Newly Discovered Serpentinite Bodies Associated with the St. Nicholas Thrust Zone in Northern Manhattan

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INTRODUCTION

Many bodies of serpentinite are scattered in and around Manhattan Island south of 59th Street based on a myriad of investigations over the years. A few years ago we reported on a newly discovered body near 43rd Street and Sixth Avenue (Merguerian and Moss 2005) and our continued examination of borings has borne fruit in the form of three newly discovered small masses in northern Manhattan in an area formally mapped as Manhattan Schist (Figure 1). The present study is based solely on drill core and petrography as the borings were largely conducted for design purposes since to this day little or no excavation has taken place. Thus, the geological map and section provided below are interpretive owing to the lack of three-dimensional field data and the lack of oriented drill core. Yet the implications of the drill core analysis we performed are quite clear – sheared serpentinites occur here within a zone of mylonitic rocks formed at the contact of the Manhattan Schist and Walloomsac formations. In the past this ductile fault boundary has been named the St. Nicholas thrust and based on regional considerations it marks the Taconian frontal thrust in NYC (Merguerian 1994, 1996, 1998; Merguerian and Baskerville 1987). This extended abstract outlines the distinction between the various schist units, provides data on the lithologies, and concludes with some structural interpretations and tectonic implications of our findings.

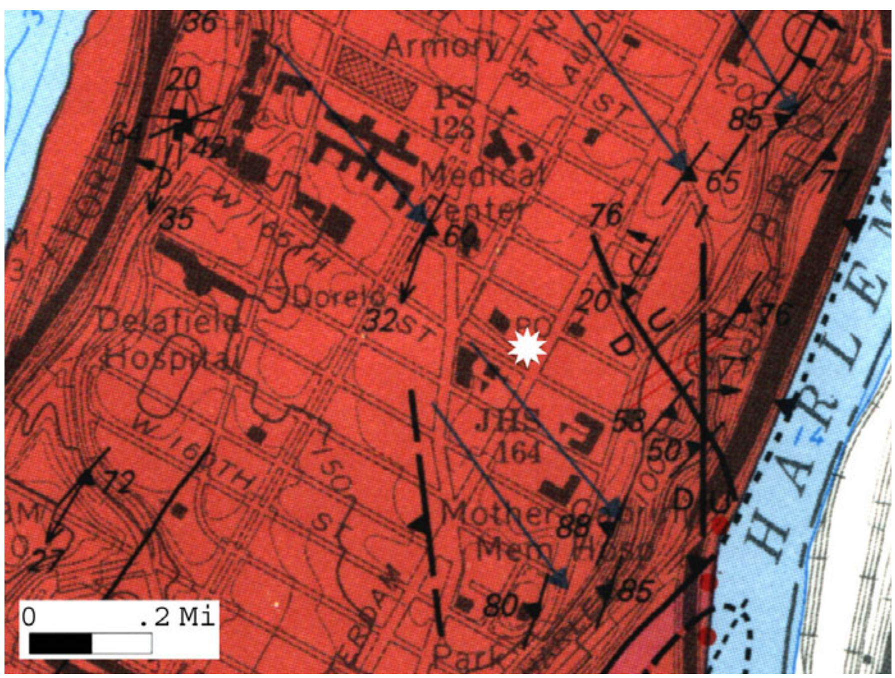


Figure 1 – Geological map of northern Manhattan from 155th Street to about 170th Street between the Hudson and Harlem Rivers (north is to the top of map). The site of this report is identified with a white star. Structural data and base map from Baskerville (1994).

NYC STRATIGRAPHY

The senior author’s research over the past three decades has produced a complex view of the schistose rocks of Manhattan that were formerly lumped together as the Manhattan Schist. Suffice here to state that the three “schistose” units of NYC can be subdivided in the field and during drill core examination based on textural and mineralogical grounds. The units are coeval, in part, and range in age from Late Proterozoic through mid-Ordovician, based on regional correlation. The schistose units are separated by ductile shear zones known as the St. Nicholas thrust and Cameron’s Line (Figure 2). Descriptions of the three units follow, starting with the structurally highest rocks of the Hartland formation, follow:

Hartland Formation. The structurally high Hartland formation (Ꞓ-Oh) is dominantly gray-weathering, fine- to coarse-textured, well-layered muscovite-quartz-biotite-plagioclase-garnet-kyanite-sillimanite schist with cm- and m-scale layers of gray quartzose granofels, and greenish amphibolite±garnet±biotite. *(Note: Minerals in lithologic descriptions are listed in relative decreasing order of abundance.)* Although commonly not exposed at the surface, the Hartland underlies most of the western part and southern half of Manhattan and the eastern Bronx.

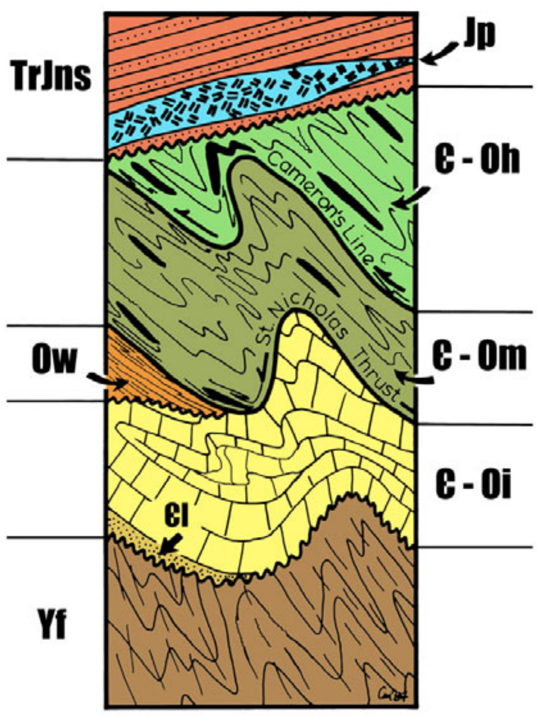


Figure 2 – Bedrock stratigraphy of New York City as described in text. Note that the polydeformed bedrock units are nonconformably overlain by west-dipping Triassic and younger strata (TrJns) and the Palisades sheet (Jp). Metamorphic units include the Fordham Gneiss (Yf), the Lowerre Quartzite (Ꞓl), the Inwood Marble (Ꞓ-Oi), the Walloomsac Formation (Ow), the Manhattan Schist (Ꞓ-Om), and the Hartland Formation (Ꞓ-Oh).

