

Geology of Manhattan Island and the Bronx, New York City, New York

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LOCATION

Four easily accessible localities in Manhattan and the Bronx (Fig. 1), have been chosen to illustrate the metamorphic geology of New York City. Streets surrounding the localities are shown in Figure 2. All outcrops are in public parks or in roadcuts that may be reached by car, bus, or subway.

SIGNIFICANCE OF SITE

The four locations consist of exemplary exposures of highgrade metamorphic rocks that have challenged geologists since Merrill (1890). They are named the Fordham Gneiss, the Yonkers Gneiss, the Inwood Marble (called limestone by Merrill, 1890), and the Manhattan Schist. These names are well known in the geologic literature, although our understanding of them has changed greatly through time. Owing to the lack of fossils in these sillimanite/kyanite-grade rocks, advances in our understanding of their age and sequence have been made largely through detailed geologic mapping studies and comparisons of lithofacies with better known fossiliferous sections of Middle Proterozoic to Middle Ordovician rocks in eastern New York State and Vermont. Since 1964, Leo M. Hall has done more than any other worker to aid present understanding of this complex sequence of rocks through detailed stratigraphic and structural mapping. The interpretations presented here depend heavily on his major contributions, but include modifications for which we must accept responsibility.

The series of localities described here allows an overview of the complex high-grade metamorphic terrane that underlies Manhattan Island and the Bronx, as well as an appreciation of the problems geologists have faced in attempting to disentangle the structural and stratigraphic history of the region.

Two stratigraphic sequences can be recognized in these complexly faulted and folded metamorphic terranes. On the east, metamorphosed Cambrian and Ordovician eugeoclinal rocks (Hartland Formation) lie on a presumed oceanic basement. On the west, metamorphosed Cambrian and Ordovician miogeoclinal rocks (Lowerre Quartzite, Inwood Marble) overlie a Proterozoic (Fordham and Yonkers gneisses) continental basement. The miogeoclinal and eugeoclinal rocks are juxtaposed along a Taconian crustal suture zone, Cameron's Line (Hall, 1976; Merguerian, 1983a), which appears to be a complexly folded and faulted east-over-west thrust fault. In New York City, the "classic" Manhattan Schist of Merrill (1890) contains at least three mappable units, of which only the lower unit, correlative with member A of Hall (1968), clearly belongs to the autochthonous miogeoclinal sequence. The middle part of the Manhattan Schist is correlative with members B and C of Hall (1976) and is allochthonous (a thrust fault

separates it from the underlying miogeoclinal rocks); however, its stratigraphic association (whether miogeoclinal or eugeoclinal) is not yet fully understood. The uppermost unit of the Manhattan Schist is correlative with the allochthonous, eugeoclinal sequence (Hartland Formation) in the upper plate of the Cameron's Line thrust.

