THE NEW YORK CITY SERIES

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Trips 2-B and 2-E

Introduction

Geologic mapping in connection with the construction of the Catskill aqueduct and the more recent Delaware aqueduct supplying the ever growing water needs of New York City has traced the rocks of the New York series through Westchester County to the southern border of the Hudson Highlands (extending northeastward from the vicinity of Peekskill). In fact, recent studies in the County have revealed much information helpful in furthering the eventual solution of several controversial aspects of New York City geology.

Starting with exposures of typical New York City rocks some 12 miles south of Peekskill, the trip crosses the County westward to the Hudson River and then follows its east shore northward to Verplanck Point in the northwest corner of Westchester County. There interesting field relations are used to highlight the several interpretations of the origin and age of the New York City series.

Lithology

The New York City series comprises three distinct formations or rock units of strongly metamorphosed character. Starting with the oldest, they are the Fordham gneiss, Inwood marble (sometines called a limestone) and Manhattan schist.

Fordham Gneiss is a well-banded biotite gneiss, rich in quartz and containing microcline and lesser amounts of orthoclase and oligoclase. Intercalated layers of granitic material exhibit streaky foliation and are interpreted as igneous injections during metamorphism. Cross-cutting later granite pegmatite dikes are common. In the lower horizons of the Fordham gneiss terrane (along the shore of Long Island Sound) intrusive amphibolites with distinct reaction rims abound. Similar rocks are common in Westchester County. The formation is quite variable in appearance and composition so that it is often difficult to distinguish it from the Manhattan formation.

Thin, discontinuous quartzite bands (Lowerre quartzite) at the top of the formation have been described from several localities in New York City and Westchester County (Merrill et al, 1902; Norton and Giese, 1957) and have recently been found in diamond drill cores in the City.

Inwood Marble is a medium to coarse crystalline, white to gray rock with calcite and variable amounts of dolomite as principal constituents. Yellow to brown staining by iron oxide is common. Accessory minerals include diopside, tremolite, phlogopite, quartz, pyrite and occasionally graphite.

Alignment of these accessories in bands and changes in degree of crystallinity impart a pseudo-bedding structure to this rock. Interpretation of this structure as primary bedding is untenable, because its attitude is now conformable with the folded secondary foliation of the Fordham gneiss below and the Manhattan schist above. It is more likely to be the result of intense plastic flow deformation and might be termed "tectonic bedding".

The Inwood is the least resistant of the three formations of the series and is responsible for the principal valleys in the region, trending in a northeasterly direction.

A granular texture is evident on exposed surfaces of the more crystalline varieties. It is not uncommon to have a handspecimen crumble upon the lightest touch as a result of solution action along crystal boundaries. Essentially the only residual mantle in this region of extensive glacial cover has been developed from this formation.

Granite pegmatite and aplite dikes are surprisingly uncommon in the marble considering their abundance in the older Fordham and overlying Manhattan formations. The dense, plastic nature of the rock during deformation at depth is believed to have confined granitic intrusions to relatively few "feeder" channels.

W.H. Bucher has reported the presence of cystoid plates in thin sections of this rock from Westchester County. No other fossil evidence has been described.

Manhattan Schist is principally a feldspar-quartz-mica schist. Generally muscovite predominates over biotite but proportions of these minerals vary greatly. The feldspars are mostly plagioclase (oligoclase and andesine). Garnet is the most common and abundant accessory mineral. Magnetite, apatite, staurolite, tourmaline and, infrequently, kyanite and sillimanite have been reported from several localities (Fettke, 1914).

The texture is generally coarse with mica flakes forming a scaly foliation (schistosity). Locally the rock may appear gneissic due to concentration of accessories as layers, augens and stringers.

Intercalated bands of hornblende schist are numerous enough to consider this rock as a member of the Manhattan formation. The hornblende schist layers may be up to 200 ft. thick extending 1000 ft. along the strike (Fettke, 1914). Hornblende prisms oriented in parallel planes produce the foliation in this rock and constitute up to 85% of its volume. Quartz, plagioclase feldspar and epidote make up the remainder. The rock is readily identified in the field by its dark color, rather fine grain and regular, rhombohedral joint pattern.

