REDEFINING THE SOUTHERN TERMINUS OF THE INTRUSIVE CONTACT BETWEEN THE YONKERS AND FORDHAM GNEISS IN VAN CORTLANDT PARK, NEW YORK CITY, NEW YORK

ISLER, Douglas, E.
Haley & Aldrich, 465 Medford Street, Boston, Massachusetts 02129, USA

VELLONE, Daniel, A.*
Malcolm Pirnie, Inc., 104 Corporate Park Drive, White Plains, New York 10602, USA
dvellone@pirnie.com

MERGUERIAN, Charles
Geology Department, 114 Hofstra University, Hempstead, New York 11549, USA

and

MERGUERIAN, J. Mickey
Geology Department, 114 Hofstra University, Hempstead, New York 11549, USA

ABSTRACT

Following the excavation of tunnels originating within Van Cortlandt Park for the construction of the Croton Water Treatment Plant in Bronx, NY, project geologists were able to identify and map the contact between the Yonkers Gneiss (Zy) and the Fordham Gneiss (Yf) formations in the side-wall of tunnel excavations. The particular orientation of tunnel excavations for the project provided a unique opportunity to view the contact at three separated locations along the tunnel alignment, redefining the southern terminus of the Yonkers gneiss intrusive into the Fordham gneiss complex. Based upon observations of the field and petrographic relationships of the rock masses exposed during tunneling operations, the contact of the Yonkers gneiss can be re-drawn from its current southern limit as shown by Baskerville (1992; 1989), Fluhr and Terenzio (1984) and Fluhr (1967) to extend farther southward in contact with the Mosholu fault at the southern end of Van Cortlandt Park.

INTRODUCTION

The Croton Water Treatment Plant (CWTP) is part of the New York City Department of Environmental Protection (NYCDEP) Bureau of Engineering, Design and Construction project to upgrade the water supply system, improve water quality and ensure compliance with stricter water quality standards. The CWTP is presently under construction in Van Cortlandt Park below the driving range of the Mosholu Golf Course and will have an estimated design capacity of 290 million gallons per day. Upon completion, the facility will provide filtration and disinfection for Croton system water conveyed to New York City through the New Croton Aqueduct (NCA). Three tunnels are under construction that connect flow from the existing NCA tunnel and will intercept and connect this raw water with the new water treatment plant onto the Jerome Park Reservoir (Figure 1). The high and low-level treated water tunnels were created by Tunnel Boring Machine (TBM) technology and the raw water tunnel was produced using conventional drill-and-blast technology.

* Corresponding Author

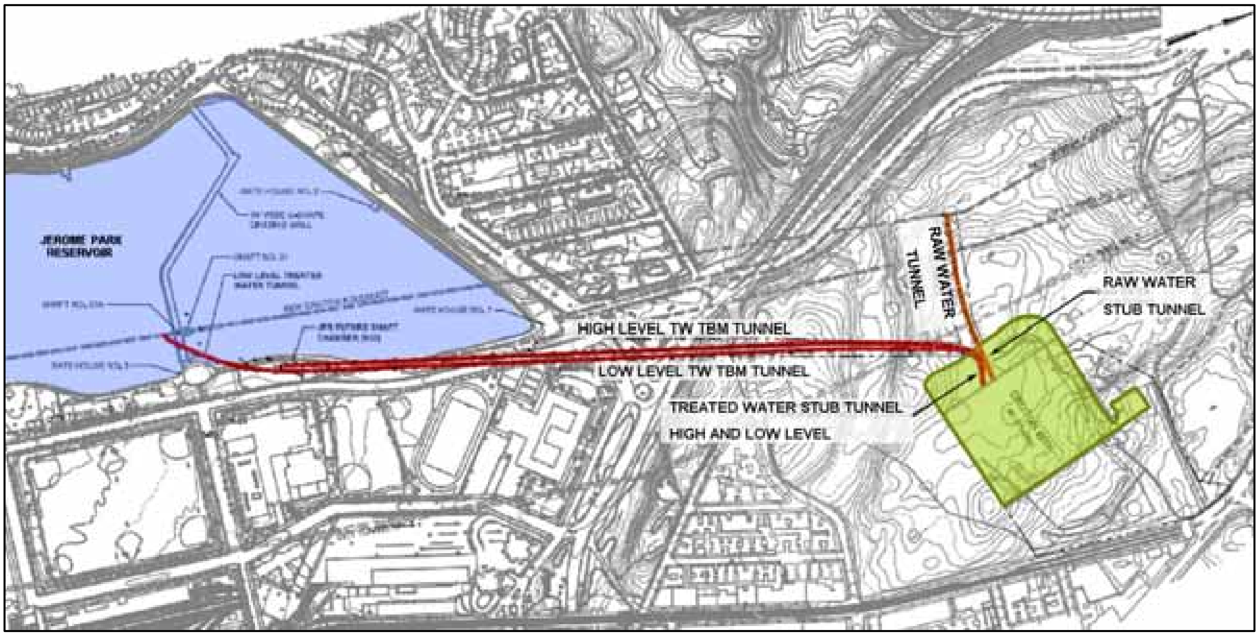

Figure 1 – Index map showing the location of the high-level treated, low-level treated, and raw water tunnels (red lines) with respect to the new Croton Water Treatment Plant (green) and the Jerome Park Reservoir (blue). Note north arrow in upper right corner.

