SERPENTINITES OF NEW YORK CITY AND VICINITY

John H. Puffer
Dept of Geology
Rutgers Univ.
Newark, New Jersey, 07102

ABSTRACT

A discontinuous chain of early Paleozoic serpentinites are exposed along the Appalachian Mountains from Quebec Canada, through the New York City area, and into the southeastern states. The Geologic Map of New York, 1970, (Lower Hudson Sheet) shows five serpentinite bodies in the New York City Area: Staten Island, Hoboken, Manhattan, New Rochelle, and Port Chester that are part of this chain. The Staten Island and Hoboken serpentinites are the largest of the five bodies and are known to contain considerable asbestos (Puffer and Germine, 1994). The serpentinites of Staten Island and Hoboken consist of about 95 percent serpentine with minor but highly variable olivine, anthophyllite, talc, magnetite, and trace amounts of several additional minerals.

The chemical range is typical of metamorphosed harzburgite and dunite suites although some unusually low CaO and Al_2O_3 values may be due to hydrothermal leaching and re-precipitation as a network of amphibole and carbonate veins in shear zones.

The mode of emplacement of the New York area serpentinites is controversial but most evidence tends to favor the Taconic obduction of the base of a Iapetus ophiolite sequence. This would force the placement of the New York area serpentinites into the Taconic suture zone (Camerons Line) between Hartland terrain (C-Oh) and Manhattan-C terrain (C-Om).

The chrysotile content of New York area serpentinites, as determined using a combination of polarized light and transmission electron microscopy and XRD techniques, is highly variable but is typically about 15 to 40 volume percent of the rock (Puffer and Germine, 1994). The widespread distribution of asbestos minerals in the serpentinites may lead to contamination of water and air supplies wherever exposures are being eroded.

GEOLOGIC SETTING

The discontinuous chain of serpentinites along the Appalachian Mountains that extends from Quebec Canada into the southeastern states (Figure 1) passes through the New York City area. The Geologic Map of New York, 1970, (Lower Hudson Sheet) shows five serpentinite bodies in the New York City Area: Staten Island, Hoboken, Manhattan, New Rochelle, and Port Chester that are part of this chain (Figure 2). The Staten Island and Hoboken serpentinites are the largest of the five bodies.

Lyttle and Epstein (1987) stratigraphically place the Staten Island meta-peridotite and the Hoboken serpentinite bodies at the base of the Hartland terrain (Figure 3) on a Taconic suture that overthrusts

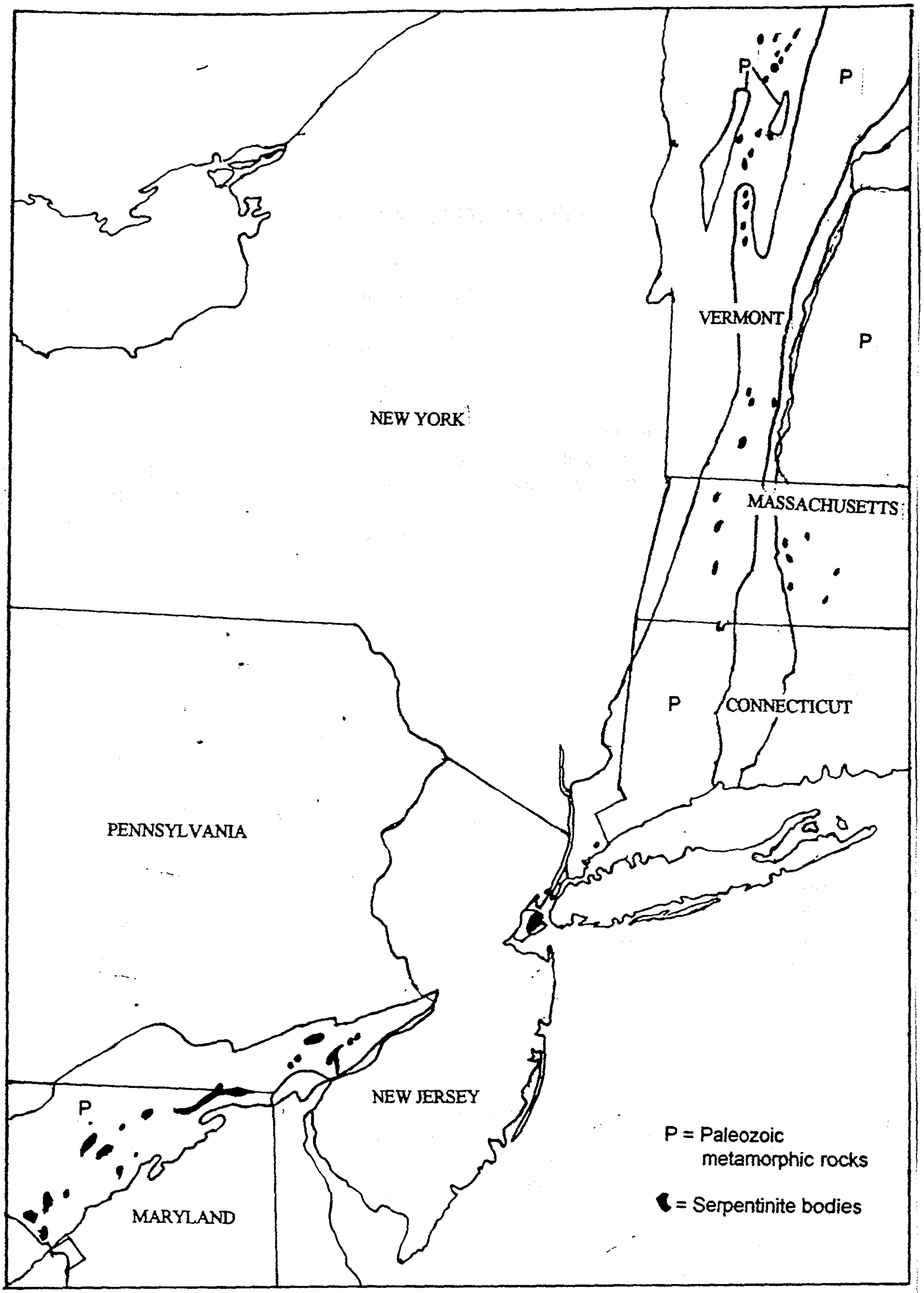

Figure 1. Serpentinite occurrences in the central and northern Appalachians appearing on the USGS "Tectonic Map of the United States" (1962).

