

TECHNIQUES OF TBM TUNNEL MAPPING - THE QUEENS TUNNEL, NYC

Charles Merguerian

**Geology Department, 114 Hofstra University, Hempstead, NY 11549-1140
geocmm@hofstra.edu or dukelabs@specdata.com.**

Introduction

The Queens Tunnel is a 23' 2" diameter circular tunnel currently being mined 655' to 763' below sea level in west-central Queens (Figure 1) by a high-performance tunnel boring machine (TBM). When completed to yield a nearly five-mile long, 20'-wide concrete-lined pressure tunnel, the Queens Tunnel will serve as a crucial link in completing Stage 2 of New York City Water Tunnel #3 (CT3), by connecting the existing Stage 2 Brooklyn Tunnel in Maspeth, Queens (Shaft 19B; base at -655') with CT3, Stage 1 beneath Long Island City, Queens (Shaft 16B; base at -763').

Work on the Queens Tunnel began in September 1995 with site mobilization and excavation of starter- and tail tunnels beneath Shaft 19B utilizing traditional drill-and-shoot technology. Underground fabrication of the TBM commenced by September 1996, after a year of on-site installation of utilities and equipment. The TBM, which had been shipped from Chesterfield, England in June 1996 and delivered in 28 truckloads of assemblies and parts, was jointly designed by the Atlas-Copco-Robbins Company and by Grow-Perini-Skanska, joint-venture contractors for the Queens Tunnel. Since the inception of mining northeastward from the Maspeth (Shaft 19B) in late October 1996, more than four miles of tunnel have been excavated, producing a 23'2"-wide, subhorizontal fresh bore hole through this deeply eroded crystalline portion of the Appalachian Mountain chain.

Tunneling should be complete by mid-1999 and preparations for the installation of forms for a poured-concrete lining are already underway. After the completion of mining, the TBM must be disassembled and hoisted out from the Maspeth Shaft (19B), which, by the end of the tunneling excavation, will be nearly five miles away from where the TBM is located.

Since May 1998, I have had the unique opportunity to map the structural geology of the Queens Tunnel at a scale of 1"=10' providing a detailed record of the subsurface geology of Queens, a place not particularly well known in the Michelin travel brochures for its rock outcrops. The dog-leg shape of the tunnel (a NE-trending leg of 10,000' and a NW-trending leg of 15,989' - See Figure 1.) offers a cross-sectional view of the region. As of March 1999, I have mapped more than 12,000' of the exposed tunnel. Although I am not at liberty to discuss any details of the subsurface geology at this time (hopefully by next year's meeting!), I have employed some techniques that I can share in this paper. Having spent the last 20+ years mapping Hartland rocks at the surface throughout the Appalachians and specifically in and around New York City allowed me to examine the geology with an "experienced" eye but could not have prepared me for the geological three-dimensionality experienced in the tunnel.