Tunnel mining and excavation was accomplished using drill-and-blast and tunnel boring operations using a Robbins high performance open main beam TBM for both treated water tunnels. Connecting the CWTP and the Jerome Park Reservoir shaft chamber, the low and high-level tunnels are approximately 3,650 feet and 3,150 feet in length, respectively, and 13.5 feet in diameter. The raw water tunnel is horseshoe-shaped, 14.5 feet by 14.5 feet, excavated using conventional drilling-and-blasting approximately 865 feet in length between the CWTP and the NCA.

GENERALIZED GEOLOGY OF THE NEW YORK CITY METROPOLITAN REGION

The New York City Metropolitan region is characterized by complex geology and structure as it overlies three physiographic units, namely, the New England Upland on the northwest, the Triassic Lowland on the southwest, and the Atlantic Coastal Plain to the southeast. New York City is situated at the extreme southern end of the Manhattan Prong, a northeast-trending, deeply eroded sequence of metamorphosed Proterozoic to Lower Paleozoic rocks that widen northeastward into the crystalline terrains of New England. The Manhattan Prong is a landscape of rolling hills and valleys whose configurations are closely controlled by the structure and lithology of the underlying bedrock. The hilly terrains are underlain by rocks that are resistant to erosion (Fordham Gneiss, Yonkers Gneiss and by various schists and gneisses of the Manhattan, Walloomsac, and Hartland formations). Generally, the valleys are underlain by brittle faults or by the Inwood Marble because of carbonate weathering susceptibility. Roughly 450 million years ago, during the Taconic orogeny, the rocks of the Manhattan Prong were tightly folded and metamorphosed. Consequently, complex fold and fracture patterns have resulted from many stages of polydeformation. The geologic structure of metamorphic bedrock is typically dominated by surfaces of foliation and gneissic layering produced by recrystallization and attendant preferential alignment of platy minerals within the rock.

The tunnel alignment is predominantly through the Fordham Gneiss complex (Yf in Figure 2), which constitutes the oldest underpinning of rock formations in the New York City area and consists of a complex assemblage of Proterozoic Y ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks (Merguerian, 2005a). Ductile deformation associated with several orogenic events has produced widespread mylonitic fabrics in the rock. In addition to metasedimentary facies, metamorphosed mafic intrusives and several granitoid intrusives, all of uncertain but presumably of Proterozoic Y and younger age, are quite numerous. Multiple sets of less deformed pegmatite dikes further cross-cut localized banded, mafic- and leucocratic migmatitic gneisses. The Yonkers gneiss (Zy in Figure 2) is a leucocratic rock mass of Proterozoic Z age and consists in this area of laminated and highly foliated granitoid gneiss with abundant xenoliths of Fordham gneiss rock types and late, presumable Paleozoic, pegmatite intrusives. Both lithologic and petrographic differences are marked between the seemingly similar leucocratic members of the Fordham and Yonkers gneisses.

GEOLOGICAL MAPPING

As part of the Construction Management services for the NYCDEP, a well-planned geological mapping program was executed during the as-built stage of construction to develop an appropriate visual and quantitative representation of the rock mass to characterize and document tunnel lithological and structural conditions for archival purposes. The recording of geologic features consisted of full-periphery circumferential mapping at the scale of 1" = 10' in the low-level treated water tunnel as discussed in Vellone and Isler (2008) and line-mapping at the scale of 1" = 5' was performed for the north sidewall of the raw water tunnel excavation and the east sidewall in the high-level treated water tunnel (see Figure 1). In addition, photographic documentation was made of key geologic features and structures.

Tunnel mapping was performed in general accordance with industry convention, as outlined in the reference document ASTM D4879 "Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock," with the noted variation that the reference orients the crown of the tunnel through the center of the map section, with the invert drawn at the map edges; a technique that permits an "outside looking in" view of the structural and lithological relationships. Instead, it was considered desirable for this application to represent the tunnel crown at the map's edges and the invert through the center of the map to account for the partial visual obstruction during mapping due to the presence of the 42-inch diameter ventilation duct suspended from the crown. This visual imparity was overcome by initial observations made during tunnel excavation advancement, prior to the placement of the ventilation line. This technique permits an "inside looking out" view of the bored tunnel excavation, consistent with prior New York City tunnel mapping performed by Merguerian (1999; 2000; 2002; 2003; 2005a).

GENERALIZED TUNNEL GEOLOGY

The general lithology along the tunnels and shafts consists of Fordham Gneiss Members A and B and Yonkers orthogneiss in Fordham Gneiss Member A. The Fordham Gneiss (Yf on engineering geologic map, Figure 2) constitutes the oldest underpinning of rock formations in the New York City area and consists of a complex assemblage of Proterozoic Z ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks (Merguerian, 2005a). In New York City, only a few attempts have been made to decipher the internal stratigraphic relationships; hence, the three-dimensional structural relationships remain obscure. Based upon earlier detailed studies in the Queens and Brooklyn water tunnels by Merguerian 2000; Merguerian, Brock, and Brock 2001; Brock, Brock, and Merguerian 2001, the Fordham consists of predominantly massive mesocratic, leucocratic, and melanocratic orthogneiss, with subordinate schistose rocks. During the Grenville orogeny, the rocks were metamorphosed to the high pressure granulite facies, which locally produced a tough, anhydrous interlocking mineral texture (Merguerian, 2005b).