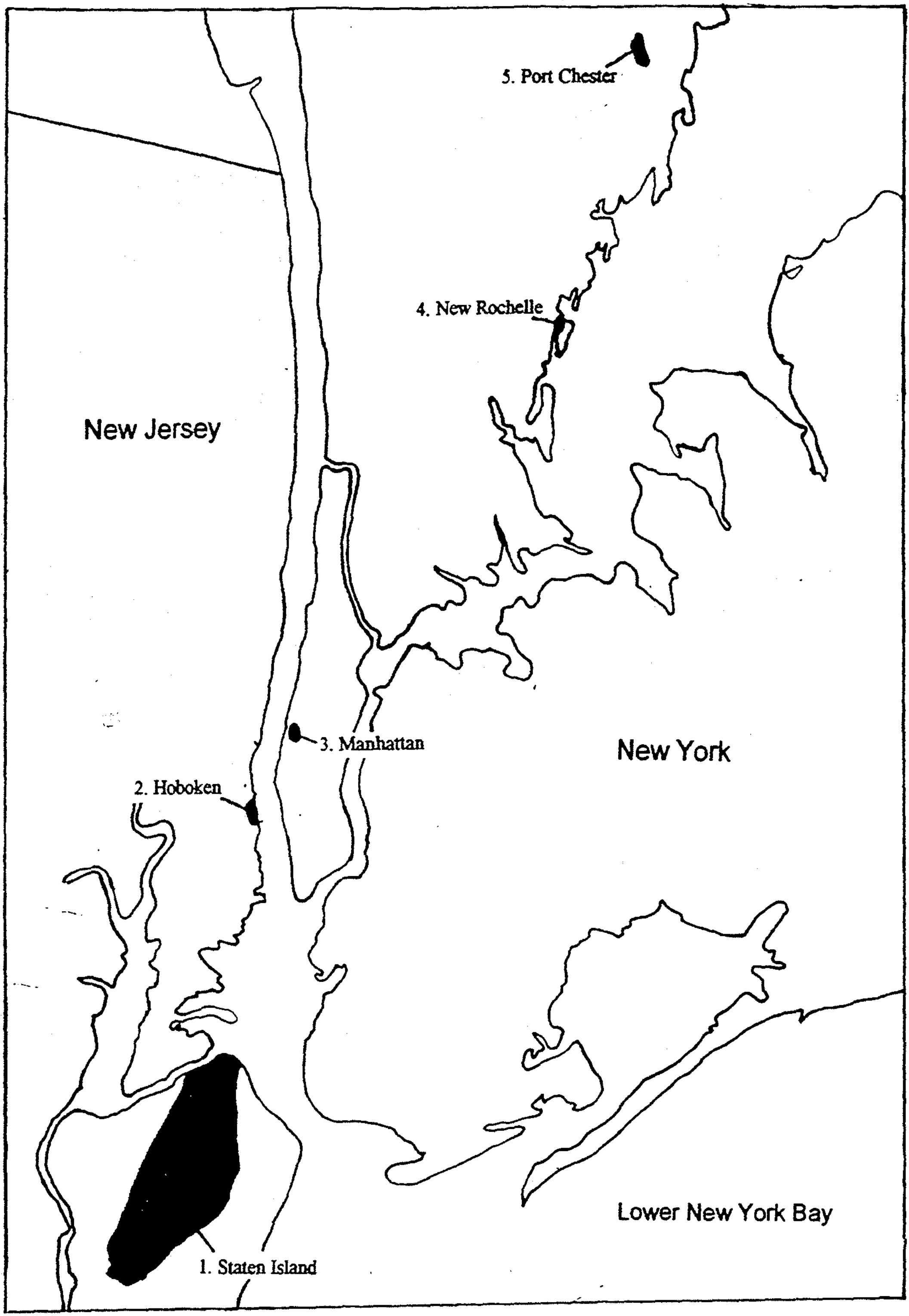

Figure 2. The Serpentinites of New York City and vicinity, based on occurrences mapped on the "Geologic Map of New York", Lower Hudson Sheet (1963).

Member C of the Manhattan Formation. The tectonic suture is presumably Cameron's Line which is defined as the tectonic boundary of the western part of the Appalachian core zone. Merguerian (1983) interprets Cameron's Line as a ductile shear zone or terrain suture that developed at the base of a west-facing Taconic accretionary prism separating Manhattan C from Hartland terrain (Mose and Merguerian, , 1985). Member C of the Manhattan Schist is not exposed on Staten Island but Hartland schist is the bedrock along the eastern edge of the meta-peridotite body on the northern end of the island. Member C of the Manhattan Formation contains common amphibolite lenses (meta-basalt) that were described by Hall (1976) as Member B of the Manhattan Formation. The Hartland Formation also contains common amphibolite lenses that chemically overlap with Member B amphibolite (Eicher and others, 1994; Merguerian and Puffer, unpublished data). Member C is a biotite schist that is petrologically and chemically similar to typical Hartland Formation (Puffer and others, 1994) and both schists overthrust still more biotite schist, the mid-Ordovician Member A of the Manhattan Formation. In addition to the confusing formation names, the stratigraphy is further complicated by overlapping chemical compositions, mineralogies, and petrologic textures among the schists.

For purposes of organizing these units into a tectonic framework, however, it is important to determine their depositional setting. Baskerville (1989) interprets Manhattan C and B as metamorphosed allochthonous transitional slope meta-sediments and discontinuous volcanics in contrast to the meta-eugeosynclinal deep-oceanic shale and interstratified volcanic of the Hartland Formation (Merguerian and Sanders, 1991). The schists of Manhattan A are interpreted as autochthonous miogeosynclinal basement cover rocks. The interpretation of the Hartland Terrain as deep-oceanic rock is based in part on it's association with the Staten Island meta-peridotite which Baskerville, 1989 views as part of an ocean-floor ophiolite suite.

PETROLOGIC DESCRIPTIONS OF THE FIVE NEW YORK AREA SERPENTINITES

In general, rocks from each of the five New York area serpentinites are indistinguishable and are probably genetically related.

1. The Staten Island Serpentinite

The Staten Island serpentinite is a wide lens shaped body (Figure 2) that trends NE-SW and comprises the bedrock of northern Staten Island. It is well exposed along a prominent ridge that extends from the northeastern shore of the island toward the southwest. The serpentinite body appears on most geologic maps as either, Cambrian, Cambro-Ordovician, or "relative age unknown". Lyttle and Epstein (1987) position the Staten Island Serpentinite above Member C of the Manhattan Schist and at the base of the Hartland Formation but contact relationships are not exposed.

The serpentine content of 36 serpentinite rock samples from 27 locations (Figure 4, with typical examples on Table 1) averages 66 percent lizardite and 27 percent chrysotile (asbestos). Minor talc, anthophyllite, olivine, chromite, and magnetite makes up the remaining 7 percent. The average olivine content of the Staten Island meta-peridotite is about 5 percent. A few samples contain as much as 50 percent olivine but it is absent from most samples. Where present, olivine typically occurs as relic anhedral micro-islands surrounded by serpentine that has replaced most of the individual grains or as larger grains veined by olivine.

Table 1 Thin Section Modes of Serpentinites and Anthophyllite Schist from Staten Island locations (Fig. 1), New York.

	4e	5b	7b	8b	10c	11c	13c
Lizardite	60		65	74	65	4	85
Chrysotile	10		15	15	10	1	15
Anthophyllite		98				65	
Talc	10		5		4	15	tr
Carbonate			5		11	5	tr
Olivine				10			tr
Opaque Oxide	20	2		1	10	10	tr

	14c	15b	15c	21b	23a	27b
Lizardite	60	50		62	70	48
Chrysotile	15	25		18	15	30
Anthophyllite			90			tr
Talc	5	5		5		3
Carbonate	10			10	tr	tr
Olivine		20		tr	15	15
Opaque Oxide	10	5	10	5	tr	4

