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Photo by Diane Dennis / New York City Department of Environmental Protection

Massive tunnel with workers, to show scale, 800 feet below the earth, at Roosevelt Island shaft: Tunnel allows rare chance to test theories on ancient forces that shaped the ground

Tunneling Back Into Time

A city dig yields billion-year-old rocks, clues to geological past

By Margaret Mittelbach and Michael Crewdson
SPECIAL CORRESPONDENTS

UNDER THE ELEVATED TRAIN in the Bronx, in what looks like an abandoned warehouse, thousands of small, coffin-like boxes are stacked on the floor, row after row. Lifting one of the lids, geologist Diane Dennis reveals the 1.1-billion-year-old contents — a narrow core of ancient rock exhumed from deep within the city.

Resembling a thin, Italianate column with a candy cane swirl, the core of black-and-white rock, called *gneiss,* is one of thousands of samples extracted during surveying for New York City's new water tunnel, the largest construction

Tunneling Back Into Time

project in the city's history. Currently being blasted and bored beneath our feet at depths from 200 to 800 feet, the tunnel — originally conceived in the 1950s — will ultimately snake through 60 subterranean miles to provide a better distribution system for New York City's water supply.

It also provides geologists a vital and valuable peek into the past. By uncovering raw walls of rock deep in the city's bedrock, the tunnel allows an unparalleled opportunity to test theories about ancient forces that shaped the ground beneath our feet.

"The tunnel construction has given us a wonderful and exciting view of New York City's rock record," says Sidney Horenstein, geologist and coordinator of Environmental Public Programs for the American Museum of Natural History.

New York City's rock record is mostly buried beneath heavy layers of concrete. When geologists want to do field work, they are left with a handful of roadcuts, exposures in the city's parks, and the occasional excavation. Further complicating their work is the fact that New York City's rocks are intensely metamorphic — meaning that they have been folded, cooked, deformed, and pressurized an untold number of times throughout the course of geologic time.

While these intense changes make the city's rocks difficult to "read," it also means they have more stories to tell about ancient volcanoes, earthquakes and the collision of the various sections, or tectonic plates, that make up the Earth's crust.

"When you look at the geology of New York City, you're looking at a giant jigsaw puzzle, with almost no hope of finding the interlocking pieces," says geologist Charles Merguerian of Hofstra University.

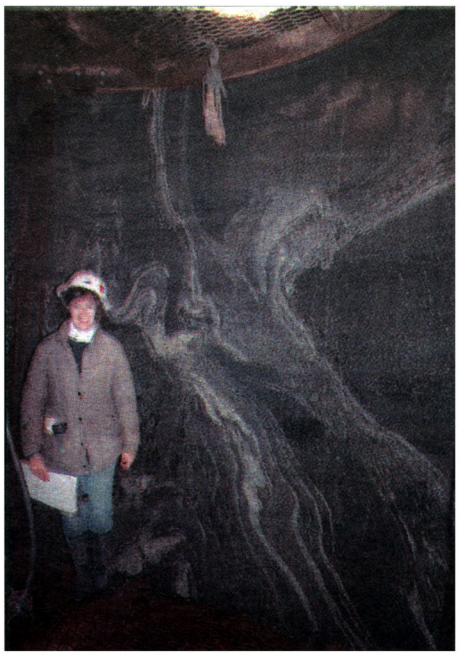


Photo by Diane Dennis / New York City Department of Environmental Protection

Diane Dennis next to banded gneiss rock, at Roosevelt Island shaft: dramatic geologic vistas revealed

Through studying the drill core samples and conducting field work and mapping in the tunnel itself, however, geologists are finding and fitting together the pieces of more than 1 billion years of geological history. "Going down in the tunnels is like walking through a time portal," Merguerian said.

Although geologists have long known what types of metamorphic rock underlie the city, it is only in the past 30 years — through the formulation of the theory of plate tectonics — that they have arrived at specific ideas about how and where these rocks might have formed. According to the theory of plate tectonics, the Earth's crust is subdivided into a series of continental and oceanic plates. Through the ages, these plates have drifted about, colliding into one another and coming apart. Geologists now believe it was through the collision of these plates that the city's metamorphic rocks — black-and-white Fordham gneiss, bright white Inwood marble, and dark-sparkly schist — were created.