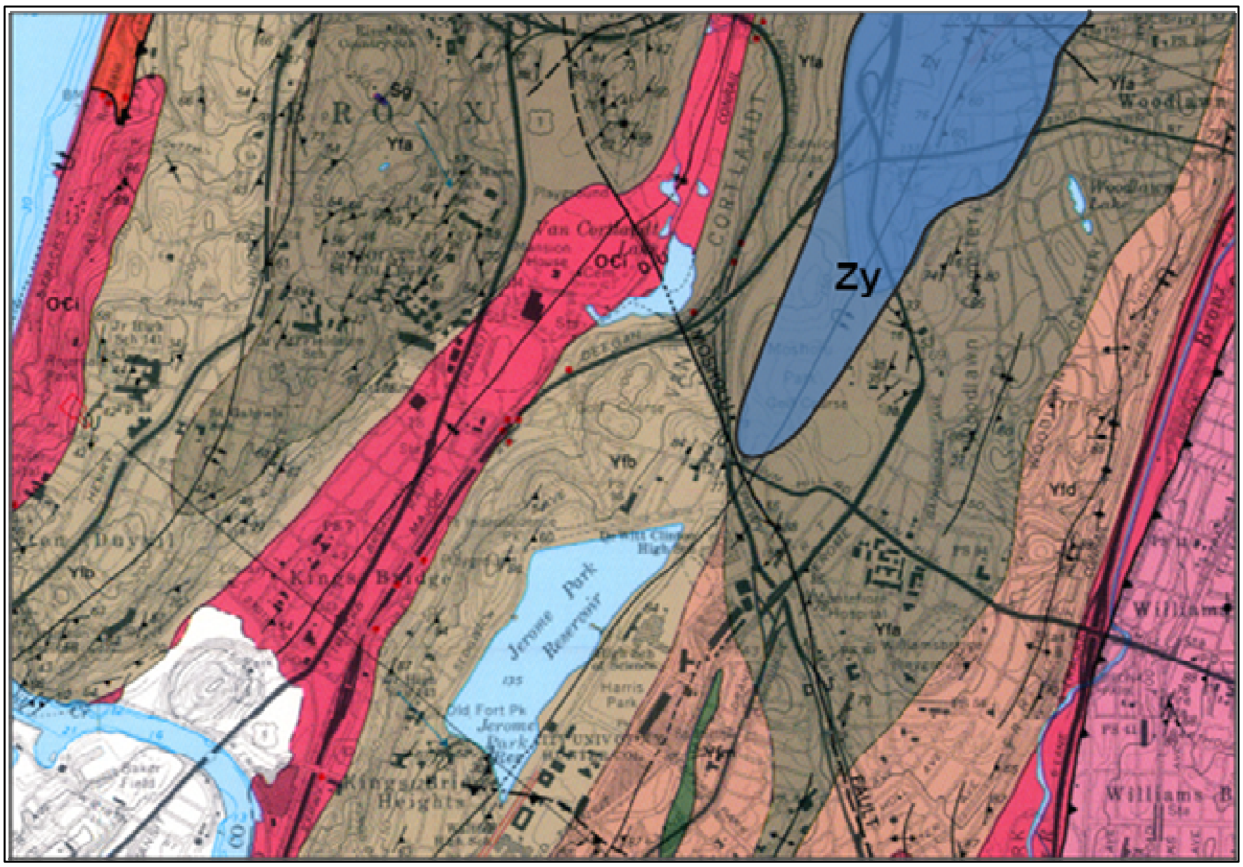

Figure 2 - Bedrock map of the tunnel alignment with proposed southward revision of the geologic contact between the Yonkers (Zy - blue) and Fordham (Yf – brown and tan) gneisses based upon observations following the excavation of two tunnels advanced using Tunnel Boring Machine (TBM) method. (Basemap after Baskerville, 1992)

The tectonic/stratigraphic units of the region have been displaced along isoclinally folded and imbricated ductile thrust faults (Merguerian, 1996). The ductile faults now appear as steep, complexly folded and migmatized zones of commingled mylonitic rocks. Widespread mylonitic fabrics in the rock can be seen following tunnel excavation (Vellone and Isler, 2008). Banded gneisses display well-developed compositional layering and strong foliation, defined by preferred orientations of quartzofeldspathic aggregates. The banded gneiss grades into more homogeneous and less strongly foliated granitic gneiss, which has a lower content of mafic minerals compared to the banded gneiss. Metamorphosed and tectonically sutured mafic intrusives and several granitic intrusive events, all of uncertain ages, are quite numerous. Multiple sets of less deformed pegmatite dikes and veins further cross-cut localized banded, leucocratic, granitic and migmatitic gneisses.

Along the tunnel alignment, two of the major joint sets strike NW-SE, while the third occurs along gneissic layering (foliation). Foliation strikes on average N10°E; however these readings can vary due to the localized effects of faulting and shouldering by nearby intrusives. Several NNW-SSE joints have created blocky conditions. The NW-trending Mosholu fault zone (see Figure 2) is surprisingly narrow but displays pervasive brecciation and chlorite alteration. Vellone and Isler (2008) identified that the Mosholu fault trends approximately N42°W, 88°SW and occurs approximately at low-level treated water tunnel Station 26+55. Here, mylonitic foliations displayed pervasive chlorite alteration and strong cleavage defined by preferred orientation of micas. The Mosholu fault zone was initially anticipated to span an approximately 1,000 foot section along the TW tunnel alignments based upon engineering for the construction of both City Water Tunnel Nos. 1 and 3; however, it was encountered as a significantly narrow and more discrete occurrence in the Croton tunnels. The Mosholu fault, as observed following the low-level treated water tunnel and high-level treated water tunnel excavations, consisted of an abrupt zone of retrograde metamorphic alteration, varying between 8 to 24 inches thick, of chloritic clayey gouge which bisects the tunnel alignment at a high angle. This chloritic zone is flanked on either side by brecciation and aligned biotite, chlorite, and graphite and is permeated by pyrite mineralization. Most of the joint surfaces are continuous and mineralized, many contain slickensides and some show slickenlines that indicate sub-horizontal offset. As found elsewhere along NW-trending faults in the region (Merguerian, 2002), pyrite-rich zones are observed suggesting hydrothermal alteration due to subsequent sulfide-rich fluid flow. Movement along the Mosholu fault is believed to have been dominantly right lateral, although a complex movement history is indicated by offsets and superimposed slickenlines along variously oriented steeply dipping surfaces (Merguerian, 1996).