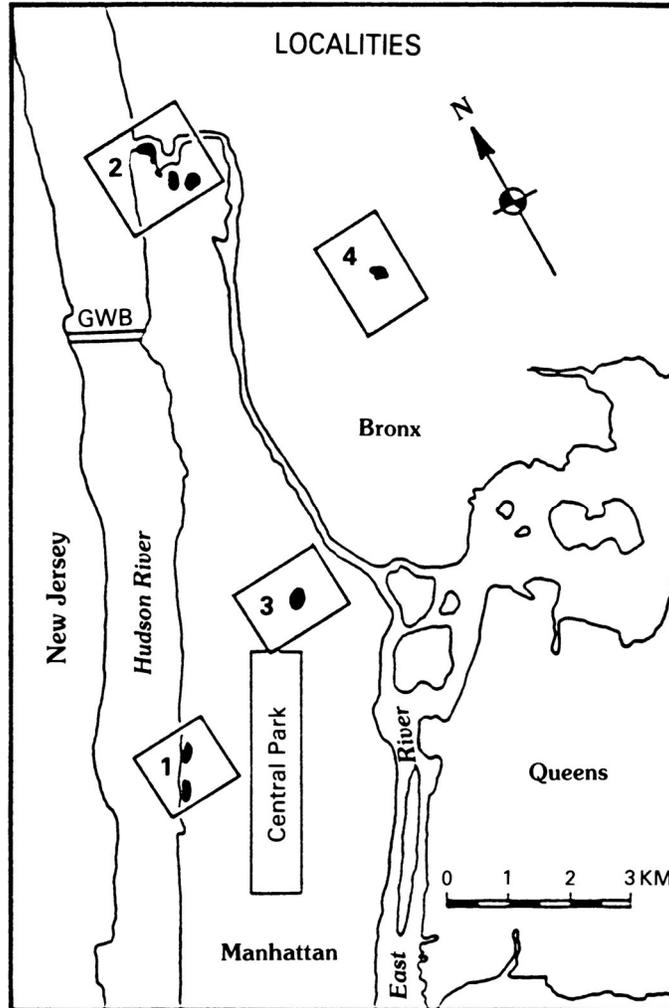


Figure 1. Index map showing the field localities mentioned in Manhattan and the Bronx. GWB, George Washington Bridge.

SITE INFORMATION

In New York City, the northeast-trending, deeply eroded Middle Proterozoic to lower Paleozoic metamorphic rocks plunge southward beneath unmetamorphosed Mesozoic, Pleistocene, and Holocene sedimentary rocks (Fig. 3). The exposed bedrock includes (1) the autochthonous sequence: Middle Proterozoic Fordham Gneiss, Late Proterozoic Yonkers Gneiss, Cambrian and Ordovician Inwood Marble, and the lower part of the Ordovician Manhattan Schist, correlative with Manhattan Schist member A of Hall (1968); and (2) allochthonous rocks including the middle and upper parts of the Manhattan Schist, which are correlative partly with Manhattan Schist members B and C of Hall (1976) and partly with the Hartland Formation.

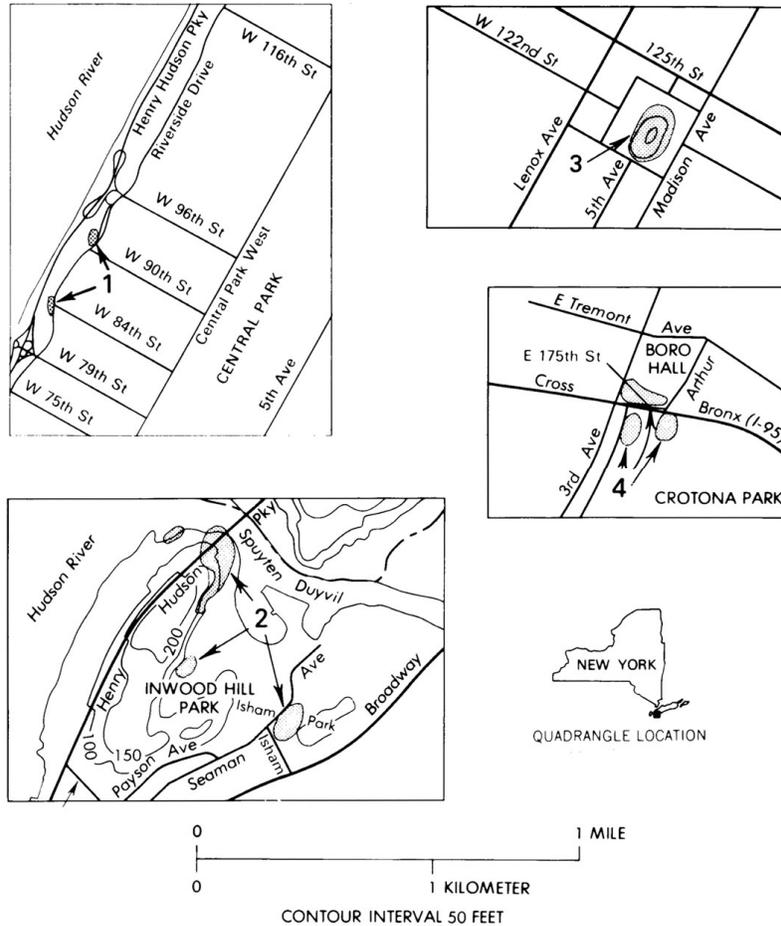


Figure 2. Cross-street locality maps showing outcrops discussed in text.