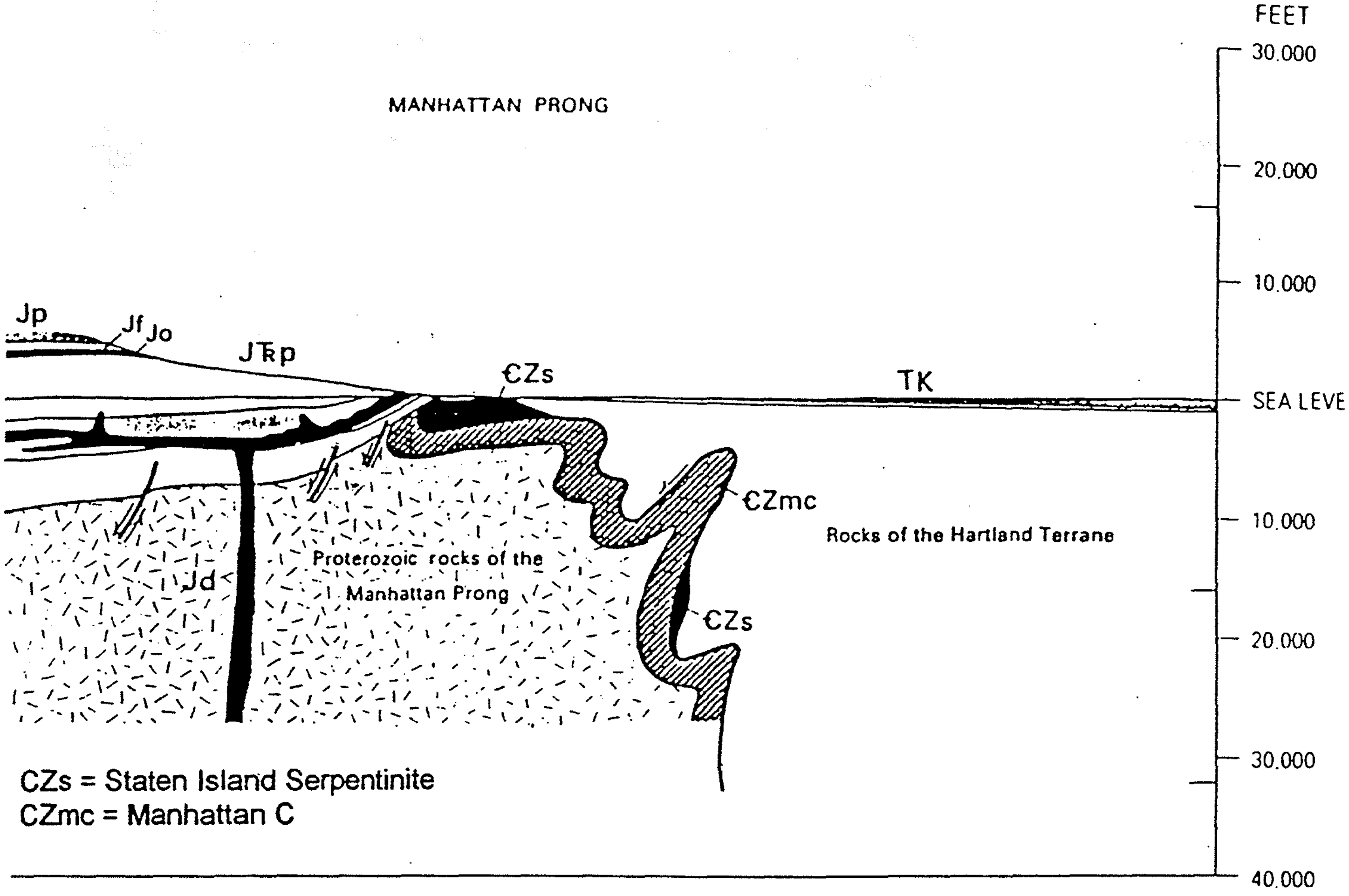

Figure 3. Cross-section through Staten Island Serpentinite (after Little and Epstein, 1987)

Electron microscopic analysis of ten samples from the I-278 outcrop (sample 8, Figure 4), indicates a chrysotile asbestos content of 54 volume percent although it is absent at a few locations. In sample 1 (Figure 4) some evidence of minor antigorite was also found.

Clues as to the original protolith are found in some of the olivine rich samples, particularly from the north-central portion of the ultramafic body. Unaltered pyroxene is rarely observed in any of the rock but phenocrysts of pyroxene that have been partially or completely altered to intergrowths of chlorite, talc and oxide are common is some of the massive serpentinite. These altered pyroxene phenocrysts make up about 15 % of some samples and indicate that such rock was a harzburgite as originally suggested by Behm (1954). However, most samples of massive serpentinite, where primary igneous textures are preserved, do not contain evidence of pyroxene and are probably dunite.

The chemical range of samples from 20 of the largest exposures of serpentinite from Staten Island includes 35 to 44% SiO_2, 0.1 to 0.8% Al_2O_3, 6 to 10% FeOt, 34 to 42% MgO, 0.03 to 3.3% CaO, 0.07 to 0.26% Cr, and 0.18 to 0.36% Ni (Table 2). The chemical data confirm a harzburgite and dunite protolith interpretation although some unusually low CaO and Al_2O_3 values may be due to hydrothermal leaching and re-precipitation as a network of amphibole and carbonate veins in shear zones.

2. The Hoboken Serpentinite.

The Hoboken serpentinite body is a lense shaped exposure about 0.7 miles long and 0.15 miles wide located along the Hudson River (Figure 2). The serpentinite is particularly well exposed at Castle Point, along a steep slope into the Hudson at the east edge of the Stevens Institute of Technology campus. The serpentinite body is in fault contact with Member C of the Manhattan Schist (Lyttle and Epstein, 1987). The fault (Cameron's Line) is positioned at the western edge of the Hoboken Serpentinite and extends to the south where it wraps around the Staten Island Serpentinite.

The chemical composition (Table 1) and mineralogy of most of the Hoboken serpentinite exposure is indistinguishable from typical Staten Island serpentinite, although subtle differences can be found, some of which are described in road log section of this chapter.

3. Manhattan serpentinite body.

The Manhattan body is mapped as a small circular area, (Figure 2). The original mapping of the Manhattan serpentinite body may have been based on observations along the Rail-cut near 57th street, or at the excavation sites of buildings that later became John Jay College of Criminal Justice and Roosevelt Hospital. In both cases, however, any previously exposed bed-rock has since been sealed off, paved or landscaped. Baskerville (1982) in describing the Manhattan serpentinite body reports "The Manhattan pod is now covered by streets and buildings."

The Manhattan serpentinite is also described by Cozzens (1843), Britton (1881), Gratacap (1904), and Merrill and others (1902). The credibility of each of these researchers is good (particularly Merrill) and it is unlikely that serpentinite was misidentified or incorrectly mapped. Serpentinite is a distinctive rock that is readily identified by experienced geologists. The Manhattan serpentinite is surrounded by Manhattan Formation (Member C) and may be a tectonic lens within Member C; although due to

Table 2. Chemical compositions of Serpentinites from Staten Island, NY, Hoboken, NJ, and Red Hill, Calif. compared with ophiolite compositions.

