THE QUEENS TUNNEL COMPLEX: A NEWLY DISCOVERED GRANULITE FACIES FORDHAM ORTHOGNEISS COMPLEX THAT DOMINATES THE SUBSURFACE OF WESTERN QUEENS

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INTRODUCTION

The Cambro-Ordovician “Hartland Formation” has long been thought to lie below the sediments of Long Island. However, new evidence from field mapping, from petrographic study, from trace-element whole-rock chemical analysis, and from zircon U-Pb dating conclusively demonstrates that an extensive tract of Grenvillian Fordham Gneiss underlies western Queens.

The only remaining bedrock exposures on Long Island are a few small patches of the Ravenswood Granodiorite, at the west end of the Island. Thus, the basement underlying the Island has been practically inaccessible, sampled only in scattered borings, building excavations, and municipal construction efforts. In the last few years, however, construction of the Queens Tunnel (Stage 2 of City Water Tunnel #3) has made a continuous subsurface section through western Queens available for study. CM mapped more than 25,000 feet of the Queens Tunnel between 1998 and 2000, and paid particular attention to lithology, faults, and structural sequence. The methodology he followed was described at a previous meeting of the Long Island Geologists (Merguerian, 1999). CM documented the rocks of the Tunnel (now cloaked in concrete) in a detailed map portfolio and set of digital photographs, and took over 161 representative samples. He named this rock suite the “Queens Tunnel Complex”; he recognized (from field and preliminary petrographic studies) that the rocks were compositionally dissimilar to the Hartland Formation as seen elsewhere, and that the rocks were more complexly deformed than Hartland ordinarily is. Although the Hartland Formation at other localities consists largely of aluminous metasedimentary rock, Merguerian demonstrated that the Queens Tunnel Complex is almost entirely composed of metaigneous lithologies; these range from leucocratic through melanocratic compositions.

In a classic case of serendipity, CM gave the keynote talk at the Annual Dinner of the Queens Mineral Society, choosing as his subject the Queens Tunnel. He illustrated this talk with Kodachrome and digital slides. PCB and PWGB, who (unlike CM) have worked extensively in the Fordham Gneiss, were attending this dinner. Geological relationships revealed by the photographs convinced them that the rocks were Fordham Gneiss, not Hartland Formation. After discussion with CM, they joined the Queens Tunnel project. The Brocks’ subsequent studies of the rocks (hand-specimen petrography, thin-section petrography, whole-rock geochemistry, and zircon U-Pb dating) have all confirmed their initial correlation of the Queens Tunnel Complex with the Fordham Gneiss.

FIELD RELATIONS OF ROCKS WITHIN THE QUEENS TUNNEL COMPLEX

CM encountered a variety of leucocratic, mesocratic, and melanocratic metaigneous rocks, and very minor amounts of metasedimentary rocks within the Queens Tunnel. The leucocratic rocks include granites of several distinct ages, and tonalitic gneisses. Among the granites are young, muscovite-bearing pegmatite dikes, similar to the “Mississippian” granites observed in many parts of the Manhattan Prong (Brock and others, 1985; Brock, 1993). Also present are some pinkish, poorly- to well-foliated granitoids of probable Ordovician age. The most abundant of the leucocratic rocks, however, are the grayish, plagioclase-rich tonalitic gneisses that resemble the typical leucocratic gneiss of the Fordham. Thus, not all mapped units are included in the Queens Tunnel Complex; the Complex refers to the Fordham-like rocks only.

In addition to the leucocratic rocks, mesocratic and mafic gneisses make up a large portion of the Queens Tunnel Complex. In the metropolitan region, only the Fordham Gneiss comprises such a broad range of bulk compositions. Some of the mafic rocks of the Queens Tunnel Complex occur in discrete, intrusive bodies that display clear crosscutting relationships against apparently older leucocratic or mesocratic gneisses (Figure 1). This type of age relationship (*i.e.,* mafic rocks younger than felsic or mesocratic gneiss) is commonly observed within the Grenvillian Fordham Gneiss. However, in the "Hartland Formation" of the metropolitan area, most mafic rocks were emplaced *before* commencement of the Taconian Orogeny, while most of the felsic gneisses were generated *during* the orogeny; thus, relative age relationships are typically the reverse of what is observed in the Fordham. Again, in this respect, the Queens Tunnel Complex resembles the Fordham Gneiss rather than the Hartland Formation.

