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## TUNNEL GEOLOGY AS SEEN BY GEOLOGISTS: MANHATTAN, NEW YORK CITY

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## Tunnel Geology As Seen By



Geologists
New York City

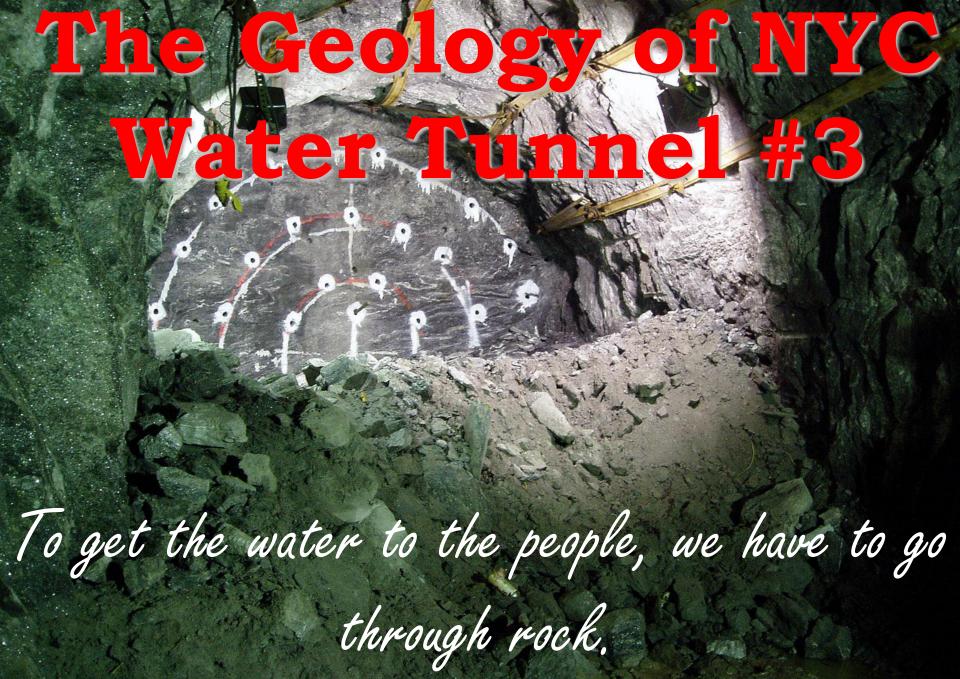


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## NYC Third Water Tunnel

- Six hundred feet below the busy streets of New York City, geotechnical engineers are boring 60-mile-long tunnel – the largest tunnel in America.
- New York City's \$ 6 billion Third Water Tunnel is one of the nation's largest and most complex public works projects ever attempted.

## WHY A NEW TUNNEL?

- In 1954, NYC recognized the need for a new tunnel to meet the growing demand on its 150-year-old water supply system.
- Construction begun in 1970 on the Third Water Tunnel, a tunnel designed to imprese the dependability of New York Chy's entire water supply system.

# Tunnel Boring Machine (TBM)

The majority of the tunnel is being carved with a 450-ton, 19-foot diameter rockchewing device called a Tunnel boring machine (TBM).

## Unique Engineering Feature Of the City Water Tunnel # 3

Unlike the older water supply tunnels in NYC, water control valves in the Third Water Tunnel will be housed in large underground chambers, making them accessible for maintenance and repair

 When completed in 2020, the size and length of the Third Water Tunnel, its sophisticated valve chambers, and its depth of excavation will represent the latest in state-of-the-art tunnel echnology.

• The tunnel boring machine, which had to be lowered into the tunnel in pieces and assembled at the bottom, is capable of excavating 50 feet of rock per day at a diameter of 23 feet - more than twice the rate previously achieved in tunnel construction through drilling and blasting methods.

Mr, Ward (former NYCDEP Commissioner) said the tunnel workers. Known as sandhogs, would add a third work shift tha could more than double progres on the tunnel construction between 60 and 100 feet per "Obviously the geological challenges of what is down there really determine what the rate of speed is," he said

# History of the NYC Water Supply System

 New York City grew from Southern Manhattan. By 1664 the population had reached about 1500. Private water supply wells were supplemented by a public well dug in 1677 near the old fort at Bowling Green. Additional public wells were constructed, generally at street intersections, in the time period prior to the American Revolution. One of these, located at Chatham Square, was called the 'Tea Water' pump because of the reputed quality of its water. The Collect Pond, located at the present site of the Criminal Courts Building was also used for public water supply.

- Shortly before the Revolutionary War, the population was approximately 22,000 and the first water works construction commenced. The reservoir was located at Broadway and White street. It was supplied from the Collect Pond and a system wells through wooden pipes made from hollowed out logs.
- By 1799 the Manhattan Company, later to become Chase Manhattan Bank, was formed by Aaron Burr and chartered to supply water to the growing city. It delivered water to about 1,400 buildings.
- The first large scale public water supply was begun in 1830 with an elevated 220,000 gallon tank at 13<sup>th</sup> St. and Broadway. The tank was supplied from a large bedrock well, 112 feet deep and 16 feet in diameter with two horizontal galleries 25 and 75 feet long and 4 by 6 feet in section. This well yielded 21,000 gallons per day. The water was distributed through 12 inch cast iron pipes.

As the population continued to increase, pollution of wells and insufficient supply forced the City to look beyond its borders for water. In 1832, DeWitt Clinton recommended the Croton River in Westchester County as a source of water. The Croton Aqueduct, working by gravity feed, had a capacity of about 90,000,000 gallons of water per day. Distribution reservoirs were located in Central Park and at 42nd Street at the present site of the New York Public Library central branch building. The Old Croton System continued in service until 1907. New réservoirs were constructed at Boyds Corner in 1873 and at Middle Branch in 1878 to supplement the water supply.

- The New Croton Aqueduct was constructed from 1885 to 1893 but was placed into service in 1890 while still under construction.
- The present water system was consolidated from those of Manhattan, The Bronx, Brooklyn, Queens and Staten Island as they became part of the City.
- Except for brief annual shutdowns for inspections from 1842 to the Civil War period, there have not been any significant interruptions of the water service to New York City.
- The N. Y. State Legislature created the Board of Water Supply in 1905. They proceeded to plan and construct facilities to impound the waters of the Esopus Creek, one of four watersheds in the Catskills, and deliver the water to New York City. The Catskill System, which included the Ashokan Reservoir and the Catskill Aqueduct, was completed in 1915. The development of the remainder of the Catskill System, involving the construction of the Schoharie Reservoir and the Shandaken Tunnel, was completed in 1928.