	New York			New Jersey			California			PCCI	Harzburg	Dunite
	Staten Isl.			Hoboken			Red Hill					
samples	ave. of 20	max.	min.	ave. of 6	max.	min.	ave. of 45	max.	min.	1	ave. of 31	ave. of 32
Wt. %												
SiO_2	39.36	44.25	35.00	39.48	43.23	36.78	39.12	44.76	35.21	41.90	43.86	43.86
TiO_2	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.12	0.01	0.02	0.02	0.01
Al_2O_3	0.39	0.81	0.10	0.42	0.75	0.08	0.33	3.03	0.09	0.74	0.77	0.36
FeO_t	7.67	9.99	5.75	7.74	8.85	6.22	7.95	8.95	5.89	7.81	8.19	8.52
MgO	39.66	41.95	34.20	40.36	42.42	36.95	39.85	50.51	33.79	43.18	45.41	49.50
MnO	0.11	0.13	0.08	0.12	0.15	0.10	0.13	0.16	0.08	0.12	0.11	0.14
CaO	0.09	3.30	0.03	0.11	1.89	0.04	0.11	3.93	0.00	0.51	0.73	0.30
Na_2O	0.02	0.27	0.01	0.02	0.17	0.01	0.07	0.45	0.00	0.01	0.11	0.03
K_2O	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.09	0.00	0.00	0.02	0.05
P_2O_5	0.00	0.01	0.00	0.00	0.01	0.00	0.004	0.01	0.00	0.00	0.00	0.00
LOI	11.94	18.25	6.20	11.41	12.96	7.42	11.85	17.00	4.63	5.62	0.00	0.00
Total	99.26	100.33	98.27	99.68	100.40	98.97	99.444	100.23	98.37	99.91	100.00	100.00
ppm												
Co	92	135	64	96	140	66				112		
Cr	2184	2571	686	2310	2597	2156	2895	7051	1395	2730	4300	5400
Cu	8	11	1	7	12	4	36	74	6	11		
Ni	2495	3603	1780	2521	2684	2361	2531	3341	1542	2339	3400	3000
Sr	2	7	1	2	6	3				0	1	4
V	25	27	18	29	34	23				30		
Zn	36	42	30	33	39	26				36		
Zr	7	9	6	8	10	5				7		

Notes:

1. Staten Island samples (after Puffer and Germine, I994), Hoboken samples, and Claifornia samples wer analyzed with. Rigaku 3030 XRF unit at Rutgers/Newark.
2. PCCI is the primary USGS peridotite standard used for analyses preformed at Rutgers/Newark
3. Harzburgite and Dunite data are averages of meta-harzburgites and meta-dunites from ophiolites recalculated to 100 % anhydrous. (Hyndman. 1989).

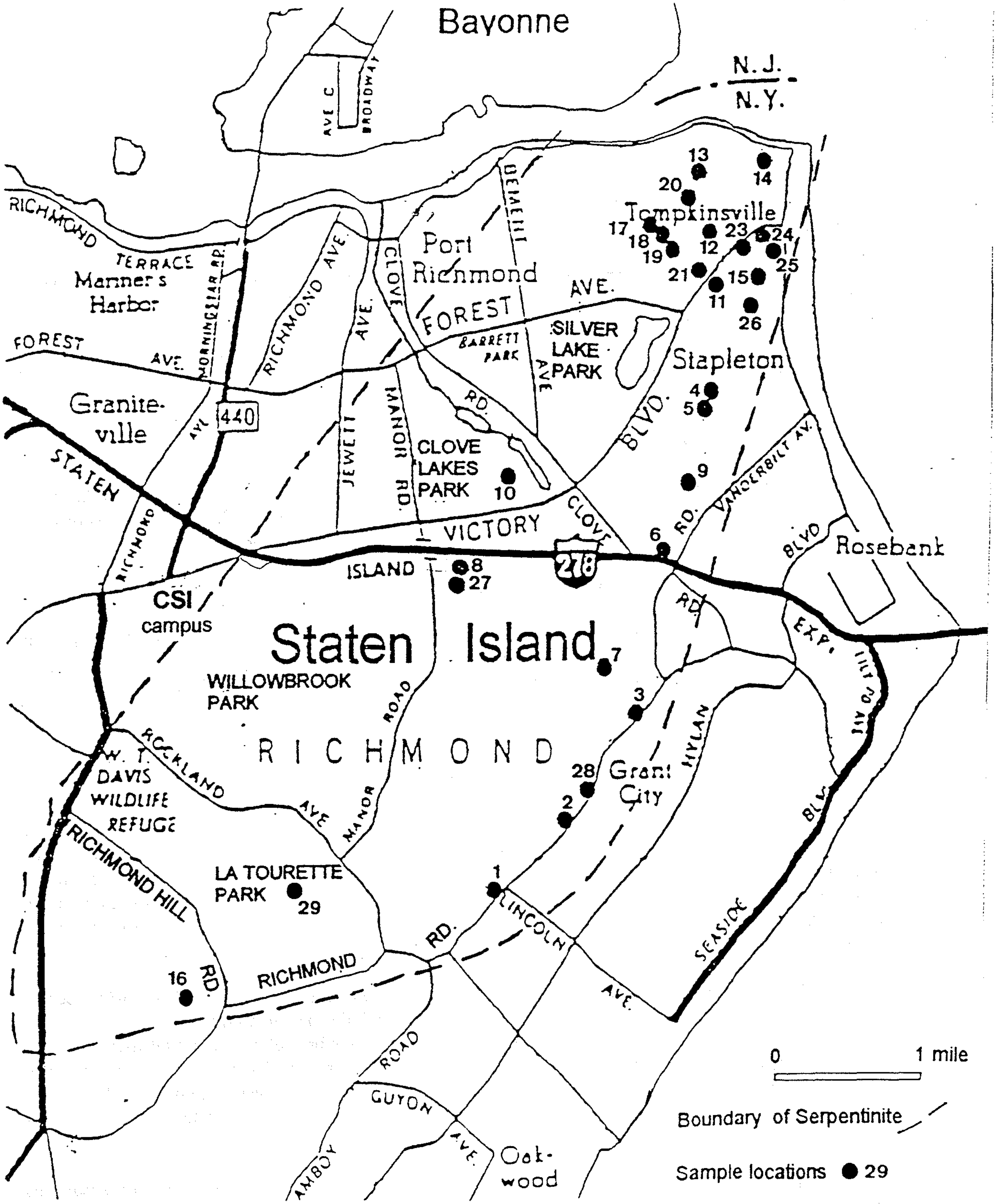

Figure 4. Staten Island Serpentinite: approximate boundaries and sample locations (after Puffer and Germine, 1994).

difficulties in mapping the extremely complex position of Cameron's Line, its placement on the Line can not be ruled out.

A small sample of Manhattan serpentinite was provided by Joseph Peters from the petrology collection of the American Museum of Natural History and was analyzed by Dr. Mark Germine for asbestos content at Rutgers/Newark. He determined that the sample contained a green serpentine-like material but x-ray and thin section analysis was inconclusive due mainly to small sample size. Chlorite could not be ruled out as an alternative to the probable serpentinite content of the sample. Chlorite and serpentine have overlapping physical and chemical properties and are not easily distinguished.

4. The New Rochelle Serpentinite Body

The New Rochelle serpentineite is a small oval body about 0.5 by 0.25 miles across. It has been mapped along Echo Bay Drive near Echo Bay in Westchester Co about 1.5 miles north of Bronx Co (Figure 2). Very little geologic work has been done on the occurrence since Merrill and others (1902).

5. The Port Chester Serpentinite Body

The Port Chester serpentinite body is a large occurrence almost one mile long and about one-half mile wide (Figure 2) that appears on maps drafted by Merrill and others (1902) and. "The Geologic Map of New York", 1970, (Lower Hudson Sheet) surrounded by "Schists and gneisses, undivided ... relative ages unknown ".

ORIGIN AND MODE OF EMPLACEMENT

The interpretation of the Hartland Terrain as deep-oceanic rock is based in part on it's association with the Staten Island serpentinite which Baskerville (1989) interprets as part of an abducted ocean floor ophiolite suite. Alternatively, the Staten Island serpentinite may be a metamorphosed olivine cumulate zone formed as part of a layered gabbroic magma chamber or an independent intrusion such as some interpretations of the serpentinites of the Pennsylvania piedmont (including Gates, 1988), although clear evidence is not presented.

