Newly Discovered Ophiolite Scrap in the Hartland Formation of Midtown Manhattan

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INTRODUCTION

Serpentinites found in the NYC area are "alpine-type" ultramafic rocks. In the New England Appalachians, they typically occur as small, zoned, highly sheared isolated pods. They are found associated with major tectonic sutures or with sheared eugeosynclinal rocks adjacent to sutured terranes. Such highly sheared ultramafic masses are interpreted as ophiolitic scraps, dismembered slices of former oceanic lithosphere. In NYC, they are found in ductile fault contact with the surrounding Hartland Formation or at the Manhattan-Hartland contact. The serpentinites are black to greenish-black, fine-textured rocks containing serpentine group minerals including chrysotile, lizardite, and antigorite together with amphiboles, chlorite, brucite, magnesite, talc, calcite, and relict chromite, magnetite, olivine and pyroxene. The mechanism of emplacement of high density ultramafic rocks from the earth's mantle into lighter density rocks of the continental crust has been explained by several interesting genetic models. This extended abstract reports on the geology and contact relationships of a small, highly deformed ellipsoidal serpentinite body that has been uncovered during recent excavation of a deep building construction site between 42nd and 43rd Streets west of Sixth Avenue in midtown Manhattan.

PREVIOUS INVESTIGATIONS

Including the famous Staten Island serpentinite (Mather 1943, Britton 1881, Berkey 1933) and Hoboken NJ serpentinite (Merrill et al. 1902, Berkey 1910, 1933), ten scattered masses of serpentine rock have been encountered in NYC and vicinity over the years as a result of construction. In addition to the masses known from Manhattan between 54th and 62nd Streets between the Hudson shore and 10th Avenue (Cozzens 1843, Gratacap 1887, Merrill et al. 1902) and one penetrated by borings beneath the Hudson River during construction of the Pennsylvania rail tunnels (Berkey 1910, 1933), a few bodies have been penetrated by recent borings in the geotechnical investigation stages of the #7 Line extension in Manhattan (Coleen Osborne, personal communication) and the southern Manhattan tunnel segment of NYC Water Tunnel #3 (Anthony Del Vescovo, personal communication).

Serpentinites of varying dimension have also been encountered beneath the Bruckner Boulevard - Cross Bronx Expressway - Hutchinson River Parkway interchange at the north end of the Bronx-Whitestone Bridge approach in The Bronx (Dr. Charles Baskerville, personal communication), near the Woodside subway station in Queens (Dr. Patrick Brock, personal communication) and were encountered during construction of the Brooklyn Tunnel segment of NYC Water Tunnel #3 (Schnock 1999). Other local bodies include the large exposures along both sides of Route I-287 in Rye, NY (Fisher et al. 1970) and one reported by Merrill (1898) at Davenport Neck in New Rochelle, Westchester County, NY. Of these ten widely distributed occurrences, **all of them** are situated within the eugeosynclinal Hartland Formation.

THE ONE BRYANT PARK SITE

Starting in late December 2004 through early February 2005 we had four opportunities to examine the bedrock geology of a large construction excavation in midtown Manhattan. The One Bryant Park site covers about half a city block between 42nd and 43rd Streets, west of Sixth Avenue and was ultimately excavated to a depth of ~60' below street level (Figure 1).

Figure 1 – View toward the SSE (Bryant Park in distance) of the One Bryant Park site showing the early stages of the excavation. Digital image taken 21 December 2004.

Most of the site is underlain by well-layered muscovite±garnet schist and interlayered muscovite+biotite±garnet granofels of the Hartland Formation trending roughly N32°E with steep NW-dipping foliation and parallel compositional layering. Subordinate amphibolite and biotite±garnet schist occurs in various places throughout the excavation. The Hartland is predominately migmatitic throughout the site and is intruded by two large masses consisting of two-feldspar granite (eastern part of site) and megacrystic pegmatite with large books of mica on the west. A large serpentinite mass was discovered in the NE corner of the excavation immediately SW of the intersection of 43rd Street and Sixth Avenue (Figure 2), affording an excellent view of the internal structure.

As deeper and deeper levels were penetrated during the excavation process, we were able to develop a three-dimensional view of the body, sample across the body and to map the contact relationships and the structure of the body as well as the geometry of the surrounding Hartland Formation (Figure 3). Based on these studies, the serpentinite mass appears to be ellipsoidal and somewhat cigar-shaped with a steep plunge of 70° toward the south. Because the mass is exposed in the corner of the excavation, a three-dimensional view is presented. The serpentinite body is roughly 5 m in diameter and extends from about 4 m below street level from the top of the excavation over 10 m to the bottom of the excavation. Massive amphibolite wraps around the top and sides of the mass but the base is not exposed so the serpentinite must extend farther down plunge below the floor of the excavation. Borings to the north and east show Hartland schist, granofels, and amphibolite but no serpentinite so the horizontal diameter may be limited to that viewed in the excavation, about 5 m.