In 1927 the Board of Water Supply submitted a plan to the Board of Estimate and Apportionment for the development of the upper portion of the Rondout watershed and tributaries of the Delaware River within the State of New York. This project was approved in 1928. After a long legal dispute with New Jersey over the right to impound tributaries of the Delaware River was won, construction of the Delaware System was begun in March 1937. The Delaware System was placed in service in stages: The Delaware Aqueduct was completed in 1944, Rondout Reservoir in 1950, Neversink Reservoir in 1954, Pepacton Reservoir in 1955 and Cannonsville Reservoir in 1964.

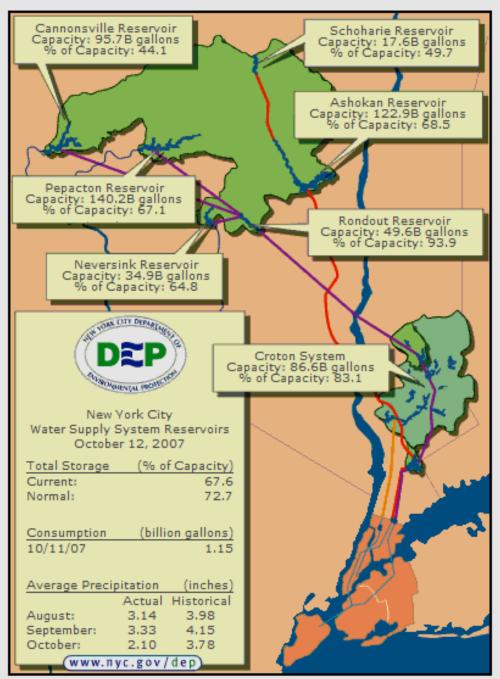
- Water for New York City is impounded in three upstate reservoir systems which include 19 reservoirs and three controlled lakes with a total storage capacity of approximately 580 billion gallons. The three water collection systems were designed and built with various interconnections to increase flexibility by permitting exchange of water from one to another. This feature mitigates the effect of localized droughts and takes advantage of excess water in any of the three watersheds.
- In comparison to other public water systems, the NYC Water System is both economical and flexible. Approximately 95% of the total water supply is delivered to the consumer by gravity. As a result, operating costs are relatively insensitive to fluctuations in the cost of energy. When drought conditions exist, however, additional pumping is required.



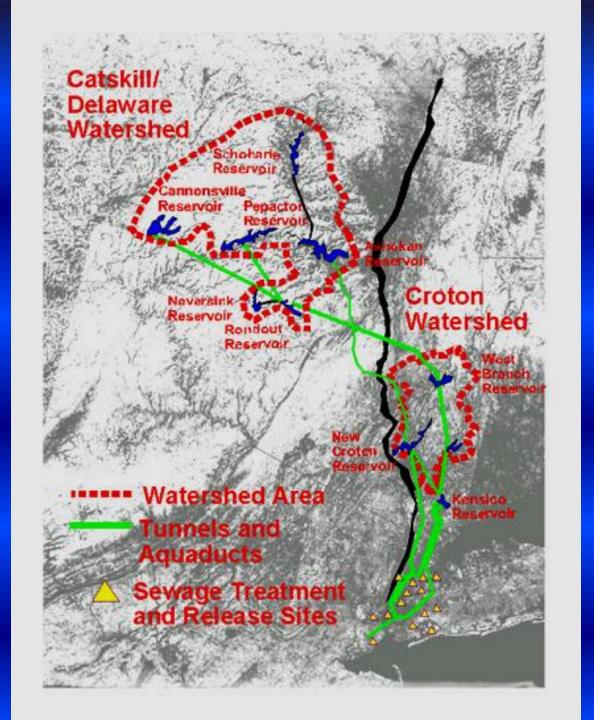




### **Current Reservoir Levels**



<sup>\*</sup> to date



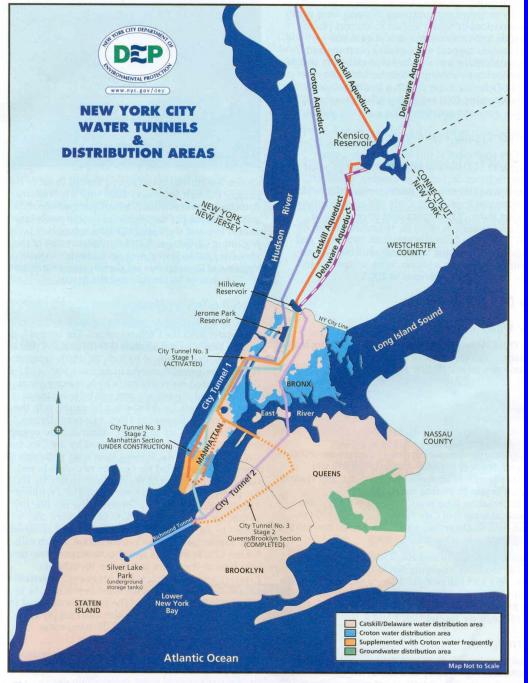


- NYC Water Tunnels No. 1 and 2 were put into operation in 1917 and 1936, respectively.
- NYC Water Tunnel No. 3 will allow the two older tunnels to be inspected and repaired for the first time since they were activated. Thereby ensuring the reliability of the finest water delivery system in the world well into the next century.

## Water Tunnel No. 3

 City Tunnel No. 3 is the largest capital construction project in New York City's history. Constructed by the New York City Department of Environmental Protection (DEP), the tunnel will eventually span more than 60 miles and is expected to be complete in 2020.  The activated portion of Tunnel No. 3, constructed in bedrock 250 to 800 feet below the surface, runs 13 miles and begins at Hillview Reservoir in Yonkers. It extends across Central Park to about 5th Avenue and 78th Street and stretches eastward under the East River and Roosevelt Island into Astoria, Queens.

 The size and length of the tunnel, its sophisticated control system, the placement of its valves in special chambers, and the depth of excavation, represent state-of-theart technology. While City Tunnel No. 3 will not replace City Tunnels No. 1 and No. 2, it will enhance and improve the adequacy and dependability of the water supply system and improve service and pressure to outlying areas of the city.