THE YONKERS - FORDHAM CONTACT

The Yonkers Fordham contact has been observed in all three tunnels, and as a result, a redrawing of the geological contact presented by Baskerville (1992; 1989), Fluhr and Terenzio (1984) and Fluhr (1967) is necessary (see Figure 2). In addition to location, observations and analysis indicate extreme differences in lithology, internal structure, and metamorphism between the two formations as outlined below. Together, this investigation evidences that the Yonkers is clearly an orthogneiss (metaplutonic rock) and that the Mosholu fault has been controlled by rupture along the Yonkers-Fordham contact.

Mapping by Vellone and Isler (2008) in the low-level treated water tunnel (Figures 3 and 4) has localized the Yonkers-Fordham contact and provided significant geological details on the differences between the two formations. Since TBM excavation and geologic mapping of the low-level tunnel was completed prior to the advancement of the high-level tunnel, full-periphery mapping was not performed in the high-level treated water tunnel. Instead, line mapping was performed along the tunnel springline and digital images recorded observations of structural controls and textural and megascopic mineralogic composition of the rock (Figure 5). Observations of the high-level treated water tunnel were found to be in agreement with those made in the low-level tunnel. Mapping, photo imaging, and petrographic analysis of the Yonkers and Fordham in the raw water tunnel by the Merguerians has supported the observations and primary conclusions provided by Vellone and Isler and has helped document the field relationships, geometry, and petrographic differences between the two rock masses (Figures 6-9).

Low-Level Treated Water Tunnel

Mapping by Vellone and Isler in the low-level treated water tunnel and observations by all authors during three visits between December 2008 and January 2009 have differentiated the occurrence of the Yonkers-Fordham contact in all three tunnels. At low-level treated water tunnel Station 36+90 interlayered migmatitic gneiss, biotite schist, and amphibolitic gneiss of the Fordham is in intrusive contact with massive well-foliated granitoid Yonkers gneiss along a permeated contact cut by late pegmatite (Figure 3). The Fordham is intruded by sill-like injections of Yonkers granitoid leading up to the contact and the Yonkers contains abundant xenoliths and screens of Fordham amphibolitic gneiss within ~270 feet of the contact zone.

The amphibolitic gneiss inclusions are few and far between after low-level treated water tunnel Station 34+20 where massive granitoid gneiss predominates. At low-level treated water tunnel Station 26+65 (northwest wall) the contact with the Fordham is permeated by lit-par-lit injections of Yonkers granitoid and cut by the Mosholu fault (Figure 4). Thus, nearly 1,025 feet of Yonkers gneiss is exposed in the low-level tunnel. Farther down station the Fordham predominates as interlayered felsic and mafic gneiss with schistose rock and migmatitic gneiss and continues down-station southward along the alignment. Although internally sheared and cut by brittle faulting, the Yonkers shows a clear intrusive relationship with the Fordham and a broad zone of permeation illustrating the former igneous parentage of the rock unit.

High-Level Treated Water Tunnel

At high-level treated water tunnel Station 37+30, migmatitic gneiss and amphibolitic gneiss of the Fordham is in intrusive contact with massive well-foliated granitoid Yonkers gneiss along a permeated contact cut by late pegmatite. The examination of the high-level treated water tunnel indicates that Yonkers gneiss also crops about 20 feet from the trace of the Mosholu fault at high-level treated water tunnel Station 26+95. The Mosholu fault exhibits an 8 inch gouge zone (located at high-level treated water tunnel Station 26+75) and may have utilized the mechanical difference between well-layered and foliated Fordham Gneiss and massive Yonkers Gneiss. The contact zone in the Fordham is permeated by granitoid injections of Yonkers gneiss (Figure 5). Thus, nearly 1,035 feet of Yonkers gneiss is exposed in the high-level tunnel. As seen in the low-level tunnel, continuing from the Mosholu fault zone farther down station and southward along the alignments, Fordham Gneiss predominates.

