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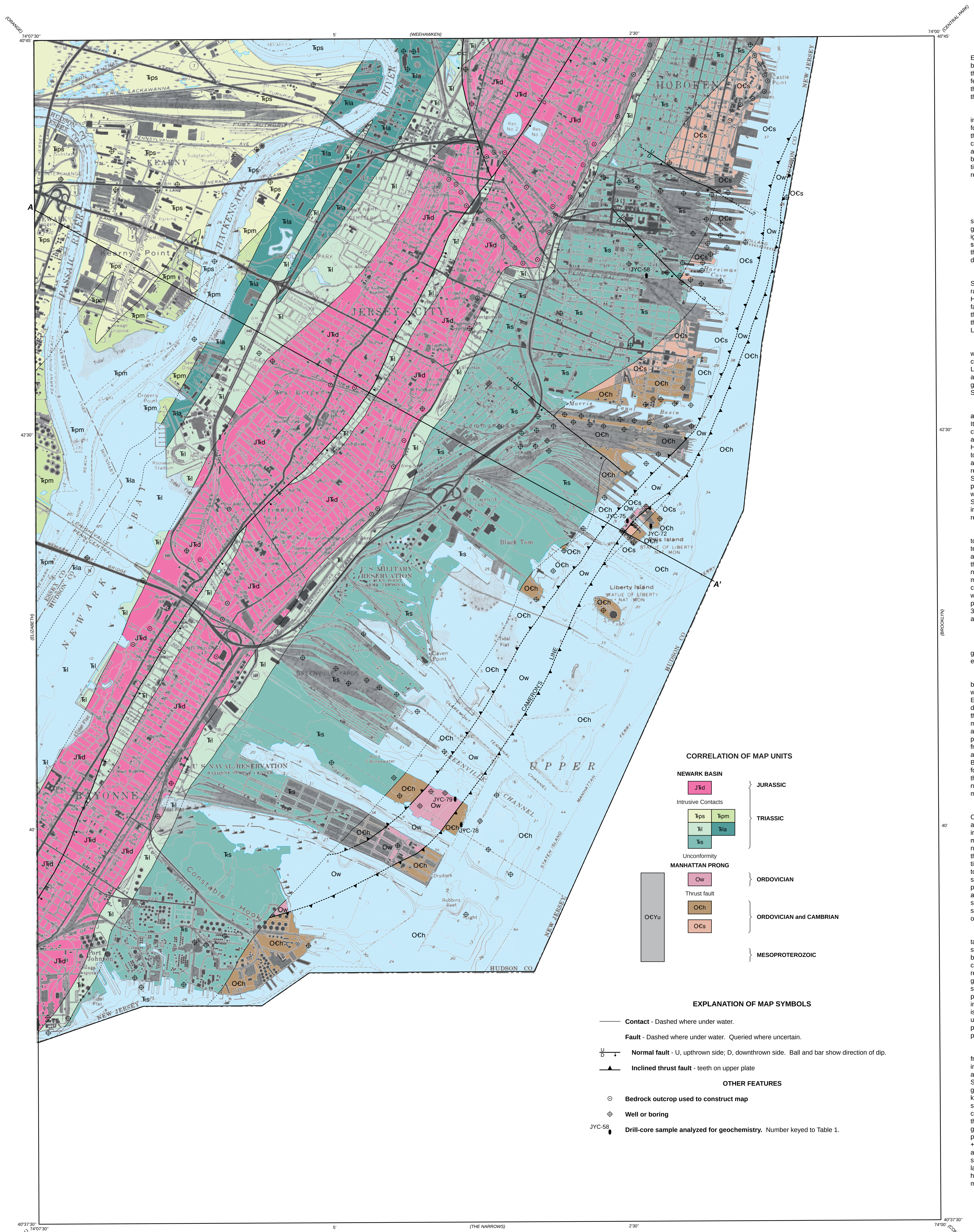

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SCALE 1:24,000

1 .5 2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETE R

CONTOUR INTERVAL 10 FEET

LOCATION IN NEW JERSEY

11.5°
MAGNETIC NORTH
TRUE NORTH
APPROXIMATE MEAN DECLINATION, 1954

Bedrock geology mapped by R.A. Volkert in 2013-2014.
Digital cartography by R.S. Pristas

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NEW JERSEY GEOLOGICAL AND WATER SURVEY 1835

Bedrock Geologic Map of the Jersey City Quadrangle Hudson and Essex Counties, New Jersey

by
Richard A. Volkert
2016

INTRODUCTION

The Jersey City quadrangle is in the northeastern part of the state, in Hudson and Essex Counties, in a mixed commercial, industrial and residential setting. It straddles the border between New Jersey and parts of Kings and Richmond Counties in New York, but the bedrock geology is shown only in New Jersey on this map. Elevations of as much as 150 feet above sea level occur east of the Hackensack River and Newark Bay, and elsewhere they are 10 feet or less. Much of the area is covered by unconsolidated deposits of varied thickness that range in age from Pleistocene to recent (Stanford, 1995).