This map of the City indicates the general areas where water can be supplied by the Croton and Groundwater Systems when they are on-line. It is possible to supply the entire City from the Catskill/Delaware System.

### STAGE 1

 Similar to City Tunnels Nos. 1 and 2, Stage 1 of City Tunnel No. 3 begins at the Hillview Reservoir in Yonkers. About 13 miles long and constructed in bedrock 450 to 800 feet below the surface, Stage 1 extends south through the Bronx, into Manhattan and across Central Park. Leaving the park around Fifth Avenue and 78th Street.

Stage 1 stretches eastward under the **East River and Roosevelt Island into** Astoria, Queens. Stage 1 is a 24-foot diameter concrete-lined pressure tunnel, which steps down in diameter to 20 feet. As water travels along this route, it rises from the tunnel, via 14 supply shafts and feeds into the distribution system.

 Three of the four unique subsurface valve chambers have already been built to allow the connection of future stages of the tunnel without removing the water or taking any other stage of the tunnel out of service. The three valve chambers are located in the Bronx at Van Cortlandt Park (Shaft 2B), Manhattan at Central Park (Shaft 13B) and Roosevelt Island (Shaft 15B).

Each valve chamber contains a series of 96-inch diameter conduits with valves and flow meters to direct, control and measure the flow of water in sections of the tunnel. Stage 2 will provide water to the lower west side of Manhattan and sections of Queens, Brooklyn and Staten Island.

More importantly, Stages 1 and 2 will provide bypass capability of City Tunnels No. 1 or 2, which is essential to maintaining the entire water supply system and avoiding problems. Stages 1 and 2 are solely devoted to improving the distribution capability of the system and will not provide any additional supply of water.

### STAGE 2

 Stage 2 consists of two sections constructed separately: The Brooklyn/Queens section has two distinct legs. The five-and-a-half mile Brooklyn leg begins in Red Hook, Brooklyn, runs through the Brooklyn neighborhoods of Park Slope, Bedford-Stuyvesant and Bushwick, to Maspeth, Queens.

The Brooklyn leg connects with the previously constructed Richmond Tunnel now serving Staten Island. From Maspeth, the Queens leg runs five miles through the Queens communities of Woodside and Astoria. The Brooklyn leg of the tunnel is 16-feet in diameter and the Queens leg is 20-feet in diameter.

The nine-mile long Manhattan section is 10 feet in diameter. It begins at the Stage 1 valve chamber in Central Park and runs south along the west side of Manhattan, east to the vicinity of South Street Seaport.

### • STAGE 3

 Stage 3 involves the construction of a 16-mile long section of tunnel. It extends from the Van Cortlandt Park Valve Chamber in the Bronx to the Kensico Reservoir in Westchester County.

 Stage 3 will connect the Kensico Reservoir, which contains water from the Catskill and Delaware Systems, to the Van Cortlandt Park Valve Chamber. From the Valve Chamber, water can be delivered to City Tunnel No. 3 or to the Hillview Reservoir for delivery to City Tunnels No. 1 or 2.

When Stage 3 is completed, City Tunnel No. 3 will operate at greater pressure induced by the higher elevation of Kensico Reservoir. It will also provide an additional aqueduct to supply water to the city, which will parallel the Delaware and Catskill Aqueducts.

#### STAGE 4

 In Stage 4, water will be delivered to the eastern parts of the Bronx and Queens. This final stage will be 14-miles long and will extend southeast through the Bronx from the Van Cortlandt Park Valve Chamber. It will then travel under the East River into the Flushing area of Queens.

· In a design departure from the two existing tunnels, valves which control the flow of water in Tunnel No. 3 will be housed in large underground valve chambers, making them accessible for maintenance and repair.

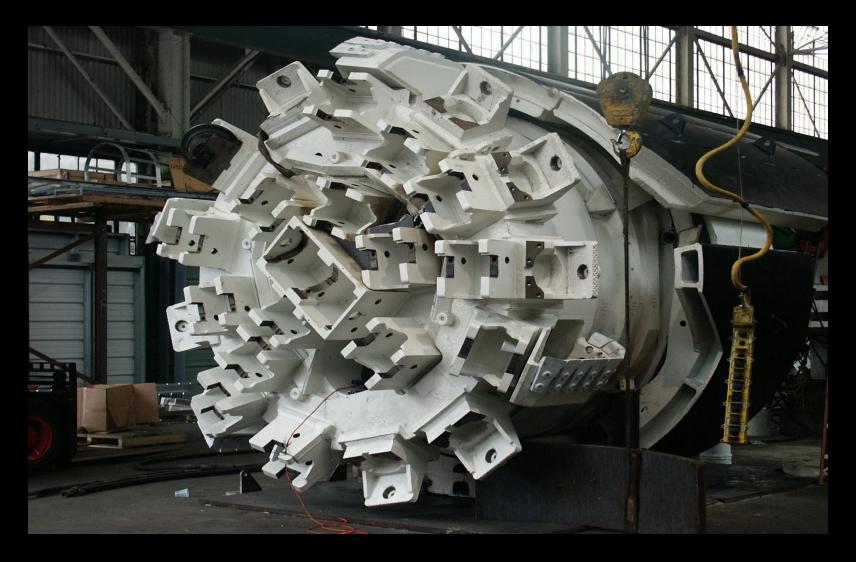
 The valves for City Tunnels No. 1 and 2 are at the tunnel level, and are inaccessible when the tunnels are in service. When City Tunnel No. 3 is completed, it will include four large underground valve/chambers, numerous riser shafts with riser valve and distribution chambers and surface access facilities.

 The largest of the valve chambers is in the Van Cortlandt Park complex. Built 250 feet below the surface, it will control the daily flow of water from the Catskill and Delaware water supply systems. These systems provide 90% of the city's drinking water.