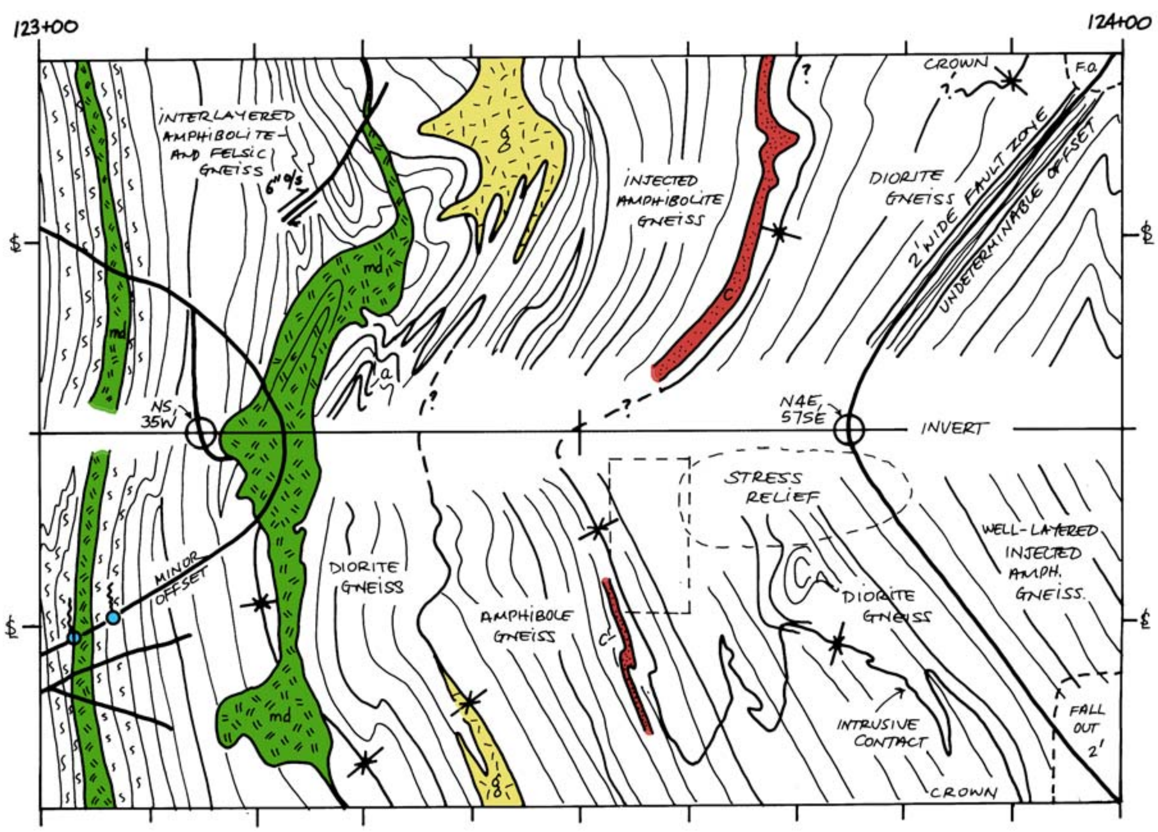


Figure 1 - Geologic map of a 100-foot section of the Queens Tunnel, showing a high degree of lithologic and structural complexity and an intrusive contact between mafic (amphibolitic) gneiss and mesocratic (dioritic) gneiss; found between Stations 123+00 and 124+00 (tunnel bearing is N71°W). Other units in this map section include mafic dikes (md), concentrations of garnet (c), and intrusive pegmatitic granites (g). The tunnel invert is shown along the center of the map and the tunnel walls curl upward into a cylinder to join at crown. The position of the tunnel springline is shown at the map edge. (Original map scale 1"=10'; tunnel diameter 23' 2".)