The quadrangle is located in the eastern part of the Piedmont Physiographic Province. Bedrock of Mesozoic age of the Newark basin underlies most of the area except for the eastern part along the Hudson River, which is underlain by pre-Mesozoic rocks of the Manhattan prong. The latter are rarely exposed and nearly completely covered by unconsolidated deposits. Bedrock there was mapped mainly from drill core samples, where available, from the logs of more than 100 borings, and from well-record data summarized by Stanford (1993; 1995). The mineralogy, geochemistry, lithological, and structural relationships of the pre-Mesozoic rocks were used to draw contacts and interpret the geological relationships.

STRATIGRAPHY

Newark basin

The youngest bedrock is Mesozoic and was deposited in the Newark basin, one of a series of northeast-trending rift basins that extend along the eastern North American margin. The Newark basin contains approximately 24,600 feet of interbedded sedimentary and igneous rocks that include Upper Triassic to Lower Jurassic conglomerate, sandstone, siltstone, and shale of fluvial and lacustrine origin, one Upper Triassic and two Lower Jurassic tholeiitic basalt formations, and sills, dikes and bodies of Upper Triassic to Lower Jurassic diabase (Olsen and others, 2011).

Sedimentary rocks in the map area include the Upper Triassic Passaic, Lockatong and Stockton formations. The Passaic Formation underlies the northwestern part of the quadrangle but is largely concealed beneath Pleistocene to recent unconsolidated deposits of the Hackensack Meadowlands. It is in conformable contact with, and underlain by, an arkosic facies of the Lockatong Formation. The contact between these formations is placed within the Walls Island Member, where predominantly reddish-brown siltstone and sandstone of the Passaic Formation give way to tan or yellow arkosic beds, or gray bed sequences of the Lockatong Formation (Olsen and others, 1996).

The Lockatong Formation consists of tan or reddish-brown arkosic beds that interfinger with cyclically deposited gray and black lacustrine siltstones 15 feet thick on average that comprise the remainder of the formation (Van Houten, 1969). The contact between the Lockatong and underlying Stockton Formation is conformable and transitional. It is placed at the base of the Wilburtha Member in the Lockatong, at the base of the lowest black or gray shale sequence, where tan to yellow arkosic sandstone and reddish-brown shale of the Stockton become more prominent (Van Houten, 1969; Olsen and others, 1996).

The Stockton Formation consists of yellowish-gray to reddish-brown arkosic sandstone and conglomerate that fine upward into siltstone and shale sequences (Van Houten, 1969). It was deposited directly on the eroded surface of the pre-Mesozoic crystalline rocks. This contact is not exposed in the map area, although the contact between Stockton Formation and both serpentinite and schist was encountered in borings along the western side of the Hudson River. Based on examination of core samples and boring logs, the basal Stockton is noted to be mainly reddish-brown sandstone, pebbly sandstone and conglomerate, although a few of the borings encountered white or light-gray sandstone interbedded with reddish-brown siltstone. The unconformable contact between serpentinite and the basal Stockton was penetrated at a depth of 75 feet below ground surface in a drill core sample from the area of Hoboken (fig. 1). The contact is sharp and no clasts of serpentinite were observed in the Stockton above the contact. The unconformable contact between the Stockton Formation and schist was penetrated at a depth of 281 feet below ground surface in drill core from near Jersey City (fig. 1). The basal Stockton there was noted to be mainly reddish-brown pebbly sandstone and conglomerate.