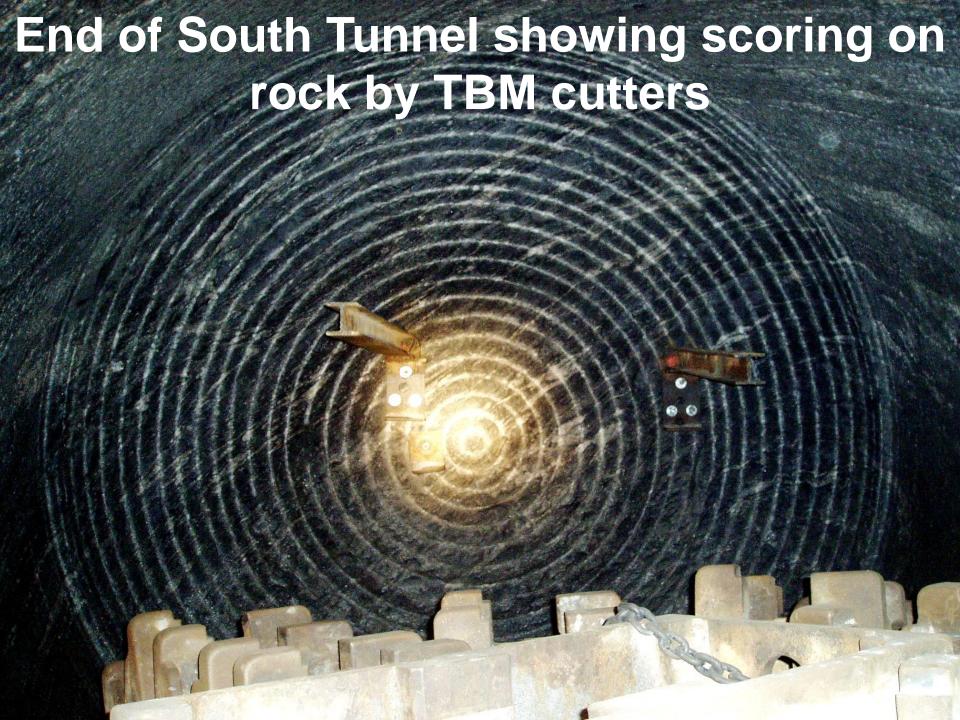
 The Van Cortlandt Park Valve Chamber is 620 feet long (longer than two football fields placed end to end), 42.5 feet wide and 41 feet high. The complex also contains nine vertical shafts; two manifolds - each more than 560 feet long and 24 feet in diameter - and 34 steel-lined lateral tunnels - each more than 100 feet long. Pressure and flow are controlled through a series of valves and flow meters.

- TUNNEL BORING MACHINE (TBM)
- Construction of Stages 2, 3 and 4 is greatly accelerated by a mechanical rock excavation technology not used before in City Tunnels. A tunnel boring machine (TBM), which has been lowered in sections and assembled at the bottom of the shaft, will chip off sections of bedrock through the continuous rotation of a series of steel cutting tools (cutters) mounted on a large-diameter, fullcircular, welded steel cutter head.

 The machine body of a TBM, which can be as long as 50 feet, is mounted behind the cutter head. It contains the drive motors and other electrical, mechanical and hydraulic equipment that provide the necessary thrust and torque that is transmitted to the cutters through the cutter head.



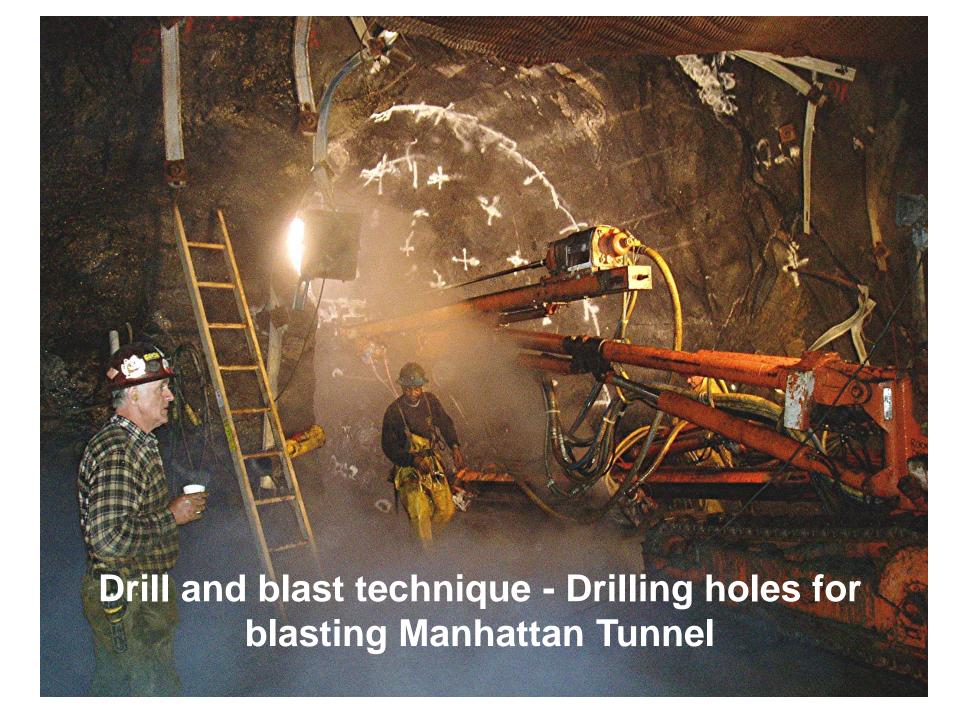
The TBM replaces the conventional drilling and blasting methods used during the construction of Stage 1. TBM excavation for NYC Water Tunnel #3 began in 1996.