In New York City, the most significant of these episodes for New York City has been labeled the "Taconic Orogeny" (the word orogeny refers to the process of mountain forming), which occurred around 450 million years ago. Geologists theorize that a volcanic arc of islands off what is now the East Coast smashed into the mainland, closing off an ancient ocean and forcing up a mountain range as high as the Alps. As the continental shelf of that ocean was squashed and forced deep underground, profound changes took place. The limestone deposits close to shore were transformed through heat and pressure into the Inwood marble of northern Manhattan and the deep-water volcanic ash and sediments, forced seven miles below the ground, became what are now the outcrops of schist visible in Central Park.

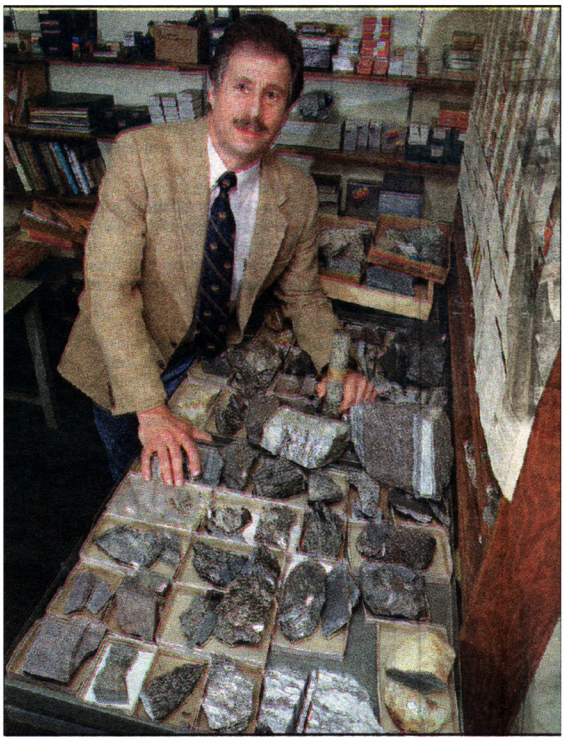
"Imagine the Japanese island chain smashing into Asia and closing off the Sea of Japan," Merguerian says. "Then you can get an idea of what we think happened four hundred fifty million years ago in New York City."

Merguerian has been descending into newly opened sections of the tunnel since 1983 to hunt for evidence of this violent past. Following tunnel crews as they blast their way through the city's subterranean depths, he is tracking the undulations of the city's ancient and heavily folded bedrock and reading never-before-told stories in their order and composition.

Once the smoke clears, every blast in the tunnel reveals new and dramatic geologic vistas: sparkling mineral deposits, bands of pink igneous rock streaking through older, darker metamorphic bedrock; chambers of blinding white marble; lines of crushed, broken rock arching through solid stone, faultlines that chronicle the city's cataclysmic history.

Such raw and unexpected views are helping to confirm concepts about continental drift and the city's earliest origins. For example, geologists have long theorized about the existence of something called Cameron's Line, an ancient fault running through New England and New York City. Cameron's Line, a 30- to 50-meter band of highly sheared rock, is thought to mark the suture between two colliding plates — the volcanic arc of the Taconic Orogeny and the proto-North American continent, the shapes that existed 450 million years ago. Cameron's Line in New York City had only been mapped in the Bronx, until the DEP started working on the water tunnel, however.

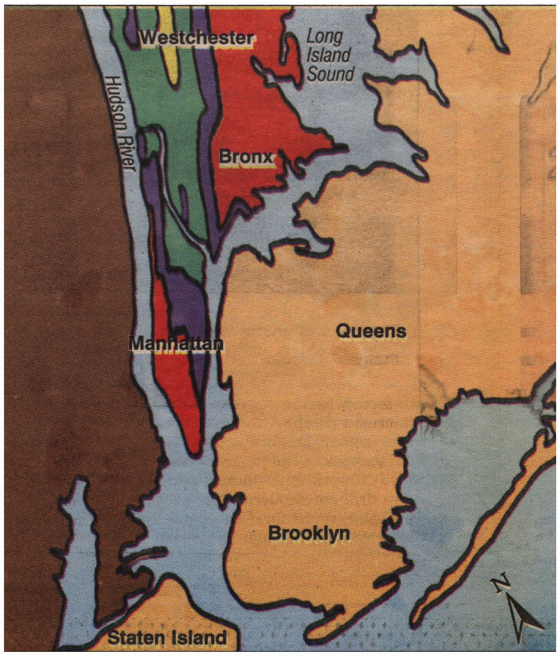
In 1986, Merguerian found the disturbed, crumbling rock of Cameron's Line in the deepest portion of the tunnel, 600 feet under the East River, where it



Merguerian with rock samples from tunnel project.

