Charles Merguerian – Print Media (1983-2014)

Merguerian wasting time in a tunnel posing for promo shots instead of getting any work done (1999).

Charles Merguerian Media Articles Since 1983

42_ Outcrop: Geology Stops in NYC_June 2014
41_AM-NY_17 Mar 2011 – New York Seen as Overdue for Significant Earthquake
40_Metro NY_17 Mar 2011 – Governor Wants New York Plant Closed
39_Educated Observer_Oct 2010 – Teaching With Passion
38_Tunneling Online_Tunneling NYC 2009
37_NYT_22 Sept 2008 – At Ground Zero, Scenes From the Ice Age
36_City At The Waters Edge_by Betsy McCully_Apr 2007
35_Scientific American_Sept 2001 – Seeing the Earth for Its Faults
34_Communicator_Apr 2001 – Shaking Things Up
33_Newsday_17 Jan 2001 – Who'da Thunk It? Some Did
32_New York Times_22 Aug 1999 – New York Underground
31_Newsday_05 Oct 1997 – They Do Geology on the Run
30_Newsday_30 Sept 1997 – In the Belly of the Earth
29_Newsday_29 Sept 1997 – The Birth of Long Island
28_DailyNews_26 Apr 1997 – The Glacier Sleuths
27_New York Times_18 Apr 1997 – Counting Sheep Rocks
26_S I Advance_13 July 1995 – Agencies Working to Make Area More 'Earthquake-proof'
25_New York Times_19 Mar 1995 – What Would Happen to Long Island in an Earthquake
24_HofstraPride_June 1994 – Hofstra University Professor Dr. Charles Merguerian Explores The Truth About Earthquakes on "ABC's World of Discovery"
23_ABC-TV_21 May 1994 – Earthquakes: The Terrifying Truth
22_USA Today_20 May 1994 – 'Earthquakes' May Rattle Folks Far From the West Coast
21_Newsday_19 Apr 1994 – Tunneling Back Into Time
20_Hofstra Pride_Apr 1994 – Geology Professor is a True Mover and Shaker
19_Aftershock_May 1991 – Aftershock by Chuck Scarborough
18_HofstraHorizons_Fall1990 – Charles Merguerian: Research into Rocks and Rumbles
17_Discover_Sept 1990 – East Coast Earthquakes
16_Philadelphia Daily News_19 Oct 1989 – City Might Be Dirty, But Its Solid Dirt
15_New York Post_19 Oct 1989 – What If? Fear of Quake Gives NY the Shakes
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13_Daily News_27 Nov 1988 – Earth Could Move Again
12_Newsday_15 Apr 1986 – Is Big Apple Rocking at the Core?
11_Newsday_15 Apr 1986 – Geologist: NYC on Shaky Ground
10_Lawton Constitution_11 Apr 1986 – Discovery of Faults Raises Threat of New York Quake
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08_Worcestor Tele_06 Apr 1986 – New York City Seen Vulnerable to Quakes
07_Sun Sentinel_06 Apr 1986 – NY Could be Vulnerable to Temblors, Authority Says
06_New York Post_05 Apr 1986 – This Warning Takes the Quake
05_ New York Times _05 Apr 1986 – Geologic Faults Found Under East River
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03_Gannett_27 Oct 1985 – The Earth Moves
02_New York Times_23 Oct 1985 – Bigger Quake in Area Called Possible
01_Landprints_Apr 1984 – Landprints by Walter Sullivan
00_New York Times Weekend_02 Dec 1983 – Story of the Eons in New York's Rocks and Cliffs

OUTCROP

Newsletter of the Rocky Mountain Association of Geologists

Volume 63 • No. 6 • June 2014

Geology Stops: New York City

By Andre Scheinwald

Editor's Note

The summer travel season is upon us so we thought that we would bring you some lessor known exhibits and sites to view along your way.

For those of you heading east to the nation's financial district - one of RMAG's newest members and our newest associate editor shows brings you some geologic relief amidst the concrete.

By the time this publishes, I will have moved to Denver from New York and as a personal sendoff I am writing a series of pieces on places of geologic interest starting on the East coast. These are all personal accounts, so at times there will be a lack of geographic continuity. I will be starting this series with four stops in New York City; focusing in and around Central Park, as well as uptown Manhattan.

The first stop of interest is on the southeast corner of 68th St. and Madison Ave. The closest way to get there is by taking the 6 train to 68th St. and walking west on 68th towards Central Park West. What you will find is not in situ, as it is the building itself. The building is composed of fossiliferous limestone with visible fossils such as crinoid stems and brain coral. One does not have to look hard; in fact, you can even see the texture of the building in Google street view. As we all know, whoever chose this building material did so poorly. You can see the structural damage from the high weathering rate of limestone in the region. What I hope the reader learns from this is that interesting geology is all around us. I have learned from this observation to pay more attention to the buildings I pass and have found interesting rock types such as oolitic limestone and sandstone with bedding.

After the first stop you can continue on to Central Park West and take the entrance into the park just south of 67th St. and 5th Ave. Follow the path west approximately 480ft (or ~146m) to find an outcrop of schist with exact coordinates of 40.769500º, -73.971000º. Depending on whom you ask, schist in the NYC region is classified as either one or two different types: Manhattan schist only, or Manhattan schist and the Hartland Formation. Whatever the case may be, this specific schist outcrop contains prominent bands of quartzite, large specimens of muscovite, and pegmatite intrusions. The outcrop is the result of sediment deposition during the Cambrian and metamorphosed by the Taconic Orogeny, 450 MYA (Merguerian and Merguerian, 2004.) Also of interest is that this outcrop appears to be a Roche moutonnée based on the smooth up-slope of the outcrop and craggy downslope. A Roche moutonnée is a glacial weathering feature with the up-slope caused by glacial abrasion and the craggy downslope from glacial plucking due to pressure melting and refreezing of the ice. Rough observation from this one outcrop indicates that glacial motion followed a northeast to southwest direction created during the Pleistocene.

Another stop in Central Park is on the east side closest to the 59th St. and Columbus Circle entrance, accessible from the 59th St. station using the A,B,C,D, or 1 train. On the northwest corner of Heckscher Playground you will find another outcrop of schist with glacial striations running from northwest to southeast, possibly indicating a series of glacial advancements during the Pleistocene as it traces a different direction than the previous stop. This outcrop is known as Umpire rock or Rat rock, and also happens to be a good location for bouldering in the city. At either

Continued on page 23 »

Continued from page 19

location in Central Park I do not recommend trying to take any samples with a rock hammer. It is frowned upon and quite possibly illegal in the parks.

The last location is at the northern tip of Manhattan in Isham Park right next to the A train 207th St. Station. Along the length of Isham St. between Broadway and Seaman Ave. are outcrops of Inwood Marble which were metamorphosed from limestone during the Taconic Orogeny (Merguerian et al., 2011). These outcrops are a stark contrast to Manhattan schist in the area due to their low lying, heavily weathered nature. Feel free to take samples of marble that have weathered off the outcrop or are loose enough to pry off.

New York City has a variety of geologic features that beckon a geologist's attention in quieter sections of the city. Some of these are the glacial Roche moutonnées in Central Park molding schist outcrops and the Inwood marble formations in northern Manhattan's Isham Park. Those of you familiar with the city and its' geology may be questioning: "What about the Palisades sill? Or the Fordham gneiss? Or the minerals you can collect at Tubby Hook?" My response is that the city has a rich and varied number of geologic landmarks waiting to be observed and researched by interested geologists visiting the area. So much so that one could write a short book on everything that can be found.

That's not to say that books have not been written on the subject. Three resources that I have not personally read are Mannahatta: A Natural History of New York City, published by Harry N. Abrams in 2013 and available for $18.71 on Amazon; Geology and Engineering Geology of the New York Metropolitan Area, published by the American Geophysical Union in 1989;and The Geology of New York City and Environs, by Christopher J. Schuberth published in 1968.

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Volunteer Position for the Managing Editor for Outcrop Open

We are seeking a volunteer to assume the position of managing editor for the RMAG monthly newsletter *Outcrop*. Applicants must be experienced geoscientists capable of identifying and capturing stories of interest to the membership both within and outside of RMAG activities. The managing editor coordinates the production of the *Outcrop* with the RMAG staff and editors working directly with the layout artist. Availability to proof and cycle material and edits quickly is a must. Inquiries should be directed to Kristine Peterson @laramidegeo.com, the current managing editor, or Larry Rasmussen, RMAG Publications Committee Chairman, larryR@whiting.com. «

- 3/17/11 By Rolando Pujol

New York seen as overdue for significant earthquake

It's seen as something of a New York City bragging right: We don't have to worry about earthquakes.

While we shouldn't be shaking in our boots, we also must avoid sticking our heads in the sand when it comes to seismic risks, experts advise. In the aftermath of the Japan earthquake, scientists caution that New York has the potential for significant temblors. And we are overdue for one of at least 5.0 in strength, which could cause structural damage and even deaths.

"This idea that New York is impervious to large magnitude earthquakes is just totally wrong," said Charles Merguerian, chairman and professor of Geology at Hofstra University and principal of Duke Geological Laboratory in Westbury.

More of a long shot would be a 7 Richter scale temblor, like the one in 1886 that walloped Charleston, S.C., which is geologically similar to Gotham. Another concern is a fault line with a billion-year history of activity -- the Ramapo – that lies within striking range of Indian Point Nuclear Power Plant, 35 miles north of the city.

"It's important to say that we're in more danger of a hurricane than a damaging earthquake," said Merguerian, while stressing the danger of blowing off the risk. "We don't want to be fear-mongers, but people should at least be aware of this potential and what to do in the event of an earthquake — public education is lacking in this area."

Consider these numbers from a landmark 2008 study by Lamont-Doherty scientists: While that nightmare 7-plus quake happens on average every 3,400 years, a 5.0 event shakes Gotham roughly every 100 years.

Just such a quake last jolted Gotham on Aug. 10, 1884 off the Rockaways, an estimated 5.2 temblor that toppled chimneys, opened a 12-foot-long gash of earth in Brooklyn and was felt as far away as Philadelphia and Hartford. Such a quake could do more damage today in a considerably more populous and developed New York. Damage ultimately “depends of the frailty of the infrastructure,” Merguerian said.

It’s important to recall that while bedrock underlies much of the New York region, in many places just beneath the surface lies unconsolidated sediment that would not respond well to a major temblor, Merguerian said.

What’s more, fault lines can be found in several locations in Manhattan. For instance, the 125th Street fault nips Central Park at the northeast and continues through the Upper East Side into the East River. (The most recent activity has been on faults like that one, which trend from northwest to southeast. Two small 2001 city quakes were along such faults.)

East Coast quakes, too, happen closer to the surface, on stiffer, cooler rock, magnifying their potential effects when compared to a similar California quake, experts have said.

Now, consider, that more than half of New York City’s housing stock is made of unreinforced masonry. Unlike California, the city had long not taken earthquakes seriously, experts say, and while the city has adopted stiffer “international” building codes for new buildings, retrofitting, which would be incalculably expensive, has not been mandated.

Infrastructure from bridges and approaches to train tunnel are areas that would warrant additional stiffing, and projects are reportedly under way to do just that.

Officials from the Department of Transportation, and Department of Buildings did not return requests for comment.

An MTA spokesman said seismic retrofitting is "not an issue" because New York is not prone to major earthquakes.

Still, Merguerian said, if you examine the pattern, we’re due for another major event. Before the 1884 quake, the previous big events had been in 1783 and 1737. But to do a better analysis, you’d need “1,500 years of data,” which we simply don’t have.

“It’s a huge guess - the question is do we feel lucky today? How about tomorrow?”

Some New Yorkers aren’t quite sure. “What concerns me is that we have many big buildings. The impact could be huge," said Dolores Myers, 50, of Bedford-Stuyvesant.

One way to measure the force unleashed by an earthquake is to compare it to the energy released by an atomic blast. Here are four scenarios as measured on the Richter scale.

5.0: The equivalent of the 1946 Bikini Atoll atomic blast.

6.0: 27 nuclear weapons

7.0: 729 nuclear weapons

8.0: 19,683 nuclear weapons

9.0: 531,441 nuclear weapons

metro

Governor wants New York nuclear plant closed

NEW YORK
17 March 2011 08:14 PM
ALISON BOWEN

As the nuclear nightmare in Japan continues, Gov. Andrew Cuomo wants to shut down a Westchester power plant, but leading seismologists say there is no cause for alarm.

Cuomo wants to shutter Indian Point, the nuclear power plant 45 miles north of Times Square — and reportedly the most at risk in the nation for earthquakes, according to a new federal study.

The plant was built along Ramapo Fault, which isn't subject to extreme earthquakes — but, as Metro reported last month, New York City is long overdue for a quake, according to Won-Young Kim, head of the seismographic network at Columbia University's Earth Observatory.

Indian Point on the Hudson River supplies 30 percent of New York City's power supply.
STEPHEN CHERNIN/GETTY IMAGES

"I wouldn't be panicked for Indian Point," said Kim, who lives 15 minutes away from the plant. He noted it survived a 4.1 earthquake in 1985.

Instead of an earthquake, what New York scientists say they're really concerned about is radiation spreading worldwide from Japan.

"It could cover the globe," said Hofstra geology professor Charles Merguerian. "If it belches forth radioactive goo, people are going to experience it." Indian Point is now under a federal safety review.

Risk: Too close for comfort?

The U.S. government recommended a 50-mile evacuation zone in Japan — which, from Indian Point, would encompass the NYC metro area.

"Even if the risk is low, the consequence is enormous and potentially catastrophic," said Phillip Musegaas from environmental group Rivergreen."Do we want to continue to take that risk?"

But can he do it?

Gov. Cuomo doesn't have any direct power, NRC spokeswoman Diane Screnci told Metro. In order to close the plant, she said, "We would have to determine that the plant was not or could not be operated safely." However, Entergy Corp. does need to renew its operating license for the reactors in 2013, and opposition from the state's top official could be influential.

Follow Alison Bowen on Twitter at @AlisonatMetro.

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THE OBSERVER'S

THE EDUCATED OBSERVER

Winter 2010

GUIDE TO UNIVERSITY EVENTS

YOU DON'T NEED A TO BE A STUDENT TO ENJOY CAMPUS LIFE

SCHOOLS OF THE STARS

A MAP OF A-LIST ALMA MATERS

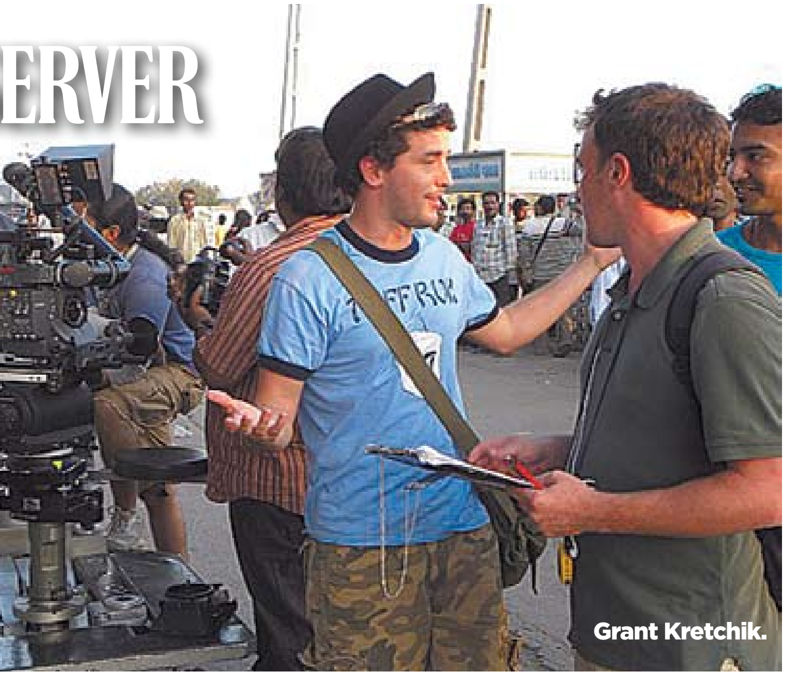
TEACHING WITH A PASSION

THREE TOP PROFESSORS SHARE THEIR SECRETS

UNDERGRADUATE APPLICATIONS

ESSAY ADVICE FROM THE EXPERTS

Teaching With Passion



A closer look at how three professors are bringing their passions into the classroom—and getting results.

Grant Kretchik, Pace University

Growing up, Grant Kretchik was lured to the stage by the glitz and glamour of the entertainment industry. But it soon became clear that acting, like any job, could be both tiring and difficult.

But, Kretchik, 31, was undaunted.

"To me, this work is like oxygen," he said. "It's like my family or friends; it's the place I'm most comfortable; it forces me to be more aware."

Kretchik graduated from Pace University in 2002 with a Bachelor's degree in Speech Communication, Media Studies and Theatre, and in 2005, from the New School University with an MFA in Acting. Having guided drama projects for friends and underclassmen throughout his student life, he was easily able to combine directing and teaching with his acting career.

While serving as the head of Pace University's BFA Acting Program and a full-time tenure track Assistant Professor, Kretchik is also responsible for spearheading the Performing Arts department's travel course to Greece and Italy. Now, Kretchik tries to channel personal mentors like veteran theatre director, Stuart Vaughan, while reminding his students that acting is not merely a "degree or career, it's a lifestyle."

"I try to raise their awareness about the community at large," said Kretchik, a resident of Jersey City. "In order to do that through art, they need to understand and create a personal relationship with it."

Kretchik believes that his position makes him responsible for encouraging his students to contribute to their communities. To this end, he makes every effort to bridge the gap between the classroom and work place and also looks into opportunities for outreach programs through partnerships with organizations such as Broadway Green Alliance.

Having recently returned from the Austin Film Festival where he celebrated the world premiere of a recent project, a romantic comedy titled "When Harry Tries to Marry," Kretchik is spending up to 15 hours a day in rehearsal in addition to his teaching schedule. He is currently assisting stage director, producer and Tony-nominee Michael Greif, in preparation for the first national Broadway tour of Next to Normal starting on Nov. 28, while also directing an adaptation of "A Christmas Carol" with Pace University's undergraduate performing arts and dance majors, which is scheduled to debut on Dec. 8 at the Schimmel Theater.

When asked to name a favorite project, Kretchik replied, "It's really whichever one I'm working on, at the time."

Alice Chun, Parsons The New School for Design

From an early age, Alice Chun's relationship with her father, an architect, and her mother, an interior designer, cultivated a deep-rooted appreciation for the creativity involved in the design process.

Today Chun, 45, a practicing architect, leads design studios in Master of Architecture and Master of Fine Arts in Interior Design programs at Parsons The New School for Design, where she is also an Assistant Professor of Design, Material Culture and Fabrication, and the Director of the Angelo Donghia Materials Library and Study Center.

After graduating with an MA in Architecture from the University of Pennsylvania in 1993, Chun happened upon teaching when a professor she was for as a Teaching Assistant was forced to spend several months recuperating from an accident. A successful semester flying solo in the classroom resulted in her being invited back to teach her own design studio.

"My role is to help students become aware of their own potential," she said. "By creating a dialogue with them, I want to be a threshold for

BY RHEA MAHBUBANI


Alice Chun.

MATTHEW SUSSMAN/THE NEW SCHOOL

my students to see what they're capable of."

A proponent of connecting academia and professional practice, Chun advocates rethinking the education meted out to today's youth.

"Why not create our own projects, empower ourselves and our students, and reach out to clients rather than waiting for projects to come to us?" she asked.

According to Chun, her belief in humanitarian design, adaptable architecture and cross-disciplinary relationships amidst different branches of design make her somewhat of a radical. Today, much of her work is centered on aiding crises-ridden communities through initiatives that offer long-term progress via housing, education and health infrastructure.

With the aim of creating a "broader-reaching educational and professional experience," Chun partnered with graduate students from Columbia University and set up a non-profit organization called Studio Unite. Rather than merely providing housing or a sole health clinic, the team functions as a "design platform connecting vulnerable communities with a high level of design expertise and resources," serving as a catalyst for the growth of sustainable communities worldwide.

Chun is currently teaching a design studio at Parsons that is focused on creating vocational school in Lagos, Nigeria, to be built as a project of Studio Unite.

"I'm driven by a sense of empowerment and am really inspired by helping communities," she said. "I want my students to also experience that."

On Nov. 18, Chun is organizing a fundraiser integrating fashion, architecture and humanitarian design, which involves Studio Unite, Parsons The New School for Design and United Nude, a shoe design company. Patrons can expect silent auction items donated by designers such as Marc Jacobs and Diane von Furstenberg.

Charles Merguerian, Hoftsra University

Charles Merguerian is fascinated by rocks.

"The texture, the colors, the minerals, the density," he said. "There's just something special about them."

At the age of four, when Merguerian's family moved to Queens, rocks in the nearby fields caught his attention. What started as a childhood hobby of became the foundation for a successful-35 year career as a professional geologist.

Merguerian, 61, Chairman and Professor of Geology at Hofstra University and the Director of Duke Geological Laboratory in Westbury, NY, believes that rocks are "portals into the history of the earth."

Despite publishing a fair amount of geological data about California and Connecticut, Merguerian's area of expertise is the geology of New York City, an interest that he has nurtured since his childhood.

"I work on the oldest rock layers which are about a billion years old up to the most recent soil layers which are 10,000 years and younger, mostly formed during the glacial periods," he said.

Merguerian first taught as a Boy Scout master and then transitioned to academic teaching at CUNY in 1972. Since then, he has taught at CUNY, Columbia University, NYU, The New School, and Hofstra.

Based on his experience as a professional jazz and blues musician, Merguerian likens teaching to performing in front of a crowd.

"There is no point in knowing something if you can't present it," he said. "The ability to present things well is very important to me, so as a result I spent a lot of time on that."

At Hoftsra, Merguerian teaches a course called Cartographic Techniques in which students learn how to draw diagrams and maps, create power points and construct attention-grabbing presentations with embedded audio and video.

"I always tell my students that you want to be known for the quality of your work," he said. "That's my basic mantra."

Along with instruction, Merguerian makes every effort to be a role model for his students, whom he considers no different from his own children, and provides emotional support and understanding. He also ensures that his courses include fieldwork, complete with opportunities for effective research and report preparation.


Charles Merguerian.

Merguerian is interested in the excavated World Trade Center site because it allows a peephole into Manhattan's rock formation. The lack of naturally exposed rock south of 59th Street makes the information obtained from drilling and building excavations a novelty, he says.

Soon, Merguerian will be mapping out areas in Isham Park as part of his involvement with the electricity-transmitting Con-Edison tunnel connecting Yonkers and the Inwood section of Manhattan. His passion feeds his productivity.

"I don't work; I just continue to do what I enjoy," he said. "I don't need motivation. If you are passionate about the things you do, even if it's selling hot dogs, it makes life much better."

Geology and Tunneling in New York City

Considerations for Planning, Design and Construction

By Dr. Christopher Snee

There is no shortage of geological information about New York City, which is a testament to its diversity and complexity. Although the geological complexity requires skill to decipher, the rocks lend themselves to simplification for the purposes of engineering. A key factor in this simplification is relating geological characteristics to the scale of the project. For example, as the cross-sectional area of an excavation increases there is a transition from dominance by intact properties to dominance by flaws and discontinuities.

In the case of the caverns that are required for several stations in New York City, the role of large-scale features such as faults, shear zones, weathering, alteration and in-situ stress control ground behavior. When we understand which characteristics apply to an engineering problem, the possible solutions become clearer and it isn't quite so important to achieve geological precision. This short note presents an overview of the geological characteristics of Manhattan that should be accounted for in planning, design and construction of tunnels.

Engineering Geology of Manhattan

The evolution of our understanding of Manhattan geology is covered comprehensively by the encyclopedic works of Professor Charles Merguerian (1996). This is only part of a substantial body of work that is a credible and evolving alternative to the Baskerville map, such as Bennington and Merguerian (2007). The quasi-official map of the city by Baskerville (1994) is the most common reference for engineering projects.

New York City is made up principally of ancient metamorphic Precambrian to Cambro-Ordovician rocks that are divided into two major units separated by at least one regional northeast-southwest trending thrust fault that runs through Manhattan. The Manhattan Formation is found west of this major thrust fault and the rocks to the east are known as the Hartland Formation. There are alternatives to this division, and further reading will introduce the Manhattan Schist, the Inwood Marble and the Fordham Gneiss. It is important to recognize that the geological names for the rocks have no engineering meaning, for example the Inwood Marble contains schist and quartz and the schist rocks contain marble, pegmatite and serpentinite. Furthermore, recent investigations (Snee, 2004 & 2006; Merguerian and Moss, 2007) have revealed that a polar change in rock type can occur on a city block scale, for example the rock can change dramatically from weak mica rich schist to very strong crystalline granite with a distinct vertical contact.

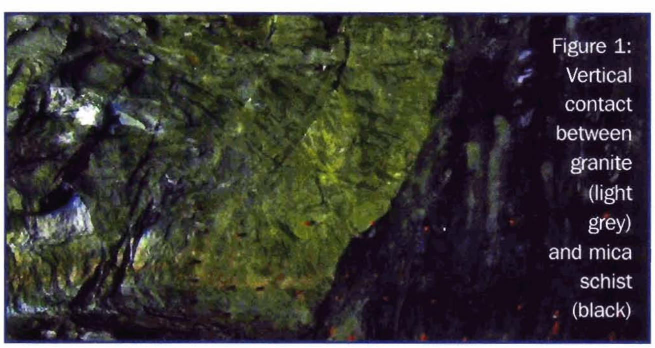


Figure 1: Vertical contact between granite (light grey) and mica schist (black)

Even though the lithology and structural geology vary quite dramatically, the following rock mass characteristics are fairly universal and possibly the most relevant from a construction perspective:

Unpredictable top of rock profile
- Local deep weathering
- Deep glacial erosion

Faults and shears
- Mineral alteration
- Joints
  - Variable joint surface characteristics
  - Open vertical joints
  - Wavy joints
  - Rotation of joint systems
  - Joint clusters
- High horizontal stresses

Rock Profile - The bedrock surface is undulating, incised and unpredictable, reflecting the geological and geomorphological past.

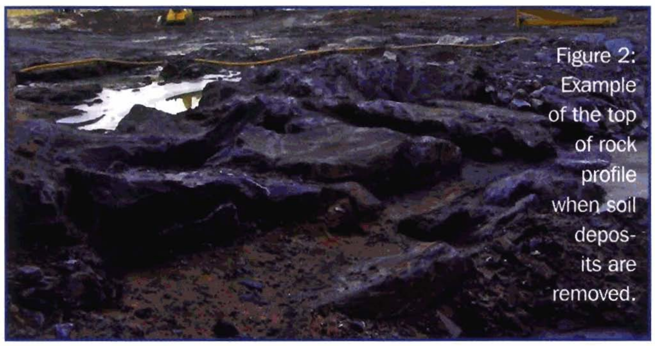


Figure 2: Example of the top of rock profile when soil deposits are removed.

Some of the deeper depressions in the top of rock are valleys created by erosion from water and ice that exploited weak rock due to faulting, shearing and hydrothermal alteration. These often became stream channels or inlets that have since been infilled by natural and anthropomorphic deposits.

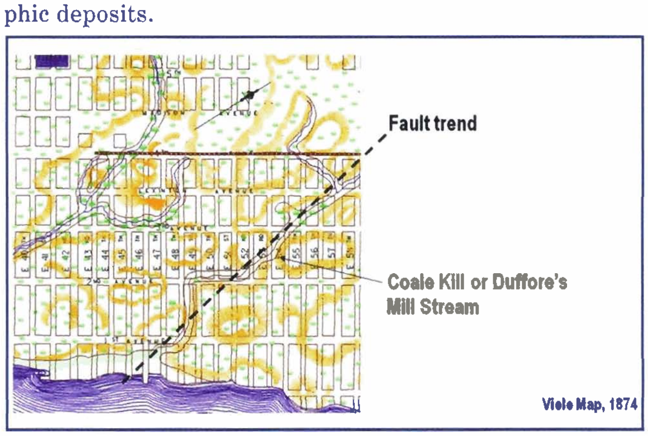


Figure 3: Extract of the Vieile Map showing the location of buried stream channels and valleys.

Geology and Tunneling in New York City

Where the rock is near to the present ground surface the glaciers have removed most of the weathered material, leaving behind a thin but impersistent mantle of decomposed to weathered rock overlain by basal till followed by a sequence of glacial till, outwash and reworked till deposits and lake deposits of silt and fine sand. There are substantial thicknesses of decomposed rock where the rock is at a substantial depth below the current ground surface such as Chinatown where it is about 300 ft thick.

Faults and shears – The geology of New York City is dominated by two large-scale thrust faults named Cameron's and St. Nicholas thrusts, which have created or influenced subsidiary faults, shear zones and joint systems (Merguerian and Moss, 2007). There are numerous but lesser thrusts and faults passing through Manhattan and these are normally associated with local increases in fracturing, decomposition, release or imposition of in situ stress and abrupt changes in rock type. The most prominent regional fault in New York City is the northwest-southeast trending 125th Street or Manhattanville Fault that is accompanied by en-echelon faults with parallel west-northwest to east-southeast strike and a very deep eroded valley from the north Harlem into the Bronx that was filled by an extensive swamp.

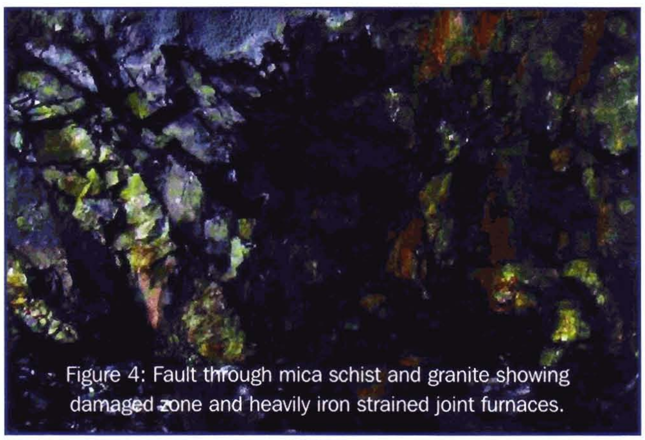


Figure 4: Fault through mica schist and granite showing damaged zone and heavily iron strained joint furnaces.

There are less well documented faults throughout the City and examples occur at Broadway and 14th Street, 12th Avenue and 35th Street, 2nd Avenue and 86th Street and 69th. These are characterized by disturbance and distortion of the foliation, fault gouge, fault breccia, mylonite and damaged zones that range between a few inches to tens of feet thick.

Figure 5: Baskerville Map for north Manhattan showing the 125th Street Manhattanville Fault

Rock ypes — *The following table presents the dominant rock types found in Manhattan.*

Table 1. Fundamental Lithology for Some Manhattan Rock Types

Rock name	General location	Mineralogy	Characteristics
Quartz mica SCHIST	Pervasive	Quartz, biotite and muscovite mica, feldspar and garnet	Strong, medium to coarse grained with distinct mineral alignment, particularly of the mica. Variable degree of segregation of metallic and alumino-silicate minerals
Mica SCHIST	West side of Midtown	Biotite, muscovite, chlorite and quartz	Moderately strong, dark grey to black medium to coarse grained, dominated by black mica with intercalated quartz lenses
Amphibole SCHIST		Hornblende, quartz, biotite and muscovite mica, feldspar and trace garnet	Strong, very dark green, coarse grained, poorly foliated with very thin garnetiferous bands. Dense, strong rock and relatively isotropic
GRANOFELS	Pervasive transitional within the schist	Quartz, biotite and muscovite mica, feldspar and garnet	Strong, medium to coarse grained, eguigranular with absent or poorly developed foliation
PEGMATITE	Pervasive	Quartz, muscovite mica, alkaline and feldspar	Strong, pink or slightly greenish light grey, very coarse grained with individual crystals of alkaline feldspar greater than 1 inch
SERPENTINITE	West side of Midtown	Serpentine, sillimanite, muscovite	Weak, light to dark green fine to medium grained with very small proportion of asbestiform minerals
GRANITE	West Side	Quartz, feldspar and mica	Strong to very strong, cream to pink coarse grained, strong brittle rock intruded in to the schist
MARBLE	North, west Midtown and Lower East Side	Calcium and magnesium carbonate, quartz and mica in banded marble	Strong, white, banded grey and brown coarse grained saccheroidal dolomite intercalated with schist near junction with schistose rocks

The majority of the rocks are classified as schist, which implies alignment and layering of the minerals and consequently a tendency to break in a preferred orientation. However, the degree of schistosity and segregation varies widely, from pure black mica schist, to gneissic texture to a complete absence of fabric in granofels.

The minerals are chemically altered to quite a significant degree yet this is not obvious by visual inspection of core samples. The alteration, which can be seen under a microscope, ranges from coating of crystal surfaces to complete conversion to another mineral. The most common alterations are:

Orthoclase	—	sericite, calcite, clay
Plagioclase	—	calcite, sericite
Hornblende	—	magnetite
Biotite	—	chlorite, pyrite, epidote
Calcite	—	dolomite

The biotite tends to be more altered than the muscovite. The plagioclase appears to be more chemically stable than orthoclase, which is usually altered to sericite by as much as 90 percent.

Joints - There are three fundamental joint families or sets in New York City, Set 1, Set 2 and Set 3, with subsets (Snee 2004). Set 1 joints are parallel to the foliation, Set 2 are sub-vertical to vertical cross-foliation joints, and Set 3 is a conjugate to foliation joints typically sub-horizontal to moderately dipping with perpendicular dip and parallel strike to the foliation. In addition there are sub-ordinate sets or random fractures produced by faulting and folding creating blocky conditions where as many as five joint sets can be found.

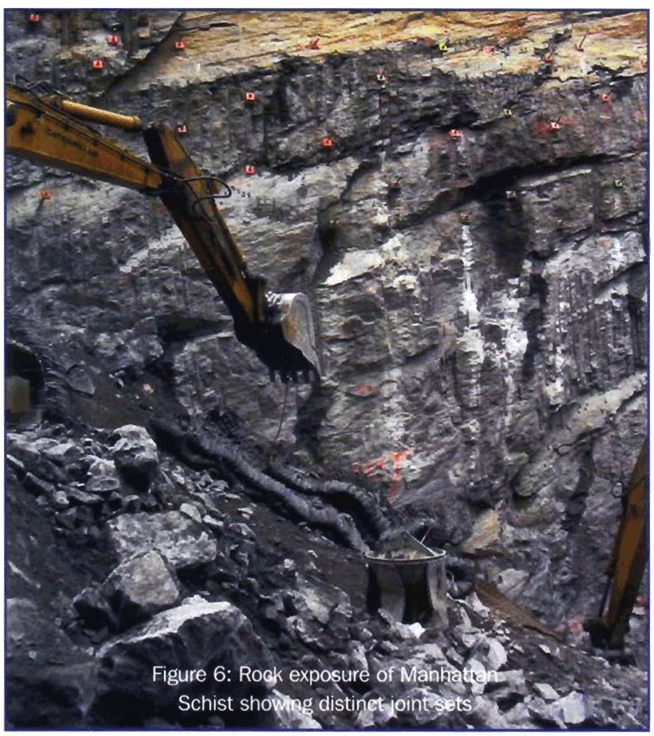


Figure 6: Rock exposure of Manhattan Schist showing distinct joint sets

Although Manhattan is almost completely urbanized, there are many useful exposures of rock that show the complex shapes of discontinuities such as beneath Grand Central Terminal and alongside the Amtrak loop track on the west side of the island around 35th Street. Recent studies of these exposures have revealed that the joints are wavy and the waviness increases the intrinsic stability of the rock mass significantly (Snee, 2006). Furthermore, frictional strength of the joints is controlled by the roughness of the profile, interlocking and coating (typically iron oxide, sericite, kaolinite and chlorite) of the joint surface.

Stress - New York City is a relatively dormant region even though it still experiences an occasional seismic "bump." However, the geological past of New York is a dramatic story of at least five mountain building phases and most recently glacial loading and unloading. The legacy is a state of stress that is extremely difficult to measure, which is unfortunate because the magnitude and orientation of in situ stress has a significant bearing on the stability of a rock mass because the stress causes the fractures and faults to lock together which encourages arching in the crown of a tunnel. Recent investigations have found that the horizontal stress at shallow depth in Manhattan is significantly higher than the vertical overburden stress and the orientation of the principal stress tensors is fairly consistent, which not only explains why excavations in rock have traditionally required little to no support but offers opportunities for economic design of support for future underground excavations (Snee 2006).