Mesozoic igneous rocks are well exposed in the map area and consist of Upper Triassic to Lower Jurassic diabase (Puffer, 1984; Puffer and others, 2009), that is the southern extension of the Palisades diabase sheet. The sheet intrudes the basal Lockatong Formation and the uppermost Stockton Formation as a west-dipping sill. The Lockatong has been thermally metamorphosed to a dark gray hornfels along the contact with Palisades diabase north of the map area. A few feet of arkosic sandstone of the Stockton have also been thermally metamorphosed close to the base of the sill. The age of the Palisades diabase is well constrained by geochronological studies. Zircon and baddeleyite U-Pb ages of 200.9 Ma were obtained by Dunning and Hodych (1990). Marzoli and others (2011) obtained $^{40}Ar/^{39}Ar$ plateau ages of 202.8 Ma from plagioclase and 201.7 Ma from biotite from the olivine zone, 30 feet above the base of the sill, and 195.1 Ma from plagioclase collected from 300 feet above the base of the sill.

Manhattan prong

Pre-Mesozoic rocks of the Manhattan prong include serpentinite, schist and minor gneiss that correlate to similar rocks that crop out on Staten Island, in New York City, southern Connecticut, and possibly as far north as Vermont and Quebec.

Serpentinite crops out in the map area only at Castle Point in Hoboken but the same body was encountered in drill core samples as far south as Ellis Island. Another small body was penetrated by drill core at Ellis Island. Although serpentinite was not encountered from Ellis Island south to the northern shore of Staten Island, its apparent absence may be due to the scarcity of drill core samples in that area. Serpentinite is a heterogeneous unit that ranges from massive, fine-grained rock composed of olivine, orthopyroxene, and chromian spinel where less altered, to rock composed of lizardite, chrysotile, talc, anthophyllite, and brucite (Okulewicz, 1979) where more highly altered. Other rock associated with serpentinite was identified during this mapping through X-ray diffraction analysis of drill core from Ellis Island as a mixture of magnesiohornblende and talc (fig. 2). This rock is preserved as a lens about 8 feet thick that is spatially associated with more common serpentinite. Based on the mineralogical and geochemical composition, serpentinite is interpreted as forming from ultramafic protoliths such as harzburgite and dunite (Okulewicz, 1979). In the Manhattan prong serpentinite occurs as tectonically transported slices of oceanic crust now spatially associated with schist formed from metamorphosed sandstone and shale of marine origin.

Preserved near the top of the serpentinite in drill core samples from the area of Jersey City is a conglomeratic interval as much as seven feet thick that is composed of unsorted, angular to subrounded, matrix-supported clasts of mainly serpentinite as much as three inches long, as well as dark-gray, fine-grained basalt; light-gray quartzite; and Fe-Ti oxide minerals in a very coarse sand matrix (fig. 3). The stratigraphic position of this interval beneath the contact with Stockton Formation precludes its origin as a conglomeratic facies of that formation. An origin as a “cemented” glacial till also seems unlikely because glacial striations on bedrock to the north in the Weehawken quadrangle suggest that ice movement was toward the south-southeast (Stanford, 1993). Therefore, clasts of reddish-brown and gray sedimentary rocks and diabase should be predominant components of a till. It is tentatively proposed here that the conglomeratic interval may have formed in a marine environment as a debris flow that was receiving locally-derived rock fragments eroded from serpentinite and spatially associated lithologies. Similar polymictic conglomerates containing ophiolitic and sedimentary clasts are recognized in southern Quebec where they unconformably overlie ophiolitic sequences (Pagé and others, 2009; De Souza and others, 2012).

The age of serpentinite in the Manhattan prong is imprecisely known because it contains no minerals that may be dated directly using conventional geochronology. Various studies in the northern Appalachian Piedmont have assigned serpentinite an age of Cambrian to Neoproterozoic (Lyttle and Epstein, 1987; Drake and others, 1996), Lower Ordovician to Neoproterozoic (Baskerville, 1994), or Ordovician (Stanley and Ratcliffe, 1985 and references therein; Brock and Brock, 2001). Serpentinite bodies that are mineralogically, geochemically and stratigraphically similar to those in the Manhattan prong crop out in Massachusetts, Vermont and in southern Quebec. In Quebec they are spatially associated with plagiogranite that yields U-Pb zircon ages of 504 to 478 Ma, and the serpentinite bodies are intruded by granitoid rocks dated at 470 to 469 Ma, indicating that the age of the serpentinite is Lower Ordovician to Upper Cambrian (De Souza and Tremblay, 2010). Extension of the ultramafic complexes of Vermont and Quebec into southern New England has been proposed by numerous workers (Stanley and Ratcliffe, 1985). Serpentinite in the Manhattan prong is here interpreted to also be Lower Ordovician to Upper Cambrian in age.