STRATIGRAPHY

The Fordham Gneiss, oldest rock unit in the region, (Y in Fig. 3), is correlative with Middle Proterozoic Hudson Highlands gneisses (Hall and others, 1975; Hall, 1976). The Fordham Gneiss contains intrusive Late Proterozoic granitoid rocks such as the Yonkers gneiss (Zy in Fig. 3); it is overlain unconformably by the discontinuous Lower Cambrian Lowerre Quartzite (Hall, 1968). In White Plains, New York, the Fordham Gneiss is overlain unconformably by the Cambrian and Ordovician Inwood Marble (O-Ci in Fig. 3). The Middle Ordovician Manhattan Schist, correlative with member A of Hall (1968; Oml in Fig. 3), containing calcite marble, unconformably overlies the Inwood Marble.

The above units constitute the autochthonous miogeoclinal basement-cover sequence of the Manhattan Prong (Hall, 1968), which includes the Bronx and Manhattan Island. Units overlying the Fordham may represent metamorphosed sedimentary rocks deposited on continental crust, now exposed only to the west of Cameron's Line. East of Cameron's Line in western Connecticut and southeastern New York, the rocks of Cambrian and Ordovician age belong to the Hartland Formation of Cameron (1951), Gates (1951), Rodgers and others (1959), or the Hutchinson River Group of Baskerville (1982b; see also Seyfert and Leveson, 1969, and

Baskerville, 1982a). In contrast to the basement-cover sequence west of Cameron's Line, the Hartland Formation and correlatives (O-Ch in Fig. 3) are a sequence of metasedimentary and metavolcanic rocks presumably deposited on oceanic crust accreted to North America during the Middle Ordovician Taconic orogeny (Hall, 1976; Merguerian, 1979, 1983a; Merguerian and others, 1984; Robinson and Hall, 1979).