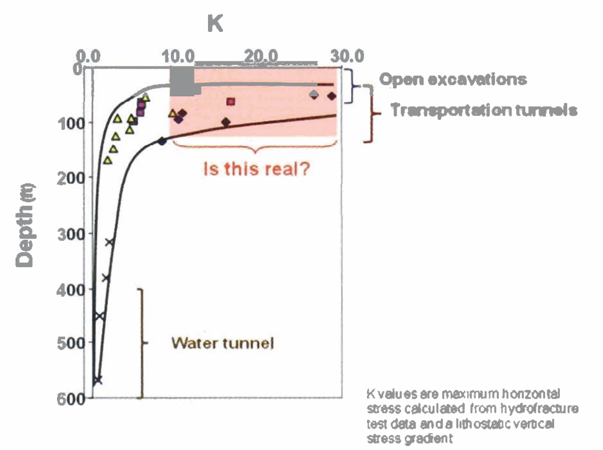


Figure 7: Calculated values of the horizontal to vertical stress ratio using the hydrofracture method in Manhattan.

In terms of the ratio between the horizontal to vertical stress, or K-value, the general cluster of data is between 2 and 5. Although K-values greater than 5 have been measured indirectly, they are counter intuitive to geological argument because they would manifest as obvious ground movements such as floor heave, slabbing from walls and explosive fracture of massive rock at shallow depth (there are anecdotal records of slabbing in deep tunnels in the New York area but not in the shallow depths corresponding to the location of the tests where high K values were measured).

Conclusions

The geology of Manhattan is complex but this complexity can be rationalized and understood for design of tunnels and caverns by characterizing and classifying the essential geological features and relating them to the geological history. It is important to reflect the reality of the geology because a substantial proportion of the strength and stability of the rock mass can be derived from features such as the waviness of the joints, the condition of joint surfaces, and the relatively high horizontal stress.

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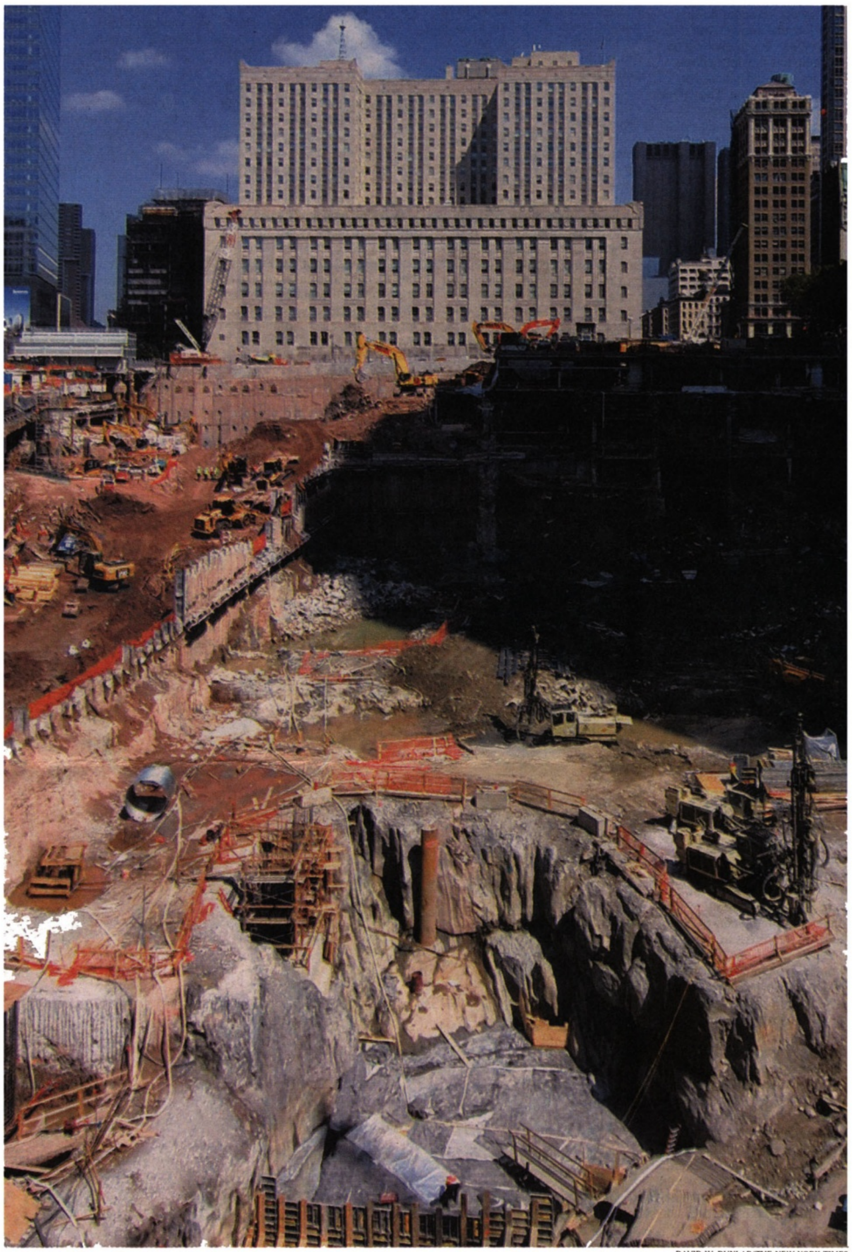
The Metro Section

The New York Times
MONDAY, SEPTEMBER 22, 2008

At Ground Zero, Scenes From the Ice Age

Trade Center Excavation Uncovers a Landscape Carved by Glaciers



DAVID W. DUNLAP/THE NEW YORK TIMES

A Glimpse of New York City, 18,000 B.C.

Excavation at the World Trade Center site has uncovered, among other geologic features, a 40-foot glacial pothole. Page B4.

The New York Times MONDAY, SEPTEMBER 22, 2008

By DAVID W. DUNLAP

Those who say the World Trade Center site is changing at a glacial pace have no idea how right they are.

A fantastic landscape in Lower Manhattan — plummeting holes, steep cliffsides and soft billows of steel-gray bedrock, punctuated by thousands of beach-smooth cobblestones in a muted rainbow of reds and purples and greens — has basked in sunlight this summer for the first time in millennia.

This monumental carving was the work of glaciers, which made their last retreat from these parts about 20,000 years ago, leaving profound gouges in the earth and rocks from the Palisades, the Ramapo Mountains and an area of northern New Jersey known as the Newark Basin.

Plumbing these glacial features and souvenirs has been critical in preparing the foundation for Tower 4 of the new World Trade Center, being built by Silverstein Properties. The concrete footings from which its columns rise must rest on firm bedrock. Engineers need a clear understanding of the rock's contours.

"You want to make sure you're not perching something on a ledge," said Andrew Pontecorvo, a supervising structural engineer at Mueser Rutledge Consulting Engineers, which is working on the trade center project.

Engineers knew in advance that there were "discontinuities" in the bedrock at the southeast corner of the trade center site, where Tower 4 is situated. Some of these were revealed in the 1960s during the construction of the original slurry wall. (George J. Tamaro, who supervised that job for the Port Authority of New York and New Jersey, is a retired partner of Mueser Rutledge.)

And when parts of the slurry wall were rebuilt after 9/11, engineers found areas where the rock anchors that stabilize the wall would not hold, meaning there were voids in the bedrock.

Borings through the ground also showed large discrepancies in the elevation of the rock underneath. "It was extreme from the variation you would interpret to what we actually encountered," Mr. Pontecorvo said.

Obviously, the bedrock topography could not be mapped with enough precision until all the soil was removed and the surface was fully exposed. But besides being an engineering necessity, the unearthing of geological features, especially a 40-foot depression known as a pothole, has offered scientists a rare window into the deep past.

"There are areas in local parks that have small vertical potholes exposed," said Cheryl J. Moss, the senior geologist at Mueser Rutledge, "but I'm not aware of anything in the city with a whole, self-contained depression on this scale."

Ms. Moss and Mr. Pontecorvo are scheduled to give an illustrated lecture on the site at 7 p.m. Wednesday at the Tribute W.T.C. Visitor Center, 120 Liberty Street, opposite the pothole.

"It's been called the Grand Canyon of Lower Manhattan," Mr. Pontecorvo said.

Charles Merguerian, chairman of the geology department at Hofstra University and a consultant to Mueser Rutledge on the trade center project, put it even more simply: "Beautiful!"

"It is very unusual to see such features near sea level," he added.

Shown photographs of the rocks, Sidney Horenstein, a geologist and environmental educator emeritus at the American Museum of Natural History, said, "You don't find such an array of rock types in the few places in the city that the glacial deposits are exposed."

Across much of the trade center site, bedrock level is roughly 70 feet below street level. In the southeast corner, however, the pothole adds another 40 feet to the depth, meaning that its bottom is about 110 feet below street level.

Yet when the pothole filled with rainwater this summer, it looked like nothing so much as a little mountain pond. Crevices around the edge were filled with pockets of densely packed cobblestones, possibly some of the very stones that the glaciers used to do the carving.

"As the ice passed over New Jersey," Ms. Moss explained, "it picked up local rocks such as red shale and sandstone and gray basalt from the Palisades. As ice melted from the advancing glacier, raging streams of water flowed in front of it. The strong currents picked up the sand, gravel and boulders and carried them downstream across the World Trade Center site.

"As these rocks bounced across the bedrock, essentially sandblasting the surface, the softer layers started to erode out and the harder rock left behind became polished. In places, the water swirled in whirlpools of varying sizes, carving out deep potholes and larger basins."

Along the east side of the pothole, the rock layers run vertically — not horizontally. The result, where the surface has been carved away in a concave form, is an abstract canvas of swirling, concentric rings; not unlike a gouge in a wall that reveals many layers of old paint.

This speaks of a period far more ancient than the glaciers, about 500 million years ago, when the edges of the colliding North American and African continental plates got shuffled together.

"That's when all this got pushed into a vertical orientation," Dr. Merguerian said. He estimated that the rock around the pothole had once been 20 miles below the surface, based on the presence of a high-pressure mineral called kyanite.

Ultimately, geology at the trade center site is in the service of construction, meaning that the pothole and other features are either being covered, filled in or blasted away. "It's nice to look at," said Robert B. Reina, a supervising structural engineer at Mueser Rutledge, "but it's all got to go."

Construction workers have developed an appreciation of this otherworldly site, even as they have labored to obliterate it. For instance, Joe Racanelli, a foreman, has been collecting those smooth and colorful cobblestones from New Jersey and lugging them home to the Bronx.

"I can't help it," he admitted.

And a mechanic who introduced himself simply as Al made it plain that this was one New York pothole he would miss.

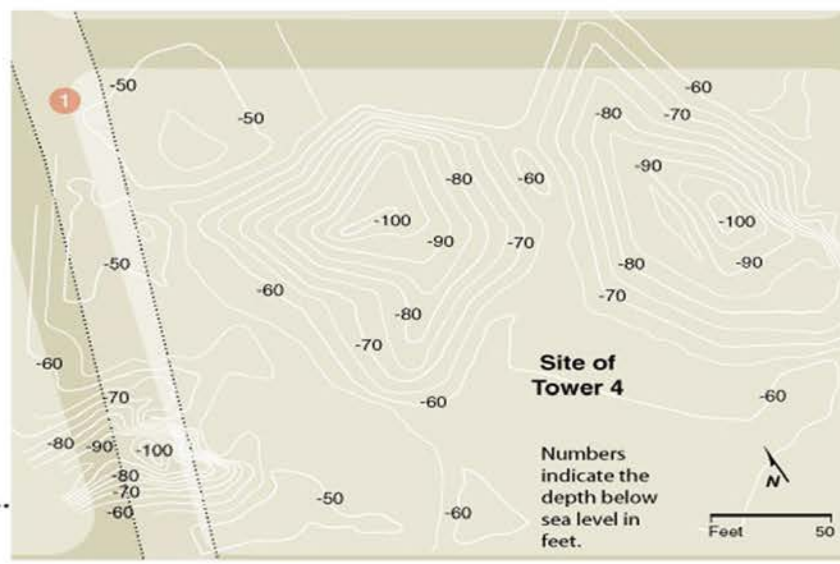
"I think they should keep it," he said. "Turn it into an aquarium. Fill it with fish. Do something special — not just another building."

The New York Times MONDAY, SEPTEMBER 22, 2008

A worker is framed by bedrock that was scoured by a retreating glacier 20,000 years ago.

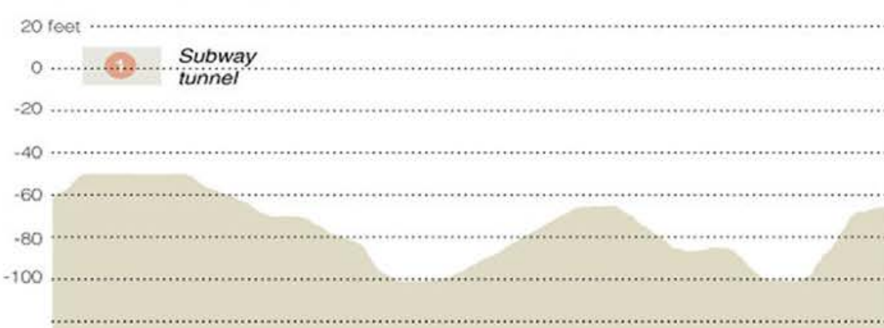
Glacial Terrain At Ground Zero

Excavations for Tower 4 at the southeast corner of the World Trade Center site uncovered a landscape carved by glaciers out of bedrock at least 20,000 years ago, with deep pools known as potholes.



BELOW CITY STREETS

Map at upper right shows bedrock contours of the Tower 4 site from above. At right is a cross section. In the measurement scale, 0 is close to sea level and is10 to 20 feet below street level. That means the bottoms of the potholes (-100) are about 110 feet to 120 feet below the street.



THE NEW YORK TIMES

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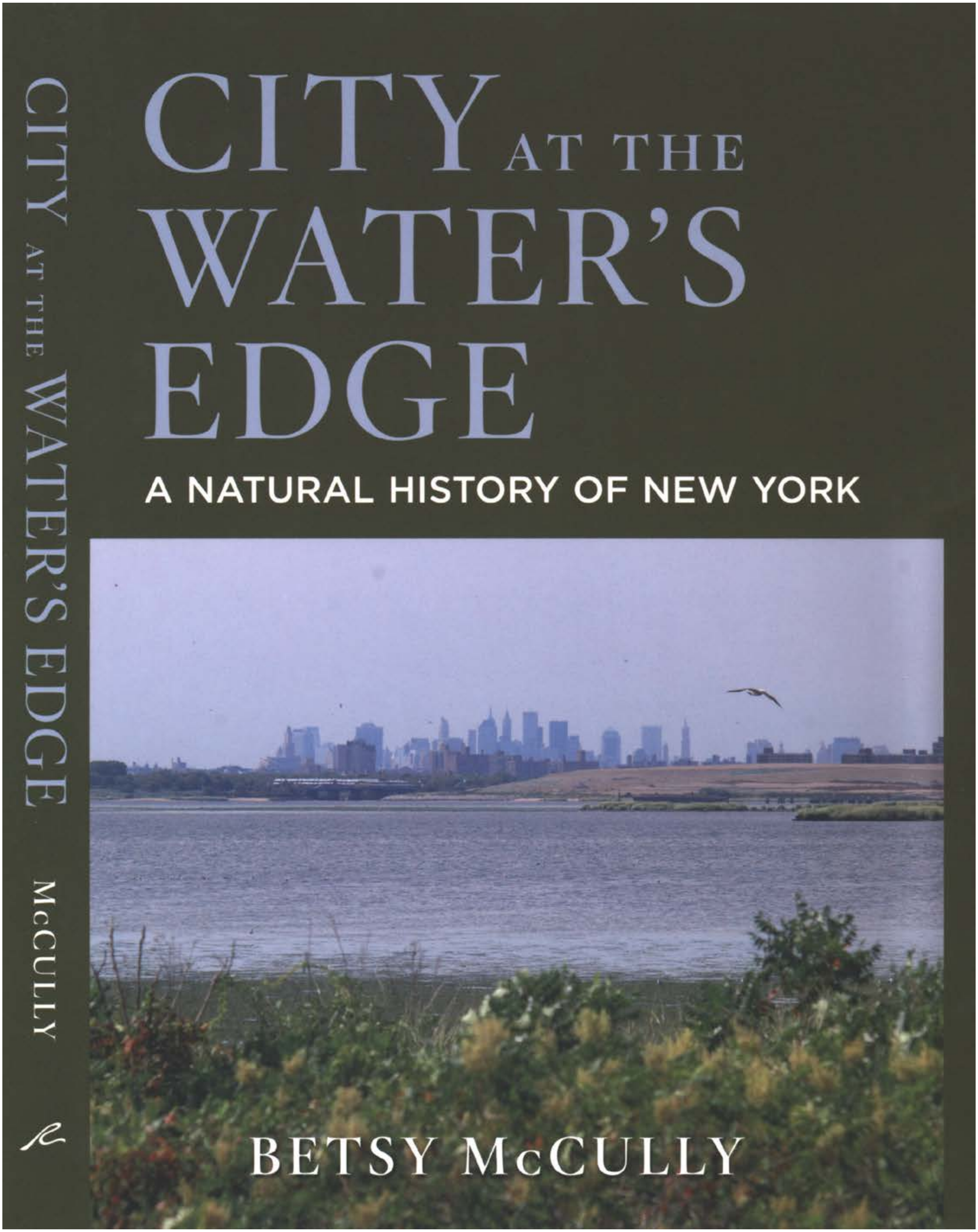
CITY AT THE WATER'S EDGE
McCULLY
CITY AT THE WATER'S EDGE
A NATURAL HISTORY OF NEW YORK
BETSY McCULLY

City at the Water's Edge

Dear Charles,
Thank you for your important contribution to my book.
Wishing you a productive 2007!
Betsy McCully

Acknowledgments

This book is the culmination of a fifteen-year project. It could not have been completed without the help of many people.

I thank my first reader, Kirkpatrick Sale, whose book *Dwellers in the Land* inspired me, and whose belief in my project encouraged me to go forward. The urban bioregionalist Peter Berg was an invaluable resource of ideas and materials on the sustainable city. I also wish to acknowledge Charles Merguerian of Hofstra University, who read and corrected a first draft of the geology chapter, and Robert Grumet, who read and commented on an early draft of the chapter on the Lenapes.

I thank my colleagues at Kingsborough Community College who have expressed confidence in my endeavor and enthusiasm for the project. I especially wish to acknowledge Gene McQuillan, Tara Weiss, Robert Singer, Len Green, Lea Fridman, Norah Chase, and Bonne August. I could not have completed the book without generous research grants from the Professional Staff Congress of the City University of New York during the years 2003 to 2005.

I spent many hours researching materials at the excellent libraries of New York City, including the library of the American Museum of Natural History, the rare book room of the Brooklyn Botanic Garden, and the New York Public Library.

In the final stages of writing my book, the meticulous editing of Audra Wolfe, senior science editor at Rutgers University Press, has made me a better writer and I believe made a better book. I am also grateful to Steven Handel of Rutgers University, who generously sent me materials on habitat restoration projects in New York City.

I wish to express special thanks to my son, Ben Cooper, who has supported me in untold ways. He has trekked with me in the wilds of New York City, as we explored its many parks and snapped countless pictures of the plants and animals which inhabit them. A professional photographer, Ben has taken several of the photos that appear in this book.

1

Bedrock New York

A cold day in January is a good time to walk the beach. Only hardy, beach-loving souls are out here on Coney Island, drawn to the shining expanse of the Atlantic lit by the low winter sun as it arcs across the southern sky. A few gulls warm their breasts in the sun, a dog races ecstatically along the water's edge distantly trailed by his bundled-up owner, and a human scavenger sweeps her metal-detector across the sand. I search for what the tide has disgorged—an interesting piece of driftwood, an unbroken conch shell—and a jagged piece of rock that glints and glitters when the sun strikes it catches my eye. I pick it up and turn the rough, flaking stone in my hand, knowing I am touching the bedrock of New York City.

This rock connects me to both the natural and human history of this place. The jetties that protect beaches and homes from the ocean's direct onslaught are comprised of ripped-up bedrock, called rip-rap. These were quarried during Manhattan's great building boom at the turn of the last century, the by-products of subways and skyscrapers. The rock I hold in my hand is a piece of Manhattan schist, one of three layers of rock that form the bedrock of New York City. The rocks bear testimony to the rich geological history of the city, a story that takes us back a billion years. Imagine a Manhattan skyline of jagged mountain peaks.[1]

This piece of schist tells me that around 450 million years ago, volcanoes erupted off the northeastern coast, spewing lava that cooled and gradually formed a volcanic island arc. Winds blew volcanic ash into a shallow marine basin, where sediments accumulated in mineral-rich layers that were gradually compressed into shale. The sediment-laden oceanic crust slid beneath the lighter continental crust in a process known as subduction, and the volcanic island arc accreted to the continent. The mica-rich shale, subjected to the intense heat of the earth's mantle, was recrystallized and transformed into the schist I hold today, plucked out of the sands of Coney Island.

Most of New York City is built on three layers of strata known as Manhattan Schist, Inwood Marble, and Fordham Gneiss. The exception is Staten

Island, where a northeast-trending ridge of Serpentinite erupts to the surface in the island's middle, peaking at 540-foot-tall Todt Hill, the highest point in New York City. Schist forms the spine of Manhattan 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

Fig. 1.1. W. W. Mather, Geological map of Long and Staten Islands with the environs of New York, 1842. (Courtesy of The Lionel Pincus and Princess Firyal Map Division, The New York Public Library, Astor, Lenox and Tilden Foundations.)

the gap between "midtown" and "downtown" in the Manhattan skyline, since tall buildings had to be anchored on solid bedrock, and not on the glacial till that fills the valleys. The contemporaneous Inwood Marble, metamorphosed from limestone, forms beds 150 to 500 feet thick beneath the Harlem River and adjacent regions known to geologists as Inwood Lowland; it underlies the East River and the Harlem Lowland and above ground forms a ridge from Dyckman Street on the upper west side northward to Marble Hill. The billion-year-old Fordham Gneiss erupts to the surface in the Bronx, forming the Riverdale and Grand Concourse ridges. The three strata of schist,

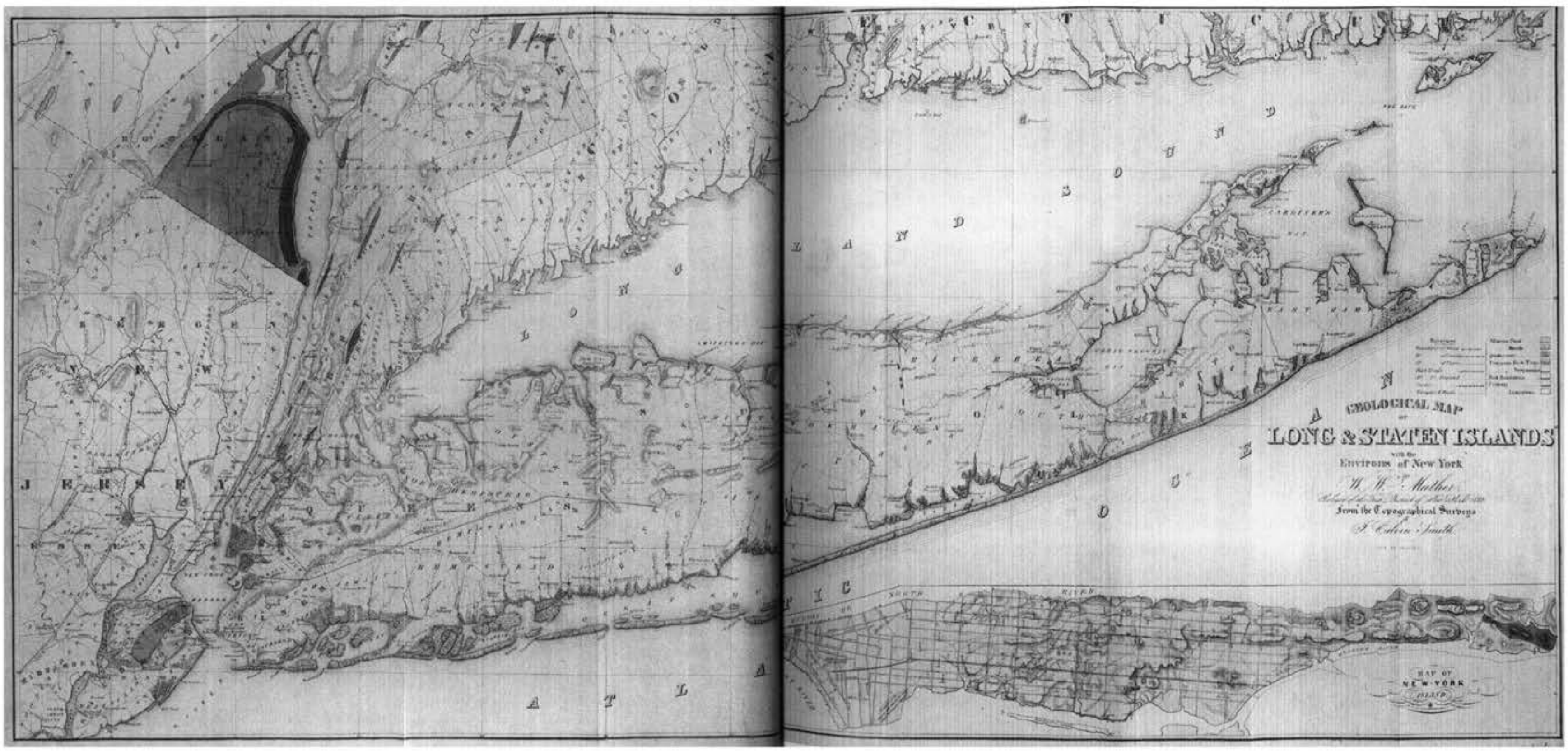

Table 1.1 Geologic Time Chart

(with selected major geologic events from southeastern New York and vicinity)

Era / Periods (Epochs)	Years (Ma)	Selected Major Events
Cenozoic		
(Holocene)	0.1	Rising sea forms Hudson Estuary, Long Island Sound, and other bays. Barrier islands form and migrate.
(Pleistocene)	1.6	Melting of last glaciers forms large lakes. Drainage from Great Lakes overflows into Hudson Valley.
		Dam at The Narrows suddenly breached and flood waters erode Hudson shelf valley.
		Repeated continental glaciation with five (?) glaciers flowing from NW and NE form moraine ridges on Long Island.
(Pliocene)	6.2	Regional uplift, tilting and erosion of coastal-plain strata; sea level drops. Depression eroded that later becomes Long Island Sound.
(Miocene)	26.2	Fans spread E and SE from Appalachians and push back sea. Last widespread marine unit in coastal-plain strata.
Mesozoic	66.5	
(Cretaceous)	96	Passive eastern margin of North American plate subsides and sediments (the coastal-plain strata) accumulate.
	131	(Passive-margin sequence II).
(Jurassic)	190	Baltimore Canyon Trough forms and fills with 8,000 feet of pre-Cretaceous sediments.
		Atlantic Ocean starts to open.
		Newark basins deformed, arched, eroded.
	200	Continued filling of subsiding Newark basins and mafic igneous activity both extrusive and intrusive.
(Triassic)		Newark basins form and fill with nonmarine sediments.
Paleozoic	245	
(Permian)		Pre-Newark erosion surface formed.
	260	Appalachian Orogeny. (Terminal stage.) Folding, overthrusting, and metamorphism of Rhode Island coal basins; granites intruded.
(Carboniferous)	320	Faulting, folding, and metamorphism in New York City area. Southeastern New York undergoes continued uplift and erosion.
(Devonian)	365	Acadian Orogeny. Deep burial of sedimentary strata.
		Faulting, folding, and metamorphism in New York City area.
		Peekskill Granite and Acadian granites intruded.
(Ordovician)	440	Taconic Orogeny. Intense deformation and metamorphism.
		Ultramafic rocks (oceanic lithosphere) sliced off and transported above deposits of continental shelf.
	450	Cortlandt Complex and related rocks intrude Taconian suture zone. (Cameron's Line). Arc-continent collision.
		Great overthrusting from ocean toward continent. Taconic deep-water strata thrust above shallow-water strata.
(Cambrian)	510	(Passive-margin sequence I).
		Shallow-water clastics and carbonates accumulate in west of basin (= Sauk Sequence; protoliths of the Lowerre Quartzite, Inwood Marble, part of Manhattan Schist Formation).
		Deep-water terrigenous silts form to east. (= Taconic Sequence; protoliths of Hartland Formation, parts of Manhattan Schist Fm.).
Proterozoic		
	570	Period of uplift and erosion followed by subsidence of margin.
(Z)	600	Rifting with rift sediments, volcanism, and intrusive activity. (Ned Mountain, Pound Ridge, and Yonkers gneiss protoliths).
(Y)	1100	Grenville Orogeny. Sediments and volcanics deposited, compressive deformation, intrusive activity, and granulite facies metamorphism. (Fordham Gneiss, Hudson Highlands, and related rocks.)
Archeozoic		
	2600	No record in New York.
	4600	Solar system (including Earth) forms.

marble, and gneiss are complexly interfolded. Each layer tells its own story from which we can reconstruct the geological map of New York City, one that delineates a continental mosaic of ever-shifting boundaries.

The boundary where North America's eastern edge fused with the volcanic island arc is an extensive thrust fault zone known as Cameron's Line, which trends southwest to northeast from Staten Island into western Connecticut. East of Cameron's Line, in western Connecticut and southeastern New York, lies the Hartland Formation, first mapped by geologist Charles Merguerian of Hofstra University in 1983. This strata was metamorphosed from shale, graywacke, and volcanic rock that had formed in deep ocean water during the early Paleozoic period. West of Cameron's Line lies the Manhattan Prong, composed of metamorphosed rocks of shallow water origin—Fordham Gneiss, Inwood Marble, Manhattan Schist, and Lowerre Quartzite (metamorphosed sandstone). The east-west division is hardly a neat one. A recent map of Manhattan drawn by Charles Merguerian and his son Mickey Merguerian of Duke Geological Laboratory depict the deep-water schist unit of the Hartland Formation as the bedrock of Manhattan south of Eightieth Street. Cameron's Line zigs and zags across Central Park. The presence of the Hartland Formation in Manhattan tells the story of a violent east-to-west overthrusting of the older schist unit onto younger schist strata during the Taconic orogeny, or mountain-building episode. Prior to Merguerian's discovery, all of the schist on Manhattan was designated as "Manhattan Schist"; now, Manhattan Schist refers to the younger layer to distinguish it from the older Hartland Schist.[2] The schist, marble, and gneiss strata of Manhattan are by no means arranged in simple layers like the leaves of a book; over hundreds of millions of years, they were intensely folded, pushed up into mountains, eroded and weathered, buried under thousands of feet of sediment, and exposed by glacial scouring.

On Staten Island, the serpentinite formation was originally formed 450 million years ago in deep water, probably at an oceanic trench, and is considered an igneous rock (derived from the earth's mantle). During the Taconic orogeny, a sliver of this deep oceanic strata was broken off and thrust westward over existing continental bedrock. Millions of years later, during the ice age, glaciation scoured and sculpted the strata into roche moutonee outcrops, a geological term that describes the rounded shape (*moutonee* is French for sheep).[3]

Cameron's Line marks the "suture" boundary where the North American plate on its eastern edge collided with the oceanic plate. It testifies to great earth-moving forces that are hardly dormant. Indeed, a number of faults crisscross Manhattan. One northwest-trending fault underlies 125th Street. South of 125th Street two more faults slice through the island, one at 14th Street; north of 125th Street five additional faults veer northwestward, as mapped by Charles Merguerian in water tunnels between 1983 and 1985. These northwest-trending faults transect the northeast-trending faults, cutting up Manhattan into blocks that are by no means stable. Climbing down into the water tunnel beneath Amsterdam Avenue at 125th Street, Merguerian was startled to find a ninety-degree rotation of "highly fractured Manhattan Schist," indicating strike-slip motion along the 125th Street fault. In fact, Merguerian

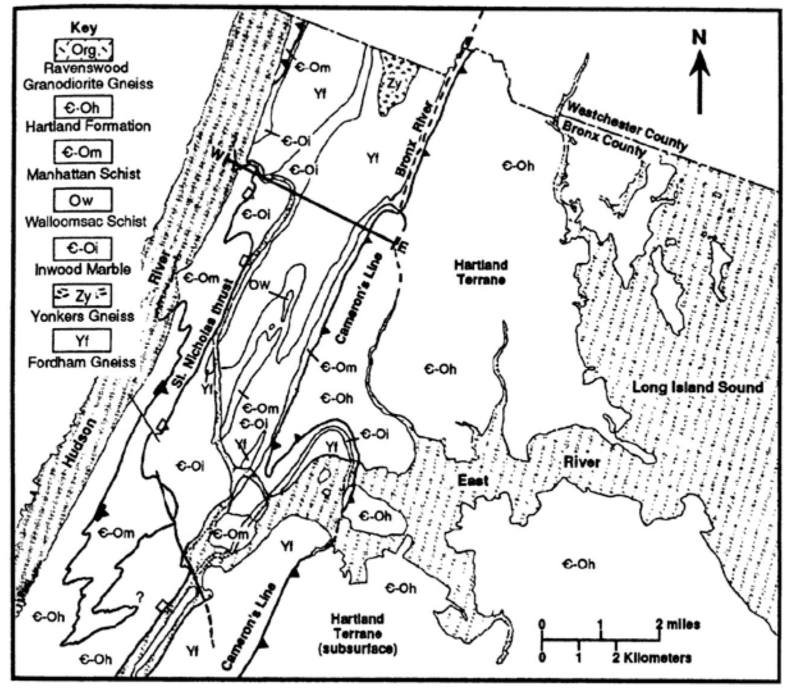

Fig. 1.2. Geological map of northern segment of New York City, including portions of Manhattan, Queens, and the Bronx. (Courtesy of Charles Merguerian, Hofstra University, 2004.)

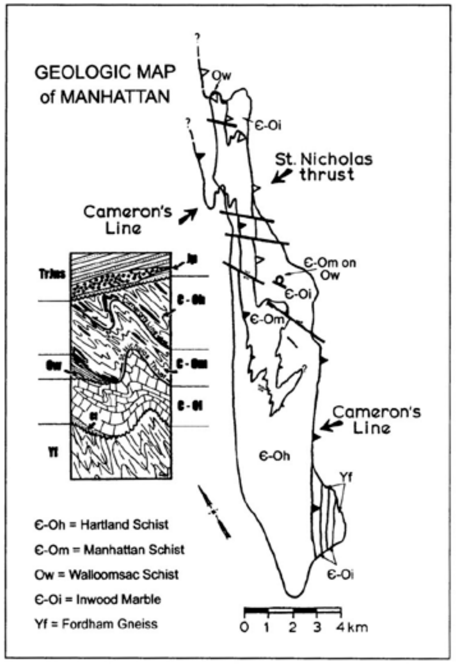

Fig. 1.3. Bedrock map of Manhattan showing the three schist units. (Charles Merguerian, Hofstra University, and Mickey Merguerian, Duke Geological Laboratory, 2004.)

notes, a magnitude 4.0 earthquake on October 19, 1985, centered in Westchester County (known as the Ardsley quake), "was related to episodic slip along a fault with a northwest trend." The last earthquake before that was in 1884—a magnitude 5.0 centered offshore to the south of Brooklyn, and felt as far away as Philadelphia and Hartford. Could it happen again? Absolutely, Merguerian assures us, and with far more damage, considering the extensive construction over landfill that has taken place in the last few decades in New York City.[4] After conducting extensive mapping of the new Queens water tunnel between 1998 and 2000, Mergeurian concluded:

> Ground-breaking rupture and seismic activity cannot and certainly should not be ruled out for this region. Because large magnitude earthquakes have struck NYC in 1737, 1783, and 1884, this new data identifies a potential failure surface along which earthquake energy could be released. Given the population, cultural development, infrastructure, and financial investment concentrated in New York City, the specter of a massive earthquake must be considered in revising existing building code designs and emergency preparedness procedures. Unfortunately, despite the scientific community's pleas for action, severely limited emergency planning exists at the present time. Clearly, this should be changed, as pre-emptive urban seismic planning is an absolute necessity in New York City.[5]

New York City is located, after all, at a site where continental plates collided and broke apart—cataclysmic events written in the rocks. According to plate tectonic theory, the earth's surface is composed of crustal blocks, or plates, that "float" on a deeper layer of plastic rock acting like a conveyor belt. The continental and oceanic plates are continually moving around, crashing into each other (what geologists call "docking") or rifting. Half a billion years ago, the North American continent was tipped over on its eastern side and bisected by the equator, placing the New York region in a subtropical zone south of the equator. The continent then was much smaller in area, and New York was part of the submerged continental shelf. Between roughly 450 and 250 million years ago, a series of continental collisions known collectively as the Appalachian orogeny culminated in the creation of the supercontinent Pangaea. The first of these mountain-building episodes, the Taconic orogeny, pushed up the Taconic mountains in eastern New York as North America collided with an offshore volcanic island arc. During this event, marine shales and limestones metamorphosed, or melted and recrystallized, into Manhattan Schist and Inwood Marble. The same event thrust a layer of billion-year-old Fordham Gneiss (metamorphosed during the earlier Grenville orogeny) onto the schist and marble strata, forming what geologists call the Manhattan Prong, an ancient ridge that extends from New England to its southernmost point beneath Manhattan. The second event, the Acadian orogeny that took place between 375 and 335 million years ago, pushed up alpine mountains in New England. Sediments that flushed westward from these mountains buried the eroded stumps of the Taconics and created the Catskill Delta. The climax event, the Alleghenian orogeny of 250 million years ago, was a huge continent-continent collision that uplifted colossal mountains. The Appalachians formed the backbone of Pangaea, comprised of the earth's continents like pieces of a jigsaw puzzle. It stood its ground for 50 million years.