Metamorphosed schist and less abundant gneiss were also encountered in borings from along the western side of the Hudson River. Most borings penetrated only schist, but in borings that encountered both schist and gneiss, contacts between them are conformable and dominated by schist with gneissic intervals ranging in thickness from 5 to 35 feet. Samples of schist are characteristically light gray, medium grained and composed mainly of garnet + quartz + plagioclase + muscovite + biotite. Some samples contain local magnetite, kyanite, or sillimanite. Most of the schist is highly micaceous and fairly uniform in texture, suggesting that it probably formed from a protolith that was dominantly shale. Some micaceous drill core samples also contain layers that are somewhat more siliceous, suggesting that the protolith was sandstone interbedded with shale. Samples of gneiss are medium grained and well foliated. They range from light-gray gneiss composed of garnet + quartz + plagioclase + muscovite + biotite, to dark gray to grayish-black gneiss composed of garnet + sulfide + quartz + plagioclase + biotite + graphite. The light-gray gneiss is similar mineralogically to the more siliceous layers in micaceous schist and likely formed from a sandstone protolith. Drill-core samples of both schist and gneiss commonly contain conformable layers less than 0.5 inch thick of coarse-grained rock that is mineralogically identical to, and has gradational contacts with, finer-grained gneiss suggesting that it formed through local melting of the host gneiss.

Correlation of pre-Mesozoic rocks

Correlating schist and gneiss from the map area to bedrock exposed across the Hudson River in New York City and in areas to the north is a formidable challenge. Pre-Mesozoic rocks in the map area are mineralogically similar to formations in New York City mapped as Walloomsac Formation (Middle Ordovician), Hartland Formation (Middle Ordovician to Middle Cambrian), and Manhattan Schist Member C (Lower Cambrian). Unfortunately, there is no published trace element or rare-earth element geochemical data available for these formations with which to identify them. Consequently, their identification is typically based on their mineral composition and engineering characteristics (Moss, 2010).

Following the work of Merrill and others (1902) in New York, Lewis and Kümmel (1910-1912) named schist and gneiss along the Hudson River in New Jersey the Manhattan Schist. Subsequent studies in New Jersey (Lyttle and Epstein, 1987) also correlated schist and gneiss to the Manhattan Schist, but to Member C as subdivided by Hall (1968). Later work by Drake and others (1996) mapped these rocks as generic Manhattan Schist because of mineralogical differences observed in drill core that did not uniformly match Member C. At that time the dominant formation recognized in lower Manhattan was Member C (Baskerville, 1994). However, subsequent work based on geologic mapping and examination of drill core from New York City (Merguerian and Moss, 2006; Moss, 2010) suggests that Hartland and Walloomsac formations and not Member C of the Manhattan Schist underlie that area. Extension of the Hartland Formation across the Hudson River into New Jersey was postulated by Baskerville (1994) and Brock and Brock (2001) based largely on the interpretation that serpentinite bodies were spatially associated with that unit and not Member C. More recent evidence suggests that serpentinite bodies encountered in New York City are not necessarily confined to the Hartland Formation and may also be present at the base of the Manhattan Schist (Merguerian and Moss, 2007).

Schist and gneiss that correlate to the Walloomsac and Hartland formations was encountered in drill-core from New Jersey. Samples of Walloomsac Formation are gray to dark-gray, fissile schist composed of plagioclase + garnet + muscovite + biotite + quartz + sillimanite and/or kyanite (fig. 4). They are characterized by locally rusty weathering and sparse amounts of graphite and sulfide minerals, similar to Walloomsac Formation from New York City (Merguerian and Moss, 2006). Based on these criteria, schist penetrated in drill core from a band extending from Jersey City south to Bayonne was mapped as Walloomsac. The basal part of the Walloomsac contains calcitic marble layers (Baskerville, 1994). White marble was recognized beneath serpentinite at an unknown depth in borings at Hoboken (Geological Survey of New Jersey, 1879), suggesting that Walloomsac Formation is present there in the subsurface. In addition, more than 60 feet of “slate” was penetrated beneath serpentinite at a depth of 656 feet below ground surface (New Jersey Geological Survey, 1936) in a well Southeast of the marble. It is here proposed that the “slate” is actually fissile, carbonaceous schist of the Walloomsac which, if correct, provides further support for correlation of that formation to the bedrock in these borings.

