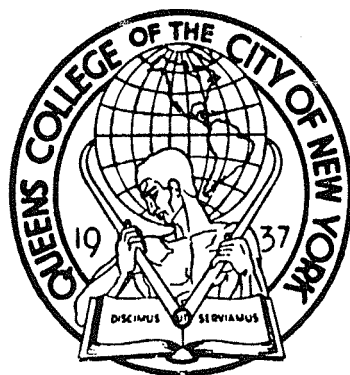


NEW YORK STATE  
GEOLOGICAL ASSOCIATION

GUIDEBOOK

TO

FIELD EXCURSIONS



40<sup>TH</sup> ANNUAL MEETING

1968

AT

QUEENS COLLEGE

CITY UNIVERSITY OF NEW YORK

FLUSHING, NEW YORK



GUIDEBOOK  
to  
Field Excursions  
at the  
40th Annual Meeting of the  
New York State Geological Association  
May 1968

Robert M. Finks, Editor

Host:

Department of Geology  
Queens College of The City University  
of New York

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Copies of this guidebook may be purchased from the Permanent Secretary,  
New York State Geological Association. Address Prof. Philip Hewitt, Department  
of Geology, State University College at Brockport, N. Y.

The organizer of the field trips described  
in this volume, and of the meeting at which they  
were given, is

Professor Walter S. Newman  
President, NYSGA, 1968



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## PREFACE

The papers brought together in this Guidebook merit comparative reading at leisure, for they often bring to bear upon problems of the local geology many independent lines of evidence. Some matters that come immediately to mind out of personal interest are:

- (1) The relation of the New York City Group to the unmetamorphosed Cambro-Ordovician sequence (Trips A, C, E, H).
- (2) The several phases of Taconian deformation (Trips A, G, H).
- (3) The nature of the pre-Triassic basement of the Newark Basin (Trips C, E, H).
- (4) Comparison of deltaic sedimentation in Devonian, Cretaceous and Pleistocene (Trips B, E, F, J).

Undoubtedly many others will occur to readers of the Guidebook.

The shortness of time available for the preparation of this guidebook made it impossible for authors to see proof of their articles and the Editor accepts responsibility for such errors as have crept in. Editorial changes were kept to a minimum.

The Editor wishes to express his thanks, on behalf of the NYSGA, to Queens College for typing the final copy which you see here reproduced by photo-offset, in particular to Mrs. Blanche J. Meixel, Supervisor of Secretarial Services, and Mrs. Helen L. Abramson, who with her staff, consisting of Mrs. Florence Altmann, Mrs. Florence Fassler, Mrs. Doretta Kaplan, Miss Marion Shapiro and Mrs. Jeanne Trush, typed and proof-read the final copy with great care, intelligence and taste.

Mrs. Lee Cogan, Editor of Official College Publications, and her assistant, Mrs. Beatrice Bergen, arranged for the printing of this volume, and provided much valuable technical advice.

Mrs. Annabelle Schwartzberg, Business Manager, made available the College's services and advanced the NYSGA sufficient funds to cover the cost of printing till these could be repaid through Guidebook sales and registration fees.

The Editor wishes to thank also Miss Carol Yanek and Mr. Nicholas F. Avignone, Geology majors at Queens College, who assisted ably with many of the tasks of editing.

Robert M. Finks,  
Editor

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## TRIP A: BEDROCK GEOLOGY IN THE VICINITY OF WHITE PLAINS, NEW YORK

By Leo M. Hall, University of Massachusetts

(Approved for publication by the Assistant Commissioner for the New York State Museum and Science Service.)

### INTRODUCTION

Stratigraphic relations, including two unconformities, are well displayed by the bedrock in the White Plains quadrangle in Westchester County, New York. Fifteen rock units within the traditional "New York City Group" have been mapped in detail there. At the lower unconformity, Cambrian Lowerre Quartzite or Inwood Marble rest on Precambrian Fordham Gneiss and Yonkers Gneiss. Along the upper unconformity, the lower member of the Manhattan Schist rests on various units of the Inwood Marble as well as the Fordham and Yonkers. In addition, a major thrust fault may occur near the base, and locally at the base, of what has traditionally been mapped as Manhattan Schist.

There is widespread evidence for at least four, and probably five, phases of deformation in the region. The Yonkers Gneiss and Fordham Gneiss were folded at least once before the deposition of the Lowerre Quartzite and younger rocks. The pre-Manhattan rocks were deformed, at least mildly, prior to the deposition of the lower part of the Manhattan Schist. A major thrust fault, correlated with Taconic thrusting, may separate member A of the Manhattan Schist from members B and C of the Manhattan Schist. Finally, all of the rocks and previously formed structural features were involved first in major nappe-like isoclinal folds and second in folds with steeply dipping axial surfaces.

The main purpose of this field trip is to illustrate the stratigraphy of the region. In doing so, some of the main structural features will also be shown.

### ACKNOWLEDGEMENTS

Field work in the White Plains quadrangle was financed by the New York State Museum and Science Service, Geological Survey. It is a pleasure to express my gratitude to the following for permitting access to their property for purposes of this field trip: East Hudson Parkway Authority, Village of Irvington, Sleepy Hollow Restorations, Inc., REA Express in Ardsley, Town of Harrison, Consolidated Edison Company, and Greenburgh School District number 8.

### STRATIGRAPHY

The stratigraphy in this region can be classified into four divisions as follows:

Precambrian: Various gneisses and amphibolites that compose the Yonkers Gneiss and Fordham Gneiss.

Cambrian-Ordovician, Quartzite-Carbonate Sequence: Quartzites and granulites that pass upward into dolomite marbles and then calcite marbles represent a shelf or miogeosynclinal depositional sequence. The Lowerre Quartzite and Inwood Marble are included in this division.

Middle Ordovician Marble and Schist: At least the lower part of the Manhattan Schist (member A) which consists of schist and some marble represents a clastic wedge that rests unconformably on the miogeosynclinal facies.

?Cambrian-Ordovician Eugeosynclinal Sequence: An assemblage of feldspathic schists, schistose gneisses, gneisses and amphibolites that represents a eugeosynclinal depositional sequence composes this division. The Hartland Formation (Rodgers and others, 1959) and probably the portion of the Manhattan Schist here referred to as members B and C are the units that make up this sequence. Although the age of these rocks is very uncertain they are probably facies equivalents of the quartzite-carbonate sequence.

The use of the phrase "New York City Group" is abandoned for rocks of the Manhattan Prong in the vicinity of White Plains because it is misleading with respect to the above interpretation. A brief description of the rocks along with their proposed correlations and ages is presented in columnar form in Table 1.

#### EVIDENCE FOR UNCONFORMITIES

Evidence for an unconformity at the base of the Lowerre Quartzite, or Inwood Marble where the Lowerre is absent, is apparent from regional mapping in the southeast corner of the Nyack quadrangle, the White Plains, Glenville and Mount Kisco quadrangles. Different varieties of gneiss are in contact with the overlying rocks from place to place (e.g. STOP 1, on this trip and Figure 1 where subdivisions of the Fordham are shown and the Yonkers Gneiss is truncated). Furthermore, some large scale folds present in the gneisses are not evident in the younger rocks (Figure 1, where members of the Fordham are indicated). Regional stratigraphic relationships indicate that this unconformity separates Precambrian rocks from Paleozoic rocks.

Member A of the Manhattan Schist is in contact with the Fordham Gneiss as well as various members of the Inwood Marble. This discontinuity at the base of member A is interpreted as representing an unconformity. The fact that marble is interbedded with schist at the base of the Manhattan is well established (Prucha, 1956; this field trip, mileages 20.5 and 29.5 as well as STOPS 6 and 7). These marble interbeds do not represent Inwood grading upward into Manhattan because they occur, with and within the schist, in contact with various members of the Inwood as well as the Fordham. Thus the marble interbedded with schist is above the unconformity. The rocks that make up member A of the Manhattan Schist are correlated with similar Middle Ordovician rocks that rest with widespread unconformity on Early Ordovician and older rocks in New York (Fisher, 1954 and 1962) and New England (Cady, 1945, p. 560; Zen, 1967, p. 40). Member B and member C of the Manhattan Schist may not be younger than member A but may be older and in thrust fault contact with the other rock units in the Manhattan Prong.

STRATIGRAPHY OF THE WHITE PLAINS AREA

AGE	FORMATION	MEMBER	BRIEF DESCRIPTION OF ROCKS	REGIONAL CORRELATION
UNCERTAIN	MANHATTAN SCHIST	C	PREDOMINANTLY BROWN-WEATHERING FELDSPATHIC SILLIMANITE-GARNET-MUSCOVITE-BIOTITE SCHIST OR SCHISTOSE GNEISS; SILLIMANITE NODULES COMMON. ALTHOUGH SILICEOUS BEDS ARE PROMINENT IN SOME PLACES, BEDDING IS NOT COMMONLY CLEARLY DEFINED.	CORRELATION OF MEMBERS B AND C IS UNCERTAIN BUT THEY MAY BE EQUIVALENT TO THE WARAMAUG FORMATION (GATES, 1952), THE HOOSAC FORMATION (HATCH AND OTHERS, 1966), AND LOWER CAMBRIAN AND CAMBRIAN (?) ROCKS OF THE TACONIC SEQUENCE (ZEN, 1967, FIG. 4).
		B	A DISCONTINUOUS UNIT OF AMPHIBOLITE AND MINOR SCHIST; ALTHOUGH THIS UNIT IS COMMONLY AT THE BASE OF MEMBER C, THERE ARE MANY PLACES WHERE IT IS WITHIN MEMBER C, SUCH AS AT STOP 10.	
MIDDLE ORDOVICIAN		A	GRAY OR DARK GRAY FISSILE SILLIMANITE-GARNET-MUSCOVITE-BIOTITE SCHIST WITH INTERBEDDED CALCITE MARBLE LOCALLY AT THE BASE.	BALMVILLE (FISHER, 1962) AND WALLOOMSAC (ZEN AND HARTSHORN, 1966).
UNCONFORMITY				
LOWER ORDOVICIAN	MARBLE	E	GRAY OR WHITE CALCITE MARBLE, COMMONLY TAN WEATHERING.	COPAKE LIMESTONE AND ROCHDALE LIMESTONE (KNOPF, 1962).
		D	INTERBEDDED DOLOMITE MARBLE, CALCITE MARBLE AND SOME CALC-SCHIST.	ROCHDALE LIMESTONE AND HALCYON LAKE FORMATION (KNOPF, 1962).
CAMBRIAN	INWOOD	C	WHITE OR BLUE-GRAY CLEAN DOLOMITE MARBLE.	BRIARCLIFF DOLOMITE (KNOPF, 1962).
		B	INTERBEDDED WHITE, GRAY, BUFF, OR PINKISH DOLOMITE MARBLE, TAN AND REDDISH BROWN CALC-SCHIST, PURPLISH-BROWN OR TAN SILICEOUS CALC-SCHIST AND GRANULITES, TAN QUARTZITE, AND CALCITE-DOLOMITE MARBLE; BEDDING ONE HALF INCH TO FOUR FEET THICK IS PRONOUNCED.	PINE PLAINS FORMATION (KNOPF, 1962).
		A	WELL BEDDED WHITE, GRAY, OR BLUE-GRAY DOLOMITE MARBLE.	STISSING DOLOMITE (KNOPF, 1962).
	LOWERRE QUARTZITE		TAN OR BUFF-WEATHERING FELDSPATHIC QUARTZITE AND GRANULITE, MICAEOUS QUARTZITE AND GLASSY QUARTZITE; DARK GRAY, BROWNISH AND LOCALLY RUSTY-WEATHERING GRANULITE AND SCHIST THAT COMMONLY CONTAIN SILLIMANITE ARE LOCALLY PRESENT AT THE BASE.	POUGHQUAG QUARTZITE (KNOPF, 1962).
UNCONFORMITY				
PRECAMBRIAN	GNEISS	E	INTERBEDDED GRAY GARNET-BIOTITE GNEISS, BROWN TO RUSTY WEATHERING BIOTITE GNEISS AND AMPHIBOLITE; AUGEN GNEISS IS LOCALLY PRESENT AT THE BASE.	UNKNOWN.
		D	RUSTY-WEATHERING SILLIMANITE-GARNET SCHIST OR SCHISTOSE GNEISS, AND SILICEOUS BIOTITE GNEISS OR QUARTZITE.	UNKNOWN.
		C	GRAY BIOTITE-HORNBLLENDE GNEISS WITH NUMEROUS PINK OR WHITE QUARTZ FELDSPAR LAYERS AND LENSES; AMPHIBOLITE AND SOME PINKISH BIOTITE AND/OR HORNBLLENDE QUARTZ FELDSPAR GNEISS.	UNKNOWN.
		B	GRAY GARNET-BIOTITE GNEISS AND AMPHIBOLITE.	UNKNOWN.
		A	BROWN WEATHERING GARNET-BIOTITE GNEISS, AMPHIBOLETE AND GRAY BIOTITE-HORNBLLENDE GNEISS.	UNKNOWN.
	YONKERS GNEISS			PINKISH OR PURPLISH-BLUE BIOTITE AND/OR HORNBLLENDE QUARTZ FELDSPAR GNEISS.

Table 1 - Stratigraphy of the Manhattan Prong in the White Plains area.

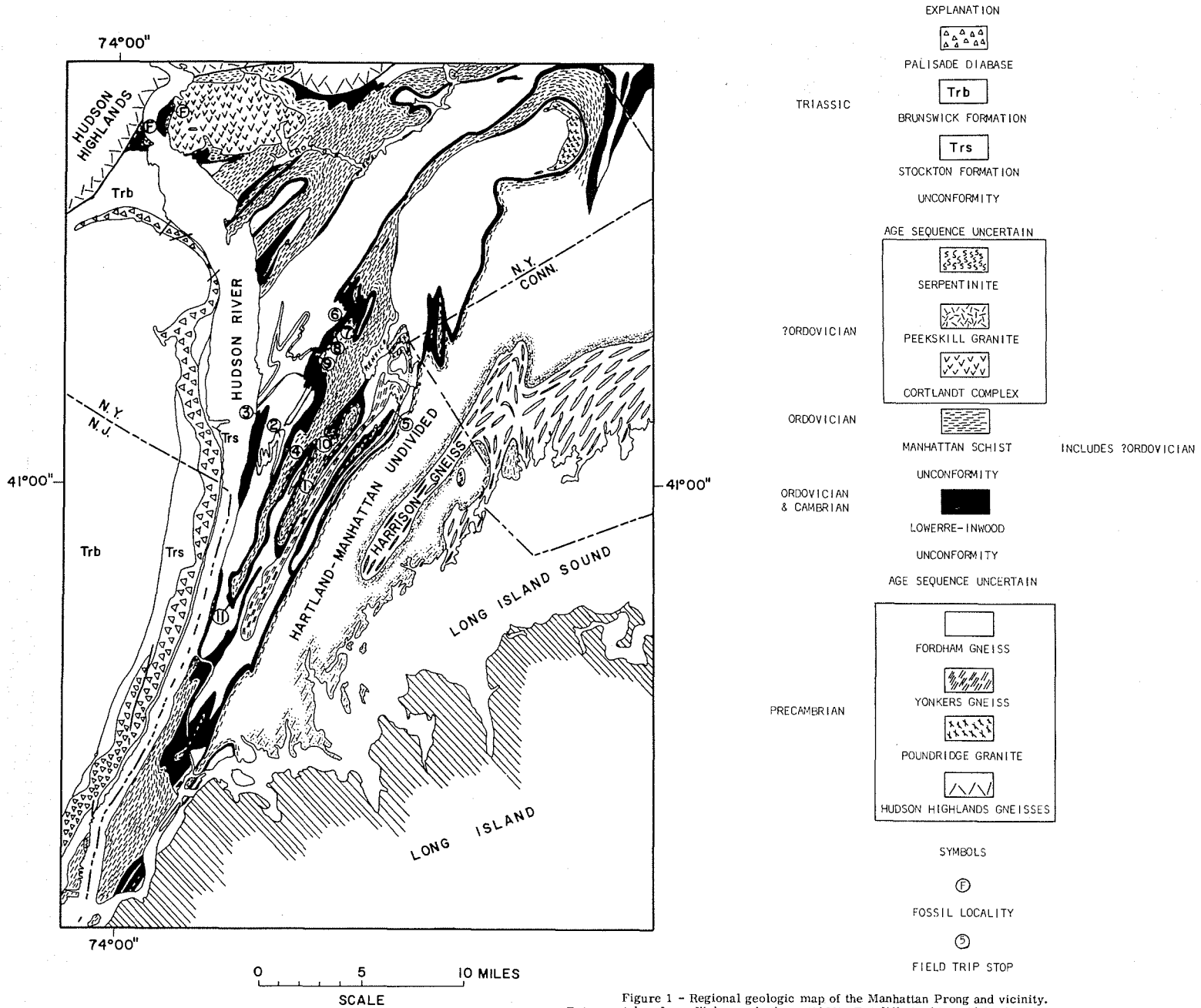


Figure 1 - Regional geologic map of the Manhattan Prong and vicinity. Data are taken from Fisher and others (1961), Ratcliffe in this guidebook and detailed field work as well as reconnaissance. Lines in the areas indicated as Fordham Gneiss represent contacts between members of the Fordham.



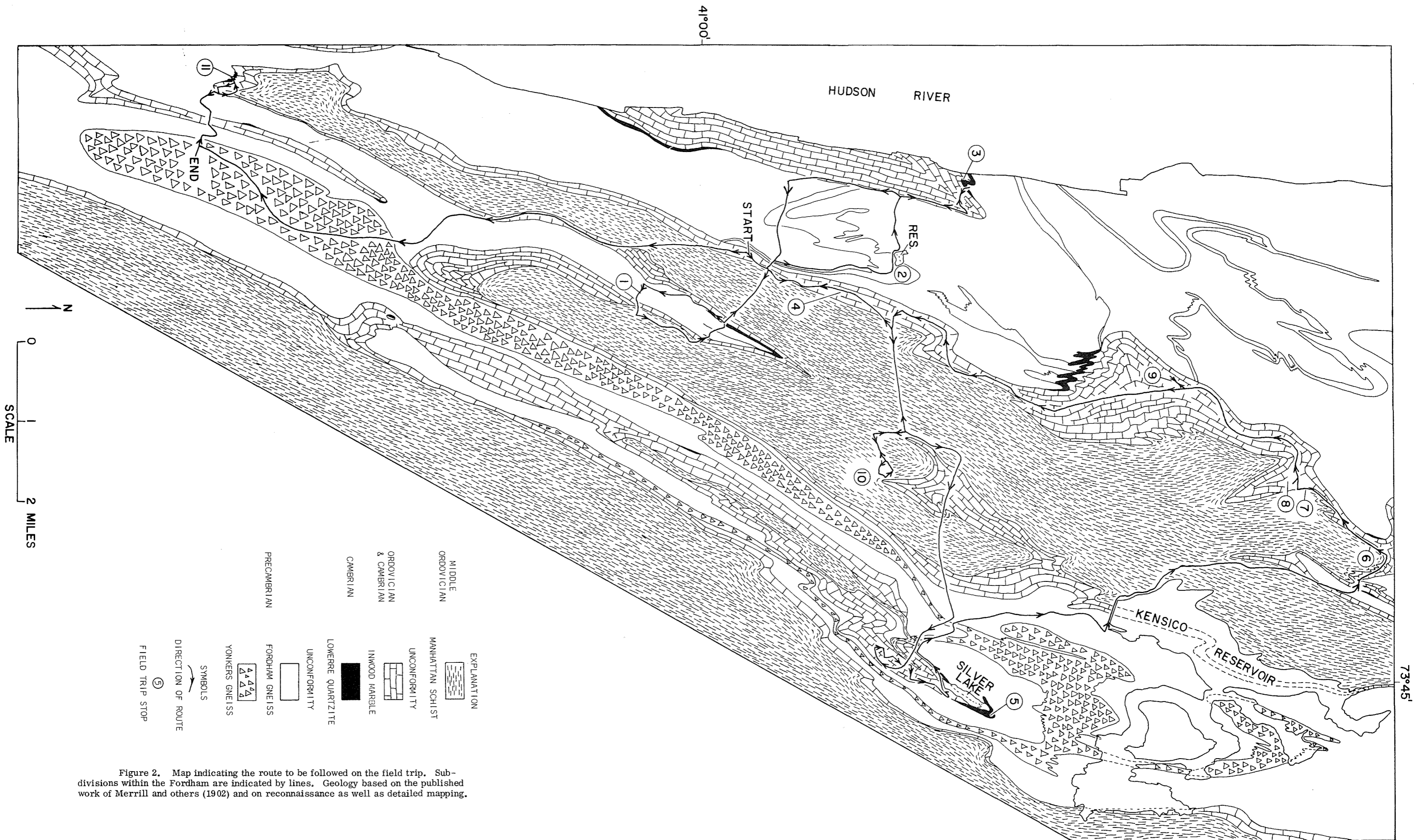


Figure 2. Map indicating the route to be followed on the field trip. Subdivisions within the Fordham are indicated by lines. Geology based on the published work of Merrill and others (1902) and on reconnaissance as well as detailed mapping.

## STRUCTURAL GEOLOGY

A fold system is apparent in the Precambrian rocks where the Fordham Gneiss has been subdivided and since these folds do not involve the Paleozoic rocks they must have formed during the Precambrian. The tectonic history of the Precambrian rocks in the Manhattan Prong is extremely complex and not very well understood at present. An example of a fold in the Fordham Gneiss is displayed at STOP 2 where a steep south plunging syncline is fairly clear.

The pre-Manhattan rocks were subjected to mild deformation in the form of tilting and/or block faulting. The angular unconformity that separates member A of the Manhattan Schist from the older rocks is the evidence for this deformational episode.

All of the rocks were subjected to at least two phases of deformation in the Paleozoic as attested to by the regional map pattern as well as the many refolded minor isoclinal folds that have been observed in the Lower Paleozoic rocks throughout the Manhattan Prong. Although one phase of folding preceded the other, this does not necessarily require two separate orogenic episodes. The earliest phase of this folding resulted in the development of large scale overturned, probably recumbent, isoclinal folds that involved the basement gneiss complex and was accompanied by metamorphism. Critical evidence for this is found at STOP 5 where Paleozoic rocks extend beneath Precambrian rocks on the lower limb of an early-phase nappe-like fold. Axial plane foliation that developed in conjunction with this early phase of folding is identifiable on the local scale in minor folds. Many examples of later stage folds are found at the local (STOP 10) as well as the regional scale (STOP 5 or between STOPS 4 & 5). In fact, much of the regional map pattern (Figure 1) is very likely the result of the later phase of folding. The later stage folds are generally more open and have an axial plane foliation, locally slip cleavage, developed in association with them.

### TACONIC THRUSTING?

The possibility that members B and C of the Manhattan Schist are in thrust fault contact with the other rocks in the Manhattan Prong suggests itself on the basis of the tentative correlation of members B and C with the Waramaug Formation in Connecticut (Gates, 1952) and the Hoosac Formation in Massachusetts and Vermont (Chidester and others, 1967; Zen, 1967). This somewhat tenuous correlation is based on regional mapping and lithic similarity of the rocks involved. (Percival, 1842, geologic map; Clarke, 1958, p. 22; Gates 1961) and is indicated on Table 1. The Hoosac Formation is Cambrian (Chidester and others, 1967) but the age of the Waramaug is less certain. Gates (1952, p. 14) indicated that the Waramaug is older than Stockbridge, an Inwood equivalent, and that it is probably Precambrian. Thus the relative ages of these units is apparently clear but if the tentatively proposed correlation is valid the Waramaug must be Cambrian and not Precambrian. Accordingly, Manhattan B and C would be Cambrian and thus in fault contact with Middle Ordovician Manhattan A. No direct physical evidence for thrusting has been found. The lack of such structural evidence may be due to the lithic similarity of some of the rocks involved as well as to subsequent metamorphism. Both of these would tend to obscure direct primary evidence of faulting. A relationship involving such large scale thrust faulting is similar to that found between the Taconic allochthon and autochthon (Zen, 1967).

If the proposition that major overthrusting took place in the Manhattan Prong is true, this faulting must have occurred prior to or at the beginning of the early phase of Paleozoic folding. Furthermore, if the thrusting is analogous to Taconic thrusting it very likely occurred at a time when Manhattan A was mud. Consequently, if such faulting did take place it necessitates a phase of deformation dominated by thrusting, or more likely gravity sliding, which may have been a separate deformational episode or the forerunner to the early phase of folding. Obviously, more evidence is needed to demonstrate the presence or absence of Taconic thrusting in the Manhattan Prong.

### ROAD LOG

#### Mileage.

- 0.0 - The road log begins at the northbound New York Thruway exit in Ardsley and the route is indicated on Figure 2. The contact between member B and member C of the Inwood Marble is exposed along the west (left) side of the exit ramp. Member C is exposed along the east (right) side of the ramp as well. The Inwood here is in the west limb of a north-plunging syncline with Manhattan Schist in the trough of the syncline underlying the hills on the east and Fordham Gneiss under the hills on the west. Leave the exit ramp and turn right (north) onto route 9A (Saw Mill River Rd.) and then proceed northward along the west limb of the syncline.
- 0.2 0.2 Turn right (east) onto Ashford Ave. and proceed southeasterly over the hill, across the synclinal trough. The exposures along the road-sides are Manhattan Schist.
- 1.0 0.8 Ashford Ave. enters Sprain Brook valley which is underlain by Inwood Marble. The ridge ahead to the east is Fordham Gneiss in the center of a north-plunging anticline. There are some small exposures of Lowerre Quartzite along the west limb of the anticline in this vicinity. The gneiss plunges out at the anticlinal nose less than a mile north of here.
- 1.1 0.1 Turn right (south) on Sprain Rd. and proceed southwesterly along the west limb of the anticline. The unpublished field notes of E. C. Eckel (New York State Museum and Science Service, Geological Survey files) report Lowerre Quartzite and Fordham Gneiss behind the houses on the east (left) side of the road but, apparently due to construction, only quartzite float exists there now.
- 2.3 1.2 Turn left (east) onto Jackson Ave.
- 2.4 0.1 STOP 1. New road cuts on Sprain Brook Parkway Construction site. The road cuts are along the left (north) side of Jackson Ave. on the approach to the new Jackson Ave. bridge that is now under construction and along the west side of the southbound lane of the Sprain Brook Parkway which is also presently under construction. We will walk north along the southbound lane of the Parkway and be picked up by the bus at Ardsley Rd. Those not wishing to walk may reboard the bus here and ride to Ardsley Rd. Be careful of traffic on Jackson Ave.

when disembarking.

Start at the west end of the road cut on the approach to the new Jackson Ave. bridge; in traversing eastward several varieties of rock types in the Fordham Gneiss will be seen in the center of the north plunging anticline. Minor structural features are abundant and many of the linear elements plunge northward apparently parallel to the anticlinal axis. Although this area has not been mapped in detail, it appears that these rocks might be grouped into three mapping units from west to east as follows:

1. Brown to rusty weathered sillimanite-garnet-biotite gneiss and smaller amounts of gray biotite-quartz-feldspar gneisses.
2. Light gray, locally pinkish, biotite-quartz-feldspar gneiss with sparse garnet. This rock looks somewhat like the Yonkers Gneiss in places.
3. Dark gray biotite and/or hornblende gneiss and amphibolite.

It would be necessary to map this area in detail to determine whether or not the above subdivision is meaningful.

After traversing to the west end of the new Jackson Ave. bridge, walk northward along the deep road cuts in subdivision 3, proposed above, and down into the Sprain Brook Valley. Walk north along the west side of the valley to Ardsley Rd. and observe several road cuts in subdivision 3. Drilling data obtained at several places along the Grassy Sprain Valley in conjunction with the highway construction now in progress reveal the predicted presence of Inwood Marble beneath the valley fill.

The contact between dark gray biotite gneiss and light gray to pinkish-gray gneiss is exposed in the road cuts at the west end of the new Ardsley Rd. bridge which is now under construction. This contact projects into the Sprain Brook Valley where it is truncated by the Inwood Marble along an unconformity. The west contact of the light gray or pinkish-gray gneisses has been mapped in detail here and it is truncated by the Inwood Marble approximately three quarters of a mile north of here. Reconnaissance indicates that these gray gneisses are very likely the same as subdivision 2 proposed above.

While the above traverse is being made, the bus will proceed as follows in order to meet the group at Ardsley Rd.:

- |     |     |   |
|-----|-----|---|
| 2.4 | -   | Proceed east on Jackson Ave. across Grassy Sprain Brook Valley.   |
| 2.7 | 0.3 | Turn left (north) onto Grassy Sprain Rd. and proceed along the east limb of the anticline. The road is near the contact between the Inwood Marble and Manhattan Schist. The hills to the east are underlain by the Manhattan in the trough of a syncline. |

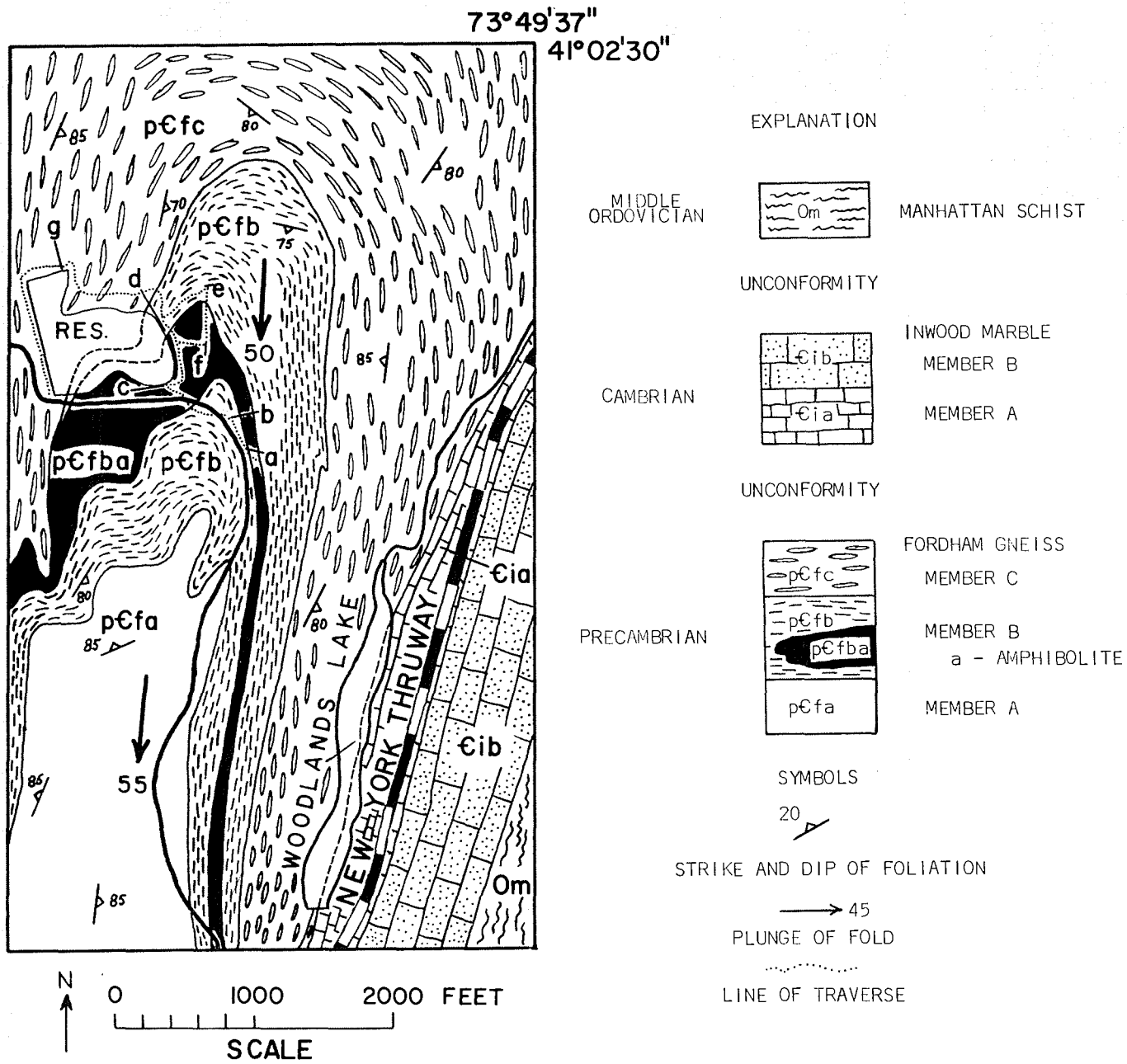


Figure 3 - Geologic map of the Harriman Road Reservoir area, STOP 2.

