TRIP G: STRUCTURE AND PETROLOGY OF PELHAM BAY PARK

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INTRODUCTION

Location and Geologic Setting.

Pelham Bay Park is located on Long Island Sound in The Bronx in New York City (Figure 1). The area mapped in detail (Scale 1 inch = 10 feet) includes North Twin and South Twin Islands which are located in the eastern part of Pelham Bay Park (Figure 2). Both North Twin and South Twin Islands are underlain by highly deformed and intensely metamorphosed gneisses, schists and amphibolites which have undergone a complex tectonic and metamorphic history involving extensive boudinage, tight isoclinal folding and metasomatism. Pleistocene glaciation and recent wave action provide excellent exposure of bedrock and permit detailed field study of these rocks.

The units of Pelham Bay Park were mapped as Hudson Schist (now Manhattan Formation) in the New York City Folio (Merrill et al., 1902). However, on the New York State geological map (Fisher et al., 1961), the rocks are designated as undivided schists and gneisses of unknown age.

Acknowledgments.

The authors wish to thank Professor Kurt Lowe of the College of the City of New York who first introduced them to this area, and the late Professor Arie Poldervaart of Columbia University who provided early encouragement and funds for initial thin sections. Thanks are also due the Society of the Sigma Xi for a Grant-in-Aid of Research that permitted continuing investigation, and the Department of Parks of the City of New York for their courtesy and cooperation.

PETROLOGY

Introduction.

For the purpose of mapping, the following units were chosen:

(a) Felsic Unit, which includes felsic gneisses and sillimanite schists; and
(b) Mafic Unit, which includes amphibolite, diopside-epidote amphibolite, plagioclase-biotite gneiss together with associated (but minor) calcite-rich layers and plagioclase-rich layers. These units are part of the Hutchinson River Group (Charles Baskerville, oral communication).

Three phases of deformation have affected these units and metasomatism was extensive during the third phase of deformation. Replacement textures are common in thin section, and rock types often change either abruptly or gradationally along strike. Relict foliations and skialiths are common. Changes in rock types accompanying metasomatism are given in Figure 3 and modes of representative samples are given in Table 1. Numbers in parentheses in the text refer to index numbers of samples in Table 1.

Felsic Unit.

The Felsic Unit underlies approximately one half of North Twin Island and almost all of South Twin Island (Plate 1). Felsic gneiss is the dominant rock type and sillimanite schist comprises only about 5% of the Felsic Unit. Contacts between felsic gneiss and sillimanite schist are gradational over distances of a fraction of an inch to several inches.

Felsic Gneiss. Major constituents of felsic gneiss are quartz, plagioclase (An_{33}), and biotite with minor garnet, muscovite, microcline, sillimanite, magnetite and apatite (Table 1, numbers 1 and 3). Locally, coarse-grained microcline is abundant. These microcline-bearing felsic gneisses (Table 1, number 3) contain approximately twice the amount of potash as the normal felsic gneisses (Table 1, number 1) and were probably formed by potash metasomatism of the felsic gneisses (microcline replacing plagioclase).

Sillimanite Schist. The sillimanite schists contain plagioclase, quartz, biotite, sillimanite, microcline, and garnet with minor amounts of magnetite and muscovite (Table 1, number 4). Biotite parallels the outlines of garnet porphyroblasts and in some cases, garnet porphyroblasts are enclosed in lenses of coarse-grained microcline.

Mafic Unit.

The Mafic Unit occurs as layers and boudins ranging from less than an inch to more than 90 feet thick. On South Twin Island, the Mafic Unit is dominantly amphibolite while on North Twin Island the Mafic Unit includes amphibolite, diopside-epidote amphibolite, plagioclase-biotite gneiss and associated plagioclase-rich and clacite-rich layers.

Amphibolite. The amphibolites of South Twin Island contain medium-grained hornblende and plagioclase (An_{37}) with minor biotite, quartz, magnetite and apatite (Table 1, number 6). Foliation is defined by the orientation of hornblende and biotite crystals, and by thin (1 to 4 mm. wide) layers rich in plagioclase and quartz. Within some amphibolites, garnet porphyroblasts occur in layers parallel to the foliation. Toward the contact with felsic gneiss, amphibolite grades into biotite amphibolite (Table 1, number 9) or mafic biotite schist (Table 1, number 10). Amphibolites also grade along strike into mafic biotite schist suggesting that potash metasomatism of the amphibolites produced the mafic biotite schist.

Plagioclase-Quartz Borders. There is often a plagioclase-quartz border up to several inches wide separating the amphibolite from felsic gneiss. This border consists of medium-grained plagioclase and quartz with minor amounts of biotite, garnet, magnetite, microcline, hornblende, apatite, muscovite and sphene. These borders are often present at the ends of amphibolite boudins (formed during the third phase of deformation). Within amphibolite, diopside increases in abundance toward the contact with the plagioclase-quartz border. Epidote, quartz, garnet, calcite and scapolite also occur within the amphibolite near this contact. Since amphibolites change abruptly both across and along strike into plagioclase-quartz borders, the borders are probably the result of metasomatism of the amphibolite.

