AMERICAN MUSEUM OF NATURAL HISTORY

Field Guide for the Geology of Central Park and New York City

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TOPICS TO TEACH BEFORE GOING ON THIS TRIP

- Rocks and Minerals (be able to identify them)
- Plate Tectonics
- Earth's History

INTRODUCTION

Stories in Stone: Reading the Rocks

Just like a good book, rocks tell stories. One role of geoscientists is to learn how to observe, analyze, and interpret rocks to make sense of the histories they record. Using observations of rock types, minerals, chemical composition, and outcrop features, geologists can determine and recreate the story under our feet.

Rocks are categorized into three main types based on how they were formed: igneous, sedimentary, or metamorphic. The natural bedrock in Central Park is primarily a **metamorphic rock** called the Manhattan Schist that has undergone extreme changes as a result of the addition of heat and pressure over time. It contains a variety of minerals, including quartz, plagioclase feldspar, muscovite (white) mica, biotite (black) mica, garnet, and aluminosilicates (silicate minerals rich in aluminum). Specific minerals such as garnet and aluminosilicates are formed during metamorphic processes and can be studied using chemistry to determine the temperatures and pressures under which metamorphism occurred.

Metamorphic rocks formed under temperatures and pressures much higher than we experience at the Earth's surface. Metamorphic rocks are formed when existing rocks (protoliths) are heated and undergo pressure changes. Using the minerals seen today in the Manhattan Schist, geologists have determined that the **protolith** was **sedimentary** rock, such as mudstone, shale, or sandstone.

Scientists have chemically analyzed some of the garnets in Central Park and determined that these rocks formed while being heated to near 600˚C and at pressure of about 5,000 atmospheres (0.5 gigapascal, or GPa). That's approximately five times higher pressure than the pressure of water at the bottom of the deepest part of the world's ocean! Earth's surface is approximately 25˚C at a pressure of 1 atm (about 0.0001 GPa). By interpreting these numbers, scientists have concluded that the rocks of Central Park underwent an extreme event of colossal scale in the past. Even though these rocks are no longer under those conditions, they retain most of the indicators of their previous conditions.

We determine a metamorphic rock's formation conditions (pressure and temperature) based on the minerals present and the chemistry of these minerals. Three **aluminosilicate minerals**, which have the chemical formula Al_2SiO_5, change their crystalline form depending on temperature and pressure (**Fig. 1**). For example, at low pressure and low temperature, the mineral andalusite forms. At higher pressure and similar or slightly higher temperature, sillimanite forms. At even higher pressure, kyanite forms. The rocks in Central Park contain both kyanite and sillimanite.

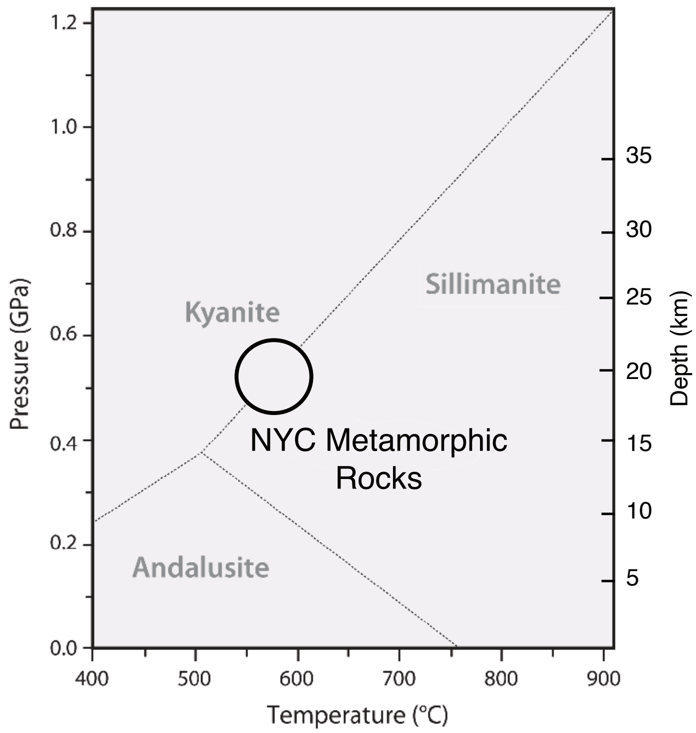

Figure 1: Pressure-temperature diagram for the aluminosilicate minerals. The maximum pressure-temperature conditions experienced by the rocks of Central Park are shown in the circle. S. Jaret/© AMNH

What was the cause of that extra 575°C and 4,999 atm of pressure? Major mountain building and continent-scale collisions produced these rocks. Continent-scale collisions force continents to bend, placing continental rocks on top of one another. This then increases the pressure and temperature of rocks at the bottom of that pile of continents. We estimate that the rocks of Central Park were at ~15 km at their deepest. An example of this happening today is the collision forming the Himalayan mountains.

