners to rebuild cost the taxpayers of New York almost $50,000,000. This cost, however, would pale in comparison with the expense and destruction of a major hurricane strike on the New York–New Jersey coast, an event that has happened in the past and will happen again. Similar to earthquake hazard, it is only a matter of time.

Section New York–New Jersey.9 Summary

- The New York–New Jersey region has an historical record of moderate earthquake events and thus should be considered a seismically active area. A damaging earthquake will eventually occur in this area.
- This region also has a history of damaging hurricanes and other coastal storms. The combination of a surging coastal population and rising sea level will amplify the damage and loss of life during the next significant hurricane event.

Review Workbook

ESSENTIAL QUESTIONS SUMMARY

New York–New Jersey.1 Introduction

▪ *What duration of time and what geological eras are recorded in rocks of the New York–New Jersey region?*
More than a billion years of geological time are recorded in the region, representing the Proterozoic Eon and Paleozoic, Mesozoic, and Cenozoic Eras.

▪ *What are the names of convergent orogenic events that took place during this time interval?*
The Grenville, Taconic, Acadian, and Alleghenian Orogenies.

New York–New Jersey.2 Ancient Roots of the Grenville Orogeny

▪ *The Grenville orogeny was part of the assembly of a Proterozoic supercontinent. What is the name of the supercontinent?*
The supercontinent was Rodinia.

▪ *Name five places within 100 miles of New York City where geologists and students can study rocks of the Grenville Orogeny.*
The Bronx, New York City water tunnels, Westchester, Hudson Highlands, Ramapo Mountains, and Housatonic massif.

New York–New Jersey.3 Carbonate Seas and the Taconic Orogeny

▪ *What types of sedimentary layers were deposited during the opening of the Iapetus Ocean, before the start of the Taconic Orogeny?*
Initially, shoreline sands and gravels, then a thick accumulation of carbonates developed on the continental margin while offshore fine-textured terrigenous muds formed.

▪ *Identify at least five rock types formed during the Taconic Orogeny.*
The rock types formed during the Taconic Orogeny included shale, graywacke, slate, phyllite, schist, gneiss, granofels, marble, and amphibolite.

▪ *Which geological province contains the metamorphic roots of the ancient Taconic Mountains? Which geological province preserves the sediments eroded off of the rising Taconic Mountains?*
The metamorphic rock of the Manhattan Prong includes the roots of the Taconic Mountains, whereas the Great Valley contains the sedimentary layers derived from the erosion of the Taconic Mountains.

New York–New Jersey.4 Assembly of a Supercontinent

▪ *The assembly of supercontinent Pangaea took roughly 250 million years and involved a collision between North America and what two other landmasses?*
The landmasses were Avalonia and Africa.

■ *What tectonic environment and what life-forms existed during deposition of the Helderberg Group of formations in the Early Devonian Period?*
During Helderbergian time, a return to passive margin conditions and warm tropical seas resulted in thick limestones bearing evidence for brachiopods, crinoids, stromatoporoids, and corals, among other ancient life-forms.

■ *After the deposition of the Helderberg limestones, what change took place in the sediments being deposited in the New York–New Jersey region and to what tectonic event can they be attributed?*
Shallow-water carbonates were replaced by an accumulation of deep-water marine shale, then by conglomerate, sandstone, and shale of the Allegheny-Catskill Plateau in response to the Acadian Orogeny.

New York–New Jersey.5 Breakup of Pangaea

■ *During early Mesozoic time, the split up of Pangaea resulted in the formation of elongate rift basins along the eastern margin of North America. Name a place on Earth today where modern rift valleys are forming.*
Rift valleys are forming in the East Africa and the Afar-Red Sea area.

■ *In the New York–New Jersey–Connecticut region, name three Mesozoic basins and the typical rock types you might find in them.*
The Newark, Pomperaug, and Hartford Basins all contain arkose sandstone, siltstone, shale, and mafic igneous rocks of both intrusive and extrusive origin.

New York–New Jersey.6 Creation of the Atlantic Coastal Plain

■ *Creation of the Atlantic Coastal Plain mirrors conditions that existed in eastern North America at other times in the past. Name at least two earlier intervals of time when passive margin conditions existed along the coast of North America.*
Passive margin shallow-water conditions existed during the Late Cambrian to Early Ordovician and during the Early Devonian Periods.