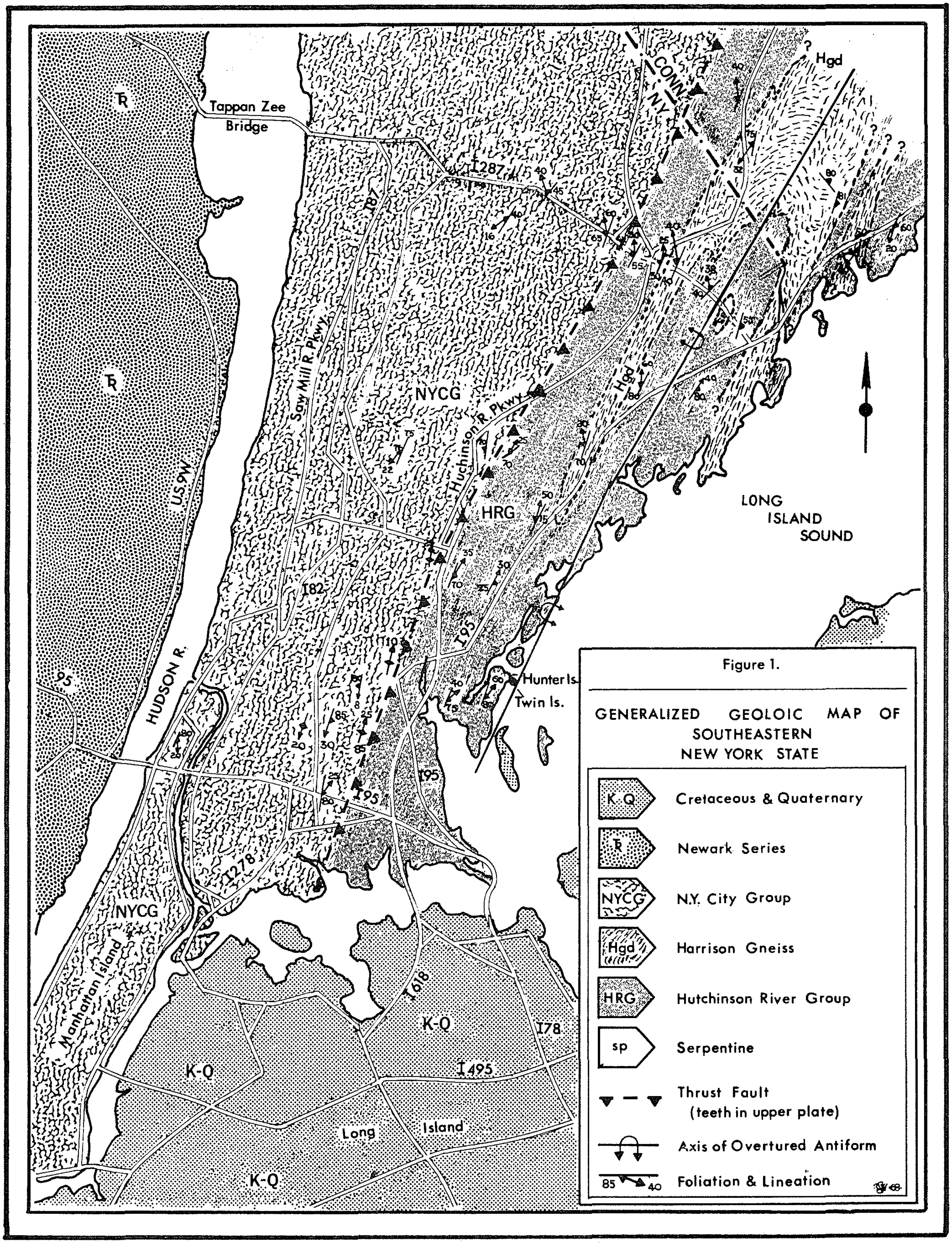

Figure 1.