The hornblende schist was initially believed to be of igneous origin representing amphibolitic sill intrusions into the ancient shales (Fettke, 1914). It is, however, rarely found cutting across the mica schist (the authors have never observed such an occurrence in the field) and is nowhere present in the underlying Inwood marble. These features speak much more eloquently for a sedimentary origin of the hornblende schist. It has been definitely established that hornblende, which originally had been interpreted as an igneous mineral exclusively, may also be formed by metamorphism of iron-bearing sediments. Thus ferruginous layers in the thick shales, later metamorphosed into mica schist, probably produced the hornblende schist.

The Manhattan schist as well as the Fordham gneiss are ridge formers in this region owing to their resistance to weathering and erosion which also makes them suitable for building stones.

A network of granite pegmatite dikes and sills (up to 15 ft. across) intersect one another indicating their later introduction toward the close of the metamorphic interval in successive "waves".

Structure

The three formations of the New York City series are conformable (indicated by interbedding of the Inwood marble with both the Manhattan schist and Fordham gneiss) and have been folded together. In the New York City area the folded structure plunges southward at angles of 15^0 to 20^0, except in the northern part of the City where plunges of 45^0 or more have been measured. The folds trend in a north-northeast direction and are somewhat overturned to the west. In Westchester County the fold trend veers toward the northeast while the plunge changes to the northeast at relatively steeper angles.

A number of high-angle thrust faults (with brecciation zones) transect the folds from northwest to southeast in New York City giving rise to (glaciated) cross valleys. In Westchester County similar faults with northeast trends appear to be more common. The exact nature of movement and displacement is generally difficult to determine.

Age Relations

Merrill et al (1902) who did the fundamental work on the geology of the New York City series gave the following ages for the three formations:

Fordham gneiss: Pre-Cambrian
Inwood marble (then called Stockbridge dolomite): Upper Cambrian to Lower Silurian (now Ordovician)
Manhattan schist (then called Hudson schist): Lower Silurian.

At that time Lower Silurian was the equivalent of Ordovician which had not been recognized as a valid term by the U. S. Geological Survey. No angular unconformity between the Fordham and Inwood formations was shown, but a disconformable relation was implied.

Berkey (1907) and Berkey and Rice (1919) questioned the Paleozoic age of the Inwood and Manhattan formations and assigned the entire series to the Pre-Cambrian. The Fordham formation was correlated with the older Grenville rocks of the Adirondacks while the Lowerre quartzite, Inwood marble and Manhattan schist were called younger Grenville. This change in correlation was based on a comparison of the New York City series with the early Paleozoic sequence of Poughquag quartzite-Wappinger limestone-Hudson River pelite group north of the Hudson Highlands (and in the Peekskill inlier). Differences in petrology, structure, degree of metamorphism and details of stratigraphic thickness and succession were believed to require a more venerable age for the New York City series.

Balk (1936) in his study of the Cambro-Ordovician rocks of the Great Valley and their progressive metamorphism eastward, traced units of the Hudson River pelite group southward across the Highlands. Although he was unable to link up these units directly with the Manhattan schist, he strongly suggested their equivalence on similarity of composition, metamorphism and structural trend. He did not question, however, the Pre-Cambrian age of the Fordham gneiss, because he considered the apparent conformity between the Inwood and Fordham as the result of tectonic influences.

Prucha (1956) established their true conformity by discovering numerous instances of interbedding between these two formations in Westchester County. But he suggested that an attempt to correlate the New York City series with the early Paleozoic metamorphics of Massachusetts and Vermont would probably be more fruitful. He also recommended the use of the New York City group in lieu of New York City series, and questioned the validity of the Lowerre quartzite as a formational unit.

Scotford (1956) studied the New York City formations in the Poundridge area of Westchester and Putnam Counties from the structural point of view. He concluded that they comprise a conformable sequence of either Pre-Cambrian or early Paleozoic (pre-upper Ordovician) age. He agreed with Prucha concerning non-existence of the Lowerre quartzite as a significant stratigraphic unit.

Paige (1956) attempted to correlate the occurence of the Manhattan schist and Inwood marble at Verplanck Point with the Annsville phyllite-Wappinger limestone sequence (Cambro-Ordovician) outcropping in the Peekskill valley and at Tomkins Cove on the west shore of the Hudson River. (See discussion of Trip 1 and Stop 2-3).