The Hartland Formation is a heterogeneous unit, but it has distinctive variants that include silver to “spangled” schist that contains abundant muscovite, as well as quartzofeldspathic muscovite-biotite-garnet schist (fig. 5). Hartland schist may be highly magnetic because of the abundance of disseminated magnetite grains (Baskerville, 1994). Borings from Ellis Island encountered serpentinite and magnesiohornblende + talc schist underlain by gray or silver, locally “spangled”, medium-grained schist composed of muscovite, biotite, plagioclase, quartz, and less common magnetite, garnet, and kyanite here correlated to Hartland Formation. The contact between these lithologies is conformable and displays no evidence of having been deformed by faulting. Other drill-core samples from borings west and east of the layer of Walloomsac Formation match these textural and mineralogical criteria and are also correlated to Hartland Formation.

Rocks correlated to Manhattan Schist Member C in previous studies (Lyttle and Epstein, 1987; Drake and others, 1996) are here reinterpreted as Hartland and Walloomsac based on mineralogical similarity. At this time it is unknown whether Member C is present in the map area. It cannot be completely dismissed, and recognition of this unit will require a more definitive means of distinguishing it from other schistose rocks.

Geochemistry of pre-Mesozoic rocks

Geochemical analyses of three core samples of Hartland Formation and two of the Walloomsac Formation from the map area are given in Table 1. All analyses were performed at Montclair State University with major elements obtained by inductively coupled plasma optical emission spectrometry and trace elements by inductively coupled plasma mass spectrometry. Major element concentrations of all samples are consistent with graywacke sandstone or shale protoliths. Overall, the two formations have similar geochemical compositions, although there are some clear differences. The Walloomsac Formation contains lower SiO_2, TiO_2, Zr, and Nb and higher CaO, MgO, Sr, and U than the Hartland Formation. Samples of schist here correlated to Hartland and Walloomsac both have high Cr (97-120 ppm) and Ni (48-60 ppm). Abundances this high are considered a reliable indicator of detritus contributed from ultramafic source rocks (Hiscott, 1984). This suggests that protoliths of both Hartland and Walloomsac may have been in close proximity to serpentinite, and possibly to each other, during deposition of their sediments. If correct, then it may indicate that serpentinite and these formations were not isolated until they were tectonically juxtaposed during the Taconian orogeny.

STRUCTURE

Schistosity

Metamorphic fabric in the pre-Mesozoic rocks is defined by well-developed and penetrative schistosity (figs. 4 and 5) formed by the parallel alignment of mainly biotite and muscovite. The absence of oriented drill core does not permit determination of the strike of this fabric in the map area, but mapping in New York City indicates that pre-Mesozoic bedrock strikes mainly northeast (Baskerville, 1994). Based on examination of drill core samples from New Jersey, the dip of schistosity is gentle and ranges from horizontal to about 30° but very locally it steepens to as much as 65°. The direction of dip is unknown. In most drill core samples this fabric is planar, but schistosity in the more micaceous lithologies is crumpled and folded into gently-plunging to recumbent structures that have been refolded. In some of these samples, garnet displays more than one generation of growth marked by an earlier one that is deformed along with schistosity and a later one that cuts across this fabric. Earliest schistosity is related to high-grade metamorphism during the Taconian orogeny and, therefore, Ordovician in age (Stanley and Ratcliffe, 1985). Similar late garnet growth was noted by Brock and Brock (2001) and attributed by them to a later stage of the Taconian orogeny.

Faults

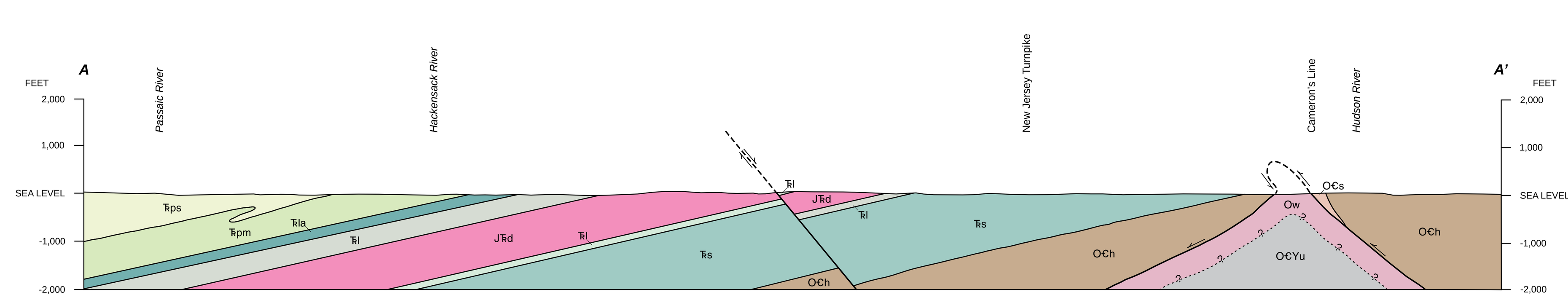
Diabase in the central part of the quadrangle is deformed by a brittle fault characterized by closely-spaced fractures, thin zones of breccia and/or clayey gouge and by slickensides locally coated by chlorite or calcite. The fault strikes north-northeast and dips moderately southeast. Kinematic indicators that consist of slip lineations on fault surfaces and offset of formations indicate that the predominant movement was normal.