Manhattan Schist. The Manhattan Schist consists of massive rusty- to sometimes maroon-weathering, medium- to coarse-textured, biotite-muscovite-plagioclase-quartz-garnet-kyanite-sillimanite-tourmaline-magnetite gneiss and, to a lesser degree, schist. The unit is characterized by the lack of internal layering, the presence of kyanite+sillimanite+quartz+magnetite layers and lenses up to 10 cm thick, cm- to m-scale layers of blackish amphibolite, and scarce quartzose granofels. The unit is a major ridge former in northern Manhattan, a result of its durability to weathering owing to the lack of layering and presence of wear-resistant garnet, kyanite, and sillimanite.

Walloomsac Formation. This discontinuous unit is composed of fine- to medium-textured, fissile brown- to rusty-weathering, biotite-muscovite-quartz-plagioclase-kyanite-sillimanite-garnet-pyrite-graphite schist and migmatitic schist containing interlayers centimeters to meters thick of plagioclase-quartz-muscovite granofels and layers of calcite+diopside±tremolite±biotite ±phlogopite ("Balmville") calcite marble, calc-schist and calc-silicate rock. Garnet occurs as porphyroblasts up to 1 cm in size; amphibolite is absent. The Walloomsac contains strongly pleochroic reddish-brown biotite, garnet, graphite, and pyrite which, taken together, are diagnostic mineralogical features of the formation.

Contact Relationships and Origin of the Schistose Rocks of New York City

The Walloomsac Formation is interlayered with the underlying Inwood at many localities in Manhattan - (1) at the north end of Inwood Hill Park in Manhattan, (2) beneath the St. Nicholas thrust on the north and east sides of Mt. Morris Park (Merguerian and Sanders 1991), and (3) in the northwestern corner of Central Park (Merguerian and Merguerian 2004), and four new localities south of Canal Street (Merguerian and Moss 2006). In the Bronx, four areas of Walloomsac rocks have been found; (1) on the Grand Concourse and I-95 overpass (Merguerian and Baskerville 1987), (2) beneath the St. Nicholas thrust along the western part of Boro Hall Park (Fuller, Short, and Merguerian 1999), (3) below the St. Nicholas thrust in the north part of the New York Botanical Garden (Merguerian and Sanders 1998), and (4) in the northeastern part of Crotona Park (unpublished data).

Because of interlayering, the Walloomsac is interpreted as autochthonous (depositionally above the Inwood Marble and the underlying Fordham gneiss). The lack of amphibolite and the presence of graphitic schist and quartz-feldspar granofels supports an interpretation that the Walloomsac Schist is the metamorphosed equivalent of carbonaceous shale and interlayered greywacke and is therefore considered correlative with parts of the middle Ordovician Annsville and Normanskill formations of SE New York and the Martinsburg formation of eastern Pennsylvania (Merguerian and Sanders 1991, 1993a, 1993b). In terms of sequence stratigraphy, we consider it part of the Tippecanoe Sequence (Merguerian and Sanders 1996).

Both the Walloomsac Schist (Ow) and the Inwood Marble (Ꞓ -Oi) are structurally overlain along the St. Nicholas thrust by the Manhattan Schist (Ꞓ-Om) which forms the bulk of the "exposed" schist on the northern half of Manhattan island and most northern Central Park exposures. The Manhattan rocks represent displaced metamorphosed sedimentary- and minor mafic rocks formerly deposited in the transitional slope- and rise environment of the Late Proterozoic to Early Paleozoic continental margin of ancestral North America (Merguerian 1977, 1983). The Hartland is in ductile fault contact with both the Manhattan and Walloomsac along Cameron's Line, another important ductile shear zone in the New England Appalachians.

The schistose rocks of NYC (Hartland, Manhattan, and Walloomsac) were originally deposited as sediment, though in vastly different environments. The Hartland was originally deposited in a deep ocean basin fringed by volcanic islands that was the receptor of huge flows of granular sediment from time to time. This produced a thick sequence of interlayered clay, sand, and volcanogenic strata. Compositional layering was preserved in the Hartland, forming a well-layered metamorphic rock mass consisting of schist, gneiss, granofels, and amphibolite. The Manhattan Schist, on the other hand, presumably originated along the edge of the former continental margin as thick clay-rich sediment with occasional sand and mafic interlayers or hypabyssal intrusives. As a result, the Manhattan Schist is much more massive in character than the Hartland. The lack of internal compositional layering as well as mineralogical differences allows for separation of the two units in the field and also during core and petrographic analysis. The Walloomsac Schist is mineralogically unique because it originated under restricted oceanic conditions and consisted of thick accumulations of carbonaceous and sulphidic clay-rich sediment with occasional sandy and calcareous interlayers. This has resulted in mineralogically distinct schist, calc-schist, and calc-silicate rock enriched in biotite, rutile, graphite, and pyrite.