GENERALIZED GEOLOIC MAP OF SOUTHEASTERN NEW YORK STATE

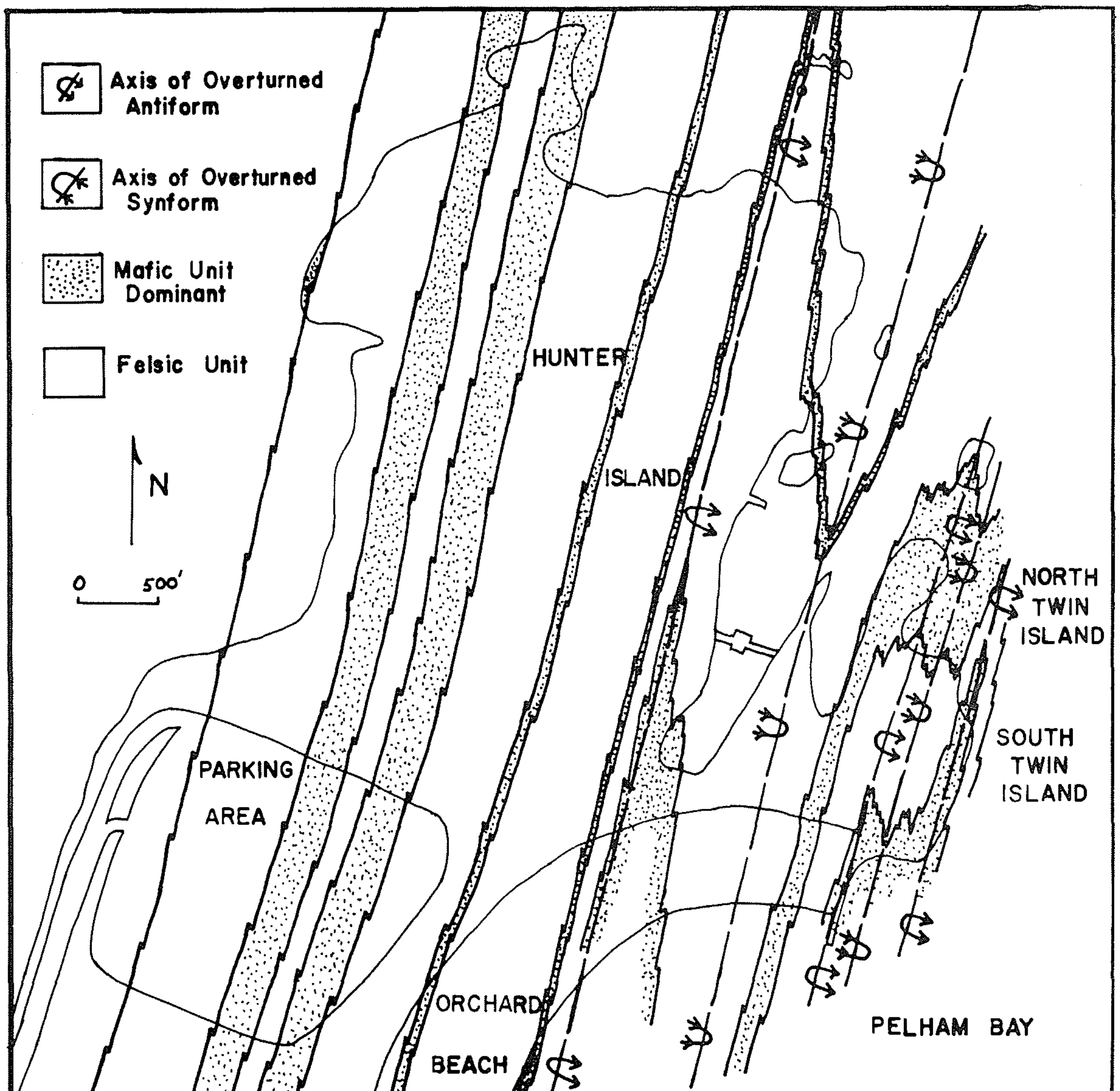

FIGURE 2. GENERALIZED GEOLOGIC MAP OF PART OF PELHAM BAY PARK

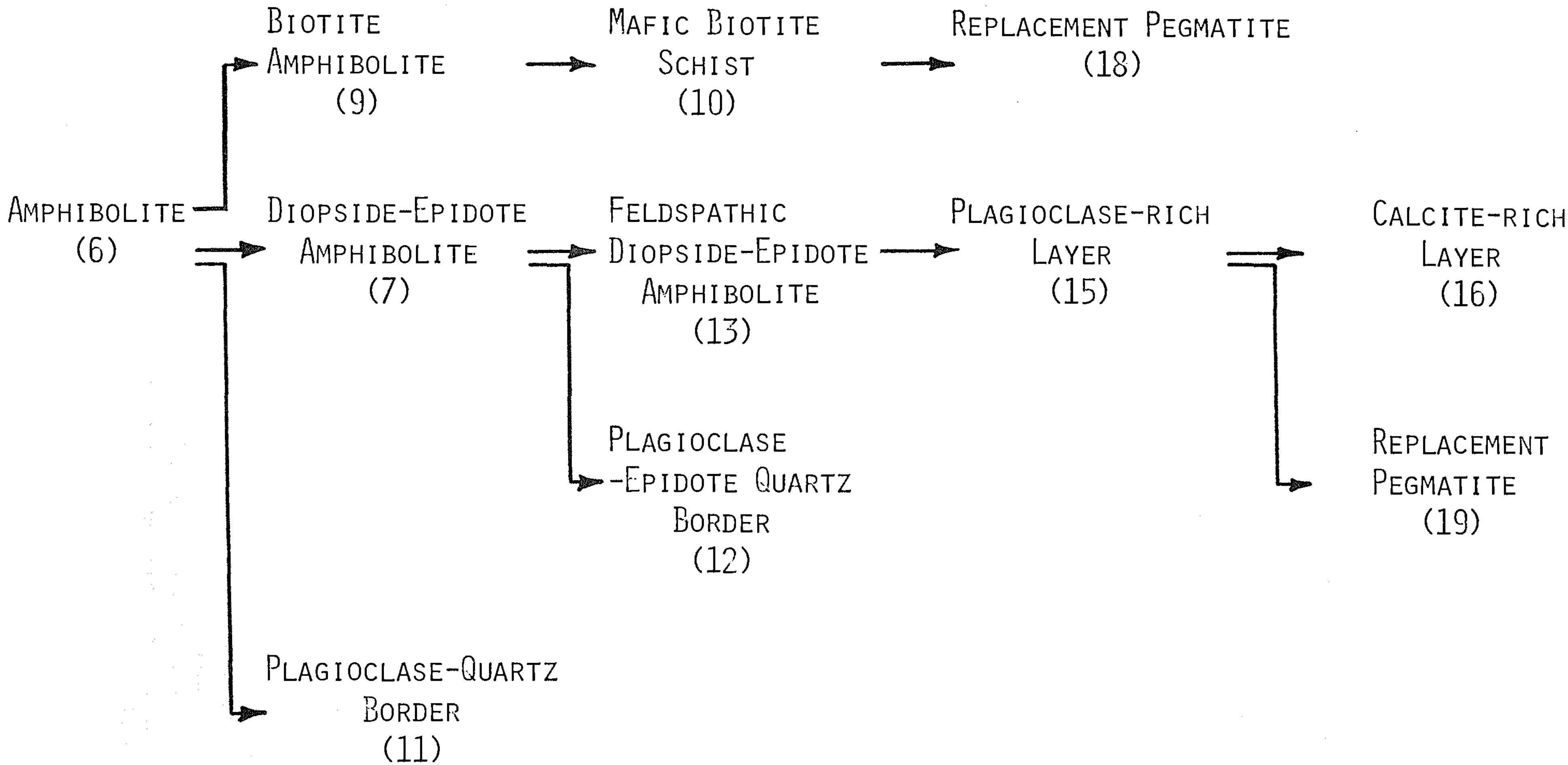

Figure 3. Changes in rock types produced by metasomatism during the third phase of deformation. Index numbers for samples in Table 2 are indicated in parentheses.

Table 1 - Modes (Volume Percent) and Calculated Chemical Compositions of Metamorphic and Metasomatic Rocks from Pelham Bay Park

Index Number	1	2	3	4	5	6	7	8	9
Quartz	45.5		27.1	9.4		1.2	0.4		3.3
Microcline	0.1		13.8	4.4		-	-		-
Plagioclase	34.5		31.5	27.1		28.7	28.6		25.7
Biotite	18.7		26.0	43.1		6.3	0.2		32.6
Hornblende	-		-	-		62.8	36.6		38.0
Diopside	-		-	-		-	15.4		-
Epidote	-		-	-		-	14.7		-
Calcite	-		-	-		-	1.1		-
Sphene	0.1		0.1	-		-	1.4		-
Garnet	-		-	4.2		-	0.2		-
Apatite	0.2		-	-		0.1	0.2		0.1
Muscovite	0.1		0.5	0.2		-	-		-
Sillimanite	-		-	11.5		-	-		-
Magnetite	0.9		1.0	0.1		0.1	0.4		0.3
Scapolite	-		-	-		-	0.6		-
Sum	100.1		100.0	100.0		100.1	99.8		100.0
Plagioclase An	30		23	39		37	37		37
SiO_2	72.2	64.2	63.8	48.1	58.1	48.1	48.4	49.2	47.1
TiO_2	0.8	0.5	1.1	1.7	0.7	0.8	1.2	0.2	1.2
Al_2O_3	11.4	14.1	13.9	23.1	15.4	14.7	13.8	14.8	15.3
Fe_2O_3	2.0	1.0	2.9	2.6	4.0	3.5	4.0	1.8	2.9
FeO	4.0	4.2	5.5	9.5	2.5	8.8	8.9	13.6	9.2
MgO	1.9	2.9	2.6	4.4	2.4	9.2	4.4	5.5	10.0
CaO	2.2	3.5	1.5	2.0	3.1	9.6	14.6	7.5	6.8
Na_2O	2.8	3.4	3.1	2.3	1.3	2.4	2.2	2.5	2.2
K_2O	2.0	2.0	4.4	4.5	2.0	1.1	0.5	1.9	3.0
Sum	99.3	95.8	98.8	98.2	99.5	98.4	98.6	97.7	97.7

1. Average of 4 felsic gneisses
2. Average graywacke (Pettijohn, 1949, p. 250)
3. Microcline-bearing felsic gneiss
4. Average of 2 sillimanite schists
5. Average shale (Clarke, 1924, p. 34)
6. Average of 2 amphibolites
7. Average of 8 diopside-epidote amphibolites
8. Average olivine basalt (Green and Poldervaart, 1955, p. 185)
9. Biotite amphibolite

Table 1 (Cont'd)

Index Number	10	11	12	13	14	15	16	17	18
Quartz	-	45.4	5.6	1.0	-	6.2	2.5	2.9	36.8
Microcline	-	-	-	0.6	0.1	-	-	24.6	-
Plagioclase	23.2	45.4	87.1	63.8	63.4	83.5	15.3	63.3	47.0
Biotite	68.0	-	-	-	35.0	1.1	0.1	9.1	16.2
Hornblende	-	0.3	-	20.2	-	3.1	4.3	-	-
Diopside	-	-	-	2.1	-	0.7	0.1	-	-
Epidote	-	-	4.0	5.1	-	1.9	4.6	-	-
Calcite	-	-	-	2.7	-	-	71.9	-	-
Sphene	-	1.9	1.6	2.2	0.5	0.6	0.7	-	-
Garnet	8.1	6.8	-	-	-	-	-	-	-
Apatite	0.1	0.2	0.1	0.4	0.6	0.2	0.2	-	-
Muscovite	-	-	-	-	-	-	-	-	-
Sillimanite	-	-	-	-	-	-	-	-	-
Magnetite	0.3	-	1.5	1.7	0.5	2.3	0.3	0.1	-
Scapolite	-	-	-	-	-	-	0.2	-	-
Sum	99.8	100.0	99.9	99.8	100.1	99.6	100.3	100.0	100.0
Plagioclase An	37	83	48	19	29	22	23	27	26
SiO_2	41.0	68.7	55.7	53.7	50.7	56.5	16.9	60.8	70.6
TiO_2	1.8	0.8	0.7	1.2	1.6	0.6	0.3	0.4	0.5
Al_2O_3	18.0	17.1	24.7	16.7	20.3	20.0	5.1	21.2	14.1
Fe_2O_3	3.2	0.1	2.6	3.8	2.7	4.1	1.2	0.7	0.7
FeO	12.5	2.9	0.9	5.3	6.8	2.7	1.1	1.8	2.4
MgO	10.5	0.7	0.0	1.8	3.5	0.9	0.4	0.9	2.6
CaO	2.3	8.3	9.9	9.1	4.0	5.8	42.3	3.5	2.9
Na_2O	1.9	0.9	4.9	5.6	5.1	6.9	1.3	5.7	3.7
K_2O	5.4	0.1	0.5	0.7	3.6	0.7	0.1	4.5	1.6
Sum	96.6	99.6	99.9	97.9	98.3	98.2	69.2*	99.5	99.1