Other faults in the area of Hoboken and Jersey City that deform both Mesozoic and pre-Mesozoic rocks are not exposed but are inferred to be present based on the displacement of contacts between these units (Drake and others, 1996; this map). The disparate depths at which the contacts were encountered, the sharp truncation of schist and serpentinite contacts, and the preservation of brittle deformation fabric in both Mesozoic and pre-Mesozoic drill core from along one of the faults (for example, fig. 1, left photo) does not support the map pattern as due to deposition of Stockton Formation on a highly irregular and pinnacled pre-Mesozoic bedrock surface. These faults strike about N.50°W. and dip steeply south with normal movement sense. Similar northwest-striking faults that cut pre-Mesozoic rocks in New York City are also recognized (Baskerville, 1994).

Ductile deformation fabric that is clearly older than Mesozoic, and here interpreted to be Ordovician and related to the Taconian orogeny, was recognized in drill core of serpentinite from Jersey City and Hoboken (fig. 6). The Taconian orogeny is a compressional tectonothermal event at ca. 450 Ma resulting from westward-directed thrusting of imbricated slices of island arc, ocean floor, and fore-arc basin sedimentary sequences onto Proterozoic basement and cover rocks of the eastern Laurentian margin (Stanley and Ratcliffe, 1985). Most core samples of serpentinite examined preserve an earlier ductile fabric that dips subhorizontally to about 30° and is locally overprinted by a later ductile deformation fabric that dips about 60° (fig. 6). Undeformed disseminated magnetite grains 1 to 2 mm long in both the Stockton Formation and serpentinite cut across a ductile fault in the serpentinite, confirming that the faulting is pre-Triassic.

In the Manhattan prong, Cameron’s Line is a major structural feature that thrusts serpentinite and Hartland Formation onto the Manhattan Schist Member C (Hall, 1976; Baskerville, 1994). In New York City, a structurally lower thrust fault beneath Cameron’s Line places Member C onto Proterozoic basement and Lower Paleozoic cover rocks that include the Ordovician Walloomsac Formation. This fault was named the Elmsford thrust fault by Hall (1976), and later changed to the Inwood Hill thrust fault (Baskerville, 1994) and the St. Nicholas thrust fault (Merguerian and Moss, 2006). Evidence supporting the extension into New Jersey of a thrust fault that correlates to the Elmsford/Inwood Hill/St Nicholas fault is not recognized.

In the map area, serpentinite and Hartland Formation are thrust directly over Walloomsac Formation which is exposed in a structural window beneath a folded thrust fault here interpreted to be Cameron’s Line. The fault extends along the western side of the Hudson River from Hoboken to Bayonne and then continues north of Kill Van Kull and Staten Island where it is concealed beneath Mesozoic rocks. The apparent absence of Manhattan Schist Member C above the Walloomsac Formation may mean that it was removed by faulting, that it was never present between the two units, or that it is present and has been misidentified here as Hartland Formation. It is noteworthy, however, that in lower Manhattan Island, New York, the Manhattan Schist is also interpreted to be absent between the Walloomsac and Hartland (Merguerian and Moss, 2006).



DESCRIPTION OF MAP UNITS

Newark basin

J̄Rd **Diabase** (Lower Jurassic to Upper Triassic) – Dark-greenish-gray to black, fine-grained, massive, hard diabase. Composed mainly of calcic plagioclase, clinopyroxene and opaque oxide minerals. Contacts are aphanitic and display chilled, sharp margins with enclosing sedimentary rocks. Thickness in the map area is about 900 feet but regionally is as much as 1,300 ft.