The metasedimentary rocks occur in two forms: some, including some scapolite-bearing calc-silicate rocks, appear to belong with the tonalitic gneisses, in the oldest part of the sequence; others (particularly biotite-rich, schistose rocks) occur as shear bounded slivers or lenses, apparently tectonically emplaced. We suspect that these schistose rocks may belong to younger parts of the section (*e.g.,* Ordovician Walloomsac Schist) rather than to Fordham Gneiss.

PETROGRAPHY AND METAMORPHISM, QUEENS TUNNEL COMPLEX

At least two major phases of metamorphism are discernable in the Queens Tunnel Complex. The oldest rocks (particularly the tonalitic gneisses) experienced both phases, but some of the youngest mafic bodies may have undergone only the later. The older metamorphism produced *coarse-grained* orthopyroxene in *leucocratic rocks*, a feature typical of the Grenvillian Fordham Gneiss but unknown in any other unit in the region; this textural feature is, indeed, one of the surest signatures of the Fordham.

Old granulite fabrics. The oldest fabrics in rocks of the Queens Tunnel Complex are medium to coarse grained, with granoblastic networks of plagioclase and pyroxene. They show little foliation, though some light-dark layering can be present. Clinopyroxene generally shows exsolution. Minor K-feldspar is sporadically present, and visible antiperthite attests to a dissolved K-feldspar component in much of the plagioclase. Early, coarse-grained garnet coexists with clinopyroxene (CPX) in several rocks, while it coexists with orthopyroxene (OPX) with or without additional CPX in others.

Prolonged metamorphism at very low H_2O activity was probably responsible for these highly dehydrated mineral assemblages. A minimum temperature of ~700^o C can be inferred. The garnet-clinopyroxene-orthopyroxene plagioclase association indicates that metamorphism occurred in the high-pressure granulite facies (Spear, 1993).

ii. Later-stage retrogression: Amphibolite- to granulite-grade alteration of primary fabrics. The pyroxene granulites were subjected to retrograde metamorphism at some later time. Coronas of hydrated minerals such as amphiboles and biotite envelope numerous old pyroxene grains. The retrogressive reactions occurred under amphibolite to granulite facies conditions. Sample reactions were:

a. OPX + CPX + plagioclase = hornblende + garnet

b. OPX + quartz = cummingtonite

c. garnet +CPX + plagioclase = hornblende + quartz

d. K-feldspar (from K-bearing plagioclase in some cases) + OPX = biotite + quartz

It is tempting to equate this retrogressive metamorphism with the Taconian orogeny; certainly, during the Taconian, the dehydration of the Paleozoic sediments provided an ample supple of water. However, it is also possible that retrogression commenced during later stages of the Grenville orogeny. The question remains open.

GEOCHEMICAL STUDY OF THE QUEENS TUNNEL COMPLEX

The metaigneous rocks units found in the Manhattan Prong and surrounding areas have distinct geochemical signatures (Brock and Brock, 1999; 2000). To test the proposed correlation of the Queens Tunnel Complex with the Fordham Gneiss, a suite of felsic, mesocratic, and mafic rocks from the Tunnel were subjected to XRF and to high-precision ICP-MS analysis at Washington State University. The major element, trace element, and rare-earth element compositions of metaigneous Queens Tunnel gneisses could then be compared with those of the Fordham Gneiss and with known metaigneous components of the "Hartland Formation".

The "Hartland" problem. Geochemical studies by PCB and PWGB have found that the rock sequences presently mapped as the "Hartland Formation" consist of at least two fundamentally different entities. The "Hartland Formation" divides roughly into western and eastern subtypes, each containing a geochemically distinct variety of amphibolite. Amphibolites in the western "Hartland" region show intraplate affinity; for the present purpose, this type of "Hartland" will be called the "Bronx Zoo" (**BZ**) type. The second, eastern variety of "Hartland Formation" contains amphibolites that display volcanic-arc affinity, and will be referred to here as the "Pelham Bay" (**PB**) type. Both the BZ- and the PB- types of "Hartland" are predominantly metasedimentary rock sequences, mostly consisting of well-layered granofels, gneiss, micaceous schist, and with subordinate amphibolite.

The two variants of “Hartland” are often indistinguishable in the field; thus, geochemistry has provided important new stratigraphic insights.