Juxtaposition of the allochthonous Hartland and Manhattan Formations with the basement cover sequence (Walloomsac + underlying Inwood and Fordham), was accommodated along deep-seated ductile shear zones known as Cameron's Line and the St. Nicholas thrust during the Taconic orogenic disturbance. (See Figure 2.)

Geology of the Site at 165th and Amsterdam Avenue

In advance of planned construction, fifteen relatively shallow borings were taken and brought to the geotechnical laboratory at Mueser Rutledge Consulting Engineers where we had ample time to examine and sample the core runs. The results of our investigations are summarized in Table 1 and the locations of borings are shown in plan view in Figure 3. The site is covered by a thin veneer of glacial drift and overlying fill varying from 13' to 38' in thickness. Depth to bedrock contours indicate two prominent valleys trending ENE and NE but their origin can only be presumed based on a lack of field data. Normally such valleys indicate the presence of eroded brittle faults. Six of the fifteen borings encountered sheared serpentinite and the others consisted of Manhattan Schist, Walloomsac Formation or tectonic mixtures of the two units.

At either end of the site metamorphic rocks displayed textures typical of Walloomsac and Manhattan rocks found in other areas of NYC. For example, Boring B-1P from the NW corner of the site displays medium-textured biotite-muscovite-garnet-pyrite-graphite-kyanite schist (Figure 4A). Diagnostic red-brown pleochroic biotite together with graphite and pyrite identify the unit as Walloomsac. By contrast at the NE corner (Boring B-5) and along the entire eastern edge of the site of the site, the Manhattan Schist occurs as massive, coarse-textured migmatitic musc-bio-gt-ky schist (Figures 5A and 4B). The borings closer to the center of the site show curious mixtures of the two lithologies in hand sample and also show petrographic evidence of mixing and shearing in the form of crystal size reduction, frayed mica, rotated porphyroblasts, and stretched and lenticular areas of polycrystalline quartz (flaser texture), all diagnostic indicators of high shear strains (Figures 5B and 6).

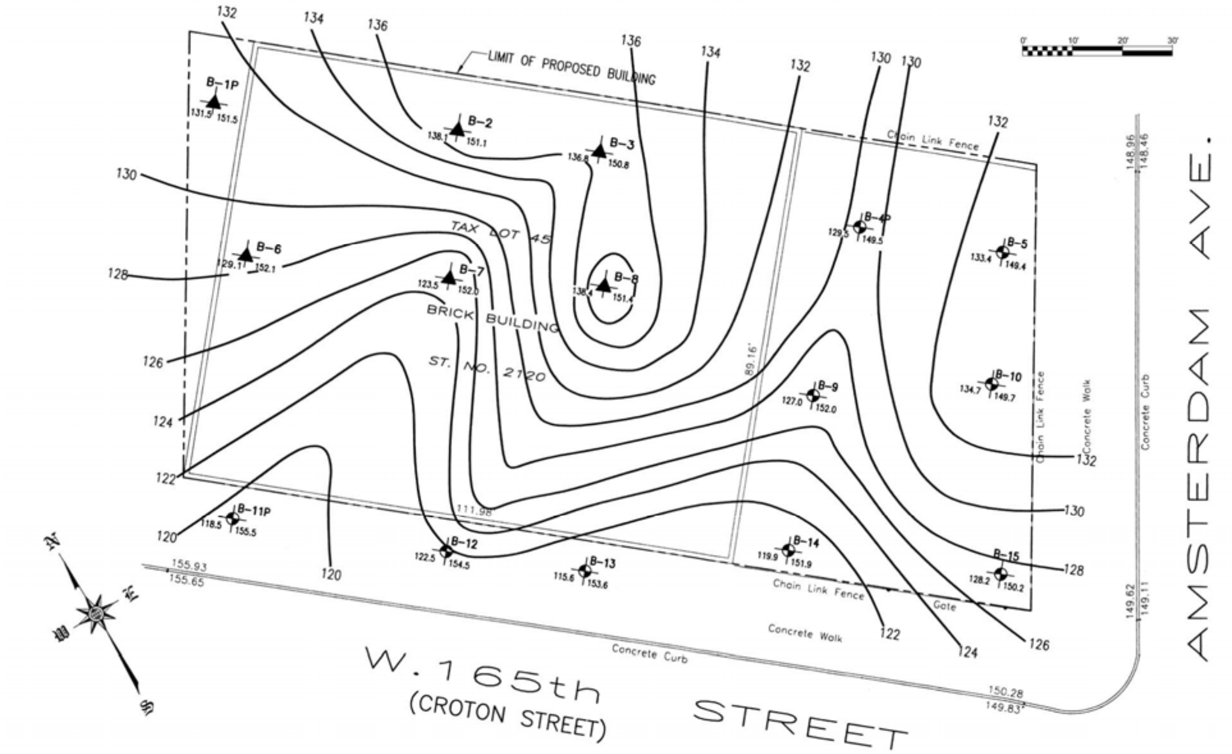


Figure 3 - Plan view of the site showing the locations of borings and the topography of the top of rock. Numbers to the left and right of the boring locations indicate elevation of top of rock (smaller value) and the surface elevation (higher value). Most of the site is covered by a thin veneer of glacial drift strata and fill (ranging from 13' to 38') but the depth to bedrock map shows two NE-trending valleys, presumably the result of faulting and accelerated erosion.