10. Mafic biotite schist
11. Plagioclase-quartz border
12. Plagioclase-epidote-quartz border
13. Average of 3 feldspathic diopside-epidote amphibolites
14. Average of 2 plagioclase-biotite gneisses
15. Average of 4 plagioclase-rich layers
16. Average of 4 calcite-rich layers
17. Average of 6 samples of pegmatite replacing plagioclase-biotite gneiss
18. Average of 2 samples of pegmatite replacing amphibolite

* also 31.1% CO_2

Diopside-Epidote Amphibolite. Diopside and epidote are rare in the amphibolites of South Twin Island, but are common in the diopside-epidote amphibolites of North Twin Island. Major constituents are hornblende, plagioclase (An_{37}), iron-bearing diopside (salite), and epidote, with minor apatite, sphene, quartz, magnetite, scapolite, calcite, biotite, and garnet (Table 1, number 7). Foliation (S_1) is defined by layers and lenses in which one or more of the major components are more abundant than in the adjacent layers. The layers are thin (less than one inch thick) and were folded during the third phase of deformation.

Diopside-epidote amphibolite is mineralogically similar to the diopside-bearing amphibolites present at the ends of amphibolite boudins on South Twin Island, which suggests that they had a similar origin. On North Twin Island, diopside-epidote amphibolites grade along strike into normal amphibolites indicating that they were probably formed by metasomatism of the amphibolites.

Plagioclase-Epidote-Quartz Borders. There are often irregular borders on diopside-epidote amphibolites which are almost completely devoid of mafic minerals (Table 1, number 12). These plagioclase-epidote amphibolite borders are often present at the ends of diopside-epidote amphibolite boudins. Such boudins are present on the limbs of folds formed during the third phase of deformation and therefore the plagioclase-epidote-quartz borders were also formed at this time. They resemble the plagioclase-quartz borders on amphibolites of South Twin Island.

These borders consist principally of plagioclase with lesser amounts of epidote, quartz, and garnet. Layers of hornblende, epidote and sphene within the plagioclase-epidote-quartz borders parallel (S_1) foliation within adjacent diopside-epidote amphibolites. Plagioclase in the borders is more calcic (An_{48} to An_{78}) than that in the adjacent diopside-epidote amphibolite (which has An_{37}). The plagioclase-quartz-epidote borders change abruptly along strike into diopside-epidote amphibolite and are probably the result of metasomatism of the diopside-epidote amphibolite.

Feldspathic Amphibolite. A thin, irregular layer of feldspathic amphibolite generally separates diopside-epidote amphibolite from plagioclase-biotite gneiss. This layer was produced by metasomatism of the diopside-epidote amphibolite and is an intermediate step in the formation of plagioclase-biotite gneiss.

Plagioclase-Biotite Gneiss. Boudins of diopside-epidote amphibolite are often separated by a matrix of plagioclase-biotite gneiss (Table 1, number 14). Plagioclase-biotite gneiss also occurs as layers within diopside-epidote amphibolite and as borders on diopside-epidote amphibolite layers and boudins. Major constituents of plagioclase-biotite gneiss are medium-grained plagioclase and biotite with minor apatite, magnetite, quartz, microcline, and muscovite. The gneiss contains numerous pegmatitic lenses and irregular patches of microcline, plagioclase, quartz and magnetite. Subparallel lenses rich in biotite are also present. The plagioclase-biotite gneiss differs from the felsic gneiss in that it contains little or no quartz and from the sillimanite schist in that is contains no sillimanite.

Plagioclase-biotite gneiss layers have not been folded (Figure 4) and therefore must have been formed after (or during the later stages of) the third phase of deformation. They grade along strike into diopside-epidote amphibolite and therefore appear to have formed by potassium metasomatism of the diopside-epidote amphibolite.

Plagioclase-Rich Layers. Layers consisting almost entirely of plagioclase (Table 1, number 15) occur within the diopside-epidote amphibolite on North Twin Island (Figure 4). Both the plagioclase-rich layers and associated calcite-rich layers are found only within diopside-epidote amphibolite and do not occur within the Felsic Unit. The layers generally parallel S_1 foliation within the diopside-epidote amphibolite, but locally, the layers truncate this foliation indicating that the layers formed after the first phase of deformation. In addition to plagioclase (An_{21}), the layers contain subordinate quartz, hornblende, magnetite, sphene, and epidote. They are chemically similar to plagioclase-epidote-quartz borders suggesting that they had a similar origin. The plagioclase-rich layers grade along strike into diopside-epidote amphibolite suggesting that they were produced by metasomatism of the diopside-epidote amphibolite. This origin is supported by textural changes within the plagioclase-rich layers including the development of skeletal hornblende and the embayment of pyroxene where they are replaced by plagioclase.

Calcite-Rich Layers. Calcite-rich layers are abundant near the ends of diopside-epidote amphibolite layers and on the crests of folds within diopside-epidote amphibolite (Figure 4). These layers vary from less than an inch to about one foot in thickness and in addition to calcite, they contain plagioclase, epidote, hornblende and quartz. Areas where calcite-rich layers are abundant are up to 25 feet across, but they grade along strike into diopside-epidote amphibolite. This indicates that the calcite-rich layers were produced by lime metasomatism of diopside-epidote amphibolite. Additional evidence to support this conclusion is that marbles generally have a lower ratio of iron to aluminum and their amphibole is tremolite rather than hornblende. Also, phlogopite rather than biotite is present within marbles.

Pegmatites.

Both replacement and injection pegmatites are present in Pelham Bay Park. Replacement pegmatites have formed within felsic gneiss, sillimanite schist, amphibolite (Table 1, number 18), plagioclase-biotite gneiss (Table 1, number 17) and plagioclase-rich layers. Replacement pegmatites are abundant within plagioclase-biotite gneiss on North Twin Island. Major constituents are plagioclase and microcline with variable amounts of biotite, quartz and magnetite. Plagioclase-biotite gneiss grades into replacement pegmatite with a progressive increase in the size and number of microcline and plagioclase porphyroblasts. These porphyroblasts are identical in appearance to the microcline and plagioclase within the replacement pegmatite. Contacts with plagioclase-biotite gneiss are extremely irregular and skialiths are common within the pegmatite.