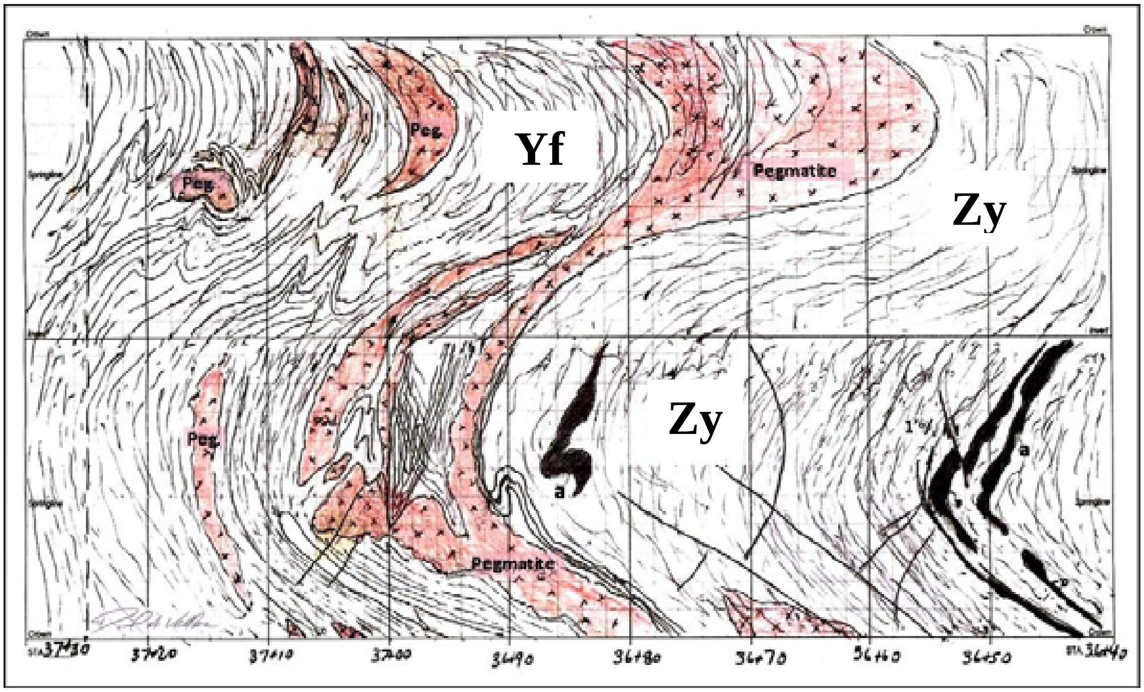

Figure 3 - Full-periphery geologic map of the low-level treated water tunnel Station 37+30 to 36+40 that shows complexly deformed Fordham Gneiss (Yf) and younger pegmatite injections (pink) and locally sheared inclusions of granulite-facies amphibolite gneiss (black) within the Yonkers Gneiss (Zy) encountered during TBM tunnel excavation (from Vellone and Isler, 2008).

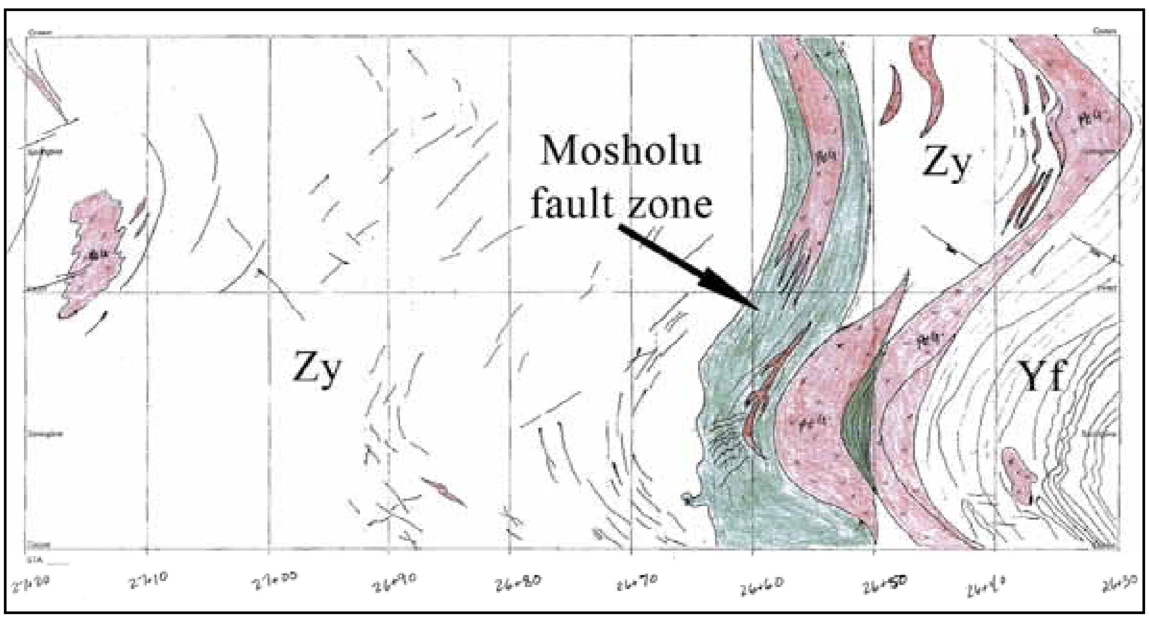

Figure 4 - Full-periphery geologic map of the low-level treated water tunnel Station 27+20 to 26+30 that shows jointed Yonkers Gneiss (Zy) in contact with complexly deformed Fordham Gneiss (Yf) along the Mosholu fault zone (green). Younger pegmatite injections are shown in pink (mapping by D.A. Vellone, 2008).