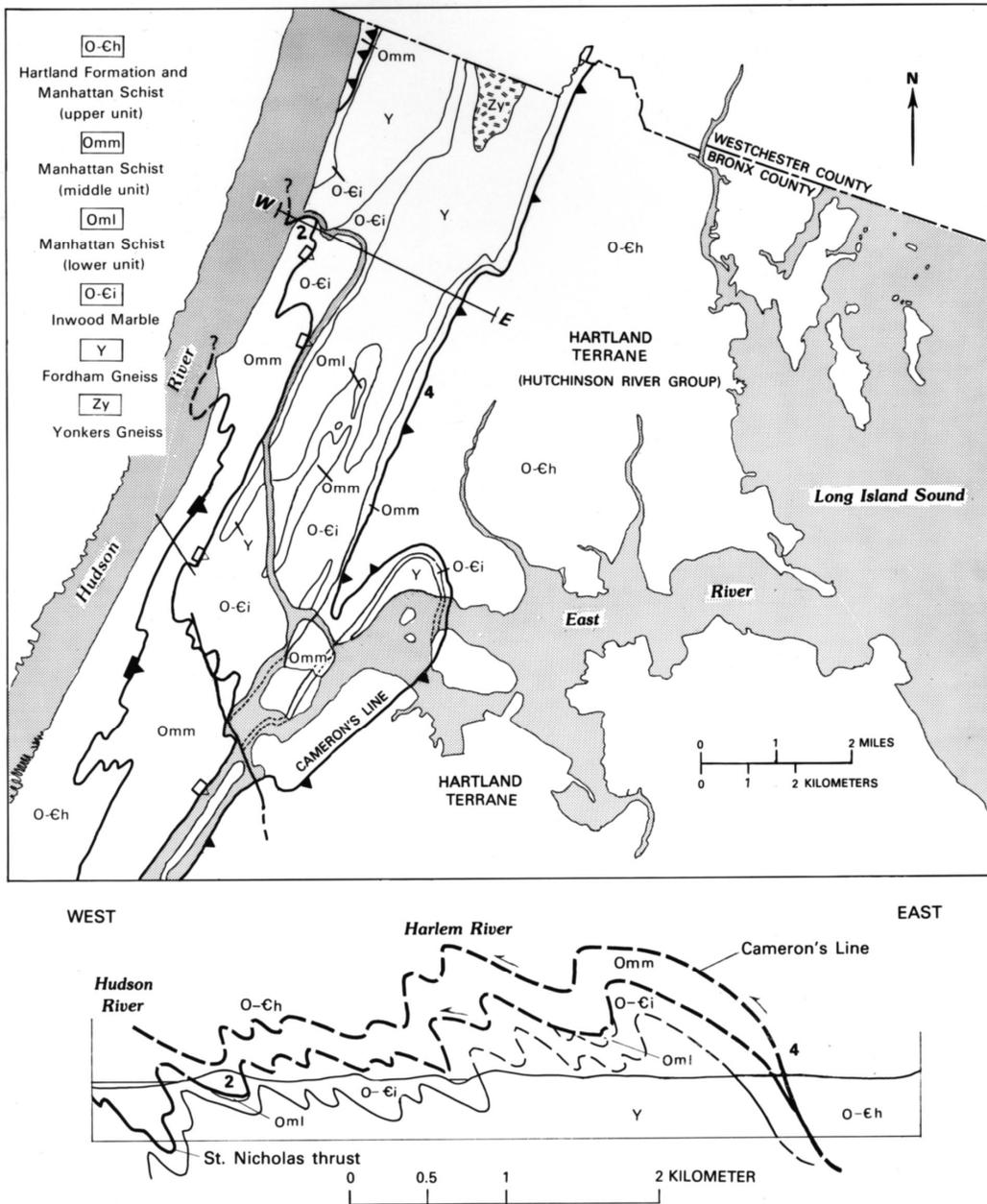


Figure 3. Simplified geologic map of the Bronx and Manhattan based on mapping by the authors. In the type locality of the Manhattan Schist in New York City, schistose rocks have been divided into a lower unit (Oml), a middle unit (Omm), and an upper unit (O-Ch) (Merguerian, unpublished data). The open thrust symbol in Manhattan is the St. Nicholas thrust; the closed symbol is Cameron's Line—barbs show dip direction of foliation. The interpretive W-E section is from the Hudson River to the central Bronx. Numbers refer to localities described in text. Some contacts are projected above the line of section.

On the basis of lithostratigraphic, structural, and geochronologic evidence, the schist on Manhattan Island is divided into three distinct sillimanite-grade lithostratigraphic units (Merguerian 1983b; Mose and Merguerian, 1985; Merguerian, unpublished data). All three, lower, middle, and upper parts of Merrill's Manhattan Schist of this report, are separated by thrust surfaces.

The lower part of the Manhattan Schist of Merrill (1890) (Oml in Fig. 3) crops out in northern Manhattan and the west Bronx (Fig. 3) where it lies unconformably above the Inwood Marble (O-Ci in Fig. 3). It is composed of brown- to rusty weathering, fine- to medium-grained, muscovite-biotite-quartz-plagioclase-sillimanite-garnet schist containing inch- to foot-scale (cm- to m-scale) calcite-tiopsidite marble interlayers (Locality 2). The unit is correlative with the Middle Ordovician Manhattan Schist member A of Hall (1968).

The lower part of Merrill's Manhattan Schist and the Inwood Marble are structurally overlain by the middle schist unit (Omm), which constitutes the bulk of the exposed schist of Manhattan (Localities 2-4; Fig. 3). This schist unit consists of rusty- to maroon-weathering, medium- to coarse-grained, biotite-muscovite-plagioclase-quartz-garnet-sillimanite-kyanite gneiss and schist. This unit is also characterized by sillimanite \pm kyanite \pm quartz \pm magnetite layers and lenses as much as 4 in (10 cm) thick, and inch to several feet thick (cm to m) layers of blackish amphibolite and quartzose granofels. The middle part of Merrill's Manhattan Schist, composed of schist and amphibolite, is lithologically similar to and correlative with the Manhattan Schist members B and C of Hall (1976) and, in part, the Waramaug and Hoosac formations in New England.