R̄ps, **R̄pm** **Passaic Formation** (Upper Triassic) (Olsen, 1980) – Interbedded sequence of reddish-brown and, less commonly, maroon or purple, fine- to coarse-grained sandstone, siltstone, shaly siltstone, silty mudstone and mudstone, and interbedded olive-gray, dark-gray, or black siltstone, silty mudstone, shale, and silty argillite. Reddish-brown sandstone and siltstone (Trps) are thin- to medium-bedded, planar to cross-bedded, micaceous, and locally mudcracked and ripple cross-laminated. Root casts and load casts are common. Shaly siltstone, silty mudstone, and mudstone (Trpm) are fine-grained, very-thin to thin-bedded, planar to ripple cross-laminated, locally fissile, bioturbated, and contain evaporite minerals. They form rhythmically fining-upward sequences as much as 15 ft. thick. Regionally is as much as 11,480 ft. thick.

Trl, **Trla** **Lockatong Formation undifferentiated** (Upper Triassic) (Kümmel, 1897) – Cyclically deposited sequences consisting of gray to greenish-gray and reddish-brown siltstone, silty argillite, dark-gray to black shale and mudstone (Trl) and white to buff arkosic sandstone (Trla). Siltstone is medium to fine grained, thin bedded, planar to cross-bedded with ripple cross-laminations and locally abundant pyrite. Shale and mudstone are thinly-laminated, platy, with local desiccation features. Arkosic sandstone is coarse to fine grained and thick to massive bedded. As much as 10 ft. of unit have been thermally metamorphosed along its contact with diabase. Thickness in the map area is about 1,000 ft. but regionally is as much as 3,500 ft.

Trs **Stockton Formation undifferentiated** (Upper Triassic) (Kümmel, 1897) – Interbedded sequence of gray, grayish-brown, or slightly reddish-brown, medium- to fine-grained, thin- to thick-bedded, poorly sorted to clast imbricated conglomerate, planar to trough cross-bedded, and ripple cross laminated arkosic sandstone, and reddish-brown clayey fine-grained, sandstone, siltstone and mudstone. Coarser units commonly occur as lenses and are locally graded. Finer units are bioturbated and contain fining upwards sequences. Conglomerate and sandstone units are deeply weathered and more common in the lower half; siltstone and mudstone are generally less weathered and more common in upper half. Lower contact is an erosional unconformity. Thickness in the map area is about 1,500 ft. but regionally is as much as 4,500 ft.

Manhattan prong

Autochthonous rocks (eastern Laurentian margin sequence)

Ow **Walloomsac Formation** (Middle Ordovician) – Tan-weathering, locally rusty, gray to dark gray, fissile schist composed of plagioclase + garnet + muscovite + biotite + quartz + sillimanite and/or kyanite ± graphite and/or pyrite. Locally contains boudins of quartz + plagioclase + mica ± garnet. Grades downward near the base of unit into calc-silicate schist and white, tan, or bluish-white marble containing calcite + diopside + tremolite + phlogopite. Maximum thickness in the map area is unknown, but north of Manhattan its thickness is estimated to be 900 to 2,000 ft. (Hall, in press). Unit is in thrust fault contact with overlying Hartland Formation.

Allochthonous rocks (transported Iapetan sequence)

OЄh **Hartland Formation** (Middle Ordovician to Middle Cambrian) (Hall, 1976) – Heterogeneous sequence of interlayered tan-to gray-weathering, gray, characteristically spangled appearing, fine- to coarse-grained schist composed of muscovite + biotite + garnet + quartz + plagioclase ± sillimanite and/or kyanite; gray, fine-grained gneiss composed of quartz + feldspar ± biotite and/or garnet; and dark grayish-black amphibolite composed of quartz + biotite + hornblende. Maximum thickness in the map area is unknown.

OЄs **Serpentinite** (Lower Ordovician to Upper Cambrian?) – Light yellowish-green to dark green, fine-grained, massive rock. Where fresh it contains olivine, orthopyroxene, and chromian spinel. More commonly altered to rock composed of various serpentine minerals that may be spatially associated with light green, medium-grained massive rock composed of talc and magnesiohornblende. Maximum thickness in the map area is unknown. Unit is present as bodies of varied size within the Hartland Formation.

OЄYu **Pre-Mesozoic crystalline rocks undifferentiated** (Ordovician to Mesoproterozoic) – Shown only in cross section.

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Table 1. Geochemical analyses of representative pre-Mesozoic rocks of the Jersey City quadrangle.