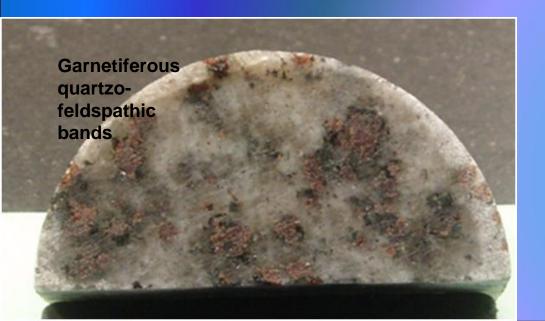


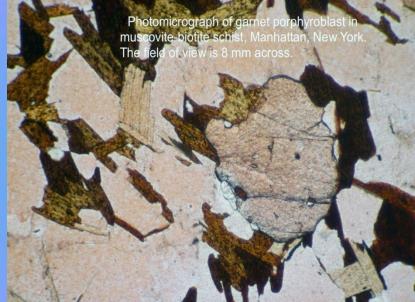




# **TUNNEL GEOLOGY**

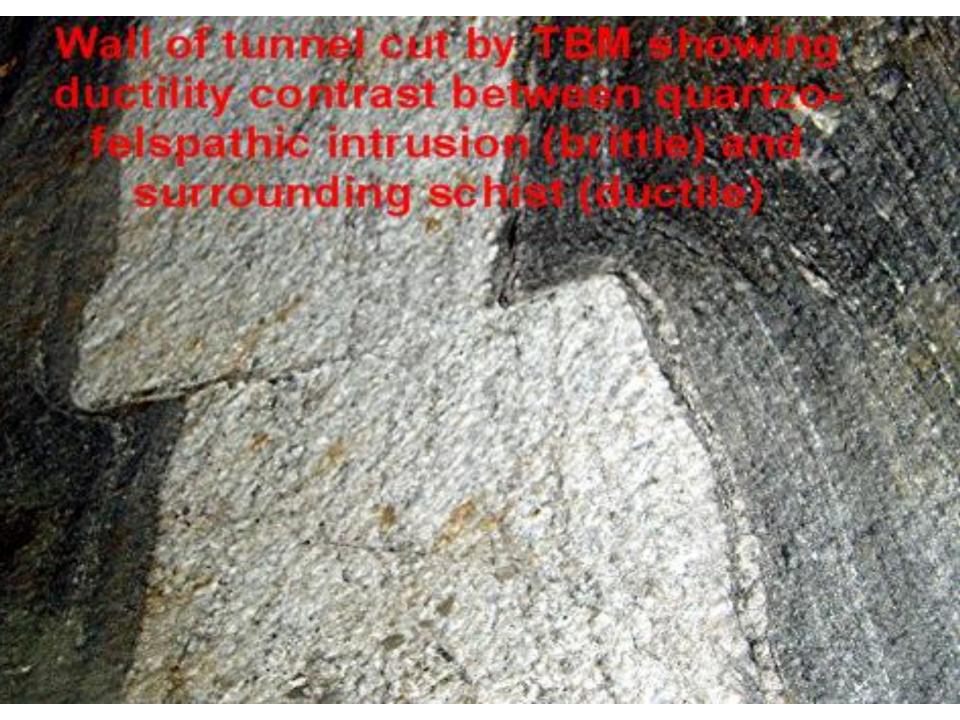
Important Rock Types
Thin Section Photomicrographs
Geological Interpretation