Figure 2 – View toward the ENE of top portion of zoned serpentinite found SW of the corner of 43rd Street and Sixth Avenue in Manhattan. The body exhibits a dark-colored massive serpentine core, light green talc schist and outer biotite schist zones and surrounding massive amphibolite. Digital image taken 21 December 2004.

The core of the body consists of mottled and internally veined, dense blackish to greenish black serpentinite with relict blackish-green pyroxene and late talc, brucite, anthophyllite, magnesite, calcite, and a white fibrous serpentine mineral (chrysotile?). These and the following are megascopic determinations made with handlens and stereoscope. Detailed petrographic and geochemical analyses are in progress. The massive core grades outward to a foliated 0.5 m zone of sheared, fissile light green talc+chlorite+anthophyllite schist. Domains of similar light green schist are found within the core of the body. The talc schist grades outward into an 8 cm zone of talc+chlorite+biotite schist then outward into a 13 cm wide zone of fine-grained, matted, sheared and highly lineated biotite schist cut by foliation parallel smoky quartz injections 2 cm - 4 cm thick (Figure 4). The biotite schist zone is in razor sharp contact with roughly 3 m of massive amphibolite which wraps around the entire body. The amphibolite is in contact with isoclinally folded pelitic schist and mica granofels of the Hartland Formation. The steeply plunging body is clearly concentrically zoned; the envelope of amphibolite + biotite schist + chlorite+talc schist can be traced continuously around the exposed sides and top of the body.

Figure 3 – View of the One Bryant Park serpentinite mass (outlined in green) near the end stage of the excavation showing the surrounding units. By our final visit some of the exposed schistose layers of the serpentinite needed support as they started to unravel along the north wall of the excavation. Support involved the installation of a concrete retaining wall and rock bolts. At this point in the excavation process the overall ellipsoidal shape of the serpentinite mass was clearly visible but the base was not exposed. Digital image taken 07 February 2005.

TECTONIC IMPLICATIONS

The association of ultramafic rocks with highly deformed rocks of probable oceanic parentage and sutures formed between former lithospheric plates provides the ammunition for interesting speculations as to the plate-tectonic significance of serpentinites and their relationship to the process of mountain building. Two contrasting hypotheses for the origin of the pre-metamorphic parent rocks of serpentinites are:

(a) Origin beneath the sea floor as the substrate of an ophiolite succession of oceanic lithosphere formed at a spreading oceanic ridge, and,

(b) Origin as primitive mantle-derived magmatic injections which rose upward from the zone of magma generation in the upper mantle through the lithosphere and crust.

Complete ophiolite successions from the oceanic lithosphere (a) can become part of the continental realm only as a result of great overthrusting, in which the interface of displacement begins perhaps 10 km beneath the ocean floor and eventually steps its way upward toward the Earth's surface along thrust faults. Examples include the Troodos Igneous Massif in Cyprus, the Thetford Mines ophiolite in Quebec, and the Bay of Islands Complex in Newfoundland.

Figure 4 – Close view of the sheared western margin of serpentinite body showing the concentric zoning that (from right to left) grades from light green talc+anthophyllite schist [1] to black and green biotite+chlorite+talc schist [2] to black biotite±chlorite schist injected by smoky quartz veins [3] to massive amphibolite [4]. Outside the view of the digital image, the amphibolite is in sharp contact with isoclinally folded muscovitic schist and mica granofels of the Hartland Formation. Digital image taken 21 December 2004.

In (b), ultramafic magma from the mantle works its way upward into the continental lithosphere through deep-seated fractures and crystallizes as intrusive igneous rocks. Such high-density magmas solidify slowly to form bodies of coarse-textured ultramafic rock. Presumably during regional deformation accompanying mountain building, the ultramafic magmas are squeezed upward into the continental crust as semi-solid crystal-rich masses. These rocks are commonly serpentinized to some degree but display cumulate textures and are typically found in association with satellitic mafic plutons as well as late granitoid plutons. Examples include the Duke Island Complex of Alaska, the Hodges Complex of Connecticut, and the Cortlandt Complex of New York. Such igneous rock complexes create zones of contact metamorphism. Field relationships allow for clear distinction between serpentinites of ophiolite (a) or igneous (b) parentage.

Because of the symmetrical zones of mica-rich rocks sheared around the core of massive serpentinite, the geology of the One Bryant Park serpentinite most resembles alpine-type ultramafic rocks found elsewhere along the core zone of the Appalachian belt. The serpentinite shows no evidence for cumulate layering or igneous textures of any kind, lacked internal igneous contacts, and did not produce obvious contact metamorphism or growth of porphyroblasts in the surrounding amphibolite. There are no satellitic mafic plutons in the vicinity. No xenoliths or cognate xenoliths were found nor was there any evidence for cross-cutting intrusive relationships typical of igneous rocks. For these reasons, the serpentinite of the One Bryant Park site is interpreted to be a scrap of dismembered ophiolite (a).