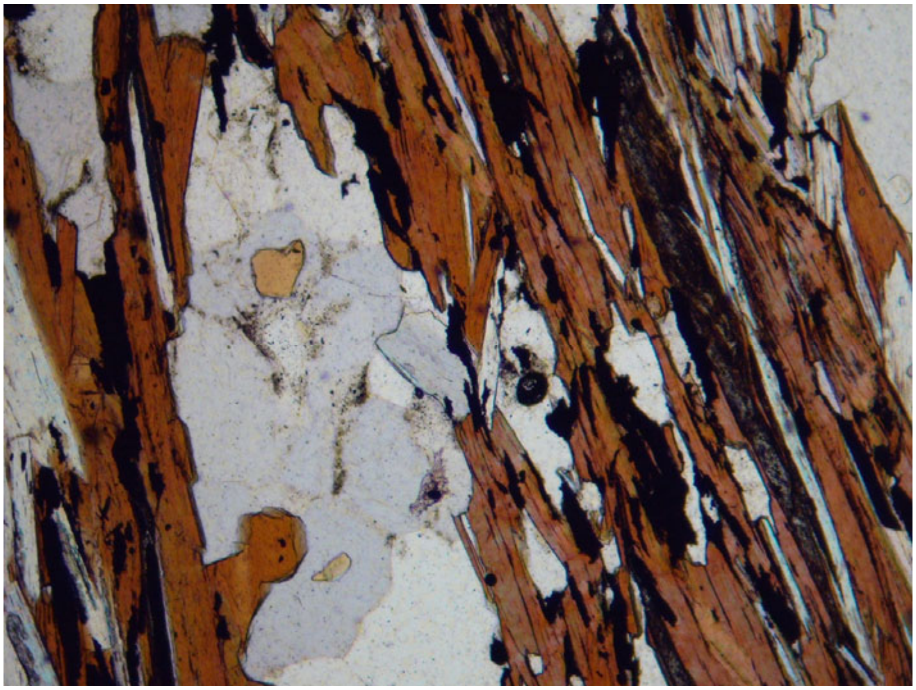
In the absence of three-dimensional field exposures, geologic interpretations based on borings can at best be considered interpretive. Our view of the geology of the construction site is shown in Figures 7 and 8 as a geologic map and section. The section runs across the northern edge of the site from Boring B-1P to Boring B-5 and therefore includes the borings depicted in Figures 4 and 5. Because none of the borings were oriented, foliation strikes and the directions of dip plotted on the geological map are projected from past measurements made by Merguerian adjacent to site but the dip amounts are measured from core runs. The geological map shows as colored circles the boring locations and lithologic interpretations summarized in Table 1. A mixed zone of Walloomsac and Manhattan rocks occupies the central area of the site. At least three of the borings (B-6, B-7, and B-13) show shearing and intermixing of lithologies. As a result, we interpret the central portion of the site as a ductile shear zone between the Walloomsac basement+cover sequence and allochthonous rocks of the Manhattan Schist, a boundary mapped as the St. Nicholas thrust. Ductile shears (small black lines) of the St. Nicholas thrust zone are projected from petrofabric study with shearing indicated in both the map and section. What is unknown at present is the degree of tectonic intermixing as a result of post-thrust shearing and transposition. The section depicts an interpretation where significant shearing and tectonic intermixing is coincident with late tight to isoclinal folding – some or all of this could post-date incorporation and emplacement of the serpentinite masses.

Boring Data

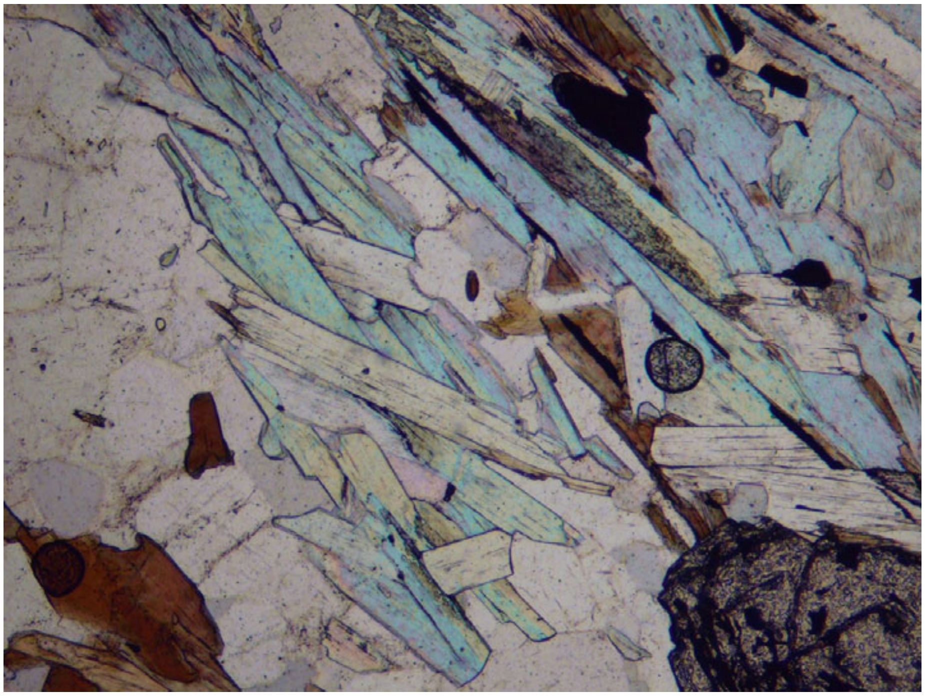
Boring #	Run #s Viewed	Unit - Brief Lithologic Description	Smpl #	Core Run	Comments
B-1P	1C 2C	Ow - Bio-musc-gt-grph-py-ky augen schist	N738	1C	Steep foliation dip; Sample @ 22.7'
B-2	1C 2C	Os - Serpentinite/soapstone	N741	2C	Sample @ 20.0'