Norton and Giese (1957) gave a brief review of the Lowerre quartzite problem, which helped little to clear up the prevailing confusion.

Gray (1956) reported age determinations on the Manhattan schist by the Lamont Geological Observatory of Columbia University using the potassium-argon method. The age of the mica was found to be 380 million years thus establishing the age of metamorphism which is approximately coincident with the Taconic orogeny. This determination did not give the age of the Manhattan schist as was erroneously reported in the article.

It might be stated in conclusion that the age correlation of the New York City series has not been established todate, but that the weight of evidence appears to favor early Paleozoic age for the rocks and Taconic age for their deformation and metamorphism.

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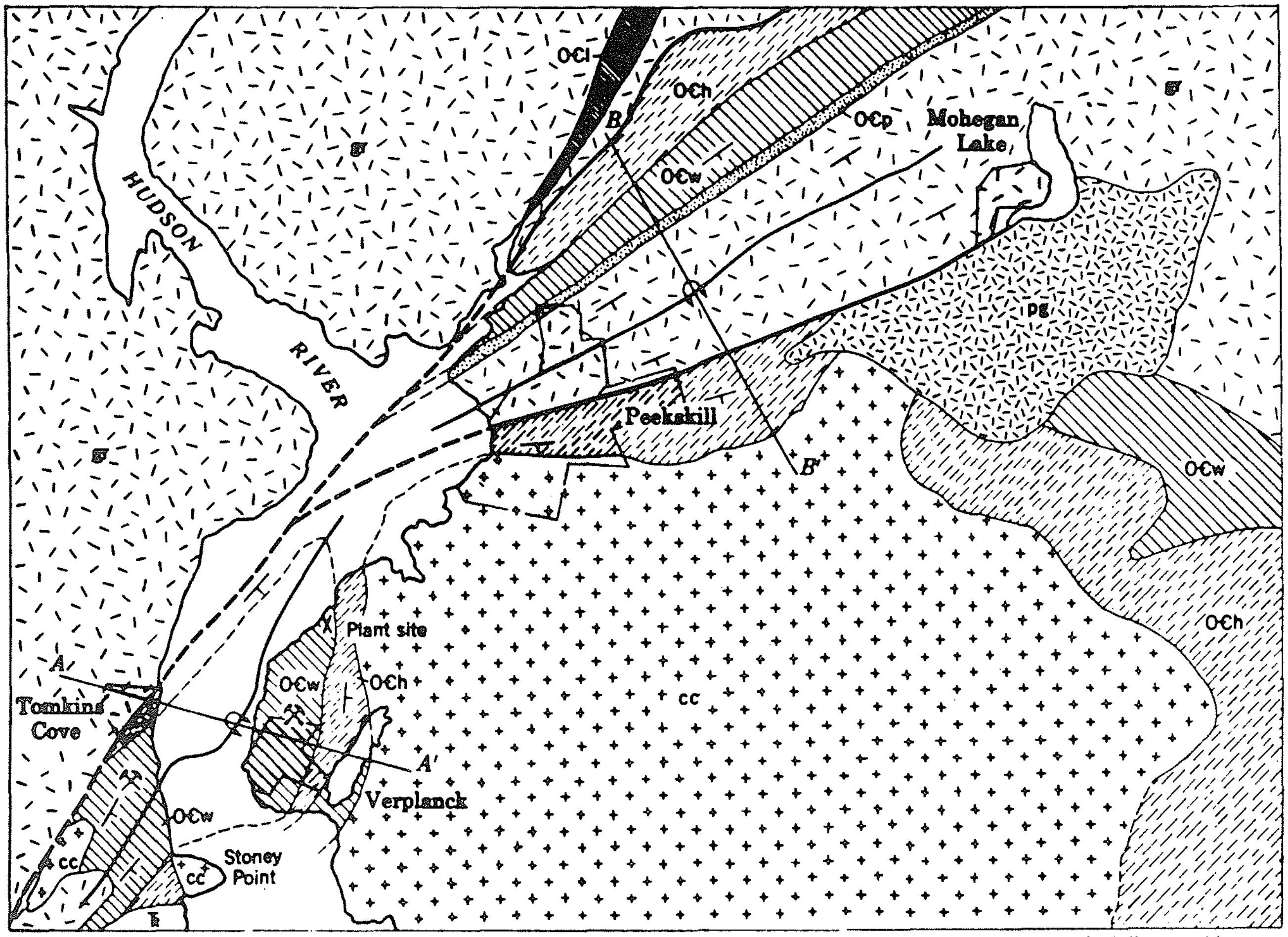
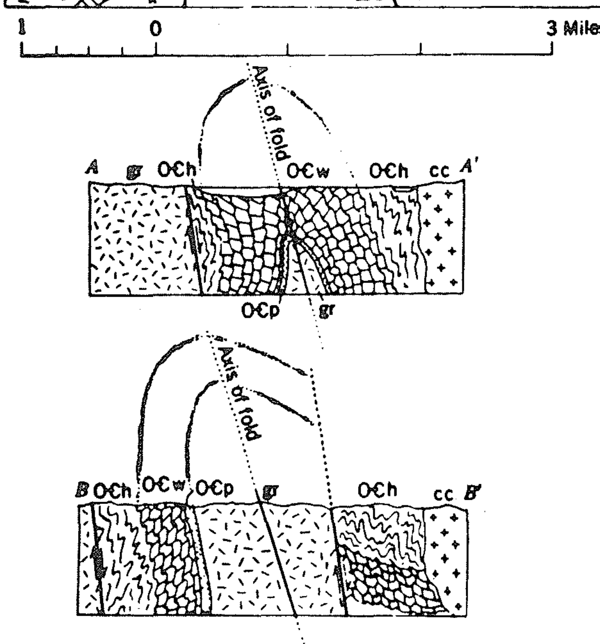
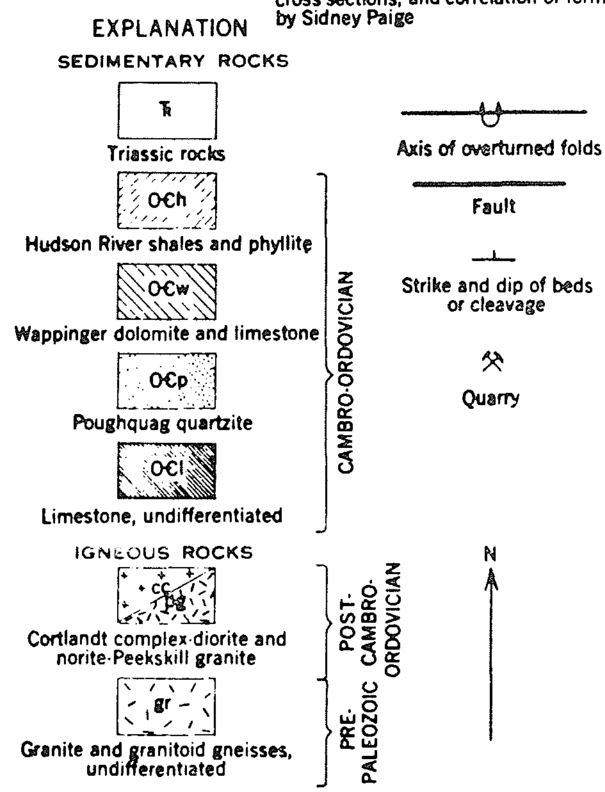