The geochemistry of BZ- and PB-type amphibolites (and the tectonic significance of these units) will be described in detail elsewhere. Here, we will present evidence that the metaigneous rocks of the Queens Tunnel Complex are geochemically related to the Fordham Gneiss, rather than to *either* BZ- or PB- type “Hartland Formation”.

RESULTS OF THE GEOCHEMICAL STUDY

The chemical affinity between the QT and Fordham Gneiss is expressed in several ways, including the ***range of rock compositions present;*** the ***tectonic affinities*** of both the ***mafic*** and ***felsic rock types;*** and ***geochemical traits particular to each suite of rocks.***

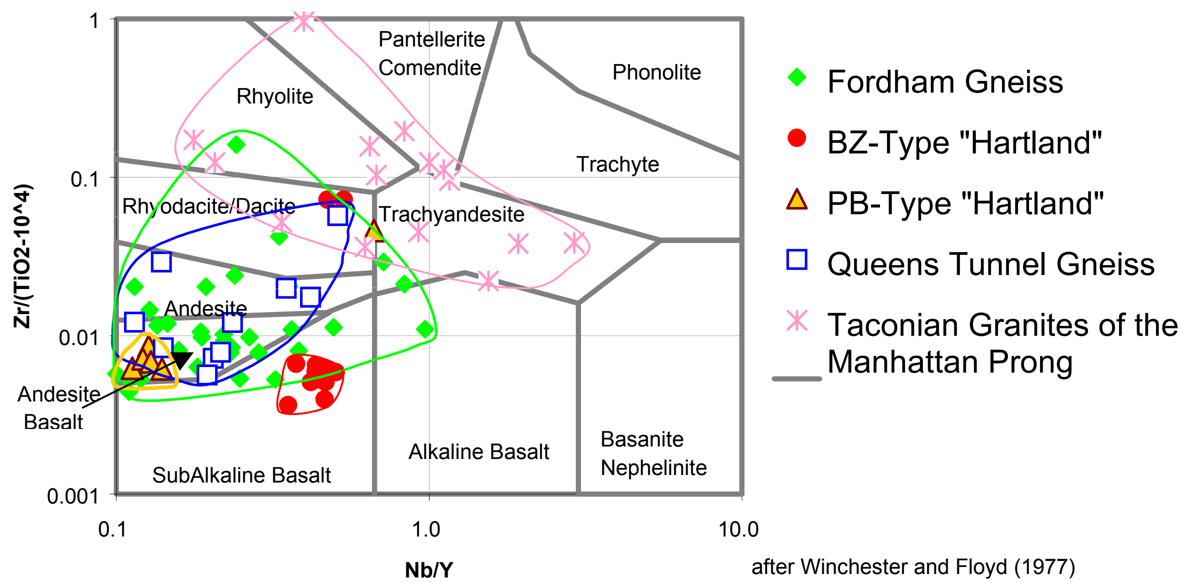


Figure 2. Trace Element Classification of Igneous Rocks

Range of Rock Compositions. Using a standard rock-classification diagram (Figure 2), the mafic rocks from the BZ- and PB- types of “Hartland” both plot in tight clusters, chemically far removed from the accompanying granitoids; metaigneous rocks from these units are **bimodal**. In marked contrast to the “Hartland” types, the Fordham Gneiss forms a continuous, chemically **unimodal** single cluster that begins in the “subalkaline basalt” field and extends upwards into the “rhyolite” field. Gneisses from the Queens Tunnel Complex replicate the same range of compositions displayed by the Fordham Gneiss.