B-3	1C 2C	Os - Serpentinite/soapstone	N737	1C	Sample @ 18.4'
B-4	1C 2C	Os - Serpentinite/soapstone	N705	1C	Sample @ 25'
		Os - Serpentinite/soapstone	N721	2C	Sample @ 30'
B-5	1C 2C	Ꞓ-Om - Massive coarse-textured migmatitic musc-bio-gt augen schist	N732	1C	Moderate foliation dip ~55°; Sample @ 22'
B-6	1C	Ow - Migmatitic bio-ky-gt-py schist (Mixed w/ Ꞓ-Om)	N739	1C	Sample @ 28.8'; Steep foliation
B-7	1C	Ow - Fine-textured migmatitic musc-bio-ky-gt-py gneiss (Mixed w/ Ꞓ-Om)	N740	1C	Sample @ 31'; Vertical foliation
B-8	1C 2C 3C	Os - Serpentinite/soapstone	N736	1C	Sample @ 17.8-18.2'
B-9	1C 2C	Os - Serpentinite/soapstone	N718	1C	Sample @ 27'
		Os - Serpentinite/soapstone	N719	2C	Sample @ 32'
B-10	1C 2C	Ꞓ-Om - Massive coarse-textured migmatitic bio-musc-gt-ky augen schist	N733	1C	Moderate dip ~40°; Sample @ 18'
B-11	1C 2C 3C	Ow - Fine-textured migmatitic musc-bio-gt-ky-tour schist	N722	2C	Sample @ 38'; Steep dip ~ 70°
B-12	1C 2C	Ow - Fine-textured migmatitic bio-musc-grph-py schist	N709	1C	Sample @ 37'; moderate to steep highly contorted foliation
B-13	1C 2C	Ow - Laminated, fine-textured bio-gt-ky-py schist (Mixed w/ Ꞓ-Om)	N742	2C	Shredded biotite; Sample @ 40'; Foliation ~70°
		Ow – Laminated, fine-textured bio-gt-ky-py schist (Mixed w/ Ꞓ-Om)	N706	2C	30% gt porphyroblasts; Sample @ 41'; Foliation ~70°
		Ow – Laminated, fine-textured bio-gt-ky-py schist (Mixed w/ Ꞓ-Om)	N723	2C	Sample vertical brittle fault @ 43' w/ flat slicked pyrite
		Ow+ꞒOm - Massive coarse-textured migmatitic bio-gt-ky-st-py schist	N707	2C	Sample @ 43'; Sheared vertical foliation cut by vertical fault
		Ow+ꞒOm - Massive coarse-textured migmatitic bio-gt-ky-st-py schist	N734	2C	Mixed lithologies; Mylonitic fabric; Sample @ 43.5'
B-14	1C 2C	Os - Serpentinite followed by soapstone	N720	1C	Sample @ 32'
		Os - Serpentinite followed by soapstone	N708	1C	Sample @ 35.5'; Core cut by moderate reverse fault w/ 2 cm calcite vein
B-15	1C 2C	Ꞓ-Om - Migmatitic bio-gt-ky schist			Moderate dip ~40°