The structurally highest or upper part of Merrill's Manhattan Schist, correlative with the Hartland Formation (O-Ch), is dominantly gray-weathering, fine- to coarse-grained, well-layered muscovite-quartz-biotite-plagioclase-garnet schist, gneiss, and granofels that contain inch- to several feet-thick scale (cm- to m-scale) layers of greenish amphibolite \pm garnet (Locality 1).

STRUCTURAL GEOLOGY

The base of the middle part of Merrill's Manhattan Schist is truncated by a shear zone, the St. Nicholas thrust (Locality 3; open symbol in Fig. 3). Grain-size reduction occurs at the thrust zone with the formation of mylonitic layering, ribboned quartz, lit-par-lit granitization, and quartz veins parallel to the axial surfaces of F_2 folds (Merguerian, 1983b). During the deformation that produced the St. Nicholas thrust, a penetrative foliation (S_2) and metamorphic growth of lenses and layers of quartz \pm sillimanite \pm kyanite \pm magnetite as much as 4 in (10 cm) thick, formed axial planar to F_2 folds; this produced large scale recumbent folds that strike $N50^\circ W$ and whose axial surfaces dip $25^\circ SW$.

Although the older metamorphic grain of bedrock in the city trends $N50^\circ W$, geometry of map contacts is strongly affected by younger F_3 isoclinal to tight folds overturned toward the west (Fig. 3). The S_3 axial surface is oriented $N30^\circ E$ and dips $75^\circ SE$. It varies from a spaced schistosity to a transposition foliation in many places with shearing near F_3 hinges. At least three phases of crenulate to open folds and numerous brittle faults and joints are superimposed on the older ductile fabrics, but they have little effect on contacts at map scale.

Locality 1. *Riverside Park, Hartland Formation.* In Riverside Park, from West 116th Street southward to West 75th Street, the upper part of Merrill's Manhattan Schist, which is equivalent to the Hartland Formation, crops out in exposures on Riverside Drive near West 90th-91st Streets and West 82nd-85th Streets (Figs. 1, 2, and 3).

The northernmost outcrops near West 90th Street consist of gray-weathering, well-layered, and slabby to laminated, lustrous muscovitic schist, containing interlayers of quartz-muscovite ± biotite granofels, 1-cm-thick glassy quartzose layers, and elliptical pods of recrystallized dark quartz.

In the outcrop, 2-3 cm metamorphic layering can be observed parallel to the axial surfaces of southeast-plunging longlimbed isoclinal and intrafolial F₂ folds. Tight southwest-plunging F₃ "s" folds are superimposed on the older folds and related metamorphic fabrics.

Outcrops to the south near West 82nd Street are lithologically identical to the outcrops near West 90th Street, except the layering is thicker (6-8 cm). A 3 ft (1 m) thick laminated black-weathering, greenish-black biotite-quartz amphibolite layer is evident in the outcrop.

Locality 2. *Inwood Hill and Isham Parks, Inwood Marble and Allochthonous Manhattan Schist.* Inwood Hill Park, on the northern tip of Manhattan Island, is bordered by Dyckman Street on the south, the Hudson River on the west, Spuyten Duyvil (Harlem Ship Canal) on the north, and Payson and Seaman avenues on the east. Isham Park occupies the flat area east of Inwood Hill Park extending eastward to Broadway between Isham Street and West 214th Street from Seaman Avenue.

Isham Park contains extensive exposures of the Inwood Marble and the middle part of the Manhattan Schist of Merrill (1890). The thrust surface separating the autochthonous marble from the allochthonous schist is not exposed. Several lithologies of marble appear: coarse-grained dolomitic marble, fine-grained calcite marble, and foliated calc-schist-all containing differentially eroded diopside, tremolite, and quartzose layers.

When entering Inwood Hill Park at Seaman Avenue and Isham Street, follow the path past the playground. The first prominent ridge contains the middle part of Merrill's Manhattan Schist. Follow the path to its curve to the west side of the ridge where the valley is underlain by a south-plunging antiform; the exposed west limb shows a tan weathering gray-white Inwood Marble just off the left side of the path.