- 3.6 0.9 Turn left (northwest) onto Ardsley Rd. (A good exposure of member B of the Manhattan Schist is in the road cut along Ardsley Rd. approximately 0.1 mile southeast of this intersection.) Proceed northwest along Ardsley Rd. entering the floor of Grassy Sprain Valley.
- 3.8 0.2 The bus will stop here in order to allow the group to board and then will continue northwesterly on Ardsley Rd. crossing the anticline.
- 4.1 0.3 Proceed straight through the dangerous intersection where the street name changes from Ardsley Rd. to Ashford Ave. Continue northwesterly on Ashford Ave. re-crossing the syncline.
- 5.1 1.0 Proceed through the major intersection and onto the bridge that overpasses the Saw Mill River, New York Thruway, New York Central Railroad tracks, and the Saw Mill River Parkway. In so doing we have traversed from the lower part of the Manhattan Schist through members A, B, and possibly part of C of the Inwood Marble down into the Fordham Gneiss.
- 5.2 0.1 THIS IS AT THE IMMEDIATE WEST END OF THE BRIDGE THAT WAS JUST CROSSED. Turn right (north) onto Northfield Ave. and proceed northward. Many exposures of member A of the Fordham Gneiss are present in the hills on the west (left) side of Northfield Ave.
- 6.0 0.8 Turn left (north) onto Cyrus Field Rd. , named after "the father of the first transatlantic cable".
- 6.7 0.7 Enter long left curve where the road changes from north-south to east-west and also changes names to Harriman Road.
- 6.8 0.1 STOP 2. Harriman Road Reservoir. Park in the driveway on the right (north) side of the road that leads into the watershed area of the reservoir. We have been allowed to visit this area through the courtesy of the Village of Irvington, Department of Public Works. This is a water supply reservoir, please conduct yourself in accordance.

This is the area of a steeply plunging structural syncline that is defined by the contacts between various members of the Fordham Gneiss (Figure 3). Minor structural features and the orientation of foliation indicates that the syncline plunges  $50^{\circ}$  to  $60^{\circ}$  toward the south. It has been possible to map a separate amphibolite within member B of the Fordham Gneiss here (Figure 3) but the amphibolite cannot be separately mapped elsewhere. We will study the syncline by traversing along and across the amphibolite-garnet gneiss contacts (see walking route, Figure 3). Disembark from the bus and proceed southeast along the northeast side of Harriman Rd. to station a. Station a - Dark amphibolite and biotite-hornblende gneiss along with some garnetiferous gneiss are exposed here on the east limb of the syncline. The contact between the amphibolite and garnet gneiss appears gradational here and it is very difficult to map the amphibolite separately from here south. The apparent gradational nature of this

contact may be due to minor folds which are abundant here. Note the pyroxene (green-weathering) rimmed by hornblende (black) indicating retrograde metamorphism. Thin sections of similar rocks in member B of the Fordham reveal amphibole lamellae within the pyroxene and these lamellae are apparently retrograded exsolved pyroxene. The textural and mineralogical relations in this rock are open to various interpretations.

Station b - The exposure of typical gray garnet-rich gneiss in the trees on the north side of the road occupies the keel of the syncline here. Elsewhere in this rock type sillimanite is locally abundant, particularly as inclusions in garnet, but only traces of sillimanite have been observed here.

Station c - Dark amphibolite in steep south-plunging minor folds. Note the trend of the foliation here and then look toward the north-east corner of the reservoir where the amphibolite-garnet is present at station d. The strike obviously changes and this contact outlines a minor fold here on the larger syncline.

Station d - We have progressed northward along the west limb of the syncline and across the garnet gneiss-amphibolite contact. This outcrop of gray garnet gneiss is structurally beneath the amphibolite.

Station e - The garnet gneiss here is in the keel of the syncline. Note the foliation athwart the trend of the amphibolite-garnet gneiss contact. This foliation is apparently parallel to the axial plane of the syncline.

Station f - The amphibolite is in the keel of the syncline here and the foliation is parallel to the amphibolite-garnet gneiss contact.

If time permits we will walk along the north shore of the reservoir across many exposures of rocks typical of member C of the Fordham Gneiss.

Station g - This is an exposure of member C of the Fordham Gneiss that here consists of biotite and/or hornblende-quartz-feldspar gneiss, with many quartz-feldspar layers, and amphibolite. These rocks are complexly deformed with many examples of refolded folds as well as boudinaged amphibolite.

Return to Harriman Road and board the bus.

- 6.8 - Proceed west along Harriman Road.
- 7.8 1.0 Turn right (north) onto Route 9 (Broadway) and proceed north more or less along the Fordham Gneiss-Inwood Marble contact.
- 8.7 0.9 Turn left (west) onto the entrance road to Sunnyside (West Sunnyside Lane). Sunnyside is the former country home of Washington Irving

who designed and remodeled the house himself and is responsible for its unique architecture.

- 9.0 0.3 Member B of the Inwood Marble is exposed in the stream on the right (north) side of the road.
- 9.1 0.1 Turn right (north) and enter the gate to Sunnyside.
- 9.2 0.1 STOP 3. Sunnyside. NO HAMMERING PLEASE! The contact between the Lowerre Quartzite and member A of the Inwood Marble is exposed here. This same contact is exposed at STOP 2 on Trip H (Ratcliffe, this guidebook).

Sunnyside belongs to Sleepy Hollow Restorations, Incorporated. This is a non-profit organization that has allowed us free access to Sunnyside for purposes of this field trip. Visitors are normally charged an admission fee. Please show your gratitude by being careful.

Proceed through the reception center to the outlet of the pond, "Little Mediterranean". Lowerre is exposed in the brook beneath the bridge and extends upstream. Here, the Lowerre consists of typical tan to buff weathered quartzite, micaceous quartzite, feldspathic quartzite and granulite. More Lowerre is exposed downstream from the bridge and a large fold is clearly displayed at the waterfall. This fold is large enough to be outlined by the Lowerre-Inwood contact on the regional geologic map (Figure 1.). Bedding attitudes indicate that the fold plunges  $60^{\circ}$  to  $65^{\circ}$  toward the southeast. A white quartz vein one to two feet thick is present in the axial region of the fold.

The contact of the Lowerre with member A of the Inwood is exposed below the waterfall and the Lowerre is relatively clean quartzite near the top. The Inwood consists of coarse white dolomite marble and a few calcite-bearing beds are also present. A bright green chromium-bearing chlorite is locally present in the coarse white dolomites. Paleontologists have assured me that the siliceous "box work" present here does not represent organic remains.

There is a fine view of the Palisades across the Hudson River. The cliffs are marked by the Palisades Sill which is in contact with the Triassic Stockton Formation at the base of the cliff a little above the surface of the river (Figure 1). An unconformity, somewhere beneath the river, separates the Paleozoic and Precambrian rocks in the vicinity of Sunnyside from the overlying Triassic rocks. This unconformity dips westward and thus projects above the ground surface at Sunnyside. Evidence for the unconformity is clear in the vicinity of Stony Point on the west side of the Hudson River, see Figure 1, Trip H, (Ratcliffe, this guidebook).

There is at least one small exposure of member A of the Inwood on the grounds of Sunnyside. We will not visit the small exposures of member C of the Fordham that are present in the wooded area north



of Sunnyside, but the unconformity at the base of the Lowerre must be present somewhere in the vicinity of the northern boundary of the grounds.

Return to the parking lot and board the bus.

- 9.4 0.2 Leave Sunnyside passing through the gate and turning left (east) onto West Sunnyside Lane.
- 9.8 0.4 Turn right (south) onto Route 9 (Broadway) and proceed south to Dobbs Ferry.
- 12.1 2.3 Turn left (east) onto Ashford Ave. and proceed east across member A and member B of the Fordham Gneiss.
- 13.2 1.1 Start across the bridge that overpasses the Saw Mill River etc. and in so doing, cross the Fordham Gneiss-Inwood Marble-Manhattan Schist contacts.
- 13.3 0.1 Turn left (north) onto Route 9A (Saw Mill River Rd.) and proceed north along the west limb of a syncline.
- 13.4 0.1 Outcrops of Manhattan Schist are on the right (east).
- 14.3 0.9 STOP 4. REA Express Terminal. This is a good exposure of rocks that are typical of member B of the Inwood Marble. It consists of interbedded gray and white dolomite marble; tan, cream colored, and locally pinkish-weathering dolomite marble; tan calc-schist and granulite.

There are several north-plunging sinistral folds with half wavelengths of three to four feet outlined by beds in the vicinity of the corner of the cut and the side of the cut parallel to the east side of the building. These are interpreted to be later stage folds and evidence for an earlier stage of Paleozoic folding is revealed locally by folded mineral lineation. There are many other minor folds throughout the exposure. It is noteworthy that the syncline at STOP 2 is very close (Figure 3) and that its orientation is apparently unrelated to the folds present here. This suggests that the syncline at STOP 2 is a structural feature that was developed due to deformation in the Precambrian.

A zone of closely spaced fractures that dip  $65^{\circ}$  west is present at the corner of the cut. This is probably related to late (Triassic?) minor fault movement.

- 14.3 - Board the bus and proceed north on Route 9A (Saw Mill River Rd.). Several exposures of member B of the Inwood Marble are along the right (east) side of the road.
- 14.6 0.3 Turn right (northeast) onto Route 100B and proceed northeast across the Inwood Marble-Manhattan Schist contact.

- 16.5 1.9 Turn left (north) onto Route 100A (Knollwood Rd.). The broad valley to the northeast (right front) is underlain by Inwood Marble in the center of a south plunging anticline. Proceed northward along the west limb of this anticline.
- 17.3 0.8 Cross Route 119 (White Plains Rd.) and turn right in order to enter the Cross Westchester Expressway eastbound. Proceed east across the anticlinal valley.
- 18.2 0.9 Large road cuts expose members A, B, and C of the Manhattan Schist on the east limb of the anticline.
- 18.3 0.1 The extensive road cuts on the left (north) side of the expressway expose member C of the Manhattan Schist in the trough of a south plunging syncline.
- 18.6 0.1 The expressway overpasses the Bronx River Valley which is here underlain by Inwood Marble. We cross the Inwood-Fordham contact and proceed down through the upper limb and across the axial surface of an early stage nappe-like fold.
- 19.6 1.0 Extensive road cuts expose multiply deformed Fordham Gneiss and Yonkers Gneiss in the core of the early stage fold.
- 20.0 0.4 A road cut on the right (south) side of the expressway exposes interbedded calcite marble and schist at the base of member A of the Manhattan Schist. The contact of these rocks with the Fordham Gneiss is essentially exposed here and is an example of a place where the Middle Ordovician rocks rest directly on Precambrian. We are on the lower limb of the early stage nappe-like fold which has been refolded into an anticline and we are here located on the west limb of this later stage anticline. The lower part of the Manhattan exposed here compares favorably with the fossil bearing beds at Stop 5 and Stop 7 on Trip H (Ratcliffe, this guidebook).
- 20.4 0.4 COMPLICATED MANEUVERS FOLLOW! Bear right onto the ramp for exit 8.
- 20.7 0.3 Turn right (north) onto Bloomingdale Rd.
- 20.8 0.1 Turn right (east) onto Westchester Ave.
- 20.9 0.1 Turn left (north) onto South Kensico Ave.
- 21.0 0.1 Turn right (east) onto Brockway Place.
- 21.2 0.2 Turn left (north) onto Belway Place and bear right (east) at the corner in 0.1 mile.
- 21.6 0.4 Turn left (north) onto Underhill Ave. All of this maneuvering has allowed us to cross the axial plane of the later stage anticline to the east limb but we remain on the lower limb of the early stage

nappe-like fold. Proceed northward along the east limb of the later stage anticline.

- 21.9      0.3      Turn right (northeast) onto Lake St. and proceed along the west limb of the later stage anticline.
- 22.2      0.3      Make a sharp (nearly 180°) left turn and then right into Silver Lake Park. LUNCH.

STOP 5. Silver Lake. We are permitted to use this park through the courtesy of the town of Harrison. Please don't litter the area with trash.

An exposure of member A of the Inwood Marble is present near the entrance to Silver Lake Park. Walk northward along the east side of Silver Lake and, in so doing, proceed along the east limb of the northerly plunging later stage anticline and at the same time along the lower limb of the earlier stage nappe-like isoclinal fold. (Figure 4). The steep topography on the west side and at the north end of the lake is underlain by Fordham Gneiss and the ridge on the east by Yonkers and Fordham. We are located on the Paleozoic rocks and the contact at their stratigraphic base projects in the air above our heads so that the stratigraphy is completely inverted here. Walk to the north end of the lake where the hinge of the later stage anticlinal fold is located (Figure 4). Walk northward, up the hill and down the stratigraphic section through the Lowerre Quartzite into the Fordham Gneiss. Note that the bedding in the Lowerre dips northward and thus projects beneath the older Fordham. In walking up the hill we are proceeding across the lower limb of the earlier stage nappe-like fold and essentially along the axial trace of the later stage fold.

The Lowerre here consists of tan to brown weathering gray feldspathic granulite, tan-weathering quartzite and micaceous quartzite, interbedded half-inch to two-inch thick beds of white quartzite and feldspathic granulite. Brown to rusty-weathering feldspathic granulite and feldspathic schist with local sillimanite nodules characterize the basal Lowerre here. The Fordham consists predominantly of gray biotite-quartz-feldspar gneiss.

Minor structural features abound in these rock exposures. Most of the linear elements plunge at 40° to 60° northwestward and apparently are parallel to the plunge of the later stage anticline.

Return to the bus.

- 22.2      -      Leave Silver Lake Park by making a right turn at the exit and then travel southwest.
- 22.5      0.3      Bear right onto Lake St. and proceed southwest. There is an exposure of Lowerre Quartzite behind the milk plant on the northwest side of Silver Lake.

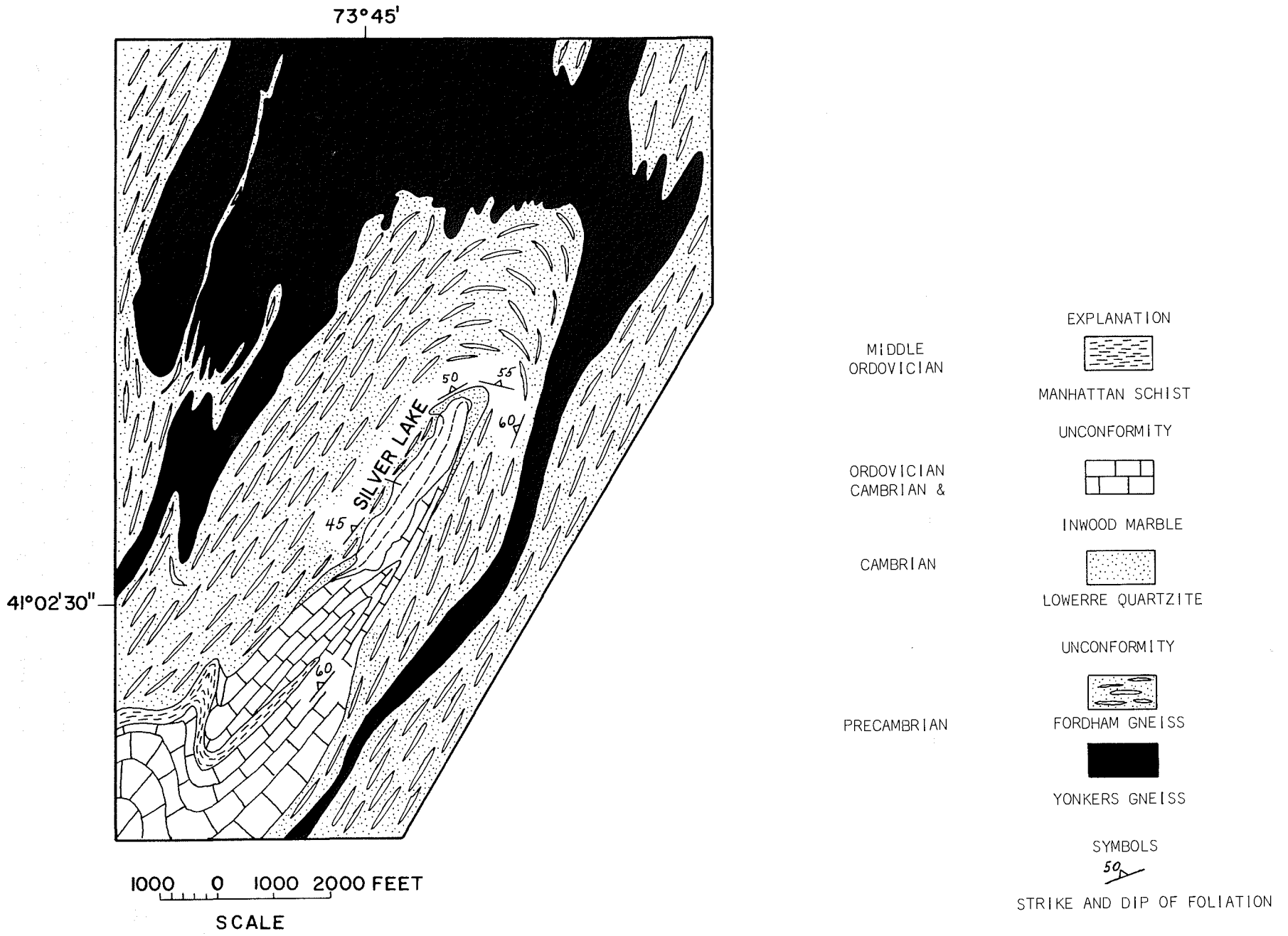


Figure 4 - Geologic map in the vicinity of Silver Lake, STOP 5.

- 23.0 0.5 Turn right (north) at Kensico Place and proceed northward onto North Kensico Ave.
- 23.5 0.5 Turn left (west) onto Grant Ave.
- 23.6 0.1 Turn right (north) onto Beech St., then left & right onto Central Westchester Parkway and proceed north across unexposed Fordham Gneiss and up through the axial surface of the nappe-like fold to the upper limb.
- 24.3 0.7 Proceed straight (northward) through the intersection, thus joining Route 22. Exposures along either side of the road are Fordham Gneiss.
- 25.7 1.4 Turn left (west) across the Kensico Dam onto W. Lake Drive. The rock facing on this dam is Yonkers Gneiss that was quarried from the hills to the east of the Kensico Reservoir called "Quarry Heights". Fordham Gneiss is at the east end of the dam, Manhattan Schist is at the west end and the Inwood Marble, though not exposed, is in between. Proceed northwesterly on W. Lake Drive.
- 27.0 1.3 Turn right (north) onto Columbus Ave. The New York City Water Supply aerators are on the right.
- 29.3 2.3 Turn left (northwest) onto Kensico Rd.
- 29.5 0.2 Interbedded calcite marble and schist at the base of member A of the Manhattan Schist are exposed in the road cut on the right (northwest) side of the road.
- 30.0 0.5 Turn left (south) onto Commerce St.
- 30.2 0.2 STOP 6. United States Post Office in Thornwood. Member A of the Manhattan Schist is exposed in the cuts alongside and behind the buildings. Characteristic gray and dark-gray sillimanite-garnet muscovite-biotite schist of member A is present here. Before the recent construction and paving, there was an exposure of interbedded white calcite marble and schist here. These rocks compare favorably with the lower portions of the Manhattan Schist that are to be visited on Trip H (Ratcliffe, this guidebook).
- 30.2 - Board the bus and continue south on Commerce St.
- 31.2 1.0 Bear right onto Elwood St.
- 31.4 0.2 STOP 7. Exposures along the east side of Elwood St. The exposures of member A of the Manhattan Schist behind the buildings as well as on the wooded slope consist of the typical fissile schist and some gray and white calcite marble beds. Definite interbedding of marble and schist cannot be proven here although there are at least two exposures that strongly suggest such a relationship.

- 31.4 - Board the bus and proceed south on Elwood St.
- 31.5 0.1 Turn right (west) onto Route 141 and proceed west across the bridge overpassing the New York Central railroad tracks.
- 31.6 0.1 Turn left (south) at the west end of the bridge and proceed southeasterly.
- 31.7 0.1 STOP 8. Member E of the Inwood Marble. Park beyond the United States Post Office at the end of the street. Walk south over the hill toward the Taconic State Parkway. An exposure of member E of the Inwood is on the west side of the hill along the east edge of the Taconic State Parkway. The contact between gray-weathering calcite marble (member D?) and tan-weathering calcite marble, typical of member E, outline a tight isoclinal fold.
- 31.7 - Board the bus and return to Route 141.
- 31.9 0.2 Turn left (west) onto Route 141 and proceed northwesterly.
- 32.3 0.4 Turn left (southwest) onto Route 9A. The large roadcut on the south side of the intersection is in member D of the Inwood and there are exposures of member E up on the hill south of the road cut. Proceed southward on Route 9A along the west limb of a syncline with Fordham Gneiss underlying the hills on the west and Manhattan Schist those on the east.
- 34.1 0.8 Turn right (southwest) into the Consolidated Edison Company driveway.
- 34.3 0.2 STOP 9. Member E of the Inwood Marble. These exposures are typical of member E of the Inwood Marble and consist predominantly of tan and gray-weathering calcite marbles. Note the many northeast plunging folds.
- 34.3 - Board the bus and return to Route 9A.
- 34.5 0.2 Turn right (south) onto Route 9A and proceed southward continuing in the Inwood Marble.
- 36.3 0.8 There is an excellent exposure of the unconformity at the base of the Lowerre Quartzite in a cut behind the A & P warehouses west of Route 9A. There are extensive exposures of Lowerre on the hillside extending all the way across the Saw Mill River Parkway to the west. Continue southward through Elmsford more or less along the Inwood-Manhattan contact.
- 39.1 2.8 Turn left (east) onto Route 100B.
- 41.0 0.9 Turn right (south) onto Route 100A (Hartsdale Ave.).
- 41.4 0.4 Turn left (east) entering the campus of Greenburgh School District No. 8.

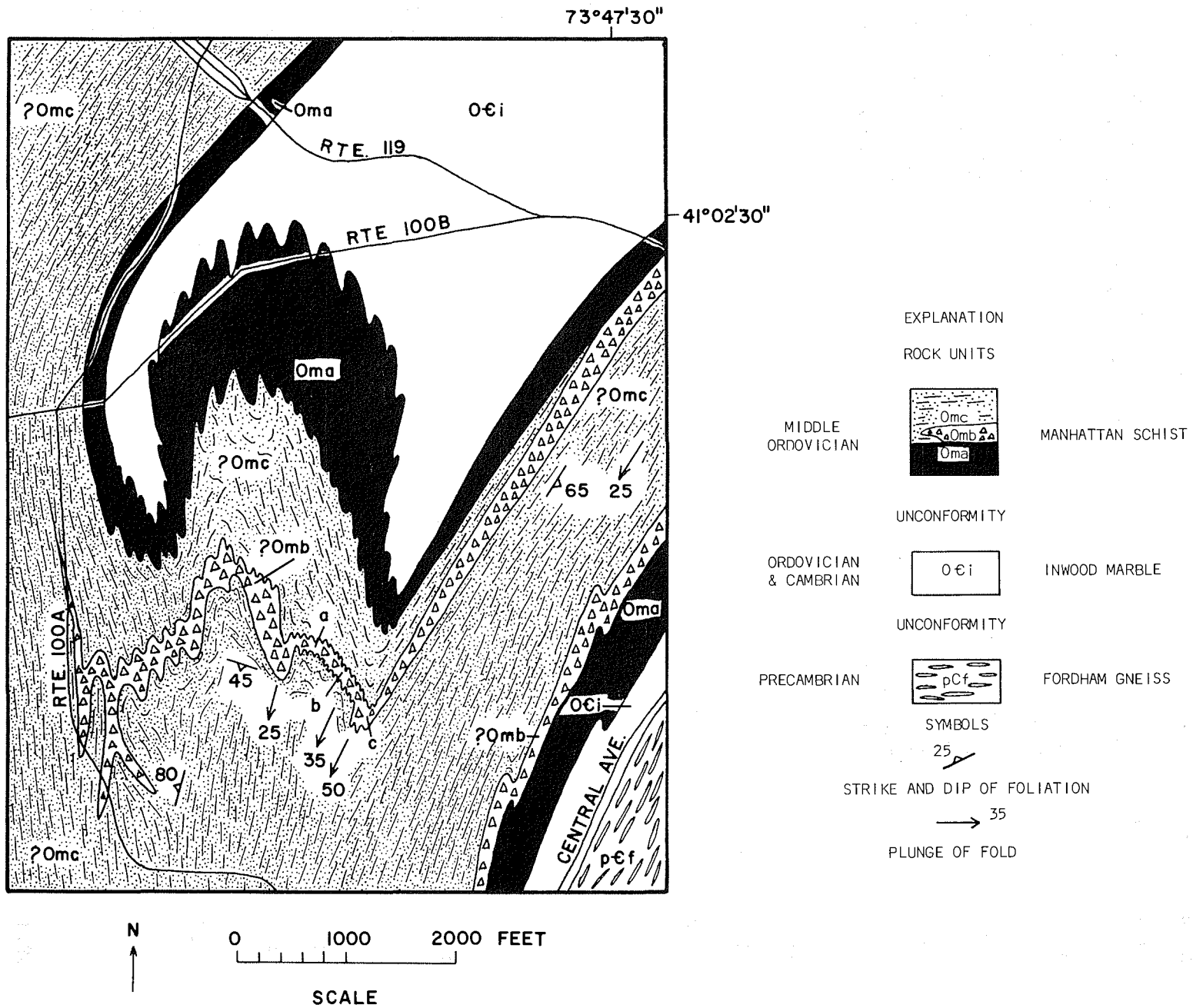


Figure 5 - Geologic map of the vicinity of the Warburg Campus, STOP 10.

- 41.8 0.4 Turn right (south) into the driveway leading to Woodlands High School; bear left at the fork.
- 42.0 0.2 STOP 10. Warburg Campus. Park in the parking lot north of Woodlands High School. This 160 acre campus is a former estate of Felix Warburg that was given to the town of Greenburgh for educational purposes. The classroom buildings on the campus accommodate 3000 students from kindergarten through high school. We have been granted permission to visit this area by the administration of Greenburgh School District No. 8.

The rocks here are at the nose of a southwest-plunging later-stage anticline (Figure 5). Evidence for two, and possibly three, phases of deformation is displayed by minor structural features. The contacts between amphibolite (member B of the Manhattan) and schist, schistose gneiss and granulite that are typical of member C of the Manhattan outline the fold (Figure 5). Note that member B is above the base of member C here.

Some areas of particular interest are indicated on the map (Figure 5) by lower case letters. The upper and lower contacts of the amphibolite are easily identified in the vicinity of point "a" where gray to brownish-weathering feldspathic garnet-muscovite-biotite schistose gneiss, gneiss and granulite with local white sillimanite nodules is below as well as above the amphibolite. Trace the contacts south-eastward by walking across the valley to exposures on the steep slope west of the classroom building in the vicinity of point "b" on Figure 5. The lower amphibolite contact is folded here and though there are several examples of the results of multiple deformation, a particularly fine example of a refolded fold is present near the north end of these exposures. Evidence for three stages of deformation is found here where the slip cleavage that deforms an earlier foliation appears to be folded.

Proceed southeast over the top of the hill where amphibolite is well exposed. An unusual occurrence of magnetite with white quartz-feldspar rims is present in the amphibolite on the southeast side of the hill. Many interesting minor structural features are present in the rocks on the hill in the vicinity of "c" (figure 5). Toward the north between the gym and the classroom building is an exposure of schist with particularly good examples of sillimanite nodules.

- 42.0 - Board the bus and leave Woodlands High School parking lot.
- 42.1 0.1 Turn left at the "T" intersection with the stop sign.
- 42.7 0.6 Turn right (north) onto Route 100A (West Hartsdale Ave.).
- 43.1 0.4 Turn left (west) onto Route 100B (Dobbs Ferry Rd.).
- 44.4 1.3 Bear left (southwest) and proceed to Route 9A.



- 45.0 0.6 Turn left (south) onto Route 9A (Saw Mill River Rd.).
- 46.4 1.4 Proceed through the intersection, south on Route 9A.
- 46.6 0.2 Bear left onto southbound New York Thruway entrance. Road cuts here expose member B of the Inwood Marble and a particularly good exposure of member B is present on the east (left) side of Route 9A between the Thruway overpass and the southbound Thruway entrance.
- 47.3 0.7 Manhattan C on the left (east).
- 47.4 0.1 Manhattan C on both sides of the highway.
- 48.6 1.2 Road cuts in the Fordham Gneiss.
- 48.9 0.3 Toll booth.
- 50.0 1.1 Yonkers Gneiss on the left (east).
- 50.5 0.5 Fordham Gneiss is on the right (west).
- 50.8 0.3 Fordham Gneiss is on both sides of the highway.
- 51.2 0.4 Fordham Gneiss is on the right (west).
- 51.5 0.3 Fordham Gneiss is on both sides of the highway.
- 51.8 0.3 Yonkers Gneiss is exposed in the old quarry on the right (west) and there are active quarries in the Yonkers a little further west. This is in the area specified by Merrill (1890, p. 388) as typifying the Yonkers Gneiss.
- 52.0 0.2 Yonkers Gneiss is exposed in a cut along the Thruway exit ramp on the left (east).
- 53.6 1.6 Highview Reservoir is on the left (east).
- 53.9 0.3 Bear right onto the exit ramp for Hall Place and McLean Ave.
- 54.1 0.2 Continue to McLean Ave.
- 54.3 0.2 Turn right (west) onto McLean Ave. Follow the winding, hilly course of McLean Ave. westerly and then northwesterly.
- 55.7 1.4 Turn left (west) onto Wolffe St.
- 55.8 0.1 Continue straight through the intersection of Wolffe St. with Van Cortlandt Park Ave. and park on the old railroad bed behind the buildings.