During this period, the mountains were being steadily eroded, their sediments flushed by streams and rivers into alluvial fans and lakes. Over time, the sediments cemented into layers of sandstone and siltstone, forming the great Permo-Triassic red beds such as those in the Connecticut River Valley and New Jersey's Newark Basin. The superabundance of oxygen in the earth's atmosphere at that time oxidized the sediments, in effect rusting them.

Two hundred million years ago, the earth began to move again. A plume of molten rock from the earth's mantle erupted with such cataclysmic force that it tore a gash in the crust. Rifting, volcanic eruptions, floods, and crustal slumping marked the breakup of Pangaea, as North America pulled away from Africa. The earth's crust was being stretched and splintered into fault blocks, which dropped down, creating basins. The basins, or rift valleys, filled with sediments and sank further, in the process tilting up ranges like the Watchung of New Jersey, west of the Newark Basin. (You can see the same basin-and-range conformation in northwest Africa, like two matching pieces in a geological puzzle.) Lava erupted and flowed through rift valleys, hardening into basalt that capped the redbeds. Where the lava intruded instead of flowing over the layers, it hardened to form blocks of dolerite encased in sandstone. Over time, the rock layers were tilted and exposed, and the sandstone envelope eroded, leaving great vertical blocks of diabase sill that extend in a 1,000-foot bed from Haverstraw, New Jersey, to Staten Island. The dramatic maroon columns of the Palisades, 400-foot-tall cliffs overlooking the west side of the Hudson River, testify to the great forces that broke apart Pangaea.

On Coney Island, a walk on the jetties here offers a chance to touch the three strata of New York City's bedrock: Manhattan Schist, Inwood Marble, and Fordham Gneiss. The whitish marble blocks are granular like sugar, many streaked with yellow and red derived from iron minerals. If you look closely, you may discern the original limestone layers of the metamorphosed rock. Both the schist and gneiss glint with mineral grains such as biotite mica. Schist is a coarse, flaky rock that separates easily along cleavage planes and may show a wavy structure. Gneiss is a denser rock, with buff bands of feldspar crystals alternating with charcoal bands of biotite mica. Both schist and gneiss may be veined with quartz and studded with garnet.

Holding a rock that I know has been pushed deep within the earth's crust and thrust high in an ancient mountain, I am humbled by the forces that

shape our planet. Plate tectonics yields a moving map of the world, a dizzying dance of the continents. One can never be sure where "here" is: this rock was not formed "here" but "there," when eastern North America was south of the equator, and the continent was flirting with Africa. It could not have been formed without being subjected to the intense pressure and heat of the lower crust, and it got there only by sliding down into it, as the heavier oceanic crust was subducted beneath the lighter continental crust. This picture of the earth consuming itself revives the ancient myth that depicts the world as a snake swallowing its tail. Envision thick sea-bottom sediments compressing into shale, sliding into the earth's mantle, metamorphosing into schist. When North America bumped into Africa, the schist strata were folded and uptilted into jagged mountains. As these mountains eroded, the weight of their sediments ultimately buried their own roots. They were inundated by a sea, exposed again when the sea regressed, and eventually became the bedrock of the archipelago that forms New York City. And I hold this rock in my hand, turning it in the light, only because humans—who settled here in the last instant of time—blasted it out of the bedrock when they wanted a subway, and transported it here when they wanted seawalls and jetties to protect their homes from the eroding onslaught of the ocean on the land they had reclaimed from the sea.

To break out of the textbook terminology of New York's complex geology, I must walk the terrain and touch the rock. Manhattan is one of the best places to explore the island's rocky past.

Twenty thousand years ago, a glacier scoured the island's surface to expose beautiful outcrops of schist. Both Hartland and Manhattan schist can be seen in Central Park. Hartland schist is exposed in the southern part of the park, while Manhattan schist crops out in the northern end. A famous example of Hartland schist is Umpire Rock, a huge hump of rock located at the school playground in the west side of the park around Sixty-third Street. Two northeast-trending brittle faults cut through the rock, and on its northwest edge, northwest-trending glacial troughs bear witness to torrents of glacial meltwater that once gouged out channels and scoured the bedrock. Although most Manhattan Schist outcrops are exposed in the park's northern half, an example in the southern half can be seen just west of the Carousel off Sixty-fifth Street, distinguished from the gray-weathering Hartland Schist by its rustier coloring.

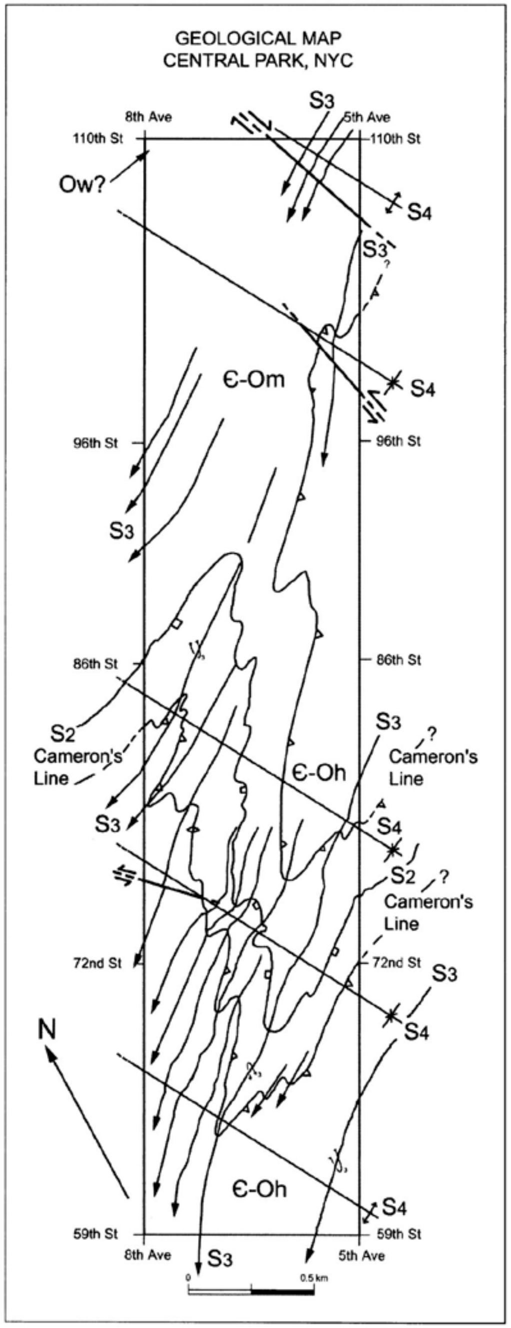

Fig. 1.4. Geological map of Central Park. (Merguerian and Merguerian 2004.)

One of the best places to see all three strata of New York City's bedrock is at the northern tip of Manhattan. Inwood Hill Park affords dramatic views of a ridge of Fordham Gneiss, just across Spuyten Duyvil Creek in the Bronx. Within the park, beautiful outcrops of Manhattan Schist are exposed, and just across the street from the park, Inwood Marble erupts to the surface. The park is located on a high schist ridge that rises 200 feet above the Hudson River on its west side, with the Harlem River to its east. The park may be reached by subway (the A train to 207th Street and Broadway), but a drive and walk allows me to experience the dips and rises of the ancient mountain terrain. Driving west on 181st Street, I turn north onto Broadway. On the west side, the forested ridge shadows the bustling neighborhood of densely built low-rise apartment buildings. Shoppers throng the hilly sidewalks of the main business district, and cars, trucks, and buses thread their way through the streets. Where Broadway crosses Dyckman Street, the terrain flattens out. This is the so-called Dyckman Street Gap, a lowland underlain by Inwood Marble. Typically, Inwood Marble — softer and more water soluble than schist — is the bedrock of the lowlands and river valleys of northern Manhattan and the Bronx.

From Broadway I turn west at 207th Street, then north onto Seaman Avenue. At Isham Street I park the car and get out to walk around the marble outcrops of the pocket park across from the entrance of Inwood Hill Park. The sugary rock crops out in a sinuous ridge, its colors ranging from white to bluish-gray, weathering to brown. Pegs of quartzite (known by the French word *boudins* for their sausagelike shape) intrude segments of the rock, indicating intense metamorphism. I pick up a broken-off piece and run my thumb over the crumbly texture.

Crossing Seaman Avenue, I enter Inwood Hill Park. I never walk alone so I am joined by my constant walking companion, my husband, Joe Giunta. We follow the path that winds uphill toward Overlook Meadow. A glacial erratic placed on the path bears a plaque that testifies to the alleged sale of Manhattan to Peter Minuet on this spot, where a giant tulip tree once grew. This is known as the Shorakapok Rock, after the name the Lenapes called their village site. North of this rock, a large field slopes down to a tidal marsh that edges Spuyten Duyvil Creek, the waterway that snakes around the island's northern tip connecting the Harlem and Hudson rivers. Inwood Marble underlies this lowland, which once served as planting fields for the Lenapes and later for the Europeans when the area was still rural.

The path takes us up through increasingly dense oak-hickory woodland that has been uncut since the Revolutionary War. The straight massive trunks of tulip trees tower over the canopy, underlain by a rich understory of sassafras, witch hazel, and viburnum. Narrow overgrown trails descend from the main path toward kettle ponds, but their remoteness discourages us from exploring. As we ascend the western ridge, we stop to examine the massive schist outcrops. The wavy structure of one outcrop testifies to the rock's heating during metamorphosis. The outcrops glint with mica flakes and garnet crystals. Muscovite mica looks silvery gray, while biotite mica looks blackish. The schist strata also contain lenses of blackish amphibolite, a metamorphosed igneous rock formed in deep water before the Taconic Orogeny.

We ascend to Overlook Meadow, listening to the roar of cars on the Henry Hudson Parkway below. The forest opens into a clearing where we can look westward across the Hudson to the Palisades. A rusty chain-link fence has been partly peeled away to allow access to the schist ledge overlooking the river gorge. We step gingerly, for the ledge tilts down to a steep drop-off. It is a somewhat hazy day, but the Palisades' sheer maroon cliffs rise across the water, offering us a window into another geological era. Indeed, the Hudson marks the boundary between two geological eras: on its west side the Palisade cliffs date to the breakup of Pangaea that began 200 million years ago; on its east side, the schist ledge dates back 500 million years, when the continents began to clump and fuse into the supercontinent Pangaea. To take us back even further in time, we continue up the path to the northernmost end of the park, where the Henry Hudson Bridge crosses into the Bronx. Looking across Spuyten Duyvil Creek, we can see billion-year-old Fordham Gneiss snaking to the surface as Riverdale Ridge in the Bronx.

Back home, I take a sunset walk along the beach and contemplate what geologists of old called the "testimony of the rocks." Here on Coney Island in Cenozoic time, buildings cluster at the edge of sand and water, themselves made of rock and mineral, worn away by salt and wind and rain and pollution, in various stages of decay. Coney Island rusts; sand drifts under the boardwalk and shapes itself into incipient dunes until bulldozed flat again. The shifting tidal lines along the beach repeat, on a microscale, the shifting boundaries of continents. Mica dust leaves silvery traces like tidal shadows. The

shore can teach us about the tenacity of life on the edge and its astounding capacity to transform itself and evolve new forms. Metamorphosis is the recurring theme of nature, whether of rocks or animals. In a few mineralized grains of sand, in a pebble or rock fragment, in the crushed mussel shells that litter the beach, in the barnacles that encrust the jetties, in the microscopic life of a small tide pool — the history of the evolving earth is telescoped.

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Seeing the Earth for Its Faults

GEOLOGICAL TOURS AND GUIDES EXPOSE THE SECRETS OF NEW YORK CITY AND BEYOND **BY MARGUERITE HOLLOWAY**

Continents collided—northwestern Africa crashed and ground against North America—and mountains as tall as the Alps rose in New England. Wind and rain beat at the peaks and wore them down, and then the land on which they stood sank below the sea. Waves and tides had their turn, and the towering ranges were largely leveled. The land lifted. The balmy weather turned cold. Ice sheets scraped across bedrock, pushing a wall of rubble before them. The climate warmed again, and glaciers melted, creating a huge lake that lapped behind the wall of glacial till. Ice sheets kept melting; the lake swelled and stretched and, ultimately, broke through the wall at its lowest part. Rivers began to flow through valleys that the glaciers had carved.

Before politics, culture and high finance, these were the forces that shaped New York City. To see New York thus is to see it with the eyes of a geologist, to see the sweep of millions of years, and to understand why certain things look the way they do and stand where they do. The scar where continents ground together runs down the Bronx River; the remnant of the mountains is the city's bedrock; the rubble pushed by the glaciers gave rise to Long Island; the great lake spilled over at the Verrazano Narrows; the Hudson and East rivers fill valleys deepened by glaciers. Wall Street and Midtown raised modern mountains of glass and granite because there was solid bedrock to build on, but in between lay insufficient foundation for skyscrapers—hence low-slung Greenwich Village and Soho. Before garbage and landfill were strewn in its wetlands, Manhattan was cut in two when very high tides swelled the rivers and they met each other in the middle of the island, at 125th Street, where a fault slices the city.

NEW YORK SKYLINE owes everything to geology. The financial district and Midtown support towering buildings because bedrock is no more than 38 to 80 feet below the surface. In Greenwich Village, however, it is about 260 feet down.

All this insight and more can come from a three-hour cruise up the Hudson River—or the East River or through New York Harbor—with Sidney Horenstein of the American Museum of Natural History. "Since geology is the basis of everything, you just cannot help, once you get involved in this, to go beyond the geology," says Horenstein, author of the Audubon Society's guide to *Familiar Fossils of North America* and coordinator of environmental programs at the museum. "Because if you look at the landscape, you can't help saying, 'What is that?' and 'How did this happen?' "

Horenstein's Circle Line trips, which

for about a decade have taken place in early summer, are as renowned for his observations about geology as they are for his historical anecdotes, questionable puns ("The reason all the lights are lit up here is that we are approaching the Battery") and sayings. On a recent sunset cruise packed with passengers and their picnics, Horenstein explains his answer to the controversial question of how the Big Apple got its name: from a bordello owner named Eve and the "apples" who worked for her. He describes how 300-million-year-old invertebrate fossils ended up in the walls of Riverside Church's bell tower: the sandstone was brought in from Indiana, site of an ancient tropical sea. And a discussion about New York's main rock formations gives Horenstein a chance to quote a favorite refrain: "The Bronx is gneiss, but Manhattan is full of schist. Inwood has lost its marbles, and New York is full of faults."

During other parts of the year, Horenstein gives talks and leads regional geological field trips. "Boats are just one aspect of it," Horenstein says. "I lead tours all over, just like a gypsy cab." One, for example, is a walking tour of Central Park, where participants can see the scratches carved in schist by roving glaciers and some of the boulders left behind by melting ice. Another lecture series covers geology and travel: how to recognize geologic features wherever you find yourself. (For information about scheduling, check the American Museum of Natural History's Web site at www.amnh.org or call the main reservations line at 212-769-5200.)

Many other paths also wander into New York's geologic past. Charles Merguerian of Hofstra University, author with John E. Sanders of myriad papers on the region's geology, has designed virtual field trips of the city and environs, which can be viewed or ordered at www.dukelabs.com. The Parks Department organizes some excursions as well. And the South Street Seaport Museum's off-site permanent exhibit "New York Unearthed" provides a window into the city's archaeology. For those who want to explore the rocks and faults alone, there is a general site for New York (www.albany.net/~go/newyorker/index.html), with references and materials, as well as several good books, including John Kieran's *A Natural History of New York City* and *Wild New York*, by Margaret Mittelbach and Michael Crewdson.

If you prefer instead to conjure the creatures that lumbered through the landscape—to envision the ground sloths, hairy tapirs, saber-toothed tigers, woolly mammoths and mastodons that were the region's wildlife during the Pleistocene—you can find fossil hunters to follow. The New York Paleontological Society, which Horenstein founded in 1970, has monthly meetings most of the year and organizes field trips to look for fossils. One such tour this summer took members to Hamburg, N.Y., to observe Devonian fossils, such as trilobites, in a quarry. Another tour entailed visiting fossil trackways in Connecticut's Dinosaur State Park. (Go to www.nyps.org.)

But no matter which city or state or region or country you are in—or whether you have easy access to a natural history or related museum—you are free to see with a geologist's eyes. Many states have a paleontological society, and although you might have to join to be able to participate in the field trips, membership is typically only about $20 for a family. A number of states also have a mineral society that leads tours—often these societies are members of the American Federation of Mineralogical Societies (www.amfed.org)—as well as a survey that details the geology of the region. The Utah Geological Survey, for instance, provides local information on dinosaur fossils.

In addition, Horenstein and other experts recommend a helpful series of books. Published by Mountain Press in Missoula, Mont., the Roadside Geology books are written by geologists for laypeople (see www.mountainpresspublish.com). Almost half the 50 states have a guide, from *Roadside Geology of Alaska* to *Roadside Geology of Wyoming*. The press also publishes books on various regions of the U.S., several national parks and a few countries, including Canada and Argentina. To see familiar places against the backdrop of aeons is truly a grand view, both humbling and haunting; in the rise and fall of the land in your mind's eye, you can see the earth breathe. SA

GLACIAL MOVEMENTS left marks on rocks that can be seen in Central Park.

the Communicator

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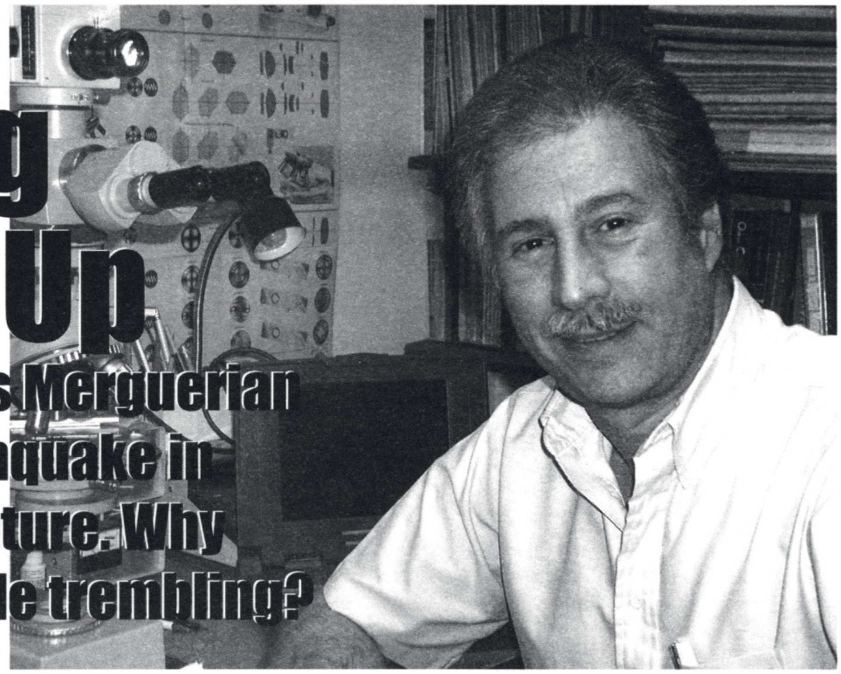
Shaking Things Up

Geologist Charles Merguerian foresees an earthquake in New York City's future. Why aren't more people trembling?



Charles Merguerian

By Brian Reiferson

Seven hundred feet below the busy streets of Long Island City, Queens, Dr. Charles Merguerian stared into the eyes of the beast. Before him in the dark tunnel stretched a northwest-tending crack, merely inches in width, that had the destructive power to take down New York City. Technically termed a "fault," the tiny crack could give at any moment with no clear warning signs, unleashing a major earthquake.

Merguerian spent two and half years and nearly 100 hours underground in the newly excavated Queens Tunnel, piecing together an updated picture of New York's subsurface geology and adding an array of new faults to the mix. The Queens Tunnel is an ongoing municipal project designed to improve New York City's water supply, he said, and has provided a wealth of new evidence for the curious geologist.

The evidence, according to Merguerian, a structural geology professor at Hofstra, shows that each passing second could be the countdown to a seismic nightmare. The mere thought of bloody victims trapped under tons of rubble, and the chaotic after effects like raging fires, broken gas lines, over-crowded streets and gridlock traffic, is enough to stir up fear in even the most jaded New Yorker, but Merguerian is by no means a fear-monger. "The city is totally unprepared for an earthquake, yet there's a resplendent seismic history of large earthquakes in our region," he said.

The problem in the city, according to Merguerian, is that hardly any buildings are up to earthquake building codes, not to mention prepared for the loss of water and power outages that could follow an earthquake. "New York is a vertical city and the major ground breakage that could occur would cause building facades to fall, blocking off traffic, preventing emergency vehicles from reaching those in need," he said.

Merguerian, whose office is adorned with numerous Godzilla pictures and figurines, has been mapping the region for years, studying core drillings, outcroppings of rock and more recently, the newly excavated Queens Tunnel. He meticulously mapped over 25,000 feet of the tunnel and in the process, confirmed what many geologists and seismologists were only hypothesizing: the existence of young, "brittle" northwest and northeast tending faults, a total of 300 in all. He also confirmed the existence of faults beneath both Dyckman Avenue and 155th Street in the Bronx, 96th Street in Manhattan and one just east of Roosevelt Island, as well as the 125th Street fault in Harlem, in separate research projects.

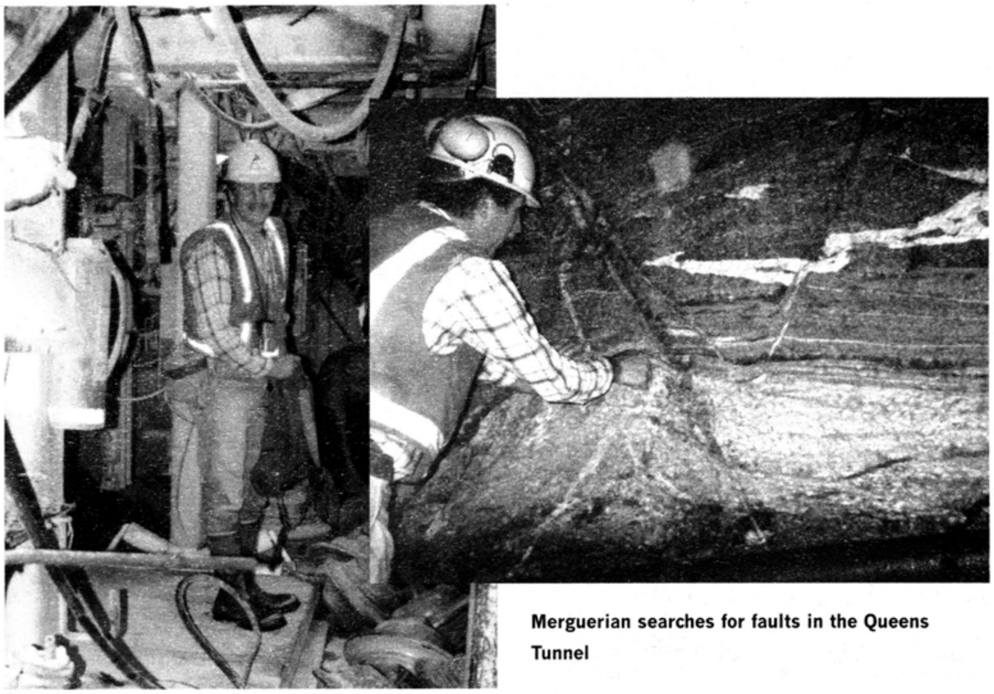
Merguerian points to the earthquake that hit Charleston, N.C. in the late 1800's, which measured a 7.2 on the Richter scale, as further evidence that a major earthquake could occur in the New York City region, since both cities have the same basic bedrock geology.

Why aren't New Yorkers scared?

"The problem is that the periodicity of earthquakes in the New York region is longer than human memory, where we have long periods of boredom, interrupted by brief periods of terror," he said. The area's last major earthquake was centered in Brooklyn, and occurred in 1884.

Long Island wouldn't fare any better than New York City, should a major quake hit. Merguerian points to the large Alaskan earthquake that took place in 1964 as a good example of what could happen here. According to Merguerian, the clays below Long Island closely resemble the clays underlying Alaska. The Alaskan quake, which measured 9.2 on the Richter scale, started with a few seconds of small tremors,

Photograph by Jonathan Duzsa



Merguerian searches for faults in the Queens Tunnel

intensifying into violent shaking which amazingly lasted for approximately five minutes. As a result, water saturated sands in between the underlying clays, liquefied and lubricated the slabs of clay, which according to Merguerian, led to the literal slumping of real estate into the ocean.

"Long Island's worst enemy would be the tsunami's that could develop, even offshore, which would totally obliterate the South Shore," he added. Tsunamis are seismic sea waves produced by earthquakes, capable of reaching over 40 feet in height.

The level of concern about earthquakes among businesses on Long Island, and those in the city, can be determined by looking at how many carry earthquake insurance. John Klein, Chief Operations Officer of American Business Continuity Centers in Woodbury, has spent 27 years in the insurance industry as a claims adjuster, mostly on Long Island. "There are a number of companies that carry earthquake insurance," he said, "but only due to the fact that they have facilities in an earthquake zone region." Continuity Centers specializes in disaster recovery for businesses, offering alternate work facilities for businesses that suffer a catastrophe, be it fire, earthquakes or flooding. "No one covers earthquakes on their policy," said Klein, "except the larger corporations that have offices nationwide."

The Multidisciplinary Center for Earthquake Engineering Research (MCEER) at the State University of New York at Buffalo is an organization that works to increase awareness of the possibilities of earthquakes along the East Coast. By doing so, MCEER hopes to greatly reduce the loss of life, as well as the damages suffered during major earthquakes, according to Andrea Dargush who is the Associate Director for Education and Research Administration at MCEER. "One thing that is a big challenge is that people don't realize there's a hazard; we're very poorly prepared," said Dargush, in reference to New York City in particular. "In general terms, I can say that the possibility that an earthquake will occur in the New York City area is certain - how large an event, when or precisely where is largely unknown," she said.

"Long Island's worst enemy would be the tsunamis, which could obliterate the South Shore."

Also devoted to increasing earthquake awareness in our area is the New York City Consortium for Earthquake Loss Mitigation (NYCEM), on the web at www.nycem.org. Much like MCEER, NYCEM serves to educate the population by estimating the potential for damage and loss in the metropolitan New York area, and has links to published research by renowned seismologist Dr. Klaus Jacob of Columbia University's Lamont-Doherty Earth Observatory. "We can deny as long as we want that earthquakes aren't happening, but it's up to us to decide whether we are prepared for the earthquake when it comes or not," said Jacob. "Earthquakes don't care whether we care." Jacob has been actively encouraging the City to update its building codes since the mid-1980s. In 1995, Local Law 17/95 was passed, which enforced stricter building code regulations to resist the effects of an earthquake.

On January 17th, a small earthquake, measuring 2.4 on the Richter scale, struck New York City. The quake was centered on the 125th Street fault in Harlem. Although it did not have the strength to cause any serious damage, those who were in the city did feel the tremors. Donald Joseph, 22, a student at Pace University, was in Harlem during the quake. "I felt the earth shake," said Joseph. " The ground I walk on every day to go to school and work, it just shook." Still, Joseph doubts that a large earthquake could hit the city. "It just seems impossible, like it just won't happen," he said, adding, "I don't think about it."

It is just such an attitude that has rendered New York City seriously under-prepared for a disaster that is inevitable, says Merguerian. In the wake of recent devastating earthquakes in India, South America and Seattle, Merguerian and seismologists like Jacob have stepped up warnings. But to date, most New York buildings are not up standard earthquake codes and emergency preparation is lacking. "We have the power to take a proactive step," said Merguerian, "but we are still completely unprepared."

What will it take for New Yorkers to realize that the potentially devastating quake could hit at any time? And where will you be when it does: in the subway, on the highway, walking down the street?

Newsday

50¢ JANUARY 17, 2001

Who'da Thunk It? Some Did

DENNIS DUGGAN


Dennis Duggan

"Oh my God, I thought a truck had smashed into our home," Janice Steele said yesterday. Steele lives in Long Island City, and her frame house on 11th Street and 37th Avenue shook. It was around 7:30 a.m.

"I ran outside ready to yell at my neighbors who keep a lot of trucks on their property, but the street was quiet. I didn't know what to think," she said.

Steele never thought earthquake.

"Even though it happened here once before. That was in 1985. That time, I thought the boiler had exploded," she said.

Her phone rang a few minutes later.

"It was Rose Gorshesky, my next-door neighbor. She's 84. She said, 'Did you hear that rumble?'" I talked to Steele yesterday afternoon at her job as office manager for Petramoor Mfg., three blocks from her home.

"In New York, you worry about a lot of things: muggings, rapes, robberies.

Who thinks of an earthquake?" she said.

Charles Merguerian, 51, a geology professor at Hofstra University who grew up in Queens, says he thinks of earthquakes. Merguerian says a few years ago he tried to warn the Giuliani administration about the inevitability of an earthquake on the East Coast but was rebuffed.

Television anchorman Chuck Scarborough is another who thinks about earthquakes. Scarborough even wrote a novel in 1991, titled "Aftershock," that dealt with just such an apocalyptic event.

"The undisputed scientific fact is that New York City is sitting on a seismic time bomb," he said yesterday as he prepared for last night's WNBC-TV broadcast.

Scarborough's book was made into a television movie, which showed New York hit by a killer earthquake that wipes out half the city's population. In the movie, motorists were suffocated in the Queens-Midtown Tunnel, which Merguerian, who was a consultant on the book, says is built along several fault lines.

But who wants to listen to doomsayers? Even if they are people who are as well credentialed as both of these men. Like the comedian says, they get no respect.

In fact, they are treated a little like the street preachers in Times Square who proclaim the end of the world to indifferent passersby.

It's different on the West Coast, of course. Earthquakes and fires there are a terrible reality. Did you know, for instance, that the building codes there are four times stronger than those in New York? I didn't know this until I talked to Scarborough, who takes his geology seriously and who agrees with Merguerian that the city fathers take quake predictions with a wink.

"It's scary," says Scarborough, adding that "scientists can differ with one another about global warming and nuclear winters, but they all agree there will be an earthquake here." That little tremor we had yesterday should be a wake-up call. But I really don't think anyone in this city takes the predictions of a quake here seriously.

Merguerian, who lived on West 125th Street, which is on one of the main fault lines in town, was online with the United States Geological Survey Web site when I reached him at Hofstra.

He has mapped the entire city for fault lines and recently finished a survey of the third water tunnel, where he stayed for 100 days.

"I found 300 fault lines there," he said, adding that none of them was worrisome.

But he said that while yesterday's quake was a hiccup on the scale of such events, "you have to wonder whether this foretells a much larger event." He has no doubt that such an event is in this city's future.

"I think in my lifetime we will see it," he said. The last big earthquake in New York came in 1884 and left "12-foot-long cracks that were 10 feet deep and two feet wide," along city avenues.

But most disturbing was the geologist's assertion that the city is not prepared for an earthquake. "I offered my services to them, but I was turned down," he said.

I asked Scarborough why he had an interest in earthquakes. "It started after the 1989 earthquakes in Armenia," he said. Scarborough eventually did a three-part series on television on quakes, which led to his writing "Aftershock." Scarborough is as pessimistic as his pal Merguerian about city planning for an earthquake here, something both consider to be certainty.

"The political will is hard to muster. It's too bad," he said. "We've been given a lot of warnings."

The New York Times

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F . Y . I .

New York Underground

Q. *Geologists say that New York City sits on top of something called Cameron's Line. Does it matter which side of it I'm on?*

A. No. Cameron's Line is a suture-like fault line that descends from New England and runs beneath the Bronx and East Rivers, touching the western edge of Queens and looping into the lower third of Manhattan before heading south beneath New York Bay and Staten Island. First identified by a geologist, Eugene F Cameron, in the 1950's, the line separates the prehistoric North American continent from the oceanic plate that smashed against it 450 million years ago.

The impact of the collision, known as the Taconic Orogeny, forced the American coastal shelf miles underground, where heat and pressure changed the material into Manhattan schist, Fordham gneiss and Inwood marble. These rocks are now found west of Cameron's Line, while to the east lie Harrison gneiss and the Hartland Formation — Long Island's bedrock — which were formed where sea-floor formations were pushed up against the mainland. Subsequent continental collisions 400 and 320 million years ago folded and refolded the bedrock, pushing portions much closer to the surface.

Cameron's Line itself is a 30- to 50-meter wide looping band of crushed and sheared rock that undulates hundreds of feet below the surface Charles Merguerian, a structural geologist at Hofstra University, began studying the line in 1977, and in 1986, during the excavation for the third New York City water tunnel, discovered an unmapped section beneath Long Island City.

DANIEL B. SCHNEIDER

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Newsday
LONG ISLAND

October 5, 1997

They Do Geology on the Run

By **D**an **F**agin
Staff Writer

Just another day on the Northern State Parkway: bumper-to-bumper traffic, orange cones, and an Ice Age geologist in a floppy hat digging for ancient charcoal.

John Sanders smiled as he dug on a sweltering July morning, unlike the irritated drivers who had to slow down as they passed the Westbury road-widening project. A few weeks earlier, a construction crew had bulldozed the edge of a small hillside, exposing rocks buried for tens of thousands of years. Now the retired Barnard College geology professor was happily chipping at the newly created cliff with a metal tool.

``This is a really nice exposure," he said, admiring arched bands on the cliff face that he said suggested the passage of an ancient south-flowing stream fed by a melting glacier. His discourse on glacial history was difficult to hear over the passing traffic, but Sanders kept talking -- and digging -- anyway.

The small band of geologists who labor to reconstruct Long Island's distant past is accustomed to working in less-than-ideal conditions, and to taking advantage of whatever opportunities come along.

Chronically short of research funds, they piggyback onto other projects, including road work, sand mining, well-digging, water-tunneling and even toxic cleanups. After big storms, they race to the shoreline to see rocks and cliffs uncovered by the pounding surf.

They even wish for a nasty nor'easter now and then. ``It's very opportunistic. You hope there's a nice big storm so you can get out there and see all the nice smooth [rock] surfaces," said Gilbert Hanson, a professor of geosciences at the State University at Stony Brook.

Lack of money isn't the only obstacle. So much of Long Island is already paved over that there aren't many good places left for fossil-hunting. Geologically rich sites such as the Flower Hill Bog in Manhasset have been destroyed by development, and many fossil cliffs around Long Island have been wrecked by seawalls and other erosion controls. The cliffs near the Montauk Lighthouse, a rich source of information for local geologists for more than a century, have been partially covered in recent years as the U.S. Army Corps of Engineers has tried to stave off erosion of Montauk Point.

What little geological research does take place on Long Island is almost conducted for public health or business reasons, not natural history. ``There's not much geology for geology's sake," said Glen Richard, another Stony Brook geologist.

Much of what is known about Long Island's ancient history has been discovered almost as an afterthought. Charles Merguerian, a professor of structural geology at Hofstra University, has shed new light on the formation of Long Island's bedrock by studying the walls of the new water tunnel that New York City is digging 700 feet below Brooklyn and Queens. A chronology of Long Island glaciers developed by Les Sirkin, a research professor of earth sciences at Adelphi University, is based in part on his many years of research in the abandoned sand mines of Port Washington -- a site that will soon be drastically altered by a planned 18-hole golf course and senior citizens housing complex.

Non-scientists have also done their part. Amateurs, mostly fishermen, have found all of the woolly mammoth and mastodon teeth discovered on or near Long Island. In 1967, for example, George Stires was fishing for ocean skimmer clams 70 miles south of the Rockaways when he netted a six-inch black object.

``It was pretty, so I took it home and washed it off, and after a while I called the Smithsonian," said Stires, of Bricktown, N.J. The object turned out to be the tooth of a mastodon, an Ice Age elephant species now extinct. It now resides in the Smithsonian Institution, where Stires has proudly visited it with his children.

The next important discoveries could come as a side benefit to the massive groundwater cleanup effort that is just getting underway in and around Brookhaven National Laboratory, Hanson said. Wells being dug in the area to test for chemical contamination also may be used to study long-buried sediments, just as they have at toxic-waste sites around Long Island.