Continental Collision and Breakup: Evidence in Central Park

About 600 million years ago, the area we currently call New York City was under water. At that time, an ocean separated the continents that would later become Africa and North America. This body of water is called the Iapetus Ocean. Due to the convergent movement of tectonic plates, the Iapetus Ocean was getting smaller, and the continents of Africa and North America were moving closer together (**Fig. 2**).

The Iapetus Ocean was a place where sedimentary rocks formed even though the ocean was growing smaller. The rocks from both the African side and the North American side of the ocean basin weathered and were eroded. Water and wind washed the resulting sediment into the ocean, where it was deposited and then compacted (lithified) into sedimentary rock.

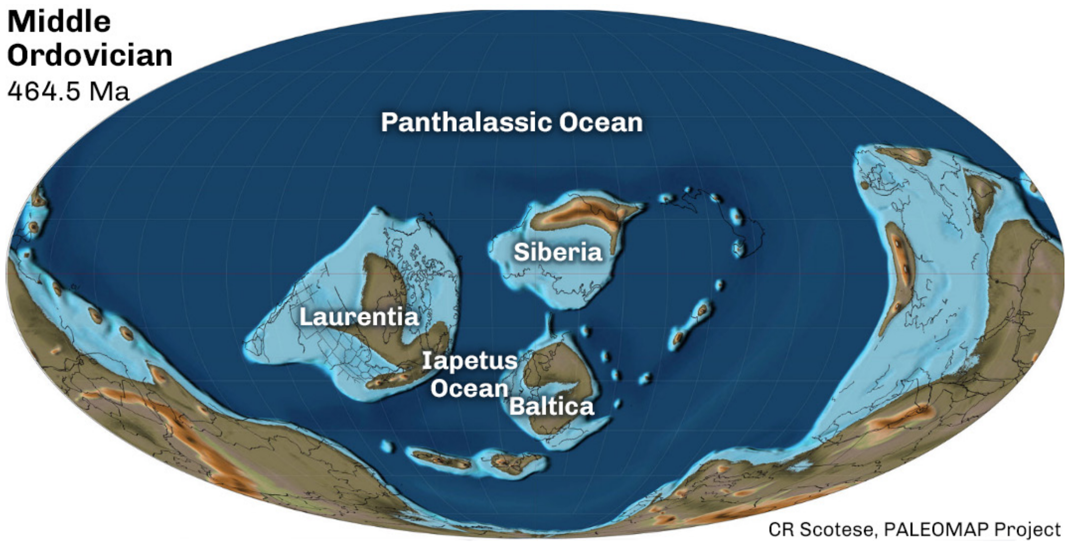

Figure 2: Artist reconstruction of what Earth looked like 460 million years ago. Landmasses that eventually become North American (Laurentia), Europe (Baltica), Russia (Siberia), and Africa (Gondwana) are labeled and shown with outlines of those modern-day continents for reference. Figure modified from PALEOMAP Project maps with permission from C. Scotese.shown in the circle. S. Jaret/© AMNH

From about 480 to 440 million years ago, North America collided with a volcanic island arc that was between North America and Africa, similar to the Aleutian chain west of Alaska (**Fig. 3**). The sedimentary rocks in the Iapetus Ocean basin were forced deep below Earth's surface, were subjected to great temperatures and pressures over time, and underwent large-scale metamorphism across the whole East Coast of North America. This collisional event caused the Taconic mountains to form along the western margin of the Iapetus Ocean (now the east coast of North America). The minerals present in the sedimentary rocks were transformed into the mineral assemblages we see today in the Manhattan Schist.