STOP 11. Type locality of the Lowerre Quartzite. This is the type locality of the Lowerre Quartzite designated by Merrill (1896, p. 26).

The portion of the Lowerre now exposed here is predominantly well bedded gray and tan-weathering feldspathic granulite and gray feldspathic muscovite-biotite schist that weathers tan to brown. Typical tan-weathering quartzite is present about forty to fifty feet above the base but is subordinate. It seems likely that more of the characteristic quartzite was exposed here when Merrill originally defined the Lowerre but that it has since been removed through the work of man. It also appears that Merrill used the modifier "quartzite" in the name Lowerre Quartzite because the most distinct rock types that characterize the assemblage of rocks in this formation are tan weathering quartzite and feldspathic quartzite.

The Fordham Gneiss beneath the Lowerre consists mainly of amphibolite with some gray garnet-biotite-gneiss. This is another place, similar to STOP 5, where the base of the Lowerre is "dirty". There are other places, such as the cut behind the A & P warehouses at mileage 36.3 (this field trip), where clean quartzite and feldspathic quartzite are directly in contact with Fordham.

The unconformity here is deformed into a series of northeast plunging sinistral folds. This is in accord with the map pattern in this vicinity (Merrill and others, 1902) which indicates the rocks here are on the west limb of a stratigraphic syncline.

- |      |     |   |
|------|-----|---|
| 55.8 | -   | Board the bus and return to Van Cortlandt Park Ave. and turn right (south) onto Van Cortlandt Park Ave. |
| 56.0 | 0.2 | Turn left (east) onto Coyle Place.  |
| 56.1 | 0.1 | Turn right (south) onto McLean Ave. and wind south and southeasterly.                                   |
| 57.4 | 1.3 | Turn right (south) onto the Major Deegan Expressway.  |

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TRIP B: CRETACEOUS DELTAS IN THE  
NORTHERN NEW JERSEY COASTAL PLAIN

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(Publication authorized by the Director, U. S. Geological Survey.)

INTRODUCTION

In recent years there has been a growing recognition of the importance of deltaic deposits in many sedimentary basins. The extensive investigation of modern deltas has resulted in the isolation and description of many of the subenvironments of this very complex sedimentation system. On this field trip, some of the subenvironments of an ancient deltaic system will be examined.

GENERAL CHARACTERISTICS OF MARINE DELTAS

Basically two general types of deltas have been recognized; a deep-water type and a shoal-water type. In all probability the deltaic beds examined on this field trip relate to the shoal-water deltas and we shall confine our discussion to this particular type.

Most modern shoal-water deltas are characterized by a preponderance of silt-sized and clay-sized clastic deposits. The lack of marked size variation within the bulk of the sediment delivered by the river obscures environmental differences. The Cretaceous deltas in New Jersey, however, are very sandy, having a large, mostly medium grained, sand content. Only one modern delta in which sand predominates has been described, the Niger River delta in Africa (Allen, 1965). The different facies(?) and kinds of material found within this delta are therefore more analogous to those of the Cretaceous deltas in New Jersey than to any other modern delta described in the literature. The Niger River delta serves as a reference standard for our interpretations of the subenvironments represented in the Cretaceous deltas in the New Jersey Coastal Plain.

A marine delta consists of two main depositional zones (Figure 1): the continental facies, referred to by most authors as the deposits of the subaerial plain, and the marine facies (including the brackish facies) commonly called the deposits of the subaqueous plain. Within these two major depositional zones, the deposits are further subdivided into the following general classes of beds: topset, foreset and bottomset. Topset beds are present in both the subaerial and subaqueous plains, whereas foreset and bottomset beds are only found in the subaqueous plain.

DEPOSITS OF THE SUBAERIAL PLAIN

The continental facies of the delta are collectively referred to as topset beds (Figure 1) (Shepard, 1960). These beds are deposited in an area dominated by fluvial processes and, therefore, the sediments have the characteristics of channel-fill and overbank deposits. However, because of the proximity of this plain to sea level,

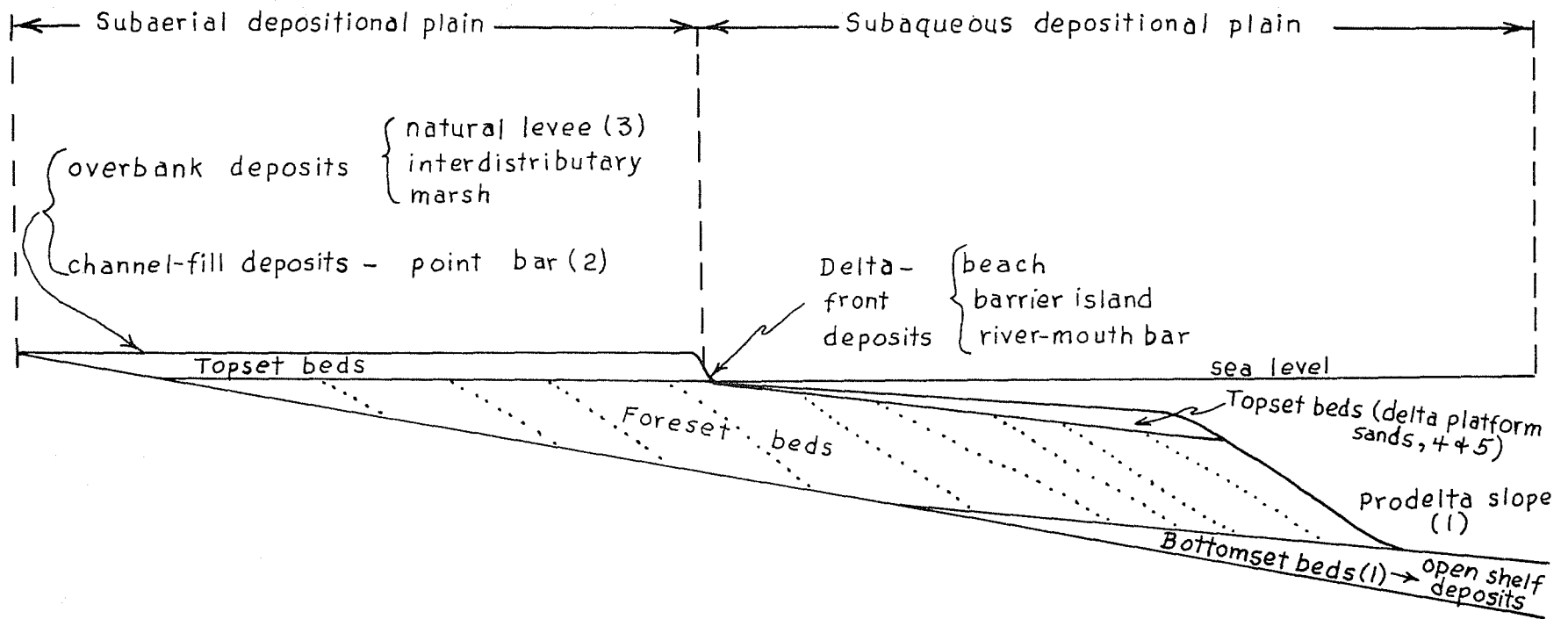


Figure 1. Schematic representation of major depositional zones in a shallow-water marine delta. Numbers indicate field trip stops at which subenvironments shown in diagram will be observed.

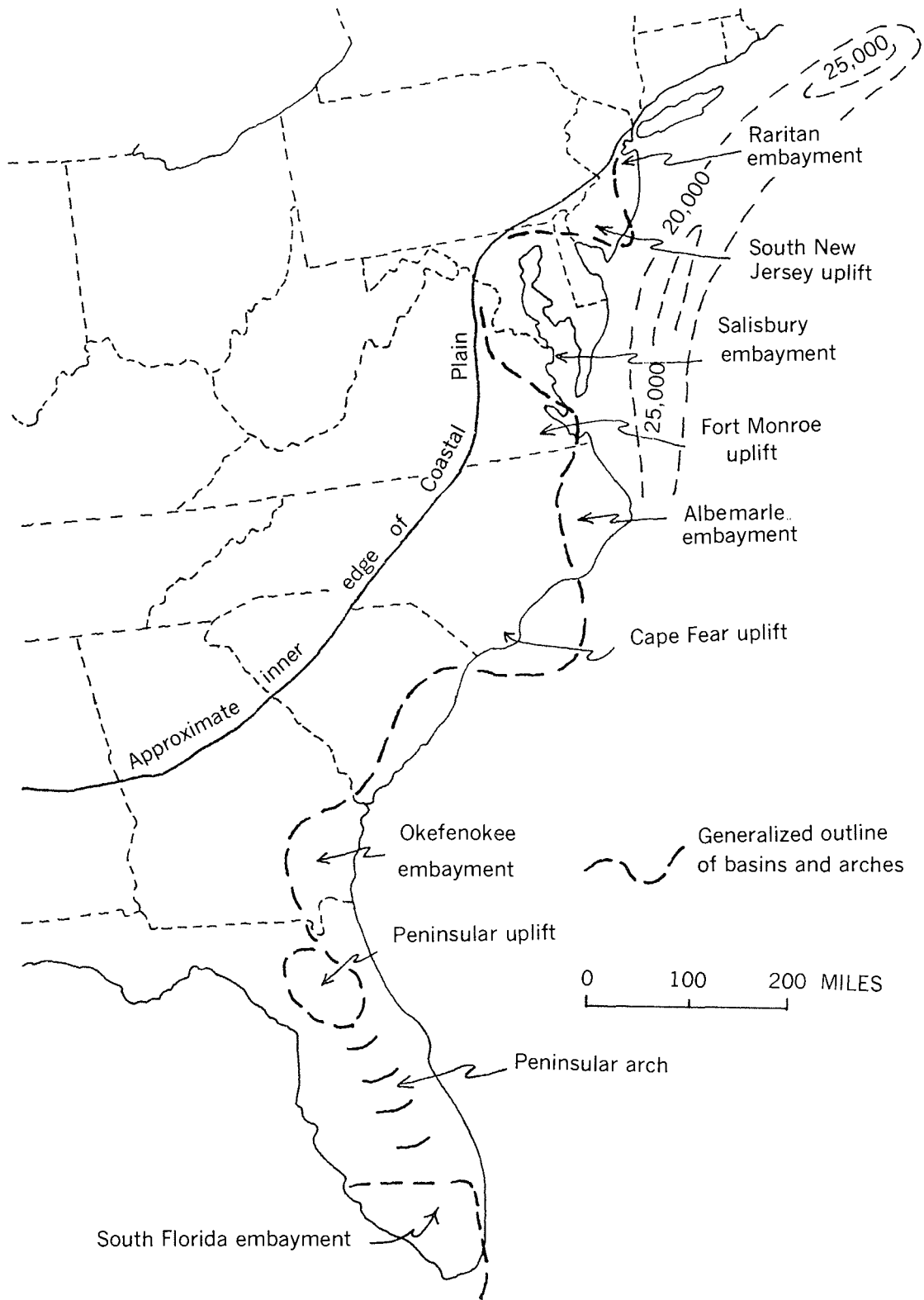


Figure 2. Major tectonic features of the basement beneath the Atlantic Coastal Plain. Contours indicate thickness of post-Triassic deposits.



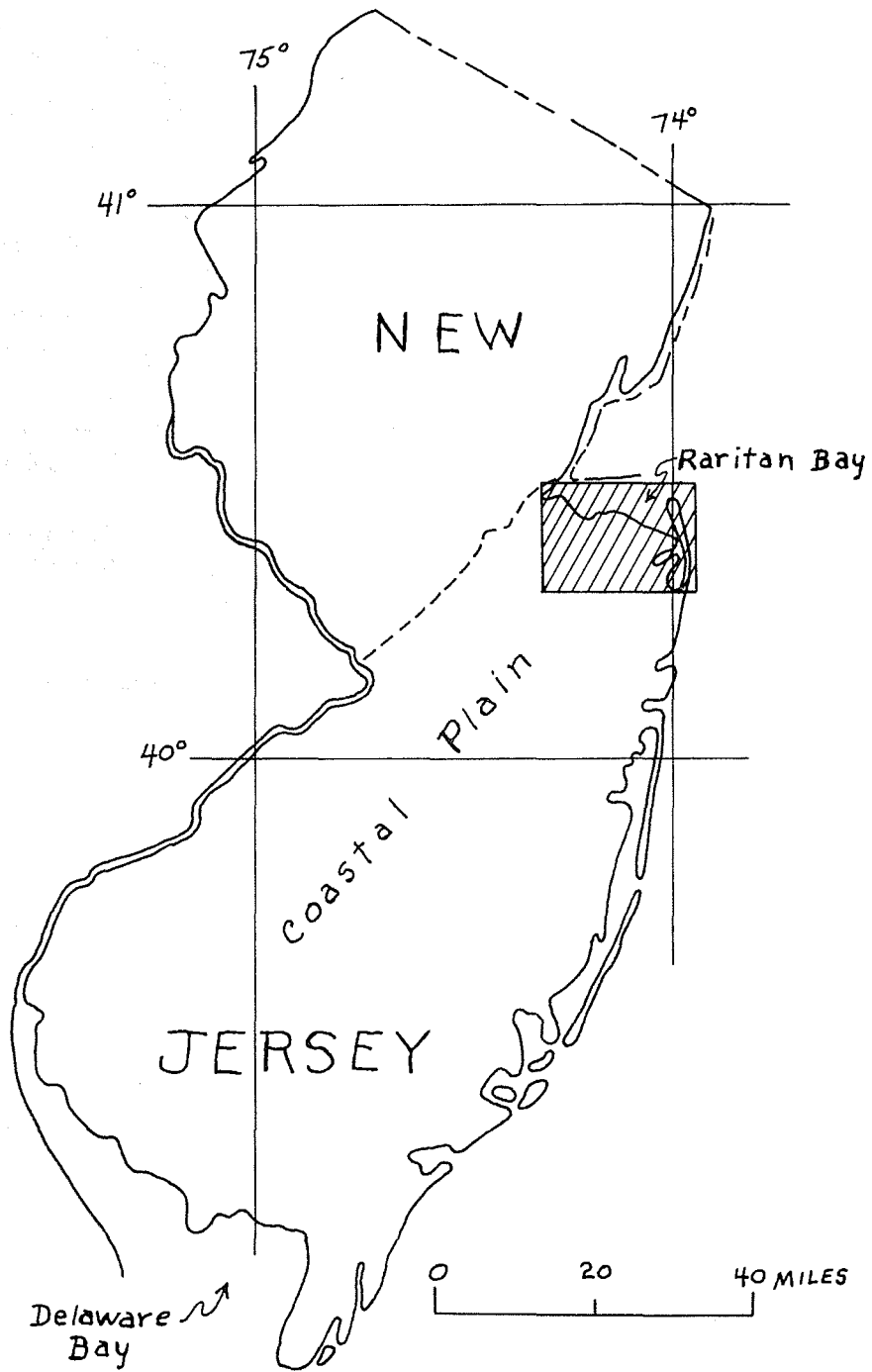


Figure 3. Index map showing location of field trip area (lined). Dashed line is inner edge of Coastal Plain.

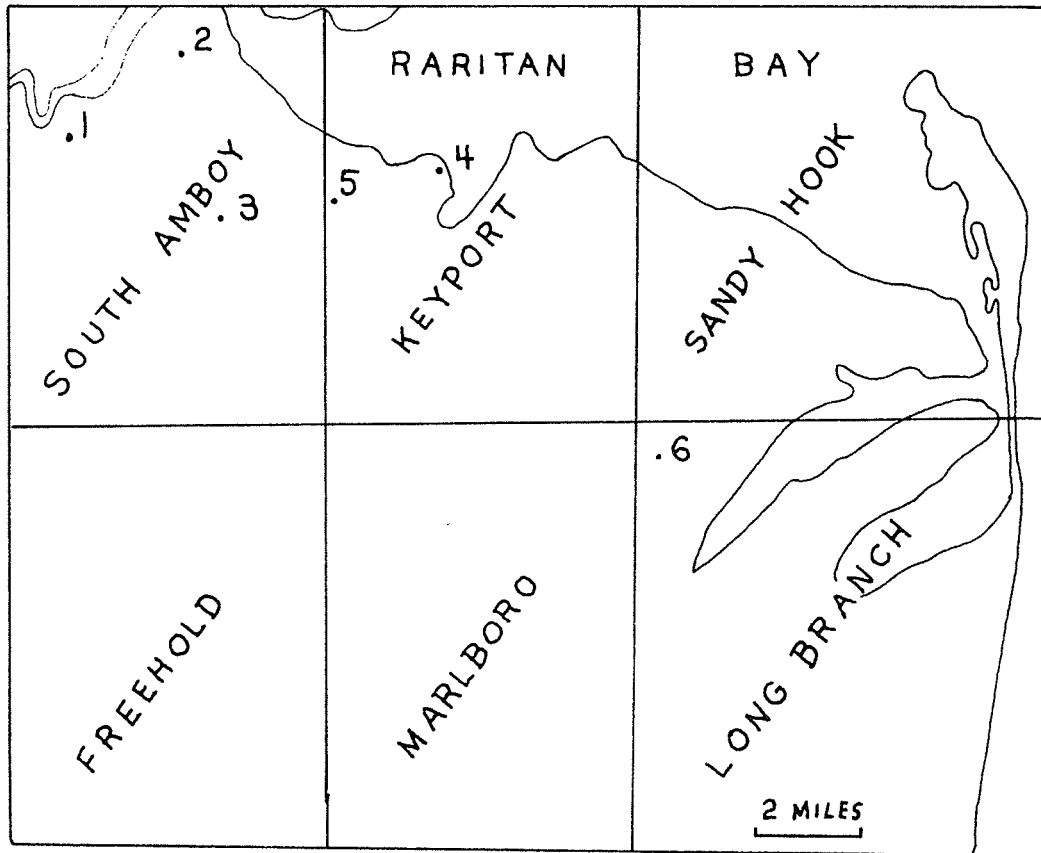


Figure 4. Map showing the six 7 1/2-minute series quadrangles in the area along the south side of Raritan Bay. Locations of field trip stops are shown by numbers.

swamp or marsh deposits are also extensively developed, especially in deltas formed in temperate to tropical regions.

### DEPOSITS OF THE SUBAQUEOUS PLAIN

The marine and transitional beds (beach, river-mouth bar, and barrier bar) of the delta are less varied than the continental beds and they commonly have greater lateral continuity.

#### Delta-front deposits.

These deposits are marginal to the subaerial delta on the oceanward side and are a zone in which the river-introduced sediments are reworked and redistributed by oceanic processes. Normally it is a zone in which sand is concentrated in a narrow zone and the finer sediments are winnowed out and transported seaward over the delta into the basin. Barrier and river-mouth bar deposits are common in this area as are beach deposits. Collectively these beds are grouped with the topset beds.

#### Prodelta deposits.

The deposits of the subaqueous plain theoretically contain the three classes of beds mentioned earlier, topset, foreset, and bottomset. Topset beds in the subaqueous plain typically are thin and commonly are horizontal to gently inclined. The foreset beds are also horizontal to gently inclined although cross-stratification is extensively developed in sandy beds. The bottomset beds are characteristically massive and very fine grained. The relationships of the three types of beds in the subaqueous depositional plain is shown in Figure 1.

We have been discussing, for the most part, the constructional aspects of deltaic sedimentation. Sedimentation within deltas, however, is highly localized in the vicinity of the major distributaries and, as these shift, the ocean erodes back into the delta and reworks these deposits. Again the character of the reworked deposits is largely dependent upon the material within the delta undergoing erosion. If a sufficient quantity of sand is available, delta platform sands (Fisk, 1955, fig. 1) are formed. These sands are marine in character (commonly supporting a large fauna) and are typically thick and massive in appearance. The "fines" winnowed out from this reworked zone are transported seaward where they are deposited on the adjacent shelf. In many respects these fine-grained deposits resemble the bottomset beds of the active delta but are typically much more fossiliferous.

### GEOLOGIC SETTING

The Atlantic Coastal Plain physiographic province consists of a thick wedge of unconsolidated sediments which borders the eastern United States. The wedge is highly variable in thickness, for the most part due to large-scale irregularities in the crystalline basement which underlies the Coastal Plain (Figure 2). As can be seen, the basement is warped into a series of broad troughs and arches along the entire Atlantic seaboard. The thickest accumulations of sediment occur in the troughs and the thinnest on the arches. Two large structural elements control sediment thickness in New Jersey, the south New Jersey uplift and the Raritan embayment. On this trip we shall see the effects of this embayment on deltas in this particular area (Figures 3 and 4).

TERTIARY	<p>Cohansey Sand</p> <p>Kirkwood Formation</p> <p>Manasquan Formation</p> <p>Vincentown Formation</p> <p>Hornerstown Sand</p>		
UPPER CRETACEOUS	<p>Red Bank Sand</p> <p>Tinton Sand</p> <table border="1" style="margin-left: 40px;"> <tr> <td>Shrewsbury Member</td> </tr> <tr> <td>Sandy Hook Member</td> </tr> </table> <p>Navesink Formation</p> <p>Mount Laurel Sand</p> <p>Wenonah Formation</p> <p>Marshalltown Formation</p> <p>Englishtown Formation</p> <p>Woodbury Clay</p> <p>Merchantville Formation</p> <p>Magothy Formation</p> <p>Raritan Formation</p>	Shrewsbury Member	Sandy Hook Member
Shrewsbury Member			
Sandy Hook Member			

Figure 5. Sedimentary marine and continental formations which crop out in the Coastal Plain of New Jersey.

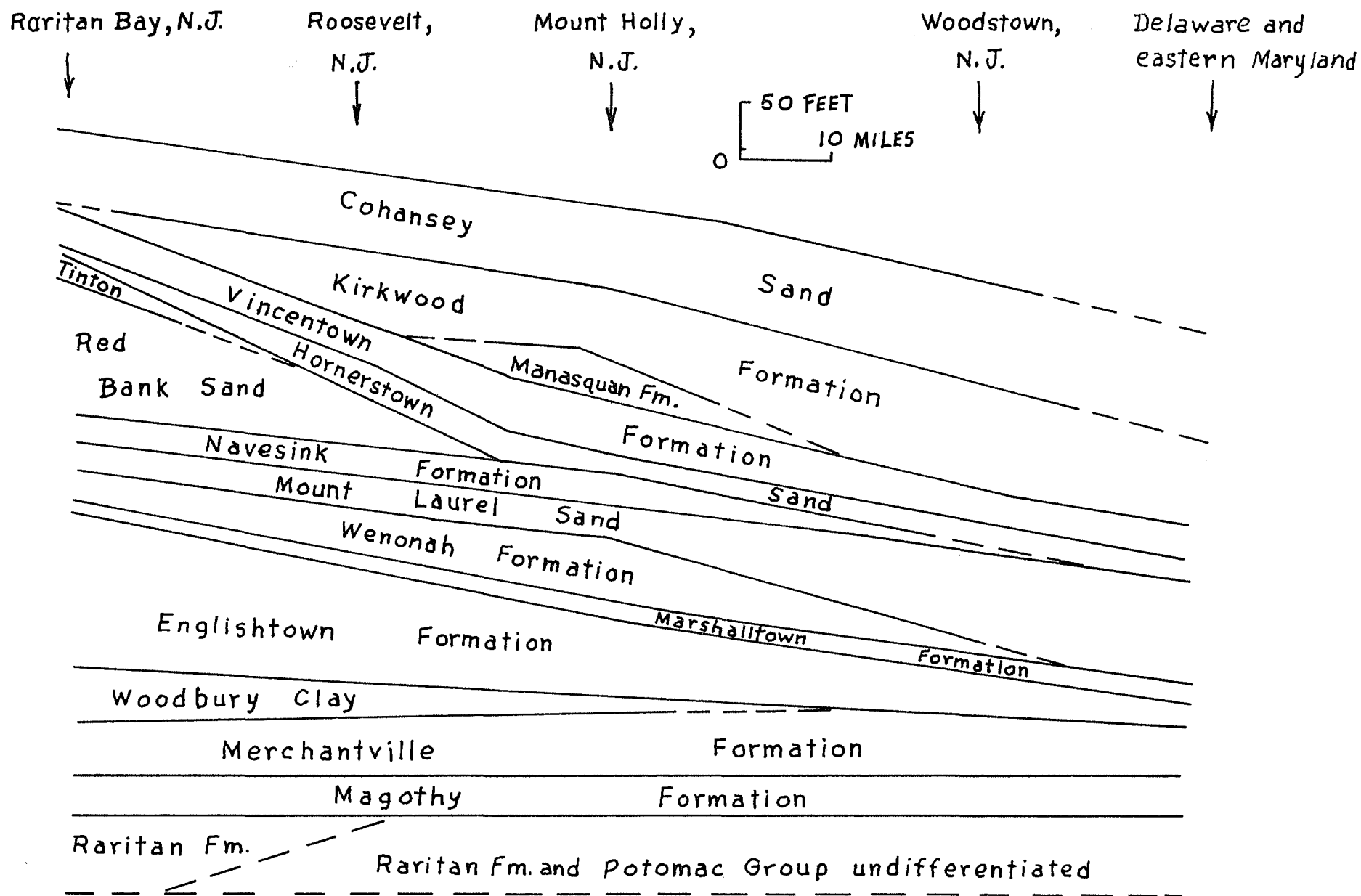


Figure 6. Generalized cross section from Raritan Bay to eastern Maryland showing the approximate thicknesses and lateral relations of the Coastal Plain formations.

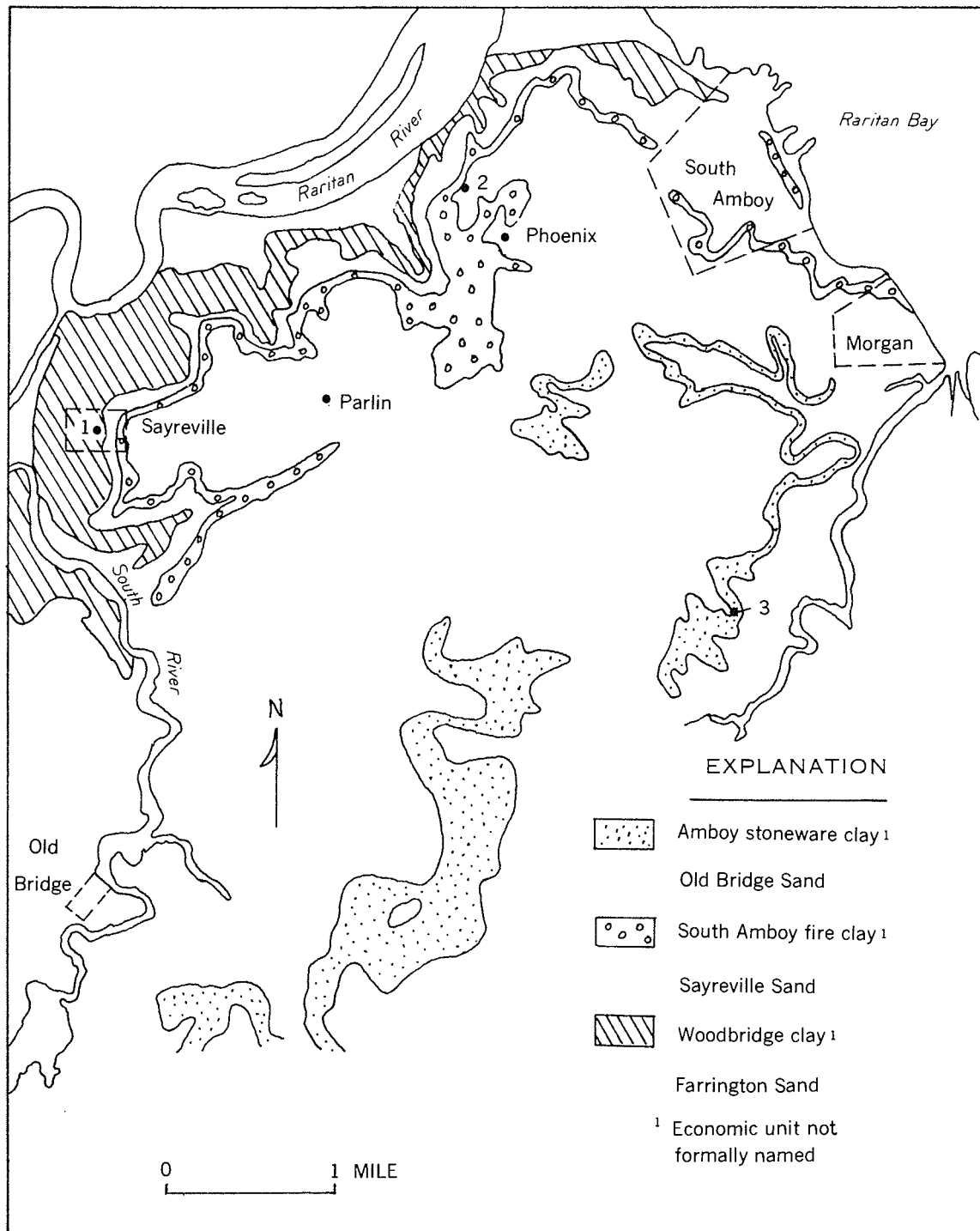


Figure 7. Generalized geologic map of the clay units of the Raritan Formation as mapped by Kümmel in 1902-03 (from Kümmel and Knapp, 1904, pl. XI). Stratigraphic position of the intervening sand members are shown in the explanation. All the clay beds are shown except the basal Raritan fire clay. Outcrops which will be visited on this trip are numbered (1-3).