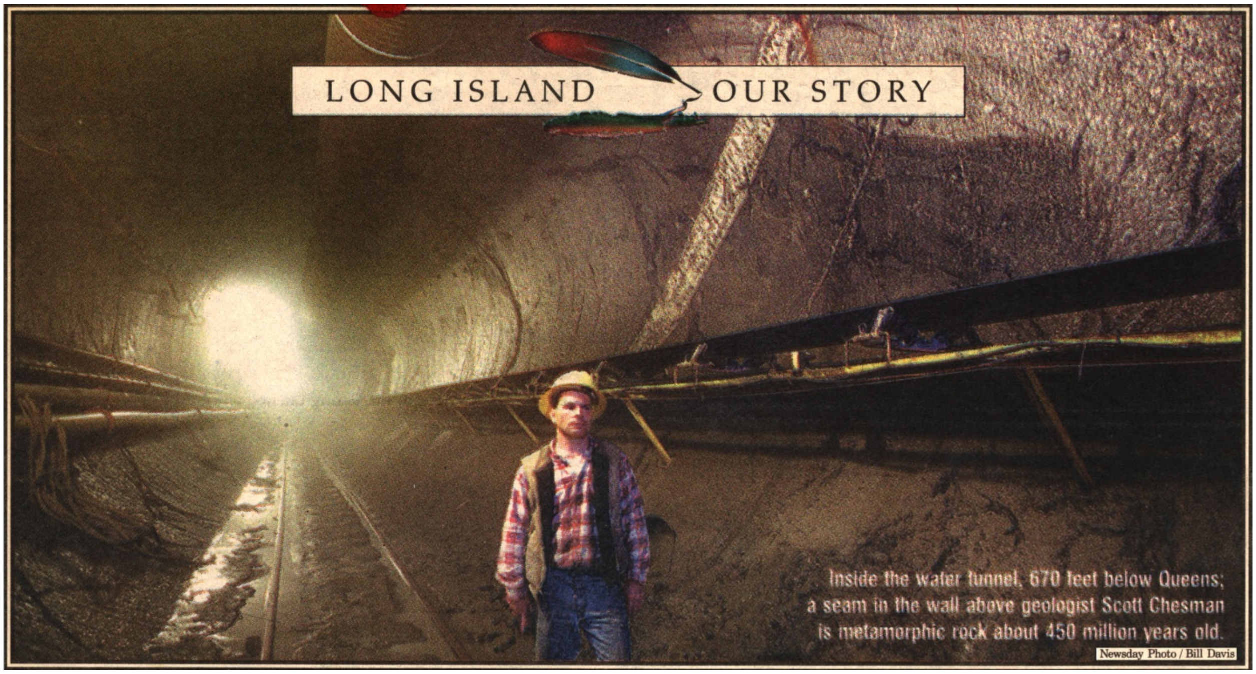
Or maybe the next big revelation will come near Exit 33 on the Northern State. Sanders hopes that charcoal buried in the roadside cliff could shed some light on the controversial question of when, and how many times, the glaciers reached Long Island.

Unlike rocks, charcoal samples are relatively easy to test and date, and Sanders has already recovered one piece of charcoal he hopes to test soon.

He won't be able to get additional samples from the site, however. The little cliff on the side of the parkway, like so many other potential treasure troves for Long Island's natural historians, is due to be covered in concrete any day now.

Newsday
LONG ISLAND

Tuesday, September 30, 1997



Inside the water tunnel, 670 feet below Queens; a seam in the wall above geologist Scott Chesman is metamorphic rock about 450 million years old.
Newsday Photo / Bill Davis

A new water tunnel offers rock-hard and ages-old clues about the formation of Long Island
By **D**an **F**agin
Staff Writer

In the Belly Of the Earth

Forged by the fiery collision of a now-vanished continent and a string of volcanic islands, the oldest pieces of Long Island are a mystery whose secrets lie buried beneath hundreds of feet of sand and soil. But there are clues, and some of the most intriguing are being revealed, inch by laborious inch, as a locomotive-sized machine drills a water tunnel through some of the hardest rock on Earth, 670 feet below Queens.

Much of the bedrock exposed by the drilling is 450 million years old. And while the primary purpose of the project is to bring more water to New York City, the incidental geology is fascinating in its own right. The long-hidden rock is the sturdy pedestal upon which eroding mountains and bulldozing glaciers later sculpted Long Island's familiar features, and it is the only real evidence of the Island's earliest history.

As revealed by the tunnel excavations, the ancient rock is anything but colorless. Even in the dim light of the construction lamps, the tunnel's sloping walls are a striking tableau of rippling stripes as delicate as spider webs and slashing faults as jarring as lightning bolts. Granite slabs speckled with garnet lie beside sheared-off chunks of blackish-green ocean crust and hardened lava from long-dead volcanoes.

``It's really extraordinary. It's the closest thing to a religious experience you can get in geology,'' said Charles Merguerian, a professor of structural geology at Hofstra University.

The epiphanies are few for bedrock experts on Long Island because here, unlike many other parts of the world, the only visible bedrock is a few small outcroppings at the northwestern edge of Queens in Long Island City. From there, the bedrock's upper boundary slopes steadily downward to the east and south. By the time that slope reaches central Suffolk County, the bedrock is more than 1,500 feet below the surface.

No one knows whether the bedrock in Queens is similar to the unmapped rock beneath Nassau and Suffolk counties. ``It's very possible that there may be a totally exotic piece of real estate down there under eastern Long Island that we don't even know about, possibly an old piece of Africa," Merguerian said, explaining that local bedrock could have originated in a different continent and been joined to North America after an ancient continental collision. ``We have absolutely no clue."

Much of the sparse evidence that does exist has come from New York City's effort to build a third water tunnel to bring drinking water down from upstate reservoirs. The Queens leg of the tunnel is the latest in a series of digs that began in 1970 and will continue until the tunnel is finished in 2015.

On an afternoon when a driving rain had curbed activity at the surface, a crew of tunnel workers -- or sandhogs, as they call themselves -- was making steady progress near the bottom of an entry shaft in Maspeth that is more than twice as deep as the Statue of Liberty is tall. Monitoring the crew's progress in guiding the 640-ton boring machine was Scott Chesman, a former sandhog who is a geologist at the city Department of Environmental Protection.

His prime mission is to see how the ever-changing composition of the rock affects the progress of the $13 million machine. But Chesman is also mapping, analyzing and even videotaping the types of rock the machine encounters in hopes of shedding new light on the origin of Long Island's basement. He has only one chance to get it right, since the tunnel's exposed walls will later be covered with concrete. And the task is tricky because newer rock -- a mere 360 million years old -- has filled in crevices and faults in the older bedrock.

``It's rock psychology, you can see all the trauma that the rock's been through," said Chesman, pointing at an intricate pattern of older granite and younger volcanic rock.

The tunnel walls in Queens are streaked with major fault lines, and many of those cracks are packed so tight with groundwater that when struck by the drilling machine they gush water at a torrential rate -- as much as 1,300 gallons a minute -- that requires a fast grouting job by the sandhogs.

The many faults along the tunnel walls are powerful evidence that our region is in an earthquake zone. Large quakes were recorded in the New York City area in 1737 and 1884, and others are sure to follow, according to Merguerian. In fact, he said, the long gap between earthquakes means that the next one, when it comes, may be a big one.

Another key discovery in the tunnels has bolstered the leading theory about how at least some of Long Island's bedrock was formed.

A half-billion years ago, geologists believe, the continent that would later become North America was rotated in a different direction. The land that would become the east coast of the United States was facing south, just below the equator, near an offshore arc of islands.

When that island chain smashed into the coast about 450 million years ago, the oceanic rocks were pushed 10 miles deep into the Earth. There, temperatures as high as 1,300 degrees transformed the rock to its super-hard form.

Later cataclysms brought the bedrock to its present position near the surface, and added new wrinkles. For instance, additional local bedrock was formed 360 million years ago when a collision on the other side of the volcano arc created what would become New England, and still more was formed about 280 million years ago in the great collision with what became Africa that pushed up the Appalachian Mountains and formed the super-continent of Pangaea. North America and Africa have been drifting apart ever since Pangaea began breaking up about 200 million years ago.

Merguerian and other experts believe it is the first of those collisions that created most of Long Island's bedrock, and the tunnel excavations support that theory by revealing new evidence of a massive fault zone -- called Cameron's Line -- that stretches from central Massachusetts to Brooklyn and is thought to mark the impact zone of that first ancient collision 450 million years ago.

``You can actually see the characteristics of Cameron's Line in the subsurface geology," Merguerian said, referring to the fault lines. ``It's right there on the tunnel walls."

Many secrets of the bedrock are still untold. But a skyscraper's length below the streets of Maspeth, inside the tunnel whose walls are covered with swirls and swoops of pressure-cooked rock, it is at least possible to begin to imagine the awesome power of the continental collisions that formed the solid foundation upon which Long Island was built.

Newsday
LONG ISLAND

September 29, 1997

Throwing Stones in Academia

By **D**an **F**agin
Staff Writer

No, it's not an all-out war between two of the leading authorities on the natural history of Long Island. Let's just say relations are icy.

Les Sirkin and John Sanders tell two very different stories about the great glaciers that shaped Long Island, and neither geologist is shy about calling the other's ideas foolish -- though the cutting remarks are never delivered directly, since the two rarely speak to each other.

The nicest thing that Sirkin, a 64-year-old research professor of earth sciences at Adelphi University, has to say about Sanders is: ``John may be a great gadfly, but I don't think he's making an enormous impact on glacial geology."

Sanders, meanwhile, complains that Sirkin won't even consider evidence that his ideas might be wrong. ``You can't dig with him and you can't ask questions. Now what does that tell you?" said the 71-year-old Sanders, a retired geology professor at Barnard College who is now affiliated with Hofstra University.

Their dispute is a personal one, but it also shows just how much of Long Island's history must still be written in pencil.

The biggest and oldest local controversy is over when, and how many times, ice sheets descended from Canada to form hills, lakes, cliffs, and every other familiar feature of Long Island.

That century-old argument would be easy to solve if rocks could be dated in the same way as fossils. But the standard technique of figuring out a fossil's age by measuring the decay of radioactive elements such as uranium and carbon-14 only works on bones, plants, or anything else that was once alive.

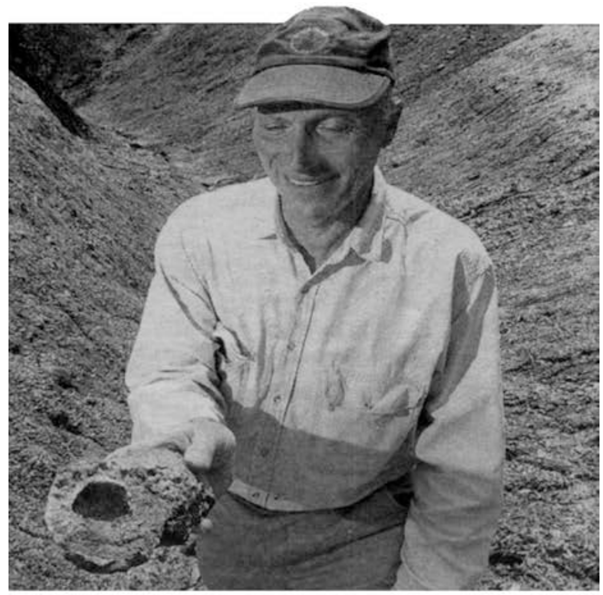
Instead, geologists study cliffs and other places where layers of rock are visible, and search those layers for buried shells, charcoal and other organic material that can be dated. They also ponder indirect evidence: fossilized pollen that shows whether the climate was cold enough for glaciers, and grooves cut into bedrock that reveal which direction the ice sheets moved.

Sirkin believes only two glaciers ever reached Long Island. He gives two possible dates for the first glacier, either 150,000 or 60,000 years ago, and thinks it covered at least the North Shore and probably additional areas before retreating into Canada.

The second glacier was here just 22,000 years ago, he says, and stopped halfway down Long Island, depositing a ridge of bulldozed rock -- a moraine -- stretching from Queens to Amagansett and continuing eastward toward Martha's Vineyard. As it retreated, the same glacier formed a second series of moraines near the North Shore, including the elevated spine of the North Fork, according to Sirkin.

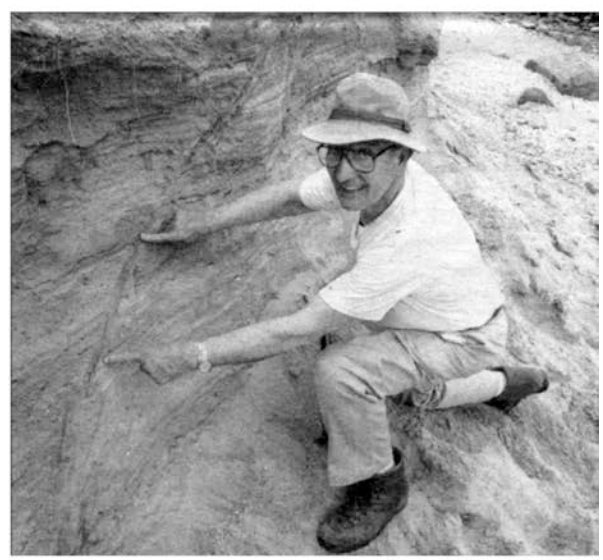
Sanders gives a very different version. He believes that glaciers reached present-day Nassau and Suffolk Counties at least four times, that the two moraines were formed by different ice sheets, and that the last time ice was in either county was about 100,000 years ago. The 22,000-year-old glacier cited by Sirkin never made it south of Connecticut or east of Queens, according to Sanders.

A clear majority of geologists in the region agrees more with Sirkin than Sanders, who acknowledges that his own ideas conflict with what he calls the ``prevailing dogma," which is also the version cited in Newsday's articles about Long Island history.



Newsday Photo/Bill Davis

Adelphi's Les Sirkin examines a concretion - a solid mass harder than surrounding rock - he found in a clay bed at the Port Washington sand pit. Below, John Sanders of Hofstra shows a line in a Montauk cliff that he says indicates a shift in the land.



Newsday Photo / Jessica Brandi Lifland

But Sanders isn't quitting. He and a Hofstra colleague, Charles Merguerian, continue to organize field trips, for amateurs and professionals alike, that are aimed at refuting Sirkin's ideas and boosting their own.

Sirkin, meanwhile, has also been busy trying to reach a wider audience, through a series of newly published books he has written about local geology. Sanders bought one copy. But, so far, Sirkin hasn't signed up for a field trip.

DAILY NEWS

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scienceSaturday

The glacier sleuths

Geo-junkies are ice guys

By NANCY O'BRIEN
Daily News Writer

FOR MORE THAN 20 years, two detectives have scoured the city in hopes of unraveling a 10,000-year-old mystery. They're not police, they're geology junkies, attempting to solve the riddle of how the city's landscape was shaped.

On their treks, John Sanders, a professor emeritus at Barnard and Columbia Colleges, and Charles Merguerian, a professor at Hofstra University, try to pry open windows to a deep and icy past.

Our area was sculpted by a succession of natural phenomena, some of which, like erosion and wind, continue. But the major force that captures the imagination is the series of glaciers that gouged, scraped and tore their way through here until 10,000 years ago.

Five massive, slow-moving glaciers crept down the continent over thousands of centuries, stopped here and melted. Each time they melted, the sea level rose.

The ice sheets at their peaks were as high as the Empire State Building and covered the city, Sanders says. "Instead of driving to Jones Beach, you'd have to drive . . . about 100 miles out to find the shoreline."

The sands of Jones Beach and the silty soil of the Pine Barrens on Long Island are part of what geologists call the end moraine. When the ice melts, the water drains over an area beyond the actual tip of the glacier, leaving boulders, gravel and sand in layers. The roughest sand is at the edge of the glacier, and the finer sand farther away.

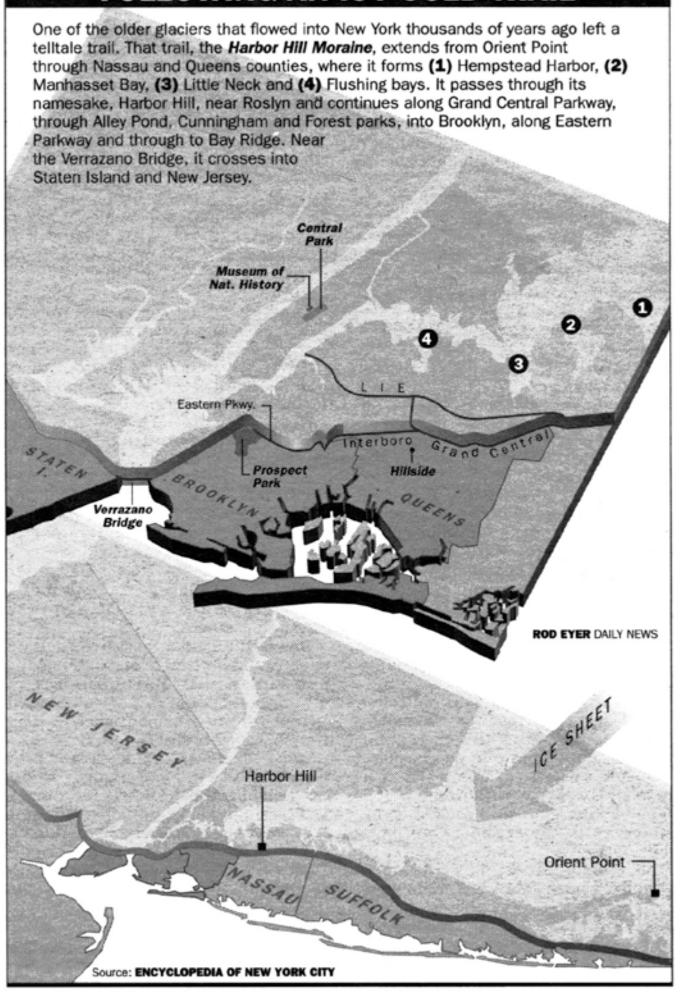
Some of those boulders were delivered here from upstate or from across the Hudson. And as the ice sheets with all their debris crept across our area, they left their marks. For children scaling rocks in Central Park, their toeholds could be the jagged edges cut into the bedrock as the glacier moved along. The couple atop those rocks is perched on what's left of peaks of the Earth's crust, scoured smooth by a river of ice that moved slower than a backup at the Queens-Midtown Tunnel.

Sanders calls Central Park a treasure trove of glacial clues. He and Merguerian have mapped them in a guidebook (see Research Guide). For one of his favorites, he sends us "across the street from the American Museum of Natural History and over the wall."

On a rock there, he says, you can see "some beautiful scratches and grooves" from the latest glacier, which rode into the park about 10,000 years ago.

FOLLOWING AN ICY COLD TRAIL

One of the older glaciers that flowed into New York thousands of years ago left a telltale trail. That trail, the ***Harbor Hill Moraine***, extends from Orient Point through Nassau and Queens counties, where it forms **(1)** Hempstead Harbor, **(2)** Manhasset Bay, **(3)** Little Neck and **(4)** Flushing bays. It passes through its namesake, Harbor Hill, near Roslyn and continues along Grand Central Parkway, through Alley Pond, Cunningham and Forest parks, into Brooklyn, along Eastern Parkway and through to Bay Ridge. Near the Verrazano Bridge, it crosses into Staten Island and New Jersey.



ROD EYER DAILY NEWS

Source: **ENCYCLOPEDIA OF NEW YORK CITY**

"Almost all the other rocks in Central Park" hold clues to earlier glaciers that were here up to 200,000 years ago, he says.

Merguerian's favorite spot in the park is east of Central Park West around 63d St. "There are tremendous, spectacular grooves" scratched into the bedrock by a glacier as it rode past Umpire Rock there, he says. One huge boulder, he says, was "pulled up and tipped upside down immediately south of its former home."

Sanders and Merguerian point to many places that may seem mundane to us as having a "resplendent glacial history."

There is, for instance, "a hill of sand and grand boulders bulldozed in front of the snout of the glacier" in Queens, says Merguerian. "It's not called Hillside Ave. for nothing."

Sanders says it was one of the older glaciers that dumped its load near Hillside before it retreated. The glacier's edge and the debris it left form the Harbor Hill moraine and can be traced throughout Long Island, into Brooklyn and Queens, across Staten Island and into New Jersey.

Some of the boulders transported here by the glaciers, Sanders says, landed inside the boundaries of the Brooklyn Botanic Garden and are labeled for the curious.

Through Sanders' and Merguerian's On-The-Rocks series at the 92d St. Y or the Central Park Conservancy's courses on rocks, aspiring geology junkies can get a spectacular view through a window to the deep past all around and beneath us.

But there is a term you'll hear while taking a tour that can send a chill down your spine: "Interglacial." As when Merguerian or Sanders say, "We're in an interglacial period right now."

Another glacier? Here?

"Yep," says Sanders. "We're overdue."

RESEARCH GUIDE

■ **FIELD TRIPS:**

Central Park Conservancy offers variety of field trips and seminars at Dana Discovery Center, 110th St. and Fifth Ave., and Henry Luce Nature Observatory at Belvedere Castle in Central Park. Call (212) 360-2720 or education registrar, 360-2736.

On-the-Rocks Field Trip Series by Sanders and Merguerian, 92d St. Y, (212) 996-1100.

Brooklyn Botanic Garden, (718) 622-4433.

■ **BOOKS:**

Field trip guidebooks for On-The-Rocks, by John Sanders and Charles Merguerian. For 22 available titles, **Web**: Dukelabs.com

"Geology of New York City and Environs," by Chris Schuberth.

"A Field Manual for the Amateur Geologist," by Alan M. Cvancara.

■ **INTERNET:**

Hofstra's Geology Department: http://www.hofstra.edu/ (Click on geology department)

Geology Link: http://geologylink.com

New York Geology Resource Page: http://nethomes.com/newyorker

The New York Times

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F . Y . I .

Counting Sheep Rocks

Q. *I am struck by the beauty of the dark, rugged outcrops that jut from Central Park's grassy, sculptured slopes. Were they placed there by the park's 19th-century landscapers, or are they part of the natural terrain?*

A. The ancient outcrops are the only element of Central Park that is not man-made, and they predate the designs of Frederick Law Olmsted and Calvert Vaux by about 450 million years. To ponder them is to gaze back in time at the deeply eroded remnants of mountains that were once as prominent as the Himalayas are today.

The park's rocky knolls are composed of metamorphic and igneous bedrock — primarily mica schist, gneiss, granite and metamorphosed oceanic material — which formed at the core of a mountain range that was pushed up when eastern North America collided with volcanic terrain about 450 million years ago, according to Charles Merguerian, a professor of structural geology at Hofstra University. This continous spine of crystalline bedrock, called the "Manhattan Prong," runs just below the surface of the island, supporting the weight of skyscrapers and emerging from the earth in Central Park and areas north of it, like Coogan's Bluff and Inwood Hill.

In the area where Central Park now sits, the mountainous bedrock ridge — part of the earth's continuous outer crust — was greatly eroded by succeeding eons, Mr. Merguerian said. At least five great glacial ice sheets that advanced from the northwest and northeast during the Pleistocene epoch, 200,000 to 20,000 years ago, dramatically altered the terrain, scraping, gouging and rounding the contours of the exposed bedrock and scattering huge boulders on the landscape.

Mr. Merguerian explained that the grinding effect of the advancing ice mass transformed many of the Central Park outcrops into asymmetrical hulks called "roches moutonnées," or sheep-shaped rocks. The south, or "lee" side of these outcrops, which were downstream of the advancing glaciers, are steep and craggy, while the north, or "stoss," sides tend to be smoothly polished and striated.

DANIEL B. SCHNEIDER

Staten Island Advance

950 FINGERBOARD ROAD · STATEN ISLAND, NEW YORK 10305

Agencies working to make area more 'earthquake-proof'

By DEBRA TORTORA
ADVANCE STAFF WRITER

A recently published traffic alert appeared routine: Construction work will cause a slowdown on the Fingerboard Road ramp to the Verrazano-Narrows Bridge.

But this seemingly ordinary traffic interruption had a startling twist — the installation of earthquake-resistant bearings, part of a statewide bridge rehabilitation program in effect since last year.

An earthquake on Staten Island? The mere thought of bloody victims trapped under tons of rubble with no help in sight is enough to shake up fear.

Although the city's Office of Emergency Management assesses that the likelihood of an earthquake hitting the city is almost non-existent, said staff analyst Barney Puleo, there is a clear controversy as to whether or not the city — including Staten Island — could be devastated by an earthquake.

Borough residents have felt tremors from earthquakes in the past, and some experts say a major earthquake could strike the East Coast at any time — they say when it does happen, New York City will be in big trouble.

"New York City has had earthquakes. New York City can have an earthquake. New York City will have an earthquake, probably within our lifetime," said Charles Merguerian, professor of structural geology at Hofstra University, Hempstead, L.I.

The state bridge rehabilitation program is one measure intended to shore up New York's infrastructure.

Whenever bridges are repaired under the direction of the state Department of Transportation (DOT), new bearings are installed to make the structure more resistant to the kind of pressure exerted by earthquakes or heavy storms, said Phyllis Hirshberg, spokeswoman for the department. The $3.4 million project will take in 17 Island areas in total.

National concern over a 1989 San Francisco earthquake spurred the city emergency management office to send a delegation to observe damages, Puleo said. Next, New York City officials began to think about preparing for an earthquake here.

"We do have an earthquake plan," Puleo said. "We know the kinds of damage that are caused by a West Coast earthquake. Basically, there are building collapses and fires caused by the breaking of gas lines — we deal with building collapses every day."

The city's general evacuation plan would be applied in the event of an earthquake, he said. "We have evacuation plans for things like hurricanes and other types of disasters."

Generally, Puleo said, public schools would be used as shelters because of their kitchen and bathroom facilities. Most shelters are on elevated land, so people would be safe during floods.

However, flooding is not usually a major concern during an earthquake.

"An evacuation route is an evacuation route," Puleo said in defense of the plan. He added that 39 states are more susceptible to earthquakes than New York.

"You must be kidding," said Klaus Jacob, a senior research scientist at the Lamont-Doherty Earth Observatory of Columbia University, Palisades, N.Y. "That's all nice talk, but it amounts to little or nothing," he said.

An earthquake measuring as high as 7.5 on the Richter scale could hit New York, Jacob said. Just because there is no record of it occurring before, doesn't mean it won't happen, he said. City officials fail to fully understand what an earthquake would do to New York, he added, and compared the city to a driver not wearing his seatbelt.

"The emergency button [the city] is going to push is the same button as if one building fell down," Merguerian said. "There's no need to lie awake and worry about it," but people should know to evacuate their homes and get to an open area in the event of an earthquake.

"I think it's inevitable for a large earthquake to strike New York — and with tremendous power," he said. "It seems ridiculous not to have some public education." He added that there is no way to predict when, where or how strong a quake will be.

But he did predict that if an earthquake hit the city at a magnitude of just 5.0 on the Richter scale, the damage would exceed that of California's 1989 quake, which measured 6.9.

"There would be a tremendous amount of damage here because of the weakness of the infrastructure," Merguerian said. He stressed that although the city has implemented new building codes, they are not nearly as effective as measures taken in California for earthquake-resistant buildings.

His mapping of the city reveals two basic faults in the earth's crust, running through Manhattan, Brooklyn and the Bronx, and hundreds of smaller faults and fractures that originate from them. Todt Hill seems to have a higher concentration of fractures and faults than other Staten Island areas, he said.

In February, Mayor Rudolph Giuliani signed a bill into law that places the word "earthquake" in the city building codes for the first time, said Vahe Tiryakian, Buildings Department spokesman. The law, which will go into effect in February 1996, will seismically enhance any new buildings constructed in the city by making them stronger.

Since 1987 the Port Authority (P.A.) has been designing buildings to withstand earthquake forces, said Joe Englot, chief structural engineer of the P.A.

Buildings are designed so that people would have time to evacuate before being hit by collapsing ceilings or walls, he said. There is no way to prevent a window from cracking, he said, but there is a way to prevent glass from falling out and injuring someone.

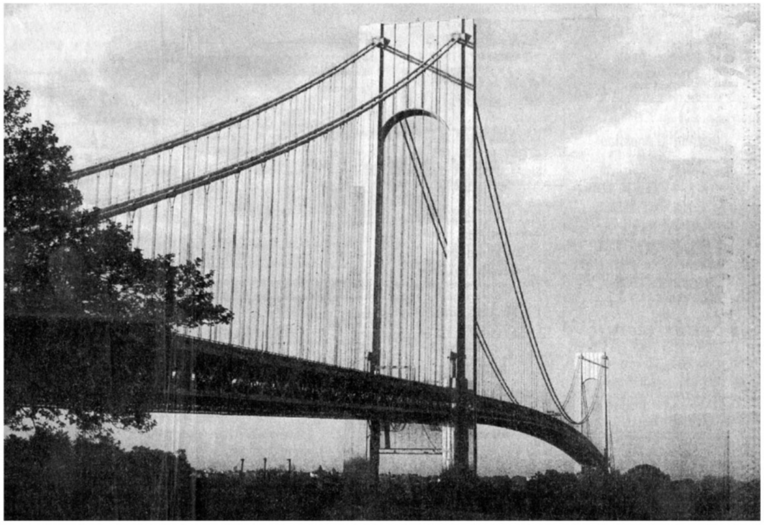
"The saving of lives is the most important thing," he said. Buildings made of concrete block and brick without steel reinforcement are the most dangerous to be in during an earthquake, he said.

Confident that bridges controlled by the P.A., such as the George Washington, Bayonne and Goethals bridges and the Outerbridge Crossing, would withstand damages during an earthquake, Englot pointed out they were constructed well with double reinforcements — if one method of support failed, another would back it up.

Schools are probably safe for shelter, he said, as they have been held to higher building standards than other types of buildings.

The last earthquake to be felt in our area was Jan. 15. It was centered in the Reading area of southeastern Pennsylvania and measured 4.6 on the Richter scale, according to the National Earthquake Information Center in Golden, Colo. Residents from West Brighton, Grant City and Port Richmond called the Advance to report they had felt tremors.

The last earthquake to cause substantial damage in the city was in 1884. It hit between Staten Island and Brooklyn, and according to the New York Times, cracks opened up in Brooklyn that were 12 feet long and 12 feet deep.



Construction work caused a traffic slowdown on the Fingerboard Road ramp to the Verrazano-Narrows Bridge recently due to the installation of earthquake-resistant bearings, part of a statewide bridge rehabilitation program.

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LONG ISLAND WEEKLY

The New York Times

SUNDAY, MARCH 19, 1995

Long Island Q&A: **Dr. Charles Merguerian**

What Would Happen to Long Island in an Earthquake

By TERRY CONSIDINE WILLIAMS

INCLUDED in the student geology laboratory manual of which Dr. Charles Merguerian, a professor of structural geology at Hofstra, was a co-writer, is a depiction of a catastrophic earthquake in New York City. The objective of the exercise, Dr. Merguerian said, is to acquaint students with the plausibility of earthquakes here.

Dr. Merguerian, 46, traces his interest in geology from his childhood, when he crawled over a large outcropping of rocks near his grandmother's house in the Bronx. He grew to appreciate the abyss of time in 25 years of geological mapping and structural analyses of deformed and earthquake-prone terrains.

A graduate of City College, where he also received a master's in field mapping, Dr. Merguerian received another master's in geology from Columbia University, where he did doctoral work in tectonics.

Dr. Merguerian lives in Westbury with his wife, Myriam, and their two sons.

What have you found in your studies of the New York City water tunnels?

My detailed work in the tunnels has shown a multitude of faults that show no surface expression whatsoever. But they are there all over the place, hundreds and hundreds of faults in the crystalline bedrock. Of course, not all of them are major failure zones.

Q. Could those faults cause earthquakes?

A. Nobody can predict earthquakes. But pre-existing faults or dislocations in the Earth's crust produce earthquakes. And pre-existing faults tend to localize new earthquakes, just as earthquakes produce new faults. So it seemed very important to me to know where the faults are. That's when I started examining the distribution of brittle faults in New York City. Brittle faults are the potential failure zones for new quakes.

Q. Does your research suggest that there is an earthquake in Long Island's future?

A. Given the geology of East Coast North America, where Long Island sits, sure there's a tremendous possibility. The same faults that have been mapped in the New York tunnel project are also in the subsurface of Long Island. And the faults found to the north of us in Connecticut project southward across the Long Island Sound into the subsurface of the Island. So an earthquake occurring in midtown Manhattan could just as easily occur here in Hempstead. If you had to pick a place in the New York City vicinity where an earthquake could occur, take a dart board with a map of New York City and Long Island, and the earthquake could occur anywhere. It could be beneath our feet here on the Island, offshore in the Atlantic or in midtown Manhattan or the South Bronx or Staten Island or anywhere in the vicinity.

Q. Where are the fault lines on the Island?

A. There is no map of the faults, because they are not exposed to the surface. But we know from geophysical data, meaning data acquired from indirect sounding methods, that there are a number of faults in the subsurface or within the crystalline bedrock of the Island. These have been described in many publications, and some of these faults you can just project from Connecticut southward or from Manhattan and the Bronx toward the southeast.

Q. How deep is the bedrock?

A. Here at Hofstra, which is mid-Island, it's down about 1,000 feet. On the South Shore it's down about 1,500 feet. On the North Shore about 600 to 700 feet.

Q. Are the seismic problems in the bedrock?

A. That's where the earthquakes would be generated, and then seismic waves would propagate upward through the sediments. The sediments here consist of a couple of layers that are overlaid by a veneer that is glacial sand, silt and clay. Collectively these are the aquifers, the layers where our drinking water is stored.

Q. What might happen to that sandwich in a major earthquake?

A. It's possible in a major earthquake which would be generated in the bedrock that some of those clay, sand and glacial layers would move and possibly liquefy. That could bring about the "shake like jelly on a plate" situation. That's what happened in the Kobe, Japan, earthquake.

Q. How large an earthquake would that be?

A. I would suspect a 6 magnitude of the Richter scale. That's larger than we've had here in the New York area. The last big one was offshore near Brooklyn in August 1884. That has been calculated, since it was before the Richter scale was devised in 1935, as a 5.5, and reportedly there were sand boils on Coney Island from liquefaction of the soil. In December 1737 we had an estimated 5.0 that was felt in Oyster Bay. Both of these were eclipsed by the devastating 7.1 in 1886 in Charleston, S.C. And that could happen here, because the geologic structure there is no different from what we have here.

Q. Isn't the East Coast considered an inactive seismic zone?

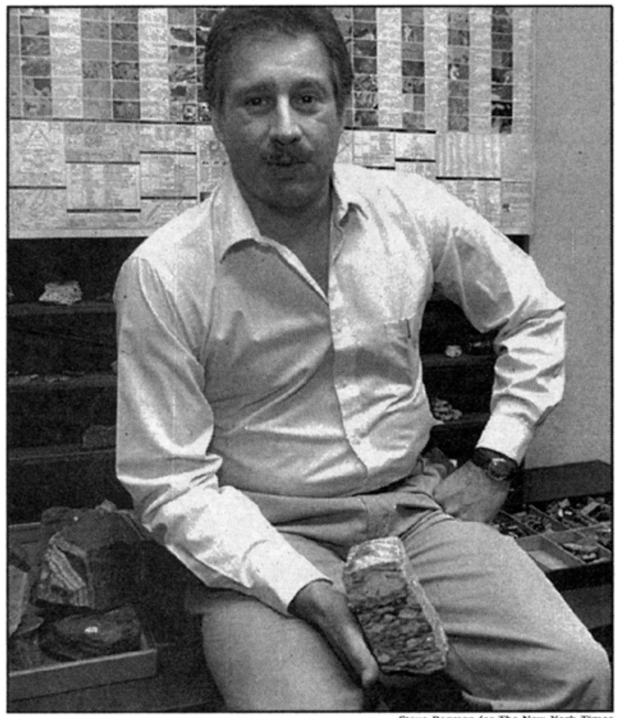
A. Not any more. I know I was brought up as a student to think we don't have earthquakes here. But if you look you'll see there have been at least 50 events that have struck the New York area over the years. Most of them have been magnitudes of less than 3, and there have been a couple of 4's. But these big ones of 5.5 and in that range can occur, have occurred and will occur.

Q. Why?

A. Because the East Coast of North America is basically in a vise. We ride the middle of the North American Plate. That plate is being pushed by the growth of the mid-oceanic Atlantic ridge. While that's happening, the San Andreas system in California is hindering our plate from going any farther West.

Q. Do you concur with the theory that earthquakes in the middle of tectonic plates like those in our region tend to be much more damaging than quakes at the edges of plates, like those in the West?

A. I have been saying for years that earthquake damage here on the



Steve Berman for The New York Times

Dr. Charles Merguerian in geology department at Hofstra.

LONG ISLAND WEEKLY

The New York Times

SUNDAY, MARCH 19, 1995

Long Island Q&A: **Dr. Charles Merguerian**

What Would Happen to Long Island in an Earthquake

East Coast could far eclipse what you get out West, given the same magnitude event.

Q. Why?

A. It's partly the geology of the area, but it's largely because of the weakness of the infrastructure. All the systems built 100 years ago are failing now without any seismic activity. Nothing here is built with any resistance to earthquake shaking.