Formation boundaries, fault lines, and igneous contacts after C. P. Berkey. Structural axes, cross sections, and correlation of formations by Sidney Paige





Formations south of Peekskill, and east of the Hudson River regarded by Berkey as of "doubtful" age and mapped as Inwood limestone and Manhattan schist, are here mapped as Cambro-Ordovician in age

—Geologic and Structural Map of Southwest Portion of West Point Quadrangle, New York (AFTER S. PAIGE, 1956)

Paige, Sidney (1956) Cambro-Ordovician age of the "Inwood" limestone and "Manhattan" schist near Peekskill, New York, Geol. Soc. Am., vol. 67, p 391-394.

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THE NEW YORK CITY SERIES IN WESTCHESTER COUNTY

Trips 2-B and 2-E

Route Description

Mileage

0	Shustin's Locust Manor - right (S) on Locust Ave.
.2	right (W) on US-6
.4	pass under Bear Mt. Pkway. and turn right onto Parkway heading east.
1.6	US-202 and NY-35 join Parkway from right (W); continue straight (E)
3.5	keep left at Y-fork on approach to Taconic Parkway
4.5	enter Taconic Parkway heading south
9.1	NY-129 joins Pkway. from right (W); follow left (E) curve of Pkway.
9.5	Pkway. turns right (S) across Croton reservoir bridge
13.5	right turn off Parkway; exit to NY-100
13.6	left (NE) on NY-100 passing under Pkway.
13.8	right (SE) on NY-133
14.0	STOP No. 2-1: Quarry behind transformer station at left (N), now used by N. Y. State for gravel and road machinery storage. Typical Fordham gneiss, the oldest formation of the New York City series.
14.0	continue (E) on NY-133
14.2	250 ft. beyond Millwood Railroad Station turn left (N) on NY-120 (Granite House Rd.)
14.4	intersection of NY-120 (Granite House Rd.) with NY-100
	STOP No. 2-2: The 3 formations of the New York City series outcrop in close proximity, although actual contacts are not exposed. Manhattan schist (garnetiferous muscovite schist) NW of the intersection along a side road; Inwood marble (medium grained, crystalline marble, here containing accessory graphite) in road cut on both sides of Granite House Rd.; Fordham gneiss (banded biotite gneiss) a short distance SE along cut-and-cover portion of Catskill Aqueduct. Formations appear conformable with nearly vertical dips. These rocks were traced continuously from the New York City line to this locality by Fluhr (1940). The thickness of the Inwood marble here is much reduced compared with that prevailing in New York City (approx. 750 ft.), a feature which is rather common in Westchester County. It has been explained by "squeezing-out" of the highly plastic rock and by faulting.
14.4	left (SW) on NY-100
15.0	pass under Taconic State Pkway.
15.2	right (W) on NY-133; Manhattan schist exposures for the next 3 miles
17.2	pass under NY-9A (Briarcliff-Peekskill Pkway.)
18.2	NY-134 joins NY-133 from right (NE)

Mileage

18.4	View of Palisades across the Hudson River (below crest of hill)
18.5	right (N) on US-9
19.2 to 19.6	Good view of strongly dissected Palisades to west and Hudson Highlands escarpment to northwest
20.3	junction with NY-9A - continue (N) on US-9
20.4	cross Croton River; Croton Point delta and moraine at left (W)
20.9	Croton Pt. Ave. (entrance to Croton Pt. Park) left (W); deltaic deposits at right (E); continue (N) on US-9
21.3	View of Palisades and Hudson Highlands
21.5	Y-intersection with NY-129; stay left on US-9; at right (E), past intersection, remnants of a worked-out gravel and sand pit (part of Croton Point glacial delta)
22.6	exposures of Manhattan schist along road
25.0	View of southeastern gateway of the Hudson River gorge straight ahead (N)
25.4	exposure of Cortlandt complex hornblende norite with spheroidal weathering having passed over contact between Cortlandt intrusive complex and the Manhattan schist a short distance back (not exposed)
25.7	entrance to F.D. Roosevelt Veterans Administration Hospital (left)
25.8	left (W) on Dutch St.
25.9 to 26.0	exposures of Cortlandt complex hornblende norite at right (N)
26.5	sharp right (N) on Sunset Rd.
27.0	intersection with Montrose Rd., straight (N) on Sunset Rd.
27.4	end of Sunset Rd., sharp left (W) on Kings Ferry Rd.
27.6	exposure of Cortlandt complex pyroxenite at left (S)
27.7	cross Greene Cove; Kings Ferry Rd. becomes Sixth St. (Verplanck)
28.2	intersection with Broadway; straight (NW) on Sixth St.
28.3	at left (SW) (in front of school) contact between Inwood marble and Manhattan schist
28.4	right (NE) on Highlands Ave.
28.7	intersection with 11th St.; park cars at left (N) off road opposite church; walk NW to Verplanck Point quarry

STOP No. 2-3: Verplanck Point Quarry (N.Y. Trap Rock Corp.)

Approach to quarry is down the flank of a large mound of tailings deeply carved by erosion into typical badland topography. Pass several large glacial erratics below (Highlands crystallines).

DO NOT walk too close to the edge of the quarry which has not been in operation for some years.