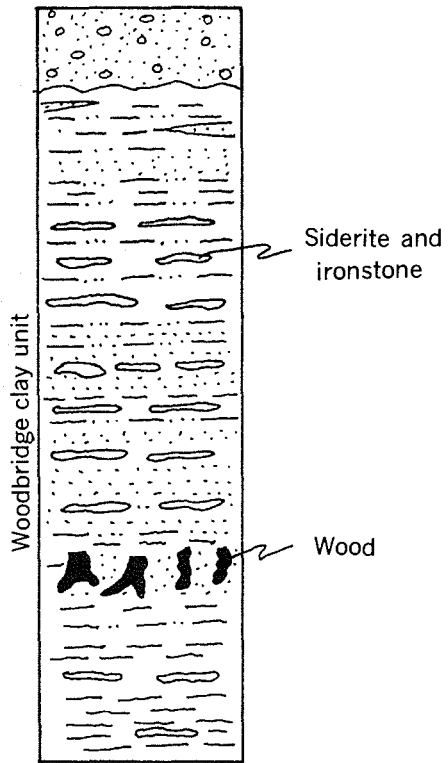


Figure 8

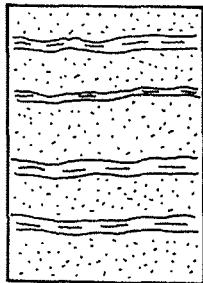


Figure 10

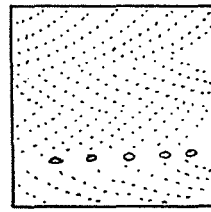


Figure 9

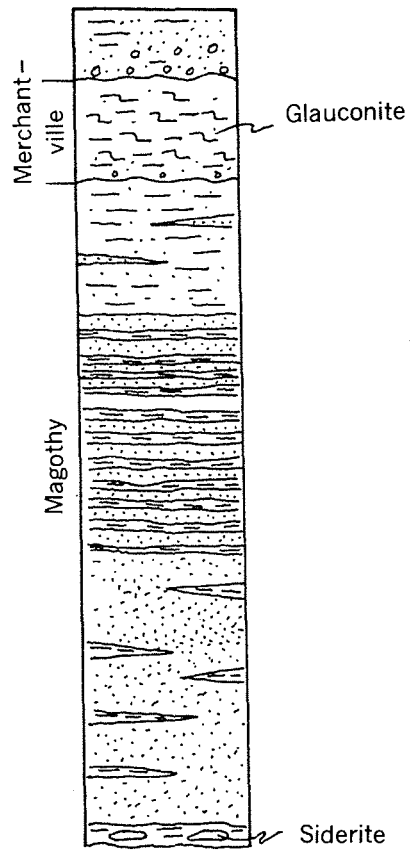


Figure 11

## PHYSICAL STRATIGRAPHY

The stratigraphic units which crop out in the New Jersey Coastal Plain are shown in Figure 5. Not all these formations are present everywhere in the New Jersey Coastal Plain; their distribution is shown in the generalized cross-section (Figure 6). As might be expected, a thicker accumulation of sediment, with more stratigraphic units, is present in the Raritan embayment than on the south New Jersey uplift.

On this field trip we shall be primarily interested in the lowest units shown in Figures 5 and 6, the Raritan, Magothy, and Merchantville Formations. Because of the thickness of the Raritan Formation, the areal distribution of its members have been reproduced (Figure 7) from the map by Kummel (Kummel and Knapp, 1904, pl. XI). It is within these members and in the two overlying formations that the deltaic characteristics are so well developed.

At the last stop on the field trip we shall examine younger shelf deposits which are typical of a large part of the New Jersey Coastal Plain. These deposits, in part, illustrate the lithofacies produced during the reworking of the deltaic deposits (delta platform sands and inner-shelf deposits).

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Explanation of Figures 8 - 11.

Figure 8. 60 foot section of the Woodbridge clay unit as seen at STOP 1. Gravel above.

Figure 9. 20 foot section of the cross-stratified Sayreville Sand Member as seen at STOP 2.

Figure 10. 25 foot section of the Morgan beds as seen at STOP 3.

Figure 11. 33 foot section of the Magothy Formation as seen at STOP 4. Merchantville Formation and gravel above.



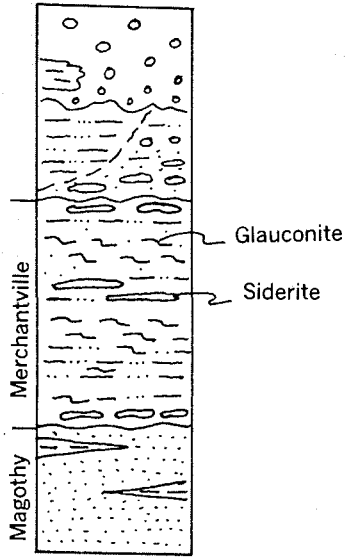


Figure 12

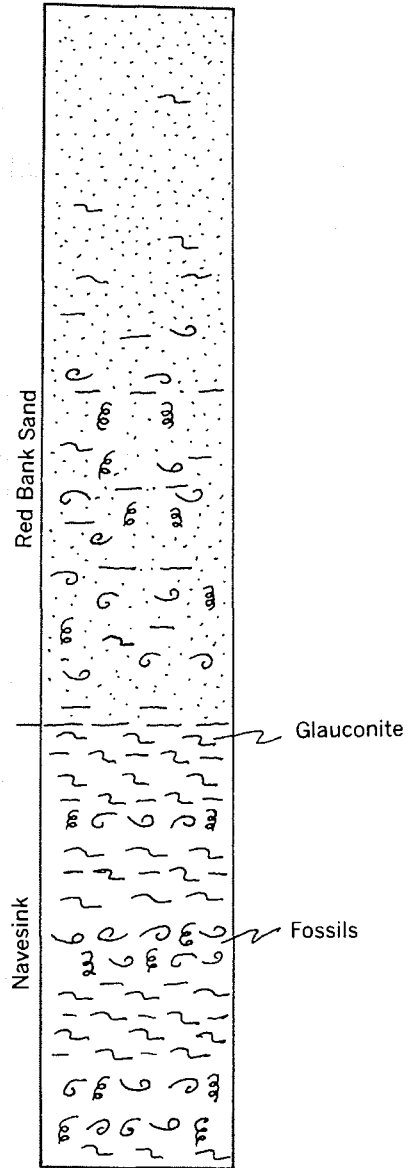


Figure 13

Explanation of Figures 12 and 13.

Figure 12. 20 foot section of the Merchantville Formation as seen at STOP 5. Magothy Formation below, Woodbury Clay spoil and gravel above.

Figure 13. 15 foot section of the Navesink Formation overlain by 25 feet of the lower part of the Red Bank Sand as seen at STOP 6.

-----

ROAD LOG

Mileage.

0.0		Proceed south from New York City; exit from the Garden State Parkway (GSP) at interchange 123 on Route 9.
0.3	0.3	Right on South Amboy Road.
1.0	0.7	Right on Ernston Road.
1.6	0.6	Left on Washington Road.
3.3	1.7	Right on first through road.
4.2	0.9	Left on Main Street.
4.5	0.3	Turn left into large pit. Walk to back of pit.

STOP 1. Woodbridge clay of the Raritan Formation (Figure 8).  
Section as follows:

5-10 feet of sand and gravel of the Pensauken Formation.

30-40 feet of interbedded sand and clay of the Woodbridge unit of the Raritan Formation. Numerous layers of siderite and iron oxide-cemented sand are present. Some sand layers contain marine fossils. Interpreted as prodelta-bottomset beds.

5-6 feet of sand and clay containing much wood. Some wood appears to be in an upright position. Probable marsh deposits.

20 feet of dark-gray clay which is weathered at the top. Possible lagoonal origin.

Return east along Main Street.

8.0	2.5	Turn left into Phoenix pit. Drive north about 0.5 mile into main pit area.
	1.0	

STOP 2. Sayreville Sand Member of the Raritan Formation (Figure 9). Section as follows:

20-40 feet of cross-stratified sand exposed in the pit walls. Interpreted as channel-fill and spit facies.

Return to Main Street, turn left and proceed east.

- |      |            |   |
|------|------------|---|
| 9.2  | 1.2        | Turn right on Route 9 (Main Street) at junction with Route 35; proceed south about 2-1/2 miles. |
| 12.7 | 2.5<br>1.0 | Turn left into Madison Township dump road. Drive about 0.5 mile to pit and dump area.           |

STOP 3. Laminated beds of sand and clay of the Morgan beds (Berry, 1906) in the lower part of the Magothy Formation (Figure 10). Section as follows:

15-25 feet of alternating beds of yellow-brown to light-gray micaceous quartz sand and clay. A considerable amount of carbonaceous matter is present throughout. Interpreted as natural levee deposits.

Return to highway (Route 9); turn left (south).

- |      |     |  |
|------|-----|--|
| 13.1 | 0.4 | Bear left onto Morristown Road; keep curving left.   |
| 16.1 | 3.0 | Turn right (east) after rounding 90 degree turn to left.   |
| 16.4 | 0.3 | Angle slightly left at fork in road. Continue on Cliffwood Avenue crossing the GSP and Route 35. |
| 19.0 | 2.6 | End of road at beach. Walk to left (northwest) along beach about 100 yards to bluff.             |

STOP 4. Magothy Formation overlain by several feet of Merchantville Formation and Pleistocene sand and gravel (Figure 11). Section as follows:

5-6 feet of Pleistocene silt, sand, and gravel.

5-6 feet of dark-greenish-black quartz-glaucanite sand of the Merchantville Formation. Interpreted as prodelta to open shelf deposits.

8 feet of dark-gray clay with some sand partings.

12 feet of alternating dark-gray to black clay and light-gray quartz sand layers. Layers are about 1/4 to 1/2 inch thick. Pyrite nodules are present throughout.

12 feet of white to light-gray quartz sand with some lignite and clay layers. The above 32 feet of the Magothy is interpreted as topset and foreset beds.

1 foot of gray-black clay with light-gray quartz sand and siderite concretions (exposed at low tide). Fossils are present in the siderite. Interpreted as prodelta and bottomset beds.

Turn around at dead end and return along Cliffwood Avenue.

- |      |     |   |
|------|-----|---|
| 21.6 | 2.6 | Turn right (north) after crossing Route 35 and the GSP.                                     |
| 22.2 | 0.6 | Angle right after recrossing over the GSP and immediately turn right into the Oschwald pit. |

STOP 5. Merchantville Formation overlain by several feet of Pleistocene sand and gravel and spoil from the Woodbury Clay (Figure 12). Section as follows:

5-10 feet or more of Pleistocene sand and gravel and disturbed Woodbury Clay. Apparently was disturbed and intermixed during excavation or subsequent pushing aside.

20 feet, plus or minus, of dark-greenish and grayish-black sandy silt and clay and sandy clay of the Merchantville Formation. Contains abundant mica, glauconite, and layers of siderite. Interpreted as prodelta and bottomset deposits.

Several feet of the upper, weathered sand and clay layers of the Magothy can be seen near the entrance of the pit.

Return to road, turn left and cross over the GSP.

- |      |     |  |
|------|-----|--|
| 22.8 | 0.6 | Turn left on Cliffwood Avenue; recross the GSP.  |
| 24.4 | 1.6 | Turn right (southeast) on Route 35.  |
| 28.6 | 4.2 | Turn right (south) on Kings Highway.   |
| 29.5 | 0.9 | Turn right (south) on Middletown Road. Pass railroad station.  |
| 31.3 | 1.8 | Park in space at right side of road just short of Poricy Brook (northwest corner of the Long Branch quadrangle). Walk downstream along Poricy Brook about 100 yards to a high bank on the southwest side of the brook. |

STOP 6. Upper Navesink Formation overlain by lower part of the Red Bank Formation (Figure 13). Section as follows:

25 feet of the lower part of the Red Bank Formation (Sandy Hook Member). Mostly fine-to medium-grained quartz sand

with considerable feldspar, much mica (green and colorless), and some glauconite, particularly in the base. The upper part of the section is weathered to brown, the lower part is dark-gray. Micro-fossils and small megafossils and shell fragments are abundant in the dark basal part, and this unit is more clayey and compact.

15 feet of greenish-black, clayey, glauconite sand of the Navesink Formation. Several shell beds are present. Exogyra, Pycnodonte, Ostrea, Choristothyris, and Belemnitella are common. (The total thickness of the Navesink is about 25 feet here).

These sediments are interpreted as open shelf marine deposits beyond the laminated prodelta beds. Except for the shell beds there is a lack of conspicuous bedding. The abundance of glauconite is suggestive of deeper water and more uniform sedimentation.

End of field trip.

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## TRIP C: THE TRIASSIC ROCKS OF THE NORTHERN NEWARK BASIN

By E. Lynn Savage, Brooklyn College of The City University of New York

## INTRODUCTION

Objectives of the Field Trip.

Outcrops to be visited on this trip have been selected to illustrate some of the problems involved in the interpretation of Triassic rock units and facies in the northern Newark Basin. (Figure 1). Where possible emphasis is directed toward general Triassic problems, as well as to those which are unique to the northernmost area of this basin.

Although it is generally accepted that much of the Triassic has been removed by erosion, there are two contrasting ideas as to whether the present northeastern end of the Newark Basin marks the former extent of the sediments:

- (1) The present outcrop area is almost the same as the original extent (McLaughlin, 1957, p. 1498; Glaeser, 1966, p. 101).
- (2) The sediments were once much more extensive, covering the area between the New Jersey-New York Trough and the Connecticut Trough (Sanders, 1963, 1960; MacLachlan, 1957, p. 13; Wheeler, 1938).

Nomenclature.

Currently there is need for reevaluation of the use of the formational names, Stockton, Lockatong, and Brunswick. These units were originally believed to represent a time sequence. Subsequently they were found to be "interfingering facies. . . . the Stockton in part contemporaneous with the lower portion of the Brunswick. The Lockatong is entirely contemporaneous with a part of the Brunswick" (Reeside, 1957, p. 1459).

Attempts to avoid the time significance which had been assumed for the three formations have led to different proposals. Reeside (1957, p. 1459), Perlmutter (1959, p. 7) and Van Houten (1965, pp. 832-833) use formation for the three rock units; Glaeser (1966, pp. 6-11) uses lithosome for Brunswick and Lockatong, but formation for Stockton; and Savage (1967, p. 3) uses lithosome for all three units.

The most recent evidence, as illustrated on this trip, indicates that in Bergen County, New Jersey, the Lockatong unit interfingers with the Stockton arkose. (Figure 2). This reemphasizes the need to eliminate time significance from the names Stockton, Lockatong and Brunswick before alternative designations can be evaluated. For example, lithosome, which refers to "masses of essentially uniform lithologic character that interfinger with adjacent masses of different lithologies" (Krumbein and Sloss, 1963, p. 301) is applicable, but its use is deferred until the downdip relationships of the units are better understood. In the present report the term with priority, formation, is applied to all three units and used properly as a rock stratigraphic unit without time significance.

BUREAU OF GEOLOGY & TOPOGRAPHY

'NEW JERSEY

LEGEND

TOPOGRAPHY

— 130 — U.S. ROADS

— 69 — STATE ROADS

— 579 — COUNTY ROADS

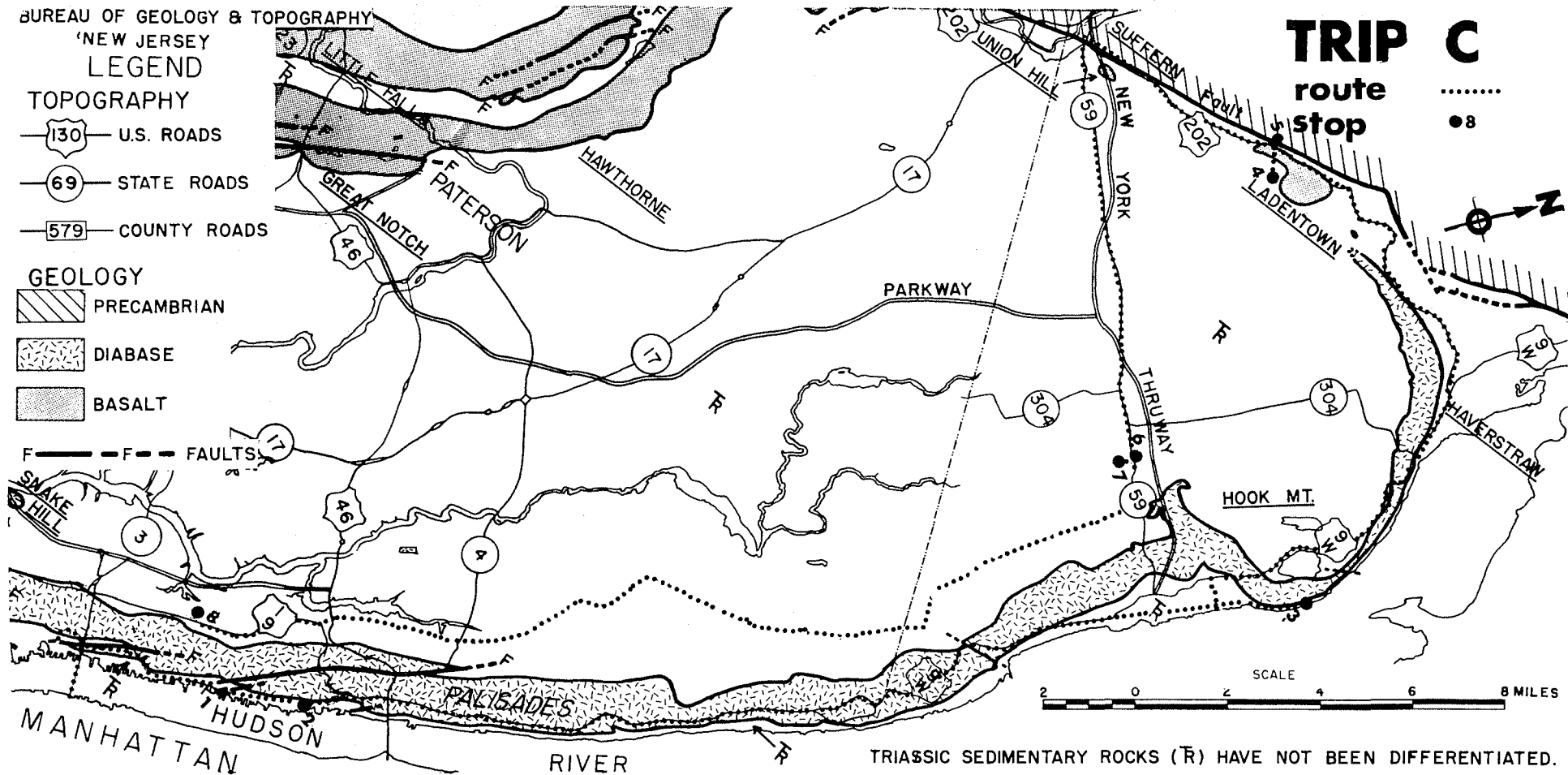
GEOLOGY

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**TRIP C**

route  
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TRIASSIC SEDIMENTARY ROCKS (R̄) HAVE NOT BEEN DIFFERENTIATED.

FIG. 1 NORTHERN NEWARK BASIN: TRIP C, ROUTE AND LOCATION OF STOPS

### Acknowledgements.

All recent information related to the Lockatong Formation, including stratigraphy, petrology, sections, and interpretation, and Figure 2, is credited to Dr. F. B. Van Houten. He also made a few petrographic studies of the Brunswick rocks in Rockland County, N. Y., and pointed out certain aspects of the geology that had not been evident to the writer.

Much of the information for Rockland County, N. Y., including stratigraphy, petrology, sections and interpretation, is from the writer's Ph. D. dissertation (Savage, 1967).

Special thanks are also due to the writer's students and those of Dr. F. B. Van Houten who helped with the preliminary field work for this trip.

### Geographic Setting.

The field trip route is located in the northernmost part of the Newark Basin and generally delineates a figure 1. It starts in the vicinity of Edgewater, Bergen County, New Jersey, at the base of the Palisades, continues to the north across the Rockland County, N. Y. boundary to Nyack, then turns westerly along the north rim of the Palisades to the western boundary of the Basin, then southwesterly near the foot of the Ramapo Mountains to Suffern, then turns east until the backslope of the Palisades is reached. Here, the route again turns south to the vicinity of North Bergen (Granton). (See Figure 1.)

### Topography.

As in other eastern Triassic intermontane basins, the basalts, diabase, sandstones, argillites (Argillite: "an unusually tough mudstone" Van Houten, 1965, p. 828), and conglomerates generally form northeast trending rolling hills and ridges. At Nyack, however, the Palisades arc into a sickle-shaped ridge trending westward across the basin (see Figure 3).

The valleys which commonly are 150-200 feet below the nearby hills, are underlain by rocks composed mostly of clay and silt, called mudstone in this paper. (Mudstone: "a massive aphanitic rock composed of an unspecified mixture of silt and clay. Shale - a fissile mudstone." (ibid).)

In the area west of the Palisades, thick accumulation of drift covers much of the area, concealing bedrock in the valleys and adding to the problems of correlation. Kummel (1897, p. 17) reports that the relief under the drift is more rugged than that of the present topography.

The width of the Palisade Sill outcrop varies, but generally is from less than 1/2 mile to 1 mile wide. It is widest at West Nyack where it is 2 miles in width. In New Jersey, the ridge has a very even crest, generally devoid of gaps, that becomes higher in elevation northward from sea level at Staten Island to 333 ft. at Ft. Lee, 433 ft. at Englewood, to its maximum height of about 550 ft. 1-3/4 miles south of the New York border (Kummel 1897, p. 61). In contrast to that crest-line, the Palisades ridge in New York is cut by many gaps, the deepest of which is the 200-foot gap at Sparkill which nearly reaches sea level. Four gaps east of Rockland Lake between Nyack



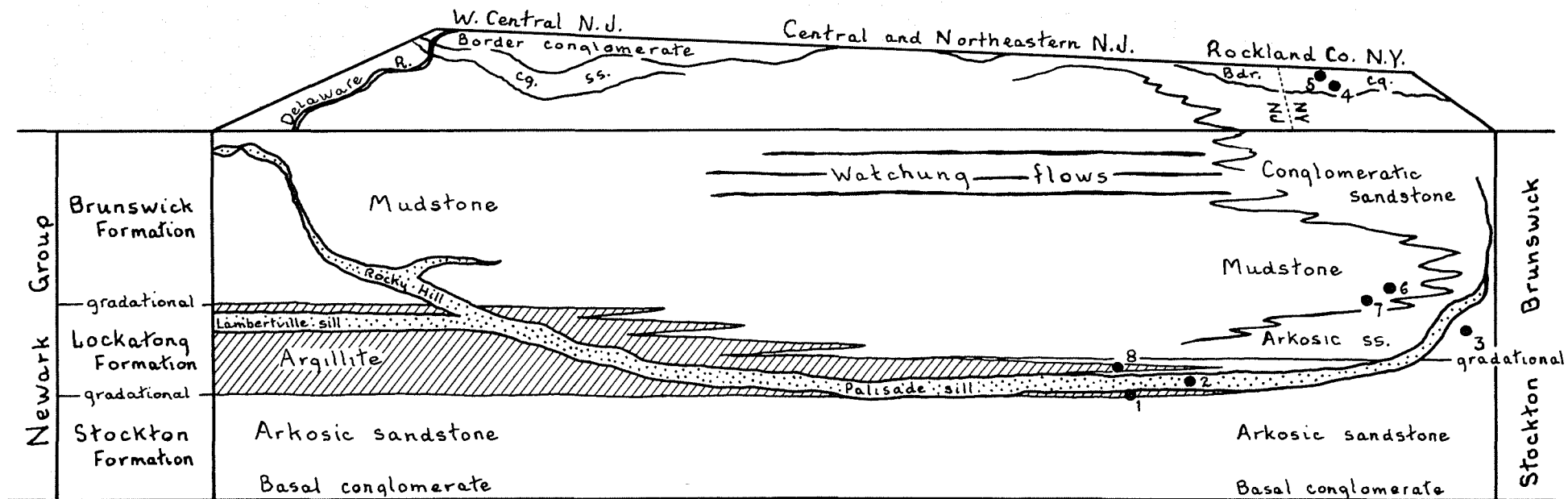


Figure 2. Schematic block diagram of Triassic Formations and lithofacies in Newark Basin, New Jersey and adjacent New York. Restored as before faulting, warping and tilting. Looking northwestward toward northwest border of the basin. Thicknesses relative. 01 - stops.

and Haverstraw, range from 190 to 230 ft. in elevation. Most of the knobs that make up the rest of the ridge in New York are from 600-700 ft. above sea level. Little Tor reaches 710 ft. and Verdreitege Hook (Hook Mountain, STOP 3) reaches 730 ft. From High Tor, where the ridge has its maximum elevation (832 ft; Kúmmel, 1897, pp. 22-23), the crest again descends and finally disappears below the glacial cover.

## ROCK UNITS

### The Triassic Sedimentary Rocks.

The Stockton Formation which is about 5000 feet thick in eastern Pennsylvania and western New Jersey, is much thinner in Bergen and Rockland Counties where it is found near the Palisade Sill, and mainly between the lower contact of the sill and the Hudson River which conceals the base of the formation. It apparently does not crop out north or west of Piermont for here it is overlain by a sequence gradational between the uppermost Stockton and the lowest Brunswick Formations (Savage, 1967, p. 34).

In eastern Pennsylvania and western New Jersey the Lockatong Formation is up to 3750 ft. thick. In northeastern New Jersey it has only recently been recognized in drill core at Newark where it is about 500 ft. thick, in a 90-foot thick section in the Granton Quarry, Bergen County (STOP 8) (Van Houten, 1964, p. 500) and in a section that is about 60 ft. thick near Edgewater (STOP 1). At the latter localities, it apparently interfingers with the upper part of the Stockton Formation. The Lockatong has not been found elsewhere in northern Bergen County or in Rockland County.

The Brunswick Formation (7000 ft. thick in western Pennsylvania and central New Jersey) underlies most of the northern Newark Basin. In Rockland County it consists of a very coarse lithofacies. Figure 2 illustrates the relationships between these rocks prior to tectonic disturbance and erosion.

1. The Stockton Formation. In the field trip area the Stockton Formation is exposed only above and below the Palisade Sill in a narrow outcrop belt. Its base is concealed by the Hudson River. The Stockton Formation here consists mainly of fairly well-sorted fine-to coarse grained yellowish-gray to pale orange, thick-bedded arkose, interbedded with reddish-brown and pale lavender silty and shaly mudstones. The latter are commonly altered to hornfels many feet from the Palisade Sill whereas the arkoses only a few feet from the contact are relatively unaffected.

Mudstone-arkose contacts, such as are found at Sneden's Landing, New York, are usually irregular, showing local erosion and scouring.

Scattered pebbles at Sneden's Landing include angular grains of quartz and of fresh pink orthoclase up to 1 inch in diameter. Feldspar in the sand and silt size fractions appears to be fresher, and the quartz mainly clearer, without strain and with fewer inclusions than that in stratigraphically higher arkoses northwest of Piermont. In addition, an abundance of zircon, rutile, and authigenic anatase, a paucity of tourmaline and garnet and an absence of metamorphic fragments, contrasts with mineral frequencies in Brunswick arkoses (Figures 5-10; Savage 1967, pp. 104-121).

Cleyposaurus (Rutiodon), a phytosaur, was found in the arkose just south of the base of the George Washington Bridge and is now on display at the American Museum

of Natural History.

2. The Lockatong Formation. A thin extension of hornfelsed Lockatong argillite into Bergen County, New Jersey is well exposed in the Granton Quarry (STOP 8), where it is preserved between the top of the Palisade Sill and a smaller sill above it. This hornfels facies also occurs under the Palisade Sill from Weehawken to Edgewater. The Lockatong Formation apparently is absent farther north in the Newark Basin.

In western New Jersey and eastern Pennsylvania these rocks reach a total thickness of about 3750 ft. and conformably overlie the Stockton Formation (Van Houten 1965, p. 826), and interfinger extensively with the Brunswick Formation. In north-eastern New Jersey exposures, they are interbedded with the Stockton Formation; the contact with the Brunswick is concealed by glacial drifts.

Where the Lockatong Formation is absent in Rockland County, New York, the Stockton arkose grades up into the Brunswick Formation.

Readily distinguished from the other formations by its distinctive bedding and dark color, the Lockatong Formation consists of asymmetrical chemical and detrital cyclic units, usually occurring as bundles of similar cycles. A generalized single chemical cycle, from oldest to youngest, consists of dark gray to black shaly feldspathic limy mudstone, thin limy and dolomitic laminae, platy limy layers typified by syneresis brecciation, and an overlying analcime-rich argillite. Such cycles are found at Edgewater, New Jersey (STOP 1). A detrital cycle consists successively of black shale, platy dark gray carbonate-rich mudstone, and an upper tough gray massive calcareous silty mudstones, as seen in the Granton Quarry (STOP 8). Average thickness of cycles in western New Jersey is about 15 feet, but detrital cycles are somewhat thicker. Both have yielded readily to thermal metamorphism, the analcime-rich layers being particularly susceptible, (Van Houten 1964, p. 497). The conspicuous hornfelsing of the sequence at Granton was no doubt due in part to its being sandwiched between two sills.

Varve counts of the chemical cycles suggest that short cycles (15 ft. thick) average 21,000 years and seem to correlate with cycles of precession, as do cycles in the Green River Shale (Eocene) of the Rocky Mountain region. These short cycles appear to be grouped into larger cycles of 100,000 years duration and these into even larger clusters spanning 500,000 years (Van Houten 1964, p. 529).

The cycles are believed to record climatic variation resulting from precession of the equinox. Apparently the changes in the pattern of rainfall were imposed on deposits of a sinking lake basin of which the sediments of the field trip area represent a minor part. During moister periods, detrital cycles (similar to the finest Stockton facies), accumulated in open lakes of low salinity. The chemical cycles accumulated in closed lakes reflecting a change to drier climates (Van Houten 1964).

Cyzicus (Estheria) ovata, a branchiopod, and fish are common at Granton and at Weehawken (Nason 1888, p. 26). Icarosaurus, a gliding reptile, was recently collected in the Granton Quarry which has also yielded other reptiles now being studied.

(See Road Log, STOPS 1 and 8, for detailed mineralogy of this formation.)

3. The Brunswick Formation. The Brunswick Formation, which is a max-

imum of 8000 ft. thick, is exposed extensively in the Newark Basin. Typically it consists of soft reddish-brown shaly mudstone and interbedded red-brown sandstone which grade into coarse cobble conglomerates to the west near the Ramapo Fault that delimit the Triassic basin.

Except for a small triangle of Stockton deposits between the New York State border and the Piermont-Sparkill area, all of the Triassic sedimentary rocks of Rockland County comprise the Brunswick Formation. Here, the formation is generally coarser than anywhere else in the basin.

The Brunswick Formation has been divided into 4 lithofacies with subdivisions. In general, each lithofacies coarsens upwards. On the basis of heavy mineral and lithic content the lowest lithofacies is more closely related to the Brunswick than the Stockton deposits to which it was previously assigned. (Savage 1967, pp. 34-35). However, the lowest feldspathic Brunswick unit is different from the overlying coarser layers of the Brunswick as well. This will be discussed further in the section below on dispersal.