Table 1 - Descriptions of all 15 borings and associated runs from proposed construction site near Amsterdam Avenue and 165th Street in Manhattan, New York. Note that 21 samples were taken for petrographic study. The lithologic units are highly sheared and include rock types from the Manhattan Formation (Ꞓ-Om), the Walloomsac Formation (Ow), and serpentinized ultramafic rock (Os). Minerals in lithologic descriptions are listed in order of decreasing abundance. Abbreviations used: (bi = biotite), (musc = muscovite), (gt = garnet), (ky = kyanite), (st = staurolite), (py = pyrite), (grph = graphite), (tour = tourmaline). The boring locations are plotted on the plan view (Figure 3) and the interpretive geological map (Figure 7).

A

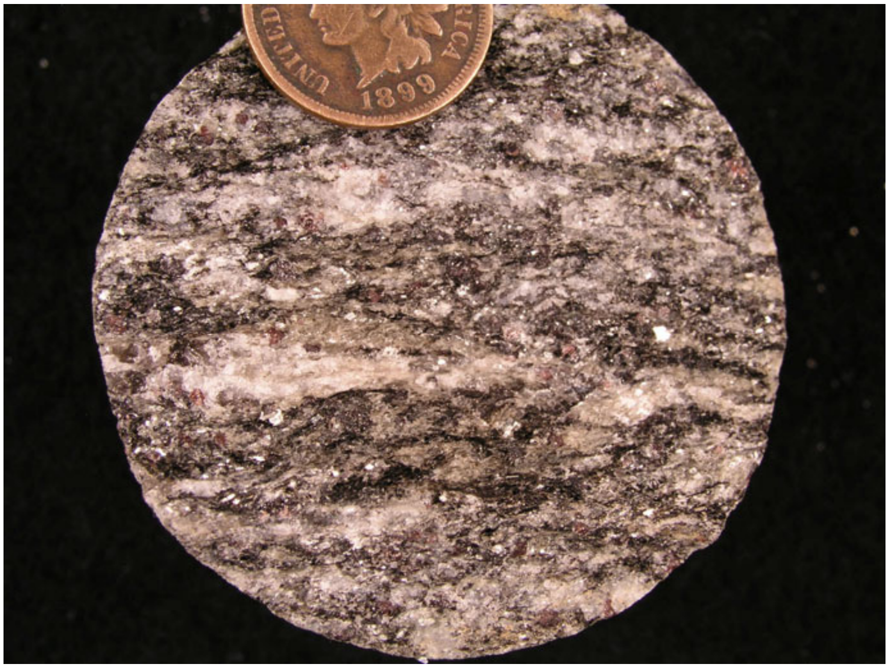


B

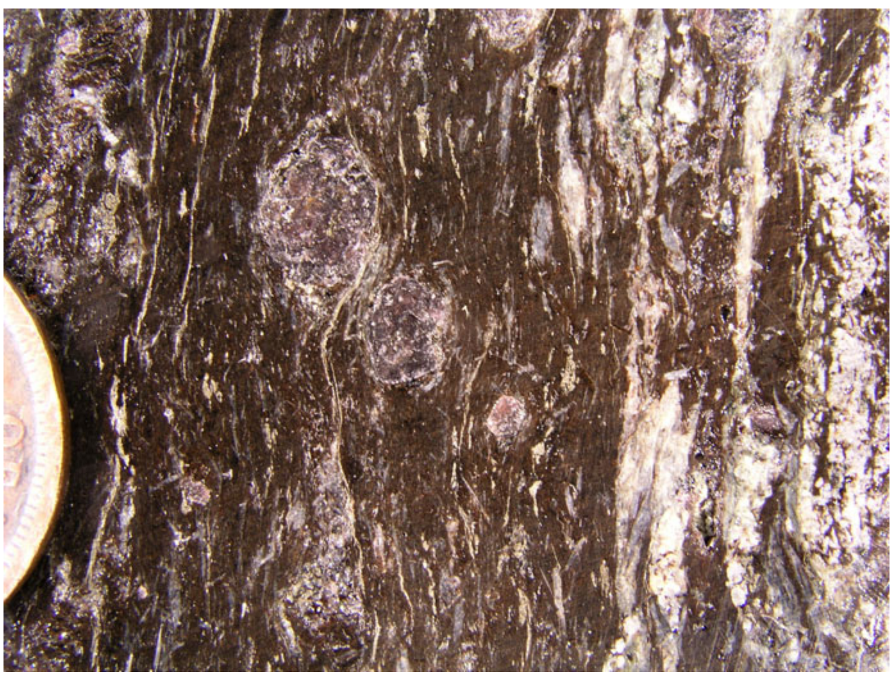


Figures 4A, 4B – Photomicrographs in plane polarized light of typical Walloomsac (A) and Manhattan Schist (B) from opposite ends of the site. The Walloomsac is sample N738 from Boring B-1P and the Manhattan is sample N732 from Boring B-5. Note the contrast in mineralogy and the medium- to coarse texture of both rock types. (Width of field ~ 1.6 mm.)

A



B



Figures 5A, 5B – Broken surface of rock core from Boring B-5 showing typical Manhattan Schist (Unit Ꞓ-Om) found along the eastern edge of the site, here a massive coarse-textured muscovite – biotite - garnet schist showing a migmatitic texture. Same sample (N732) as shown above in Figure 4B. In Figure 5B, close view of sawn drill core consisting of predominately Walloomsac with some intermixed Manhattan Schist from sample N734 near south center of site (Boring B-13). Note the overall flaser texture and dense, laminated fabric in the Walloomsac consisting of fine-textured red-brown biotite. Garnet and kyanite porphyroblasts are rotated and sheared and quartzofeldspathic segregations and pyrite show extreme stretching and disarticulation. This unique boring captures the mylonitic contact (St. Nicholas thrust) between the Walloomsac and light-colored Manhattan lithotypes to the left and right of the image. Edge of Indian Head cent for scale in both images.

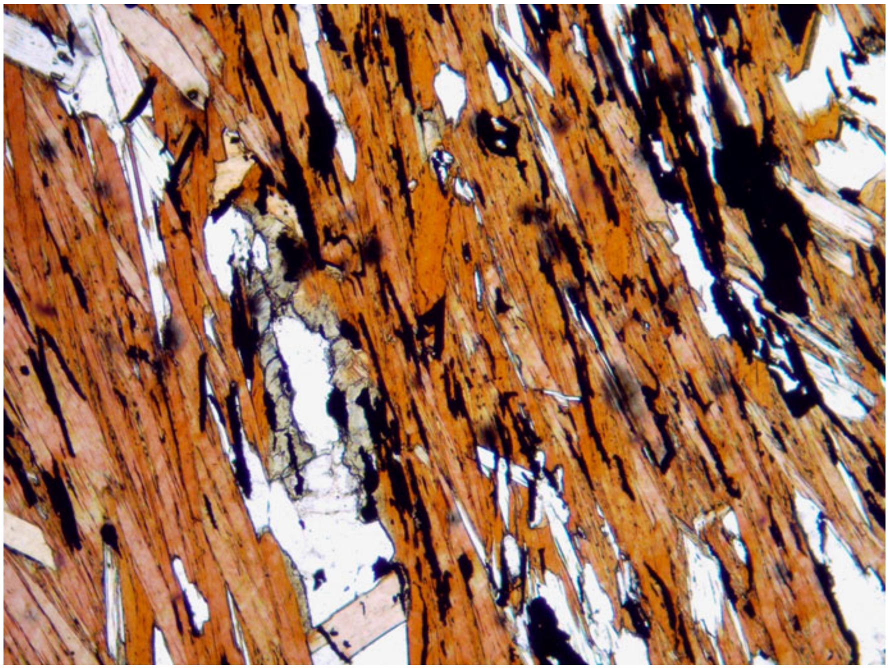


Figure 6 – Photomicrograph in plane polarized light of sample N-723 from Boring B-13 at south center of site. Note the shear fabric characterized by frayed red-brown biotite, reduced crystal size, and lenticular polycrystalline quartz, all indicators of high shear strains.