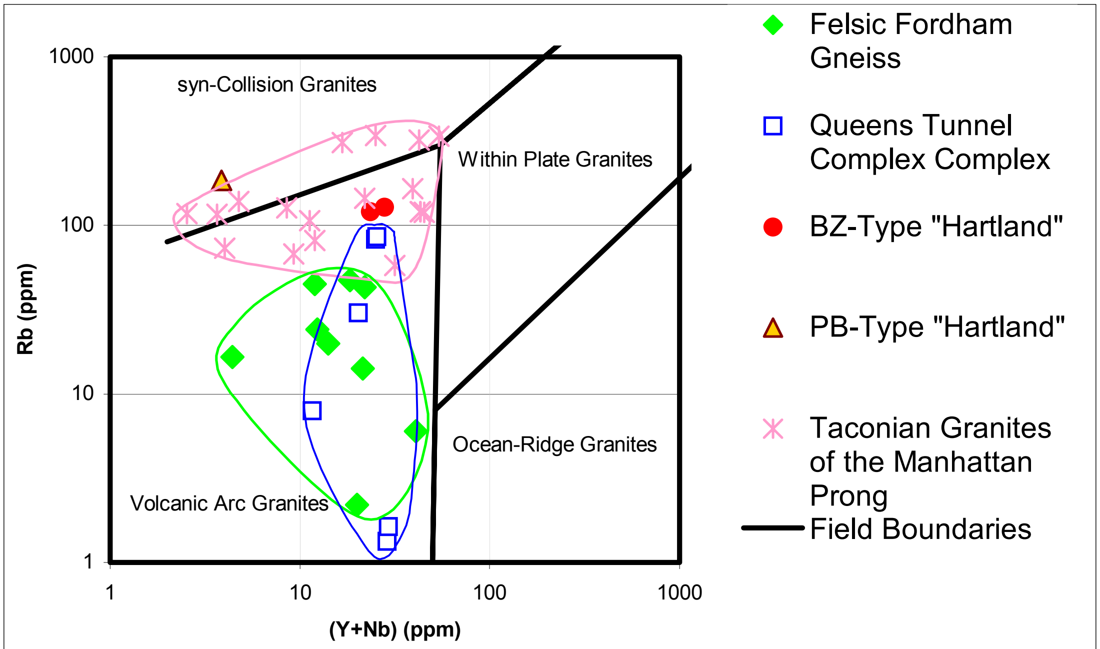
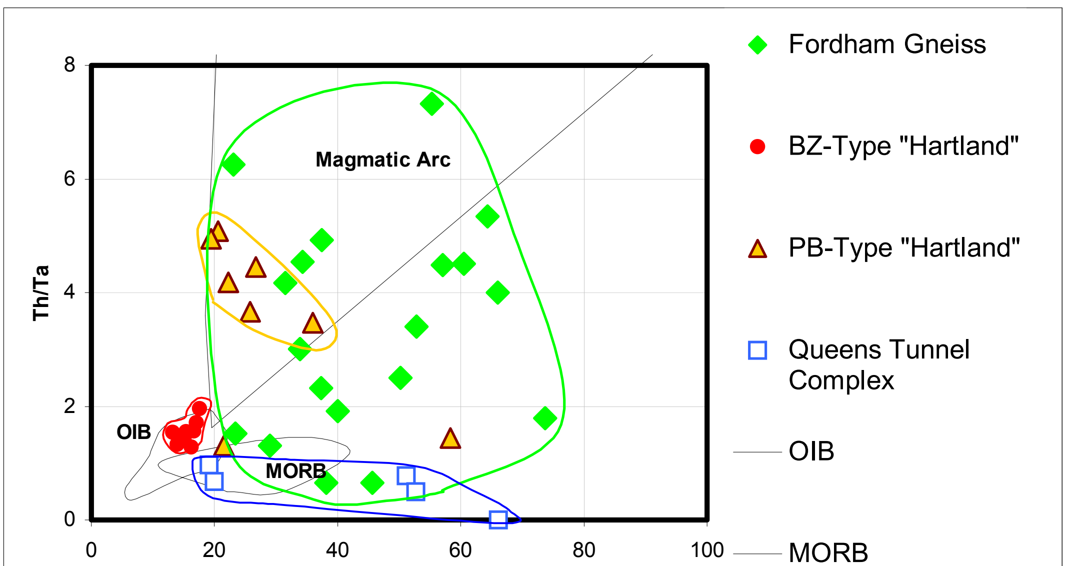


Figure 3. Tectonic Affinities of Felsic Rocks

after Pearce *et al*. (1984)

Tectonic Affinity, *Felsic Rocks*. Figure 3 is a tectonic-discrimination diagram for felsic rocks. Compositions of Taconian-aged (Ordovician) granites from all portions of the Manhattan Prong are shown for comparison with the Fordham, "Hartland", and Queens Tunnel Complex rocks. On this diagram, felsic gneisses of the Fordham plot solidly as volcanic-arc granite; the Taconian-aged Manhattan Prong granites fall in a separate cluster, which overlaps the syn-collisional/volcanic arc granite field boundary. The two granites from the "Hartland" that we have analyzed are indistinguishable from Taconian granites of the Prong. However, the felsic gneisses of the Queens Tunnel Complex show the same range of compositions as do Fordham "volcanic arc" granites.