Figure 3 illustrates the 4 lithofacies which are modified after Savage (1967, p. 35). These are as follows, from oldest to youngest (east to west):

1. Arkosic lithofacies:
  - a. Reddish-brown, massive, well-sorted, medium to fine-grained, feldspathic sandstone, and red shaly silty mudstone. Rare coarser layers include quartz and feldspar clasts up to 1 inch in diameter.
  - b. Massive red and lavender micaceous siltstone, shaly and limy mudstone, and micaceous reddish-brown sandstone, interbedded with, and underlying, pale light gray to yellow-and greenish-gray arkose. Rare pebbly layers in the arkose include angular quartz (mainly 1 inch, but as much as 2-1/2 inches in diameter), angular pink orthoclase clasts up to 2 inches in diameter, and rare (1 inch) gray limestone clasts, pegmatite with book mica, schist (to 1 inch), quartzite, and red mudstone clasts. (STOP 3.) There is also a unique greenish-gray bed of pellets and clasts of silty mud, many of which contain a carbonate core. Burrowing is common in mudstone layers.
2. Red-brown silty shaly mudstone interbedded with red-brown and buff finely banded feldspathic sandstone, the latter with scattered quartz clasts 1/2 to 1 inch in diameter. Near the Palisade Sill the shaly mudstones are altered to hornfels. Rootlike structures and burrows occur in these deposits.
3. Red-brown gravelly sandstone and pebbly quartz conglomerate with rare lithic clasts (up to 1 foot in diameter). Among the clasts which consist mainly of (1 inch) quartz, quartzite, shale and Green Pond Conglomerate (Silurian), there are rounded pieces of fine to medium-grained dark red-brown fossiliferous sandstones (Devonian?). Just south of the Palisade Sill near Lake Lucille, granite gneiss and gabbro clasts were noted by the writer.

4. **Cobble Conglomerates:** There are two areas of cobble conglomerates: in each, limestone fragments predominate. The more northerly Stony Point outcrop may be somewhat lower stratigraphically than the westerly one. The Stony Point cobble conglomerates consist of shaly to silty gray limestone and quartzite clasts (up to 10 inches in diameter) in a matrix of red shaly limestone. The western cobble conglomerates consist mainly of light tan to gray cherty limestone and dolomite cobbles. The largest clasts presently exposed are over 4 feet in diameter; a 12 foot cobble has been reported, but most of the cobbles are less than about 1 or 2 feet in diameter. The cobbles also include pink and gray quartzite, purple-red quartz conglomerate (Green Pond, Silurian) and in vicinity of Suffern, amygdaloidal basalt. Along the eastern margin of outcrop of this conglomeratic lithofacies dark reddish-brown fossiliferous sandstone clasts (Devonian?) are found. These have not been found to the west where the highest strata of the unit are exposed. Apparently most of the Devonian(?) rocks had been stripped from the source area by the time the youngest conglomerate was deposited.

From southeast to northwest these surface outcrops provide a succession of changing facies deposited at different times. It is not known whether these facies also continue very far down dip of each unit, or whether the same rock types were continuous eastward in any deposit now eroded from the updip portions of the units. Moreover, interfingering relationships along strike are difficult to decipher because soil, glacial drift and urban development conceal basic data. Subsurface information is needed to determine the detailed stratigraphic relations of these facies.

The great variability of these nonmarine facies makes it very difficult to reach meaningful conclusions from the limited data, no matter how rigorously they are analyzed.

#### Note on Pebbles and Distribution.

The composition and distribution of clasts of pebble size and larger are illustrated in Figure 4. The sizes of the pebbles increases to a maximum between Suffern and the Ladentown area to the north. Rare clasts up to 1 foot in diameter occur as far east as the position of Spring Valley.

#### Note on Minerals and Distribution.

Quartz in the Brunswick Formation has more inclusions than that in the Stockton and is more strained. In addition, the angularity of grains increases (markedly to the north, at Stony Point the grains are shard-like). The quartz at Tomkins Cove appears strained.

Feldspars are increasingly weathered in the younger rocks from southeast to northwest in the lowest Brunswick facies. At Cherry Hill (STOP 6) the potash feldspar is weathered but the sodium feldspar is rather fresh. In general the Stockton has more fresh feldspar than the Brunswick.

The distribution of heavy minerals are illustrated in Figures 5, 6, 7, 8, and 9.

The varieties of heavy minerals in the Brunswick Formation include mainly

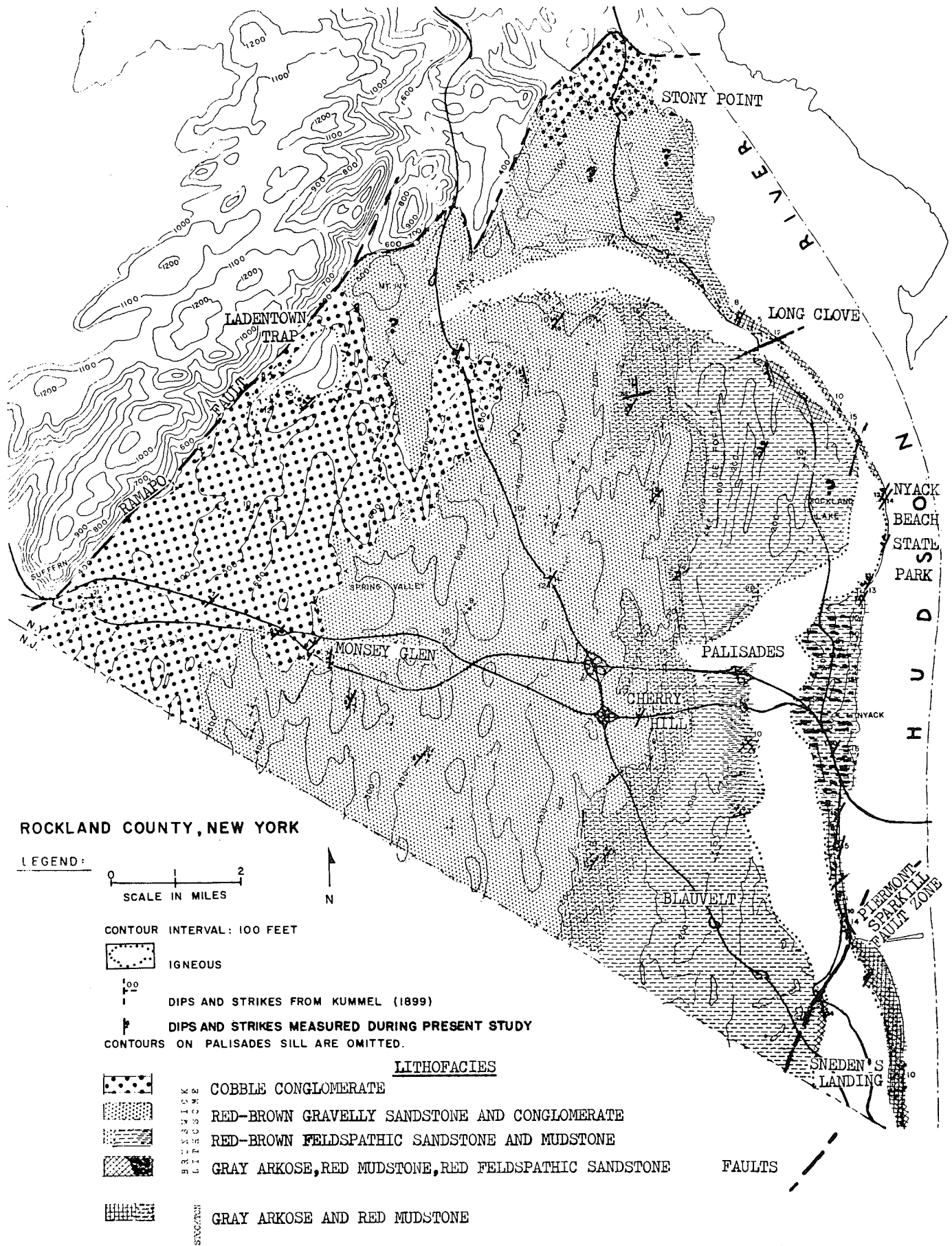


FIG. 3 GEOLOGIC MAP ILLUSTRATING DISTRIBUTION OF LITHOFACIES OF THE STOCKTON AND BRUNSWICK FORMATIONS (UPPER TRIASSIC) IN ROCKLAND COUNTY, NEW YORK

apatite, garnet, rutile, authigenic anatase, tourmaline and zircon, as well as hematite and magnetite. Rarer varieties included biotite, chlorite, very rare epidote and hornblende, muscovite, sillimanite(?), tremolite, and pyrite. Leucosene with (?)ilmenite cores frequently make up 15% of the fraction. (Savage 1967, pp. 104-115).

Garnet, never exceeding 18%, frequently is almandite found as dodecahedrons, as at Nyack (STOP 3). In general garnet appears to be more common to the north and northwest and at Nyack.

Rutile which is also abundant in the Stockton, is frequently found along with authigenic anatase in the Brunswick Formation. It often occurs as prismatic crystals.

Tourmaline varies from brown to green to indigo-blue indicolite. Green tourmaline is common in the Stockton; and in the Brunswick, it increases to the northwest. Brown tourmaline apparently is restricted to the Brunswick and is widespread throughout the formation. This common variety consists of prisms and broken fragments of larger grains. Indicolite, present in only minor amounts, is scattered throughout the Brunswick. Total percentages appear to increase in a northerly direction.

Zircon, which comprises as much as 16% of the Stockton heavy minerals, does not exceed 6% in the Brunswick Formation, but it appears to be somewhat more abundant in higher Brunswick strata to the west.

The ratio of sedimentary rock fragments to metamorphic rock is illustrated in Figure 10. The sedimentary varieties include red and brown shales, red shaly siltstones, pale siltstones. The metamorphic varieties include low-grade phyllite(?) frequently replaced by chlorite, quartzite with mosaics of strained quartz, both red and pale muscovite schists, schists with streaks of (?)magnetite, gneiss with streaks of magnetite, and possibly granite gneiss. Sedimentary rock fragments apparently are more common to the north whereas metamorphic rock fragments increase to the southwest (Savage, 1967, p. 115).

According to these data the heavy mineral content changes laterally within units, rather than vertically from unit to unit, except for zircon and possibly lithic fragments. Except for the Stockton and lowest Brunswick Formations where apparently some correlation may be possible, correlation by heavy mineral content appears to fail in the higher stratigraphic units.

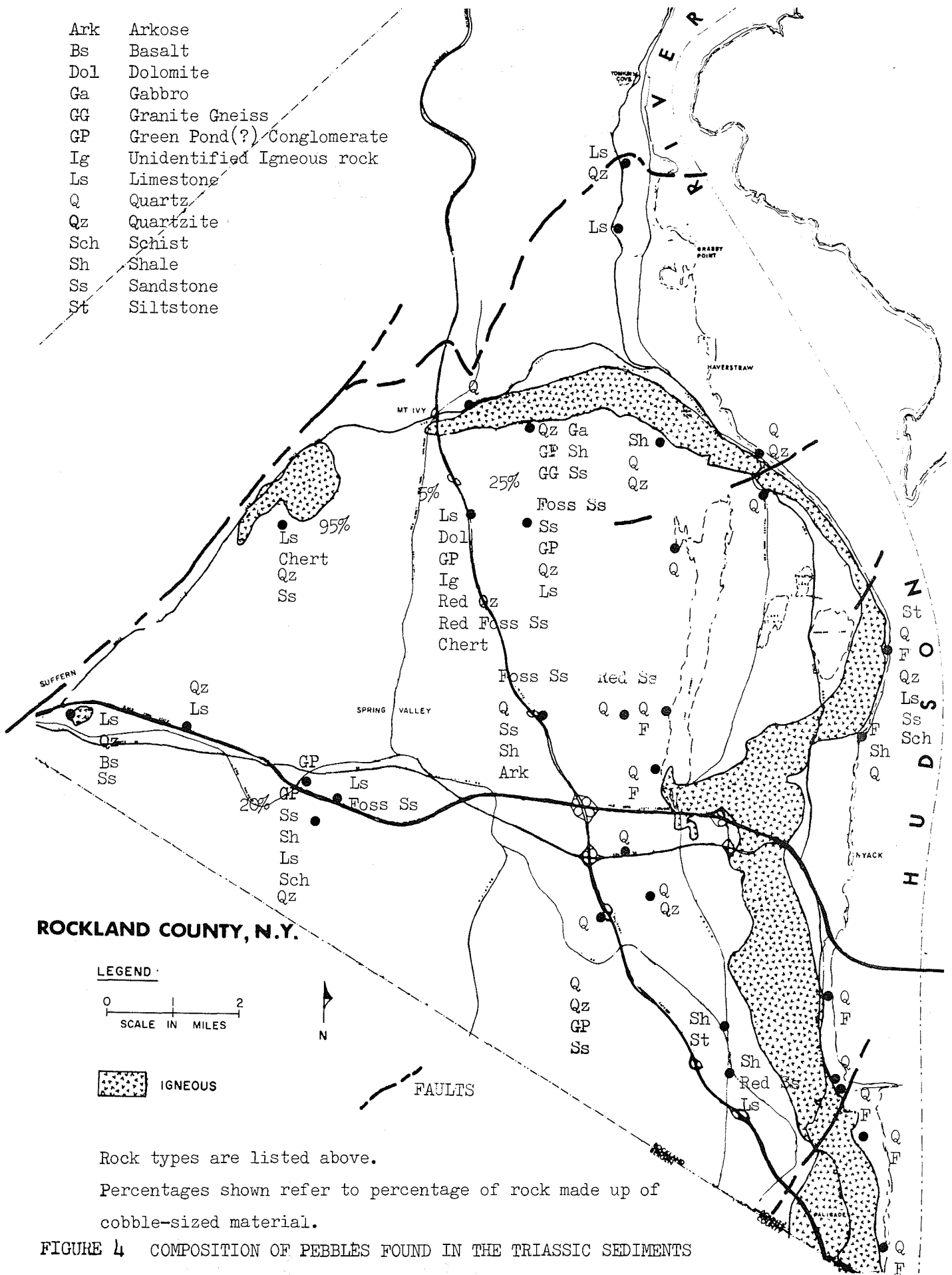
## IGNEOUS ROCKS

The igneous rocks of the Newark Basin include three lava flows in central New Jersey which may be synchronous with those of the Connecticut Valley. These flows apparently did not extend to the north in Rockland County, New York.

The Palisade intrusion is a sill throughout most of the Newark Basin but may be a dike in the Rockland County, New York area according to Lowe (1959). The rock type of the Palisade intrusion varies from basalt at its chilled borders to diabase in its interior. Gabbro has also been noted at Casper Hill, New York.

Within the field trip area, a zone of olivine diabase is present south of the Piermont-Sparkill area. The accumulation of the olivine by gravitational differentiation has recently been questioned and several theories have been proposed to explain its

- Ark Arkose
- Bs Basalt
- Dol Dolomite
- Ga Gabbro
- GG Granite Gneiss
- GP Green Pond(?) Conglomerate
- Ig Unidentified Igneous rock
- Ls Limestone
- Q Quartz
- Qz Quartzite
- Sch Schist
- Sh Shale
- Ss Sandstone
- St Siltstone





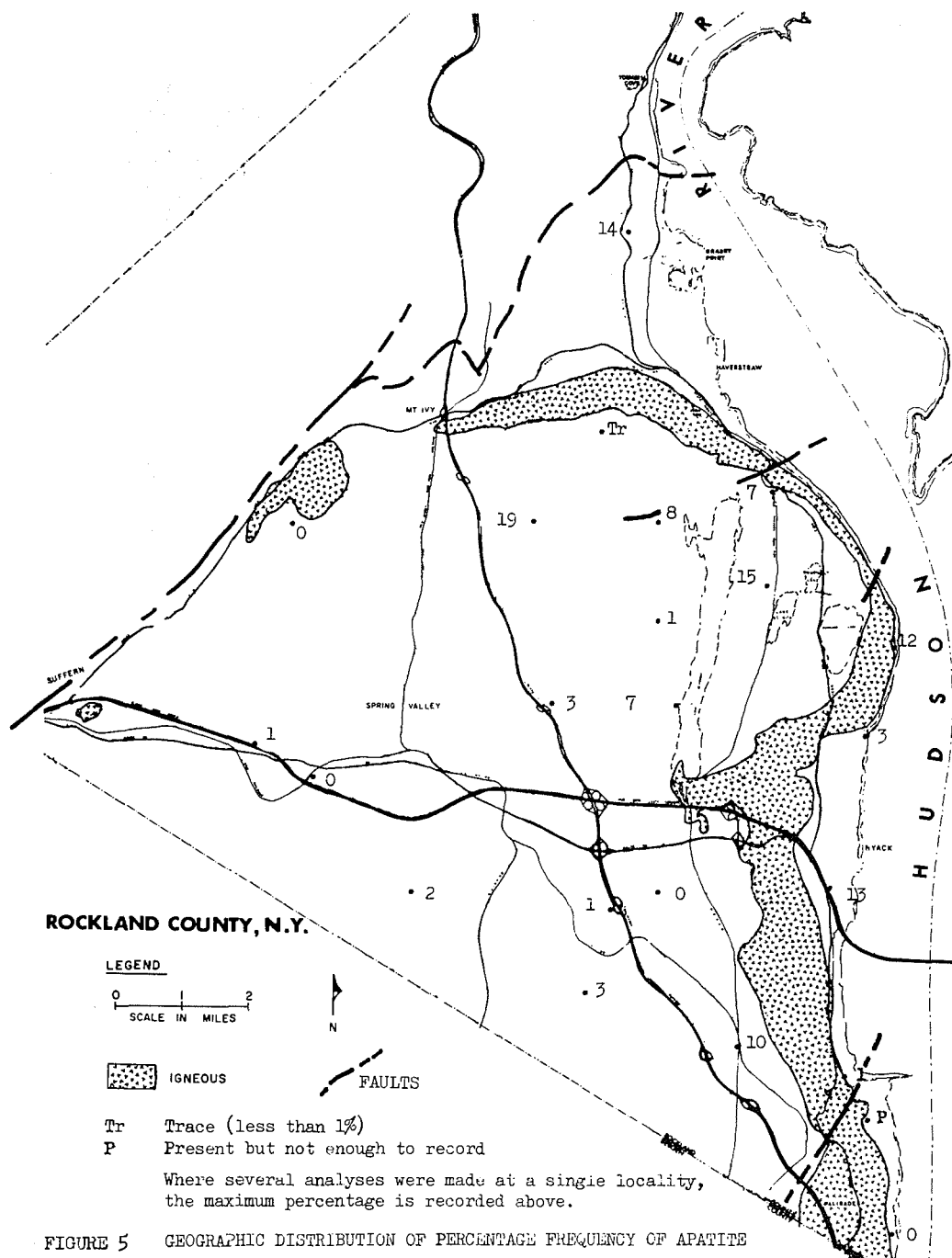


FIGURE 5 GEOGRAPHIC DISTRIBUTION OF PERCENTAGE FREQUENCY OF APATITE

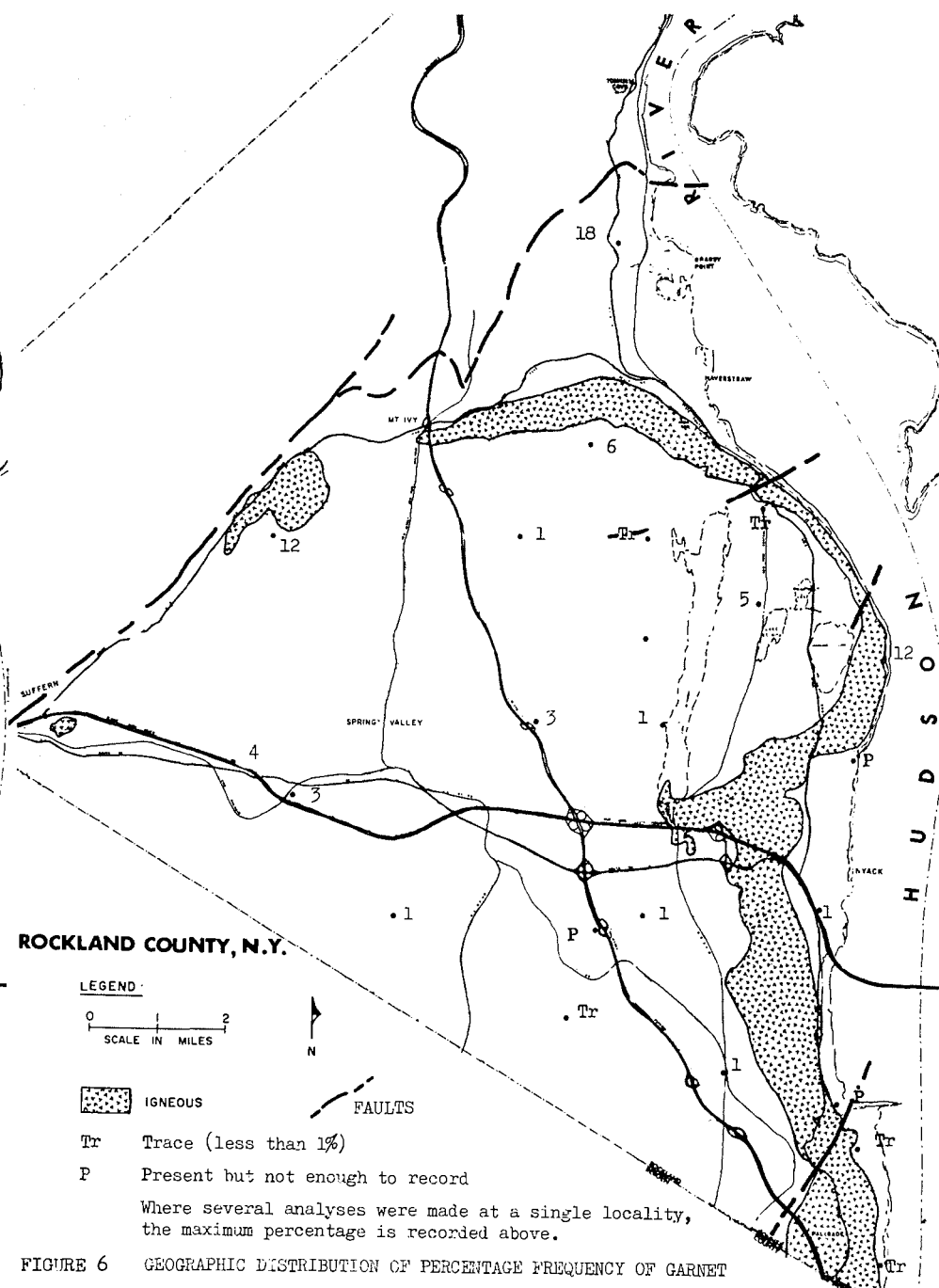
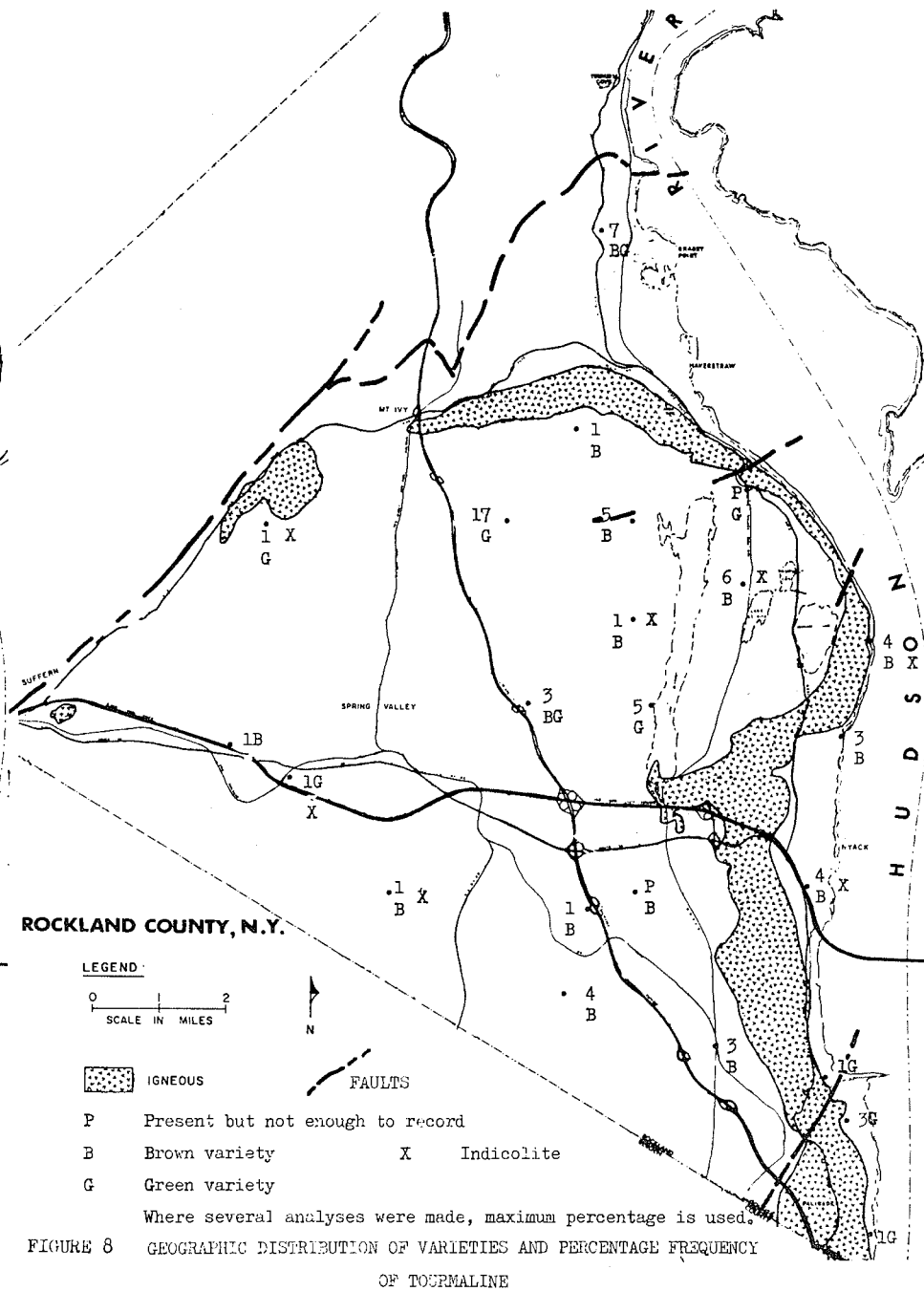
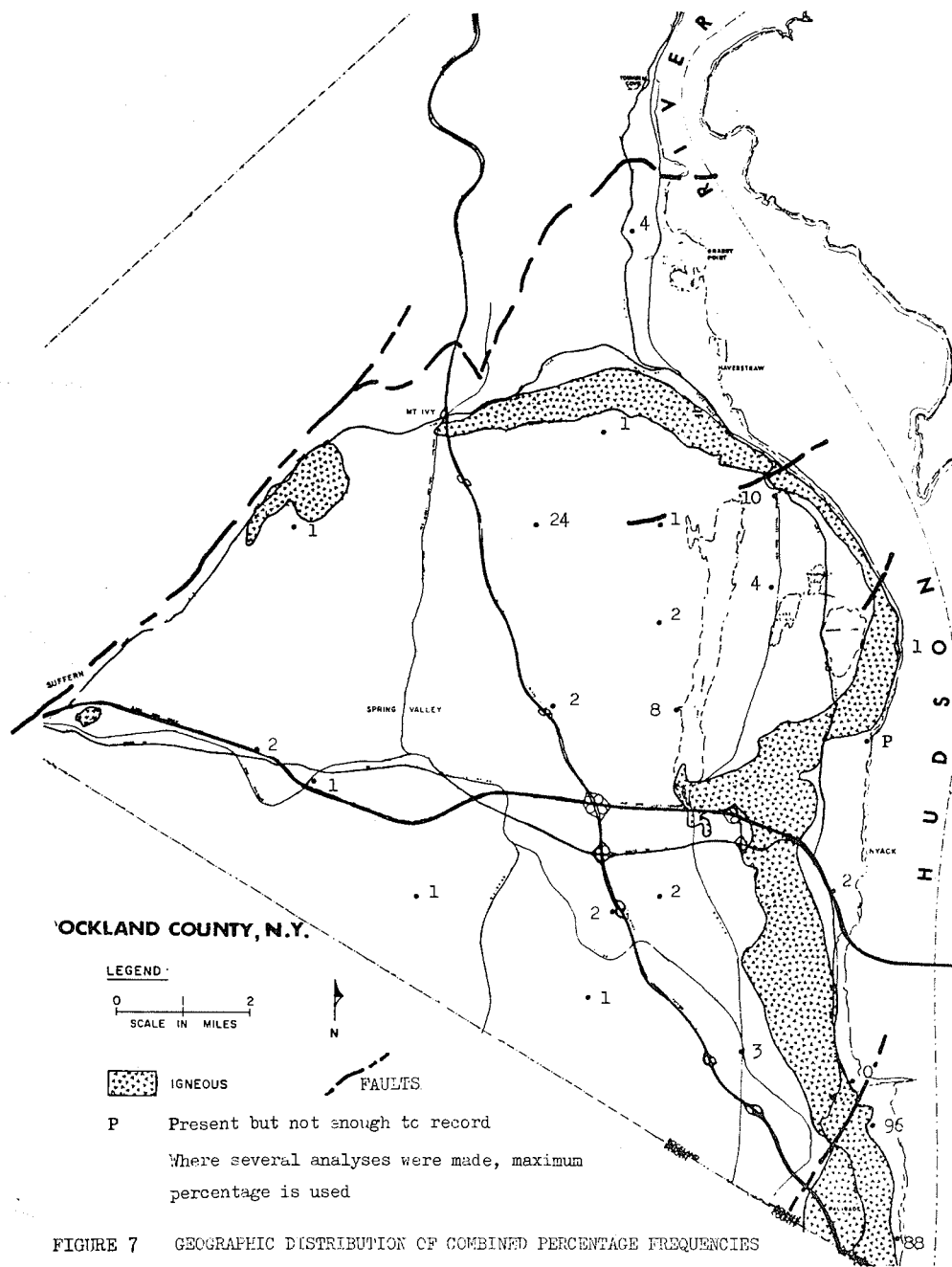