As mentioned above 40% of the borings were situated in serpentinite and define three NE-trending lenticular bodies, the largest of which is 120’ (~40 m) in length. The philosophy behind viewing the serpentinite borings as separate masses is based on a lack of continuous data, inherent conservatism, and application of the concept that rock sample textures help illustrate map-scale lithologic patterns. It is indeed possible that the six borings are from a single highly folded mass but the truth to this prospect may never be known. We have adopted our segmented, lenticular view of the serpentinites shown in Figures 7 and 8 based on known pod-like exposures of serpentinites found in NYC and a reverence for the weak mechanical strength of the rock type. Petrographic study indicates that the serpentinite contains some relict olivine and pyroxene but mostly consists of coarse-textured anthophyllite, acicular colorless amphibole, and talc. As such they are interpreted as mantle slivers (dismembered ophiolite) caught up in a ductile shear zone. What is unusual about this locality is the fact that serpentinites are typically associated with Cameron’s Line and the eugeosynclinal Hartland Formation in NYC and throughout New England (Merguerian 2006). This is the first report of serpentinite in contact with Walloomsac rocks along the St. Nicholas thrust zone, a well-positioned candidate for the Taconian frontal thrust in NYC as it separates overthrust slope-rise strata from foreland basin materials. Perhaps the unusually high graphite content of the Walloomsac at this unique structural position helped facilitate dislocation, shearing, and incorporation of offscraped mantle slivers (now serpentinites).

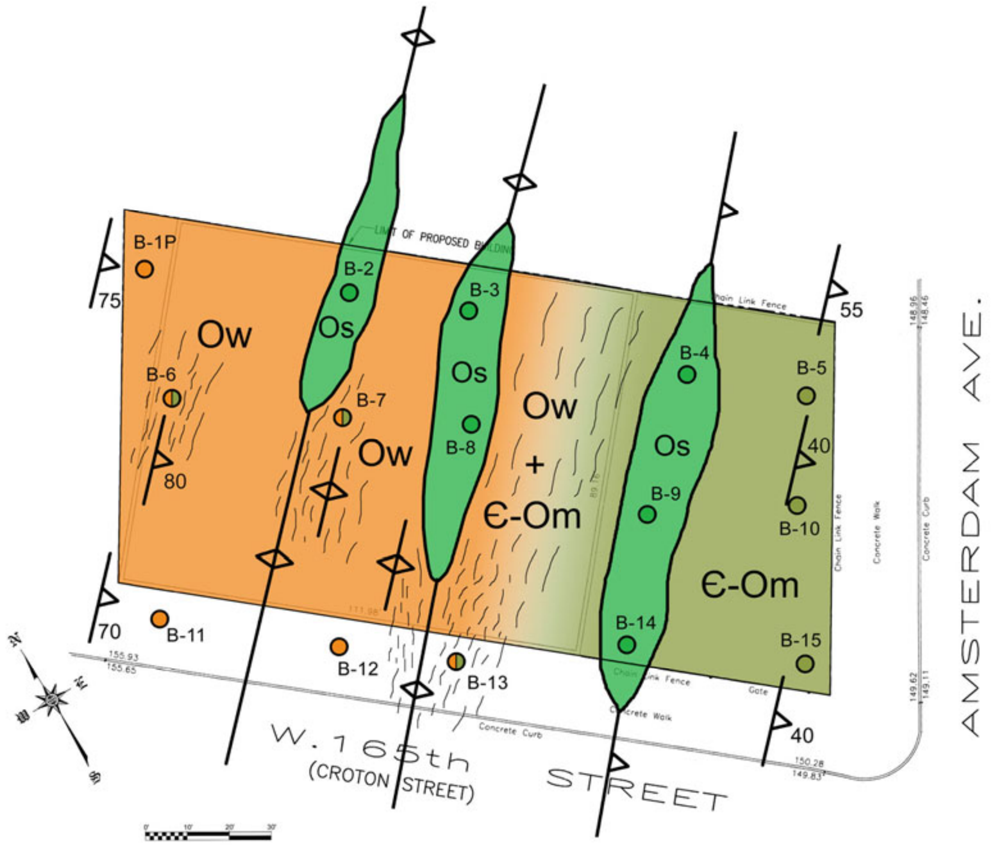


Figure 7 – Geologic map showing boring locations and lithologies mapped as a result of boring analysis (both visual and petrographic). Naturally, the map is interpretive since no actual exposed rock was examined but six of the fifteen borings (40%) penetrated serpentinite. (See Table 1.) Strikes are projected from measurements made by CM adjacent to site; dips were measured from core. Ductile shears (small black lines) of the St. Nicholas thrust zone are projected from petrofabric studies.

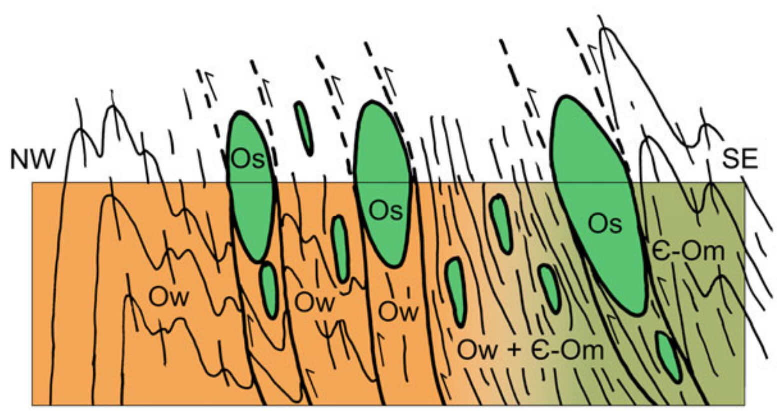


Figure 8 – Geological section across the northern part of Figure 7 (From Boring B-1P to B-5) showing our preferred interpretation of the geological relationships of the site. The St. Nicholas thrust zone (Ow + Є-Om) is interpreted as consisting of sheets of sheared, intermixed rocks from the upper (Є-Om) and lower (Ow) plates. Depicting our bias of NYC shear zones, the serpentinites are interpreted as slivers since field connection has not been demonstrated.