Sample (wt. %)	JYC-58	JYC-72	JYC-78	JYC-75	JYC-79
	Hartland Formation			Walloomsac Formation	
SiO_2	62.99	61.44	60.33	57.54	57.87
TiO_2	1.51	1.07	1.13	0.73	0.77
Al_2O_3	15.15	18.78	19.07	17.68	17.74
Fe_2O_3*	10.27	8.09	9.30	6.18	7.06
MgO	2.69	2.75	2.98	3.92	3.57
MnO	0.15	0.06	0.22	0.14	0.13
CaO	2.49	0.43	0.62	6.42	6.94
Na_2O	3.14	1.58	1.24	1.56	0.99
K_2O	1.76	5.57	5.78	3.96	3.09
P_2O_5	0.14	0.10	0.23	0.13	0.14
LOI**	0.34	n.d.	n.d.	n.d.	n.d.
Total	100.63	99.88	100.91	98.25	98.30
Sample (ppm)	JYC-58	JYC-72	JYC-78	JYC-75	JYC-79
	Hartland Formation			Walloomsac Formation	
Rb	60	203	189	191	144
Ba	545	818	696	517	791
Sr	241	38	89	521	567
Y	42.3	25.3	44.0	26.4	31.5
Zr	417	211	221	133	138
Nb	21.7	24.8	29.2	12.2	14.7
V	166	110	133	106	122
Co	26	22	24	17	20
Cr	120	97	97	101	112
Ni	60	48	58	49	54
Hf	9.20	5.80	6.02	3.53	3.77
Ta	1.10	1.67	1.92	0.92	1.02
Th	12.8	13.9	17.7	11.4	12.0
U	1.09	2.26	2.26	3.52	4.30
La	51.40	40.6	59.6	33.9	44.0
Ce	106	81.1	116.5	75.7	77.1
Pr	13.70	9.40	13.60	9.40	9.60
Nd	50.8	35.5	52.4	35.0	36.0
Sm	10.30	7.17	10.52	6.64	7.04
Eu	1.96	1.39	1.94	1.38	1.44
Gd	8.85	5.72	8.30	5.38	5.73
Tb	1.39	0.877	1.273	0.779	0.873
Dy	7.88	5.13	8.27	4.32	5.42
Ho	1.55	0.913	1.633	0.877	1.099
Er	4.31	2.05	4.18	2.39	3.01
Tm	0.636	0.250	0.603	0.386	0.480
Yb	4.39	1.40	3.86	2.79	3.19
Lu	0.731	0.204	0.582	0.442	0.476

* Total Fe as Fe_2O_3
n.d., not determined
** LOI, loss on ignition

Figure 1. Left photo: Unconformable contact (left of coin) between fractured and brittly deformed basal Stockton Formation (above) and serpentinite (below) from a depth of 75 feet below ground surface in drill core from Hoboken. Right photo: Unconformable contact between Stockton Formation pebbly sandstone and conglomerate (above white lines) and gneiss (below lines) from a depth of 283 feet below ground surface in drill core from Jersey City. Note the difference in grain size in basal Stockton between the two core holes. Coin for scale is 1 inch in diameter.

Figure 2. Representative samples of serpentinite and related rocks recovered in drill core. Left photo: Massive rock composed of magnesiohornblende + talc spatially associated with serpentinite from Ellis Island. Right photo: Massive serpentinite composed of serpentine minerals + opaque oxides from Hoboken. Coin for scale is 0.75 inch in diameter.

Figure 3. Possible sedimentary debris flow interbedded with massive serpentinite in drill core from Jersey City. Coin for scale is 0.75 inch in diameter.

Figure 4. Representative samples of Walloomsac Formation. Left photo: Quartz + plagioclase + biotite ± garnet ± sulfide gneiss from Jersey City (table 1, sample JYC-75). Coin for scale is 1 inch in diameter. Right photo: Muscovite + biotite + quartz + plagioclase ± garnet ± sulfide ± graphite schist from Jersey City. Coin for scale is 0.75 inch in diameter.

Figure 5. Representative samples of Hartland Formation. Left photo: Quartz + plagioclase + biotite ± garnet schistose gneiss from Hoboken (table 1, sample JYC-58). Right photo: "Spangled" biotite + muscovite + quartz + plagioclase + magnetite + garnet schist from Jersey City (Table 1, sample JYC-72). Coin for scale is 1 inch in diameter.

Figure 6. Ductile fault deforming serpentinite from a depth of 66 feet below ground surface in drill core from Jersey City. Note the gently-dipping fault fabric toward the upper part of core that dips at about 30° overprinted by the more steeply-dipping fault fabric in the center of the core that dips about 60°. Coin for scale is 0.75 inch in diameter.