FIGURE 6 GEOGRAPHIC DISTRIBUTION OF PERCENTAGE FREQUENCY OF GARNET



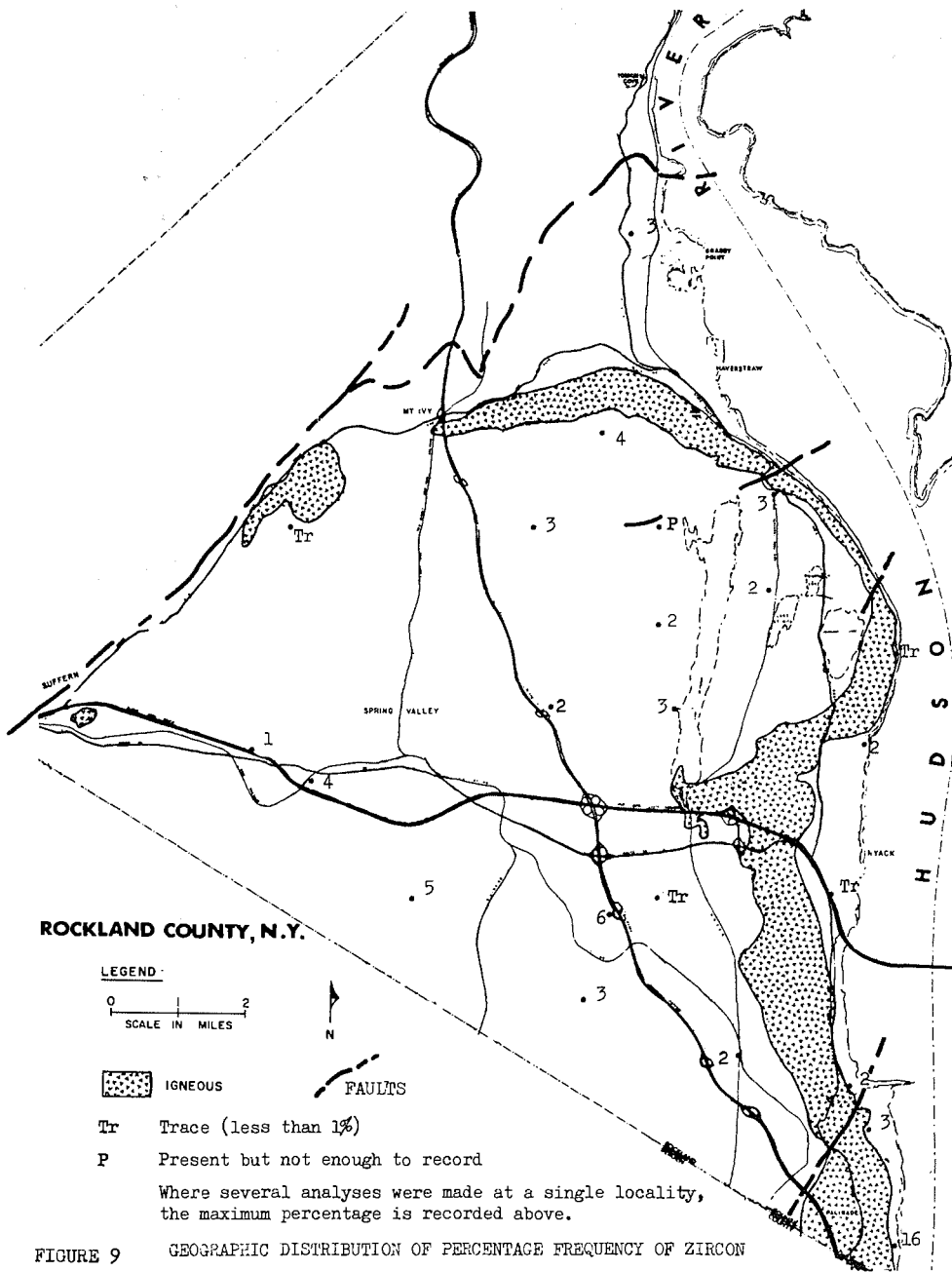


FIGURE 9 GEOGRAPHIC DISTRIBUTION OF PERCENTAGE FREQUENCY OF ZIRCON

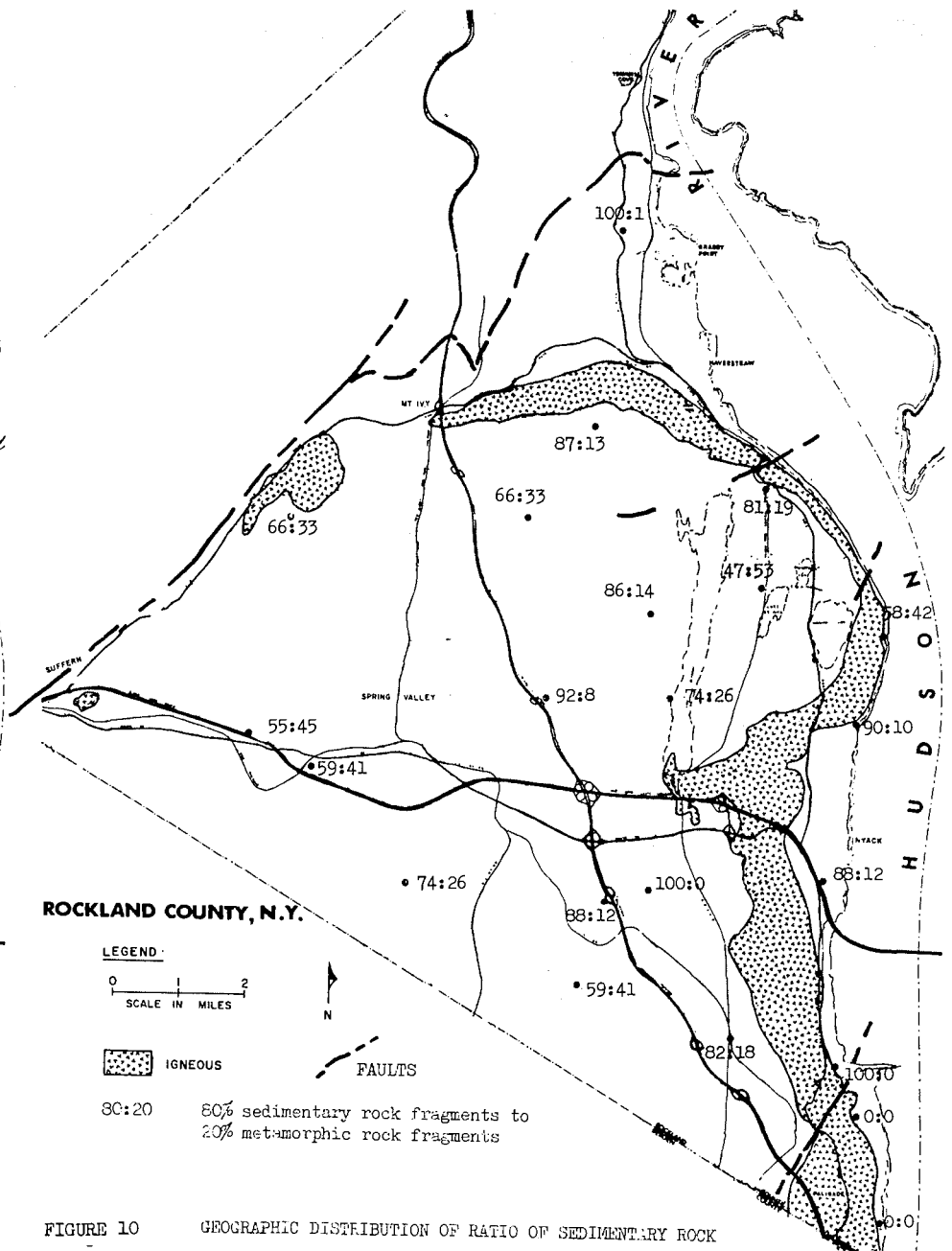


FIGURE 10 GEOGRAPHIC DISTRIBUTION OF RATIO OF SEDIMENTARY ROCK FRAGMENTS TO METAMORPHIC ROCK FRAGMENTS

origin. (Discussion at STOP 2.)

Maximum thickness of the sill in the field trip area is about 1000 feet (Kümmel, 1940, p. 105). Regionally it is not conformable, and cuts across the Newark Formations. Locally, the base of the sill rises and falls markedly in elevation, from 600-700 feet to sea level.

In many places the Palisade diabase has been quarried for trap, an operation that still continues. Just south of the New York State border zeolites were found near the base of the sill. (Nason, 1888, p. 38.) Xenoliths of Newark rocks have been caught up in the lower and rarely the upper parts of the sill.

The sill is marked by joints that resulted from cooling and, as a result of frost action along these, huge talus blocks accumulate at the foot of the steep cliffs. These talus cliffs are especially well developed in Rockland County from just north of Nyack to Haverstraw.

#### The Ladentown Trap.

This body measures 2 miles by 1 mile and is separated from the Mt. Ivy terminus of the Palisades (Figure 20). Across the 2 mile gap between the two traps, glacial deposits conceal any relationship between them. Kummel and previous workers suggested that the Ladentown body connects with the Palisades across the gap.

The rock here is finer-grained than the diabase of the sill except in its chilled borders. In places the Ladentown igneous rock is a vesicular basalt. Kummel reportsropy or pahoehoe structures similar to those in the Watchung flows. This, together with the curved cooling joints that are like those in lava flows, suggests that this rock is a flow (Kümmel, 1898, p. 41.)

No other lava sheets have been reported in Rockland County.

### STRUCTURE

The Newark strata dip northwestward from a positive gravity anomaly over a low arch that separates them from their mirror image in the Connecticut basin, where the dip is eastward. Faults bound each of these basins at the borders where the thickest sequence of sedimentary rocks is preserved.

In the field trip area, the strike of the sediments is NE-SW and the dip is from  $5^{\circ}$  to  $15^{\circ}$  NW, in a faulted monocline. Locally, there are small open folds but these are relatively few and commonly obscured by glacial drift. Unlike most of the sequence, the border cobble conglomerates locally dip eastward away from the northwest border fault and toward the older Triassic sedimentary rocks.

The Palisade Sill is generally conformable with the strata until Nyack, where the ridge arcs toward the river across progressively older sediments. It then parallels the river to a point north of Nyack Beach State Park (STOP 3), where it curves back to the west across progressively younger sediments forming a "sickle-shaped" arc. In this structure the intrusive is reported to change from a  $15^{\circ}$  SW dipping sill to a steep-dipping  $45^{\circ}$  SW dike. It has been suggested that the diabase becomes a semi-circular dike dipping  $40-50^{\circ}$  towards the center of the sickle (Lowe, 1959).

### Faults.

Many small faults cut the Palisade Sill and the sedimentary rocks. The diagonal fault at the Lincoln Tunnel Plaza (Figure 12) and that at Sparkill Gap (Figure 17) are but two that exist in the field trip area.

The most prominent fault is usually inferred from topography. The differentially eroded scarp of the Pre-cambrian crystallines of the Ramapo Mountains marks the position of the Ramapo fault which terminates the Newark Basin to the west. The zone of slickensides exposed near Suffern, New York, is one of the few direct exposures of the fault zone.

### CROSS-STRATIFICATION AND DISPERSAL

Cross-strata are frequently obscured by soot or are inaccessible. Coupled with glacial cover and urbanization, available outcrops for this study are sharply curtailed.

In Rockland County, cross-beds with a single exception of tabular cross-strata at Nyack (STOP 3), are trough shaped with curved basal contacts. Cross-beds vary from thin to thick-bedded layers, from small to medium scale, most being in the range of smaller medium sized cross-strata. The best preservation is found in the light arkoses and red sandstones (Savage, 1967, p. 43).

201 measurements were made in Rockland County and corrections were made for tectonic tilt. From one to 57 readings were made at any one outcrop. It was found that the average dispersal direction for the Brunswick is easterly, thus indicating derivation from a westerly source. It must be noted, however, that the strata in the area are only the beveled edges of the units and the information available may pertain only to the small strip exposed and not downdip. It is of interest, however, that the Stockton Formation at Snedens Landing shows dispersal to the northwest (Savage, 1967, pp. 43-52). Uncorrected measurements farther to the south (Van Houten), indicate that in northern New Jersey, the dispersal of the Stockton was more westerly. If these preliminary dispersal directions (illustrated in Figure 11) are examined in conjunction with the lithology of the units involved, it is obvious that some of these are not entirely compatible with what would be expected.

Preliminary studies indicated that the dispersal direction of the Stockton was to the west or northwest. This is reasonable since presumably a southeast or eastern source which could supply detritus of the necessary composition is feasible in that direction. The next highest sediments, stratigraphically, are exemplified by the sediments at Nyack (STOP 3) which seem to have a southeasterly dispersal. These sediments are not too much higher than the Stockton. The presence of feldspar and mica at Nyack along with large clasts of lithic fragments, e.g., schist, phyllite, garnet, etc., raises questions as to the source direction. A continuation of the study of the dispersal directions is being made because the composition of the sediments at Nyack, except for the metamorphic fragments which appear to be absent in the Stockton, seems to indicate either a source similar to that of the Stockton or a source to the northeast or east.

The feldspar and mica found at Cherry Hill, (STOP 7), also indicate that the southeastern dispersal direction obtained should be questioned.

The reason for raising these doubts about these preliminary results is that the

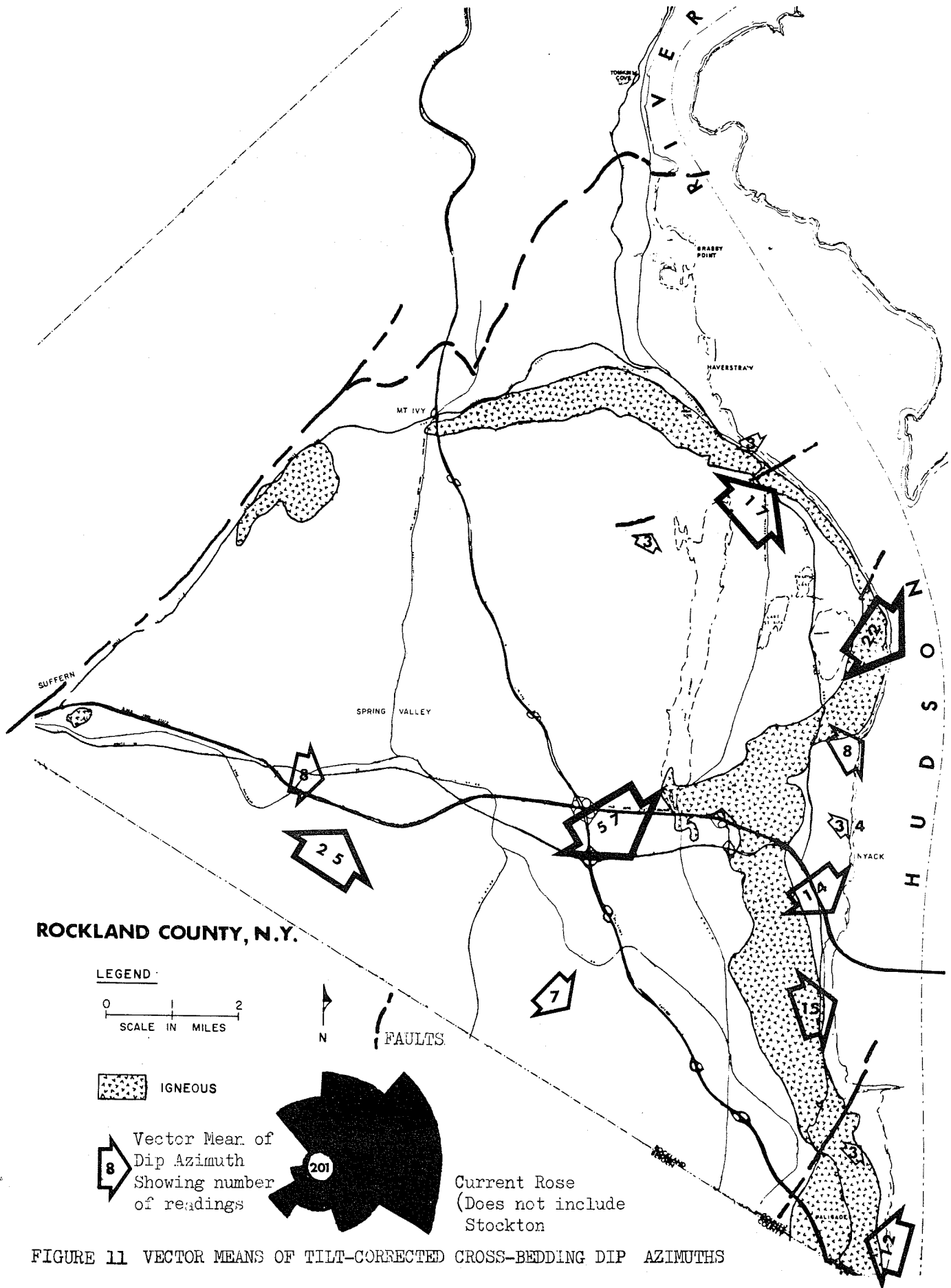


FIGURE 11 VECTOR MEANS OF TILT-CORRECTED CROSS-BEDDING DIP AZIMUTHS

border cobble conglomerates (not noted on Figure 11) have a dispersal direction to the south and east. Since the border cobble conglomerates are composed of Paleozoic clasts (which might be referred to (?)Kittattiny (Cambro-Ordovician) limestone, Green Pond (Silurian) conglomerates and (?)Devonian fossiliferous sandstones, this constitutes evidence that late in Triassic sedimentation the Ramapo Mountains to the west were still covered by Paleozoic sediments. It is interesting to note that the fossiliferous Devonian(?) sandstone appears to be more abundant along a line somewhat to the east of the border conglomerates, in slightly older strata. This would seem to be an indication of progressive stripping of the Paleozoic from the Ramapos. In Rockland County no granite gneiss has been found to any great degree except for a few isolated cobbles. This would seem to indicate that the Pre-cambrian crystallines had not as yet been uncovered in this area. If this premise is accepted, it then follows that it is not possible to derive feldspar from a westerly direction at the time that the lowest Brunswick sediments such as are found from the Stockton upper contact to Cherry Hill, were being deposited.

These inconsistencies may be explained by recalling that only a small part of the total rock layer is available for any individual stratum: its beveled edge - for making cross-bedding measurements. The concealed downdip cross-strata might rapidly reverse the directions if available since these sediments represent deposition by mature meandering streams which are characterized by the reversal of direction of half of each meander.

It is, therefore, suggested that unless further studies indicate an outright change in the dispersal direction, the following be considered among possible solutions:

1. The early Brunswick was derived from the east or northeast and once delivered might have spread longitudinally in various directions such as are indicated by the present studies. The sediments at Cherry Hill certainly seem to be smaller in size in the individual strata, and better sorted than those lower stratigraphically at Nyack. This possibility would assume that in Rockland County, the Brunswick would be derived initially from an eastern source, was distributed in varied directions locally. Later on sedimentation continued with progressive contamination from the west which shed only sedimentary rock debris.

2. A possible alternative view might be that the arkoses were derived from crystallines further to the northwest that had been stripped off the Paleozoic rocks. This would be compatible with the dispersal directions obtained so far, especially at Cherry Hill.

One other conclusion seems to be implied by the fact that the Ramapos at the beginning of Triassic sedimentation were still mantled with early Paleozoic sediments. To the east and southeast of the Triassic basin are presently exposed schists, marbles and gneisses, the metamorphosed equivalents of the same Paleozoic sediments that once existed on the Ramapos. It seems logical, therefore, to conclude that the basement beneath the Triassic sediments consists continuously of essentially the same lower Paleozoic rocks which start as gently folded sediments on the west and become progressively more intensely metamorphosed to the east and southeast. Although the contacts beneath the Triassic rocks are hidden by the Hudson River on the east tunnel borings have indicated a metamorphic basement along the west side of the river. (Berkey 1948, pp. 62-63.) Therefore, since deep erosion had occurred prior to Triassic sedimentation, it seems likely that the basal Triassic sediments were initially deposited on a differentially eroded basement of varied relief as has been suggested by McLaughlin and Willard (1949), prior to tilting of the basin.

The eastward extent of the Triassic basin must have been somewhat greater than it is at present, if only to account for enough cover for the Palisade sill. The angularity of the fragments in the Stockton seem to require a nearby source. The garnet and schist of the earliest Brunswick also require a nearby source. The various members of the New York City series or equivalent rocks provide source rocks for the earliest Triassic sediments. If these were the sources, this might be construed as evidence against broad terrane hypotheses inasmuch as these rocks had to be exposed in order to be shedding rock debris. However, this is still inconclusive and much more work needs to be done in order to further define the relationships of these sediments.

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## ROAD LOG

By F. B. Van Houten and E. L. Savage

Leave Sheraton-Tenney Hotel parking lot. Proceed to 82nd St. (first major intersection which is overpass on Grand Central Parkway). Turn right, then immediately left onto entrance to Grand Central Parkway. At next intersection and stop sign turn diagonally across road onto Brooklyn-Queens Expressway. Continue through Queens-Midtown Tunnel. At exit follow DOWNTOWN sign. Turn left (downtown) to 34th Street. Turn right on 34th Street, across town, to Lincoln Tunnel at 41st Street and 10th Avenue. Distance through tunnel 1.8 miles.

Mileage.

0.0	0.3	Toll booth, west (New Jersey) end of Lincoln Tunnel. Use RIGHT lane.
0.3	0.4	Tunnel plaza and portal to north (left) are at southwest end of fault (Figure 12 A, B) cutting diagonally across Palisade Sill. Dropped block is on east (right) side. There are many such faults along the Palisades.
0.7	0.1	Turn right (north) onto Hudson Boulevard East.
0.8	0.1	Jointed diabase on left.
0.9	0.2	Continue on Hudson Blvd. East; bear right (east) at traffic light.
1.1	1.0	Small park on right (east) commemorates duel between Aaron Burr and Alexander Hamilton. Regional erosion surface levels top of sill (Figure 13).
2.1	0.2	Turn right (east) at traffic light onto 60th St. Descend past gray apartment-house garages to River Road.
2.3	0.2	Olivine zone in Palisade Sill on left (see Figure 15A).
2.5	0.1	Sewage treatment plant near base of sill.
2.6	0.5	Metamorphosed rather well-sorted yellowish-gray to very pale orange Stockton arkose and overlying chilled border of sill on left.  Coarse-grained arkose at contact, locally cross-bedded with dispersal to S or SW, contains abundant plagioclase and orthoclase, some quartz, pale green diopside and vermiculite, and minor sphene and talc. Fine-grained arkose within 12 inches of the contact consists mainly of albite, with minor vermiculite and talc, and a trace of chlorite.
3.1	0.2	Stockton arkose on left.
3.3	0.3	Large columnar joints with smaller joints in lower part of sill. Talus.

- 3.6 0.2 Stockton arkose and cliff of sill on left (just south of Lever Brothers Research Center). Bedded, coarse to very coarse-grained arkose with 2-foot unit of tabular cross-bedding with dispersal to SW.
- 3.8 0.1 Well-bedded, very dark, fine-grained Lockatong hornfels.
- 3.9 0.1 "Town of Edgewater" road sign on right.
- 4.0 0.1 Intersection of Gorge Road (uphill to left) and River Road (diagonally to right).
- 4.1 0.1 STOP 1. Gorge and River Roads. Lockatong Hornfels. Time here: 30 minutes. Park in lot of Celatex Corp. (Allied Chemical).

A composite section of Lockatong hornfels and interbedded Stockton arkose is exposed in the excavation (watch for falling rock) on River Road (Figure 14A) opposite the Mobile Service Center and in the roadcut on the west side of Gorge Road (Figure 14B). This sequence (strike N 40°E, dip 15°W) consists of (1) about 18 feet of dark gray, well-bedded Lockatong hornfels in 3 well-developed cycles, overlain by (2) about 15 feet of bedded, rather well-sorted yellowish-gray Stockton arkose, which is in turn overlain by (3) about 50 feet of dark gray, well-bedded Lockatong hornfels below the Palisade Sill.

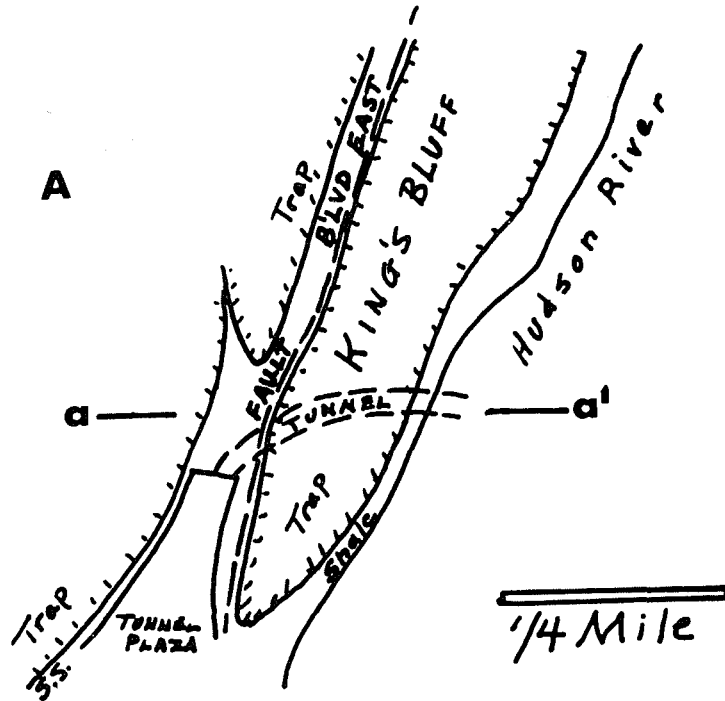
1. The asymmetrical cycles in the excavation are analcime-bearing "chemical" cycles like those found in western New Jersey and adjacent Pennsylvania (Van Houten, 1964, 1965). Because of their unique composition, these deposits were easily altered by isochemical thermal metamorphism. In contrast, the arkose 50 feet below the sill is virtually unaltered.

In pattern, each cycle (Figure 14C) originally consisted of a lower very dark gray to black shaly to platy carbonate-rich feldspathic mudstone (converted to a biotite-albite hornfels) with thin laminae and local beds (1 to 3 cm) of calcite and dolomite, a middle platy carbonate-rich portion with abundant disruption by shrinkage, converted to a calc-silicate hornfels, and an upper massive analcime-rich argillite, now commonly with a spotted fabric produced by metamorphism to a biotite-albite-analcime hornfels.

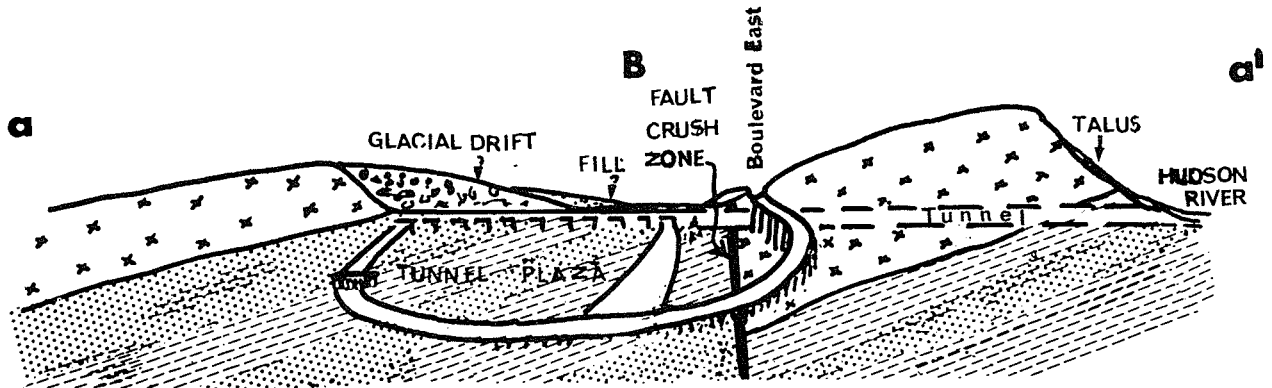
2. The slightly metamorphosed arkose 50 feet below the sill consists mainly of plagioclase, orthoclase and quartz, some vermiculite, and a trace of talc.

3. Spotted Lockatong hornfels of a tetrital cycle within 5 feet of the sill consists mainly of biotite and plagioclase, some orthoclase and andalusite, and a trace of chlorite and magnetite. Lockatong hornfels 15 to 20 feet below the sill contains minor analcime.

FIGURE 12



A. MAP ILLUSTRATING LINCOLN TUNNEL PLAZA AND DIAGONAL FAULT CUTTING PALISADE SILL (MODIFIED AFTER KUMMEL 1898)



B. SECTION OF PALISADE SILL AT LINCOLN TUNNEL PLAZA INCLUDING PORTAL AND ROAD TO BOULEVARD EAST. LOOKING NORTH. DOWNDROPPED BLOCK IS ON EAST. (MODIFIED AFTER BERKEY 1948)

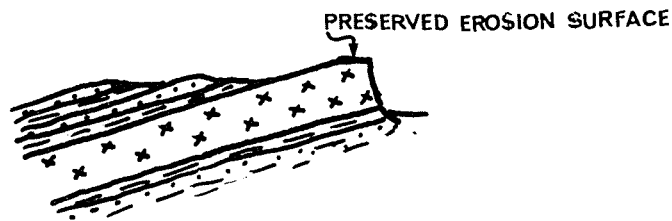
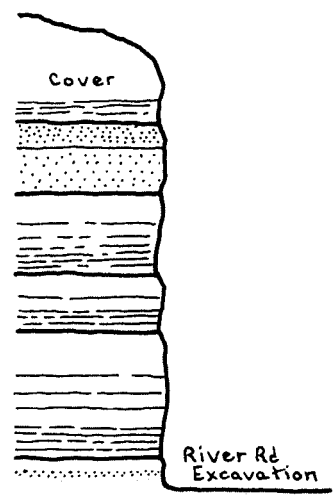
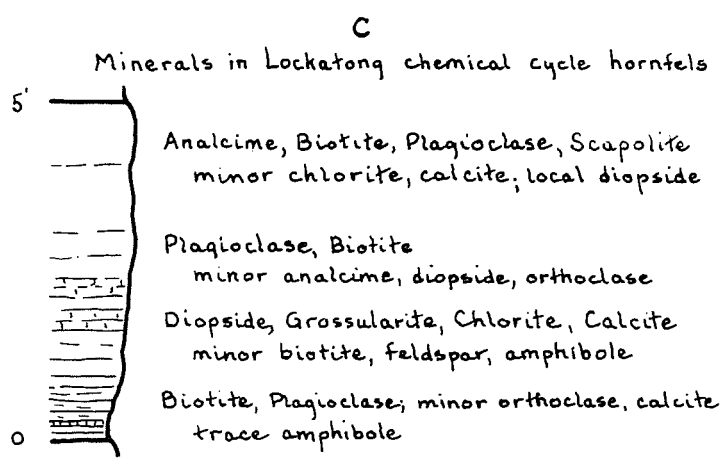
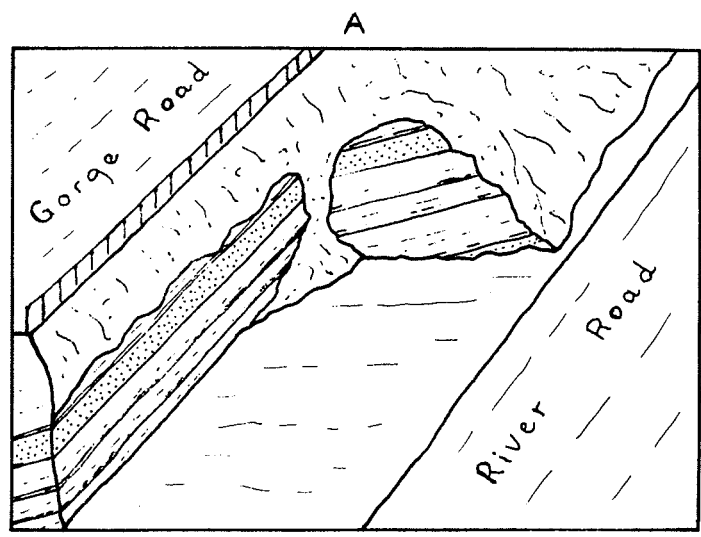
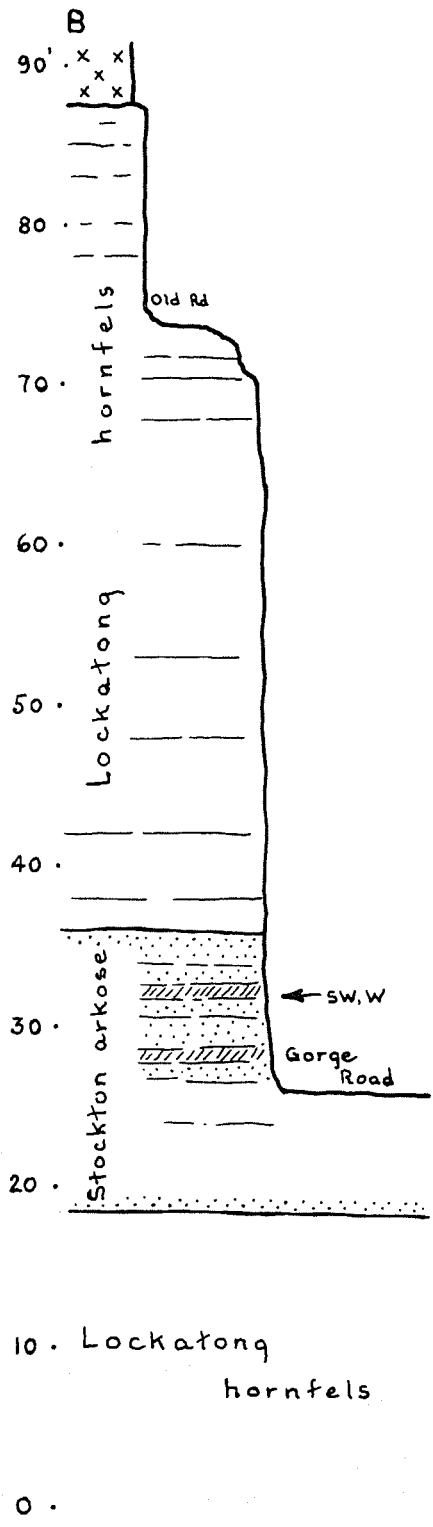


FIG. 13

SECTION OF PALISADE SILL ILLUSTRATING PRESERVED EROSION SURFACE (SCHOOLEY)

Figure 14. Hornfels zone below Palisade Sill, STOP 1.