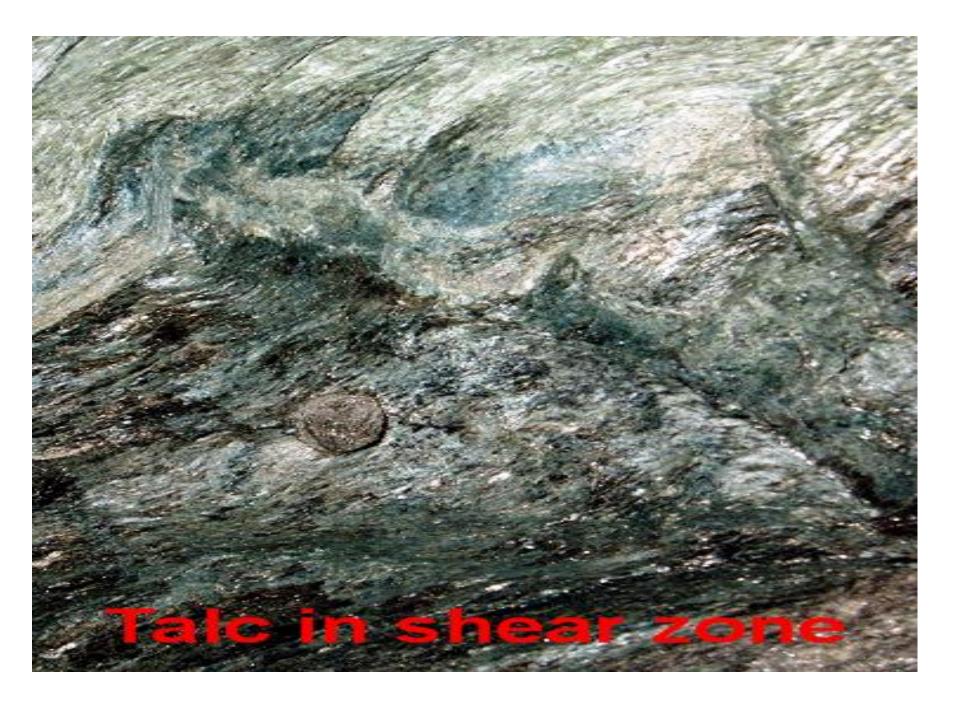




## Extremely Biotite-Phlogopite Rich Schist, Manhattan, N. Y.









## Coarse Grained 'Clean' Marble, Manhattan, N. Y.



#### Gametiferous Biotite-Muscovite Schist in Contact With Quartzo-Feldspathic Band



#### Garnetiferous Biotite Gneiss, Southern Manhattan, N. Y.



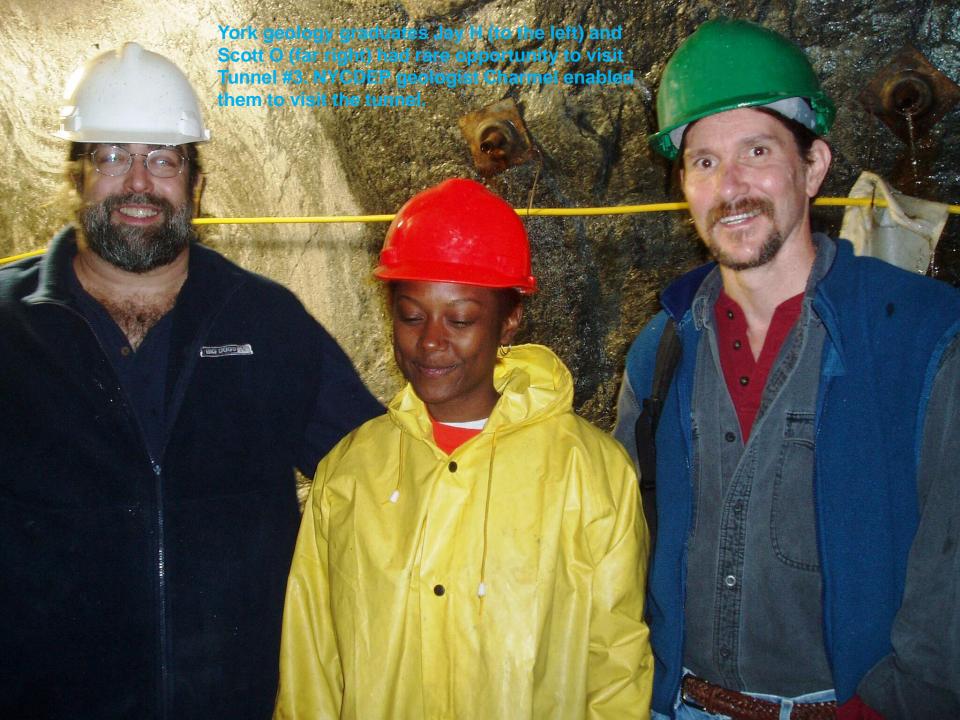


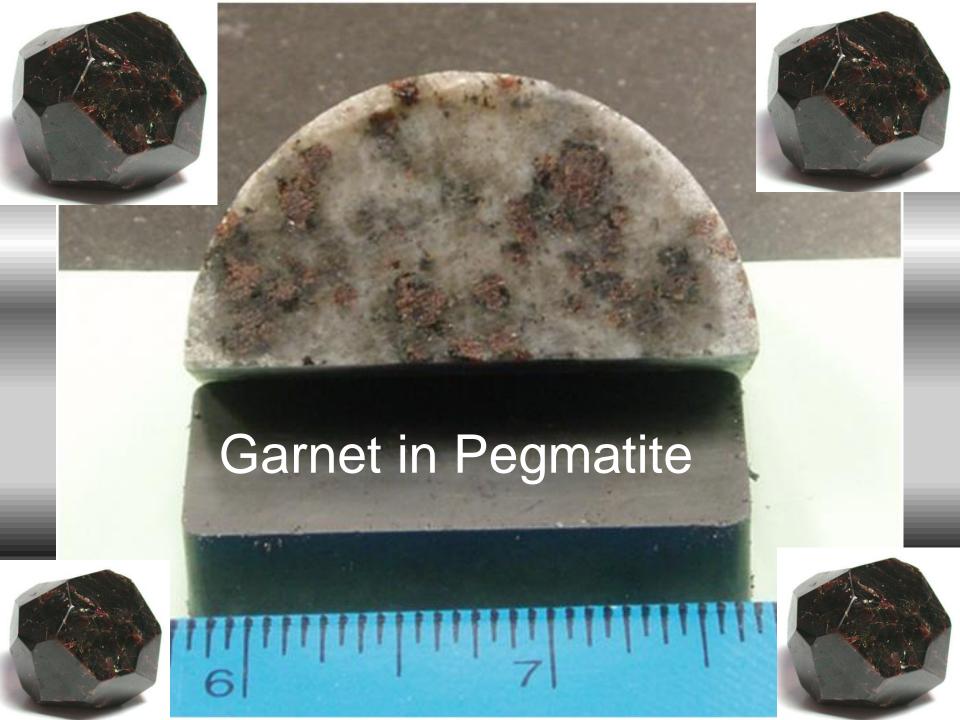
Typical Garnetiferous Muscovite-Biotite Schist of Manhattan

### Calcitic Marble With Numerous Pyritiferous Zones



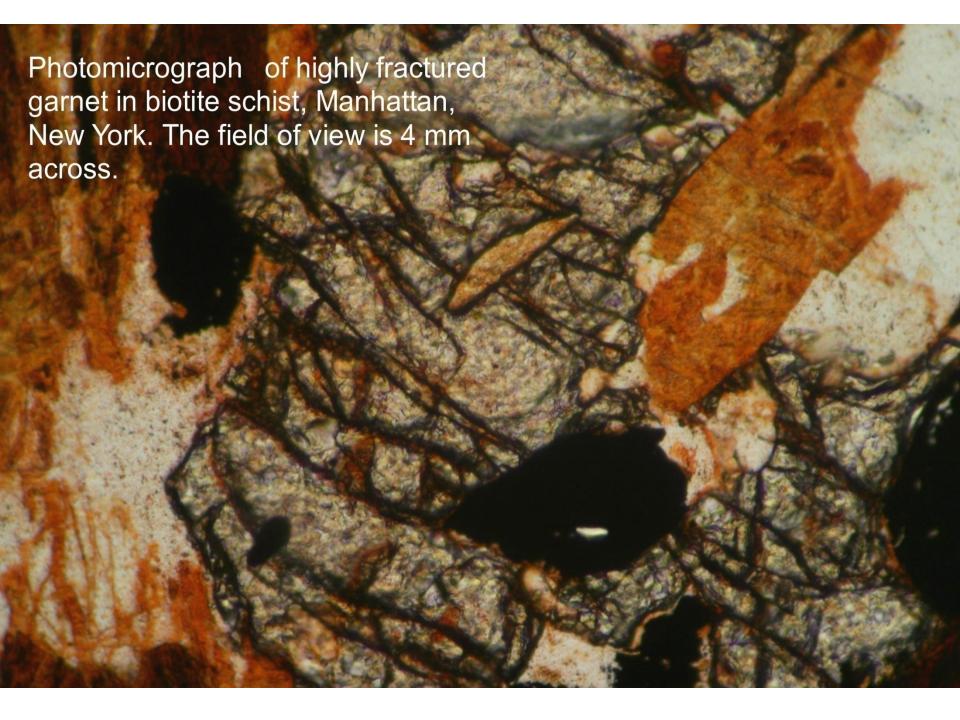
andaker (left) and Schleifer (right) of CUNY jointly inspected thousands of linear feet rock core ide the tunnel excavated by the TBM.