Injection pegmatites vary from several inches to 20 feet wide. The walls of the dikes are generally straight and parallel, and contacts with the wall rocks are sharp. In one area, foliation within the wall rocks was deflected during emplacement of the pegmatite. Major constituents of injection pegmatites are microcline, quartz, plagioclase and muscovite with minor amounts of garnet, tourmaline and apatite. Biotite, which is generally present in replacement pegmatites, is usually absent in injection pegmatites.

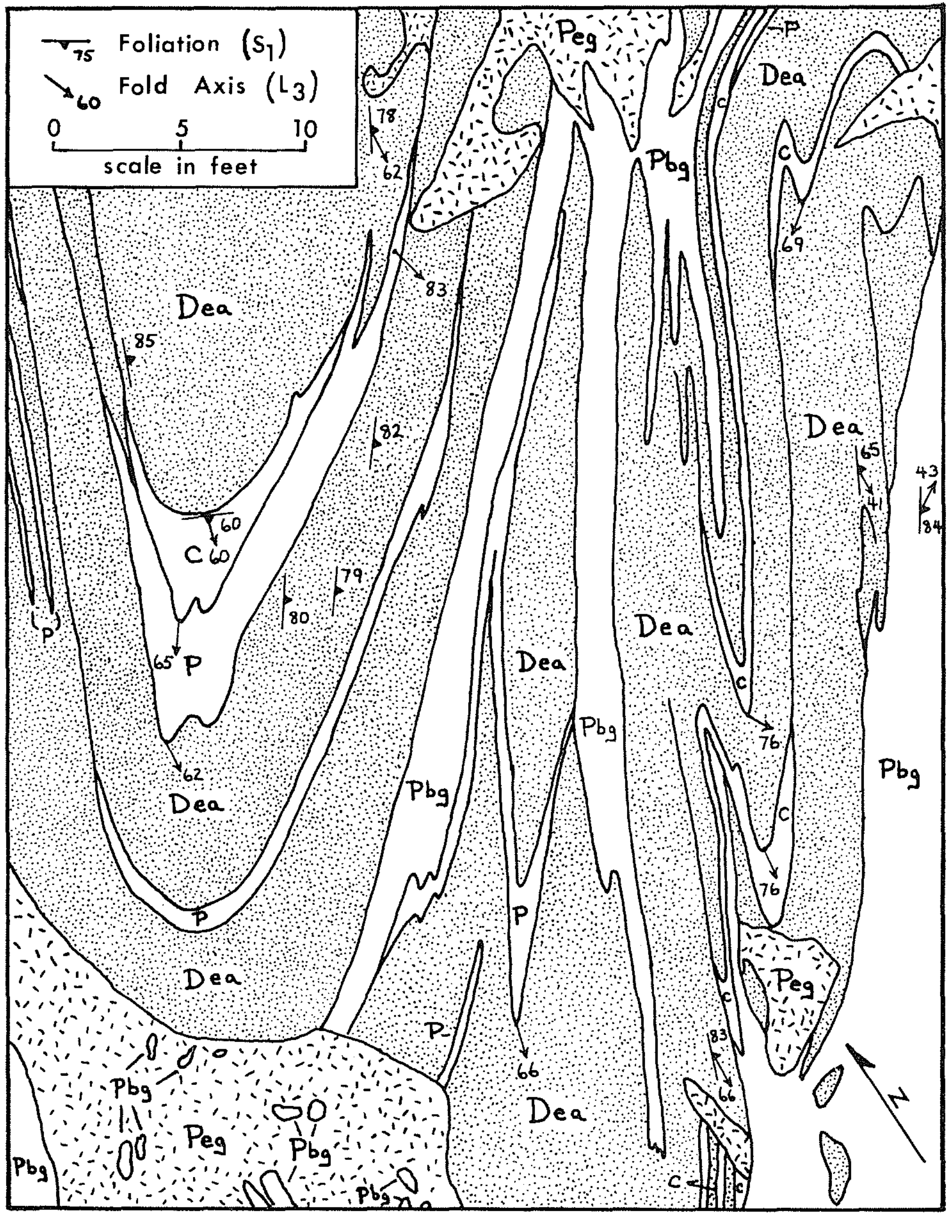

FIGURE 4. LAYERING WITHIN DIOPSIDE-EPIDOTE AMPHIBOLITE, NORTH TWIN ISLAND (STOP 8).
PBG = PLAGIOCLASE-BIOTITE GNEISS;
P = PLAGIOCLASE-RICH LAYER;
C = CALCITE-RICH LAYER;
DEA = DIOPSIDE-EPIDOTE AMPHIBOLITE;
PEG = REPLACEMENT PEGMATITE

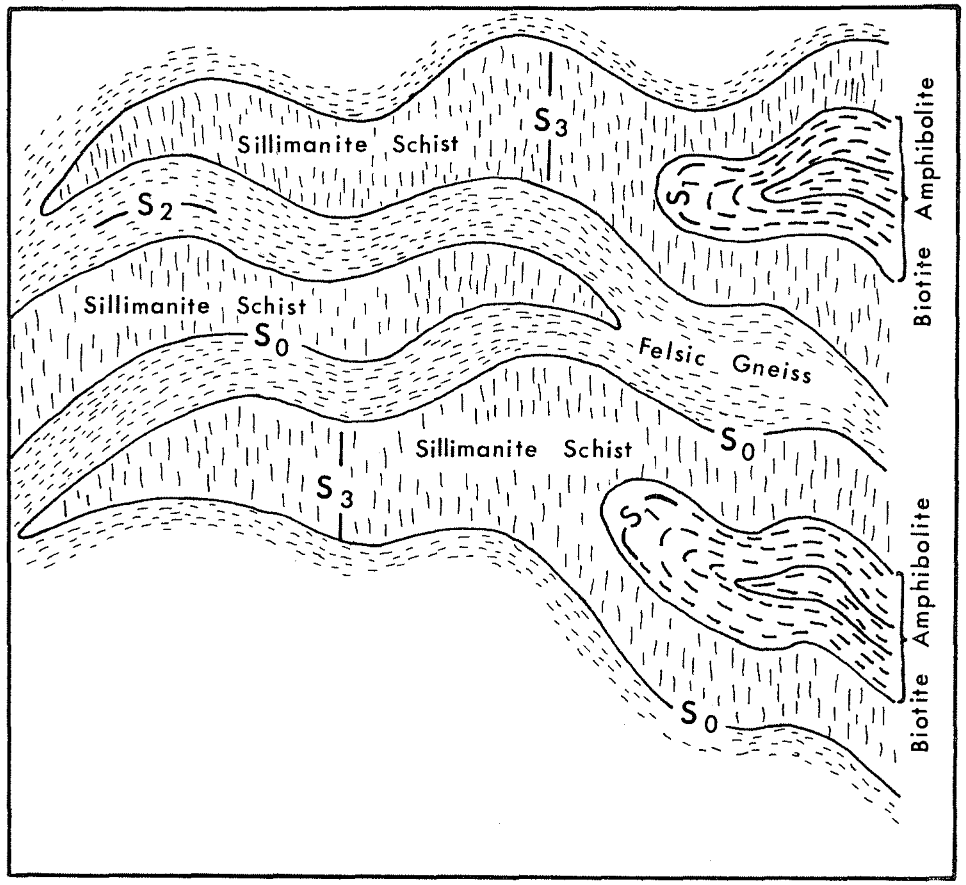

FIGURE 5. DIAGRAMMATIC SKETCH OF THE RELATION BETWEEN FOLDS AND FOLIATION AT STOP 11.
S_0 = BEDDING; S_1 = EARLY FOLIATION;
S_2 = AXIAL PLANE FOLIATION OF FOLDS PRODUCED DURING THE SECOND PHASE OF DEFORMATION; S_3 = AXIAL PLANE FOLIATION OF FOLDS PRODUCED DURING THE THIRD PHASE OF DEFORMATION

STRUCTURE

Structural features in Pelham Bay Park include four sets of foliations and two sets of folds with steeply plunging axes which parallel mineral lineations. The relation between folds and foliations is shown on Figure 5.