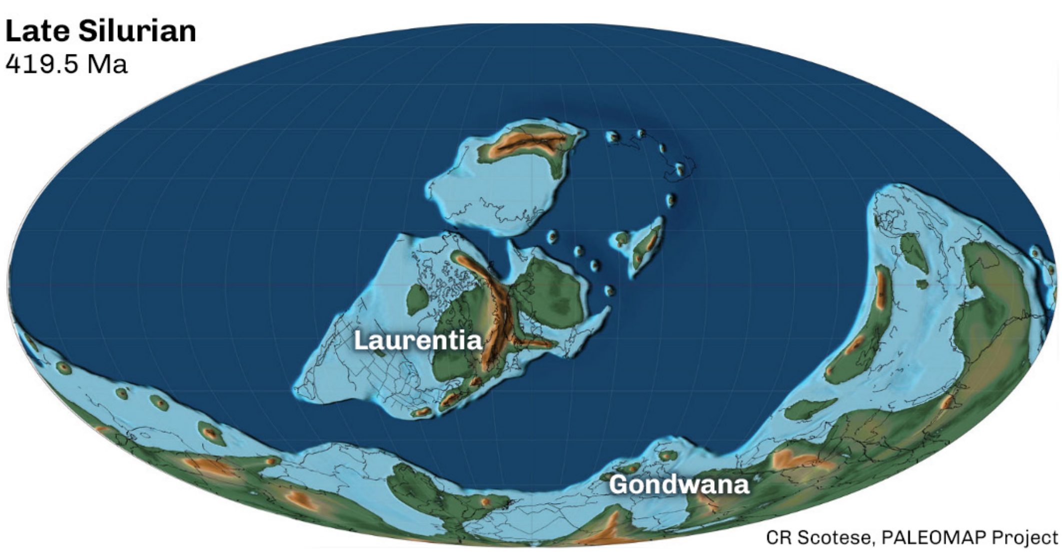

Figure 3: Artist reconstruction of the continents around 420 million years ago, just after the first major collision, the Taconic orogeny. Figure modified from PALEOMAP Project maps with permission from C. Scotese.

Two additional mountain-building events occurred later: 1) about 375 million years ago, North America collided with the microcontinent called Avalon, causing another mountain-building event called the Acadian orogeny, and 2) about 325 million years ago, the North American and African continents closed together, forming the supercontinent Pangea. That event caused the Alleghenian orogeny.

As they are today, tectonic plates were constantly moving and changing during the time of Pangea. About 250 million years ago, the supercontinent began to break up as North America and Africa separated from each other. Then Africa and South America began drifting apart as new crust formed at the Mid-Atlantic Ridge. The water forming the Atlantic Ocean filled the new space between those continents, gradually getting larger until it reached the shape and size we see today.

Current Research Questions

One of the questions scientists at the American Museum of Natural History are interested in figuring out is where the rocks of Central Park originally came from. Were they sedimentary rocks that originated in Africa or in a volcanic arc, or did they originally start out on the North American side?

Geoscientists can determine this by studying rock and mineral chemistry. One mineral found in these rocks, zircon (zirconium silicate, with the chemical formula $ZrSiO_4$), is particularly useful for determining where and when the source material for the Manhattan metamorphic rocks formed. Zircons contain small amounts of uranium, which is a radioactive element that can be used as a “clock” to measure the age of the mineral. The age is when the uranium was “locked in” the crystalline mineral. Using radioactive elements like this is called “absolute dating” because it allows us to determine precisely when an event occurred in years. This is similar to the carbon-dating method sometimes used in paleontology and archeology.

The zircons in the Manhattan Schist have a long geologic history. They originally formed in rocks somewhere else, eroded into the Iapetus Ocean, and were then metamorphosed. The age of the zircons indicates the time the zircon formed at its original source (or protolith). This allows geologists to tell which side of the ocean these rocks came from. Zircons that came from North America should have very old zircons, with ages close to 1 billion years. The zircons from the other side of the ocean—from what is now Africa—should be much younger, closer to 500 million years old. We can figure out the source of sediments because the source rocks (protolith) on each side of the Iapetus Ocean were not the same age.

Recent research by scientists at the American Museum of Natural History shows that all the rocks in Central Park were sourced from old parts of North America (greater than 1 billion years old). Just north of New York City, in Connecticut and Massachusetts, similar metamorphic rocks are found. In those localities, geologists have determined that the metamorphic rocks were formed during the collisions that built Pangea ~500 million years ago. They have shown that the protoliths of those rocks came from both Africa and North America. The ongoing work is continuing to further understand the story of metamorphism and find evidence of sediments from these old continents.

Key Words

- **Aluminosilicate minerals:** minerals containing a high amount of aluminum, specifically with a formula $Al2SiO_5$.
- **Metamorphic:** related to or produced by metamorphism
- **Protolith:** preexisting rock
- **Sediments:** rocks or minerals deposited by water, wind, or glaciers
- **Sedimentary rocks**: rocks formed from the compaction and cementation of sediments
- **Tectonic plates:** large blocks of Earth's crust that slowly move over the surface

ESSENTIAL QUESTION

How can observations of rocks in Central Park inform our understanding of local geologic history?