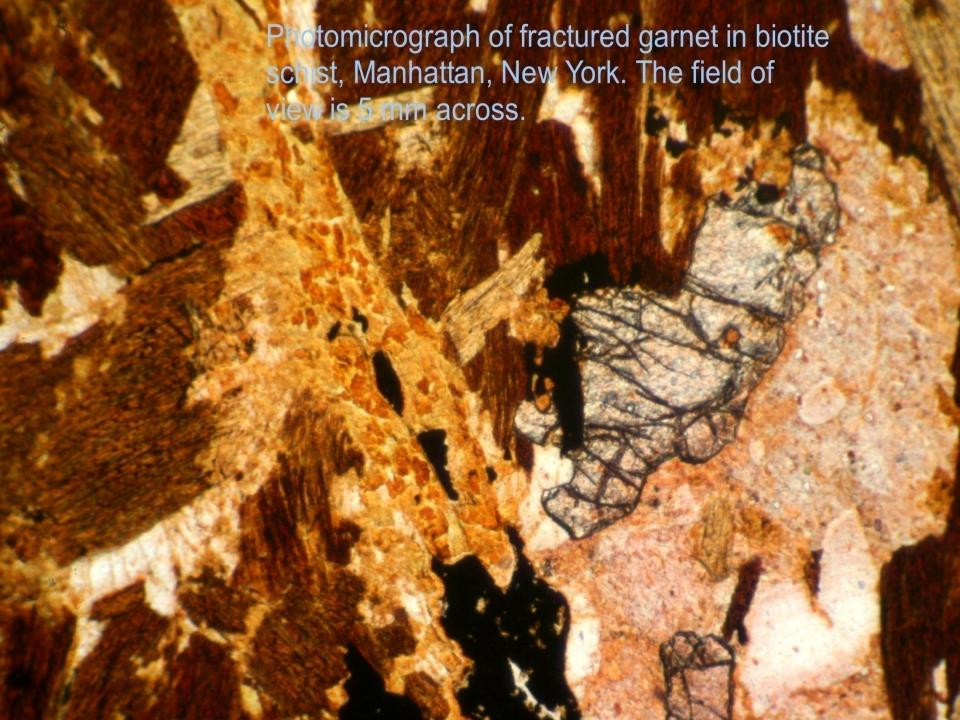


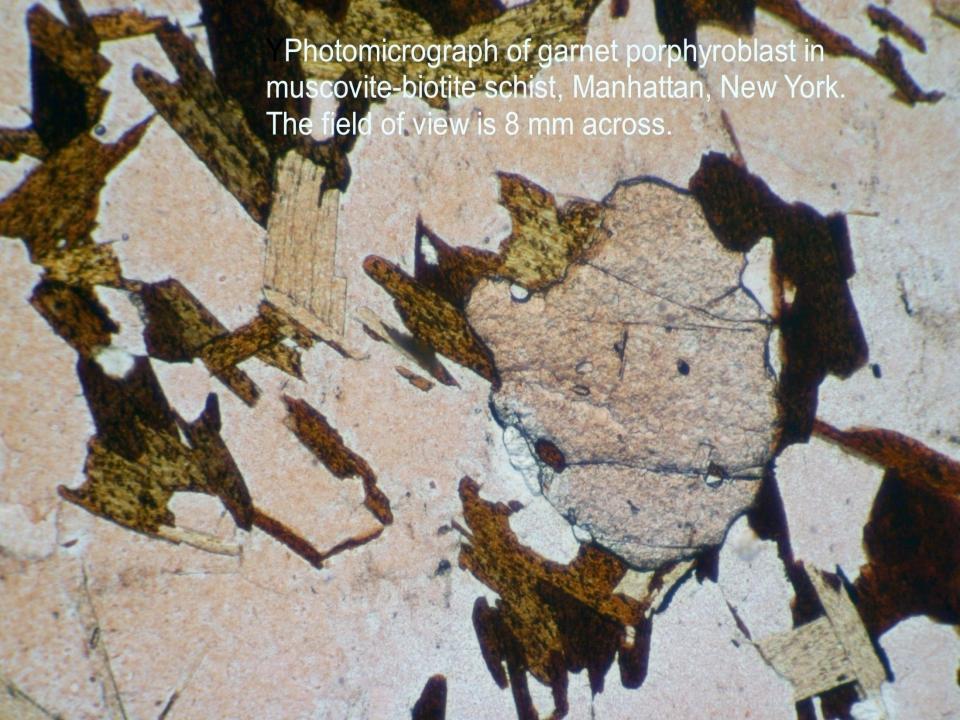


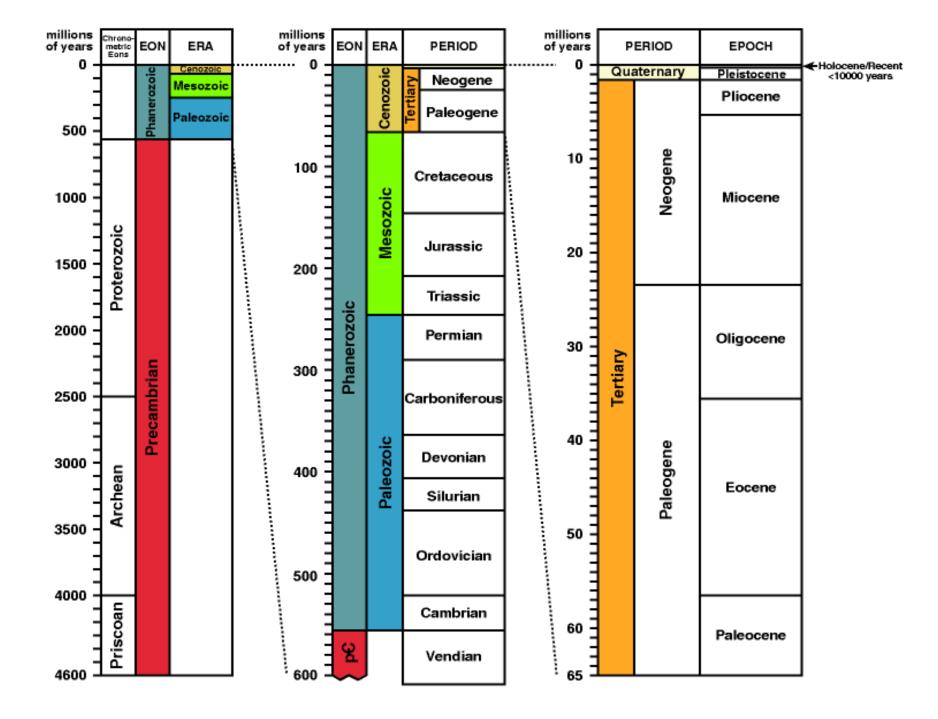
#### Contact Between Pegmatite and Biotite-Hornblende Schist