- A. Sketch of excavation on River Road showing 3 Lockatong chemical cycles and overlying Stockton arkose. Looking northwestward.
- B. Composite section from River Road to base of sill above Gorge Road. Tongue of Stockton arkose in succession of Lockatong cycles.
- C. Model of hornfelsed Lockatong chemical cycle in River Road excavation.



The following additional accessory minerals have been found in this hornfels facies (Lewis, 1908, p. 136-147): pale green augite, apatite, cordierite, epidote, hornblende, sillimanite, scapolite, dark-green spinel, sphere, tourmaline, and vesuvianite.

The variations in mineral assemblages found here and in the Granton Quarry (STOP 8) resulted largely from differences in composition and amount of water present, and not from major differences in temperature and pressure.

- 4.2 0.1 Continue north on River Road.
- 4.3 0.2 Large xenolith (15 feet by 30 feet) of Lockatong hornfels about 15 to 20 feet above base of sill, exposed behind Virginia Lee Lace Co. Baking produced coarse-grained biotite-plagioclase hornfels with chlorite, pale green and colorless pyroxenes, and more coarsely crystalline stringers of chlorite, biotite, calcite, diopside, albite and very pale green muscovite.
- 4.5 0.1 Railroad overpass. Sill exposed on left (west), hornfels in cut to east (right).
- 4.6 0.1 Lockatong hornfels below sill behind Edgewater Welding Co.
- 4.7 0.5 Stockton arkose and Lockatong hornfels behind Edgewater sewage treatment plant.
- 5.2 0.5 Continue north past traffic light at Russell Avenue.
- 5.7 0.3 Turn left (west) up Dempsey Avenue to Undercliff Avenue at top of hill. Turn right (north)
- 6.0 STOP 2. Palisade Sill and Lockatong Hornfels along abandoned trolley route. Time here; 1 hour. Park on east side of Undercliff Avenue, opposite small park with 3 benches.

Traverse through Palisade tholeiitic diabase sill (Figure 15 A, B, C) - up (southwest) an abandoned trolley route along a brook, behind houses:

Lockatong Hornfels below sill, as at STOP 1.

Irregular cross-cutting contact (Figure 16A).

Xenolith 2 feet thick, 15 feet above base of sill; unusually coarse-grained biotite-plagioclase hornfels.

Olivine diabase, generally about 15 feet thick, 50 feet above the base at switch-back on trolley route. Dr. S. Bhattacharji will discuss its origin.

Normal diabase throughout the middle of the sill.

Upper coarse diabase with pegmatitic schlieren.

Upper chilled border.

Hypotheses proposed to explain differentiation of the diabase sill and to account for the layer of olivine diabase are:

1. Gravitational settling of early-formed olivine and later pyroxene crystals (F. Walker, 1940). Although widely cited as such, the Palisade Sill probably is not a good example of gravitational differentiation.
2. Fractional crystallization (Figure VH 2, C) by ionic diffusion and convection circulation of magma, supplemented by minor gravitational settling of large olivine crystals (Hess, 1956, p. 1960).
3. Fractional crystallization, with late-stage injection of a new pulse of magma into the partially crystallized mush. Large olivine crystals concentrated by gravitational settling (K.R. Walker, 1962; 1967 in press).
4. Mechanical or hydrodynamic flow differentiation, with central concentration of early-formed olivine crystals during intrusion of the magma. Crystal mush then settled as a result of fluctuation of velocity and pressure (S. Bhattacharji, 1967).

- |     |     |   |
|-----|-----|---|
| 6.0 | 0.1 | Proceed north on Undercliff Avenue to next corner. Turn right on Hudson Avenue, to bottom of hill (River Rd.). Turn left (north) on River Road.                   |
| 6.1 | 0.4 | Bear left on NY 5W which leads to top of sill.  |
| 6.5 | 0.3 | Olivine zone halfway up cliff on left.  |
| 6.8 | 0.1 | Olivine zone is at road level.  |
| 6.9 | 0.2 | Palisades Amusement Park on left at top of sill.  |
| 7.1 | 0.7 | Intersection of NY 5W and 67. Turn right (north) on NY 67 (Palisades Avenue).   |
| 7.8 | 0.1 | Outcrop of sill on right.   |
| 7.9 | 0.7 | Horizon Towers apartment complex on right.  |
| 8.6 | 0.1 | Cross Main Street on Fort Lee.  |
| 8.7 | 0.2 | Sign to George Washington Bridge. Use lane farthest LEFT. A phytosaur, <u>Clepsysaurus</u> ( <u>Rutiodon</u> ) was found in the Stockton arkose below the bridge. |



Figure 15. Vertical section of Palisade Sill.

A. Composite profile from "trolley route" (STOP 2) to Granton Quarry (STOP 8).

- a. Lockatong hornfels and Stockton arkose, as at STOP 1.
- b. Chilled border of sill with white veins and xenoliths.  
See Figure 16A.
- c. Olivine diabase 3 to 20 feet thick.
- d. Normal diabase, coarser and more acidic toward the top.
- e. Coarse diabase with pegmatitic schlieren.
- f. Chilled border with white veins, xenoliths rare.
- g. Lockatong hornfels and Stockton arkose. See Figure 16B.

B. Percentage by weight of olivine, plagioclase and pyroxene (Walker, 1940).

C. Model of crystallization sequence (Jacobsen, 1949).

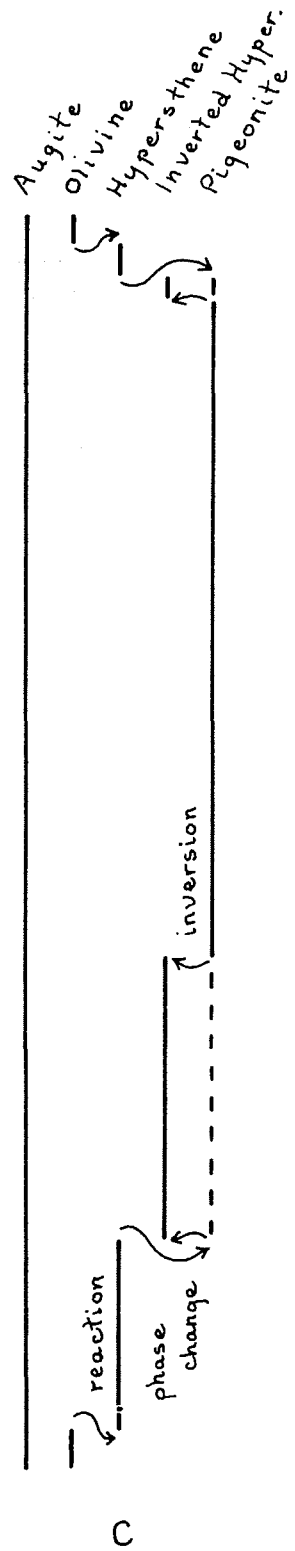
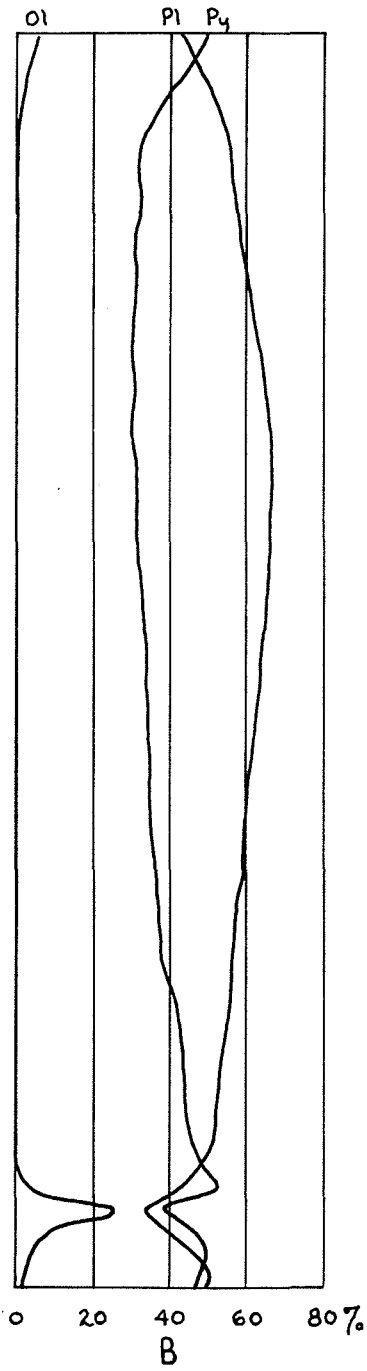
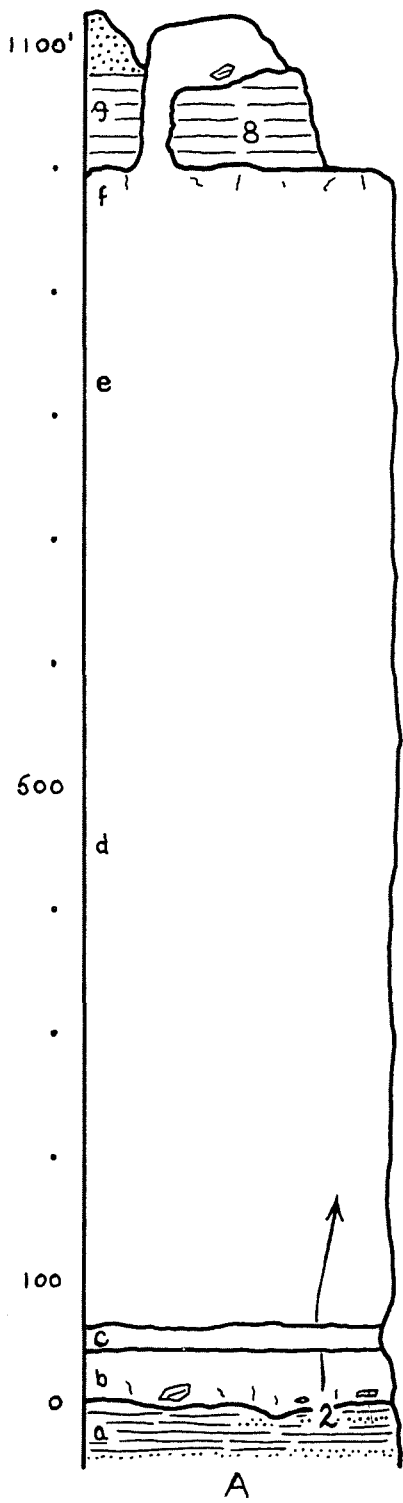
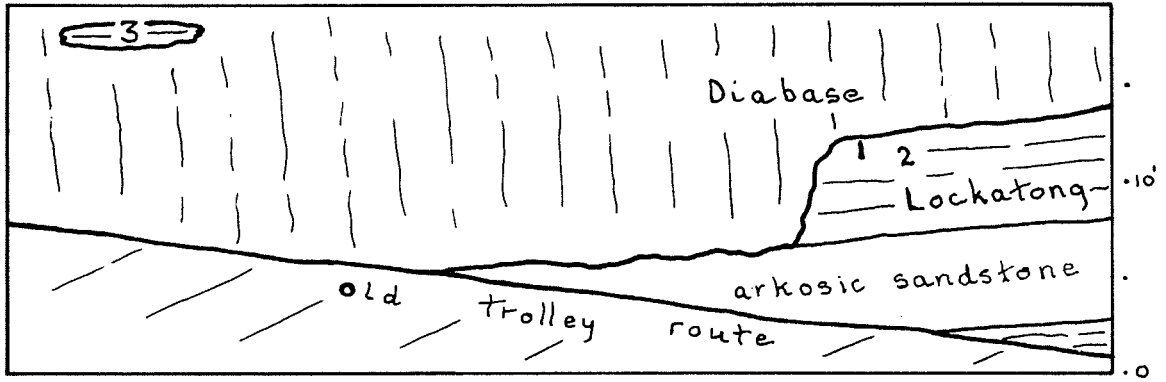


Figure 16. Lockatong hornfels at STOPS 2 and 8.

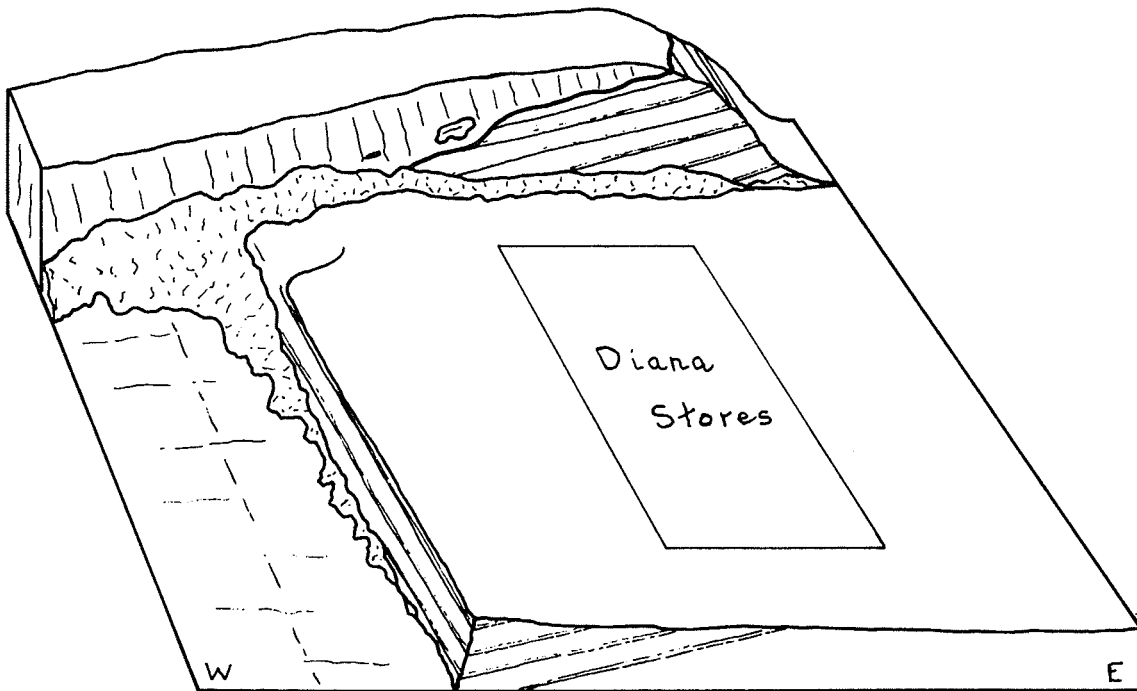
A. Sketch of contact zone at base of Palisade Sill, STOP 2, showing irregular contact and tongue of arkose. Uppermost Lockatong hornfels: 1. Abundant plagioclase and biotite, minor orthoclase, scapolite, muscovite and diopside, trace of chlorite. 2. Abundant scapolite and chlorite, minor analcine, trace of plagioclase and magnetite. 3. A 2-foot thick xenolith 15 feet above base of the sill: very coarse-grained plagioclase and biotite, minor very pale green and colorless pyroxenes, and trace of chlorite.

B. Sketch of north end of Granton Quarry, North Bergen, New Jersey, STOP 8. Five complete hornfelsed detrital cycles and xenoliths in wall of upper level and 2 complete cycles along wall of lower level lie above the Palisade Sill and below a subsidiary sill. See Figure 15.

A



B



8.9	0.3	Turn left onto access road at sign to US 9W.
9.2	0.1	Outcrops of sill on both sides of road.
9.3	0.3	Turn right onto US 9W North.
9.6	0.2	Cross Palisades Interstate Parkway access road.
9.8	0.5	Outcrop of sill.
10.3	0.2	Prentice-Hall Book Company on right.
10.5	0.7	Outcrop of sill on left.
11.2	0.2	Cross NJ 505.
11.4	0.6	REST STOP. 15 minutes.
12.0	0.3	Outcrop of sill on right. Lipton Company on left.
12.3	0.6	Outcrop of sill on left.
12.9	0.6	Traffic light, road to Tenafly. Continue north on US 9W.
13.5	2.6	Glacially polished diabase on right.
16.1	0.2	Cross NJ 502 at Closter.
16.3	0.5	Jointed diabase on both sides of road.
16.8	0.1	Service road to Palisades Interstate Parkway North.
16.9	1.7	Service road to Palisades Interstate Parkway South.
18.6	0.1	Glaciated diabase on right.
18.7	1.0	Palisades Interstate Parkway access road.
19.7	0.1	Underpass
19.8	0.2	Entrance to Palisades Interstate Parkway North on left.
20.0	0.1	Cross road to Lamont Geological Observatory of Columbia University.
20.1	0.8	New Jersey-New York and Bergen County-Rockland County boundaries.
20.9	1.2	Cross Oak Tree Road.

Along Hudson River at Sneden's Landing approximately 45 feet of light gray thick-bedded and locally cross-bedded Stockton arkose is interbedded with reddish-brown to pale lavender baked mudstone. Dispersal was to the northwest (Figure 11). Locally dikes of arkose have been injected into the mudstone. The arkose contains angular pebbles of quartz and pink feldspar as much as an inch in diameter; in contrast to sandstone found north of Piermont (and higher in the stratigraphic sequence) zircon, rutile and anthigenic anatase are abundant, tourmaline and garnet are rare, and metamorphic rock fragments are absent (Savage, 1967).

- 22.1    0.2    Outcrops of diabase at entrance to Tallman's State Park. Olivine zone.
- 22.3    0.1    Continue north on US 9W, across NY 340.
- 22.4    0.4    Sparkill Gap. Sparkill (formerly Overpeck) Creek in the gorge is the only stream that flows eastward across the Palisade Sill into the Hudson River. Presumably it flows along a cross-fault (such as seen at Lincoln Tunnel plaza) that has offset the sill more than 900 feet westward on the north side.

According to Johnson (1931) the Hudson River originally flowed southwestward on the Schooley erosion surface above the position of the sill, was superposed on it and cut a water gap (Figure 17). Later a subsequent stream flowing on relatively non-resistant rocks east of the sill captured the ancient Hudson drainage by headward erosion. Overpeck Creek then reversed the original drainage direction. This explanation does not account for the coincidence of the gap and a cross-fault (see Thornbury, 1954, p. 234-240, for discussion of the problem).

Between Piermont and Nyack Beach State Park (STOP 3), there are many outcrops and abandoned quarries of "brownstone" which was used extensively for building-stone more than 50 years ago. Most of the rock is a dark brown to reddish brown well-sorted medium to fine-grained arkose, commonly interbedded with reddish brown mudstone. Some of the lighter colored arkose is coarser grained, but conglomerate is rare. Presumably these deposits are a gradational sequence between the uppermost part of the Stockton Formation and the lower part of the Brunswick Formation, and differ in heavy mineral content, sedimentary-metamorphic rock content and dispersal direction from those in the upper part of the Stockton Formation to the south (Savage, 1967, p. 34).

- 22.8    0.3    Glacial till overlying diabase on right.
- 23.1    0.2    More till on diabase on right.
- 23.3    2.1    Outcrop of diabase on left.

- 25.4 0.3 Town of Nyack road sign. Bear right onto Broadway (downhill). View of south end of Verdreitege Hook (Hook Mountain) portion of Palisade Sill above Nyack Beach State Park.
- 25.7 0.1 Overpass
- 25.8 0.6 Stop sign. Continue on Broadway (middle road).
- 26.4 1.0 Large glacial erratic on right, on lawn of library built of "fieldstone."
- 27.4 0.8 Upper Nyack School on left.
- 28.2 0.3 South end of Verdreitege Hook with spectacular talus slope. 5 minute stop for photographs.

North of Nyack the Palisades are as much as a mile west of the Hudson River because the sill intruded a higher part of the west-dipping Newark sequence. Then it swings back to the river at Nyack Beach State Park, cutting across somewhat lower Newark strata (Figure 3). At its north end the intrusion is a dike that intrudes successively higher Brunswick beds (Figure 2) and turns sharply to the west almost perpendicular to strike; at its western end it completes a sickle-shaped arc. Diamond-drilling in a quarry at Little Tor near Haverstraw shows that the intrusion dips about 45°SW (Lowe, 1959).

A distinct olivine-rich zone is absent at the northern end of the Palisade intrusion as it is at its southwestern end in west-central New Jersey.

- 28.5 0.5 Nyack Beach State Park. Take road to right down steep hill. Park buildings of typical reddish-brown arkose. Outcrop at base of hill, near entrance to Men's comfort station, consists of cross-bedded reddish-brown mudstone interbedded with micaceous reddish-brown sandstone and greenish-gray arkose.

STOP 3. Nyack Beach State Park. Lower Brunswick deposits.  
Time here: 1 hr. 45 min.

LUNCH will be served after a 1 and 1/3 mile walk to outcrops in the lower part of the Brunswick Formation.

The Park authorities have made this convenient stop available to us. Do not disturb the foliage or the crops. Please collect specimens only in those areas where there has been recent blasting of ledges.

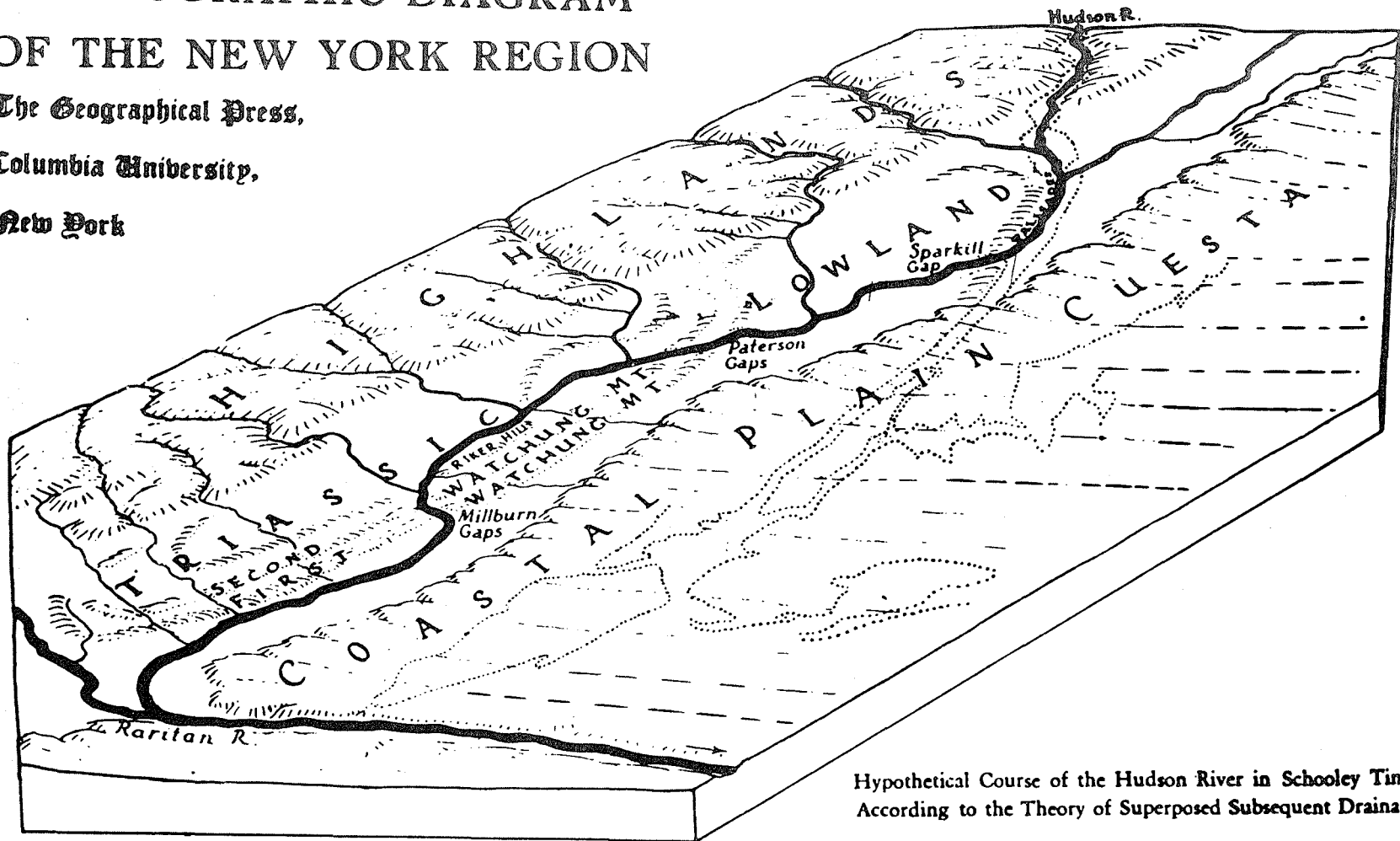
Watch out for copperhead snakes, yellow-jacket wasps, poison ivy and poison sumac.

# PHYSIOGRAPHIC DIAGRAM OF THE NEW YORK REGION

The Geographical Press,

Columbia University,

New York



Hypothetical Course of the Hudson River in Schooley Time,  
According to the Theory of Superposed Subsequent Drainage

DIAGRAM TO ILLUSTRATE Professor Johnson's THEORY FOR THE ORIGIN OF  
THE GAPS IN THE WATCHUNG RIDGES. (Drawn by E.J. Raisz for Johnson: Atl. Slope)

FIG. 17

ANCESTRAL COURSE OF THE HUDSON RIVER. ACCORDING TO JOHNSON (1931) A SUBSEQUENT  
STREAM FLOWING ON RELATIVELY NON-RESISTANT ROCKS EAST OF THE PALISADE SILL LATER  
CAPTURED THE HEADWATERS OF THE HUDSON, LEAVING SPARKILL GAP. (FROM JOHNSON 1931)



Traverse along footpath leading north from north end of parking area. Distances noted below were measured from beginning of the path.

200': 15 to 20 feet of yellowish-gray arkose crop out 40 inches above the path.

895-950': Picnic tables; old quarry in reddish-brown mudstone and yellowish-gray arkose.

1450-1570': Outcrop exhibiting rapid facies changes, especially at north and south ends:

7': Massive reddish-brown mudstone; cross-bedded; marked channelling.

8': Reddish-brown shale.

13': Micaceous reddish-brown siltstone and shale; cross-bedded. Scattered pebbles of quartzite and quartz, and pieces of shales.

8': Reddish-brown shale.

2': Massive reddish-brown mudstone.

Path level

1570-2215': Much talus.

2215-3745': More talus; columnar joints in diabase. Note sinuous joint surfaces. Pass fireplaces.

3745-3925': Tree-clad slope.

4040-4405': Outcrop near open stone shelter:

10': Massive light gray arkose, locally cross-bedded.

2': Reddish-brown mudstone.

4': Thin-bedded, pale reddish-brown arkose, interbedded brown mudstone.

8': Massive, tough light-gray arkose, rare cross-bedding and coarse layers with pebbles of angular quartz as much as 2 1/2 inches in diameter, pieces of feldspar as much as 1 inch long and intraformational mudstone clasts.

Path level.

Continue along winding path. Diabase above is conspicuously jointed. Sing-Sing prison across river to east.

5571-6039' : At south end diabase is at path level. Rises to north to reveal contact with arkose which has not been metamorphosed more than a few feet from the sill. Beware of yellow jacket nests in brush near this contact.

6039-6080' : Cover. Beyond retaining wall 10 feet of cross-bedded light-gray arkose overlies reddish-brown mudstone.

6230-6420' : Cover.

6445-6465' : Arkose with rare gray limestone and quartz clasts to 1 inch in diameter; pink feldspar to 2 inches in diameter, and rare pebbles of pegmatite.

6570' : Arkose in large block is cross-bedded, contains clasts of quartz, red sandstone, pink feldspar, shale, mica schist, and relatively abundant almandine garnet.

6575' : Excellent outcrop extends northward for about 1000 feet. Exhibits rapid facies changes and variety of sedimentary features characteristic of fluvial sedimentation (Figure 18A). N62W, 13°W.

5' : Yellowish-gray arkose with large scale channeling and cross-bedding.