Folds and Foliations.

The compositional differences between felsic gneiss and sillimanite schist is probably primary in origin and therefore contacts between them are parallel to original bedding (S_0). An axial plane foliation (S_1) developed during an early period of deformation. This foliation (S_1) has been folded about L_2 fold axes. A second axial plane foliation was produced during the second phase of deformation (S_2) and is defined by oriented biotite crystals in the felsic gneiss. During the third phase of deformation, a third axial plane foliation (S_3) has developed where deformation was intense. Axes (L_3) of folds produced during this deformation plunge steeply to the northeast in most of Pelham Bay Park, but fold axes and mineral lineations (L_3) within a diopside-epidote amphibolite on North Twin Island plunge both to the north and to the south, (Plate 1).

Twin Island is located on the crest of a major antiformal fold (Figure 2) formed during the third phase of deformation. This fold can be traced northward into the southeastern corner of Connecticut (Figure 1). Drag folds on the west limb of the fold indicate that it extends at least one mile west of Twin Island. The fold is isoclinal and the axial surface dips steeply to the east in the vicinity of Twin Island. However, near the town of New Rochelle, the axial surface becomes vertical and north of New Rochelle, the axial surface dips steeply to moderately to the west. The plunge of the axis of the fold generally varies from 15^o to 60^o in a northerly direction (northeast to northwest) but locally the plunge is vertical or steeply to the south. Drag folds near the shoreline of southwestern Connecticut plunge gently to the south or southeast indicating a change of plunge of the eastern limb of the anticline (Figure 1.)

Mineral lineations (L_3) formed during the third phase of deformation were folded about southward plunging chevron folds (F_4) on the shoreline within the town of New Rochelle. This indicates a fourth phase of deformation, but this phase did not affect the units of Pelham Bay Park.

Boudinage.

Amphibolite and diopside-epidote amphibolite behaved in a brittle fashion while felsic gneisses generally behaved plastically during the last period of deformation. Boudins of diopside-epidote amphibolite are well developed on the northern end of North Twin Island. These boudins are separated from one another both in the horizontal and vertical planes and "necking" prior to separation produced pillow shaped boudins. Steeply plunging mineral lineations (L_3) within the boudins were rotated during necking. L_3 lineations in felsic gneiss were not rotated and therefore rotation of lineations is not due to refolding of earlier lineations. Boudinage on the limbs of folds has produced rootless folds, especially within amphibolite layers.

Isoclinal Folds.

Extremely tight isoclinal folds present in many areas were produced during at least two periods of deformation. Ratios of amplitude to wavelength as high as 30:1 were measured. Tighter folding that involves stretching and boudinage of fold limbs may produce what appears to be a simple layered sequence. However, the presence of dextral and sinistral drag folds and associated rootless folds within the layered sequences shows that the beds were complexly folded. When deformation is extreme, even the rootless folds may be destroyed and only an axial plane foliation is left as evidence of intense deformation. Thus, extreme isoclinal folding may result in apparent structural simplicity when deformation is very intense.

Joints and Faults.

A set of steeply dipping, east-west joints cuts the units of Pelham Bay Park. Minor normal faults with a displacement of several inches to several feet were produced by movement on this joint set.

Original Rock Types.

Due to the difficulty in identifying primary structures, determination of original rock types must stem from study of fabric and bulk composition of the present rocks, together with detailed analysis of metasomatic and structural events.

The calculated chemical composition of felsic gneiss and sillimanite schists (Table 1) suggests that they were probably formed by the metamorphism of interbedded graywackes and pelites.

The calculated chemical compositions of the amphibolites is similar to that of an olivine basalt (Table 1, number 8). The contact between amphibolite and felsic gneiss is usually parallel to bedding within the Felsic Unit which suggests that the amphibolites were mafic flows, sills and/or tuffs before metamorphism. *En echelon* amphibolite bodies in the east-central part of South Twin Island are probably metamorphosed sills or dikes. A small amphibolite dike on Hunter Island cuts across bedding in the Felsic Unit.

AGE AND CORRELATION

No fossils have been found in the Hutchinson River Group in Pelham Bay Park. However, a K/Ar measurement of 380 million years (Mid-Devonian) was made by Long and Kulp (1962) on biotite from a "biotite-plagioclase-quartz schist" (Felsic Unit?) from North Twin Island. Thus the metamorphic rocks of Pelham Bay Park are pre-Devonian.

Possible correlations for these rocks are the Fordham Gneiss, the Manhattan Formation, the Taconic Sequence of eastern New York and Vermont, or the Hartland Formation of Connecticut. The felsic gneisses of the Fordham Gneiss generally contain hornblende and no sillimanite (Scotford, 1956) while the felsic gneisses of Pelham Bay Park contain no hornblend and may contain sillimanite. The Hutchinson River Group contains much less schist than either the Manhattan Formation, (Scotford, 1956) the Hartland Formation (Rodgers *et al.*, 1959), or the Taconic Sequence (where it is intensely metamorphosed). Also, no quartzite was observed within the Hutchinson River Group, but it has been reported to occur in the Hartland Formation (Rodgers *et al.*, 1959) and Waramaug Formation (Rodgers *et al.*, 1959) which is probably equivalent to the Taconic Sequence.

The most likely correlation seems to be with the para-gneisses within some of the gneiss domes of Connecticut such as gneisses of the Waterbury dome in eastern Connecticut. Rodgers believes that the Waterbury Gneiss may be unconformably overlain by the Straits Schist Member of the Hartland Formation. Therefore, if the Hutchinson River Group correlates with the Waterbury Gneiss, it is probably older than the Hartland Formation. Possible relationship to sequences in other areas is shown in Figure 6.

The units of Pelham Bay Park have no known basement and may have been formed from sediments deposited at the base of the continental slope on oceanic crust. These sediments may have been derived in part from mountains uplifted during the Grenville orogeny.

Reconnaisance mapping in other parts of New York City as well as in parts of Westchester County (Figure 1) indicates that the northeastward plunging folds (F_3) were formed at the same time as the southward plunging folds within the Manhattan Schist on Mahattan Island. They were also probably formed at the same time as the northwestward plunging folds within the Poundridge area (mapped by Scotford, 1956). Both the plunge of the fold axes and the dip of the axial planes of these folds is somewhat variable, but changes seem to be gradational indicating that they are probably formed at the same time.