Along the path that extends northward (up-slope) on the side of the west ridge, massive brown-weathering blackish amphibolite of the middle part of Merrill's Manhattan Schist crops out. The rocks on top of the ridge above the amphibolite are massive muscovite-biotite-plagioclase-quartz-garnet-sillimanitekyanite gneiss and schist containing weathered aluminosilicate nodules. The ridge is a south-plunging F₃ synform overturned toward the northwest.

At the top of the ridge beneath the Henry Hudson Bridge, a steep dirt trail leads down to the river, where a coarse-grained gray-white calcitic marble is exposed at low tide. Above the marble, the schist unit consists of biotite-quartz-plagioclasesillimanite rock containing abundant garnet porphyroblasts. Here, the schist contains an S_2 mylonitic foliation composed of millimeter-scale ribboned quartz striking $N45^\circ E$, and dipping $55^\circ SE$ with a strong down-dip lineation that plunges 50° in a $S34^\circ E$ direction. The zone is structurally complex, consisting of what may be, according to our interpretation, a thrust consisting of intercalated lithologies of the lower and middle schist units together with mylonitic amphibolite.

Locality 3. *Mount Morris Park, Inwood Marble and Allochthonous Manhattan Schist.* Mount Morris Park, centered at West 122 Street and Fifth Avenue, contains an erosional remnant of the middle part of Merrill's Manhattan Schist, which forms a klippe protruding above the Harlem Valley. The Inwood Marble crops out on the Madison Avenue side of the park. The marble is gray to tan weathering and contains schistose zones with layers and nodules that consist of diopside, tremolite, and quartz. The klippe is terminated to the south (West 120th Street) by a normal fault exposed at street level trending $N75^\circ W$, dipping $72^\circ SW$.

The contact between the middle schist unit and the Inwood Marble is exposed in the outcrop, where it is marked by a shear surface. The shear surface truncates lithologic layering in at an angle of 10° and is accompanied by shearing and imbrication of lithologies, as well as 0.8 to 1.2 in (2 to 3 cm) S_2 mylonitic layering parallel to the axial surfaces of reclined F_2 folds. Disharmonic southwest-plunging F_3 folds are exposed on the thrust surface at the northern edge of the klippe.

Locality 4. *Cross Bronx Expressway, Cameron's Line, Allochthonous Manhattan Schist and Hartland Formation.* Boro Hall Park in the Bronx is surrounded by East Tremont Avenue on the north, Third Avenue on the west, Arthur Avenue on the east, and East 175th Street on the south, which also serves as the westbound service road for the Cross Bronx Expressway, (I-95).

Along the north side of East 175th Street, the outcrop nearest the intersection with Third Avenue is a brown- to rustyweathering, medium-grained, gray, biotite-muscovite schist of the middle part of Merrill's Manhattan Schist (B and C units of Hall) containing several pegmatite dikes. Test borings for the I-95 overpass near this locality indicates that marble occupies the Third Avenue valley to the west.

East of the outcrop is a soil-covered, 100 to 130 ft (30 to 40 m) wide, $N40^\circ E$ trending shallow swale. The Hartland Formation crops out to the east of the swale and also south of I-95 along strike with this northern outcrop (Fig. 2). The Hartland rocks consist of brown- to tan-weathering gray muscovite-biotite-quartz-plagioclase-garnet schist and gneiss with granitoid sills and layers of greenish amphibolite. Cameron's Line, the contact between the middle part of Merrill's Manhattan Schist on the west and the Hartland Formation is not exposed, but presumably occupies the swale between the outcrops.

The simplified W-E cross section (Fig. 3) shows the structure of New York City and how the St. Nicholas thrust and Cameron's Line place the middle part of Merrill's Manhattan Schist

and the Hartland Formation, respectively, above the Fordham, Inwood, and lower part of Merrill's Manhattan Schist basement-cover sequence. The major F_3 folds produce digitations of the structural and lithologic contacts, which dip gently south (downward from the cross section shown in Fig. 3 toward the viewer).

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