In east face of quarry (looking north) is well-exposed contact between Manhattan schist above and Inwood marble below showing interbedding. Dips are steeply to the east (into quarry face). The Inwood marble, except for its rather fine texture, appears to be typical. In the schist, biotite predominates over muscovite and the texture is fine-grained and more gneissic than schistose. The variation from the typical lithology of the Manhattan schist in New York City is attributed to the influence of the Cortlandt intrusive pluton.

Depending on the water level in the quarry (the water is approx. 150 ft. deep) evidence of isoclinal folding of the marble can be seen in the north face of the quarry.

Collapse of the top of the east quarry face recently exposed a discontinuous zone of coarse Inwood marble breccia in a greenish to reddish crystalline matrix, close to the contact with the Manhattan schist. Mr. S. Schaffel who first observed this curious rock believes that it is of tectonic origin and that the matrix was affected by gaseous or hydrothermal solutions from the Cortlandt intrusive. Angular fragments of marble appear to be quite fresh and unaltered. Detailed microscopic examination of this rock (unreported from any other Inwood marble locality) will be undertaken in the near future. This interpretation then assumes at least post-Taconic age for the Cortlandt intrusive (see discussion of age relations of the New York City series).

$1^1/_2$ miles to the southwest across the Hudson River can be seen the Tomkins Cove quarry (N.Y. Trap Rock Corp.) in Wappinger limestone (Cambro-Ordovician). As discussed under age relations of the New York City series in the preceding pages, several attempts have been made to correlate this series with the Cambro-Ordovician rocks of the Hudson valley. At this locality the Wappinger limestone and Annsville phyllite (Cambro-Ordovician) are in rather close proximity to the Inwood marble and Manhattan schist (uncertain age), with only the width of the Hudson River intervening. This feature makes the correlation of these two rock sequences a tempting possibility. Let us then review briefly the several alternative lines of reasoning:

(1) The Verplanck Point rocks could be the metamorphic equivalent of the Tomkins Cove sediments on the basis of similar composition, stratigraphy and structure. Paige (1956) suggested an anticlinal arch across the Hudson River along which the progressive kinetic metamorphism took place in an easterly direction. The same author also indicated that contact metamorphism associated with the Cortlandt intrusion could account, at least in part, for the metamorphosed nature of the rocks at Verplanck Point.

(2) The authors cannot agree with this interpretation. Contact metamorphism would require an unusually broad contact zone around the margins of the intrusive, a feature which does not seem to be present in other localities at similar distances from the intrusive contact. Also the characteristic contact emery deposits in the mica schist seem to be absent here.

Progressive metamorphism could offer a plausible explanation were it not for the remarkably short distance in which a typical phyllite is supposed to have changed to a biotite-muscovite schist. One way out of this dilemma would be the assumption of westward thrusting (under the Hudson River) to account for the present proximity of the two contrasting metamorphic terranes.

(3) Verplanck Point rocks of the New York City series could be older than the Cambro-Ordovician sediments at Tomkins Cove. In that case the two rock groups must be in unconformable contact with each other beneath the river.

Mileage	
	It becomes evident that the clue to this problem of correlation is buried under the Hudson River whose bedrock profile and structure are not known in this locality.
	Note a typical kame ridge (in cross-section) on top of the north quarry face.
28.7	right (SE) on 11th St.
28.8	STOP No. 2-4: Contact between Inwood marble and Manhattan schist on right (S) side of road. Note bands of small cubic pyrite crystals in the marble (influence of the Cortlandt intrusive ?).
29.0	left (NE) on Broadway
29.2	Manhattan schist exposures along road
29.7	pass entrance to Con Edison plant (left)
30.0	start of massive, glaciated exposures of Cortlandt complex augite norite at right
30.2	sharp right (SE) on Bleakeley Ave.
30.6	left (N) on US-9
31.0	cross Welcher Ave. (traffic light) intermittent exposures of Cortlandt complex augite norite for the next $1^1/_2$ miles
32.5	pass under US-202 (Main St.); last exposures of Cortlandt complex rocks (augite norite); continue straight (N) on US-9
33.1	intersection with US-6-202 (from left-N) - stay right (E) on Bear Mt. Pkway.
36.0	right at exit to US-6 (E-bound) and left (NE) on US-6 passing under Pkway.
36.2	left (N) on Locust Ave.
36.4	left at headquarters.