■ *What ages and types of sediments are common in coastal plain strata, and what kinds of fossils are found in them?*
The Atlantic Coastal Plain strata consist of unconsolidated gravel, sand, glauconite, and mud from the Cretaceous, Tertiary, and Quaternary Periods. These strata contain the fossils of marine vertebrates and invertebrates.

New York–New Jersey.7 Ice Age Landscapes

■ *Global cooling and the formation of glaciers took place during the Pleistocene Epoch. Name three features each of glacial erosion and glacial deposition found in this region.*
Features of glacial erosion include glacial polish of rock outcrops, chattermarks, striations, and roche moutonée. Features of glacial deposition include till, outwash, drumlins, and erratics.

■ *Glacial deposits have produced major landforms and topographic features in the New York-New Jersey area. Name at least three examples of these.*
These major landforms and topography include Harbor Hill Moraine, Ronkonkoma Moraine, Roanoke Point Moraine, Bangor Moraine, tunnel valleys, and kame and kettle topography.

New York–New Jersey.8 Economic Mineral Resources

■ *Name a dozen economic mineral resources found in the New York–New Jersey–Connecticut region that have been mined for hundreds of years.*
These mineral resources are iron, zinc, cement, building stone, aggregate, emery, copper, cobalt, mica, clay, feldspar, and gemstones.

■ *The Franklin Furnace District of northwestern New Jersey has been a rich source of metals. Name the main ore minerals from this area and the metals that are extracted from them.*
Franklinite, willemite, and zincite are the main ore minerals that have yielded zinc, iron, and manganese.

New York–New Jersey.9 Geological Hazards of the Region

■ *Name three types of geological hazards associated with the New York–New Jersey area.*
Hazards in the New York–New Jersey area include earthquakes, liquefaction, hurricanes, and coastal erosion.

■ *Why are moderate earthquakes, which cause little damage in West Coast cities such as Los Angeles, such a potential danger for East Coast cities such as New York and Newark?*
The buildings and infrastructure of the East Coast have not been engineered to withstand ground motion because a moderate earthquake has not occurred in more than 100 years.

ESSENTIAL TERMS TO KNOW

Aggregate – loose geological material such as sand, gravel, or crushed rock used as filler in concrete, asphalt, and other building materials, or as material for road and rail beds.

Allochthon – a mass of rock that has been moved from its place of origin by tectonic forces.

Amazonia – a Paleozoic continental landmass that combined with other landmasses to form modern South America.

Anorthosite – a coarse-textured plutonic igneous rock composed almost entirely of calcic plagioclase feldspar.

Aquifers – a body of rock or unconsolidated sediment capable of holding and transmitting useful quantities of fresh groundwater.

Cameron's Line – the boundary in the Manhattan Prong between the Manhattan and Hartland Formations, interpreted as a deep-seated shear zone formed at great depth during the Taconic Orogeny.

Chattermarks – crescent-shaped fractures found on the surface of glacially polished bedrock that formed by point-load compressive fracturing of the bedrock by rock fragments carried within the base of a glacier.

Cuesta – a ridge with a gentle slope on one side and a steep slope on the other.

Diabase – an intrusive igneous rock with the mafic mineral composition of basalt, but with an interlocking texture intermediate to basalt and gabbro.

Dolostone – a sedimentary rock similar to limestone, but with the chemical composition $CaMgCO_3$.

Drift – any sedimentary material transported and deposited by a glacier.

Erratic – a rock boulder plucked by glacial ice from bedrock and transported to a different location.

Flood basalt – a large outpouring of basaltic lava covering hundreds to thousands of square kilometers, erupted over a relatively short span of geological time.

Geological provinces – large regions with distinctive landscapes underlain by rock units with similar formational, structural characteristics, or both, that relate to a common sequence of geological events.

Geotectonic cycle – a cycle of rifting, plate divergence, plate convergence, and collision during which a supercontinent breaks up, continents drift apart, continents converge, and a new supercontinent re-forms on a timescale of 500 million years or longer.

Glauconite – an iron-rich micaceous mineral that forms light to dark green, sand-sized grains in sediment-starved marine environments.

Liquefaction – the temporary transformation of loose solid material such as sand into a liquid mass due to seismic shaking.

Lithosphere – the outermost tectonic layer of the Earth consisting of the crust and the rigid upper mantle above the asthenosphere and corresponding to the plates of plate tectonics.