after Leat & Thorpe (1989)
and Kent *et al*. (1997)

Figure 4. Tectonic Affinities of Mafic Rocks

Tectonic Affinity, *Mafic Rocks.* Figure 4 is a Th/Ta *versus* La/Ta tectonic-discrimination diagram for mafic rocks. On this diagram, BZ-type "Hartland" plots in the ocean-island basalt field; PB-type "Hartland" plots almost entirely in the magmatic arc field. The Grenville-aged mafic gneisses of the Fordham fall in a broad swath overlapping both the magmatic arc and MORB fields. Here again, rocks of the Queens Tunnel Complex overlap with Fordham Gneiss, but are distinct from both the BZ- and PB- types of "Hartland". The Queens Tunnel mafic rocks appear to be compositionally restricted compared with Fordham from the northern Manhattan Prong; only the MORB-like compositions are represented.

Other Contrasting Geochemical Traits. Mafic rocks of the Fordham Gneiss and the Queens Tunnel Complex both show strong depletions in Th, Ta, and Nb, along with enrichments in Ba and K; this pattern distinguishes both units from the (oceanic island-like) BZ-type "Hartland". The PB-type "Hartland" also shows depletion in Ta and Nb (though not, usually, in Th), and also has some enrichment in Ba and K. However, the PB-type "Hartland" has low concentrations of LREEs, especially La, shows enrichment in Sr, and depletion in P. This suite of characteristics dependably serves to distinguish mafic rocks of both Fordham Gneiss and the Queens Tunnel Complex from PB-type "Hartland".

In summary: The Queens Tunnel Complex geochemically resembles the Fordham Gneiss, but geochemically contrasts with both the BZ- and PB- types of "Hartland Formation". (1) Queens Tunnel rocks are unimodal (like Fordham); both BZ-type and PB-type "Hartland " are bimodal. (2) Mafic gneisses of the Queens Tunnel Complex show "MORB"-like tectonic affinity, in common with many Fordham gneisses, but unlike the vast majority of "Hartland" amphibolites. (3) Felsic rocks of the Queens Tunnel Complex and Fordham Gneiss share a common volcanic arc geochemical signature. Felsic rocks of the metropolitan-area "Hartland" geochemically resemble Taconian granitoids of the Manhattan Prong. (4) Mafic rocks of the Queens Tunnel Complex and the Fordham Gneiss share similar patterns of trace-element enrichment and depletion. These patterns differ from the trace-element behavior observed in BZ- and in PB- type "Hartland". Overall, rocks from the Queens Tunnel Complex share the trace-element traits of the Fordham Gneiss and do not share those of either "Hartland" subdivision.

GEOCHRONOLOGICAL STUDY OF THE QUEENS TUNNEL COMPLEX

The Fordham Gneiss belongs to the Grenville orogen, along with such other basement outliers as the Hudson Highlands, the Adirondack Mountains, and the Green Mountain massif. Many Grenvillian gneisses in these regions are ~1.0 Ga in age. However, U-Pb geochronological study of the Fordham Gneiss has been very limited. When Grauert and Hall (1973) studied zircons from the Manhattan Prong, they found a substantial spread in Pb-Pb ages in grains from the Fordham Gneiss. An old inherited component could be 1600-1700 Ma; the youngest zircon ages were about 980 Ma. This same zircon population, they found, was apparently recycled into the sediments of the Manhattan Schist. More recently, Aleinikoff (1985) did a combined U-Th-Pb and Sm-Nd isotopic study of Hall's (1968) Fordham Member C; he placed the minimum crystallization age of Member C's protolith at 1170 Ma.

For the present study, we sampled two tonalitic gneisses within the Queens Tunnel Complex for U-Pb zircon age determination. The two samples ("9+45" and "68+15") were sent to Geochron Laboratories and analyzed at the Department of Earth and Planetary Sciences at M.I.T.; Samuel Bowring interpreted the results.