Evidence of any clear association with the fractionated gabbroic rocks of a mafic intrusion such as thermal metamorphism at serpentinite contacts or xenoliths within the serpentinite is also absent from Staten Island. In addition, if the serpentinite body was formed at the base of a gabbroic intrusion before it was tectonically displaced, some evidence of the kind of tholeiitic trend fractionation that is a characteristic of layered gabroic plutons might be preserved. The absence of any clear fractionation trend (Puffer and Germine, 1992)) or any clear layering, such as the cryptic and rhythmic layering of the Bushveld, argues against such a mode of origin.

Merguerian and Sanders (1994) also discuss each of the two principal emplacement mechanisms that have been proposed for the Staten Island serpentinite and are diplomatically non-committal, but seem to favor ophiolitic emplacement over intrusive plutonism. They point out that if the Staten Island body was a pluton its chilled igneous margins and any contact metamprphism would have been obscured by subsequent metamorphism and faulting. Therefore, the absence of such contact relationships are "difficult,

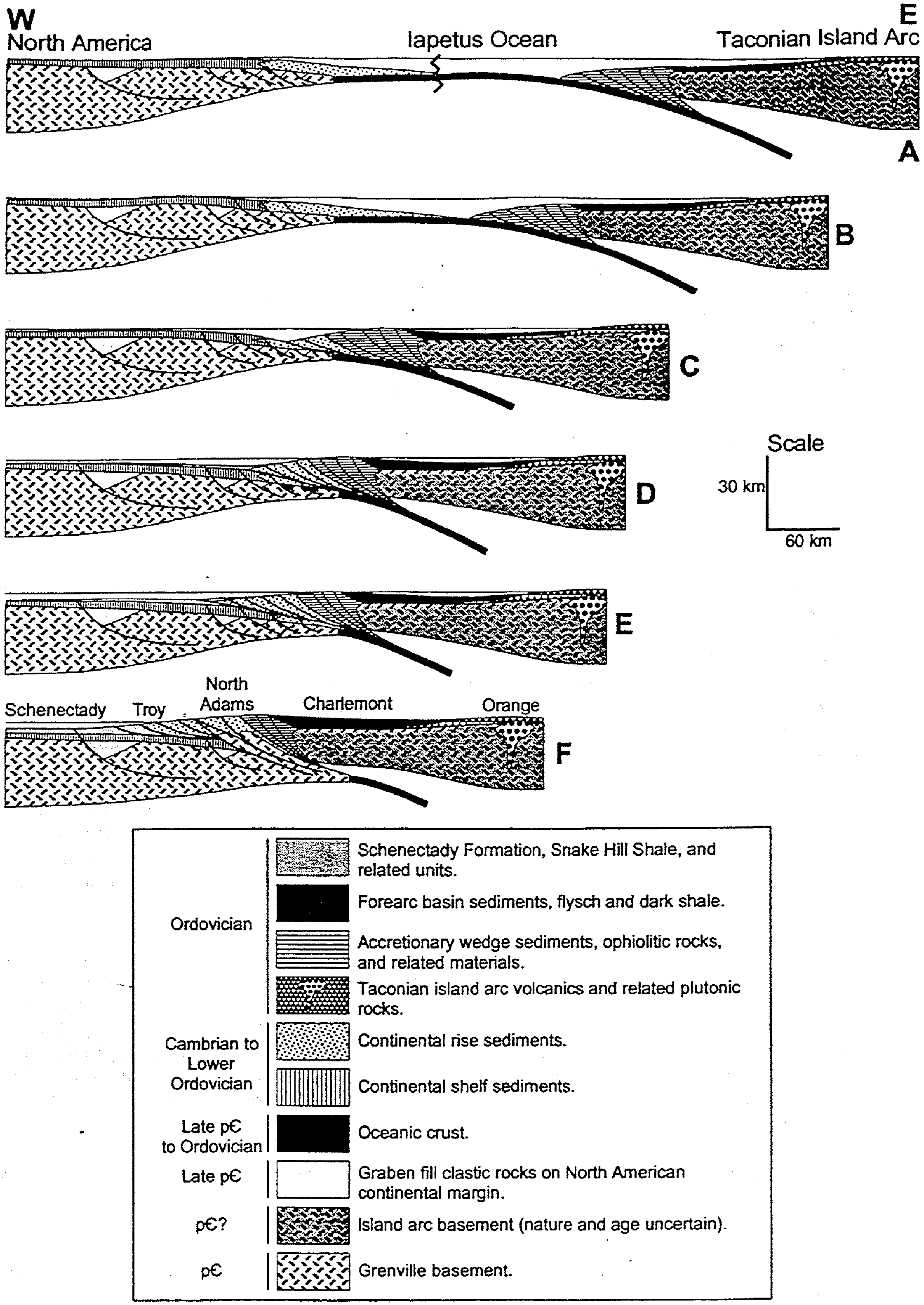

Figure 5. Schematic cross sections showing the tectonic development of the Taconic development of the Taconic Orogen from Early Middle Ordovician (A) to present (F) adapted from Rowley and Kidd (1981).

if not impossible to prove" (Merguerian and Sanders, 1994).

However, most well documented peridotite plutons are either emplaced as isolated, hypabyssal, hot-spot related diatremes such as the lherzolite of Kilberns Hole, New Mexico and the kimberlite mines of South Africa, or as integral portions of layered gabroic plutons such as those associated with most world-wide chrome and platinum mining districts. In contrast the New York area serpentinites are chemically and tectonically unlike any known hot-spot related lherzolite or kimberlite and are missing all of the cumulate layering of oxides (particularly chromite) and sulfides that are characteristics of layered gabroic plutons. If the New York bodies were tectonically removed from a layered gabroic pluton, pods of chromite or sulfide cumulate might be expected.

Instead all evidence points to emplacement as an abducted layer-three portion of a Iapetus ocean floor ophiollite during the Taconic orogeny. Evidence includes:

1. The New York area serpentinites are associated with meta-sediments and meta-volcanic rocks of probable eugeosynclinal to deep-oceanic shale and interstratified arc volcanic affinity (the Hartland Formation). The associated Cambro-Ordovician schists may include layer one melange and/or flysch sedimentary wedges associated with Taconic subduction. The tectonic setting of the New York City area, in general, resembles the tectonic setting of western New England (Figure 5) as convincingly described by Rowley and Kidd (1981) as a Taconic subduction zone that includes abducted ophiolites. But as noted by Moores (1981) in his classic description of overthrust belts where deep-water or oceanic rocks are thrust over continental marginal sequences "Evidence of ophiolite complexes may be absent or only fragmentary. Examples of such occurrences include the the Antler sequence in the Cordillera, the Taconic system of the northern Appalachians, and the Ouachitas system." Moores (1981), however, describes a second type of overthrust where decollement-style fold and thrust belts of miogeosynclinal rocks are thrust over shelf deposits. He includes the Appalachian Valley and Ridge Province, extending from Alabama to New York as an example of this second type. As applied to New York City the Hartland/Manhattan-C suture (Camerons Line) may be an example of the first type while the St Nicholas Thrust over Manhattan-A and Inwood Marble may be an example of the second type.