The age of the last intense folding (third phase of deformation) in Pelham Bay Park is probably Mid-Devonian (Acadian Orogeny) as indicated by the K/Ar date on biotite from the area. The date of the second phase of deformation is probably Upper Ordovician (Taconian Orogeny) for the following reasons:

a) This deformation probably correlates with a period of recumbent folding which affected the rocks of the New York City Group; and

b) The Manhattan Formation probably correlates with the Hudson River Pelites of Dutchess County and is therefore probably Mid-Ordovician, setting a maximum age for this deformation.

The age of the first recognized phase of deformation may be Mid-Ordovician (Vermontian Orogeny) correlating with the time of emplacement of the Taconic Klippe. Thus, the age of the Hutchinson River Group may range from Late Precambrian to Mid-Ordovician.

ROAD LOG

Mileage.

Leave the Sheraton-Tenney Hotel and take Ditmars Blvd. west to 94th St. Take 94th St. south to the Long Island Expressway (Interstate 495). Take the Long Island Expressway eastbound to the Throgs Neck Bridge Exit. Proceed north on the Clearview Expressway (Interstate 78) across the Throgs Neck Bridge.

0.0 Throgs Neck Toll Booths. Begin measured mileage. Take right hand fork and continue northeast on the New England Thruway (Interstate 95).

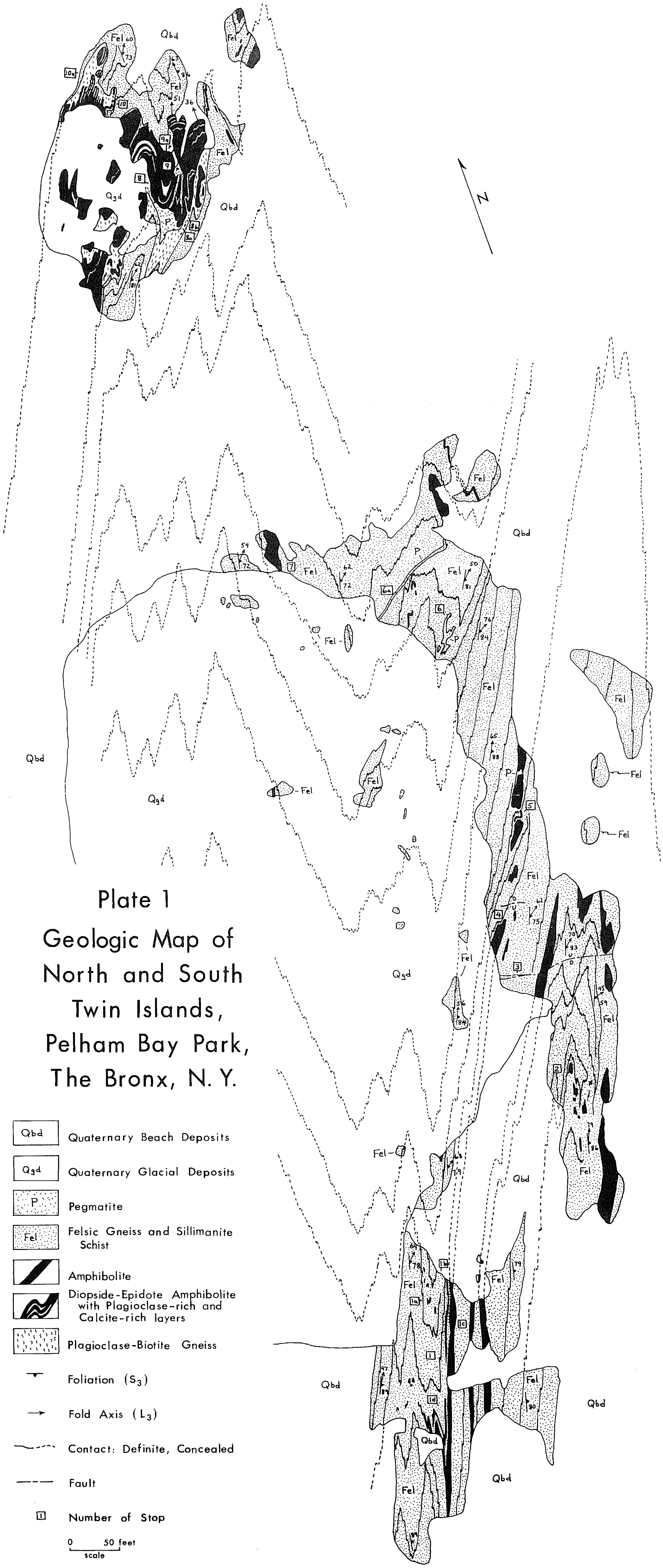

Plate 1
Geologic Map of North and South Twin Islands, Pelham Bay Park, The Bronx, N. Y.

3.8 3.8 Take the exit for Orchard Beach and City Island.

5.0 1.2 At traffic circle, take road southeastward to Orchard Beach.

5.6 0.6 Intersection with another park road. Turn left and follow the road to the parking lot for Orchard Beach and park in the northeastern corner of the lot.

Distance Between Points.

Take the path which leads to the beach and follow the path along the beach to the northeastern end of the beach. The first stop is on the outcrop just east of the Breakwater on the southern end of South Twin Island (Plate 1).

2400' STOP 1. The rocks here include felsic gneiss, sillimanite schist, and amphibolite. Note the rootless fold in an amphibolite at the north end of the outcrop (STOP 1-A. see Plate 1). This amphibolite continues along strike into mafic biotite schist on the west limb of the fold. The west limb of the fold was stretched and thinned during the third phase of deformation. A plagioclase-quartz border is present on the amphibolite near the trough of this synclinal fold.

The amphibolites on the eastern side of the outcrop pinch and swell along strike. Note the presence of pegmatite (Table 1, number 18) replacing the amphibolite and mafic biotite schist (Table 1, number 10) in a thin amphibolite layer which has been separated by boudinage (STOP 1-B). Mineralogy of the pegmatite: plagioclase, quartz and biotite.

The amphibolite in the center of the thicker amphibolite layer (STOP 1-C) contains little biotite (Table 1, number 6), but biotite increases in abundance toward the contact of the amphibolite (Table 1, number 9) with felsic gneiss.

Isoclinal folds can be seen at the south end of the outcrop (STOP 1-C, see Plate 1) especially at low tide. The axial planes of these folds strike N20°E and dip 80°E. Fold axes have an average bearing of N44°E and plunge of 62°NE.

Where folding during the third phase of deformation was particularly intense (STOP 1-D), biotite within sillimanite schists was rotated parallel to the axial planes (S_3) of the latest set of folds (F_3).

Proceed northeastward along the shoreline.

300' STOP 2. Rootless fold in amphibolite (See Plate 1). A Plagioclase-quartz border (Table 1, number 11) is present at the ends of the amphibolite which have been separated by boudinage. Near the contact with the plagioclase-quartz border, the amphibolite contains diopside, epidote, calcite and scapolite.