If the earthquake that occurred in New York City in 1884 occurred today we would be looking at a tremendous loss of life and a severe monetary problem. But nobody talks about earthquakes here. We have no specific plan.

Q. What does it mean to say that the bedrock here has a very strong directional capability?

A. It means that the energy from earthquakes can travel great distances through our bedrock. Seismologists call that High Q, and in New York the High Q favors transmission in crystalline bedrock in a northeasterly direction. For example, the 1988 earthquake in Montreal that was felt in New York City traveled right down the spine of the Appalachians.

Q. How would that affect the Island?

A. Anything occurring north of the Island could travel down beneath the Island. The energy of an earthquake occurring anywhere along the Connecticut River Valley, for instance, could be focused southward beneath the Island. So, you wouldn't have to have an earthquake directly beneath Long Island to have the effects of an earthquake transmitted here. The 3.5 quake Long Islanders felt in October 1981 was reported as being centered in Long Island Sound, directly south of Madison, Conn., and about 10 miles northwest of Greenport.

Q. Would bedrock's being closer to the surface on the North Shore than on the South Shore make a difference in a quake?

A. Yes. It would probably create a situation where the North Shore residents would feel it more. Not necessarily sooner, just more intensity.

Q. Do the two lines of faults intersect?

A. Yes. The prominent Northeast and Northwest families of faults meet somewhere near the Nassau-Suffolk border. And the point I always try to make is that the crevices or cracks where they do meet are the areas that I think are particularly liable for seismic activity.

Q. Would liquefied soil and boiling sand contaminate water supplies?

A. I don't think so. There might be some compaction of the aquifers, if we had a big enough earthquake, where you'd lose some storage capabilities but not much.

Q. Would underground objects like oil tanks and septic systems be affected?

A. Ground slumping because of liquefaction could cause local building collapse, particularly in older high-density neighborhoods. Septic systems and fuel-oil storage tanks could begin polluting the ground-water aquifers. Gas mains could fail and fires could result. In addition, I think the Nassau North Shore cliffs, which are inherently unstable, would react poorly in an earthquake, because of the shallow depth of the crystalline bedrock under them. Amplification of seismic wave energy might result in major landslides. Expensive North Shore property could be severely damaged.

Q. How would the Long Island Rail Road and airports be affected?

A. Local track failure is a possibility, particularly in areas underlaid by artificial fill or glacial-lake deposits, which are scattered throughout the Island. Airport runways built on fill may not fare too well in an earthquake. Large crevasses may open such as the 12-foot-long 10-foot-deep ones reported in the 1884 quake.

Q. What do you see as the major problem in a quake?

A. Generally we're in pretty good shape on Long Island. In most places we have a relatively flat terrain. We wouldn't suffer from landslides. If there were any disruption of road surfaces it would be from breaking of roads due to shaking of the soils. What's more, we're not constructed vertically, with lots of tall buildings.

But a major problem for the Island might be tsunami, a Japanese term for harbor waves or seismic sea waves. Those can be very destructive, because they can have wavelengths of up to 900 feet, be up to 90 feet high, travel up to 500 miles an hour and in general last for 10 to 60 minutes. If we had a 6.0 earthquake offshore we could be dealing with very serious tsunami. And sometimes earthquakes occurring on land will send a compressional wave out, and the water will be pushed away and then come back as tsunami. ■

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Hofstra University Professor Dr. Charles Merguerian Explores *The Terrifying Truth About Earthquakes* on "ABC's World of Discovery"

It Can Happen Anywhere, even in New York

Hofstra University Geology Professor Dr. Charles Merguerian appeared on "ABC's World of Discovery," Saturday, May 21, 1994 on the ABC Television Network. Actor Martin Sheen hosted and narrated the one hour national broadcast of "Earthquakes: The Terrifying Truth."

Today, at least 39 states in the United States (including New York, Illinois, Missouri, South Carolina, Texas, and of course, California) face real seismic danger. Cities such as New York City, St. Louis, Little Rock, Memphis, Boston, Anchorage, Seattle, Louisville, Chicago, Charleston, Portland, Reno, and Salt Lake City are all at risk for sizable quakes, and most are ill-prepared for their fate.

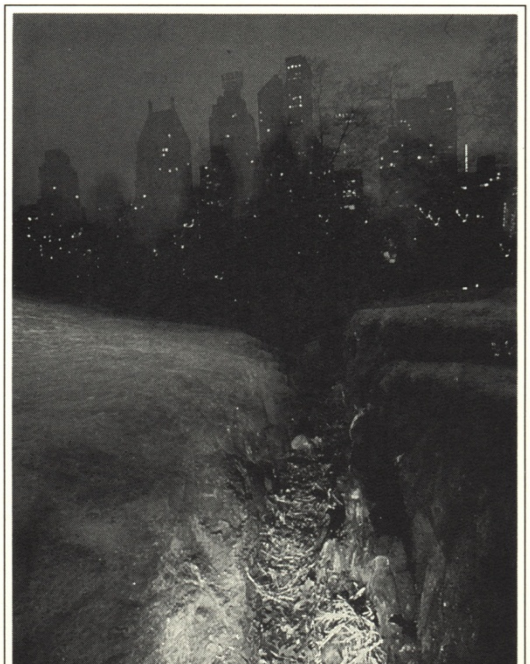
"Earthquakes: The Terrifying Truth" included footage of quakes in action and coverage from some of the more notorious jolts from this century. Dr. Merguerian and other eminent seismologists explained what science can and can't predict, and how the panic resulting from predictions themselves could cost more lives than the damage of an earthquake.

Beyond California, "Earthquakes: The Terrifying Truth" revealed that New York City is "a seismic time bomb." Dr. Merguerian has identified numerous fault lines throughout New York City. "Earthquakes can and have occurred in New York City," said Dr. Merguerian.

Dr. Merguerian is a Professor of Structural Geology at Hofstra. He is the President of Duke Geological Laboratory in Westbury, New York and chief geological consultant for Geoteknika Resources in Winsted, Connecticut. He has worked as a consultant for the United States Geological Survey, the California and Connecticut State Geological Surveys, the New York City Department of Environmental Protection, and numerous geotechnical and engineering firms. His consulting experience encompasses basic and site-specific geologic mapping, subsurface engineering geology and foundation analysis, mineral exploration, and expert courtroom testimony.

Dr. Charles Merguerian has over 20 years of experience in geologic mapping and structural analysis of complexity deformed metamorphic terrains, plutonic and volcanic districts, and areas underlain by sedimentary and glacial strata. His chief interests lie in ductile- and brittle-fault analysis and earthquake-hazard assessment of crystalline terrains, and tectonic studies of Phanerozoic orogenic belts. His secondary interests lie in computer analysis of geologic processes and data presentation, prediction of ore and mineral deposits according to plate tectonic setting, and geophotography. He has performed pure and applied research and publishes maps and reports from such widely separated areas as New York City, western Connecticut, eastern New York, western Massachusetts, central and southern California, and Nevada.

Dr. Merguerian's recent research efforts focus on field and tunnel mapping and laboratory research on the surface and subsurface structure of New York City and vicinity, resolving fine details in the local structure, stratigraphy, and metamorphism. His work documents the existence of numerous ductile and brittle faults which crosscut Manhattan Island and the East River Channel and affirms the seismic potential of southeastern New York, long thought to be invulnerable to earthquake hazard.



Geologists including Hofstra's own Dr. Charles Merguerian fear the worst should New York ever suffer a major earthquake. Photo: 1994 Capital Cities/ABC Inc.©

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TV GUIDE

Shock Waves ▶

"Earthquakes: The Terrifying Truth" on World of Discovery examines the dangers of earthquakes in California, Tokyo and New York (right, a fault in Central Park).

8 P.M. (ABC) 7 14763 **8** 14745

THE NATION'S NEWSPAPER
USA TODAY
NO. 1 IN THE USA . . . FIRST IN DAILY READERS

USA TODAY FRIDAY, MAY 20, 1994

'Earthquakes' may rattle folks far from the West Coast

By Alan Bash
USA TODAY

Graceland, all shook up.

That's the scenario put forth on ABC's *World of Discovery* special Saturday (8 p.m. ET/PT), in which geology experts predict a large-scale earthquake to rock Elvis' final resting place sometime in the next 50 years.

Memphis is, after all, the big city closest to an earthquake zone in the central U.S., says Kaye Shedlock of the U.S. Geological Survey. With a magnitude 6 quake on the Richter scale, "Graceland would shake from side to side, (sink) about an inch, but weather it fairly well," she says. Other parts of town might not be so lucky.

In true-to-sweeps form, *Earthquakes: The Terrifying Truth*, hosted by Martin Sheen, seeks to shatter the belief that only the West Coast has to fear the movement of the earth.

"It's a myth that the East Coast is immune," says Hofstra University's Charles Merguerian, who appears on the special. Merguerian says a big quake tends to hit the Big Apple about every 120 years, with the last one coming in 1884.

The special features footage from January's quake in Southern California, interspersed with Hollywood's big-screen versions of the Big One — mayhem in the streets, the letters on the Hollywood sign peeling off the mountain.

"It's certainly on the high-impact end," says geologist Allan Lindh of the one-hour documentary. Lindh, — who also weighs in during the show — says that although the documentary may be a bit alarmist, he's happy it will at least "be a wake-up call" to the country's central and eastern regions.

People can do simple things to prepare for a quake, he says. "If you've got a children's room, you should attach (standing bookcases) to the walls; your kids should know to get under the table; they should know where the gas-shutoff valves are."

Viewers, though, shouldn't lose sleep over an impending Big One, says Lindh. "They've got tornados and hurricanes and crime on the streets to worry about."

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Newsday
LONG ISLAND

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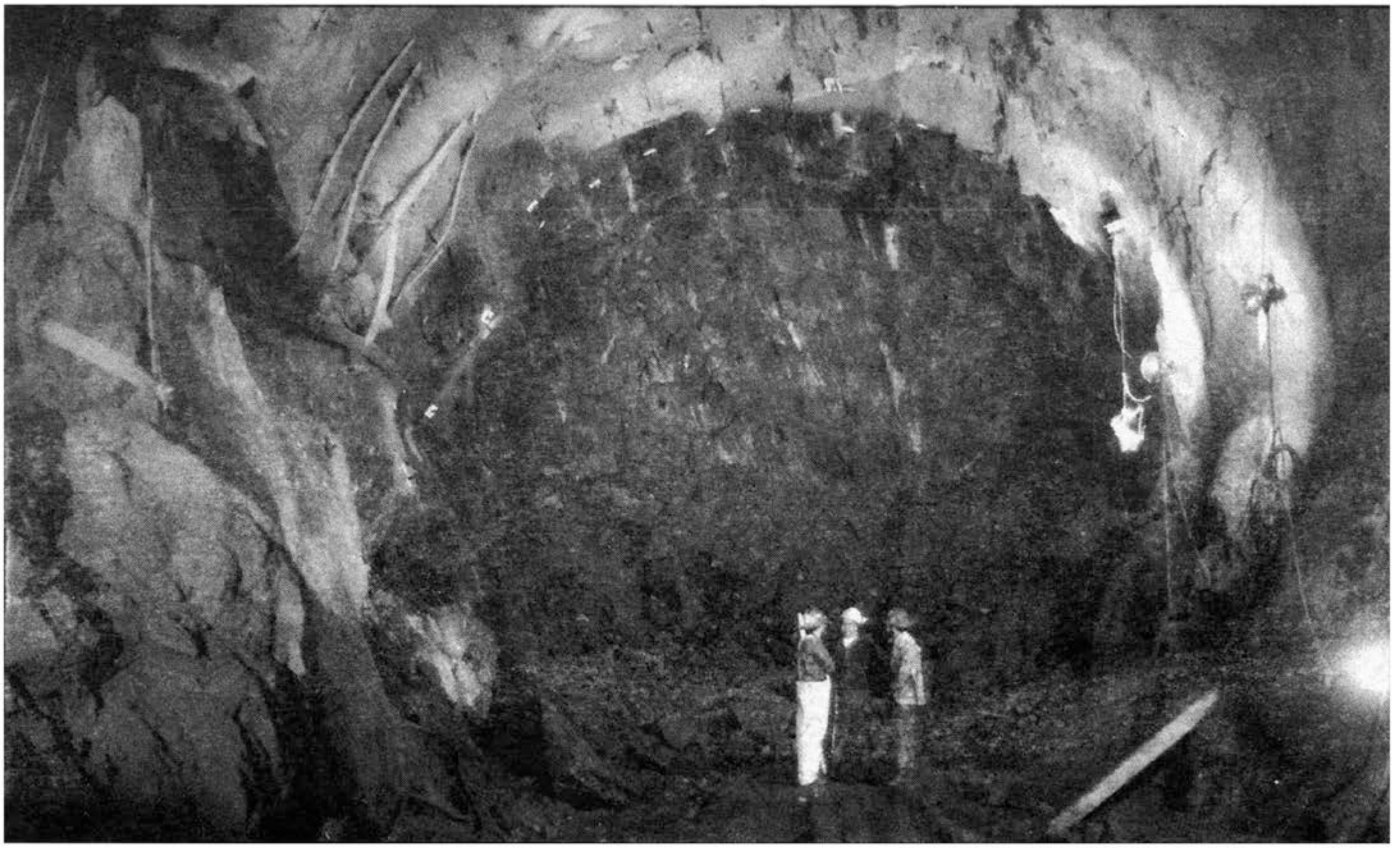


Photo by Diane Dennis / New York City Department of Environmental Protection

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.

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

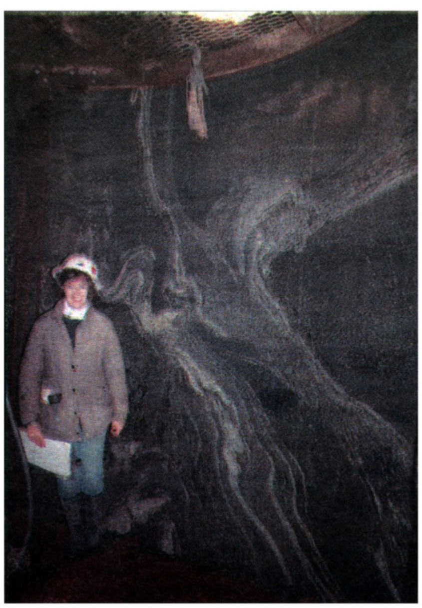


Photo by Diane Dennis / New York City Department of Environmental Protection

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

Merguerian with rock samples from tunnel project.

Rocky Terrain

The distribution of metamorphic rocks in the New York City area

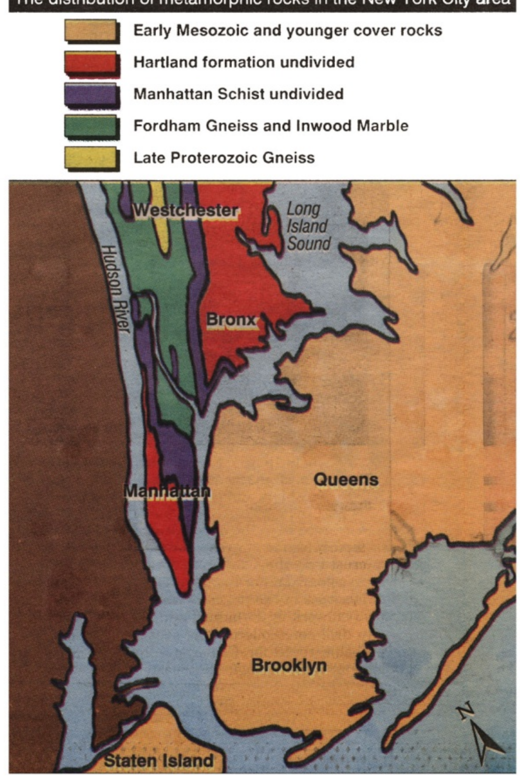
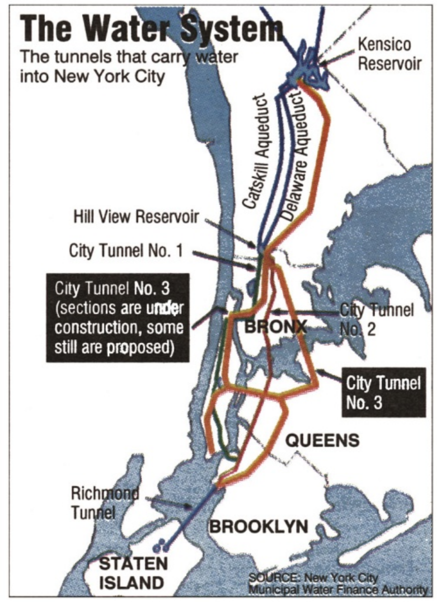


Photo by Diane Dennis New York City Department of Environmental Protection

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.

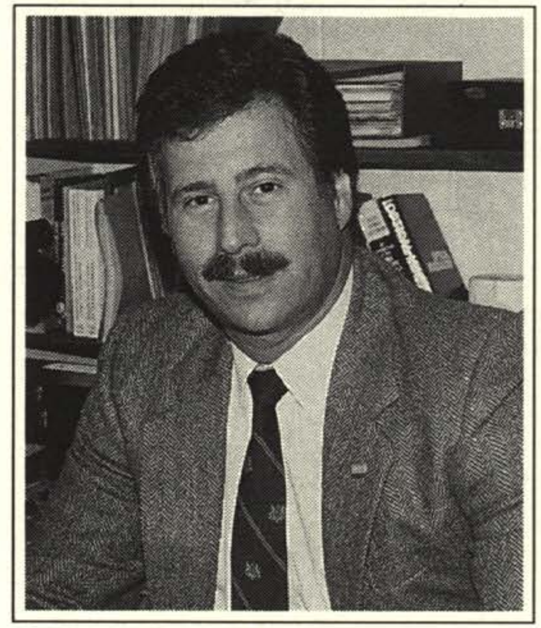
"As a geologist reading and interpreting the rock record, you can feel the structure, unravel the pressures, and visualize them in three dimensions," Merguerian says. "It's a very special feeling when you walk over a terrain that you understand better than anybody else. It makes you feel at one with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

Geology Professor is a True Mover and Shaker

In the aftermath of the January 17, 1994, Los Angeles earthquake, Associate Professor Charles Merguerian (Geology Department) was interviewed by Chuck Scarborough on WNBC-TV. He offered his opinion on the possibilities of a similar earthquake striking the New York City area based on his research on existing faults and their bearing on localizing modern and ancient earthquakes. In addition, Dr. Merguerian was interviewed by Bob Salter of WXRK (92.3 FM) for a one-hour Sunday morning broadcast on January 23, 1994, in which he was able to elaborate on his research efforts in the region and to promote Hofstra's leading role in geologic investigations of this area. Dr. Merguerian also was contacted by many local and regional newspapers for his opinions on seismic activity in the northeast.

Earlier, in November 1993 Dr. Merguerian took part in filming of a documentary titled "Earthquake" to be nationally broadcast later this year on WABC-TV. Location shooting included the new New York City water tunnel presently under construction in the subsurface of Brooklyn, the famous 125th Street fault in upper Manhattan, and faulted exposures in Central park.

On a more professional level, Dr. Merguerian is presenting new data on his research at three conferences to be held in March (Northeast Section of the Geological Society of America), April (Stony Brook State University Conference on the Geology of Metropolitan New York and Long Island), and in May (National Association of Geology Teachers). In addition, this spring he will conduct two field trips for the New York Academy of Sciences (Bear Mountain and the Hudson Highlands and mines and dinosaurs of central Connecticut), a field trip for the Center for Teaching Excellence, and a field trip for the May NAGT meeting (northern end of the Newark basin in New York).



Professor Charles Merguerian

HOFSTRA PRIDE

AFTERSHOCK

To Charles,
Thank you for the inspiration and for sharing your considerable knowledge with me!
Good luck in '84!
Best,
[illegible]
May 1991

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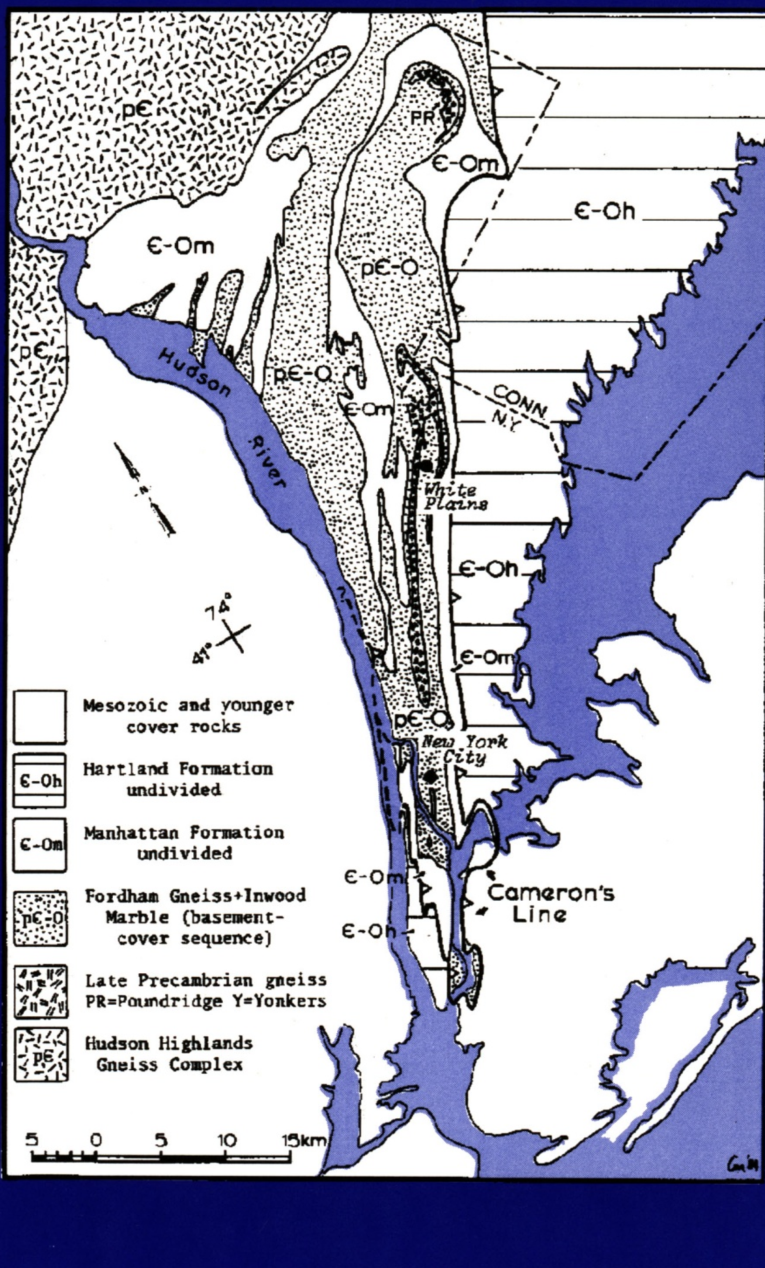
Laurie McCall's skills as a television news field producer were invaluable during my initial reporting of New York's vulnerability to seismic disaster. Dr. Charles Merguerian, Professor of Structural Geology at Hofstra University, drew a chilling road map of the area's faultlines and helped me understand the peculiar behavior of what we think of as solid ground during an earthquake's shock.

HOFSTRA HORIZONS

Research at Hofstra University

Fall 1990



From California to New York, this "hard rocker" is redefining our understanding of past geologic events.

Charles Merguerian : Research into Rocks and Rumbles

Included among the rock specimens, shelves of books and journals and computer programs contained in the office of Geology Professor Charles M. Merguerian is his earthquake outfit. The image that comes to mind is of a hard hat, boots and seismic measurement devices. This outfit, however, consists only of a sports jacket and tie. Merguerian dons it quickly whenever an earthquake occurs anywhere in the world and waits for the media to show up. He has gained a reputation as one of the New York area's resident experts on the question, "Can it happen here?"

Merguerian has an insouciant manner that belies his extensive research background. Despite the media attention and drama, he considers earthquakes among the least interesting areas of geology. He traces his pursuit of the discipline to a childhood love of rocks; he could always be found examining the local outcrops behind his grandmother's house when he visited her in the Bronx. Originally setting out to study paleontology, his attention was diverted by a professor during his undergraduate years at the City University of New York. Rather than deepening his interest in fossils, he became a "hard rocker," specializing in igneous and metamorphic rocks. He thus distinguishes himself from the "soft rockers" who study sedimentary and coastal geology.

New England, specifically the geology of western Connecticut, was the location of Merguerian's earliest research projects. Like so many other scientists, he compares his work to that of Sherlock Holmes and other detectives. The rocks he deals with are deformed and folded by high temperature and pressure. The study of these materials requires keen observation, detailed knowledge of geophysical processes and deductive skills. The ultimate task is to take thousands of seemingly unrelated facts and correlate them into a single, unified theory. Merguerian's

Charles M. Merguerian

fascination with such complexity and preference for the outdoors led him to pursue extensive fieldwork when he went on to earn his Master's Degree, also at CUNY.

His undergraduate mentor became his graduate advisor. When it came time to begin work on the Master's thesis, that advisor voiced his doubts about the original mapping of an intrusion of rock in western Connecticut. Spending three summers mapping Litchfield County, Connecticut, Merguerian traced a fault known as Cameron's Line, and discovered that it served as a boundary between two plates that collided sometime in the geologic past. It separates rocks formed on North America from plates that moved from somewhere off the continent. Across Cameron's Line are a series of intrusions of anomalous rock known as the Hodges Complex. Merguerian's research task was to determine whether these variations represented physically transported slices of oceanic crust and mantle or whether they were genuine intrusions.

The thesis resulted in a reinterpretation of the geology of western Connecticut. It documented the first real evidence of what Cameron's Line is, of the relative ages of the subsurface rocks and what the intrusion represents in geologic history. Merguerian proved that the fault line, which extends into New York City, is not only a fundamental plate boundary that separates two distinctive sequences of rocks, but that it dates back to a time when there were excessive collisions taking place, approximately 480 million years ago. Merguerian is especially pleased with the fact that his Master's level work was used to update the official Connecticut state geologic maps.

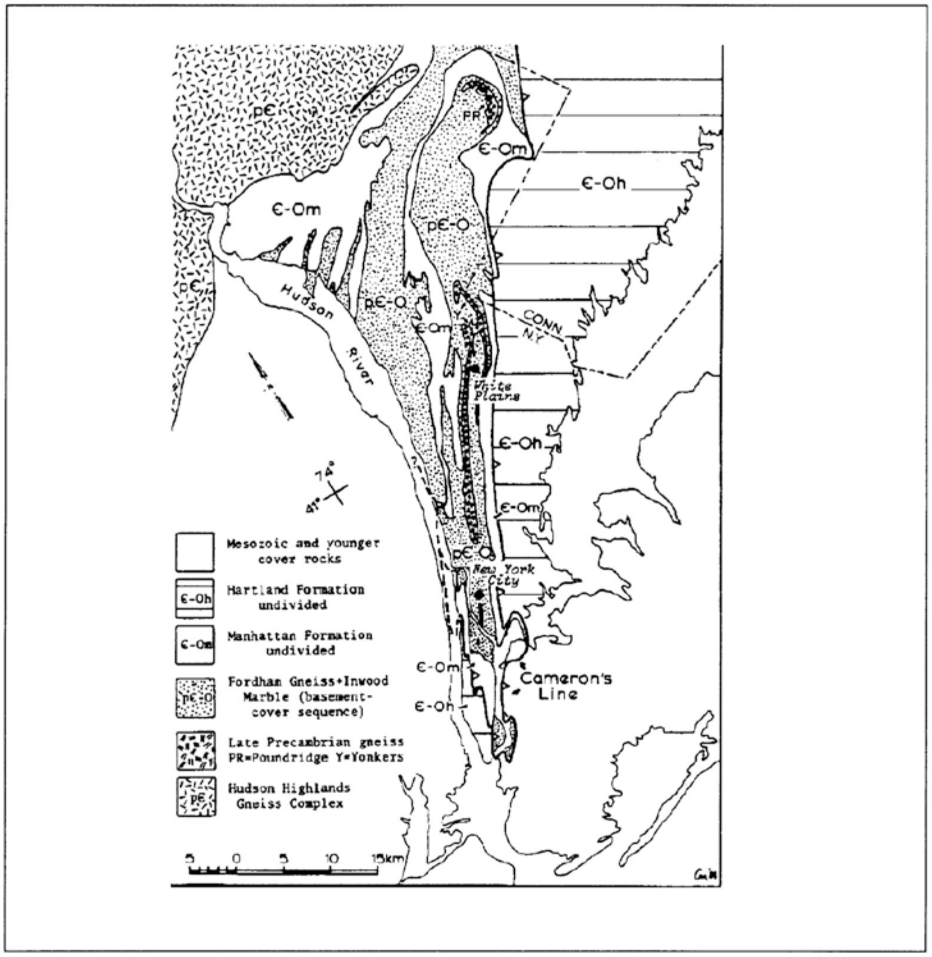
Continuing for the doctorate at Columbia University, Merguerian's work in Connecticut gave him the opportunity to conduct a similar project in the Sierra Nevada mountains in California. On the western flank of the Sierras exists a belt of metamorphic rock that had been all but taken for granted by the official geologic surveys of California. These rocks had not been studied since the 1800s. Even at that time, interest in them was economic rather than scientific. The area, of course, was the site of the California Gold Rush, and the belt that was the subject of Merguerian's doctoral dissertation contained rocks that were, in part, receptors for gold bearing fluids.

Finding himself in a gold mine of untapped geologic data, Merguerian began to apply his Appalachian techniques for the analysis of metamorphic rock formations. Similar to the work he conducted in Connecticut, his task was to investigate two dissimilar types of rock formation that were separated by a boundary. These are known as the Calaveras and Shoo Fly Formations. The boundary was not well defined either in terms of what it was or where it went. Merguerian's advisor had observed a fundamental difference in the texture of the rock, but he himself was not an expert in the application of Appalachian metamorphic techniques. The job took twelve months, spread over the course of four summers camping in the National Forest. At its conclusion, Merguerian had mapped over four hundred square miles of hitherto virgin terrain, with approximately fifty square miles documented in the most minute detail.

His findings were similar to those in Connecticut. The dissertation demonstrated the presence of a ductile contact, known as the Calaveras/Shoo Fly Thrust, which separated two metamorphic terrains of disparate age and equally different structural history. He defined the chronology of structural development and published a number of studies, some with colleagues, mapping contiguous areas, defining the rock units, their thicknesses, the structural geometry, the nature of the boundary and the dates of many of the intrusions. It was a comprehensive structural picture, including upper and lower age limits, that Merguerian refers to as "nuts and bolts" geology.

The findings showed a plate boundary between rocks that were indigenous to North America, the Shoo Fly complex, and the Calavaras complex, which proved to be completely exotic to this continent. The study revolutionized the awareness of the metamorphic history of the foothills of California. It was the first time geologists documented the existence of two distinct belts. Further research has revealed the existence of a third belt, all of them formed through the collisions of massive land movements in the earth's most distant past. Merguerian points out that the California work is not universally accepted. But he adds quickly that the detractors are not field geologists, but base their conclusions on geophysical data.

The work for these two studies took place between 1973 and 1981. Merguerian began his teaching career at Hofstra in 1981, a number of years before he actually concluded the data analysis and presentation to finish his Ph.D. He characterizes this period as a homecoming, both literally and intellectually. Even before completing the California study, he rekindled his childhood love of the geology of New York City. He bemuses the fact that the subsurface structure of the City had not been examined in over one hundred years, well before modern, sophisticated analytical techniques were developed. Merguerian's ex-



Simplified geologic map of the Manhattan Prong showing the distribution of Precambrian to lower Paleozoic metamorphic rocks.

perience and expertise led him to go beyond previous descriptions, which were narrowly focused, and approach the geology of New York City from a regional perspective. His interest is in how the smaller area relates to the larger region.

Almost immediately upon his return, he began a comprehensive mapping program of the New York metropolitan region, a program he is still involved with. The mapping concentrated on the surface geology until approximately five years ago when he was given the opportunity to explore the unfilled water tunnels being built by and under the City of New York. The tunnels are drilled into solid rock, 800 feet beneath the surface. As Merguerian puts it, "...a geologist's dream."

Based on his surface mapping, Merguerian had developed a number of hypotheses that he was able to test further through access to the water tunnels. He traced Cameron's Line into New York City, through the East River and up through the West Side of Manhattan. The sequence of exotic rock he identified in Connecticut, known as the Hartland Formation, is also found in New York City. He points out how similar the various rocks, those that are part of the Manhattan Schist and those that are not indigenous, look to the untrained eye. They are very different, the latter originating from an exotic oceanic island sequence of rock.

This part of his work was partially funded by the U.S. Geologic Survey. While exploring the exposed bedrock of the water tunnels he was able to see the sequence characteristic of Cameron's Line in plain view of his scientific vision, confirming the theory he had begun to develop as a graduate student. The experience is similar to that of the detective or historian who gets the opportunity to embark a time machine and verify his or her theories first hand.

One segment of Merguerian's observations in the water tunnel that crossed westward from Queens into Manhattan resulted in some unnerving conclusions. He saw that Cameron's Line was accompanied by a number of relatively fresh, brittle fault lines deep in the bedrock of the City. An outcome of this finding is his ability to state publicly, with disquieting assurance, that the earthquake potential in New York is much higher than had been assumed previously. While his curiosity is much keener concerning the geochemical composition and texture of the rock formations he has observed and documented, he has received the most recognition from the media over his predictions concerning the next New York earthquake.

Merguerian also points out that the water tunnel today is a lost data resource, as it has been cemented over and dedicated to its designated use. He indicates several trays of rocks on his laboratory table as having come from the water tunnels, noting that if he didn't leave his lab for the field again, he would have enough material in those trays for many additional research projects.

Charles Merguerian, from his earliest recollections of his grandmother's rock pile, appears driven to locate and assemble the pieces of the massive jigsaw puzzle that is the subsurface geology of New York City. Just as he was waking up from his geologist's dream of access to a cross-sectional view of rock 800 feet deep, he received a phone call from a colleague about some drill core the City decided to discard. He explains that, consistent with the building code, each time a new construction project is approved, a sample of the subsurface rock must be extruded and examined. The purpose is to insure that the bedrock is strong enough to support the building about to be erected. This drill core is of no scientific interest to the City, other than the evidence it provides regarding the construction project.

After so many years, the City disposes of these samples, which had been stored under the Brooklyn Bridge. Once the building goes up, the opportunity to obtain such samples of the subsurface rock formation is virtually lost forever. Merguerian was able to obtain approximately 1,000 boxes of drill core, each about twenty-five feet long, as well as another thousand boxes of soil samples from around the City.

Merguerian arranged for this collection to be transported to Hofstra University, where today it is stored under the football stadium. He estimates that it is worth multiple millions of dollars, calculated on the basis of $100 per foot to drill it. As a scientific resource it is priceless. Merguerian remembers feeling totally overwhelmed by the potential represented by this material. His first priority was to make it accessible to the scientific community by producing a catalogue, identifying the core and soil, its origin and location on a map grid of New York City. He also had to label each of the 2,000 boxes. He successfully obtained a grant from the Hudson River Foundation for this purpose.

He is currently in the process of computerizing the information on the drill core. He explains that the core is a three-dimensional representation of the subsurface structure and is extremely well suited to computer applications. He has produced a three-dimensional topographic map of the New York area and now is in the process of including the underlying structures.

He returns again to earthquake potential. The drill core confirms even more definitively his earlier conclusions about the potential for seismic activity. It reveals a series of faults crossing under the area. Unlike San Francisco where such activity is expected, the New York infrastructure is not built with even the recognition that earthquakes are possible. Merguerian notes that an earthquake of relatively low magnitude would create massive destruction and chaos.

He emphasizes again that his interest lies in documenting the geology of New York, noting that such a project was all but assumed impossible for lack of data because of inaccessibility to subsurface samples. But Merguerian, his colleagues in the Hofstra geology department and his students, who are exclusively undergraduates, are actively engaged in producing the definitive geological map and history of the City of New York. Despite his exhortations about seismic potential, he seems to believe this to be a long range project.

CAN IT HAPPEN HERE?

Although Charles Merguerian considers the study of earthquakes tangential to his primary professional interests, he is emphatic about his concern that New York is complacent about earthquake potential and preparedness. His mapping of Cameron's Line into New York City and the data provided by the New York drill core and soil sample collection at Hofstra demonstrate that New York City is in far greater jeopardy of significant seismic activity than has been assumed. A strong (magnitude 5) earthquake occurred off the coast of Brooklyn approximately 100 years ago. Smaller quakes have shaken the area during the past ten years.

What is earthquake preparedness? In cities like San Francisco an earthquake mentality develops among the population and municipal agencies. That attitude of expectation and resignation ameliorates much of the panic that otherwise could occur. When major quakes are reported, the rest of the country is impressed by the speed with which normal routines are restored. San Franciscans seem to take it all in stride, as demonstrated in the fall of 1989.