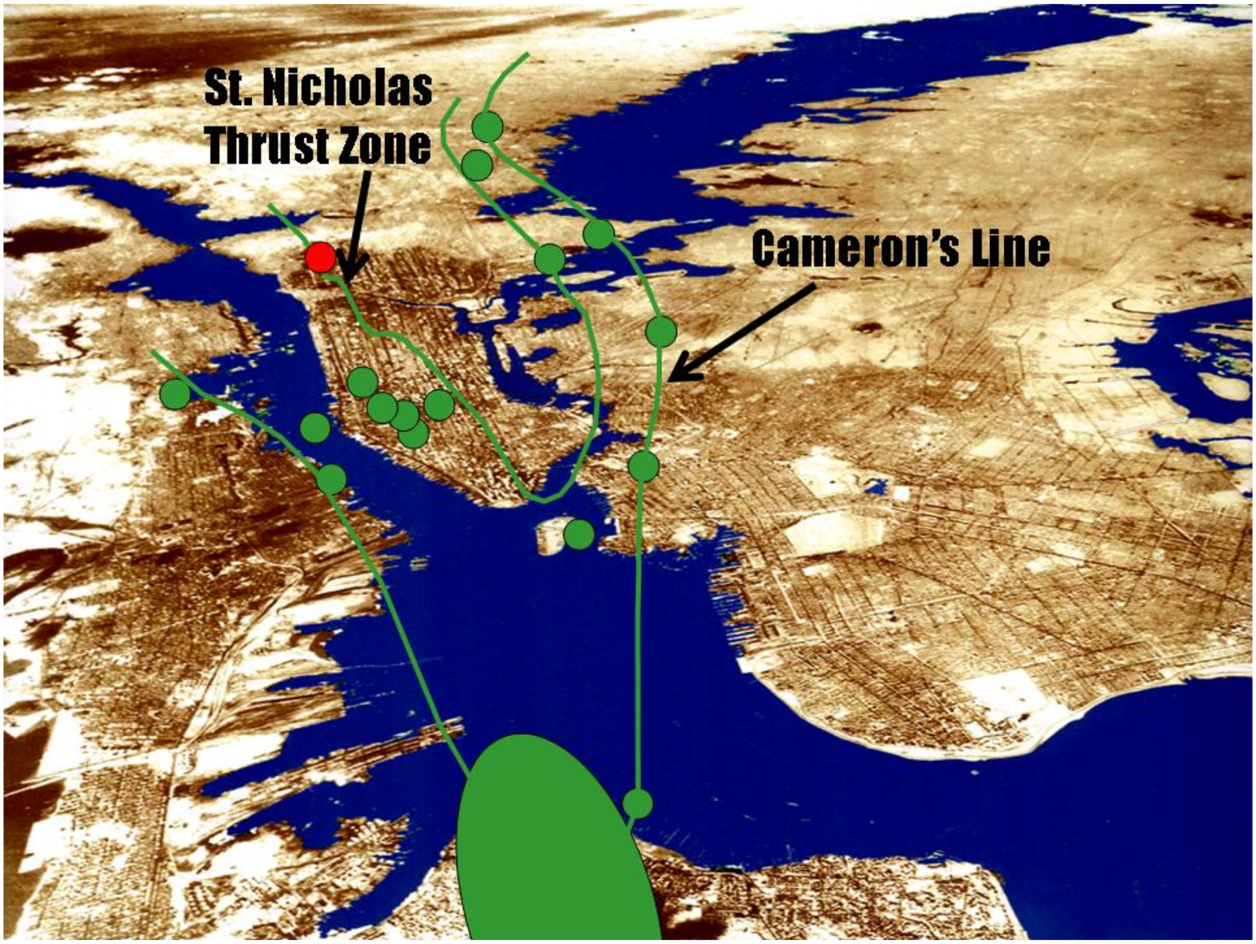


Figure 9 – Cartoon showing distribution of 18 known areas of serpentinite in the New York City area with the site of this report shown in red. The green lines surround areas of serpentinite and is broadly coincident with the location and geometry of the St. Nicholas thrust and Cameron's Line, two important elements of the Taconian suture zone in New York City.

CONCLUSIONS AND IMPLICATIONS

Although our work is in progress, our preliminary results indicate that a small structural window exposes elements of the basement-cover sequence in the shallow subsurface of northern Manhattan, structurally beneath the St. Nicholas thrust. We have identified three serpentinite masses sheared in association with this regionally important tectonic contact and interpret them as dismembered ophiolite. The serpentinites of this study are the northernmost of any described in Manhattan and lie within a continuous belt of serpentinites that traverse the NYC area (Figure 9). The green lines of Figure 9 outline the area of known serpentinite and is broadly coincident with the location and geometry of the St. Nicholas thrust and Cameron's Line, two elements of the Taconian suture zone in NYC. The width of the belt is best understood by recognizing that serpentinites can not only be found at the structurally higher thrust boundary of Cameron's Line but also (as based on this study) at the structurally lower thrust sheet boundary (the St. Nicholas thrust). In addition, we can see no reason why they could not occur within sheared rocks of the intervening Manhattan Formation.

ACKNOWLEDGEMENTS

We would like to thank **Al Brand** and **Jong Choi** of Mueser Rutledge Consulting Engineers for their assistance in providing data and for obtaining client permission to publish. We would also like to thank the client for allowing us to publish proprietary information obtained from their project. **Jim Tantalla** and **Zach Young** of Mueser Rutledge Consulting Engineers were most helpful in arranging the logistics of our core study. **Hallie Thaler** and **Matt Jensen** (geology majors at Hofstra University), assisted as lab technicians and curators for research specimens used in this study. We are indebted to the **H. Manne Vb** and **Mr. Jenkins** of Duke Geological Labs for support and assistance in the field and laboratory.

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Filename: CMCJM2007.doc