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UWSR Eco Letter
March/April 2025

COMMENTARY:
Geology of New York City and Surroundings

You leave your apartment and head out to do some errands or meet a friend or go to a meeting. You feel the rigid sidewalk beneath your feet. The sound of an approaching subway train rumbling up through a grate makes you think of the complex systems underneath that make the subway possible and support the City's electrical, technical, water, and sewage needs.

We live only on the topmost layer of the crust of our planet and there is so very much more beneath. But what? If you take a walk in one of our beautiful parks, you'll see the slope of the land and some impressive rock outcroppings. If you go online, some of the many images there of the "blue marble" that is our Earth from space reveal the wrinkles of mountain ranges and the divots of lakes. We know how the crust of the earth formed continents that came together or drifted apart over eons, and that each part of the current individual continents has its own geological character.

So, what's under us here in the New York area?

First, a basic – and greatly simplified – summary of the Earth's composition and how it changed over vast amounts of time.

The *crust* on which we live is the Earth's uppermost and coldest layer. Just beneath it is the *mantle*, a thick layer of solid, silicate rock that separates the crust from the Earth's outer *core* and that makes up the vast majority of the planet's volume. Magma is created when the upper mantle partially melts over prolonged periods of time in response to extreme heat from the liquid outer core. When that magma reaches the surface of the earth, as it does when volcanos erupt, it is called lava.

The Earth's continental crust formed over billions of years. It's 30–70 kilometers thick and composed of sedimentary, metamorphic, and igneous rocks. *Sedimentary rock* is formed from the accumulation and compaction of sediments, including sand, mud, clay or bits of seashells; *metamorphic rocks* are those that have been changed from their original form by intense heat and pressure (such as the mountain-building events discussed below); and *igneous rock* is formed when molten rock, both magma or lava, cools and solidifies (New Jersey's Palisades across the Hudson River are an example).

The crust is relatively rigid and it broke into massive jigsaw puzzle pieces known as tectonic plates – large, solid slabs of rock that vary in size from a few hundred to thousands of kilometers across that essentially "float" on the Earth's mantle. The geology of the Earth's rocky crust has been influenced primarily by tectonic movement, as well as by volcanos, glaciers, water flow or freezing, and chemical weathering.

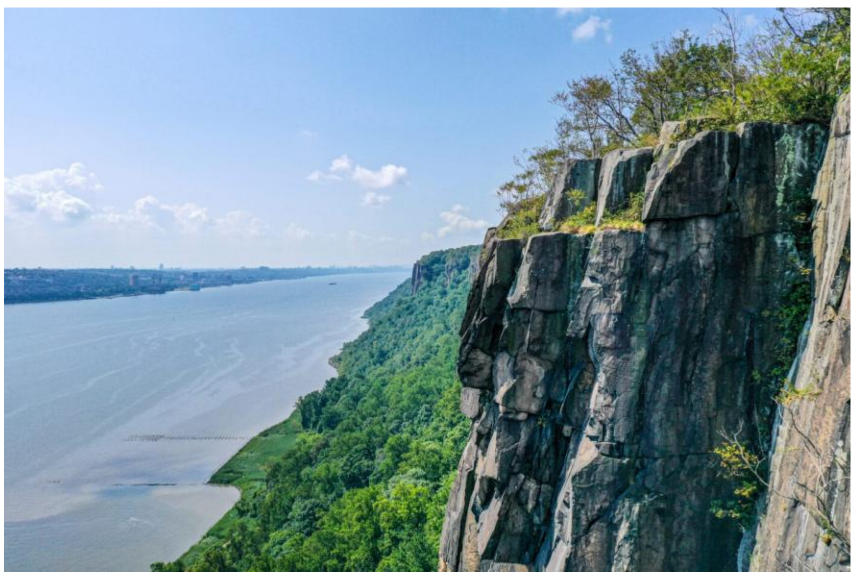
Tectonic plates can either be pushed together or pulled apart, and each action has distinct results. Two things can happen when tectonic plates are pushed together: (1) they collide, squeeze together, and push upwards to form mountains (these extended episodes of mountain building are called *orogenies*); or (2) one plate slides underneath the other and melts deep in the crust to form magma, which rises and creates a ring of volcanic mountains that are gradually eroded over hundreds of millions of years by water flow, freezing or glaciation, a process that produces sedimentary rock such as sandstone. Tectonic plates can also pull apart, or rift, creating valleys and basins, as well as causing volcanic eruptions, which result when magma plumes rise from the mantle to the Earth's surface.