Preparedness is also reflected in the building codes. In the wake of the most recent San Francisco quake, a civil engineer was interviewed and asked how buildings were made earthquake proof. "They're not," he responded. It would be much too expensive even to approach such a standard. Buildings are constructed to protect human life as much as possible. The buildings take the damage, not the people in them.

Charles Merguerian's concern in New York is the absence of an earthquake mentality- the "It can't happen here" attitude. While little can be done about existing structures, Merguerian takes every opportunity to campaign for changes in local codes as they apply to future construction. He notes that even a moderate earthquake in New York City would inflict greater costs in property damage and human life than more serious quakes in San Francisco. Adapting building codes to the new evidence we have would be an effective, low cost way of preventing some of the injuries and deaths resulting from a quake.

The advice remains essentially unheeded, although minor code changes have been made. Buildings, bridges and tunnels continue to be built with little recognition that an earthquake is possible. It is an unfortunate example of the reactive attitude we take when dealing with disaster.

EAST COAST EARTHQUAKES

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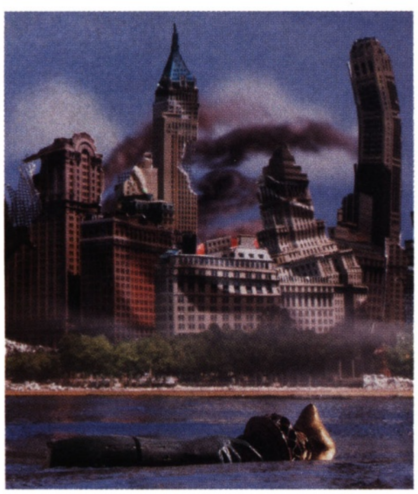

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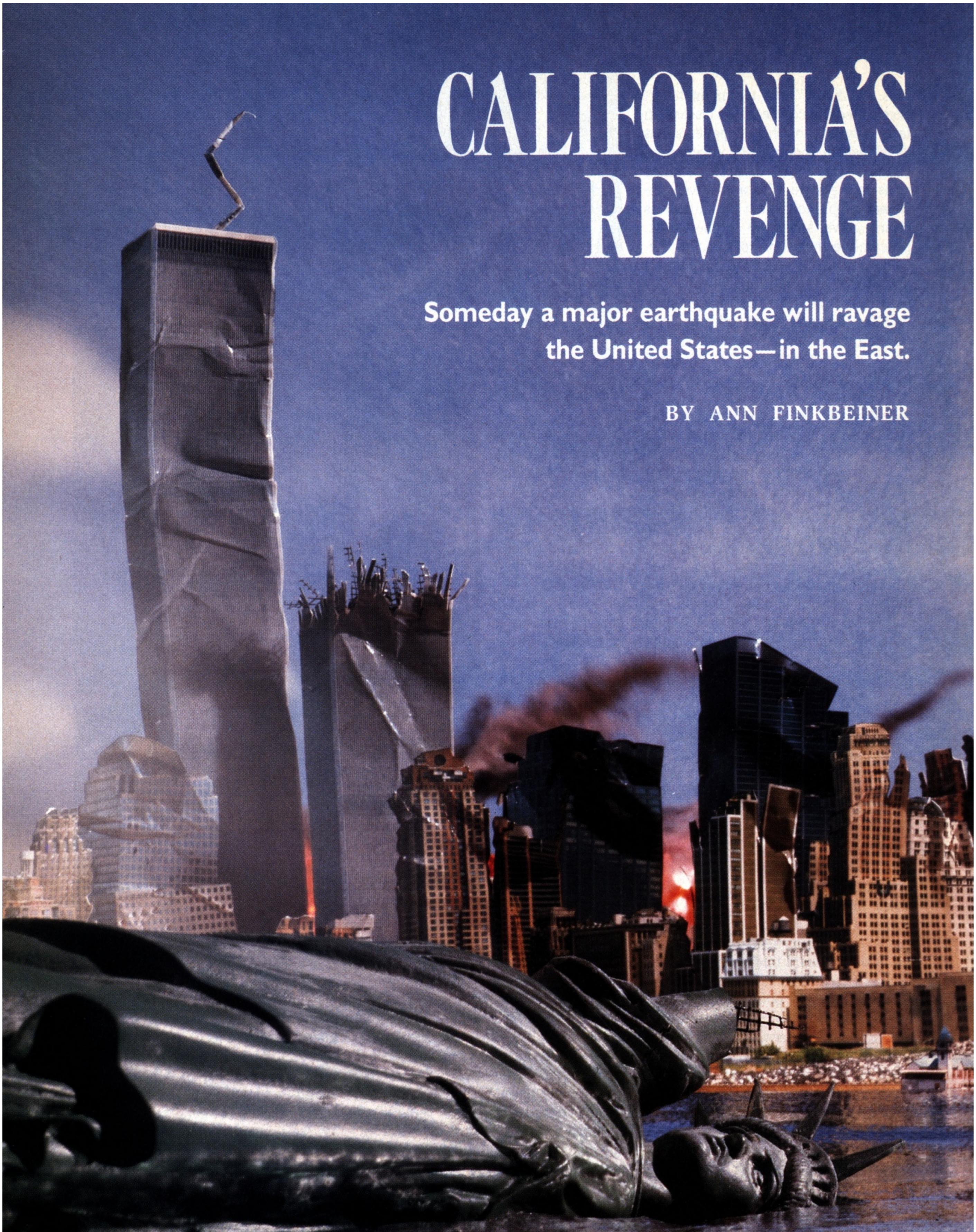


CALIFORNIA'S REVENGE

Someday a major earthquake will ravage the United States—in the East.

BY ANN FINKBEINER

The earthquake that struck near Santa Cruz on October 17, 1989, killed 62 people and was felt over 66,000 square miles. But most of San Francisco and large parts of Santa Cruz itself were unscathed. The earthquake that struck Charleston on August 31, 1886, flattened the city. Few buildings went untouched. Nearby dams burst, and the floods washed trains off their tracks. In a town of 50,000, as many as 110 people died. The quake cracked walls in Chicago, 750 miles away; it was felt over an area of 1.5 million square miles, from Massachusetts to Wisconsin to Bermuda.

Of course, as everyone knows, earthquakes are not supposed to happen in South Carolina. California is another story: even well before October's quake geologists were saying there was a good chance of an earthquake of roughly that magnitude (7 on the Richter scale, about the same as the Charleston quake) striking precisely that segment of the San Andreas Fault. Geologists even know why the San Andreas, that egregious scar on the California landscape, is so quake-prone. It marks the boundary between two of Earth's shifting, crust-bearing plates—the one that carries the Pacific Ocean and the one that carries North America. As these two giant slabs grind past each other at a few inches a year, they get stuck at certain points. Stress builds up over decades and then gets released all of a sudden. Most earthquakes happen in the heavily faulted rock at plate boundaries, and not only in California: the devastating quakes that struck the Philippines and Iran this summer are recent examples of this process.

Charleston is different. Like the rest of the East, it is nowhere near a plate boundary—the eastern edge of the North American plate is a ridge that runs down the middle of the Atlantic. For a long time it was assumed the rock under Charleston must have huge, hidden faults. But when geologists combed the area in the 1970s and early 1980s, they came up empty. There was nothing special about Charleston, they concluded, that distinguished it from the rest of the East.

"Until the early eighties, people could look at the Charleston quake as peculiar to that area," says John Armbruster of Lamont-Doherty Geological Observatory. "But now we have to admit the possibility of a large quake coming out of nowhere. The Charleston quake was a wild card. That scares the hell out of people."

What has started to scare geologists and building engineers is the growing realization that nearly all of

PHOTOGRAPH BY J. R. ROST

eastern North America—everything east of the Rockies—must be considered vulnerable to damaging earthquakes. Quakes happen less frequently in the East than in the West, but also less predictably; in most cases, as in Charleston, geologists can't even find the guilty fault. What's more, when an eastern quake does occur it is felt over a much wider area than a quake in the West—precisely because the East is not crisscrossed by fault-shattered rock, which tends to dampen the spread of shock waves.

And unlike much of the West, the more heavily populated East is not at all prepared for a major earthquake. San Franciscans were spared a grimmer disaster this past year by building codes enacted decades ago, but most people in the East live and work in buildings that are not much better equipped to resist shaking than Charleston was in 1886. Seven years ago that city, now with a metropolitan population of 500,000, commissioned a report on what a magnitude 7 quake might do these days. The estimate was more than 2,000 deaths, more than 8,000 serious injuries, and $2.4 billion in damage.

Charleston's quake was not the strongest ever to strike east of the Rocky Mountains. In December 1811 and January and February 1812 the area around the Mississippi River town of New Madrid, Missouri, was rocked by three earthquakes, the description of which is a series of superlatives.

John Bradbury, a Scottish naturalist who was traveling down the Mississippi to collect plant specimens when the first quake occurred, wrote that the sound was "equal to the loudest thunder but more hollow and vibrating." Other sources reported geysers of sand and black water shooting into the air as high as trees, leaving behind craters 5 to 30 feet wide. The ground rolled in waves several feet high, knocking people down. Collapsing riverbanks changed the Mississippi's course and even created new lakes; one of them, Reelfoot Lake, now covers 18,000 acres 20 feet deep and is littered with the trunks of drowned cypress trees. "All nature," wrote Bradbury, "seemed running into chaos."

Not only were the New Madrid earthquakes strong—judging from their effects they were probably between magnitudes 8 and 9—but their reach was unparalleled. They cracked sidewalks in Charleston and collapsed scaffolding around the Capitol in Washington. They damaged well-constructed buildings over an area of 235,000 square miles, 20 times the area damaged by the San Francisco quake of 1906 (a magnitude 8.3). People felt the shaking over perhaps 4 million square miles, the largest area ever affected by any recorded quake. "If we could pick any earthquake in the forty-eight states that, if it recurred, would cause the greatest damage," says Armbruster, "it would be New Madrid."

Even geologists have neglected eastern earthquakes, partly because they're much less frequent than western ones and partly because they're harder to understand.

Other eastern earthquakes, although not as spectacular, have been strong enough to cause damage. In 1929 a 7.2 quake on the coast of Newfoundland set off a large underwater landslide and triggered a tsunami that killed 27 people. The Charlevoix region, northeast of the city of Quebec along the St. Lawrence River, has had five earthquakes over the past 330 years that were magnitude 6 or greater; the most recent one, a magnitude 7 in 1925, was felt strongly as far away as New York City.

New York itself is not immune: in 1985 a magnitude 4 quake, centered just north of the city in Westchester County, woke up people throughout the area. Although it didn't do much else, it was an unsettling reminder. The fault that triggered it is one of a family of intersecting faults, some of which extend directly under Manhattan; among them are faults under 125th Street and 145th Street, as well as several under the East River. "For years now I've been beating the drum that seismicity isn't dead around New York," says geologist Charles Merguerian of Hofstra University, who has trekked into subway and water tunnels to map the city's hidden faults. "The mechanism may be different from the one in California, but it warrants concern."

All told, since the late seventeenth century eastern North America has had 16 earthquakes larger than magnitude 6 and several hundred larger than magnitude 4. (Each step up in magnitude increases an earthquake's strength by ten times, so magnitude 6 is 100 times stronger than magnitude 4.) Although Charlevoix and New Madrid are now the most seismically active areas—they feel minor tremors on a regular basis—quakes have occurred in many other parts of the East. The past century happens to have been comparatively quiet, which is why there is a lack of public concern.

Historically, even geologists have neglected eastern earthquakes, partly because they're much less frequent than western ones and partly because they're harder to understand. In a way the advent of plate-tectonic theory in the 1960s simply made them more puzzling. Once it was realized that Earth's outer shell is broken into a dozen or so plates that slide over the hot mantle, it became perfectly clear

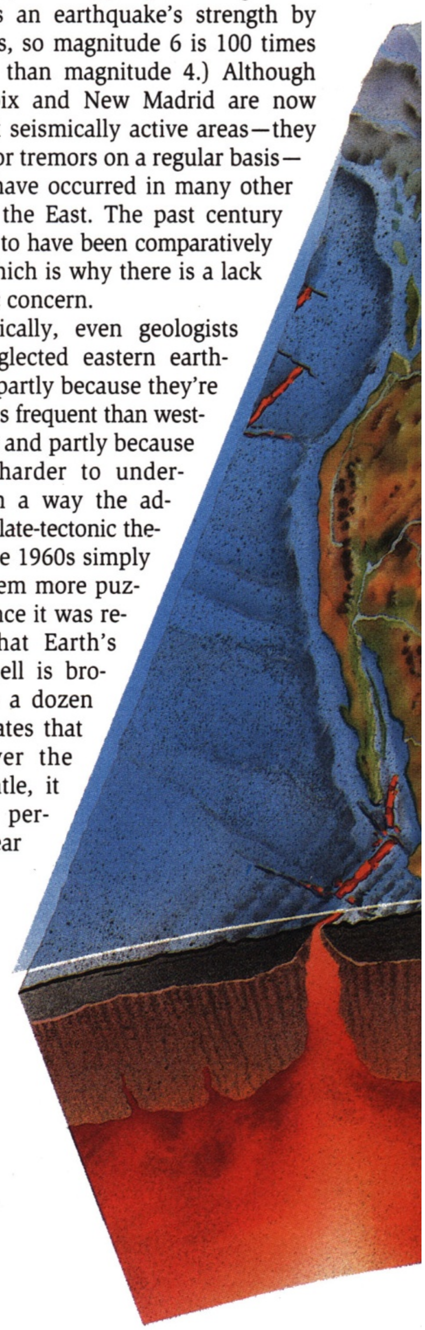
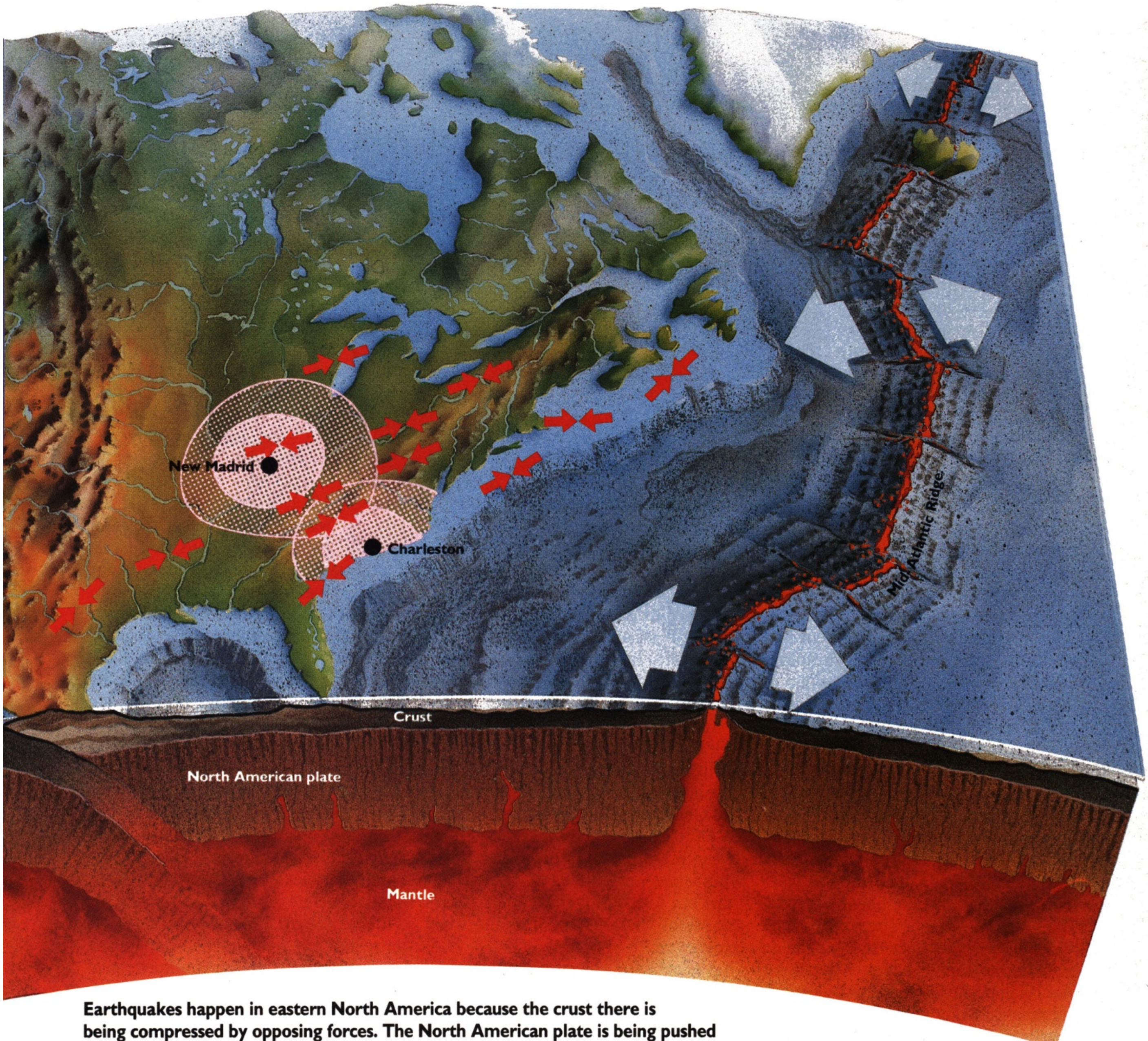


ILLUSTRATION BY IAN WORPOLE

why earthquakes occur at plate boundaries: that's where the plates rub past each other or ram into each other. The middles of the continental plates, on the other hand, are far from this jostling, and for the most part they have been coherent, unbroken rock for at least 2 billion years.

Earthquakes happen nonetheless in the middle of plates because the plates are not perfectly rigid. They are under a lot of stress, and as a result they deform, not just at their boundaries but in the center as well. Geologists can measure the long-term effects of this stress; one method involves examining oil-well boreholes to see how much and in what direction the circular hole has been squeezed out of shape. This past year Mary Lou Zoback of the U.S. Geological Survey and her husband, Mark Zoback of Stanford, assisted by many collaborators, assembled a global map of such measurements. The map shows



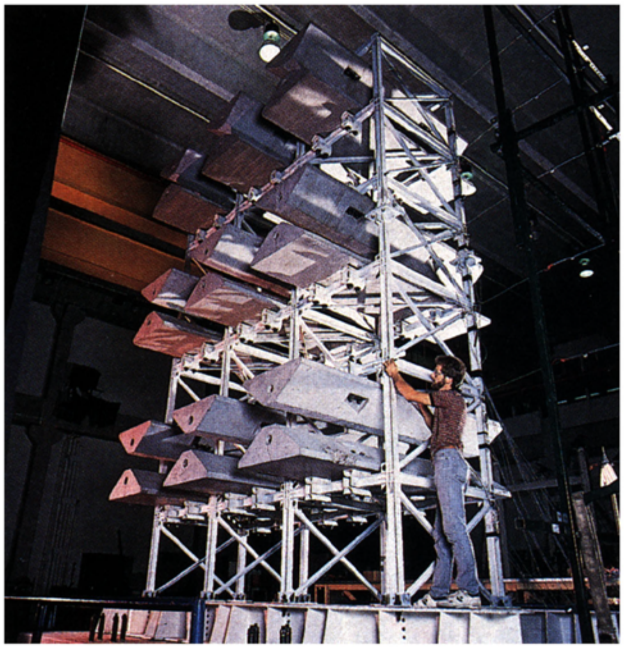
Earthquakes happen in eastern North America because the crust there is being compressed by opposing forces. The North American plate is being pushed toward the west-southwest by hot rock welling up from the mantle along the Mid-Atlantic Ridge, while Europe and Africa are pushed to the east-northeast. (A similar ridge in the Pacific is pushing ocean floor under Mexico.) The motion of the plate is resisted, however, by drag exerted by the underlying mantle. The resultant compressional stress (red arrows) was released in huge earthquakes at New Madrid, Missouri, in 1811 and Charleston, South Carolina, in 1886. Both quakes did serious damage over enormous areas (dark pink) and moderate damage (light pink) over still larger ones.

that eastern North America is being compressed along an axis that runs east-northeast to west-southwest. That, as it happens, is roughly the direction North America is moving over the mantle.

North America is being pushed by the ridge that runs down the middle of the Atlantic. The ridge is a spreading center: it marks the boundary along which the European and North American plates are spreading apart. As the plates spread, the hot, liquid rock of the mantle oozes up into the gap and congeals to form new ocean crust. The force of the upwelling helps push the plate away from the ridge, toward the west-southwest. But the plate doesn't glide along like an air-hockey puck. Its motion is thought to be resisted by drag exerted by the underlying mantle. The two opposite forces may well account for the compressional stress in eastern North America.

Knowing where the stress comes from, however, doesn't tell you where it is going to be released. And for a long time the geographic distribution of earthquakes in eastern North America has appeared to be more or less random. Recently, though, Arch Johnston and Lisa Kanter, two geophysicists at Memphis State University (not far from New Madrid), discovered an intriguing pattern to midplate quakes. After plotting the locations of more than 800 such quakes around the world, Johnston and Kanter found that most of them occurred in just two kinds of geologic settings.

The first can be found in the coast of continents that were once ripped apart to form a new ocean. For example, 200 million years ago the Atlantic didn't exist; Europe and North America were joined in the supercontinent Pangaea. Then Pangaea began to stretch thin along a long line—either because it was being pulled apart from its edges or because it was being pushed from below by upwelling magma. Eventually it was torn completely in two, and the rift became the Mid-Atlantic Ridge. The continental margins of North America and Europe are the old edges of the rift, now separated by an ocean. They are regions of weak, thin, and cracked crust. The Charleston quake occurred in such crust; so did a magnitude 6 quake that shook Cape Ann, near Boston, in 1755.



Engineers at the State University of New York at Buffalo test quake-dampers on a six-story model.

PHOTOGRAPH COURTESY NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH, STATE UNIVERSITY OF NEW YORK AT BUFFALO

The other typical setting for a midplate quake, according to Johnston and Kanter, is along lines where the crust began thinning out into a midocean ridge but for some reason stopped. These failed rifts are also regions of weakened crust. A failed rift lies under the St. Lawrence River, near Charlevoix. A large failed rift called the Reelfoot Rift runs right under the Mississippi River, from southern Arkansas past New Madrid and into southern Illinois.

Together continental margins and failed rifts make up only a quarter of Earth's stable continental crust, but they account for nearly half its moderate quakes (between magnitudes 4.5 and 6), 60 percent of the serious ones (between magnitudes 6 and 7), and all the ones above magnitude 7. "We didn't start out to look for this pattern," says Johnston. "It just fell out as the study progressed."

A geographic pattern to past quakes, however, is still no basis for forecasting future ones. In California, geologists can sometimes forecast the likelihood of a quake occurring at a certain place within a certain time because they have only to look at the ground to find an active fault. When an earthquake happens along the fault, the ground on one side is offset in relation to the other, and each succeeding earthquake exaggerates the offset. Ground that was once flat now has hills and valleys; roads and streams and long outcroppings of rock have jags in their paths.

"In places along the San Andreas," says Mark Zoback, "you find the other half of a rock outcrop a couple of hundred miles away." By dating each jag, geologists can estimate how often and at what intervals earthquakes recur on that fault, and thus get a rough idea of when the next one should be expected.

In the East this method generally doesn't work. For reasons no one knows, eastern faults generally do not break the surface. (The most notable exception to this rule in the United States is the Meers Fault, a wall between 9 and 15 feet high that runs for 18 miles across southwestern Oklahoma.) And no fault has generated the changes in topography—the jags and hills and valleys—that repeated earthquakes should cause. If the 1811 earthquake at New Madrid was a repeat of earlier earthquakes, says Johnston, "we ought to have a lot of topography here that we just don't have."

Within only the past two years have Johnston's colleagues Eugene Schweig and Ronald Marple discovered a subtle topographic feature near New Madrid that may be the surface expression of a deep-seated earthquake-generating fault. Called the Bootheel Lineament, it's a 50-mile-long, 30-to-60-foot-wide linear depression, filled with sand in many parts, that is nowhere more than two feet deep. Marple first noticed it on aerial and satellite images.

It's not clear why faults in the East don't generate more visible topography. Perhaps they move back and forth, so offsets in any one direction don't accumulate. Or perhaps, as Armbruster suggests, the crust is so thick and strong that faults can't move too much, and "if an earthquake moves a fault once, the next earthquake will have to go somewhere else."

"It's a tough question for midplate earthquakes," says Johnston, "maybe *the* question. We not only don't have a good handle on the repeat time of major quakes, we don't even know whether they repeat at all."

To get around this problem, Mark Zoback and his colleague Paul Segall are trying to develop a new approach to prediction that does not require geologists to study faults. The Global Positioning System, a network of radio-emitting satellites that the Department of Defense is deploying as a navigation aid, also makes it possible to measure minute deformations of the crust—the deformations move the radio receivers—as they happen, inch by inch.

In principle the system should make it possible to measure directly which areas of the crust are being squeezed together rapidly and are thus accumulating dangerous levels of stress. Zoback and Segall plan to test the idea around Charleston and New Madrid, on the assumption that those areas are still feeling a strong squeeze. Then they'll look for similar rates of stress accumulation elsewhere in the East in hopes of identifying other quake-prone areas.

But this sort of prediction, if it ever works, is still in the future. For now the only approach to predicting earthquakes in the East is statistical: researchers look at the number and magnitude of earthquakes a given area has had in the recent past and then extrapolate into the future. New Madrid, for example, has been estimated to have earthquakes of magnitude 4 every year or two, magnitude 5 every 10 to 20 years, magnitude 6 every 70 to 100 years, and magnitude 8 every 500 to 1,000 years.

"If you look where quakes have occurred recently, you may be looking in the wrong places. Maybe the next big one will occur in the place that's been quietest."

Using the same method, Armbruster and Klaus Jacob of Lamont-Doherty have estimated that New York City should have a magnitude 5 earthquake every 100 years and a magnitude 6 every several hundred to 1,000 years. But even the researchers themselves don't put much stock in their estimate. "It's the best we've got," says Armbruster, "but that doesn't say much for it."

One obvious flaw in the statistical approach to prediction is that it ignores the quiet places, the ones that don't even have little earthquakes at the moment—the wild cards, as Armbruster calls them. Charleston, for example, was seismically quiet for years before 1886. (In looking through the local newspapers for the 80 years before the disaster, Armbruster found no reports of tremors. "Would I have known to get out of town?" he asks. "I wouldn't.") It has been quiet again for the past century. The Boston area was quite active throughout the eighteenth and nineteenth centuries but is now much quieter. The Meers Fault in Oklahoma, which had a magnitude 7 or 8 quake 1,200 years ago, was quiet for millions of years before that and has been quiet since.

In the East, it seems, quiet periods can mean anything: a lull after the previous earthquake or the quiet before the storm of the next one or a truly earthquake-free zone. "It's impossible to say whether quiet periods are ominous or not," says Zoback. "The real enigma of eastern earthquakes is that faults turn on, produce earthquakes rapidly, then turn off and are quiescent for hundreds of thousands or millions of years. That's scary." Says Armbruster: "I kind of like the view that if you look where quakes have occurred recently, you may be looking in all the wrong places. Maybe the next big one will occur in the place that's been quietest for the longest period."

One thing that is certain is that a big one anywhere in the East will be felt over an enormous area. For an earthquake of a given strength in California, an earthquake of the same strength in the East will reach an area 100 times larger. In the West seismic waves bounce around in the shattered, faulted rock and die out before they get far. But in the comparatively solid rock of the East, where faults are much fewer and smaller, the waves move easily over long distances. A large quake under Boston, for instance, would hit New York hard, too, not to mention all the smaller cities in between.

It makes sense, then, to try to esti-

A strong earthquake can force up geysers of water-saturated sand. This resultant crater, or "sand blow," was photographed shortly after the 1886 Charleston quake.

PHOTOGRAPHS COURTESY J. K. HILLERS, U.S. GEOLOGICAL SURVEY mate the odds of a large earthquake taking place anywhere in the East rather than just in specific locations. Such estimates are tentative at best. But earlier this year, addressing an audience of insurance executives, Jacob hazarded his best guess: there is a 61 percent chance, he said, that a magnitude 6 quake will take place somewhere east of the Rockies in the next 20 years; and there is a 10 percent chance of a magnitude 7 quake—roughly equivalent to the one that leveled Charleston.

Like eastern North America, Newcastle, Australia, lies in the middle of a plate, and in December it was struck by a 5.5 quake. Magnitude 5.5 is only a moderate earthquake. But this one killed 12 people, injured 200, and caused $1.5 billion in damage. Much of the damage was due to the failure of unreinforced masonry. Buildings that have metal skeletons or are made of wood tend to flex during an earthquake, but unreinforced masonry—bricks and mortar, concrete, cinder block—snaps like chalk or simply disintegrates. In New York City, half the one-, two-, and three-story buildings are unreinforced masonry; around 70 percent of the four-, five-, and six-story buildings are. That is typical of the East.

In fact, most buildings in the East are built not only with the wrong material but with the wrong design to withstand earthquakes. They are designed to hold up against the force of gravity, to take what engineers call a vertical load; and for this, roofs, floors, and foundations need not be tightly connected to walls. Earthquakes, however, exert a lateral load: they push a building from side to side. Skyscrapers of 20 stories or more usually have steel skeletons designed to withstand the lateral loads of wind, so they are somewhat protected against earthquakes too. But most other eastern buildings are not, and in an earthquake their verticals and horizontals simply separate. The floors above are deposited on the floors below. Engineers call it pancaking.

Several other eastern cities besides Charleston have commissioned studies estimating what would happen if the largest historic quake for that area were to recur today. In the six cities that have grown up around New Madrid, according to the worst-case scenario, nearly 5,000 people would die, many of them schoolchildren herded together in buildings of unreinforced masonry. The total damage in those six cities alone would be $52 billion. (A magnitude 8 quake in New Madrid, of course, would damage a much wider area.) A recurrence of the 1755 Cape Ann earthquake, magnitude 6 or so, would cause 360 deaths in the Boston area, 12,000 injuries, and perhaps $6 billion in damages. New York City's worst likely earthquake is also thought to be a magnitude 6; the number of deaths has not been estimated, but the damage to buildings has been put at $8 billion from shaking alone—that is, not counting the destruction wreaked by fires springing from ruptured gas lines.

In the long run, the way to avoid such disasters is to change the way buildings are built. Engineers know how to keep buildings from falling during most quakes. Even during the extremely damaging earthquakes in San Fernando in 1971 and in Mexico City in 1985, modern buildings with seismic designs stayed up and protected their occupants. A few states and cities in the East—including Massachusetts, Connecticut, Charleston, and Memphis—have already adopted codes requiring varying degrees of earthquake protection. Most have not.

Moreover, building codes would apply only to new construction. To guard against disaster in the short run, one would have to retrofit old buildings—strengthening them by anchoring the walls to the foundation, running rods across them to hold them together, and generally beefing up all the connections. Indeed, the Historic Charleston Foundation, which looks after the country's oldest historic district, is considering retrofitting its buildings against both earthquakes and—since Charleston seems prone to natural disasters—hurricanes. But in general the idea of governments requiring all buildings to be retrofitted is probably unthinkable—at least until a major disaster strikes.

And one almost certainly will strike, although geologists can't say where or when. "We've had two major earthquakes since the beginning of the 1800s," says Armbruster. "We haven't had a major one in this century yet, so maybe history will average and we'll have a major quake every hundred years. If you're considering any one site, maybe you're not worried. But if you're considering the East as a whole, then you're worried." ❑

Few buildings in Charleston survived the 1886 quake undamaged.

Ann Finkbeiner is writing a book on caring for people with AIDS.

PHILADELPHIA DAILY NEWS
THE PEOPLE PAPER
THURSDAY
OCTOBER 19, 1989

City Might Be Dirty, but It's Solid Dirt

By Ramona Smith

Daily News Staff Writer

What are the chances of a great quake in the Quaker City?

Not very great, say experts who have studied the seismic activity on the East Coast.

Over the years, the Philadelphia area has had its share of geologic shakeups. The shocks were enough to light up police switchboards in April 1984, rattle dishes in the city three times in 1982 and 1983, and set off a series of aftershocks in the Northeast in March 1980.

But the occasional shaking in the Delaware Valley has amounted to mere quivers when measured against the deadly destruction Tuesday in California.

"I wouldn't envision a ... 6.9 earthquake here," said Charles Merguerian, a structural geologist from Hofstra University in Hempstead, N.Y., who has studied the likelihood of East Coast quakes.

Then — like other Eastern earthquake experts — he hedged his bets.

"But it can happen," Merguerian said.

When the earth trembles in the Philadelphia area, the cause may lie in the neighborhood or far away.

Earthquakes in Charleston, S.C., in 1866, near Boston in 1755, and in northern New Jersey and southern New York state more recently have sent shock waves into eastern Pennsylvania.

Most local earth-shaking centers on geologic fault lines — breaks in the deep rock layer — that lie in the city's northern suburbs and along the Delaware River.

Most recent quakes have been below 3.7 on the Richter scale, and have clustered primarily along the Huntingdon Valley fault, which runs from the Delaware River below Trenton to Conshohocken, Montgomery County, crossing corners of Northeast Philadelphia and Chestnut Hill. This week's quake in San Francisco measured 6.9.

Unlike California, the Delaware Valley does not lie on the clashing edges of two vast geologic plates, says Stephen Phipps, a geology professor at the University of Pennsylvania. The nearest edges lie thousands of miles to the east in the Atlantic Ocean and thousands of miles to the west at the San Andreas fault, the source of this week's quake in San Francisco.

In active faults, great segments of rock move and press against one another with destructive force. But here, says Phipps, the faults are mere remnants of ancient geologic struggles.

Still, he said, there's a chance Eastern faults may be "potential targets for reactivation." Some geologists believe that recent tremors near Lancaster may stem from a reactivated fault.

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NEW YORK POST

THURSDAY, OCTOBER 19, 1989

WHAT IF? FEAR OF QUAKE GIVES N.Y. THE SHAKES

By MARY PAPENFUSS, ANNE E. MURRAY, DON BRODERICK, CHRIS OLERT, RICHARD STEIER and GRETCHEN LANG

New Yorkers are in for a shock — it *could* happen here.

If it does, the disaster could make the San Francisco tragedy look like a cake walk, experts say.

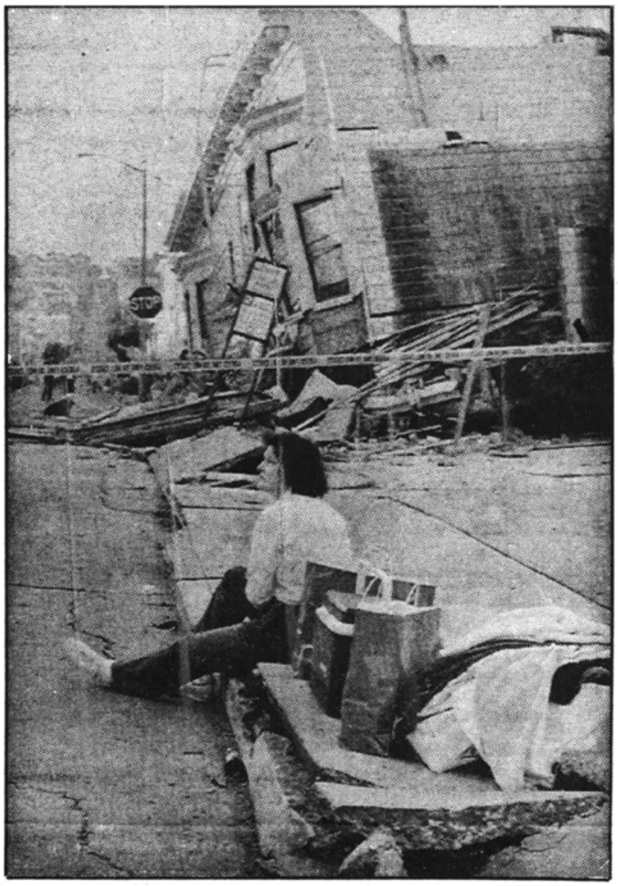
"I hate to think what would happen if we had a major earthquake here. The city is absolutely unprepared for it," quake expert Dr. Charles Merguerian told The Post yesterday.

That possibility is not so remote, according to Merguerian, a geology professor at Hofstra University in Hempstead, L.I.

The city is being "squeezed in a vise" between major faults to the east and west, he cautioned.

"Whether that stress goes in small tremors or in one big earthquake is hard to say," he said.

City officials are trying to prepare, persuaded to take action after the Armenian earthquake. They're drafting a plan coordinating 15 agencies to deal with multiple fires, water shortages, emergency shelter, gas line explosions and hospital mobilization.



Associated Press

HOMELESS: *A woman whose home was destroyed by the quake sits on the sidewalk with the few items she's managed to salvage.*

But there's no plan to deal with collapsed bridges.