Rocky Terrain

The distribution of metamorphic rocks in the New York City area



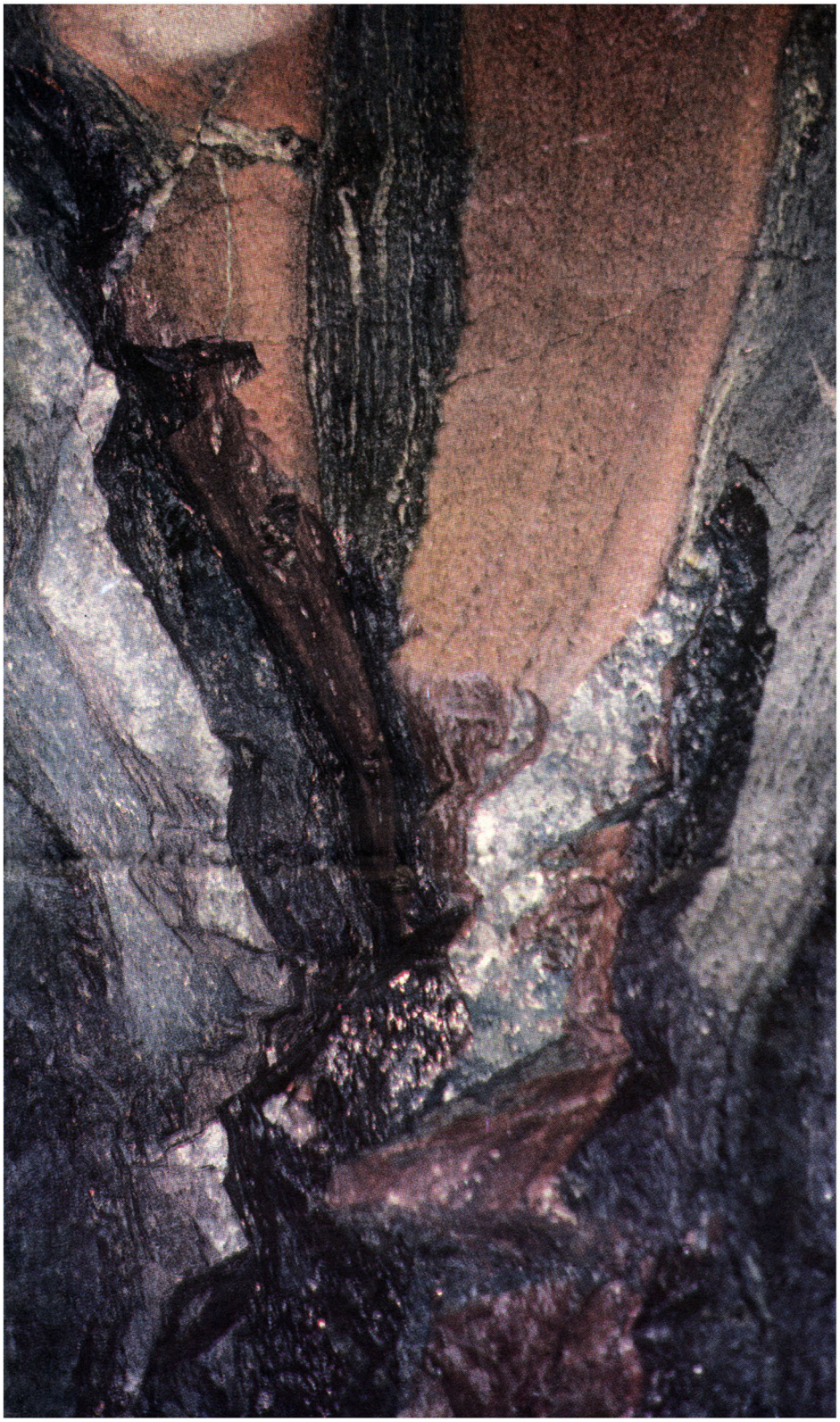
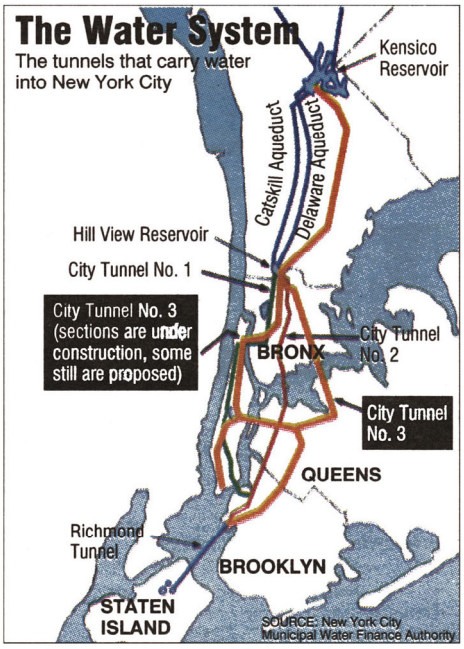