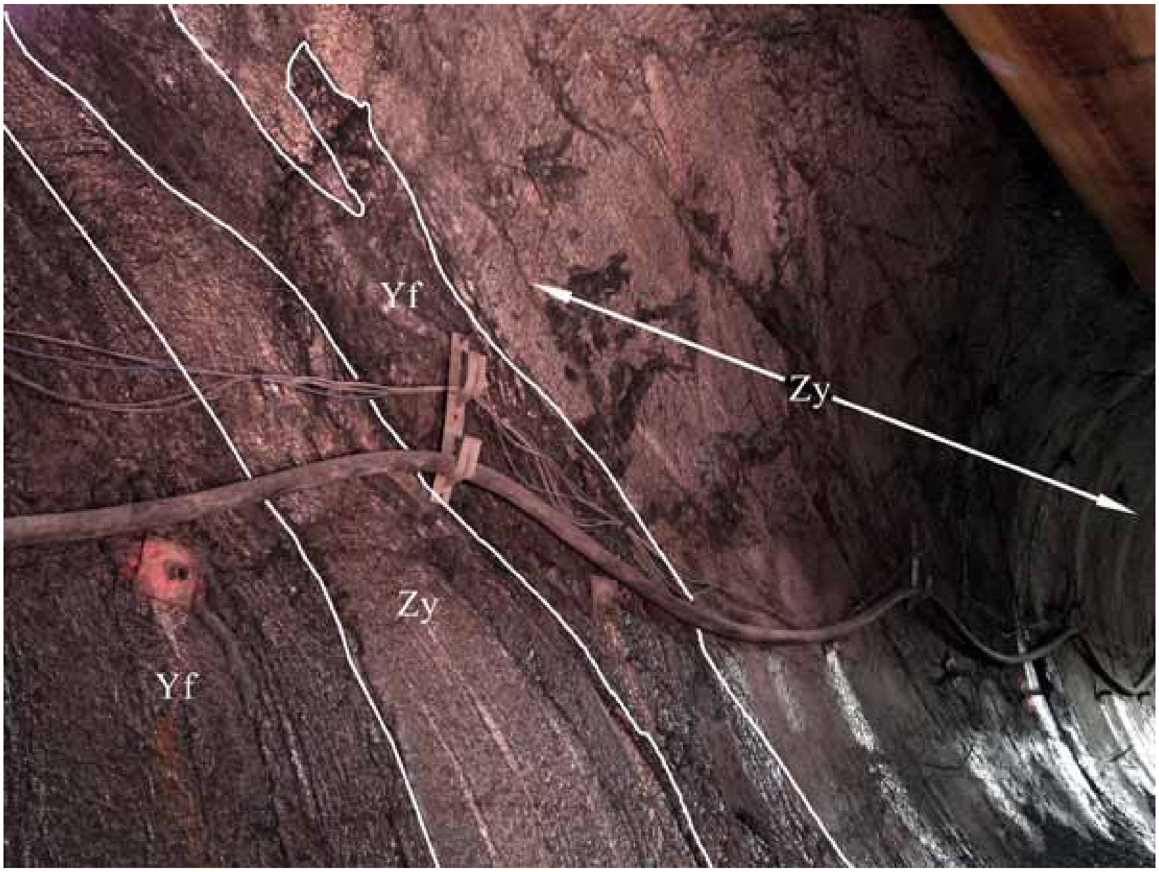

Figure 5 – View of southeast wall of high-level treated water tunnel showing permeated and deformed contact of Fordham Gneiss (Yf) with Yonkers Gneiss (Zy). (Digital image of Station 26+95 and annotations by C. Merguerian.)

Raw Water Tunnel

The Raw Water Tunnel is at an elevation located approximately 50 feet below, and at a high angle to the two treated water tunnels (see Figure 1) and when completed will bring untreated water from the Croton Aqueduct up gradient (~11 percent slope) to the Croton Water Treatment Plant. During site visits between December 2008 and January 2009, a series of high resolution digital images of the north wall of the tunnel were captured prior to concrete tunnel lining. Since the tunnel was excavated using conventional drill-and-blast technology and was fairly well illuminated, time-exposure photography was used in combination with supplemental lighting in some instances, to document the geological relationships.

Rocks found in the Raw Water Tunnel came from the same two formations – the Yonkers and Fordham gneisses. The Fordham Gneiss of Proterozoic Y age consists of banded and interlayered blackish and whitish gneiss and schist (Figure 6). The mafic layers consist of coarse-textured green to light-green amphibole (hornblende) and clinopyroxene together with subordinate flattened plagioclase and quartz and aligned biotite. The felsic interlayers consist predominately of plagioclase with lesser K-feldspar (+/- perthite) and quartz, together with aligned biotite. The pervasive layering and compositional variation of the rock types suggests a metasedimentary or metavolcanic origin. Mingled with the banded portion of the Fordham are thick massive layers and irregular masses of clinopyroxene-hornblende-plagioclase-biotite mafic gneiss showing alteration to calcite, interpreted to be the product of metamorphism of former mafic intrusives.

Figure 6 - Typical well-layered and foliated Fordham Gneiss (Yf). Station 5+85, north wall raw water tunnel, Croton Water Treatment Plant, Bronx, New York. (Digital image by C. Merguerian).

The Yonkers Gneiss of Proterozoic Z age (Figure 7) contains many screens and xenoliths of Fordham lithotypes, particularly near the contact, and consists of pinkish, light- and dark-gray granitoid gneiss with laminated to well-layered appearance. The microscope shows that the rock consists of crudely aligned potash feldspar (both microcline and orthoclase in varying proportions), quartz, and plagioclase (up to 95 percent) together with biotite and alkalic hornblende as primary phases. Metamorphic recrystallization has resulted in crudely foliated textures in the quartzofeldspathic areas with reduction in crystal size suggesting high strain. Small pleochroic biotite crystals are aligned parallel to and bounding the feldspar and quartzose segregations.

Figure 7 - Typical Yonkers Gneiss (Zy). Station 5+50, north wall raw water tunnel, Croton Water Treatment Plant, Bronx, New York. (Digital image by C. Merguerian).