So far, the only key portion of the plan in place is a two-story command post on the eighth floor of police headquarters in lower Manhattan — a building plagued by structural problems.

Capt. Eugene Guerin, executive officer of the city's Office of Emergency Management, said yesterday that the city's buildings commissioner gave him his personal assurance that the building could withstand an earthquake.

"We have a lot of emergency . . . equipment, and for better or worse, this is our command post," he said.

Buildings Commissioner Charles Smith said structures here already are "designed in such a way that we feel they would resist a significant tremor."

Still, he plans to propose building codes making future structures more earthquake resistant.

Dr. T.T. Soong of the National Center for Earthquake Engineering Research at the State University of New York in Buffalo, which studied city buildings said:

"It's obvious a large percentage of the city's structures could not withstand a quake. If an earthquake the size of San Francisco's happened here, it would be a much, much bigger disaster."

Three faults cross the city — 125th Street through the East River, Inwood in upper Manhattan and into The Bronx and the third farther north in The Bronx.

After studying subway and water tunnel construction two years ago, Merguerian discovered new faults crossing the others, creating an ominous gridwork of fissures.

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Daily News Magazine
NEW YORK • JANUARY 8, 1989
RATTLER
When The Great Quake Comes

FUTURE SHOCK

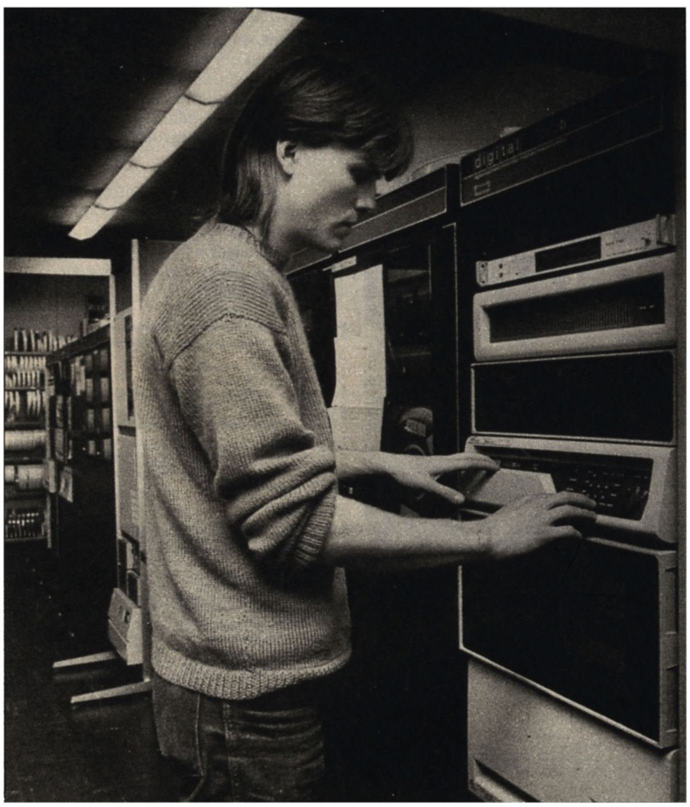
It's "inevitable" a major quake will strike the East, and New York's one of four cities on the hit list.

By DICK SHERIDAN

THE SCENES PLAYED out last month on New York TV sets were hardly holiday fare. No miracles on 34th Street in Stipak. Few wonderful lives in Yerevan. On Dec. 7, the towns and cities of the mountainous land of Armenia were laid flat by a killer quake.

As New Yorkers prayed for the tens of thousands dead and joined a worldwide aid effort for the hundreds of thousands injured and homeless, few envisioned their bedrock-steady city meeting a similar fate.

But only two months earlier, U.S. quake specialists had met in Washington with government and private-sector disaster planners to discuss "The Catastrophic Earthquake: The Federal Response to the Inevitable Eastern Earthquake." They had heard Robert Ketter, director of the National Center for Earthquake Engineering Research (NCEER) at the State University of New York in Buffalo, warn that New York was one of four eastern cities on the likely hit list of a major quake—magnitude 7 or higher on the Richter scale—"almost certain" to strike the eastern United States by the year 2010. The probabilities, according to Ketter, were "75% to 95% that an earthquake will occur somewhere in the eastern United States before the year 2000. Before the year 2010, the numbers are nearly 100%."



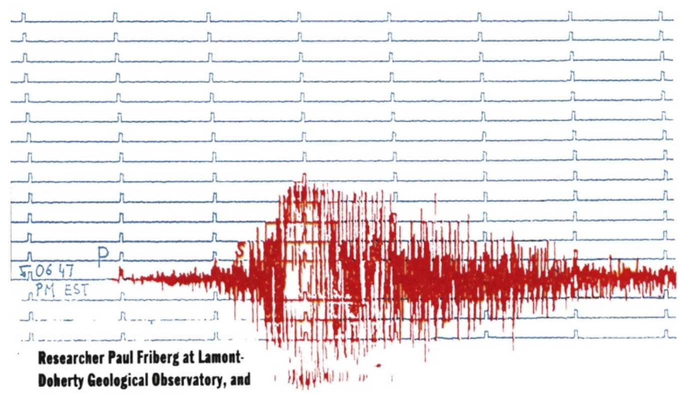
Indeed, on Nov. 25, shock waves from a massive quake did rumble through the city. Shortly after 7 p.m., with shoppers and tourists and homebound workers jamming subways and highways, bridges and tunnels, New York's storied bedrock rattled. Tremors shook the gneiss and schist rock that millions of years ago had been laid down to become the footing to the present-day towers of the city. In Queens, the geologically younger Ice Age sediment quivered.

Within seconds, the city settled back into rock-solid routine. No reported injuries, no real damage.

Most New Yorkers hadn't even noticed. But seismologists in Canada and the U.S. had: 6.0 on the Richter scale. In Ottawa, Peter Basham, chief of seismology and geomagnetism at his nation's Geological Survey, said the temblor had struck at 6:46 p.m., about 12 miles below the evergreen forests of central Quebec Province, near the small mill and lumbering town of Chicoutimi. It was "the largest earthquake to hit eastern North America since a magnitude 6.2 quake near Timiskiming in western Quebec" 53 years ago. Basham calls the likelihood of a major, destructive quake striking the East "a perfectly reasonable one, based on the fact that we haven't had a magnitude 7 event since 1929"—when an offshore quake struck the Grand Banks, off Nova Scotia—"and the kind of activity we've had this century."

A spokesman at the National Earthquake Information Center in Lakewood, Colo., confirms Chicoutimi's power. "Quakes registering 6 could cause considerable loss of life and property damage in a heavily populated area," he says. And at the U.S. Geological Survey's (USGS) eastern headquarters in Reston, Va., Randall Updike, deputy chief of the Office of Earthquakes, Volcanoes and Engineering, says it was not merely the quake's power that had caused it to be felt from Canada's eastern seaboard as far west as Detroit and south to Washington. "The rocks in the East are much older, more brittle than those in the West," he notes. "They ring like a bell when struck."

Though no deaths were reported and damage was "minimal," scientists along the East Coast are concerned: Chicoutimi gives added proof that large



Researcher Paul Friberg at Lamont-Doherty Geological Observatory, and (above) graph of Nov. 25 quake.

quakes can happen in the normally tranquil eastern half of North America – even the New York City area. Cautions one quake watcher: The Nov. 25 temblor was "a very timely warning . . . We should certainly be doing something about it."

"Nobody is predicting a particular quake at any particular place or time," stresses Ketter. "What we are saying is that a major earthquake will strike." And New York is a possible victim of this "inevitable" quake (along with Memphis Tenn., and Charleston, S.C., scenes of past destructive temblors), he adds, because the city lies at the southern end of a proven earthquake-prone arc that runs up the coast through Boston, another likely target, to the Grand Banks – the site of the '29 jolt.

"Earthquakes certainly can and do occur in southern New York State, in the vicinity of the city," concurs Dr. Klaus Jacob, a senior research scientist with Columbia University's Lamont-Doherty Geological Observatory in Palisades, N.Y. "Large quakes apparently occur here at intervals of something like 50 to 100 or 200 years."

But tremors strong enough to topple chimneys occurred in the city in 1737 and 1783 – before any accurate records of such events were kept – and in 1884 (see page 12). "The '84 quake was the most severe we know about," says Jacob. "It did limited damage, but could do considerably more harm were it to recur today – perhaps as much as $7 billion." (On Oct. 19, 1985, the latest news-making quake, a magnitude 4 shiver, spilled morning coffee when it rumbled through the Westchester community of Ardsley, 20 miles north of the city. The Ardsley tremor, by one account, was the 16th of magnitude 3.5 or more to hit since colonial times.)

The infrequency of quakes in New York and elsewhere in the East make them difficult to study, Jacob and others say. Explains USGS' Updike: "The data set here is so small that it's difficult to make any kind of real estimate of when or where an earthquake is likely to occur. . . . You have no repeat times on which to base a prediction. For example, we know a major quake hit Charleston, S.C., in 1886. However, we don't know whether that kind of event is likely to repeat every 100 years, every 150 years, or every 200 years."

A lack of knowledge of eastern U.S. faults – cracks in the rock – also hampers studies here, Updike says. "Out West, an airline pilot can look down and see faults. Here, they're buried underground – beneath trees, pavement, buildings – and people." Yet faults are the stuff of earthquakes. These shakers occur when the underlying rock – the lithosphere, a brittle, 60-mile-thick shell that forms

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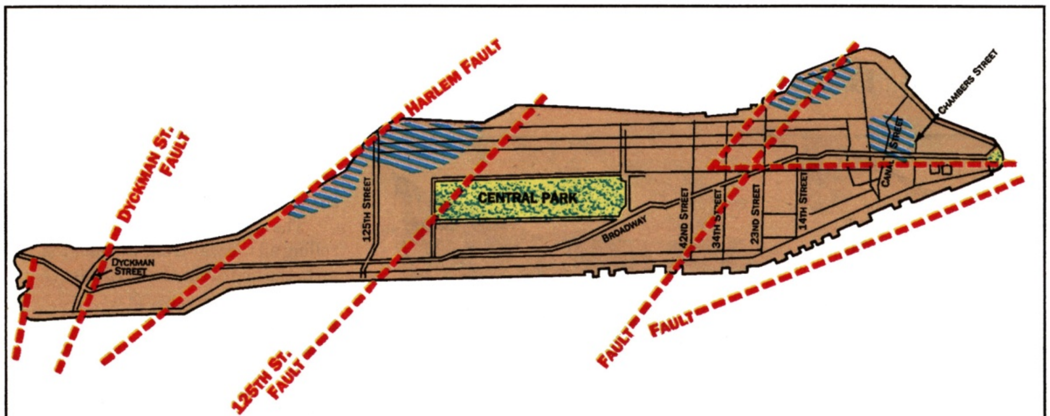
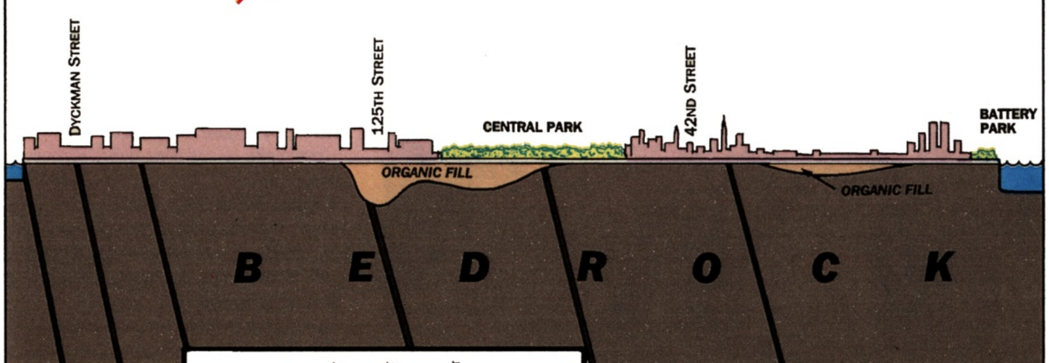
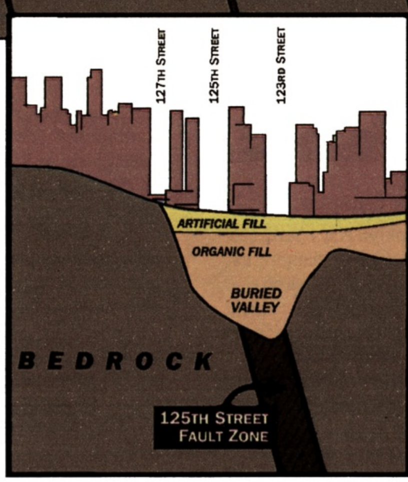
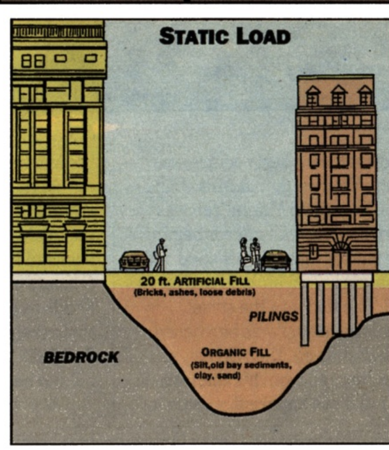


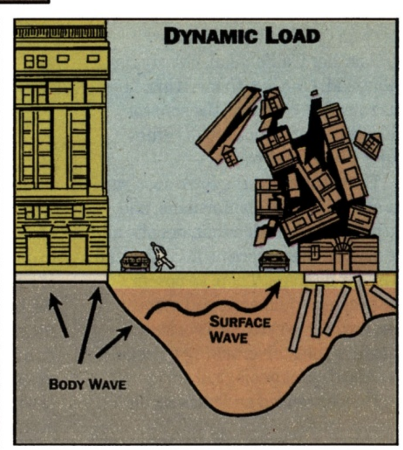


Left: Manhattan's skyline, with tallest towers seated on bedrock and lower buildings on pockets of organic and man-made fill that could spell disaster in a quake. Former marshes (blue areas) and faults, cracks in the rock, running beneath some of island's major cross-streets are also troubling. Particularly worrisome is the deep layer of fill (below left) that overlays 125th Street Fault.

Below: Static load (center) shows buildings at rest on bedrock and on pilings driven into soft fill. As quake strikes (right), shaking sets off initial body waves that ripple through rock and below pilings. When waves hit fill, they amplify into surface waves, liquefying soil and further endangering pilings.







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ILLUSTRATIONS BY RODRICK EYER/DAILY NEWS
SOURCE: JOHN SANDERS, PROFESSOR OF GEOLOGY/COLUMBIA UNIVERSITY

from page 11

the Earth's outer crust—breaks or moves. The shell itself is composed of a dozen or more pieces called "tectonic plates" that are continually colliding with or sliding past each other. Because the sliding and colliding builds up tremendous pressure, quakes most frequently occur on or near the edges of the plates, where the pressure is greatest and faults are most liable to form.

Last month's Armenian temblor, for example, took place along the boundary of the Eurasian plate, in a region made volatile by pressure from the African and Arabian plates. The eons-long tectonic collisions of these plates have raised the Caucasus Mountains and dotted history with recurring destruction. An even worse record has been piled up by the 24,000-mile-long Pacific plate boundary—the site of nearly half the world's great quakes. California sits astride this zone—with its infamous San Andreas and related faults forming the boundary between the northward-moving Pacific plate and the westward-moving North American plate.

So far, the U.S. has been spared truly catastrophic temblors. Only three quakes have caused more than 100 deaths—the highest toll, 452, occurred in the 1906 San Francisco quake—and areas away from plate boundaries (New York lies near the center of the North American plate) are considered relatively inactive. However, the strongest U.S. quake, or series of quakes, shook not California but the heart of the continent. Between December 1811 and February 1812, three huge tremors rumbled along the Missouri-Tennessee border near current-day Memphis. Known as the New Madrid quake—for the Missouri town nearest the epicenter—they caused little human misery because at the time the area was only sparsely populated. But they set church bells ringing in Boston, 1,000 miles away, and changed the course of the mighty Father of Waters. Were they to recur now, experts say, present-day Memphis and five nearby cities could suffer thousands of deaths and crippling devastation.

The Mississippi Valley is not the only focus of concern for seismologists, however. Dr. Charles Merguerian, a professor of structural geology at Hofstra University in Hempstead, L.I., has studied the faults underlying New England and mapped those beneath New York City. His work has shown two major sets of faults under New York. One set trends northeasterly, the other northwesterly under Manhattan—beneath 155th, 125th, 96th and 14th Streets. The sets intersect in a crude checker-board pattern. Says Merguerian, "Where two sets of faults intersect, they form structures that are likely to move under stress." And, he notes, the North American plate is being stressed—pushed from the east by seafloor spreading in the mid-Atlantic Ocean at the same time that it's grating up against the Pacific plate on the west. "The real scary thing is that while there is a lot of movement, we don't have many earthquakes," which could act as small, nonlethal releases of energy. Instead, says Merguerian, "the strain on the plate is locked in; it builds up. So, you can't rule out a major quake in New York."

But it might not take a major trembler to stagger New York. Destructiveness isn't determined solely by size, experts say, but also by time of occurrence, building practices, soil conditions and population density. The city certainly has people enough and, perhaps, the right mix of older, nonquake-resistant buildings and soft soils that could stir up a disaster and bring death to hundreds, or even thousands, of New Yorkers.

No estimates of possible casualties from a major New York quake have been drawn up. The single existing study performed on the likely impact of a quake here was a 1987 preliminary report commissioned by NCEER. That study merely evaluated the potential building-stock damage that a quake of magnitude 6 would inflict on the city. Its conclusion: A New York-area quake—of the same magnitude as the Nov. 25 Chicoutimi shocker—would be "a disaster unparalleled in New York's history."

According to Charles Scawthorn, chief author of that report and vice president of research and development for San Francisco-based EQE, the largest U.S. engineering consultant firm specializing in earthquake design and damage mitigation, the study examined what would be likely to happen to New York's 800,000-odd buildings if the temblor hit 17 miles southeast of City Hall, off the Rockaways at about the same location as the quake of 1884. In such a case, says Scawthorn, "we found that New York's building stock would sustain roughly $11.2 billion in damage—about 2.8% of a total estimated value of nearly $404 billion in all five boroughs." At 11 miles from City Hall, somewhere around the Rockaway Inlet, Scawthorn's study found that the same quake would cause $18 billion in structural damage, or about 4.5% of its total value; and at five miles from City Hall, in the Prospect Park section of Brooklyn, the damage total would soar to $25.9 billion, or about 6.4%.

The destruction would be highest in sections of the city closest to the quake's epicenter—in these three instances, around Jamaica Bay, in southern and southwestern Brooklyn and in lower Manhattan. And in all three scenarios set up by the study, all kinds of building construction—wood, steel-frame, reinforced concrete, reinforced masonry and unreinforced masonry—would fall prey, in varying degrees, to the quake's shaking. The hardest-hit structures would not be New York's famed towers, but rather its numerous old brownstones and rowhouses, its unreinforced masonry structures, says Scawthorn.

"However," he notes, "we did not look at possible tall-building resonance," the swaying effect that proved disastrous in the 1985 Mexico City quake when about 200 mid- to high-rise buildings toppled and 10,000 died.

Where a New Yorker lives and works might determine his chances for survival during a large quake, since all areas of the city do not share the same grounding in bedrock. Softer soils in some of the boroughs may increase the vibrations of the shaking caused by an earthquake, says Lamont-Doherty's Jacob. "A good portion of Manhattan and the Bronx – the higher areas in particular – are all right, geologically speaking," the earth scientist says. "But large sections of Queens and Brooklyn are on glacial sediments that are either Ice Age end moraines – the area along the Interboro Parkway in Brooklyn is an example – or coastal-plain sediments laid down at a period when the ocean covered part of the land – such as Flushing Meadows where Shea Stadium now sits. I wouldn't want to be at a ballgame during an earthquake. In a quake, such unconsolidated sediment could be subject to site amplification, what we call the 'Jell-O pudding effect.' "

That same effect could give some large housing projects a bad case of the jitters as well – even in Manhattan. "You just have to drive along the East River Drive," notes Jacob. "Those projects in East Harlem, for instance, were built on stuff nobody else wanted. Landfill, reclaimed land, the kind of low-lying area that during the time of the Dutch was marshland. That's very poor building ground." Battery Park City and the World Trade Center are among other Manhattan sites that might be on very shaky ground, he adds.

And the timing of a quake also might influence New Yorkers' chances of survival. Were a quake to hit during rush hour, when the city's overworked, undermaintained roadways, bridges and tunnels are packed with commuters, "unsound seismic engineering" might put this infrastructure to a severe stress test, according to Hofstra's Merguerian. For example, he says, New York's tunnels aren't totally rooted in bedrock, but sit in mud "that could liquefy during a quake, and it would flow. The tunnels would be left without support" while above water, some city bridges "aren't seated in the same material at both ends. Dissimilar materials may react differently in an earthquake, putting severe stress on the structures."

Both Jacob and Merguerian emphasize, however, that these scenarios are largely educated guesses – based on their professional knowledge and experience – and not specific scientific analyses, which they urge should be carried out. Meanwhile, city officials and others point out that no hard evidence yet indicates that New York faces any imminent threat from a killer quake. Building experts say that New York's high-rise buildings are designed to withstand extremely strong hurricane wind loads, which should help them resist the shaking of an earthquake. And George Zandalasini, deputy director for bridges at the city Transportation Department's division of highway engineering, says that New Yorkers "shouldn't get excited about our vulnerability. Though earthquake force is not the controlling factor in structure design here, we do conform to the standards for forces that this region can reasonably expect to face."

NCEER's Ketter, for one, has heard such reasoning before. Local authorities, he says, are slow to react to the warning signals. "The eastern United States – including New York – has no planning, no building codes, no zoning ordinances that take earthquakes into account," Ketter says. "We don't provide any education in schools to tell children how to cope, we don't teach businesses how to stay in business, we don't train hospital emergency units on what to do with patients in an earthquake. Weeks after the Thanksgiving weekend quake, we are still getting calls from hospitals about what they should have done to care for cardiac patients during that quake.

"The major problem regarding earthquakes in the eastern United States is a lack of awareness that there is a problem." ■

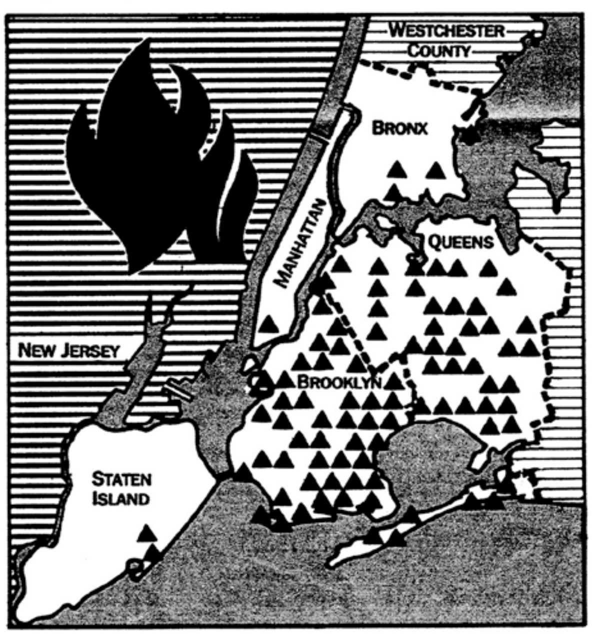
Dick Sheridan is assistant editor of The Magazine.

RIDING OUT A QUAKE

What do to in those seconds an earthquake lasts? Some experts advise:

- "I'd like to be out in the open, away from structures liable to collapse or have things fall off." – *Charles Scawthorn, structural engineer*
- "I'd prefer to ride out a quake either in a wooden building of less than three stories or a newer building 15 stories or higher. These would be the safest. Don't run outside, because the first things that come down in a quake are architectural ornamentation as well as chimneys and water towers that many older buildings have. . . . Inside a building, I'd tell people to stay away from large plate-glass windows. The safest place might be a doorway in an older building. Doorways were solidly built in the old days. Stay away from top-heavy things like appliances or bulky equipment liable to topple." – *Robert Ketter, director of the National Center for Earthquake Engineering Research*

AFTERMATH: Post-quake fires, caused by snapped power lines and gas-main ruptures, are an urban quake hazard. A 1987 study of a potential New York quake off the Rockaways shows 130 fires could be expected in the five boroughs, mostly in Brooklyn and Queens. Map shows possible sites.



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DAILY NEWS

50¢ Sunday, November 27, 1988 NYDailyNews.com

Earth could move again

Northeast quake peril

By JOEL SIEGEL
Daily News Staff Writer

The East Coast earthquake may have startled millions Friday night, but it didn't faze the experts. These things have happened before, seismologists said yesterday, and they undoubtedly will happen again.

And next time, they warned, the damage could be far, far worse.

Friday's quake, centered 90 miles north of Quebec City, Canada, measured 6.0 on the Richter scale, making it the most powerful Eastern earthquake in decades.

It rocked the United States from Maine to Wisconsin to Washington, D.C. New Yorkers were among those shaken.

"It's important that the public and government ... appreciate the fact of reasonable-size earthquakes in the Northeast and the potential of damage," David Simpson, of Columbia University's Lamont-Doherty Geological Observatory, said yesterday.

The most severe quake centered in metropolitan New York occurred in 1884, toppling bricks and cracking plaster from Hartford, Conn., to Pennsylvania. It measured 5.0 on the Richter scale.

Dr. Charles Merguerian, a Hofstra University professor who has studied geologic faults beneath New York City, thinks serious damage could result if a quake like Friday's was centered here.

"The tunnels (under the East and Hudson Rivers) would probably snap ... and water towers would be leaping off buildings," he said.

The Northeast U.S. experiences an average of 100 quakes annually, Simpson said. Most are so small, only delicate instruments notice them. By comparison, thousands of seismic events strike California each year.

But Eastern quakes can still be dangerous. At least 60 people died in 1886 when a quake measuring 7.5 rumbled through Charleston, S.C.

No quake design

About 95% of all earthquakes occur in areas where massive "plates" of the Earth's crust rub against each other, Simpson said.

But the eastern U.S. and Canada are smack in the middle of the North American plate. So how do quakes in this region occur?

One theory is that stress and strain from the plate's edges are transmitted through the Earth's crust, causing shifts in the crust thousands of miles away. But nothing is proven.

One thing is sure: "The New York area is not seismically still," Merguerian said.

"Not to be an alarmist, but it scares me a little bit that here in the Northeast we build buildings with no concept of earthquake design," he added.

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Newsday

50¢ APRIL 15, 1986 NEW YORK EDITION

Is Big Apple Rocking at the Core?

The *terra* underneath New Yorkers' feet may not be as *firma* as previously believed, according to a study released yesterday at Hofstra University.

In fact, according to Charles Merguerian, a geology professor at Hofstra, the very bedrock of Manhattan has fault lines previously unknown and may be more susceptible to earthquakes than believed.

"Everyone has thought that we are not in danger in the metropolitan area because we are not near a plate boundary, like California," Merguerian said in an interview after presenting his findings at a conference called "The Geology of Southern New York."

"But there are still stresses in our crust," he said. "Even though they may date to collisions that took place as far back as 450 million years ago, they are still locked in rocks."

Merguerian, whose presentation on the geology of New York City highlighted the conference, studied drill corings, newly excavated water tunnels and outcroppings of rock wherever he could find them. The result is a new geologic mapping of New York that turned up younger "brittle" faults beneath both Dyckman Avenue and 155th Street in the Bronx, 96th Street in Manhattan and one just to the east of Roosevelt Island. He also confirmed the existence of a fault beneath 125th Street.

While there is a consensus that there is seismic life in the metropolitan area, geologists emphasize that they have yet to decide whether a major earthquake is at all possible, yet alone when it might occur.

"There is enough evidence to say there is something to think about," said Michael Greenman, a geologist who does subsurface investigations of new city construction for the Department of General Services.

Merguerian said the 63rd Street water tunnel, which is currently under construction, provided crucial evidence of movement in the deeper, so-called "ductile" faults, which are reactivated when the brittle faults, which measure no more than two inches in width and extend through Manhattan, move.

"You can see the fresh-looking greenish activity in the ductile fault here," he said, referring to a photograph of the tunnel's bare rock. "It indicates a recent northwest trend."

The direction of movement, or trend, is especially significant because it reflects the movement of last October's earthquake in Westchester, which measured 4.0 — considered moderate — on the Richter scale.

"The northwest trend of the brittle faults appears to be the same as the quake in Westchester," Merguerian said. "This demonstrates the possibility of activity in an area previously thought to be free of it."

Other geologists see some validity in Merguerian's study.

"There seems to be a correlation between the geometry of his brittle faults and our own earthquake studies," said Leonardo Seeber of Columbia University's Lamont-Doherty Geological Observatory.

Engineers of the city's tall buildings are taking note of the new discussion, but thus far do not consider it necessary to alter their standards.

Filename: 12_Newsday_15April1986.pdf

Newsday
LONG ISLAND
50¢ APRIL 15, 1986 LONG ISLAND EDITION

Geologist: NYC on Shaky Ground

The ground underneath New Yorkers' feet may not be as solid as previously believed, according to a study released yesterday at Hofstra University.

In fact, according to Charles Merguerian, a geology professor at Hofstra, the very bedrock of Manhattan has fault lines previously unknown and may be more susceptible to earthquakes than believed.

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"But there are still stresses in our crust," he said. "Even though they may date to collisions that took place as far back as 450 million years ago, they are still locked in rocks."

Merguerian, whose presentation on the geology of New York City was the highlight of the conference, studied core drillings, newly excavated water tunnels and outcroppings of rock wherever he could find them. The result is a new geologic mapping of New York that turned up younger "brittle" faults beneath both Dyckman Avenue and 155th Street in the Bronx, 96th Street in Manhattan and one just to the east of Roosevelt Island. He also confirmed the existence of a fault beneath 125th Street.

Long Island, which sits atop sand, is not affected by the faults. "If you're built on rock and it moves, there can be a problem," said Lee Koppelman, executive director of the Long Island Regional Planning Commission. "But if you're built on sand like Long Island, which has no fault lines running through it, there is no problem. Even if there was a strong enough tremor in Westchester, we might feel it, but sand is a good absorber of shock."

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Several engineers of some of the city's tall buildings are taking note of the new discussion, but thus far do not consider it necessary to alter their standards.

"Despite what geologists are saying," said Irwin Cantor, chief executive officer of the Office of Irwin Cantor, engineer for Trump Tower and other buildings, "the engineering community has not had to think about upgrading the structure of high-rise buildings. By designing for wind, we have prospective earthquakes covered."

April 11, 1986

Discovery of faults raises threat of New York quake

© 1986 *N.Y. Times News Service*

NEW YORK — Recently identified faults under the East River have reawakened concern that, contrary to widespread belief, New York City may be vulnerable to moderately severe earthquakes, according to an authority on the geology of the New York area.

"New York City has always been considered safe from earthquakes, but that is now being reevaluated," said the expert, Dr. Charles Merguerian of Hofstra University in Hempstead, N.Y. Geologists, he added, are having to reconsider the "seismic potential" of the area.

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Another of these faults traverses the Inwood section of Manhattan and continues into the Bronx. A third, parallel to the others, lies farther north in the Bronx.

Additional faults have been identified running under the city from southwest to northeast, parallel to the Hudson Highlands, which cross the Hudson River in the vicinity of Bear Mountain and West Point. These faults also run parallel to Cameron's Line, which extends from Massachusetts to New York City and marks a "suture" where formations once widely separated were pushed together as the two sides of an ocean ancestral to the Atlantic converged some 400 million years ago.

Merguerian has found where that suture is crossed by the new subway tunnel from 63d Street in Manhattan to Long Island City, Queens.

None of the scientists who have examined the faults that are evident in the water tunnel or subway tunnel have reported any sign of recent activity.

Last October, New Yorkers were reminded that earthquakes occur in this city as well as in California when one rated at magnitude 4 on the Richter scale of severity occurred in Westchester County.

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Geology professor to speak at University symposium

■ **By Steve York**
Special to the Chronicle

Geology professor Charles Merguerian will be one of the featured speakers at the University's all-day symposium on the geology of southern New York this Monday.

Merguerian's recent fame was noted in last week's *New York Times*, *New York Post*, and over local radio and television stations. He has discovered seven faults in the East River water tunnels, approximately 700 feet below New York City.

The faults run in north to west, as well as north to south directions. Some of them are parallel to an ancient and reactive fault zone called Cameron's Line.

His recent evidence has been cooberated by several other New York geologists, including Leonardo Seeber of the Lamont-Doherty Geological Observatory.

Merguerian said he also thinks the New York City area is no longer seismically inactive and that city developers should take this into account when constructing new buildings.

Merguerian also said the local seismic potential for an earthquake has been underestimated in the past.

The symposium talks, which will be held in the Student Center Theatre Monday, are free to students with ID.

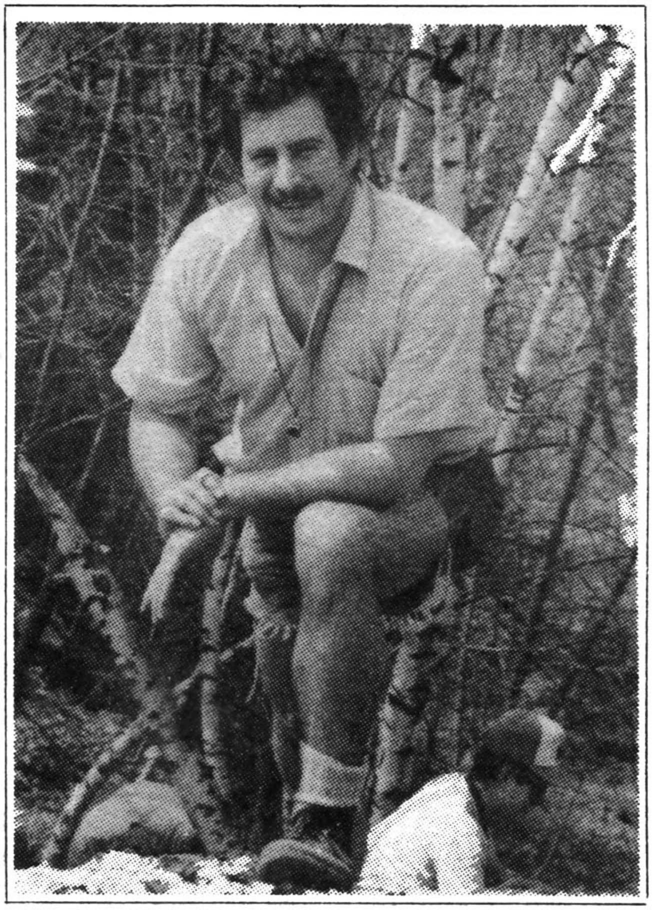

Photo by Steve Muller

Prof. Charles Merguerian

Worchester Telegram

April 6, 1986

New York City Seen Vulnerable to Quakes

N.Y. Times News Service

NEW YORK — Recently identified faults under the East River have reawakened concern that, contrary to widespread belief, New York City may be vulnerable to moderately severe earthquakes, according to an authority on the geology of the New York area.

"New York City has always been considered safe from earthquakes, but that is now being reevaluated," said the expert, Dr. Charles Merguerian of Hofstra University in Hempstead, N.Y. Geologists, he added, are having to reconsider the "seismic potential" of the area.

While the city's high-rise buildings are not considered particularly vulnerable to earthquakes of moderate severity, this may not be true of other structures, such as the water tanks perched atop many older buildings. Merguerian said the earthquake potential should be taken into account in designing new structures.

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News/Sun-Sentinel, Sunday, April 6, 1986

N.Y. could be vulnerable to temblors, authority says

The New York Times

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Merguerian has found where that suture is crossed by the new subway tunnel from 63rd Street in Manhattan to Long Island City, Queens. The line runs north and south under the channel between Roosevelt Island and Queens.

None of the scientists who have examined the faults that are evident in the water tunnel or subway tunnel have reported any sign of recent activity.

Last October, New York [illegible] were reminded that earthquakes occur in this city as well as in California when one rated at magnitude 4 on the Richter scale of severity occurred in Westchester County. Damage was slight, but geologists such as Seeber warned that a more severe one was possible.

Filename: 07_SunSentinel_06Apr1986.doc

NEW YORK POST

Saturday, April 5, 1986 35 CENTS

THIS WARNING TAKES THE QUAKE

By ROBERT WEDDLE

NEW York could be hit by a devastating earthquake, scientists said yesterday.

Reporting on ground-breaking new research, they said high-density fault lines have been discovered beneath the East River.

"The idea of a seismically dead New York is out the window," said Prof. Charles Merguerian of Hofstra University on Long Island.

His shocking view was backed by Leonardo Seeber of the Lamont Doherty Geological Observatory in Palisades, N.Y., who heads the New York-New Jersey Seismic Network.

Merguerian said he discovered seven faults and hundreds of minor earth fractures last summer during construction of an East River water tunnel linking Manhattan to Long Island City.