Photo by Diane Dennis New York City Department of Environmental Protection

This sample of gneiss rock, with the pink garnet band, is from the Roosevelt Island shaft and is one of thousands extracted.



separated schist (formed from the ancient ocean's crust during the Taconic Orogeny about 450 million years ago) from Fordham gneiss, the 1.1-billion-year-old bedrock of the proto-continent. Since then, using his fieldwork in the tunnel and Hofstra's own extensive drill core collection as proof, he has mapped a probable route for Cameron's Line, a warped and looping trail through southeastern Manhattan and parts of Brooklyn and Queens. He hopes to see Cameron's Line appear again when workers start tunneling beneath Brooklyn later this year. "When you walk over Cameron's Line, you're walking through an ancient subduction zone," Merguerian says, "and you realize that the rock you see in Manhattan was actually formed far away, deep in the ocean. It makes you feel the abyss of time."

While geologists like Merguerian want to learn more about the city's rock record so that they can learn more about the Earth's history, other geologists want to know how the city's geology will influence the construction of roads, subways, bridges and buildings. Although most New Yorkers don't think much about what's underneath their feet, the underlying geology has a profound impact on New York City's shape and design. For example, the city's world-famous skyline, with a cluster of skyscrapers in midtown and another cluster at Wall Street, owes its existence to the hard metamorphic bedrock that nears the surface at both of these sites. In between, no tall buildings can be built, because the bedrock dips down, forming a saddle filled by loosely packed sands and gravels.

Similar constraints apply to the construction of the new water tunnel. At an estimated total cost of $5 billion, the tunnel is the largest construction project ever undertaken in New York City, burrowing through miles of solid bedrock in the Bronx, Manhattan, Brooklyn and Queens. The geologists working on the tunnel's route don't care how the bedrock originally formed or when — they want to know how the rock will react to blasting and boring going on 24 hours a day beneath city streets and homes.

For every mile of tunnel, geologists working for the DEP take hundreds of rock profiles to give them an idea of the depth at which bedrock begins and what it is made of. Using a diamond-bit drill, geologists go down as far as 800 feet, extracting core samples for every 10 feet of rock along the way. While the discovery of an ancient fault — such as Cameron's Line — along the route of the tunnel thrills theoretical geologists, faults present problems for the city's geotechnicians.

"When we run into a fault, we don't think about the origin of that fault in the Earth's history," says Dennis, a geologist and engineer with the city's Department of Environmental Protection. Dennis, who's in charge of the core collection, has spent much of the last 12 years underground, advising tunnel crews during blasting with plastic explosives. "Rocks along faults are disturbed and act more like soil than bedrock," she said. "We try to figure out how that fault will react when we go through it. Will rocks come crashing down on our heads? Will it leak water?"

Since the excavation for the new water tunnel began in 1970, tunnel crew members — called sandhogs — have removed more than 2 million cubic yards of rock. While most of the work in Manhattan and the Bronx has been completed, crews are currently blasting new shafts in Brooklyn and the work in Queens is yet to begin. "The farther you go from Manhattan, the lower the bedrock is," says Mike Greenberg, the DEP's chief of Water Works Construction. "In Brooklyn and Queens, we have to go down through sand, gravel and boulders before we get to the bedrock. It's all glacial till."

The excavations of the original two tunnels, constructed in 1917 and 1936, also required intense scrutiny of the bedrock along their routes. And the geologists of the day, most notably Charles Berkey and Thomas Fluhr, wrote the book on practical geology in New York City. Today, geologists — both practical and theoretical — still use drill cores and field records from the construction of the old Water Tunnels No. 1 and 2 to piece together the city's geological puzzle and read new stories in its rocks.

"As a geologist reading and interpreting the rock record, you can feel the structure, unravel the pressures, and visualize them in three dimensions," Merguerian says. "It's a very special feeling when you walk over a terrain that you understand better than anybody else. It makes you feel at one with the Earth — even in a crazy place like New York City." ■

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