Correlation to Standards: A Framework for K-12 Science Education

Scientific and Engineering Practices
- Analyzing and interpreting data
- Constructing explanations

Crosscutting Concepts
- Patterns
- Cause and effect
- Systems and system models
- Energy and matter: flows, cycles, and conservation
- Stability and change

Disciplinary Core Ideas
- ESS1.C: The History of Planet Earth
- ESS2.A: Earth Materials and Systems
- ESS2.B: Plate Tectonics and Large-Scale System Interactions
- ESS2.C: The Roles of Water in Earth's Surface Processes

Connections to the Earth Science Reference Tables

- **Page 3:** Generalized Geologic Map of New York State
- **Page 5:** Tectonic Plates Map
- **Page 6:** Rock Cycle in Earth's Crust
- **Page 7:** Scheme for Metamorphic Rock Identification
- **Pages 8–9:** Geologic History of New York State
- **Page 16:** Properties of Common Minerals

STOPS IN CENTRAL PARK AND LOCATION-SPECIFIC NOTES FOR TEACHERS

NOTE: This work was carried out in coordination with and permission from the New York City Department of Parks and Recreation and the Central Park Conservancy. Individual collecting or sampling within Central Park is strictly prohibited without prior authorization and the requisite permits.

Questions You Could Ask Students at Any Outcrop

- Which minerals are present? What size are they?
- What do you notice about the texture of the outcrop?
- What type of rock is this? How do you know?
- For crosscutting relationships: Which rock is older? How do you know?

MAP AND FIELD DESCRIPTIONS

Figure 4: Map of Central Park. Adapted from: https://en.wikivoyage.org/wiki/Manhattan/Central_ParkScotese.

• STOP 1: 110th Street

This is an example of the Manhattan Schist (referred to as the “110th Street Member”). There is prominent layering (foliation) defined by biotite, graphite, and magnetite. The rock is magnetic. It also contains large (~30-cm wide) quartz veins, as well as millimeter-size garnets (reddish or dark brown).

This outcrop also has some glacial striations that are perpendicular to the foliation and parallel, or close to parallel, to 110th Street. Lastly, there is an overall knobby texture with more resistant quartz and feldspar minerals standing up against the more easily eroded mica (both biotite and muscovite), as seen in Photo 1b, below.

Photo 1a (top) and 1b (bottom). S. Jaret/AMNH

• STOP 2: Harlem Meer

There are two types of rocks here: Manhattan Schist and a granitic pegmatite. The schist looks similar to the schists at Stop 1, with well-defined foliation defined by muscovite and biotite. Also look for folds in the quartz and feldspar layers. The pegmatite is a very coarse-grained rock (crystals up to 1 foot across!) with large pink potassium feldspar. The feldspars have good examples of cleavage. This pegmatite is similar in composition and texture to a newly identified granite at the Bronx Zoo that we call the Bear's Den Granite. Here it probably occurs as a dike or sill (intrusion) that crosscuts the schist.

Photo 2. S. Jaret/AMNH

• STOP 3: The Loch

This is one of the only places in Central Park where classic igneous rocks are visible. Here you see granitic rocks (quartz, muscovite, alkali feldspar, plagioclase feldspar) with two textures: coarse grained and slightly finer grained. The two textures are both intrusive, and the difference in grain size relates to cooling time; the larger grains took longer to cool. Look for very large (cm-size) crystals of muscovite mica (at pen point in Photo 3a).

The relationship between these rocks and the schists in the rest of the park is currently not known. The contact (where igneous and metamorphic rock meet) is not exposed here, and we have not yet (as of 2022) studied these rocks in detail. Nonetheless, they are excellent examples of igneous rocks to show students because igneous rocks are relatively rare in NYC.

Photo 3a. Large muscovite crystals are seen in the pegmatite at the Loch. S. Jaret/AMNH

Photo 3b. The pegmatite has large feldspar (albite) crystals with good examples of mineral cleavage. S. Jaret/AMNH

• STOP 4: The Pool (A)

Here you will see a large glacial erratic perched on Manhattan Schist. The erratic is a fine-grained granite (sometimes called "aplite") that does not resemble the bedrock in New York City. It was brought here by the glaciers 12,000 years ago, during the last ice age. When the ice melted, it dropped this boulder—and many others—onto the ground. You can find other erratics scattered around the park and on the north shore of Long Island.

• STOP 4: The Pool (B)

Here you will see a large (3-foot) dike of the coarse-grained pegmatite seen at Stop 2 cutting across the Manhattan Schist. This is a good example of crosscutting relationships. The grains differ in size between the center of the dike and the edges. The edges are finer grained than the center. This is because contact with colder schist caused the edge to cool more quickly. Also notice the large potassium feldspar almost the size of your head.