Continue northward along the shoreline.

100' STOP 3. Small normal fault (Plate 1). Slickensides on the fault plane at the western end of the outcrop indicate that the motion was dominantly dip-slip. Erosion of breccia along the fault has produced a small "rift".

Continue north along the western side of the outcrop.

50' STOP 4. Pegmatite replacing amphibolite. Note the very irregular, gradational contacts. Mineralogy: plagioclase, quartz and biotite.

Continue northeastward along shoreline.

100' STOP 5. En echelon amphibolite layers suggesting the amphibolites were originally dikes or sills. Note replacement pegmatite in the amphibolite.

Proceed northward along shoreline.

200' STOP 6. Injection pegmatite dike. Walls are generally sharp, but local assimilation of the felsic gneiss has caused some irregular contacts. Mineralogy: microcline, quartz, plagioclase, with minor tourmaline (black), garnet and apatite.

Note large eratics and glacial striations on bedrock.

75' Another injection pegmatite (STOP 7-A). Note straight, parallel walls. Layers of sillimanite schist are offset indicating dilation of the wall rocks during emplacement of pegmatite. Contacts are very sharp and muscovite crystals near the contacts tend to be oriented normal to the walls of the dike. This pegmatite almost certainly crystallized from a granitic melt.

Proceed eastward along the shoreline.

225' STOP 7. Thick amphibolite layer with calcite-diopside-scapolite pods. This mineralogy is similar to that of the diopside-epidote amphibolites of North Twin Island. Cross the tombolo (which may be covered at high tide except for stepping stones) which connects North Twin Island with South Twin Island (Plate 1). Continue to large fold just east of the center of the island.

400' STOP 8. Folded diopside-epidote amphibolite, plagioclase-rich layers (Table 1, number 15), and calcite-rich layers (Table 1, number 16). Folding is somewhat disharmonic within the calcite-rich and plagioclase-rich layers. These layers grade along strike into diopside-epidote amphibolite on the limbs of the fold (Figure 4). Changes in mineral assemblages going from diopside-epidote amphibolite on the limbs of the fold to plagioclase-rich layers along strike at the crest of the fold are:

(a) hornblende-plagioclase with minor pyroxene, scapolite, epidote and calcite;
(b) plagioclase-hornblende-epidote with minor quartz and pyroxene; and
(c) plagioclase with minor quartz and magnetite.

The plunge of the fold is to the south, indicating that it is an antiform (up-arched foliation surface). However, along strike to the north on both limbs of the fold, the plunge of the folds changes to vertical and then to plunging northward. Thus, there are two antiforms along the continuation of the amphibolite layer, with no intervening synform. S_1 foliation has been folded about the antiforms.

Just east of the fold, there are several plagioclase-biotite gneiss layers within the diopside-epidote amphibolite (STOP 8-B). Ellipsoidal hornblende nodules occur within diopside-epidote amphibolite near the contact with plagioclase-biotite gneiss on the eastern side of North Twin Island (STOP 8-C). The nodules are 2 to 4cm. in length and 1 to 2 cm. across and lie in a calcite matrix. They are separated from the calcite by a 2 to 5mm. wide zone of medium-grained pyroxene and scapolite. A thin rind of epidote surrounds some scapolite grains and separates them from adjacent calcite. Intermediate axes of the ellipsoids are parallel to the foliation and long axes are parallel to mineral lineations in the surrounding mafic gneiss.

Diopside-epidote amphibolite grades along strike into normal amphibolite (STOP 8-D) suggesting that it formed by metasomatism of amphibolite.

Proceed northward.

STOP 9. Replacement Pegmatite. Plagioclase and microcline porphyroblasts are abundant within plagioclase-biotite gneiss near the contact with replacement pegmatite (Table 1, number 17). In fact, the replacement pegmatite is simply a coalesced mass of porphyroblasts. Contacts are gradational and extremely irregular.

Note the plagioclase-biotite selvage surrounding a diopside-epidote amphibolite boudin at the contact of the boudin with replacement pegmatite (STOP 9-A).

A plagioclase-epidote-quartz border is present at the end of a layer of diopside epidote amphibolite which has been separated by boudinage (STOP 9-B). This border grades abruptly along strike into amphibolite (very thin border) and then into diopside-epidote amphibolite. Relict foliation (S_1) is present in the plagioclase-epidote-quartz border. The border, which is 87% plagioclase, 5-1/2% quartz and 4% epidote, developed by metasomatism of diopside-epidote amphibolite. The composition (Table 1, number 12) is similar to that of an anorthosite.

Proceed to the northwest.

75' STOP 10. Boudins of diopside-epidote amphibolite within plagioclase-biotite gneiss. There are several areas where diopside-epidote amphibolite can be traced along strike into plagioclase-biotite gneiss suggesting that the plagioclase-biotite gneiss was produced by metasomatism of diopside-epidote amphibolite. Steps involved are:

(a) feldspathization of diopside-epidote amphibolite;
(b) conversion to feldspathic amphibolite; and
(c) replacement of hornblende by biotite, forming plagioclase-biotite gneiss.

Calcite-rich layers and pods are present within diopside-epidote amphibolite boudins. Calcite-rich layers are also abundant at the ends of the diopside-epidote amphibolite layers which have been separated by boudinage (STOP 10-A). The zone containing calcite-rich layers is 25 feet wide, but it grades along strike (to the south) into diopside-epidote amphibolite containing no calcite-rich layers. This suggests that the calcite-rich layers were produced by metasomatism of diopside-epidote amphibolite.

Note the curved mineral lineations and curved fold axes within the boudins (STOP 10-B). The rotation of lineations and fold axes occurred during "necking" prior to separation of the boudins.

Return to South Twin Island and follow the western shoreline to a gravel road near the center of the western shoreline of the island.

1000' Take gravel road westward across the bridge to Hunter Island.

900' Turn right (north) along the east shore of Hunter Island to a small outcrop of felsic gneiss and sillimanite schist just south of a thick amphibolite layer (Figure 2).

1000' STOP 11. Open fold. Felsic gneiss, sillimanite schist, and biotite amphibolite show evidence of 3 phases of deformation because in this area the last phase of deformation was not intense enough to obliterate signs of the earlier deformations. Biotite and amphibole crystals are oriented parallel to compositional layers within the biotite amphibolite. This foliation (S_1) is probably an axial plane foliation formed during an early period of intense deformation. This foliation has been folded about a set of fold axes (L_2) which plunge steeply to the southeast. Large amphibole crystals are oriented parallel to these fold axes. A second foliation (S_2) is defined by biotite crystals oriented parallel to the axial planes of the F_2 folds within the felsic gneiss. Within sillimanite schist, biotite and sillimanite are oriented parallel to the axial plane (S_3) of the latest set of folds. Axes of these folds plunge steeply to the northeast in this area. The relation between the folds and foliations is shown in Figure 5.

Return to the gravel road by taking path southward along the shoreline.

1000' Take gravel road south to fork in the road.

800' Take right hand fork and return to the parking lot. We will eat LUNCH on the tables just north of the parking lot.

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