2. The lithology of the schists and amphibolites associated with the New York City area serpentinites is also very similar to the schists and amphibolites associated with the ophiolites of California. There is a growing consensus that California was gradually assembled by the accretion of exotic terrains that are bordered by suture zones characterized by serpentinite lenses (Coleman, 1977; Ehrenberg, 1975; and Saleeby, 1990). Virtually all of the serpentinite of California are generally interpreted as ophiolites; and to the extent that most of the serpentinites of eastern North America, including those of the New York City area, are petrologically and geochemically virtually identical to the Californian serpentinites (Table 1) it is quite likely that they are also ophiolites.

3. The ultramafic portion of all ophiolites consist of irregular pod shaped meta-dunite bodies contained within meta-harzburgite. Most of the Staten Island body is chemically equivalent to a meta-dunite although some rock chemically equivalent to meta-harzburgite is also present (Puffer and Germine, 1994).

4. Steiner (1995) has recently found what he interprets as ophiolite nodules in NYC Water Tunnel No. 3. through the Ravenswood Granodiorite. It has not yet been determined just how common these nodules are, but they may be significant.

Still another alternative interpretation has been offered by Germine (1990) who suggests that the Staten Island meta-peridotite cannot be an integral part of either the Manhattan schist or the Hartland Terrain because of the disparity in metamorphic grade. Germine (1990) interprets the Staten Island meta-peridotite as lower grade rock that was abducted between the two formations.

EXTENSIONAL STRUCTURAL ACTIVITY ?

The New York City area presently occupies a central position in the North American Plate with none of the structural activity typically associated with plate margins and no known source of extensional force (such as a hot-spot) that could generate active local motion. Hollick (1909), however, suggested that the eastern escarpment of the Staten Island serpentinite is fault controlled and that the development of serpentine-group minerals was related to shearing- and slippage along fault and shear surfaces. Merguerian and Sanders (1994) share this view. It is not clear if this fault scarp has been maintained by recent faulting that has raised the soft serpentinite through relatively hard schists that are presumably more resistant to erosion. The style of faulting, however, has been described as normal by Miller (1970), very unlike the compressional Taconic overthrusting that probably carried the Hartland terrain and the serpentinite over the schists of the Manhattan C.

The Staten Island serpentinite, therefore, is currently interpreted as a fault-bounded horst-block by Merguerian and Sanders, (1994) as originally suggested by Hollick (1909), Crosby (1914) and then by Miller, 1970. Behm (1954) has divided the Staten Island serpentinite into two zones: a highly sheared outer serpentinite characterized by an abundance of talc, anthophyllite, and magnetite, and a relatively massive, undeformed inner zone composed largely of partially serpentinized peridotite. Miller (1970) proposed that this inner zone is a horst displaced from the adjacent zones along NE trending normal faults. The western boundary of the inner zone is defined by the Silver Lake Fault and the eastern boundary by the Todt Hill fault.

If the Staten Island serpentinite and other New York area serpentinites have been uplifted along normal faults in an extensional setting, almost like salt diapirs, as suggested by an extrapolation of Miller's (1970) interpretation, than the age of the serpentinites would be older than the adjacent schists unless the source was younger rock located beneath allocthonous terrains. Depending on the reality or extent of such uplift, any interpretations pertaining to the Taconic activity (such as Figure 3) is subject to serious reexamination.

ENVIRONMENTAL CONSIDERATIONS

Despite the softness of most serpentinites, they tend to occur as topographic highs. This is presumably either because they are less susceptible to chemical weathering than adjacent rock or because they tend to transmit shearing because of their softness and get squeezed upward like viscous fluid. As transmitters of shearing the first environmental consideration for the New York City area would be the earthquake potential of serpentinite bodies.

Perhaps a more serious environmental consideration is the combination of both the topographic elevation of the serpentinite bodies and their asbestos content. Since most eastern North American and Californian serpentinites, including the serpentinites of the New York city area, are found as topographic highs or steep slopes, they are exposed to relatively high erosion rates. Although chrysotile tends to degrade during weathering to non-asbestiform alteration products, the constant downslope movement of freshly eroded serpentinite tends to spread chrysotile throughout the environment. This was found to be a particularly serious problem in the area near the asbestos (and mercury) bearing serpentinite of New Idria, California (Coleman, 1996). Some prudent caution may be also warranted around many of the large exposures and actively disturbed serpentinite excavations in the New York City area particularly at sites that are densely populated down wind or down stream.

The two major kinds of asbestos (as defined by Germine and Puffer, 1989) found in the serpentinites of the New York City area are chrysotile and to a lesser extent anthophyllite. Asbestos, however, is typically not easily recognized in samples of New York area serpentinite. In thin section, only lizardite was recognized in one Route 287 sample (Puffer and Germine, 1994), but using electron microscopic techniques, 50 percent chrysotile was measured as tubules with an outer diameter of 200-300 microns. Fiber lengths are typically only 0.5 to 6 microns which is beyond the resolution of polarizing light microscopy although some fibers are megascopic.

Two varieties of massive chrysotile asbestos were recognized in samples of serpentinite (Germine, 1981). One variety occurs in irregular masses and in veins ranging up to a centimeter in width. This type is composed of cross-fiber and randomly oriented fiber, and is often associated with olivine. The second variety has a pearly luster and platy to fine-grained meerschaum-like texture. This type of massive chrysotile occurs in veins, fracture fillings, and pore fillings. Electron microscopic examination indicates that it is composed of tubules with a diameter of 300 to 400 angstroms. Fiber lengths were generally less than one. micron but up to 5 microns (Germine, 1981).

Asbestos with a megascopic fibrous appearance is much less common than massive varieties on Staten Island but occurs in veinlets typically less than 1 mm to 3 mm wide. The fibers are white to light green and silky. The veins readily fiberize and posses the flexibility that is a characteristic of asbestos (Germine and Puffer, 1989).

ACKNOWLEDGMENTS

I thank Alan Benimoff for his careful review of this manuscript and Mark Germine for several years of unsurpassable expert help and council with asbestos related issues.

REFERENCES

Ageitos, D. M.; Buehler, S. C.; Eicher, J. C.; Rodda, T. D.; and Puffer, J. H., 1993, Serpentinites of Staten Island, New York and Castle Point, New Jersey: Geochemistry: The Bulletin New Jersey Academy of Science, v. 38, p. 17.

Baskerville, C.A., 1982, The Foundation Geology of New York City, in Legget, R.F., ed., Geology under cities: Geological SOciety of America Reviews in Engineering Geology, v. 5, p. 95-117.

Baskerville, C.A., 1987, Bedrock and engineering geologic maps of Bronx County and parts of New York: U.S., Geological Survey Open-File Report 87-360, scale 1:24,000, 3 sheets.

Baskerville C.A., 1989, Geology and Engineering Geology of the New York Metropolitan Area: 28th International Geological Congress, Field Trip Guidebook T361, p. 39-48.

Baskerville, C.A., 1989, New York City: Juxtaposition of Cambrian and Ordovician miogeoclinal-eugeoclinal rocks: in Baskerville, C.A., ed., Geology and Engineering geology of the New York Metropolitan Area: 28th International Geological Congress Field Trip Guidebook T361, p. 39-48.

Behm J.J., 1954, The petrology of the serpentinite of Richmond County (Staten Island), N.Y., Proc. of the Staten Island Inst. of Arts and Sciences, v. 16, p. 1-39.

Benimoff, A., Rice, S.B., Moore, P.B., and Sclar, C.; in prep., Picrolite from the Staten Island Serpentinite. submitted for review.

Britton, N.L., 1881, On the geology of Richmond County, New York: New York Academy of Sciences, Annals, v. 2, p. 161-182.