He took rock samples and scores of photographs, which he plans to present at a Hofstra symposium April 14 in Hempstead, L.I.

"I'm not predicting a major earthquake," he said. "But we can no longer say it is impossible.

"Architects should take this into account in designing new buildings."

The East River faults, one inch wide by hundreds of feet long, have been covered by fresh concrete since Merguerian collected his data.

Similiar faults also were discovered by Merguerian and Seeber last year in a Manhattan-Yonkers water tunnel beneath 125th Street.

The faults ran west-northwest — the same direction as the faults in the earthquake that struck Westchester last October, said Seeber.

That quake registered 4.0 on the Richter scale, ranking it as a minor temor.

"We know there is danger," Seeber said. "The question is how much.

"I would say a major earthquake in New York City is unlikely, but it is possible — and it would be a major disaster.

"A magnitude 7.0 [severe] quake hit Charleston, S.C., just 100 years ago," Seeber said.

"Whether that could happen here is the most important question on my mind."

Seeber, whose network records all seismic activity in New York and New Jersey, said his view is the "conservative" one in the field.

The last sizable quake in New York City damaged buildings but caused no death or injury, he said. It occurred in 1884 and was estimated at magnitude 5.0, or moderate.

A quake like the Westchester one strikes once every 30 years in the New York area, said Seeber, who has been monitoring seismic activity for 15 years.

The New York Times

NEW YORK, SATURDAY, APRIL 5, 1986 50 cents

Geologic Faults Are Found Under East River

By WALTER SULLIVAN

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"New York City has always been considered safe from earthquakes, but that is now being reevaluated," said the expert, Dr. Charles Merguerian of Hofstra University in Hempstead, L.I. Geologists, he added, are having to reconsider the "seismic potential" of the area.

Faults Shown on Maps

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Last October, New Yorkers were reminded that earthquakes occur in this city as well as in California when one rated at magnitude 4 on the Richter scale of severity occurred in Westchester County. Damage was slight, but geologists such as Dr. Seeber warned that a more severe one was possible.

Quakes strong enough to topple chimneys have occurred in the city in 1737, 1783 and 1884. While major quakes are rare on the East Coast, one in Charleston, S.C., in 1886, estimated at magnitude 7.5, destroyed much of that city and took at least 60 lives.

None of the East Coast faults has been a source of frequent earthquakes in the manner of the San Andreas Fault in California. The most active one in the New York area is the Ramapo Fault along the southeast margin of the Hudson Highlands.

Dr. Merguerian is to present his findings in more detail during a day of lectures on geology of southern New York at Hofstra on April 14.

THE CITIZEN REGISTER

MONDAY, MARCH 3, 1986 GANNETT WESTCHESTER NEWSPAPERS 35 CENTS

New quake evidence

Experts say bigger tremors are possibility for area

By Bill Falk
Staff Writer

Scientists studying seismic activity on the East Coast — including a controversial finding of a "mind-boggling" ground shift under New York — now say it's possible the metropolitan area could someday suffer a major, destructive earthquake.

No one can predict when such a quake could occur, scientists say. In fact, it might not happen for decades or centuries — if at all. But geologists and seismologists studying the New York area say bits and pieces of recently unearthed evidence point to one clear conclusion: It's time to abandon the long-standing assumption that New York is immune to California-sized quakes.

"The entire East Coast was considered basically seismically inactive, but now that view is being re-evaluated," said Charles Merguerian, a professor of geology at Hofstra University and a specialist in the New York City area.

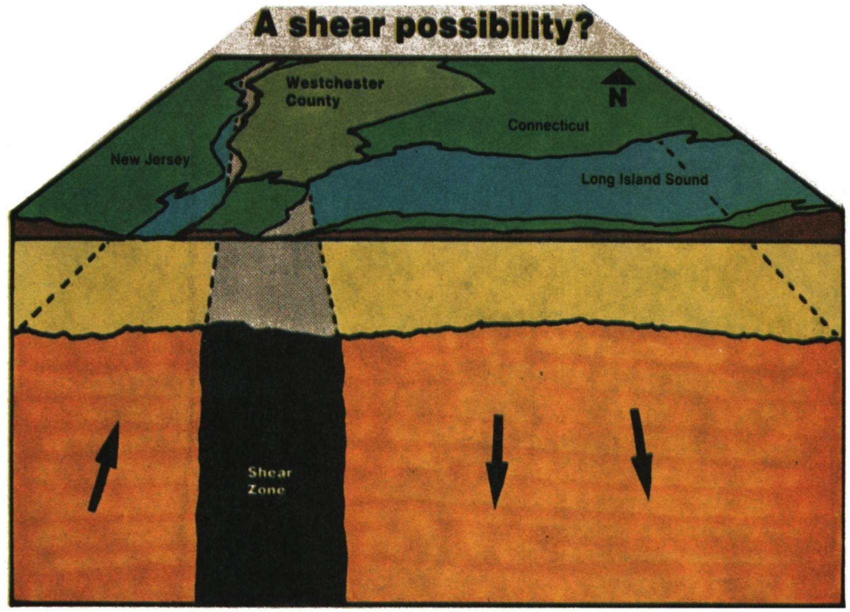
"The evidence is still vague," said Leonardo Seeber, a research scientist at Columbia University's Lamont-Doherty Geological Observatory in Palisades in Rockland County, "but I think the possibility is there for a large earthquake."

Seeber said he and other scientists plan to make public officials "aware of our shift in thinking."

The evidence prompting that shift includes several recent developments:

• The two dozen small-to-moderate sized quakes (most of them too small to be felt) that shook the bedrock under southern Westchester in 1985. The tremors — including an Oct. 19 quake measuring 4.0 on the Richter scale — occurred in an area with little previous seismic activity and with no previously identified faults.

Seeber said the frequency of the quakes suggested they could be occurring on "a



Gannett/Ray Vella

SHEAR SPECULATION — One theory for possible major earthquake activity in the future is an undiscovered "shear zone," or fault, somewhere under New York, perhaps miles under the Hudson River. Such a fault might be an eons-old remnant of a time when two tectonic plates, or giant slabs of rock that make up the Earth's crust, met under what is now New York.

QUAKES

From page one

creeping fault" — a geological formation previously associated only with areas of strong underlying stress.

• A study by three Stanford geophysicists that indicated the ground in the New York metropolitan area was being distorted out of shape by tremendous subterranean forces. The study was published in the British scientific journal "Nature," almost simultaneously with Westchester's strongest quakes in October.

In the study, the scientists revealed evidence that the Earth was moving along an unseen, deeply buried fault at the rate of approximately one-half inch a year.

That's a huge amount by geological standards, equivalent to the movement along the San Andreas fault in California.

The study's findings have been greeted with astonishment and skepticism. John Armbruster, a Lamont-Doherty seismologist, called the results of the Stanford study "mind-boggling" and "paradoxical."

"You'd have to conclude that if what they're saying is true," Armbruster said, "a spring is coiling underneath us, and eventually you'd have to have a large earthquake."

Mark Zoback, one of the study's authors, conceded it was hard to explain his findings. One possible explanation, he said, is that there is an undiscovered, major "shear zone," or fault, somewhere under New York, perhaps miles under the Hudson River. Such a fault might be an eons-old remnant of a time when two tectonic plates, or giant slabs of rock that make up the Earth's crust, met under what is now New York, he said.

• Earthquakes in areas that, like New York, have no apparent geological structure or mechanism to explain them. The most recent of these was a 5.0 quake that rattled Cleveland on Jan. 31.

The quake occurred in an area considered seismically more stable than New York City. It strongly shook the earth under a new nuclear plant about to go into operation — a plant built, like the two reactors at Indian Point in Buchanan, under the assumption they would not have to withstand violent earthquakes. There had never been a 5.0 quake recorded near Cleveland.

"To us, this is all evidence that you can't take the simple-minded view that the quakes of the past few centuries are the ways things are — that history over that short a period of time will repeat itself," Armbruster said. "It's pretty clear now that we don't understand all the quakes that can happen in an area like New York."

For decades, scientists, public officials and engineershave operated on the assumption that major earthquakes do not occur in New York City and its suburbs. That assumption was based on scientists' understanding of how earthquakes occur and on the record of the past three centuries.

During that time, the largest quake to strike the New York area, in 1884, measured approximately 5.0 on the Richter scale. A quake of that size — 10 times more powerful than the 4.0 quake that rumbled through Westchester on Oct. 19 — can inflict some damage to buildings.

Elsewhere on the East Coast, however, one major quake has occurred in relatively recent history. In 1886, a quake estimated at almost 7.0 caused tremendous damage in Charleston, S.C. That quake unleashed 1,000 times more power than the Oct. 19 quake in Westchester.

Scientists initially assumed the Charleston quake was caused by some geologic structure peculiar to that area, but a 10-year study completed several years ago uncovered no explanation for the quake —no fault, no quirk of geology.

This fact has led scientists to wonder if the Charleston quake might be an example of the kind of earthquake activity that occurs regularly on the East Coast over intervals of 500, 700 or 1,000 years.

"If it's true that Charleston isn't unique," Armbruster said, "then maybe within 100 years we'll see another magnitude-7 quake along the coast."

Such a quake, scientists agree, would cause enormous destruction in New York City or other major urban areas on the East Coast, all built under the assumption that huge quakes only occur in California.

"As far as I'm aware, no public officials in New York have yet considered what happens in a major earthquake," said Hofstra geologist Merguerian. "That's the scary part."

The current scientific model for how earthquakes occur offers no explanation for the Charleston quake, or even for the small quakes that occurred in Westchester.

Over the past two decades, scientists have come to understand that the Earth's outer crust consists of tectonic plates that creep along a semi-molten interior. These plates meet, collide and slide under each other at moving boundaries, or faults, such as the San Andreas in California.

This slow, tortuous movement — sometimes giving way to sudden, fitful slippage along the faults — is what produces earthquakes.

Although this model explains very well 95 percent of the 800,000 earthquakes that occur throughout the world each year, it provides no mechanism for those that occur away from the plate boundaries, in so-called "intraplate" areas.

New York sits on one of these intraplate areas. The entire East Coast is situated almost midway on the North American plate, which is bounded to the west by the Pacific coast and on the east by the mid-Atlantic ridge. In theory, interplate areas should be subjected to little seismic strain and should exhibit little deformation, or movement. That's what makes the Stanford study so hard for scientists to accept. Even the study's authors confess to astonishment at their findings.

"We were really immensely surprised," said Zoback, one of the geophysicists who carried out the study. "It doesn't seem to make sense."

A review by another group of scientists suggested the Stanford group overestimated the rate of the Earth's deformation by one-third. Still, that would represent an enormous amount of motion for New York and would leave the study's basic conclusions intact.

The Stanford study involved a computer analysis of measurements taken by the National Geodetic Survey between 1872 and 1973. The survey periodically takes sightings between "benchmarks," or markers, anchored in the Earth throughout the New York metropolitan area.

By measuring the change in angles between these benchmarks, the Stanford scientists were able to gauge how much movement had occurred in the underlying earth.

The scientists found virtually no movement in Pennsylvania, New Jersey or eastern Long Island. In the metropolitan area itself, extending north and east to Connecticut, and west into Putnam County and across the Hudson River to Rockland County, the analysis showed what by geological standards is a huge amount of movement.

Since this movement deep within the Earth's surface doesn't have an immediate outlet in a fault running to the surface, Zoback said, it could pose a large earthquake threat.

Miles down, the tremendous weight of the rock above creates heat and pressure which make the Earth's interior partially molten and elastic, like heated plastic. At that depth, the rock can respond to strong seismic stress without fracturing. Closer to the surface, however, rock does not easily bend and change shape in response to pressure. If there's no large, surface fault on which the land can creep, the strain generated from below bends and slowly distorts the crust. This is the kind of distortion Zoback believes he sees in the New York area.

Eventually, the stress builds to the point where the upper crust can no longer bend — and then it snaps, like a plank of wood bent too far.

When the Earth's crust snaps suddenly along miles-long fault lines, tremendous energy is released in the form of an earthquake.

"Movement of a few centimeters a year isn't very big," Zoback said. "But if that accumulates over 100 years, that's enough strain to produce a large earthquake."

He said the recent Westchester quakes probably were expressions of the stress he detected. "It's all part of the same process," Zoback said. "There's obviously a relationship."

Lamont scientists weren't so sure, pointing out that while Zoback's evidence points to a fault line heading north, the Westchester quakes appear to run on a buried fault pointing west-northwest.

Zoback conceded his study suggests a major earthquake as only one of several possibilities.

"It's something to think about, and it's a cause for concern," Zoback said. "But it's not something people should be staying up nights worrying about."

Lamont seismologist Armbruster said he and most of his colleagues remain skeptical about the Stanford study.

"But because we can't explain Zoback's results doesn't mean they should be thrown away," Armbruster said. "The Westchester quakes, the Zoback results, the Cleveland quakes all highlight how ignorant we are. We need to keep on trying to collect information so that one day, we will understand what we don't understand today."

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the earth moves

explaining earthquakes an occupation as old as man himself

By Bill Falk
Staff Writer

When the ground under their feet heaved and rolled, the people of ancient Japan blamed it on the thrashing of the namazu, a giant catfish believed to have carried the earth on its back.

The Greek mathematician and philosopher Pythagoras thought earthquakes were caused by fighting among the buried dead.

Today, seismologists attribute earthquakes to an equally fantastic, if less poetic, process: the creeping of 3,000-mile wide, 50-mile thick slabs of rock, or "plates," across the earth's semimolten interior, like stone rafts on an ocean of boiling rock.

Yet modern scientists concede this theory of plate tectonics does not explain some kinds of earthquakes, such as the Westchester-based tremors that shook the New York metropolitan area last week.

In fact, experts studying last week's quake and aftershocks concede they have no clear idea of why the earthquake occurred, or why the town of Greenburgh just south of Ardsley has been the center of 14 tiny to moderate tremors in the last nine months.

The first of these tremors struck in January and was followed by another in May. Then on Oct. 19, a foreshock and the main quake roused millions of people from their sleep in the metropolitan area. Seismologists at Columbia University's Lamont-Doherty Geological Observatory in Palisades said as many as 10 aftershocks followed, including one Saturday afternoon felt by residents of the Yonkers area.

Scientists also do not know whether the sudden spurt of seismic activity in the Ardsley area marks the end of earthquake activity there for decades to come or is merely the prelude to a more powerful and possibly destructive earthquake in the near future.

Charles Merguerian, a professor of geology at Hofstra University, said a quake measuring 5 or 6 on the Richter scale — 10 times or 100 times more powerful than the Oct. 19 quake, respectively — could be brewing slowly in the bedrock below the metropolitan area.

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"Not to be an alarmist, but it's possible," said Merguerian, one of a few geologists in the world to specialize in the New York City area. "But I think (last Saturday's) quake was a good thing. It's good to have smaller earthquakes like that one because it releases strain."

Charles Baskerville, a research geologist for the U.S. Geological Survey who also specializes in the New York area, said he thought the small quakes could be building to a larger one — perhaps as large as the 5.0 quake that rocked the metropolitan area in 1884. A 5.0 earthquake generally causes minor damage to buildings, breaks windows and causes objects to fall.

Other scientists, including the seismologist Alan Kafka of the Western Observatory in Boston, another specialist in the geology of the metropolitan area, said such speculation was totally without scientific foundation.

"We really don't know what causes earthquakes in the Northeast," Kafka said.

Merguerian readily conceded he and other geologists could only guess the meaning of the recent tremors.

"We can all speculate on this, but in the end it really doesn't mean a damn," Merguerian said. "What's going to happen is going to happen."

The problem is not that geologists and seismologists know nothing about what causes earthquakes. They know quite a bit — but not about the kind of earthquake that struck the New York area.

The reigning theory of plate tectonics has enabled scientists to explain 95 percent of the 800,000 earthquakes that rumble through the earth's crust each year.

Seismologists know that most quakes occur at the boundaries of the 12 moving plates that make up the earth's crust. As the massive plates inch toward each other, enormous pressure builds on either side of the fault between them, contorting and twisting solid bedrock like so much soft wood.

Finally, the rock can no longer withstand the mounting strain, and it fractures like a ruler that's been bent too far. The two facing slabs, or plates, are then free to lurch under or alongside each other to a new position of reduced stress.

The most powerful earthquake on record, a 9.2 quake that struck Chile in May 1960, moved the earth on either side of the fault line 60 feet. In contrast, the Ardsley quake resulted from a side-to-side movement of about a half-inch along a buried fault line, scientists at Lamont-Doherty estimate.

After a quake on a major fault line releases the strain between plates, the process begins anew. The continental plates resume their slow, constant movement against each other until the day — years, decades or centuries later — that the pressure builds to an explosion within the earth.

But while the vast majority of earthquakes, especially powerful ones, occur along or near the faults dividing the world's major plates, about 5 percent do not. They occur in the middle of the giant plates, away from obvious sources of stress, and away from the active, visible boundaries that have excited scientists.

"Almost all the attention and work and funding has gone to the study of the plate boundaries," said Dr. Leonardo Seeber, a seismologist at Lamont-Doherty. "Now, with this earthquake, we're seeing some attention to interplate areas like New York."

New York and Westchester are close to the middle of the North American plate, which extends from the middle of the Atlantic Ocean to California. Major quakes within this plate are much rarer than they are along the boundaries, but they are not unknown.

A series of powerful earthquakes measuring about 7.5 on the Richter scale struck New Madrid, Mo., in 1811 and 1812, causing huge fissures in the earth, churning the Mississippi River into such a froth that it temporarily flowed backward and destroying the homes of the settlers who lived there.

Though 20 million people live in the metropolitan area, its underlying bedrock has been the subject of less study recently than the remote areas of Antarctica and Alaska. Most scientists at Lamont-Doherty, which lies almost directly across the Hudson River from the area where the Oct. 19 quake occurred, specialize in distant areas of the world.

Craig Nicholson, a seismologist at Lamont-Doherty, said one reason for the general lack of interest in the New York City area is that much of the earth is covered by buildings and roads.

Merguerian said the presence of buildings was not the only reason.

"Most geologists are afraid to work in the city," he said. "I live in the city, so it doesn't bother me."

Merguerian has studied the city's geology in subway tunnels, excavations and the massive water tunnel now being constructed beneath Manhattan. He said "a wealth of information" about the area was available to any geologist willing to look for it.

The city's underlying layers of metamorphic rock, Merguerian said, are veined with hundreds of small faults, or cracks. But he said he could not pinpoint a single fault line that would account for the Ardsley quake.

Lamont-Doherty scientists are still trying to identify a fault line along which the quake occurred. They believe the fault is buried under the surface, running either northeast or northwest through the Ardsley area.

Seismologists attempting to account for a buildup of pressure along the small, intraplate faults have looked to the overall theory of plate tectonics for an explanation. One possible explanation is that the North American plate's pressing up against the Pacific plate causes a compression of the entire plate — a form of strain that is transmitted through the rock until it finds an area of weakness on an old fault. An earthquake like the Ardsley quake then occurs.

Kafka, a self-described "renegade" who was once on the staff at Lamont-Doherty, scoffs at this hypothesis.

"I've heard that," Kafka said. "But whether that has anything to do with the quakes in the Eastern U.S. is another question. There isn't any evidence to support it."

Kafka said many of his colleagues in seismology made the mistake of thinking of intraplate quakes as smaller versions of quakes that occur at plate boundaries.

In truth, Kafka said, the quakes that occur within plates "are an entirely different animal." These quakes may occur on faults, he said, but not because of faults.

And locating a fault under Ardsley, he said, will do nothing to reveal why the earthquakes occurred and whether more are coming.

"People get mad at me when I say that," Kafka said. "People want to blame earthquakes on faults. It makes everyone's life easier.

"People don't like the answer, 'I don't know,' " he said. "But I think that's the only answer we've got right now."

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Bigger Quake in Area Called Possible

By WALTER SULLIVAN

The earthquakes recorded in recent days near Ardsley, N.Y., may be foreshocks for a more severe one yet to come, according to Columbia University seismologists.

They said such a quake could occur at any time within months. They stressed, however, that this was a possibility, rather than a probability, and other specialists expressed doubts regarding the prognosis.

The Columbia seismologists said they could not estimate how much more severe a new quake might be than the one that occurred Saturday. Its magnitude was measured at 4.0 on the Richter scale of ground motion, a relatively small earthquake that caused little damage.

Dr. Leonardo Seeber and other earthquake specialists at Columbia's Lamont-Doherty Geological Observatory in Palisades, N.Y., said in a series of interviews that their recent analyses of past earthquakes in the New York area showed that those roughly centered on the city and sufficiently strong to topple chimneys, measuring 5.0 or greater on the Richter scale, occurred in 1737, 1783 and 1884.

Last Big Quake

Because a century has elapsed since the last big quake, the specialists said, the possibility of a recurrence must be considered. They said they could not entirely rule out an earthquake comparable to one estimated at magnitude 7.5 that hit Charleston, S.C., in 1886, destroying many homes and taking at least 60 lives.

On the other hand, Dr. Alan Kafka of Boston College, who published a paper on New York earthquakes in the Oct. 1 issue of The Bulletin of the Seismological Society of America, described the cause of these earlier quakes as "an enigma." He termed any predictions for a recurrence premature.

According to Dr. Seeber, the dozen or so small aftershocks recorded since the main earthquake last Saturday are not as numerous as would be expected if the quake on Saturday was the main event. Normally, he said, there are about 10 times as many aftershocks in the extremely weak class of magnitude 1.0 than of magnitude 2.0, which is 10 times stronger, but such a pattern has not been observed.

Dr. Kafka said yesterday that he did not consider this a strong argument for further quakes. Dr. Seeber could not be reached for further comment.

A more typical swarm of aftershocks, Dr. Seeber said earlier, followed the Goodnow earthquake of Oct. 7, 1983, in the heart of the Adirondacks four miles east of Newcomb, N.Y. Rated at magnitude 5.2, it was the strongest in the state since a 1944 earthquake that toppled 90 percent of the chimneys in Massena.

Dr. Seeber said he suspected that the Goodnow earthquake and others in this part of the continent, including the one Saturday, were controlled by a combination of geological factors and faults.

Faults in New York City Area

Those faults cutting across the New York City area lie in two directions: from southeast to northwest, parallel to a fault under 125th Street, and from southwest to northeast, parallel to the Hudson Highlands and a geological feature known as Cameron's Line.

A preliminary analysis of fault movement in the Ardsley quake by Columbia seismologists has indicated movement in one of those two directions, but as yet has not shown which.

The region of the Goodnow earthquake in the southeastern Adirondacks, whose cause Dr. Seeber likens to that of the Ardsley temblor, is cut by a multitude of faults trending from west of south to east of north. Some of them can be traced for 60 miles or more and contain long, narrow lakes such as Indian Lake and Long Lake. Last summer Dr. Seeber and his colleagues searched the region, however, and found little evidence of recent motion along those faults.

Furthermore, analysis of the Goodnow earthquake and its aftershocks showed that the deep crust had ruptured for only a mile, compared with slippages along many miles of fault typical of California earthquakes. To assess those in the East, Dr. Seeber said, one must avoid a "California mentality."

The geological factor involved in both the Adirondack and Ardsley quakes, Dr. Seeber suspects, was the existence of a deep-lying marble formation. In the high temperature at a depth of four miles, where the Ardsley quake occurred, marble becomes plastic and can readily respond to stress, whereas surrounding formations of more rigid rock remain unaltered until the stress reaches a high enough level to cause rupture and an earthquake.

According to Dr. Leo M. Hall of the University of Massachusetts in Amherst, the Inwood marble of Westchester County underlies Central Park Avenue very close to the epicenter of the Ardsley quake. It forms a valley flanked on both sides by much more rigid rocks: Fordham gneiss on the east and Manhattan schist on the west.

The digging of two new tunnels under New York City has helped trace the paths of Cameron's Line and the 125th Street Fault. Excavation of a water tunnel under the east side of Manhattan has enabled Dr. Seeber to photograph a band of crushed rock where the 125th Street fault cuts across it.

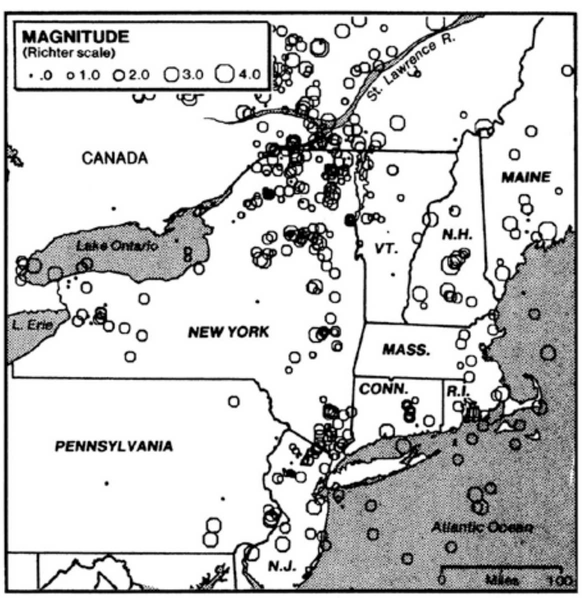
Dr. Charles Merguerian of Hofstra University has found where the new subway tunnel from 63d Street to Long Island City crosses Cameron's Line. The latter, he discovered, lies under the channel between Roosevelt Island and Queens.

Cameron's Line is a so-called suture zone where converging land areas became joined as the European-African land mass collided with North America 400 million years ago. Although the Ardsley quake took place only two miles from the line, Dr. Hall doubts that the quake originated on it. Unlike the San Andreas Fault of California, it has not been a source of many quakes.

Parallel to it and more active, however, is the Ramapo Fault along the southeast margin of the Hudson Highlands. It passes within a few miles of the Consolidated Edison Company's nuclear reactors at Indian Point.

According to the Consolidated Edison Company, the reactors there are designed to shut down at the start of any quake of magnitude 7.0 on the modified Mercalli scale, an index of local destructiveness. That would be 10 times as violent as any quake recorded within a 200-mile radius of the plant since the 1800's.

Dr. Kafka argued that the significance of the Ramapo Fault has been exaggerated. He said he believed the quakeprone area surrounded the entire basin between the Hudson Highlands of northern New Jersey and the Bear Mountain area and the east bank of the Hudson River. He also questioned efforts to relate the earthquakes to motion of North America over the earth's deep interior, or mantle, as the continent drifts away from the Mid-Atlantic Ridge. The picture, he said, "is much more complicated."



The New York Times/Oct. 23, 1985

Location and intensity of earthquakes over the period 1972-1983.

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For Charles Merguerian
With warm regards
and thanks for your help.
Walter P.

Landprints

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FRIDAY, DECEMBER 2, 1983

Story of the Eons In New York's Rocks and Cliffs

Weekend

The New York Times/Dith Pran

Profs. Charles Merguerian, left, of Hofstra University and Leo M. Hall of University of Massachusetts, at 165th Street and Riverside Drive examining vertical section of a fold formed when African land mass drew close to East Coast eons ago.

By WALTER SULLIVAN

THE most obviously dramatic features of the New York landscape are monumental skyscrapers and bridges. But rocks throughout the metropolitan area bear witness to past events grander and more awesome than anything to be seen on Earth today.

Some of these witnesses to geological eons long gone are accessible by subway or on foot. Others are within an hour's drive. Almost all can be appreciated without any special scientific knowledge. They have a tale to tell of lava pouring across the landscape, driving before it armies of dinosaurs, of vast slabs of marble pushed across the Bronx and Manhattan, of flowing ice that gouged deep grooves in the rocks of Central Park.

In the city, alongside Riverside Drive, notably at 165th Street, you can see ledges studded with garnets, tourmalines and other stones, though these are not of gem quality. The contorted folds of these ledges were produced by extreme heat and compression when the African land mass drew closer.

The most dramatic relicts of all are the Palisades, forming a mighty wall along the west bank of the Hudson River. Now that most of the leaves have fallen, they are visible for their full height from outlooks on the Manhattan shore. The Palisades were formed some 200 million years ago, when Africa pulled away from its long marriage with North America, and the modern Atlantic Ocean began to form. This great pulling apart rent the earth's crust to great depth, forming long rifts such as the Connecticut Valley and the Jersey Meadows.

Then, millions of years later, the split penetrated so deeply that lava rose from the molten interior. Some of it, prevented from rising farther, spread sideways between layers of rock, cooling into vast underground slabs. The Palisades are the edge of such a slab, or "sill," which has been tilted up toward the east sufficiently to raise its edge above ground level. Underground, it is about 1,000 feet thick, but its upper edge, overlooking the river, has been planed off by erosion.

There are few excursions in the New York area as awesome as the descent of these cliffs via the drive at the Palisade Avenue Exit of the Palisades Interstate Parkway — the first exit north of the George Washington Bridge. This is scenery on the grandest scale. A stream tumbles down the cliff, repeatedly crossed by the road, which zigzags down to the park on the river. Last weekend, rain-swollen, it was a classic mountain torrent.

That this great slab formed underground is evident near the foot of the long hill where Interstate 80 leads west from the Washington Bridge. The rock walls flanking the highway resemble the Palisades in their towering columns and dark, uniform texture. Just before the sloping slab disappears underground alongside the Englewood Golf Course, it is crowned by reddish rock of clearly different type.

This is the layer that was severely baked as the lava intruded under it. The effect was like that of shoving a red-hot spatula into a loaf of bread, which would toast the layers both above and below the hot metal. The toasted layer beneath the sill can be seen along Henry Hudson Drive a mile and a half from the entrance, off River Road in Edgewater. The road is

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closed to vehicles for the season, but open to walkers.

Watchung Mountains

During the great rifting, not all the lava stayed underground, as is dramatically evident in both New Jersey and Connecticut. Lava poured onto the surface, flooding large areas. Each episode produced a sea of basaltic rock like the lunar seas. Then, gradually, soil formed and life returned, only to be buried by new floods.

In New Jersey, three periods of eruption were spread over a two-million-year period. The resulting beds of volcanic rock, after having been buried by the passage of time, tilted up toward the east in the same manner as the Palisades. Their edges now form the three parallel ridges of New Jersey's First, Second and Third Watchung Mountains.

First Watchung Mountain is crossed by Route 46 at Great Notch, and Interstate 80 climbs onto its shoulder overlooking Paterson. This and the other two parallel ranges run southwest toward Somerville, forcing a wide detour by Interstate 287. Railroads in the area ride on ballast, or crushed stone, quarried from these formations. The homogeneous rock is ideal for the purpose.

Similar seas of lava poured across central Connecticut and have been tilted in the opposite direction — up toward the west — as in the Hanging Hills of Meriden and nearby Mount Higby, whose shoulder is crossed by Interstate 91. West Rock, overlooking New Haven, was intruded underground, like the Palisades.

Manhattan Marble

Few New Yorkers realize that marble underlies much of their city. Marble, being so easily eroded, has made Manhattan an island by creating the Harlem and East Rivers. It came from a vast accumulation of tiny seashells that formed off the East Coast before Africa began to approach. At that time, the North American continent was near the Equator, and the nearby ocean teemed with life.

The resulting accumulation of shells formed into limestone thousands of feet thick. The limestone was shoved far inland during the collision of the two continents. Some of it was buried, heated and compressed sufficiently to convert it into the marble deposits now quarried from Vermont to Alabama.

Some of it can be seen, forming a strangely undulating surface in Isham Park, a couple of blocks from the terminal station of the IND subway's A train at 207th Street. Beneath White Plains, this so-called Inwood marble is more than 2,000 feet thick. A sculptor would find most of it hopelessly crumbly, although some of it, which contains volcanic material, forms the east wall of Central Park near 88th Street. Since the marble is chemically similar to limestone, it is quarried in some areas for grinding into fertilizer.

East Harlem is a lowland because it rests on this marble, but to the west, Morningside Heights and Washington Heights are formed of two layers of erosion-resistant rock — Manhattan schist — which began as layered sea-floor sediment far offshore. As Africa approached, the rocks were buried so deeply that they became soft enough to be folded and refolded repeatedly. Now that they have reappeared, the complex folds are evident in many of the parks.

Moraine and Serpentine

More than once, great ice sheets advanced as far as New York City, then paused for thousands of years, depositing great heaps of material along the front, where they melted as fast as the rock-laden ice advanced. This formed hills and ridges of rock, gravel and sand that survive as "terminal moraines."

The Long Island Expressway, for much of its length, was built along the top of such a moraine. Water from the melting ice spread vast amounts of sand and gravel to the south, forming the great apron, or "outwash plain," of the South Shore. This moraine forms Montauk Point and continues to Block Island and beyond.

In the opposite direction the moraine continues to Staten Island, where it can be seen in cross-section at the southwest extremity of the island by turning left along the shore at the end of Hylan Boulevard. A later ice advance deposited the material that now forms the North Shore of Long Island, continuing as Orient Point, Fishers Island and beyond.

The flowing ice carried in its belly sharp rocks that carved Central Park's ledges, much as machine tools might have done. The resulting grooves, oriented to the west of north, can be seen in many parts of the city, but particularly north of the Avenue of the America's entrance to the park between the Wollman Rink on the east and the Loeb Memorial and Heckscher Playground on the west. The rock was not only deeply grooved but also polished by the ice so that the intricate folds formed a few hundred million years ago are wonderfully displayed.

Among remarkable products of the ice ages are potholes drilled into the ledges of Inwood Hill Park, west of Isham Park. Whirlpools formed by water plunging down off the ice swirled boulders violently about and carved holes large enough to hold a person. A group of these can be seen if one walks past the open meadow west of Isham Park and uphill along a walk that bears left beyond a boulder that marks the site where Manhattan was allegedly bought from the Indians.

The upheavals that produced the rocks of New York City were so great and profound that they are hard to imagine. They brought up from deep beneath the sea floor great masses of serpentine, a mineral which, when of sufficiently high quality, can be polished to form what resembles a green marble.

This rock is known as verd antique and is superior to marble in that it does not readily dissolve. The Staten Island Expressway, leading west from the Verrazano-Narrows Bridge, climbs onto a great mass of serpentine visible in the complex interchange near its summit. When the Cross Westchester Expressway was built, it, too, cut through such rock west of Rye.

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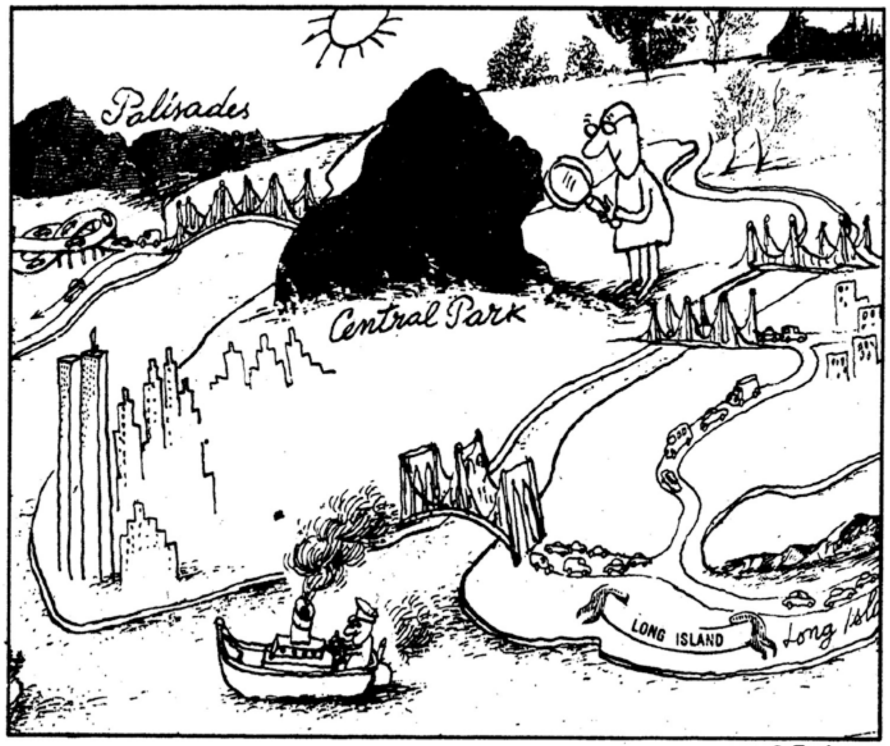
The City's Shoreline

New York's shoreline has largely been shaped by another geological process that can be seen in action. This is the role of waves in spreading sand to form barrier islands, like Long Beach, Jones Beach or Fire Island, and spits or hooks, like Rockaway Beach and Sandy Hook.

According to Prof. John E. Sanders of Barnard College, Fire Island, when not interrupted by human activity, grows westward a foot a month. In 110 years, it advanced five miles. During winter storms, waves tend to strike its shore from the northeast, constantly pushing the sand westward, and a visit to one of those beaches during such a storm can be an awesome experience.

A book, "Rock Trails in Central Park," published by the Greensward Foundation, is available by mail for $5.95 from the Friends of Central Park, Post Office Box 610, New York 10021.



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