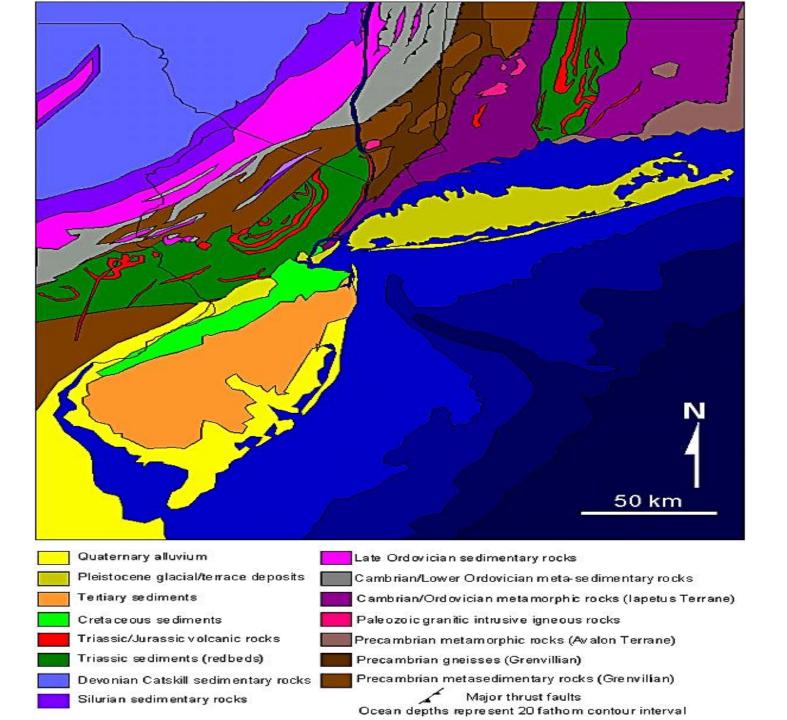




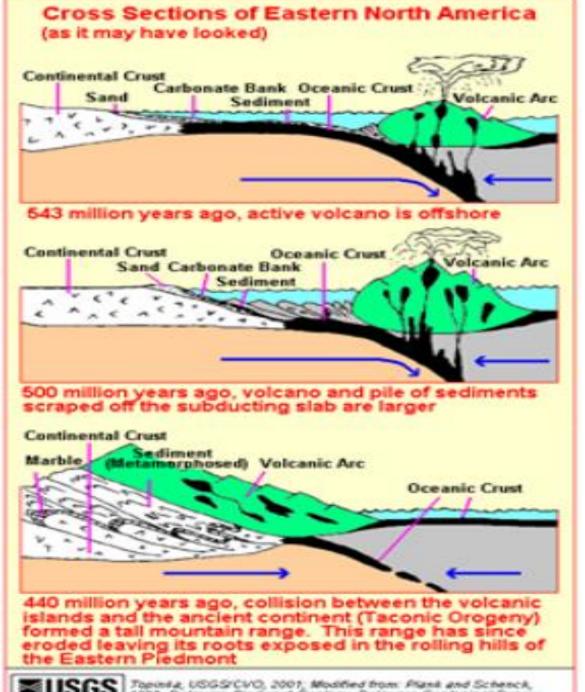












■USGS Topinsa, USGS/CVO, 2001; Modified from: Plant and Schenck, 1993, Delaware Predmont Geology, Delaware Geological Survey

## Conclusions

Geology plays a key role in the construction of the water tunnel. Acquisition of proper geological information is vital to any tunnel construction in terms of resources, time, and most importantly welfare of personnel involved in tunnel construction.

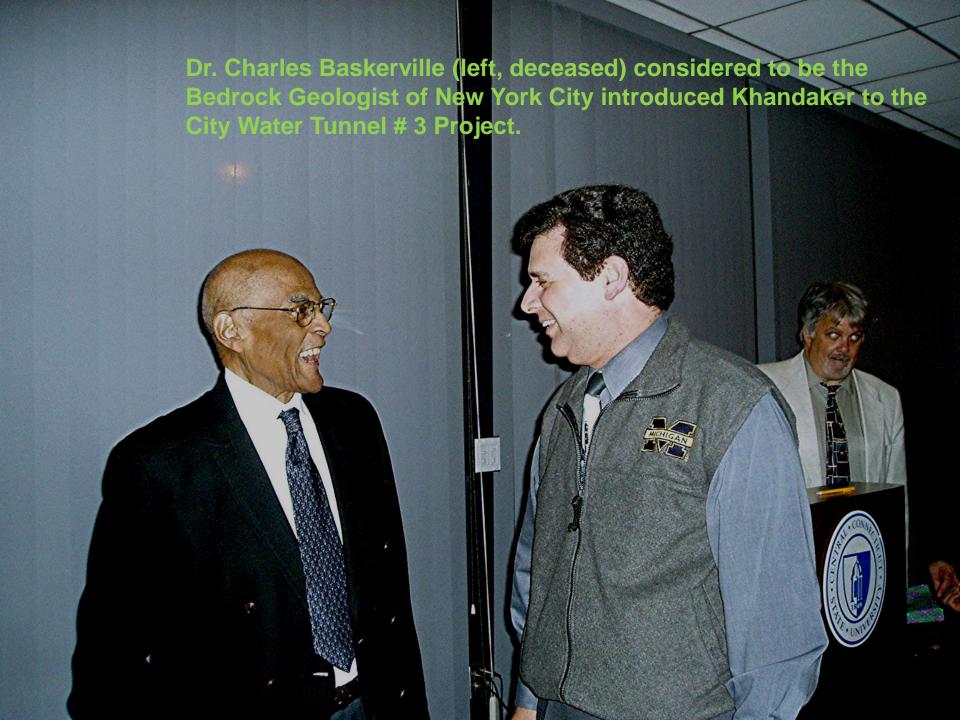
Manhattan portion of the City Water Tunnel opened-up a plethora of geological treasure both for academics and geotechnical personnel.

Geotechnical challenges included weathered zones, caving, water seepage, and at times greater anisotropic in terms of bedrock geology and structural fabric.

TBM/drilling operation dependent on local conditions and daily rate ranged from tens of feet to 200 feet.

Presence of garnetiferous unit coupled with quartzo-feldspathic bands and aplite often slowed down TBM progress; however these were not uniformly distributed throughout the entire tunnel alignment. **Currently the Geology Discipline** has a contract with the URS Corporation to investigate core samples obtained from the proposed route from Kensico Reservoir to Hillview Reservoir. This will allow us to involve geology majors and give them hands-on training in geotechnical techniques.









## Conference Presentations Involving Tunnel Geology

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\*\* York College Geology Students

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**Belal Sayeed (Jenny Engineering)** 