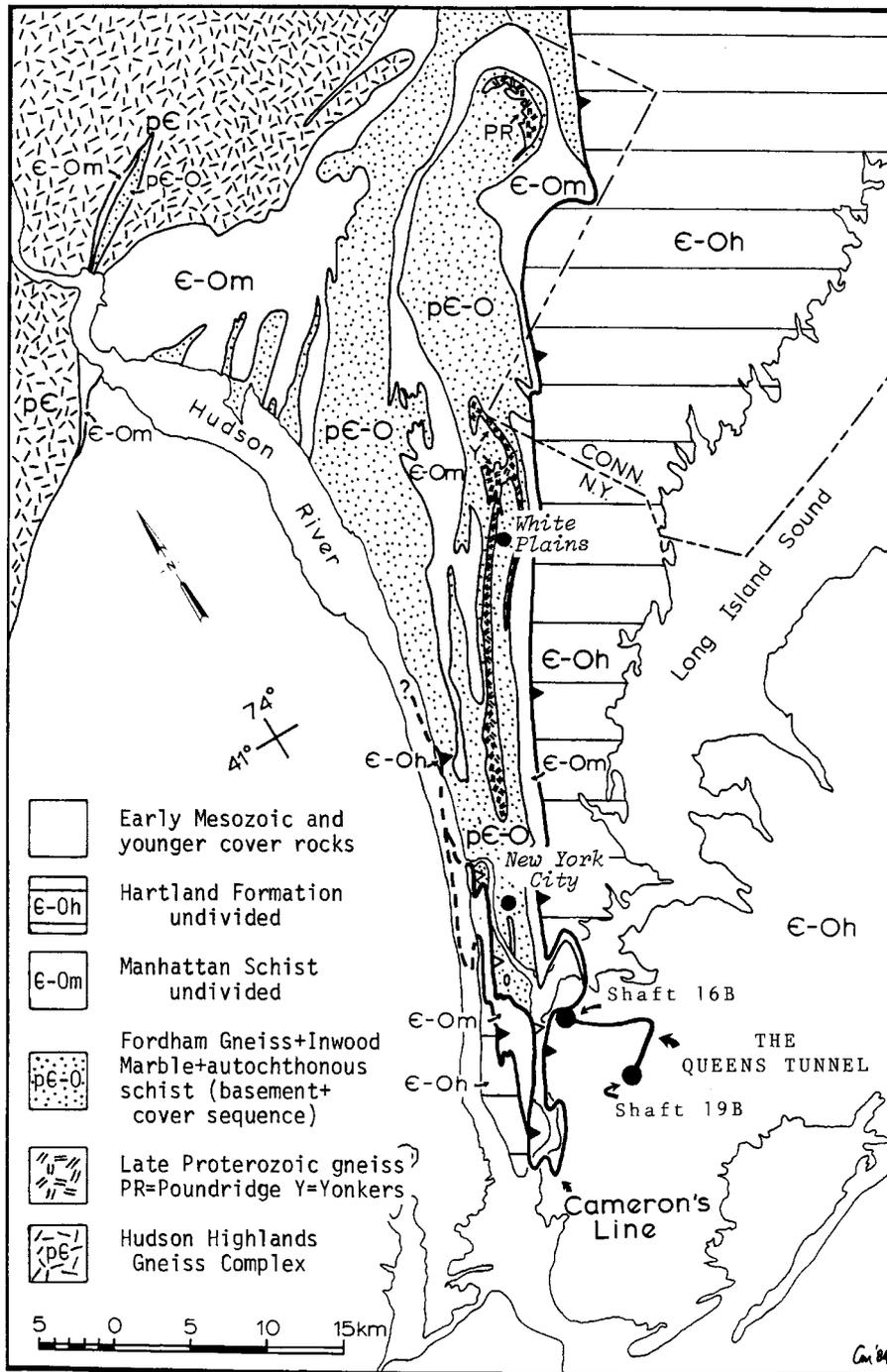


Figure 1 - Simplified geological map of the Manhattan Prong showing the distribution of metamorphosed equivalents of the Sauk and Tippecanoe (included in pE-O), and Taconic (E-Om and E-Oh) sequences in the vicinity of New York City. The Queens Tunnel (Stage 2, NYC Water Tunnel #3) is rooted in the Hartland Terrane and extends for nearly five miles northeastward from Shaft 19B in Maspeth to Woodside where a 116° curve changes the tunnel trend to northwesterly. When completed,

the Queens Tunnel will terminate at existing Shaft 16B (already constructed during Stage 1) in the subsurface of Long Island City.

Regional Geology

New York City is situated at the extreme southern terminus of the Manhattan Prong (See Figure 1.), a northeast-trending, deeply eroded sequence of metamorphosed Proterozoic to Lower Paleozoic rocks that widen northeastward into the crystalline terranes of New England. Southward from New York City, the rocks of the Manhattan Prong plunge unconformably beneath Cretaceous sedimentary rocks and overlying Pleistocene (glacial) sediments. The area of the Queens Tunnel is nestled within the Hartland Terrane, a zone of highly sheared eugeosynclinal metamorphic rocks of Cambrian to Ordovician ages that were sutured to North America during the Taconic orogeny along a ductile shear zone known as Cameron's Line. (See Figure 1.)

Field Mapping in a Cylinder

Beginning in late May 1998 I began a geologic survey of the Queens Tunnel, mapping the structural geology and the fracture index, including a detailed database on orientation and characteristics of faults and fault zones. Mapping has delineated an amazingly complex structural history for the rocks of the Queens Tunnel. The presence of superposed folds and the multitude of faults (both ductile and brittle varieties) serve to complicate the geology beyond simple understanding. After a steep learning curve, structures can be visualized in three-dimensions and mapped accurately as described below. Great pains were taken to map and document the lithology, folds, fault- and joint patterns, paying particular attention to structural sequence and to note any geological controls on the integrity of the tunnel.

Phase One - Get the Field Map Done

Tunnel mapping commenced in late May of 1998 and should be completed by the end of this summer (1999). Never fully realizing the scope and dimension of the project, I first began by slicing up cylinders to see how planes of different orientation (then folds and irregular masses) would look with the cylinder unwrapped. After calculating the circumference of the tunnel, I constructed a template for mapping that unwrapped the cylindrical tunnel section onto flat graph paper (10 boxes/inch) measuring 10" by 7". Recognizing that a few feet in the crown were simply not available for view (because of a tunnel-length 50" ventilation duct), the 72.75' circumference of the tunnel was scaled to the observable 70' on the mapping template. Thus, the template for each individual map sheet covered 100' of exposed tunnel, as measured parallel to the centerline, or 7,000 square feet of cylindrical area. Pre-cut 8.5" x 11" frosted mylar was used for the archival field maps because the overall humid to wet environment eliminated the use of paper-based maps underground. Station numbers, which were painted every five feet on the left wall along the springline, were relied upon for location and the field maps were carefully drafted underground with ink and scale-constant mylar in 100' sections at a scale of 1" = 10'. A full #00 Rapidograph and Magic-Rub eraser were the preferred "tools of the trade" for this phase of the mapping, where accurate drawing of the structural features was to be accomplished.