Photo 4a. S. Jaret/AMNH

Photo 4b. S. Jaret/AMNH

• STOP 5: Rock of No Hope

The name of this outcrop comes from The Public Theater's Free Shakespeare in the Park program. The line for tickets stretches along the path from the Delacorte Theater to this spot. If the line stretches beyond this outcrop, you have little chance of receiving a ticket.

Here we see the Manhattan Schist. Notice that the rocks are folded in multiple directions. Looking to the south (back facing the swing set), you can see folds shallowly plunging. Several quartz and feldspar veins are folded. At the southern end of the outcrop, a large pegmatite dike crosscuts the schist, showing the difference in grain size between the center and the edge of the dike.

NOTE: If you can bring students to only one outcrop, we recommend this one because it has the greatest variety of geological phenomena present in a single outcrop.

Photo 5a. S. Jaret/AMNH

Photo 5b. S. Jaret/AMNH

• **STOP 6: East 79th Street** (location is labeled "Cedar Hill" on some maps of the park)

Here we see another example of the schists present in Central Park. In this location are two varieties: a light-colored schist and a dark-colored amphibolite. Multiple generations of folds are present, including a prominent upright fold set. Although the schists here look slightly different from other schists in the park, the geochemistry and ages suggest that they are not different, having formed from the same source sediments prior to metamorphism ~460 million years ago.

Photo 6a. S. Jaret/AMNH

Photo 6b. S. Jaret/AMNH

• STOP 7: Roche Moutonnee

The story here is glacial. The last ice age (~12,000 years ago) covered this area under an ice sheet, which has since retreated. Here you can see evidence of the motion of the ice. There are two ways to tell:

1. The shape of the outcrop. When ice moves over areas with preexisting variations in topography (even subtle variationson the order of just a few feet), the ice will ride up the back slope, smoothing it out, and ride over the front, creating a jagged, craggy front surface.
2. Glacial striations. Glacial motion also can leave grooves in the underlying surface in the direction in which the ice was moving.

Here you can see evidence of both the craggy surface and glacial striations. Have students walk around the outcrop and decide which side is the front. Then climb onto the top and look for glacial striations. **Ask students which way the ice moved.**

ANSWER: It's a trick question. The striations are perpendicular to the craggy front of the outcrop. Ask them how this could be. The answer is that there are two different periods of glacial motion here. Ice moved one way first, and then the other. The glacial striations likely represent the second period of motion, although we don't know that for sure.

Photo 7. S. Jaret/AMNH

- ## STOP 8: Overlook Rock

Here we see well-foliated and well-folded schist. It contains quartz, plagioclase, muscovite, biotite, garnet, and occasionally magnetite. Also visible are some examples of partial melt (coarse-grained white and light pink) pockets. Multiple dikes on the schist illustrate crosscutting relationships.

Photos 8a (top) and 8b (bottom). S. Jaret/AMNH

• STOP 9: Heckscher Playground

Here we see a large glacial erratic of pegmatitic granite resting on the schist. The erratic is clearly texturally different from the bedrock. It was deposited here during the last ice age. This granite is part of an igneous body we call the Bear's Den Granite, most of which is found in the Bronx Zoo but that also occurs in a few other spots in the north part of Central Park (including at Stop 2).

Photo 9. S. Jaret/AMNH

• STOP 10: Umpire Rock

This large exposure of schist shows many good examples of folding. Multiple generations of folds are visible, and you can see the folds from multiple angles by looking down at the rock or at cross-sections in some of the edges of the steeper faces.

There are also many dikes crosscutting the schist and large, very visible glacial striations, as well as coarse-grained partial melt pockets.

Minerals present include quartz, plagioclase, biotite, large muscovite, and millimeter-size garnets.

NOTE 1: The variety of features at Umpire Rock is greater than at any of the other outcrops in the southern section of the park, so if time is a consideration, this stop can accomplish a lot.

NOTE 2: This spot is quite popular with tourists and has a fairly steep back surface. It may be hard to keep students away from it or from trying to climb it or jump off.

Photo 10a. S. Jaret/AMNH

Photo 10b. S. Jaret/AMNH

PHOTO SOURCES

Photo 6b: Jaret et al. 2021, Geology of Central Park, Manhattan, New York City, USA: New geochemical insights, in Florsheim, J., Koeberl, C., McKay, M.P., and Riggs, N., eds., 2021 GSA Section Meeting Guides 2021 GSA Section Meeting Guides 2021 GSA Section Meeting Guides 2021 GSA Section Meeting Guides: Geological Society of America Field Guide 61, p. 1–14, https://doi.org/10.1130/2020.0061(02).