Thus, there are profound mineralogical and textural differences between similar appearing litholgies in the Fordham and Yonkers gneiss units. Firstly, the Yonkers does not contain a mafic facies. In comparing the felsic rocks, the feldspars show marked difference in composition and relative proportion. Alkalic sea-green colored amphibole was found in the Yonkers gneiss (N810, 811, 812) but only light green amphibole in the Fordham felsic rocks (N815A). The Fordham contains two different alignments of biotite foliation and late, idioblastic biotite overgrowths while the Yonkers presents a simpler, crude foliation dominated by segregations of quartzofeldpathic minerals and biotite alignment.

In addition to 17 overlapping high-resolution digital images, 21 field stops and 8 rock samples were collected from the raw water tunnel for petrographic study. The annotated composite profile shown as Figure 8 is the result of the investigation with the geological observations tabulated below. Occurring as a screen in the Yonkers (N813 in Figure 8), the Fordham mafic gneiss shows relict replacement textures (amphibole replacing clinopyroxene) indicating a former plutonic origin.

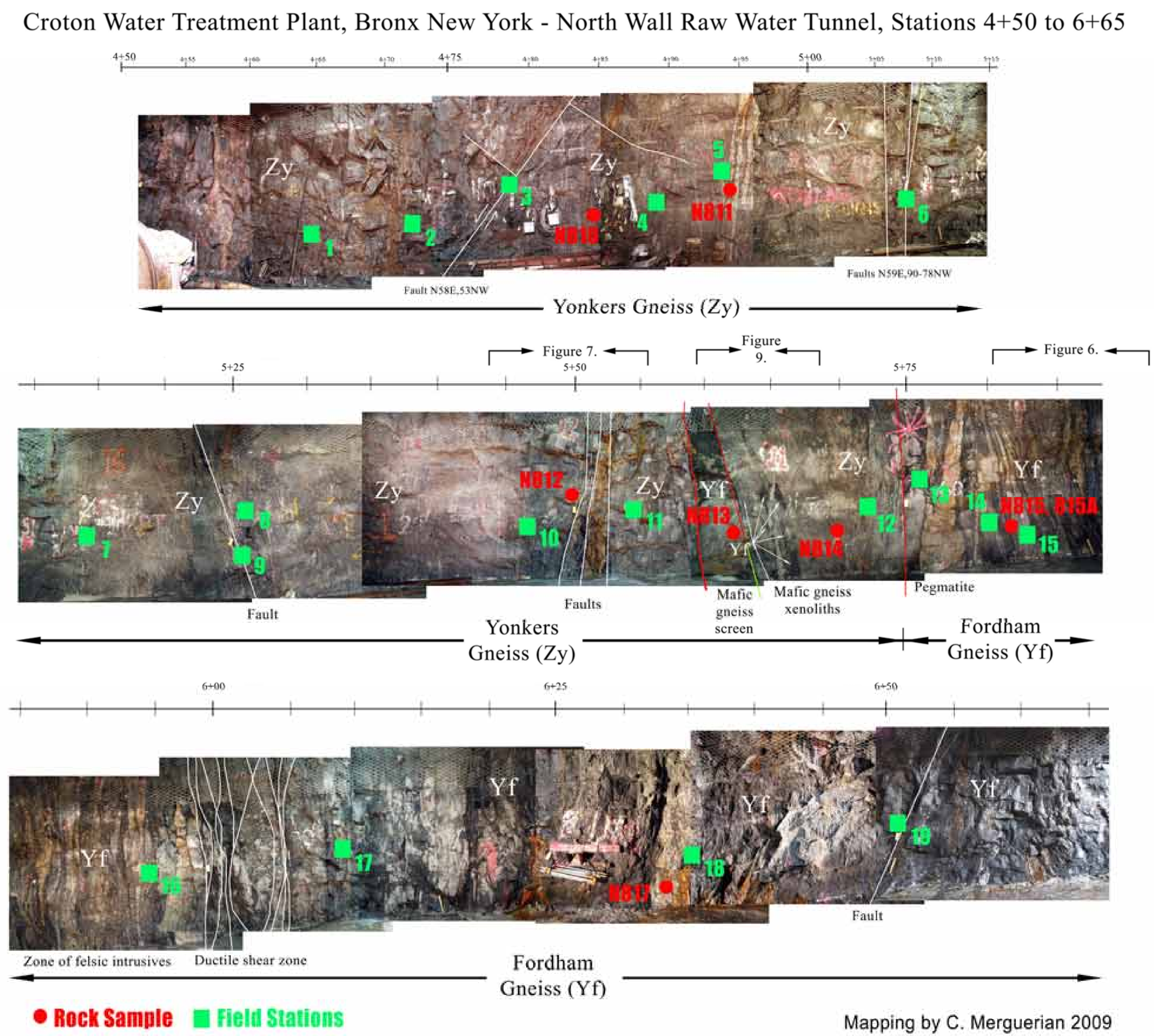

Figure 8 – Composite annotated image showing the geology of the Fordham-Yonkers contact exposed in the north wall of the Raw Water Tunnel of the Croton Water Treatment Plant, Bronx, New York.

Field Observations Keyed to Figure 8
Raw Water Tunnel, Croton Water Treatment Plant
(Dec 2008 – January 2009)

Stop 1 – (4+64) Zy Granitoid with layering and foliation = N21°E, 77°SE.

Stop 2 – (4+73) Zy Granitoid with layering and foliation = NS, 76°SE.

Stop 3 – (4+79) Normal fault (N58°E, 53°NW) in Zy cuts older fault (EW, 52°S), ~ 1.0-1.5m possible offset.