The Grenvillian Orogeny – widely considered to be the oldest orogeny in our area – occurred roughly between 1 and 1.3 billion years ago. This orogeny is named after the village of Grenville in Québec, which lies on the Canadian Shield (metamorphic rock that underlies much of Eastern Canada and the U.S.). It is in Grenville that evidence for metamorphism of rocks is best preserved and visible for study in exposed mountain roots. Rock created during this period underlies all the other rock of New York State, and gneiss, a metamorphic rock of the Canadian Shield, surfaces in the Fordham area of the Bronx, as well as in the Hudson Highlands.

Three later orogenies followed the Grenvillian and influenced our area. The first, the Taconic, began about 550 million years ago and lasted about 110 million years. It occurred primarily in eastern Canada and New York State, but it extended south into Georgia, and in its later stages formed the metamorphic schist bedrock underlying most of Manhattan as well as the marble in the northern part of the island. It also resulted in the Taconic Mountains, which, at their peak, rivaled the Andes in height. The Taconic Orogeny was the first of three mountain-building events that uplifted the Appalachians, followed by the Acadian (about 415 to 360 million years ago) and Alleghenian (325 million to 260 million years ago) Orogenies. Eroded particles from the Acadian Orogeny formed much of the sedimentary rock of today's Catskill Mountains.

The Palisades cliffs that Upper West Siders can easily see across the Hudson River extend all the way from Haverstraw, NY south to Staten Island. They are part of a sill of igneous diabase (a sill is a flat sheet of igneous rock that forms between layers of older rock). The resultant cliffs are about 50 miles long and 1,000 feet thick and vary in height from 300 feet above sea level to their highest point at 832 feet in High Tor State Park in Rockland County. They began forming 200-250 million years ago (when the Earth's land mass was concentrated in a single supercontinent known as Pangaea) when magma intruded through giant cracks in the Newark Basin sandstone above it, producing the diabase sill. As these vertical volcanic gushers of magma solidified and cooled underground, the mass contracted and created intense pressure that subsequently produced vertical cracks several hundred feet long, transforming the sill into polygonal columns.

Over millions of years glaciation, river flow and freezing ice eroded the sandstone around it revealing the more durable rock cliffs on the Palisades' eastern side. (The columnar appearance of the Palisades looked like the stockades used by Native Americans to protect their villages and earned them their English name, but the Lenape called them "Wee-Awk-En," meaning "rocks that look like trees.")



Drone footage of the Palisades in summer

The Palisades form the western border of the ***Hudson River*** in the New York City region. We live, of course, at its mouth, where it enters the Atlantic and where it also receives a northern flow from the ocean's tide, making it more literally a tidal estuary or fjord. Traveling almost 300 miles south from Lake Tear of the Clouds, its source on Mt. Marcy in the Adirondack Mountains, the river cut a deep gap into the ancient gneiss rock of the

Hudson Highlands. The course and character of the Hudson along its entire length reflect its underlying geological structure and the modifications of Pleistocene glaciations.

The bedrock foundation of the Hudson was established in the mountain-building episodes described above. The Northern Hudson Valley is a section of the larger Appalachian Ridge-and-Valley province, which was formed during the Alleghenian Orogeny. The softer parts of these rock units (chiefly sedimentary) were eroded to form the valleys, and the harder parts of the folds formed the mountain tops and ridges. Streams and rivers, such as the Hudson, developed these valleys and mainly flowed south, following the lines of the more easily eroded strata. The deep gorge through the Highlands was primarily formed by glacial activity and by the erosive power of the Hudson River itself, both following pre-existing fault lines within the bedrock.

During much of the last ice age of the Pleistocene glaciations – the ***Wisconsin Glaciation*** about 75,000 to 11,000 years ago – the Hudson Valley was covered by a thick sheet of ice as much as 10,000 feet thick that blanketed the land as far south as New York City where it was about 1,000 feet in Manhattan. Sometime after it reached here, its furthest point, the Earth began to warm and the front edge the glacier melted, depositing a *terminal moraine*, a raised ridge of rock and other debris (or till) that it had scraped from the earth in its retreat. Parts of this moraine run from the southern tip of Staten Island through Brooklyn and Queens. As the glacier thawed, it also left behind *glacial erratics,* larger boulders the ice had carried south from their origins further north. You can see a large glacial erratic perched on schist in Central Park just north of the pond at West 103rd Street, and there are others scattered throughout the Park.