Massif – a massive topographic and structural feature commonly formed of rocks more resistant to erosion than the surrounding area.

Nonconformity – a contact between metamorphic or igneous (crystalline) rock and overlying sedimentary rock that indicates a significant interval of time before deposition of the sedimentary rock, during which the crystalline rock was undergoing uplift and erosion.

Orogeny – the geological process of forming mountains.

Pangaea – the supercontinent that formed during the Late Paleozoic Era and that rifted apart during the Mesozoic Era.

Passive continental margin – a continental margin leading into an ocean lacking plate boundary interactions and characterized by low relief and either carbonate sedimentation or low rates of accumulation of terrigenous sediments.

Red beds – sedimentary layers characterized by a distinct reddish color imparted by the presence of oxidized iron minerals, indicating deposition in an environment exposed to the atmosphere (such as a floodplain or perennial stream channel).

Rifting – the process of rupturing the lithosphere to create a new divergent plate boundary.

Roche moutonée – a distinctive curled or fleecy shape imparted to exposures of bedrock that have been scoured and plucked by glacial flow.

Rock flour – finely pulverized rock that has not been extensively chemically weathered, produced by abrasion at the base of a glacier. Deposits of wind-blown rock flour are called *loess.*

Rodinia – the supercontinent that formed during the Middle Proterozoic Eon and that rifted apart before the start of the Paleozoic Era.

Seismicity – the phenomena of earth movements and earthquakes.

Storm surge – a sudden, temporary rise in local sea level caused by strong winds blowing water against the coast combined with the decrease in atmospheric pressure associated with large hurricanes.

Striations – linear scratches that are oriented in the direction of ice flow, formed on the surface of glaciated bedrock as rock fragments are dragged at the base of the glacier.

Stromatoporoid – moundlike fossil organism common in shallow-water Paleozoic limestones. These were most likely a relative of living sclerosponges, a group of sponges that form a mineral foundation for their living tissue.

Subduction zone – a convergent tectonic plate boundary where the oceanic lithosphere of one plate bends downward and sinks into the mantle beneath the lithosphere of another plate.

Supercontinent – an agglomeration of several large continental landmasses that result from plate tectonic convergence causing continents to mass together on one side of the globe.

Terrigenous sediment – sediment such as gravel, sand, silt, and clay derived from the weathering and erosion of rock on a continent.

Thrust fault – low-angle fault produced during compressive tectonics that displaces one mass of crust physically above another.

Tunnel valley – steep-sided, anastomosing valley eroded into unlithified sediments at the base of a glacier by meltwater flowing through tunnels beneath the ice.

Volcanic island arc – a generally curved, linear volcanic landmass produced by the generation and emplacement of magma above an active subduction zone.

Wind gap – a gap in a mountain ridge originally eroded by a stream, but now elevated and dry.

REVIEW QUESTIONS

1. Why is the New York–New Jersey region a particularly good place for geologists and students of geology to study the history of the Earth?
2. What are the four major collisional tectonic events that are recorded in the rocks of the New York–New Jersey region? Which geological provinces contain the geological products of each event?
3. Which geological province in the region formed during a tectonic rifting event? What important geological features are produced during rifting?
4. What is a passive margin? What is the geological evidence for a passive margin, and which geological provinces in New York and New Jersey contain evidence for passive margin conditions?
5. Where in the New York–New Jersey region can you find volcanic features? What are these features and how did they form?
6. Which geological provinces are likely to contain fossils, and which geological ages are represented by fossils in each province?
7. What are the most common glacial features that can be observed in the New York–New Jersey region? How did these features form?
8. What is the origin of Long Island? What are the major topographic features of the landscape of Long Island?
9. What are the important economic mineral resources of the New York–New Jersey region?
10. What are the two major geological hazards facing residents of the New York–New Jersey metropolitan area?

APPLY YOUR KNOWLEDGE QUESTIONS

1. Compile a sorted list of historic earthquakes of magnitude 2 or greater in the New York–New Jersey area, with the largest earthquakes listed first. List the date, location, and Richter scale magnitude for each event. Use the Internet to find this information (http://www.ldeo.columbia.edu/LCSN/big-ny-eq.html).
2. How does the topography of the New York–New Jersey region depend on the underlying lithology (rock type) and geologic structure?