Five zircon fractions were separated from each sample. The zircon grains were rounded to subrounded, as is typical in high-grade metamorphic rocks. Each grain was abraded prior to dissolution. As described below, results from both of the samples support a Grenville origin for the Queens Tunnel Complex.

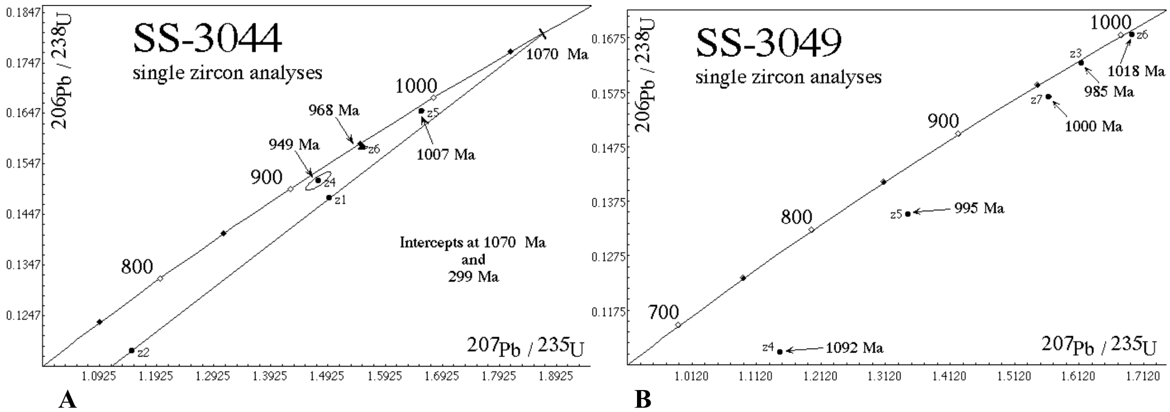


Figure 5 (A) - Concordia diagram for Queens Tunnel Complex sample SS-3044. The upper intercept of 1070 Ma estimates the age of an inherited component. The younger component is expressed by the zircons plotted close to the concordia, which have Pb-Pb ages ranging from 949 to 1007 Ma. **(B)** Concordia diagram for sample SS-3049. A nearly concordant grain with a 985 Ma age best approximates the age of the youngest component. Strongly discordant zircon z4 has a Pb-Pb age of 1092 Ma, which is attributed to an inherited component.

Sample SS-3044. Zircons show a range of colors and shapes; at least two age populations are present. The age of the oldest component, approximately 1070 Ma, is based on an upper intercept age derived from two dark, U-rich grains (Fig 5A). The other three zircons plot in a subparallel array, close to the concordia curve. These younger grains have Pb-Pb ages ranging from 949 Ma to 1007 Ma. The reason for this spread in ages is unclear, but could be due to multiple generations of zircon growth or to inheritance of slightly older component.

Sample SS-3049. Zircons in this rock resembled those of sample SS-3044. Thin overgrowths on some grains were removed by abrasion; in spite of this, Bowring believes that variable metamorphic overgrowth probably causes the scatter near the 1000 Ma mark on the concordia curve. Three grains in this cluster have Pb-Pb ages ranging from 985 to 1018 Ma. The grain with the 985 Ma age is nearly concordant (Fig 5B), and gives the best estimate of the age of the youngest component. The oldest component (attributed to inheritance) is estimated at 1092 Ma, the Pb-Pb age of the most strongly discordant grain.

Summary. The two tonalitic gneisses share similar zircon populations. An inherited component, estimated in the range 1070-1092 Ma, is present; most of the zircons are ~ 1.0 Ga in age. This is the similar to the younger age found among zircons of the Fordham Gneiss by Grauert and Hall (1973).

CONCLUSIONS

Field data, petrography, whole-rock geochemistry, and zircon U-Pb geochronology of the Queens Tunnel Complex unambiguously establish that this entity consists of Grenvillian rocks essentially identical to the Fordham Gneiss. Conversely, they all indicate that the Queens Tunnel Complex cannot be associated with the Hartland Formation. Published geologic maps that indicate the presence of "Hartland Formation" under western Queens are in error and should be revised.

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