As described above, all of the serpentinites of NYC and vicinity are within the Hartland Terrane, a vast sequence of sheared aluminous schist, granofels, and amphibolite that presumably represent metamorphosed deep-water shale, graywacke, and basaltic oceanic crust of a former oceanic basin. Regional considerations on the timing of mountain building and deformation of the metamorphic rocks of the Manhattan Prong suggest that the main pulse of deformation occurred during the Taconic orogeny of medial Ordovician age (roughly 450 million years ago) when a volcanic arc off eastern North America collided with the passive continental shelf edge of North America (Figure 5). Because the serpentinites of NYC and vicinity appear to be associated with sheared eugeosynclinal rocks and ductile faults, they are interpreted as dismembered slivers of 450 Ma (or older) mantle formerly situated between a colliding Taconian volcanic arc and the stable shelf edge of proto North America (Merguerian 1983).

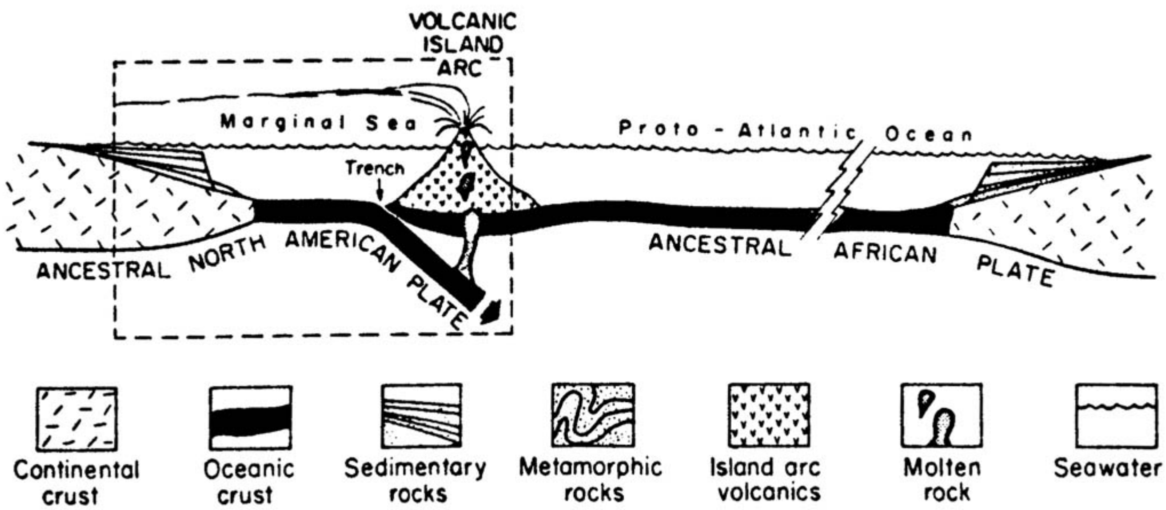

Figure 5 - Plate-tectonic "cartoon" showing inferred reconstruction at beginning of Medial Ordovician time. This interpretation shows the former ocean floor and volcanic island arc moving against North America, with a seaward-dipping subduction zone beneath the island arc. (Y. W. Isachsen, 1980, fig. 4, p. 7.)

Modern studies of orogenic belts indicate that the occurrence of serpentinite along the internal, deformed core zones of mountain ranges has resulted from physical injection of partly solidified masses of mantle as tectonic slivers (slices) during compression that accompanies convergent mountain building. In the Hartland Terrane throughout New England, occurrences of serpentinite, amphibolite (± deformed pillow lava), and mica schist with stratabound metalliferous deposits, represent layers of the ophiolite trinity (Merguerian 1981). An example would be the Forge Hill ophiolite in Massachusetts (Emerson 1898). In deeply eroded terrains, such as the Appalachians, where significant deep-seated shearing, metamorphism, and imbrication of rock units have taken place, complete three-layer ophiolite sequences are seldom recognized (Merguerian 1979). In fact, given the enormity of shearing in such former convergent margin settings, metamorphosed dismembered ophiolite is the expected norm rather than the exception. In NYC and vicinity, the association of serpentinite and the Hartland

Formation allows the interpretative view that they are slivers of dismembered ophiolite preserved in a sheared eugeosynclinal matrix.

In the Coast Ranges of western California, exotic blocks of serpentinite and eclogite "swim" in a sea of sheared but weakly metamorphosed eugeosynclinal strata of the Franciscan Complex. The serpentinites are interpreted as dismembered ophiolite with imbrication of surrounding oceanic strata the result of shearing in a former subduction zone. We view the Coast Range serpentinite association as a type-example of what occurs during the subduction process at convergent margins and suggest that the regional geology of the Coast Ranges is similar to that of the Hartland Terrane, albeit exposed at a much shallower erosion level.

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