Mapping was complicated at times by visual obscurity in the form of "variations of darkness", walls and inverts covered by muck, dust, leaking water, support, and in some cases grout. The invert is largely obscured because of the locomotive trackway and muck thrown from the conveyor. A tunnel-length 24"-wide belted muck conveyor system is installed on the left rib which, although of an open design, manages to obscure some of the geology. Four sets of pipes

continue the length of the tunnel along the right wall, together with various large-scale tunnel installations for power and muck handling and a 50" air duct suspended from the crown, also served to further obscure a clear view. Washing the tunnel walls proved to be the single greatest help in overcoming these problems. A diver's halogen flashlight proved an essential tool.

Given the time constraints and the enormous scope of the tunnel mapping, on average 1.5 hours were allocated for each 100' section of tunnel mapped underground. After the mapping of each 100' section was completed, digital images of important geological relationships were taken (roughly 1,200 total to date) and later keyed with descriptions to the maps in a searchable database. Beginning in May 1998, raw digital images at 1280 x 960 resolution and 16.7 million colors were downloaded as ~400 Kb *.jpg files, imaged in SHQ (super-high quality) mode. All images were saved in numerous formats (Zip, Jaz, CD-R) for archival protection. Images were processed using Adobe Photoshop 5.0. Almost all images needed to be brightened and increased in contrast because of the generally poor lighting conditions but excellent results, including the ability to annotate features, were obtained using this non-film imaging method. The ability of the digital camera to auto-focus in dim light and compensate for exposure was of great utility. Kodachromes were also taken but needed severe bracketing (up to 2 stops beyond normal aperture settings) because of variable lighting conditions. Accurate focusing was especially difficult in the low-light conditions.

Phase Two - Field Checking and Fault Data

Field checking of contacts and measurement and analysis of faults and joints took place during subsequent field checks. The field maps were first checked when the faults and joints were surveyed to determine their characteristics (orientation, width, filling type and consistency, roughness, seepage, displacement, and mineral coatings) for a fault- and joint database using Microsoft Excel. A secondary check was made when the University of Trondheim Fracture Class system was applied to the entire tunnel over a five-day period, and finally when additional support and water leakage patterns were measured over a three-day period.

The presence of iron in the train tracks, piping, ductwork, and the conveyor system precluded the use of a Brunton compass for standard strike-and-dip measurements. After discussions with Scott Chesman (Geologist, NYC DEP), I constructed a laser-pointer leveling device that was able to accurately measure the strike of features with respect to the tunnel trend. By climbing up on the piping of the tunnel right wall and having a clear view of the left wall, features such as faults, foliation, and dikes are relatively easy to view and trace across the crown. Great care was taken to properly calibrate the device to the centerline trend in the various curves (four) of the tunnel. Dips were measured using a Brunton compass and checked by calculation from the field maps. Strikes were checked from the field maps, as well. By the end of this phase an upgraded mylar-and-ink field map and two annotated paper copies were produced for each 100' section of the tunnel.

Phase Three - Final Map Preparation

Final drafting of the integrated field maps took place after the field checks had been completed. Mylar and ink were deemed the best media choice for this phase. Final maps were redrawn at scale (1"=10') from the archival base map which incorporated any new information surveyed during Phase Two. During the final-drafting stage, digital images from that 100' section were carefully examined for added accuracy. The final maps were checked for errors and then scanned at 400 dpi resolution as *.gif files and ported to Photoshop where color

enhancement resulted in *.psd files of about 2 Meg/100' map section. As a side project, with the assistance of my students, we were able to "pick" the true 24-bit colors of distinctive units from the digital images and "colorize" them on the map units and explanation. Once in this digital format, variable scaling and piecing together of maps into longer sections is facilitated.

Naturally, the final Queens Tunnel Map Portfolio is a work in progress whose preliminary version includes all basic geologic data on 11" x 17" map sheets that individually show 200' of the tunnel. Eventually, 130 of these map sheets will cover the entire of the Queens Tunnel.

Very few rock samples were taken for petrographic analysis in this preliminary stage of mapping because of the time-critical need to complete the mapping at about the same time as the TBM completes mining. As such, the lithologic descriptions that appear throughout the maps and in the map explanation are based on field descriptions while underground and also on surface-based megascopic analysis of some collected rock samples. A thorough sampling and petrographic study is planned (Phase Four) after mapping has been completed but before the concrete lining of the tunnel is poured in the wake of the TBM's removal. Thus, traditional- and computer-based mapping techniques were of great help in recording the geology of the Queens Tunnel.

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