Stop 4 – (4+89) Zy granitoid with layering and foliation = N30°E, 81°NW.

Stop 5 – (4+94) Upright tight folds of foliation in Zy with axial surface (N31°E, 90°) parallel to foliation. Folds plunge N31°E@12°.

Stop 6 – (5+08) Fault in Zy parallel to foliation (N59°E, 78°NW).

Stop 7 – (5+14) Foliation in Zy (N29°E, 76°NW). Asymmetric folds were found in the Yonkers Gneiss at Station 5+18.

Stop 8 – (5+26) Asymmetric folds of foliation in Zy with axial surfaces (N25°E, 77°SE) and plunge 32° into S18°W.

Stop 9 – (5+25) Biotitic shear in Zy (N23°E, 73°SE).

Stop 10 – (5+46) Foliation in Zy (N30°E, 87°SE).

Stop 11 – (5+55) Foliation in Zy (N20°E, 83°NW). A 1 m thick screen of Yonkers mafic gneiss is centered at station 5+60 and a xenolith of the same mafic rock is infolded near the Yf label in Figure 8 and in expanded view below (Figure 9).

Stop 12 – (5+72) Foliation in Zy (N34°E, 78°SE).

Stop 13 – (5+75) Sheared contact (N24°E, 90°) of Yonkers orthogneiss (Zy) to left and Fordham gneiss (Yf) to right.

Stop 14 – (5+80) Lit-par-lit injected biotite schist and granofels in Yf with foliation (N41°E, 75°SE).

Stop 15 – (5+82) Lit-par-lit injected biotite schist and granofels in Yf with foliation (N41°E, 75°SE).

Stop 16 – (5+95) Intrafolial isoclinal folds of foliation in Yf with axial surfaces (N25°E, 82°NW) and plunge 19° into N12°E.

Stop 17 – (6+09) Foliation in Yf (N27°E, 80°NW).

Stop 18 – (6+35) Foliation in Yf (N17°E, 78°SE).

Stop 19 – (6+51) Foliation in Yf biotite schist (N8°E, 82°NW).

Stop 20 – (6+74) Gneissic layering in Yf mafic gneiss (N7°E, 79°NW).

Stop 21 – (6+82) Contact and parallel foliation between mafic gneiss and biotite schist in Yf (N31°E, 75°NW).

Figure 9 - Diffuse xenoliths of Fordham mafic gneiss flattened into foliation of Yonkers Gneiss near contact zone. Note late pegmatite dike cutting across the xenolith-Yonkers boundaries. Station 5+65, north wall raw water tunnel, Croton Water Treatment Plant, Bronx, New York (Digital image by C. Merguerian).

CONCLUSIONS

Following the excavation of three tunnels originating within Van Cortlandt Park for the construction of the Croton Water Treatment Plant in Bronx, NY, the intrusive contact between the Yonkers Gneiss (Zy) and the Fordham Gneiss (Yf) formations were identified by textural and megascopic mineralogic composition variations in the side-wall of tunnel excavations. In each instance, the structural contact was further delineated by the occurrence of younger pegmatite injections occurring at or near the interface boundary. Petrographic analysis of samples in thin-section from select locations in the raw water tunnel has identified textural, mineralogic, and structural differences between the Yonkers and Fordham gneisses. Therefore, it may be concluded that the Yonkers is clearly an orthogneiss (metaplutonic rock) that was intruded into already deformed metasedimentary and metaplutonic rocks of the Fordham.

Based upon analysis of mineralogical differences between the two formations and observations of the textural and megascopic composition of the rock surfaces exposed during tunneling operations, the contact of the Yonkers gneiss can be re-drawn from its current southern limit as shown on Baskerville (1992; 1989), Fluhr and Terenzio (1984), and Fluhr (1967) to extend southward in contact with the Mosholu Fault at the southern end of Van Cortlandt Park. As a result, it may be inferred the location of the Mosholu fault has been controlled, at least in part, by rupture along the Yonkers-Fordham intrusive boundary, where the Yonkers has acted as a resistant boss structure.

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ABOUT THE AUTHORS

Douglas E. Isler, PG is currently the Lead Tunnel Geologist throughout the execution of contract CRO-313 for the construction of the Croton Water Tunnels and previously for the treatment plant main excavation (contract CRO-311). Doug is a Senior Engineering Geologist for Haley and Aldrich, Inc., located in Boston, Massachusetts with over 30 years of experience in tunneling, mining, geotechnical and environmental projects.

Daniel A. Vellone, M.S., PG is currently the Resident Tunnel Geologist throughout the execution of contract CRO-313 for the construction of the Croton Water Tunnels. Dan is a Senior Engineering Geologist for Malcolm Pirnie, Inc., located in White Plains, New York. Additionally, Dan is Adjunct Faculty in the Department of Civil Engineering at Manhattan College, instructing upper-level undergraduate courses in geology, earth science and soil mechanics.

Charles Merguerian, Ph.D., serves as Chairman and Professor of geology at Hofstra University in Hempstead, New York and is also President of Duke Geological Laboratories in Westbury, New York. He has gathered over 35 years of experience as field geologist performing mapping and structural analysis with expertise in the geology of the New York City area.

J. Mickey Merguerian is an undergraduate student in the Department of Geology at Hofstra University in Hempstead, New York and field and laboratory assistant at Duke Geological Laboratories. Mickey was responsible for the sample preparation for thin-sectioning and performed all of the petrographic examinations.

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