Cadmus, Denise; Hodgson, Richard; Gatto, Lisa M.; and Puffer, J. H., 1996, Geochemical Traverse Across Cameron's Line, Boro Hall Park, Bronx, New York, in Geology of Long Island and Metropolitan New York, Program with abstracts, Long Island Geologist, SUNY Stony Brook, p. 26-32.

Coleman, R.G., 1996, New Idria Serpentinite: A Land Management Dilemma: Environmental & Engineering Geoscience, v. 2, p. 9-22.

Cozzens, I., Jr., 1843, A geological history of Manhattan or New York island: New York, W.E. Dean, p. 11-39.

Eicher, J. C., Ageitos, D. M., Seeber, F.C., Kaplan, C. H., Buehler, S. G., and Puffer, J. H., 1994, Geochemistry of the Amphibolites of Central Park, New York City: in Hanson, G.N., (editor), Geology of Long Island and Metropolitan New York, SUNY Stony Brook, p. 44.

Germine, M., 1980, Determination of chrysotile content in serpentinites using X-ray diffraction (abstract): Bull. of the New Jersey Academy of Science, v. 25, p. 63-64.

Germine, M., 1981, Asbestiform serpentine and amphibole group minerals in the northern New Jersey area: Masters Thesis, Geology Department, Rutgers University, Newark, New Jersey, 239 pp.

Germine, M. and Puffer, J. H., 1989, Mineralogical definition of asbestos: Geological Society of America, Abstracts with Program, Northeastern Section, v. 21, p. 17-18.

Germine, M., and Puffer, J. H., 1989, Origin and development of flexibility in asbestiform fibers: Mineralogical Magazine, v. 53, p. 327-335.

Germine, M., and Puffer, J. H., 1990, Geochemistry of the New York Group Serpentinite. Empire State Geogram, abstract, v. 26, p. 16.

Germine, M. Puffer, J. H., and Maresca, G. P., 1981, Water supply contamination from bedrock asbestos in the northern New Jersey area: Geological Society of America, Abstracts with Program, v. 13, No, 7. p. 458.

Germine, M. and Puffer, J. H., 1989, Mineralogical definition of asbestos: Geological Society of America, Abstracts with Program, Northeastern Section, v. 21, p. 17-18.

Gratacap, L. P., 1904, Geology of the City of New York, 2nd ed.: New York, N. Y., Henery Holt and Company, 119 p.

Hall, L.M., 1968, Times and origin and deformation of bedrock in the Manhattan prong: in Zen, E-an, White, W.S., Hadley, J.B., and Thompson, J.B., eds., Studies of Appalachian geology: northern and maritime: Interscience Publishers, New York, p. 117-127.

Hall, L.M., 1976, Preliminary correlation of rocks in southwestern Connecticut: in Page, L.R., ed., Contributions to the stratigraphy of New England: Geological Society of America Memoir 148, p. 337-349.

Hess, H. H., 1955, Serpentines, orogeny, and epeirogeny, in Poldervaart, Arie, Ed., Crust of the Earth: Geological Society of America Special Paper 62, p. 391-407.

Hollick, C. A., 1909, Notes in connection with specimens recently obtained from serpentines of Stasten Island, N.Y.: New York Academy of Sciences, Annals, v. 19, p. 315-317.

Imfeld, K. L.; Kaplan, C. H.; Kosinski, J. S.: Seeber, F. C.; and Puffer J. H., 1993, Serpentinites of Staten Island, New York and Castle Point, New Jersey: Petrology: The Bulletin New Jersey Academy of Science, v. 38, p. 17.

Little, P.T., and Epstein, J.B., 1987, Geologic Map of the Newark 1 degree X 2 degree Quadrangle, New Jersey, Pennsylvania, and New York, Map 1-1715, U.S. Geological Survey.

Maresca, G.P., Puffer, J.H., and Germine, M., 1983, Chrysotile asbestos content of Silver Lake Reservoir, Staten Island, New York: Geological Society of America Abstracts with Programs, v. 15, no. 3, p. 138.

Maresca, G.P., Puffer, J.H., and Germine, M., 1984, Asbestos in lake and reservoir waters of Staten Island, New York: source, concentration, mineralogy, and size distribution: Environmental Geology and Water Science, v. 6, p. 201-210.

Maresca, G. P., Puffer, J. H., and Germine, M. 1983, Chrysotile, asbestos content of Silver Lake Reservoir, Staten Island, New York: Geological Society of America, Abstracts with Program, Northeastern Section, v. 15, No. 3, p. 138.

Merguerian, Charles, 1983, Tectonic significance of Cameron's Line in the vicinity of Hodges complex--An imbricate model for western Connecticut: American Journal of Science, v. 283, p. 341-368.

Merguerian, Charles, and Sanders, J.E., 1991, Geology of Cameron's Line and the Bronx Parks: Guidebook for On-The-Rocks 1990-91 Fieldtrip Series, Trip 21, Section of Geological Sciences, New York Academy of Sciences, 88 pp.

Merguerian, Charles, and Sanders, J.E., 1994, Staten Island and Vicinity: Guidebook for On-The-Rocks 1990-91 Fieldtrip Series, Trip 33, Section of Geological Sciences, New York Academy of Sciences, 151 pp.

Merrill, F.J.H., Darton, N. H. and others, 1902, Description of the New York City District: U.S., Geological Survey Geological Atlas, Folio 83, 19 p., 2 sheets.

Miller, W., 1970, Structural geology and tectonism of the Staten Island Serpentinite: Brooklyn College of City University of New York, Department of Geology, Master's Thesis, 64 p.

Moores, E.M., 1981, Ancient Suture Zones within Continents: Science, v. 213, p. 41-46.

Newland, D.H., 1901, The serpentines of Manhattan Island and their accompanying minerals: School of Mines Quart., v. 22, p. 307-317, 399-401.

Ohan, A.A., Kureshy, A.; and Kaarsberg, E., 1975, Geological aspects of Staten Island, New York: in Wolff, M.P., ed., Guidebook to Field Excursions: New York State Geological Association, 47 th Annual Meeting, Hofstra Univ, Hempstead, N.Y., Oct. 1975, Hempstead, New York, Hofstra Univ., 327 p.

Okulewicz, S.C., 1979, Petrology of the Staten Island alpine ultramafic body: Masters Thesis, Brooklyn College, New York, 92 pp.

Puffer, J. H., 1980, Toxic Minerals: The Mineralogical Record, v. 11, p. 5-11.

Puffer, J. H., Germine, M., Hurtubise, D. O., Mrotek, K. A., and Bello, D. M., 1981, Asbestos distribution in the Central Serpentine District of Maryland and Pensylvania: Environmental Research, v. 23, p. 233-246.

Puffer, J. H. and Germine, Mark, 1993, Distribution of asbestos in the serpentinite of Staten Island, New York and Castle Point, New Jersey: Geological Society of America, Northeastern Section, Boston, Mass. Abstracts with program v. 25, #6, p. A-350.

Puffer, J. H.; Maresca, G.; and Germine, M., 1983, Asbestos in water supplies of the northern New Jersey area: Division of Water Resources, Center for Coastal and Environmental Studies, Rutgers University, New Brunswick, 88 pp.

Puffer, J. H., and Germine, M., 1994, The Staten Island Meta-Peridotite: in Benimoff, A.I., (editor), Geology of Staten Island, New York, Field Guide and Proceedings, Geological Association of New Jersey, p. 1-25.