As the ice melted further and retreated, the Hudson Valley became submerged in water, covered by what geologists call Glacial Lake Albany and, to the north, Glacial Lake Vermont. To the west was an even bigger lake, Glacial Lake Iroquois, which was about three times larger than Lake Ontario is now. A huge ice dam separated Lake Iroquois from the other two lakes and, about 13,000 years ago, as the climate continued to warm, the ice dam was breached and floodwaters poured down the Hudson River Valley and across another hundred miles of coastal plain into the North Atlantic. Exactly how and where Lake Albany drained is still an open question. One theory proposes that, at first, the Hudson River emptied into the Atlantic Ocean through a more westerly course through the Newark Basin in northern New Jersey, and then on into the Atlantic Ocean via Raritan Bay. A build-up of water in the Upper New York Bay eventually allowed the river to break through the land mass of the Narrows (part of the glacial moraine), which connected Staten Island to Brooklyn, and to establish its present course. On the continental shelf (coastal plain), south of New York City and below the surface of the Atlantic Ocean, the Hudson Canyon marks the course of the ancestral Hudson.

To the east of the Hudson River lies the ***Manhattan Prong****,* a belt of ancient metamorphic rock created during the Grenvillian and Taconic Orogenies, that forms the bedrock of the entirety of the Bronx and Manhattan, the upper part of Staten Island, the western edge of Brooklyn and Queens, parts of Westchester County, and upland portions of Southwestern Connecticut. Most of Manhattan's bedrock has long since been covered by sediments, artificial fill, and other human-made features, making it difficult to see the extent of the bedrock.

The Manhattan Prong consists primarily of three types of metamorphic rock:

1. *Manhattan Schist* was formed from sedimentary rock such as mudstone, shale, or sandstone over a billion years ago during the Grenvillian Orogeny and modified during the Taconic Orogeny. Schist forms the island's spine from the Henry Hudson Bridge on its north end to the Battery on its southern tip; it dips abruptly several hundred feet below ground at Washington Square and makes a gradual ascent beginning at Chambers Street. These dips and rises account for the gap between Midtown and Downtown in the Manhattan skyline, since tall buildings originally had to be anchored on solid bedrock and not on the glacial till that fills the valleys. The schist bedrock also dips at the125th Street and Dyckman Street Faults. *Glacial striations* occur where rocks contained within the glacier cause scratches in other rocks or with bedrock in which it comes in contact. Examples of these striations can be seen at the schist outcrop along the drive near 110th Street and Central Park West and also at Umpire Rock (see below).

   Other outcroppings of Manhattan Schist are visible in many locations in Manhattan. Prominent examples include: Umpire Rock, in Central Park at about West 63rd Street (south of Heckscher Ballfields); the large cliff overlooking the Hudson just west of Riverside Drive at about West 83rd Street; and rock cuts along Central Park West from 103rd to 110th Streets. The tall retaining walls in Riverside and Morningside Parks are also made of schist.

2. *Inwood Marble* was formed from limestone created by the seashells of an ancient ocean about 450 million years ago. The 150- to 500-foot-thick marble beds lie beneath the Harlem River and adjacent regions, including Inwood. You can see beautiful outcrops of Inwood Marble in Isham Park at the corner of Seaman Avenue and Isham Street.

3. *Fordham Gneiss* was formed from igneous rocks like granite, also about 450 million years ago during the latter part of the Taconic Orogeny. It forms the Riverdale and Grand Concourse ridges in the Bronx. You can see exposed portions of the Riverdale ridge at the Wave Hill Overlook in the Northwest Bronx.

More Information:

- Field Guide for the Geology of Central Park and New York City (American Museum of Natural History)
- The Flood that Created the Hudson Valley (Times Union)
- Geology of New York: A Simplified Account (Isachsen, et al., New York State Museum Educational Leaflet 28)
- Geology of the New York Region (US Geological Survey)
- Grenvillian Orogeny (Science Direct)
- Hot Rocks: A Geological History of New York City Parks (NYC Parks)
- New York's Remarkable Geological Features: A Glimpse into Earth's History (Betsy McCully)
- Shaped by Nature and Man: The Geological History of the Palisades (American Museum of Natural History)