Puffer, J. H., Ageitos, D. M., Buehler, S. C., Eicher, J. C., Kaplan, C. H., and Seeber,F.C., 1994 Geochemistry of the schists of Central Park, New York City: in Hanson, G.N., (editor), Geology of Long Island and Metropolitan New York, Long Island Geologists, SUNY Stony Brook, New York, p. 86-92.

Rowley, D.B., and Kidd, W.S.F., 1981, Stratigraphic relationships and detrital composition of the medial Ordovician flysch of western New England: implications for the tectonic evolution of the Taconic orogeny: Journal of Geology, v. 89, p. 199-218.

Steiner. J. C., and Chesman, S. C., 1996, Tonalitic gneisses and mafic to ultramafic associations in the Red Hook section of Brooklyn: Evidence for the tectonic emplacement of a dismembered ophiolite: Geological Society of America, Abstracts with Programs, Northeastern Section, v. 28 p.101.

SERPENTINITES OF NEW YORK CITY AND VICINITY ROAD LOG

Miles From Start	Miles Between Points	
0.0	0.5	Start at the parking lot near the outcrop of Palisades diabase, proceed to the exit, and turn right onto Victory Blvd.
0.6	0.1	Continue on Victory Blvd. then turn right onto South Gannon Ave.
0.7	0.1	Continue on South Gannon then enter I-278 east.
3.4	2.7	Continue on I-278-East then exit at Clove Rd. and turn right onto Ocean Terrace.
3.6	0.2	Continue on Ocean Terrace and enter former campus of College of Staten Island.
4.0	0.4	Drive to parking lot near the west edge of the campus and park, then take path to Stop 1.

STOP 1. STATEN ISLAND SERPENTINITE

Caution!! At the outcrop, stay on the unused roadway, do not go near I-278; watch out for falling rocks and do not attempt to climb loose rock faces.

This is the most extensive exposure of serpentinite in the New Your City area. The serpentinite here contains variable amounts of relic olivine and minor amounts of anthophyllite schist. Both the highly foliated and the massive types of serpentinite are exposed here. The serpentinite exposed within a few cm of any of the closely spaced astamosing shear planes visible on both walls of the raod cut, tends to be green, highly foliated, and includes migascopically fibrous minerals, The rock furthest removed from the shear-planes is relatively dark-green to black and is massive.

An average mode based on 12 thin sections cot from the 1-278 exposure is 88 % serpentine, (mostly lizardite and chrysotile), 3 % olivine, 2 % talc, 2 % anthophyllite, 3 % opaque oxide (mostly fine grained magnetite but also including coarse magnetite, chromite, and picotite.), and 2 % carbonate (including dolomite and magnesite). About 1/2 of the serpentine is lizardite with highly variable concentrations of chrysotile ranging from absent to 70 % but averaging about 50 %. Minor antigorite is also present including the fibrous variety (picrolite, Bemimoff and others, in prep) Olivine is commonly found in the massive, black rock typically as relic microislands surrounded by serpentine that has replaced most of the individual grains. Talc and anthophyllite are typically found together as a coarse fibrous schist or less commonly as individual grains disseminated within the rock or in veins. The opaque oxides consist largely of the kind of finely disseminated magnetite that is typically expelled from olivine during hydration to serpentine. Olivine can hold more iron than serpentine so the excess iron is typically left as an intergrowth of magnetite and serpentine.

Chrysotile is not readily recognizable in most hand specimens or thin-sections of samples from this exposure. In thin section, only lizardite was recognized in one sample, but using transmitting electron microscopic (TEM) techniques (Puffer and Germine, 1994) abundant chrysotile was found.

Ten samples collected on the south side of the I-278 outcrop, spaced approximately 50 feet apart, were ground in a rock grinder, mixed, split and prepared on an EM grid, TEM point count data indicate a total chrysotile content of approximately 54 volume percent. Germine and Puffer (1994) also performed selected area electron diffraction analyses (SAED) and energy dispersive x-ray spectroscopy (EDEX) on several particles, confirming chrysotile as the major component and lizardite as comprising most of the remainder, with a minor talc component.

The same kind of analyses was conducted on another sample of serpentine from this roadcut (Sample 8p, Figure 4). It contains 38 percent chrysotile as confirmed by SAED and EDXS. The results were within the error range of the Puffer and Germine (1994) XRD estimate.

At least two varieties of massive chrysotile were recognized in samples of serpentine at the roadcut using TEM techniques (Germine, 1981). One variety is light to medium green and has a smooth fracture. It occurs in irregular masses and in veins ranging up to a centimeter in width. This type is composed of cross-fiber and randomly oriented fiber, and is often associated with abundant olivine. The second variety is a light green to white substance with pearly luster and platy to fine-grained meerschaum-like texture. This type of motive chrysotile occurs in veins, fracture fillings, and pore fillings. TEM examination indicates that it is composed of tubules with a diameter of 300 to 400 angstroms. Fiber lengths are generally less than 1 micron but also occur up to 5 microns (Germine, 1981).

Chrysotile with a megascopic fibrous appearance is much less common that massive varieties at this outcrop but occurs in veinlets typically less than 1 mm to 3 mm wide. The fibers are white to light green and silky. The veins readily fiberize and poses the flexibility that is a characteristic of all asbestos (Germine and Puffer, 1989). Asbestiform anthophyllite from this roadcut consists of straw-colored aggregates on anthophyllite fiber in association with gray to yellow-brown talc. The anthophyllite fibers range up to 18 cm in length in silky and splintery aggregates that are fairly rigid.

Slip-fiber veins of picrolite from this outcrop measuring 1 to 3 mm thick are also described by Germine (1981) and Benimoff and others (in prep.).

4.4	0.4	Drive to the exit of CSI and turn right on Ocean Terrace.
4.6	0.2	Continue on Ocean Terrace and turn left onto Clove Road.
4.8	0.2	Cross I-278 and enter I-278-west.
7.7	2.9	Take I-278 to the exit onto 440 north.
13.2	5.5	Proceed on 440 north across Bayone Bridge (toll) and enter I-78-east (New Jersey Turnpike extension) at interchange 14A.
18.2	5.0	Proceed on I-78 east to the exit onto 12th-street-east.
18.7	0.5	Take 12th street to Henderson and turn left just before Holland Tunnel toll gate.
19.5	0.8	Proceed on Henderson across RR-tracks where Henderson becomes Jefferson then turn right onto 4th street near the center of Hoboken.
20.0	0.5	Continue on 4th street to River Road and turn left at the Hudson River.
20.5	0.5	Take River Road north and park across from the serpentinite exposures along the east edge of Stevens Institute of Technology.

STOP 2. CASTLE POINT SERPENTINITE

This is probably the second most extensive exposure of serpentinite in the New York City area. The rock here is chemically (Table 2) and mineralogically indistinguishable from the I-278 exposure but is more highly foliated. Most rock surfaces are bright green. Close inspection reviels common grains of chromite. The network of thin white veins are composed largely of magnesite. Minor quantities of talc is visible on freshly broken rock surfaces.

Some of the bright green serpentinite has a glassey gem-like appearance that is a variety called Williamsite. The Williamsite is composed of very fine-grained chrysotile.

Chemical anslysis of four typical bright green samples from this exposure are consistent with meta-dunite although a two dark samples containing pseudomorphs of orthopyroxene are slightly richer in alumina and calcium and are interpreted as meta-harzburgite.

20.5 33.3 Return to CSI at the Victory Blvd. exit of I-278 by reversing the last 12.8 miles of the road-log.