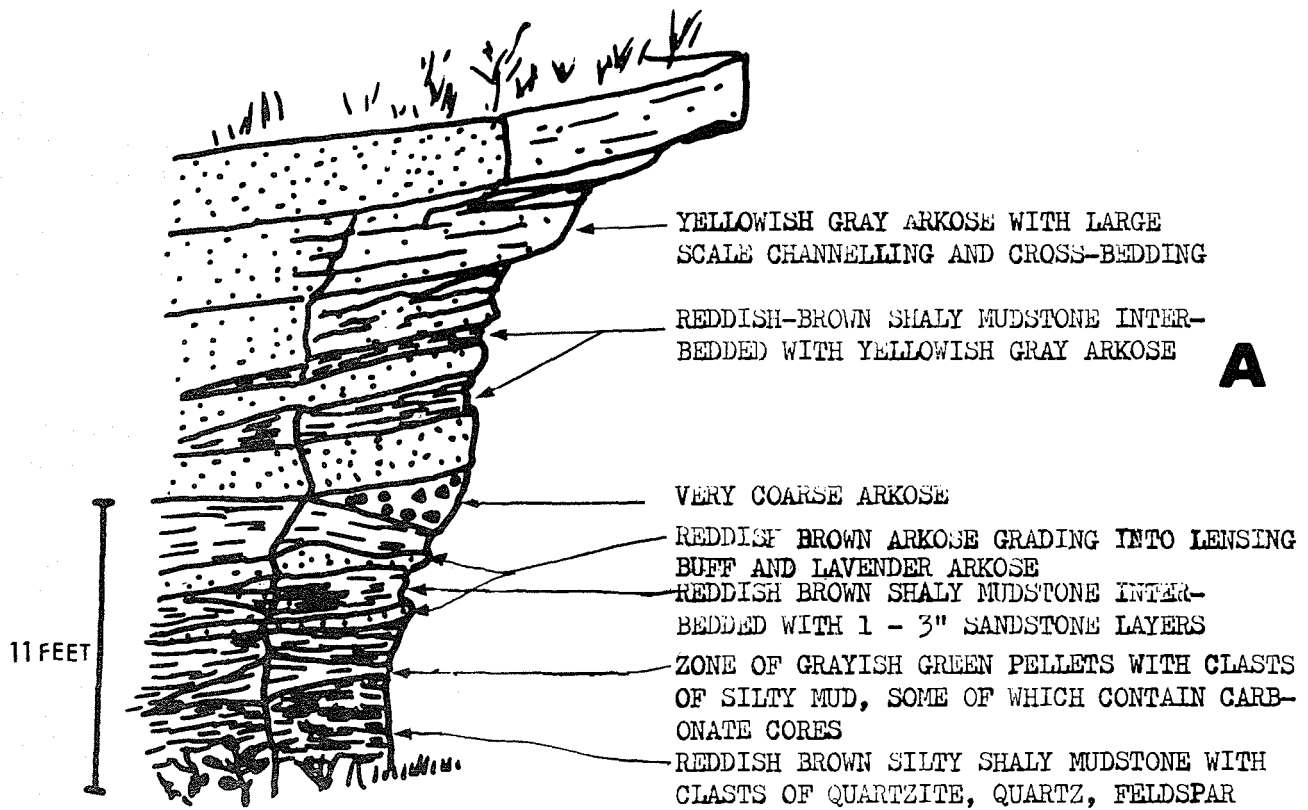
6' : Interbedded yellowish-gray arkose and reddish-brown mudstone. Unit pinches out to north.

11' : Reddish-brown to lavender mudstone with irregular upper contact. Cross-bedding, with scour and fill, burrowing, mud-cracks, and ripplemarks (2 inch crests, N68W), as well as load and flute casts. Interbedded with layers of medium to coarse-grained micaceous reddish-brown arkose grading (Figure 18A) into lensing buff and lavender arkose with pebbles of limestone and feldspar. The lower part of the mudstone also contains pebbles of quartzite, quartz and feldspar. About 5 feet above the base at the south end of the outcrop a greenish-gray layer consists largely of rounded grains of silty mudstone. Some may be Paleozoic lithic grains, but many with concentric structure, elongate shape and calcite cores apparently are intraformational mud pellets.

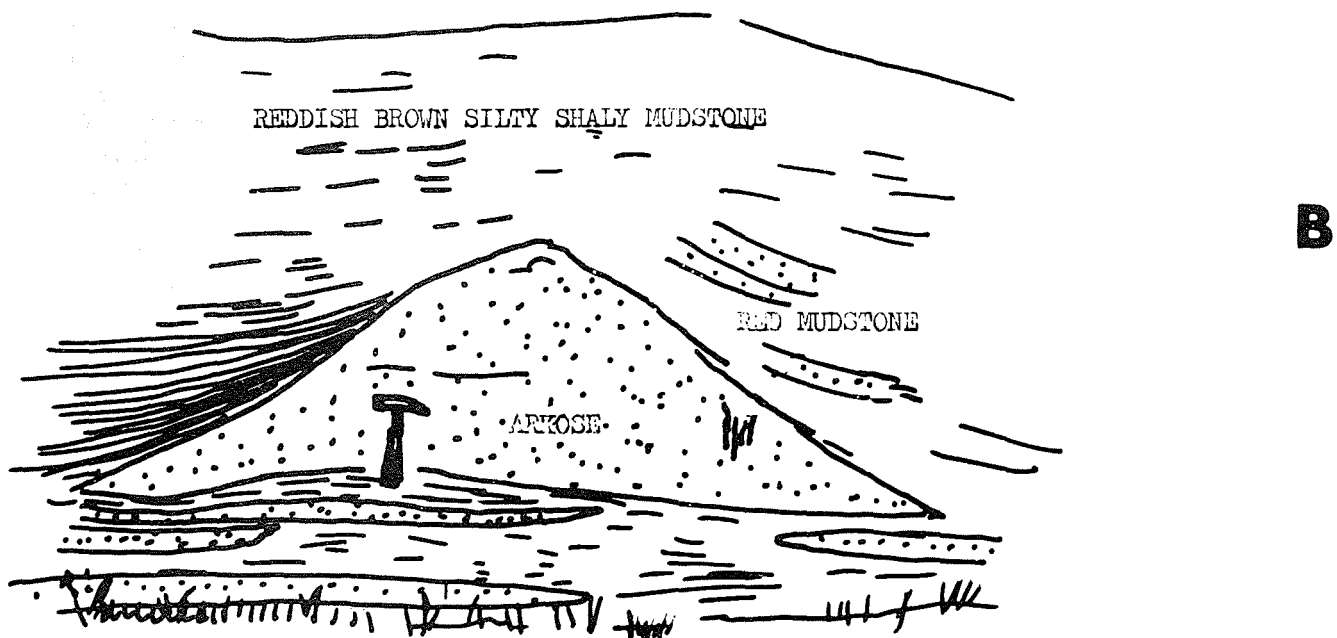
6580' : Very coarse arkose with angular quartz as much as 1 inch in diameter, pieces of shale parallel to bedding, and clasts of limestone and feldspar, interfingers with reddish-brown mudstone.

6665' : Well-developed tabular cross-bedding, rare in Newark rocks in Rockland County.

Figure 18

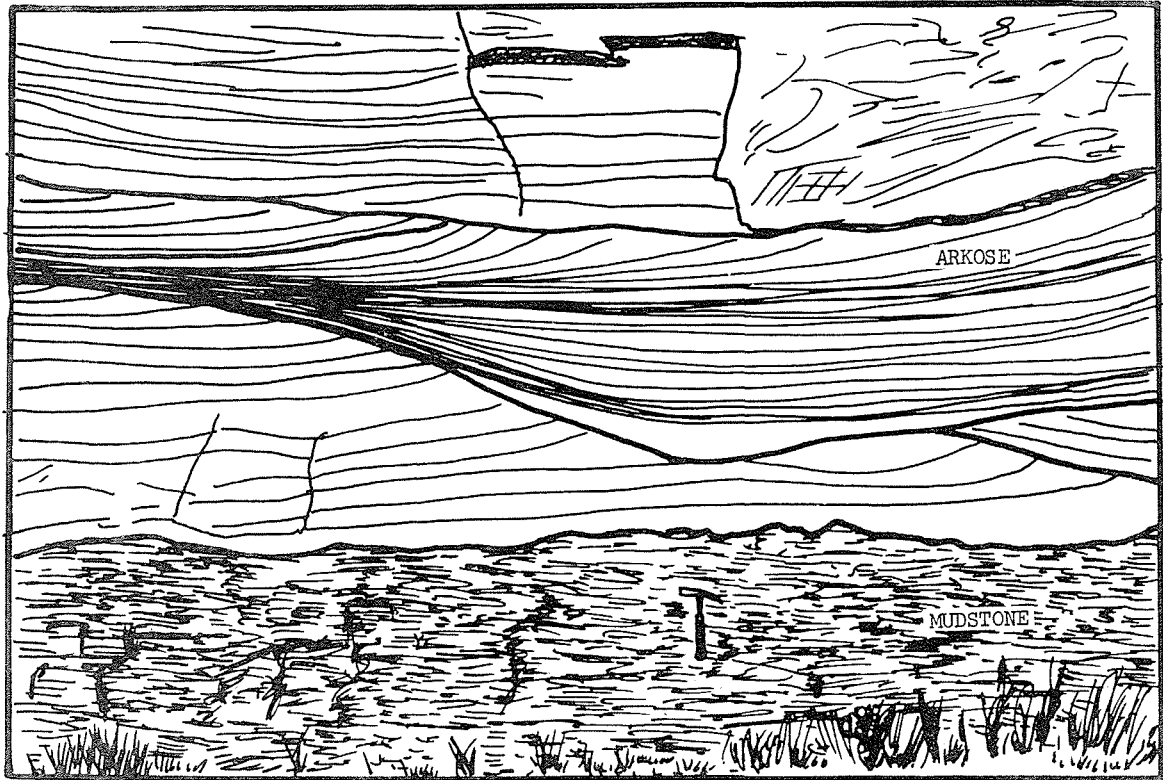


A. GENERALIZED SECTION OF STRATIGRAPHY AT NYACK BEACH STATE PARK (STOP 3)

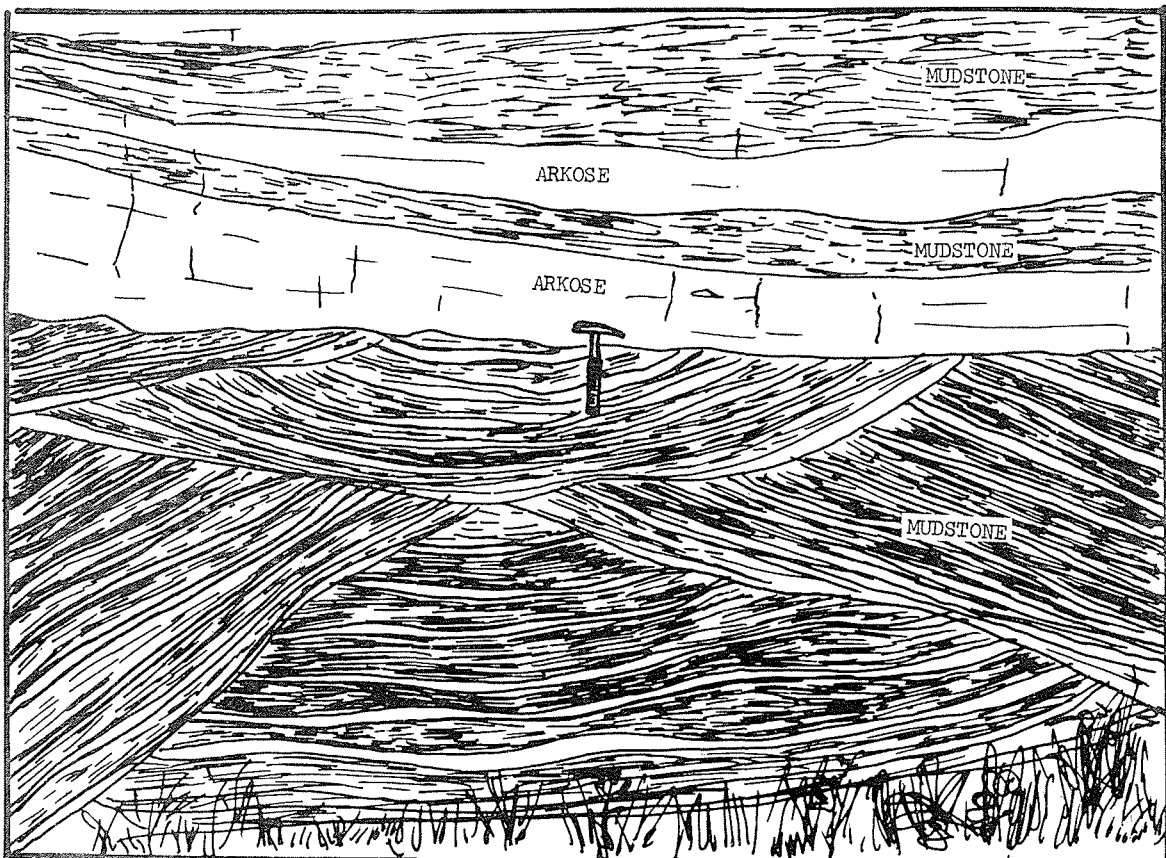


B. DETAIL OF ARKOSE CHANNLED ON BOTH SIDES. REDDISH-BROWN MUDSTONE AT NORTH END OF ARKOSE WAS PROBABLY INJECTED DURING BURIAL. (STOP 3)

Figure 19



A. YELLOWISH GRAY ARKOSE OVERLYING REDDISH BROWN SHALY SILTY MUDSTONE. NOTE RARE LARGE SCALE CROSS-BEDS IN ARKOSE WITH CURVED BASAL CONTACTS. SKETCHED FROM A PHOTOGRAPH. (NYACK BEACH STATE PARK STOP 3)



B. TRANSITIONAL ARKOSE-SHALY, SILTY MUDSTONE UNIT OVERLYING REDDISH BROWN MUDSTONE INTERBEDDED WITH REDDISH BROWN SILTY SANDSTONE WITH MARKED CROSS-BEDDING AND SCOUR AND FILL. LOOKING WEST. SKETCHED FROM A PHOTOGRAPH. (NYACK BEACH STATE PARK STOP 3)

6755' : Upper contact of lower reddish-brown mudstone unit is about 5 feet above the path.

6755-6770' : Arkose scoured by channels. Reddish-brown mudstone dikes at north end probably was injected during burial (Figure 18B).

6775' : 5' : Massive yellowish-gray arkose.  
5' : Interbedded reddish-brown mudstone and tan arkose.  
11' : Reddish-brown mudstone.

Path level.

Northward the top of the extensively burrowed lower unit is 8 feet above the path and is overlain by mottled arkose 11 feet thick which in turn is overlain by 4 feet of yellowish-gray arkose with large scale cross-bedding (Figure 19A).

6930' : Slumped mudstone 3 feet above path.

6980-7015' : Six inch layers of reddish-brown mudstone interbedded with reddish-brown silty sandstone a few inches thick with marked cross-bedding and scour and fill (Figure 19B).

7185' : Well-developed cross-bedding in yellowish-gray arkose.  
Return to Park. LUNCH will be served at tables south of the parking area. Time here: 30 minutes.

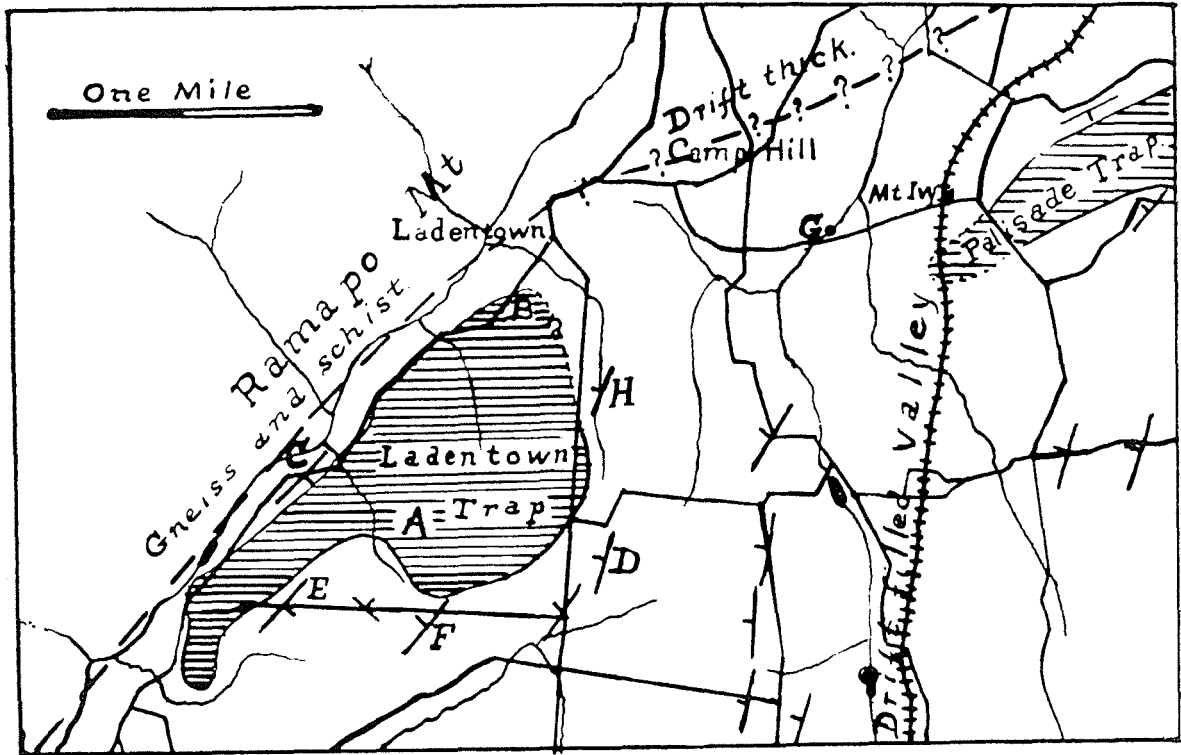
- |      |     |  |
|------|-----|--|
| 29.0 | 1.1 | Leave Nyack Park, onto Broadway.   |
| 30.1 | 0.5 | Turn right onto Birchwood Avenue; offset to left at 30.3.  |
| 30.6 | 0.3 | Turn north (right) onto US 9W North at Rockland Lumber Mart.   |
| 30.9 | 0.4 | Thermally metamorphosed yellowish-gray arkose and reddish-brown mudstone (as seen at STOP 3) in excavation on left.  |
| 31.3 | 1.0 | Beginning of roadcut through Verdreitege Hook to inner side of the "sickle" (Figure 1).  |
| 32.3 | 0.4 | Rockland Lake Landing Road. Gaps to east (right) and northeast (ahead) across Palisades may be controlled by faults (Thompson, 1959) or are former superposed stream valleys (Kümmel, 1898, p.24). |
| 32.7 | 0.9 | Continue on US 9W North. Erratics on shore of Rockland Lake.   |
| 33.6 | 0.9 | Cross road to Congers at traffic light.  |
| 34.5 | 0.4 | Gneiss and diabase erratics in till on right. Some are more than 6 feet long.  |
| 34.9 | 0.4 | Excavation in till.  |

- 35.3 0.5 Cross NY 303.
- 35.8 0.1 Junction with NY 304.
- 35.9 0.2 Unusually well-developed polygonal jointing in diabase at right, and in New York Trap Rock Quarry at Little Tor above road to left. North side of "sickle."
- 36.1 0.1 Talus slope up hill on left.
- 36.2 0.7 Arkose above tough reddish-brown mudstone on left, on northern and outer side of the "sickle."
- 36.9 0.5 Talus with very steep angle of repose.
- 37.4 0.5 Scarp has receded to the west.
- 37.9 0.4 Continue on US 9W North across New Main Street (to Haverstraw).
- 38.3 0.6 Turn left onto US 202 West. Road follows the north rim of High Tor and progressively crosses younger strata to the west.
- 38.9 0.9 West Haverstraw road sign. Ramapo Mountains visible to the west.
- 39.8 1.6 Glacial erratics common.
- 41.4 0.5 Deposit of meltwater delta (?) on right; in lowland between sill (left) and Ramapo Mountains (right).
- 41.9 0.2 Cross NY 45 South.
- 42.1 0.2 Cross NJ and NY Railroad tracks.
- 42.3 0.4 Cross Palisades Interstate Parkway access road. Mt. Ivy Sand and Gravel Company quarry in Mt. Ivy meltwater delta dispersed to the south or southwest. About 5 feet of steeply dipping, light tan foreset beds above 8 to 10 feet of horizontal dark brown and reddish-brown to dark gray beds, and overlain by very poorly-sorted glacial (?) deposits.
- 42.7 0.2 Intersection with east end of old NY 202.
- 42.9 0.1 Cross Camp Hill Road.
- 43.0 0.6 Ramapo Mountains rise to west.
- 43.6 0.1 Cross NY 306.
- 43.7 0.2 Cross west end of old NY 202.
- 43.9 0.6 Outcrop of Ludentown diabase.

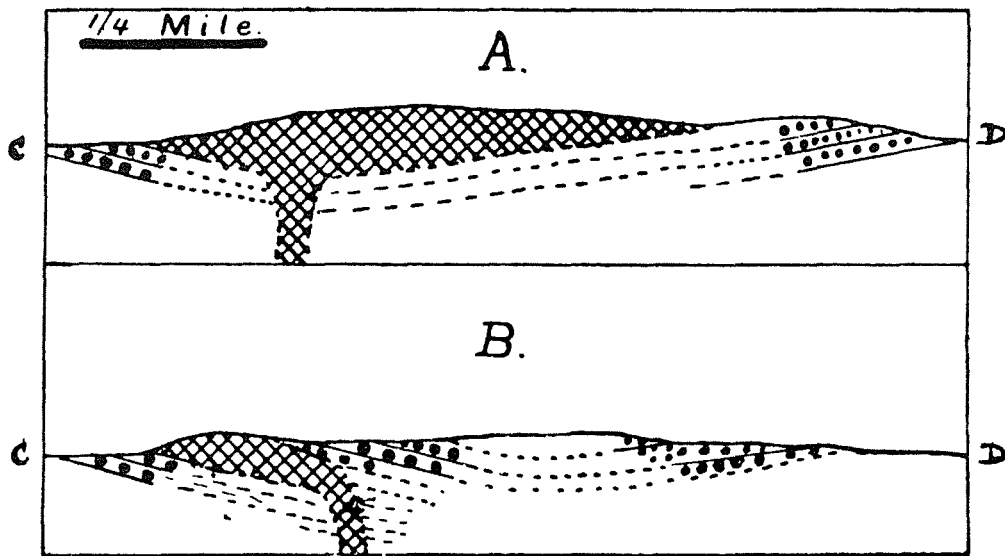
The Ladentown diabase extends for about 2 miles along the road, forming a series of low hills. It is crossed by several streams and is locally covered by glacial drift. The rock varies from fine-grained diabase to medium-grained vesicular basalt with intersertal texture, and structures like pahoehoe have been reported.

This igneous mass may connect with the Palisade diabase across the 2-mile drift-covered stretch to Mt. Ivy (Kümmel, 1898, p. 41). The flow-like features of the Ladentown sheet and its position high in the stratigraphic sequence suggest that here the northwest end of the Palisade intrusion may have reached the surface.

- 44.5 0.1 Steep hill of diabase on left (east).
- 44.6 0.2 Jointed diabase on left.
- 44.8 0.1 Closely-spaced, curved joints in diabase on left differ markedly from the large-scale vertical jointing in the sill along the Hudson River.
- 44.9 0.1 Crossing north end of Wilder Road.
- 45.0 0.1 East-dipping poorly-sorted conglomerate with clasts of Paleozoic rocks. In lower part some clasts are 1 to 2 feet in diameter.
- 45.1 0.4 Limestone conglomerate underlying hill.
- 45.5 0.1 Hill steepens on left. Ladentown diabase.
- 45.6 0.1 Turn east (left) onto Limekiln Road.
- 45.7 0.4 Hill of Ladentown diabase and outcrop at road level on left (north). Fine-grained vesicular diabase with intersertal texture, but without flow texture in specimen examined. Interstices filled with very dark devitrified glass; scattered patches of iddingsite, amygdules of wordenite with a slender vein of quartz in some.
- 46.1 0.1 Intersection of Wilder Road and Limekiln Road. One of several abandoned quarries in limestone conglomerate on farm on southeast corner of intersection. Exposure of conglomerate on glaciated surface between old barn and house, just west of the private driveway.
- 46.2 STOP 4. Limekiln Road. Border Conglomerate in Upper Brunswick Formation. Time here: 20 minutes. This spectacular border conglomerate consists of rounded clasts as much as 4 feet in diameter in gravelly reddish-brown sandstone. Most of the clasts are gray cherty limestone, formerly quarried for burnt lime. Clasts of quartzite and sandstone are also present. The conglomerate is remarkably closely packed with little matrix. Conglomerate in this area east of the Ladentown diabase dips about 5° west (Kümmel, 1898, p. 40). See Figure 20 A, B.



**A** Sketch map showing relations of trap and sedimentary beds near Ladentown.



**B**

Sections showing the supposed relations of the Ladentown trap to the adjoining conglomerate.



This fanglomerate facies occurs at several places along the western boundary of the Triassic basin and is well-known as the "Potomac Marble" from Point of Rocks, Maryland.

- 46.2 0.6 Return to US 202 on Limekiln Road (travel west).
- 46.8 0.7 Turn left onto US 202. Proceed southward. Ramapo Mountains to the west. The road parallels the Mahwah River which flows along the fault zone at the western border of the Triassic basin.
- 47.5 Intersection with old US 202. Outcrops of limestone conglomerate on both sides of the road.

STOP 5. Old US 202. Border Conglomerate in uppermost Brunswick Formation. Time here: 30 minutes.

The section exposed along the west side consists of about 10 feet of boulder conglomerate interbedded with, and overlain by reddish-brown gravelly sandstone. The clasts consist largely of a variety of Paleozoic limestones, together with red sandstone and Green Pond (Silurian) conglomerate and quartzite.

On the east side of US 202 the deposits are less coarse, and exhibit well-developed cross-bedding with dispersal direction to the south. The regional dip of the sequence is to the southeast, toward the Ladentown diabase (Figure 20 A, B).

A 12-foot limestone boulder has been reported just south of here.

- 47.5 3.0 Continue south on US 202.
- 50.5 0.1 Gneiss of Ramapo Mountains exposed on right .
- 50.6 0.2 Turn right onto Pavillion Road. Exposure of slickensides in the Ramapo Fault zone. Present relief between Precambrian crystalline rocks and Triassic sedimentary rocks is due to differential erosion. Top of hill on gneiss; quarry in diabase of Union Hill seen to the southeast.

At Union Hill, the trap is associated with dark purplish-red cobble conglomerate which contains clasts of quartzite, reddish-brown, greenish-gray and gray limestone, and amygduloidal basalt. The largest clasts present are as much as 1 foot in diameter and one 3 feet in diameter has been reported. About 30 percent of the clasts here are limestone.

- 50.8 0.4 Return to US 202.
- 51.2 0.1 Turn left from US 202 onto NY 59 East.
- 51.3 4.2 At light, NY 59 bears left at Lafayette Avenue through Suffern.
- 55.5 0.8 Glacial erratics on right.

- 56.3 1.0 Glacial drift on right.
- 57.3 0.9 Spring Valley.
- 58.2 2.0 Howard Johnson Restaurant. REST STOP. 15 minutes.
- 60.2 0.2 Cross entrance to service road to Palisades Interstate Parkway, South.
- 60.4 0.6 Cross entrance to service road to Palisades Interstate Parkway, North.
- 61.0 STOP 6. East end of Cherry Hill - NY 59. Brunswick Formation.  
Time here: 30 minutes.

The Clarkstown Police will conduct our group across the highway to the best outcrops on the north side of the road.

This section in the lower part of the Brunswick Formation is about 0.2 miles long and consists of about 125 feet of strata (N30E, 6°W) composed of interbedded buff to reddish-brown feldspar-rich sandstone and reddish-brown mudstone. Many of the layers have well-developed cross-bedding (Figure 21) commonly in the 1 to 2-foot sets; one cross-bedded unit is 11 feet thick. Dispersal direction generally is to the southeast, although some cross-beds dip westward (Figure 11). Unbedded mudstone and fine-grained sandstone apparently were mottled by burrowers.

The feldspar-rich sandstones here, as in much of the Stockton Formation, contain relatively abundant sodic plagioclase.

The traverse proceeds from east to west along the outcrop:

Top of Sequence (west end).

50'+: Reddish-brown mudstone, variably silty and fissile, with local sandy layers. On south side of road, at about this level, a 1-foot pebbly layer contains quartz clasts as much as 1/2 inch in diameter.

20': Reddish-brown sandstone interbedded with mudstone that is variably fissile. Base is marked by scour and fill, or flutes, and the basal bed contains intraformational mud chips. Lowest sandstone unit is conspicuously parallel-bedded, with convolutions overturned to the east. Local ripple-marks have crests trending N27°E. Scour and fill is common throughout the sequence.

Mudstone in the lower part of the unit contains a thin layer of drab mudstone with calcareous pellets. An 11-foot silty mudstone with thin layers of sandstone in the middle unit is conspicuously cross-bedded.

15' : Reddish-brown, cross-bedded mudstone, commonly weathers into slivers and chips. Drab calcareous nodules in upper part.

4' : Reddish-brown sandstone with very thin mudstone interbeds, and a 3-inch layer of mudstone in the middle. Round mudstone clasts on some bedding planes; scattered quartz pebbles, locally in small lenses.

2.5' : Reddish-brown fissile mudstone, with interbedded sandstone

10.5' : Reddish-brown feldspathic sandstone. Commonly medium-grained with rare pebbles and locally cross-bedded.

5' : Reddish-brown fissile mudstone.

East end of Outcrop.

61.0    1.3    Continue east on NY 59.

-----  
The following stop is optional:

61.1    0.1    At east end of Cherry Hill outcrop turn right onto Cherry Hill Lane.

61.2    0.4    Turn left onto Foxwood Road.

61.6    0.4    Turn right onto Sickletown Road.

62.0    0.1    Backslope of Palisade Sill to east (left).

62.1    0.6    Optional STOP 7. Conglomerate in lower Brunswick Formation  
Time here: 10 minutes.

Low ridge on lawn 157 Sickletown Road (Wright's property) consists of reddish-brown quartz pebble conglomerate and sandstone, locally cross-bedded. Clasts are principally rounded quartz as much as 1 inch in diameter, a few pebbles are as much as 4 inches in diameter. This conglomerate, about 1/2 mile from STOP 6, emphasizes the lateral variation in Triassic deposits in Rockland County.

62.7                    Return north on Sickletown Road. Turn east on NY 59.

-----  
62.3    0.3    Turn south on NY 303.

62.6    3.8    Outcrop of Palisade Sill on left.

66.4    1.8    Access road to Palisades Interstate Parkway.



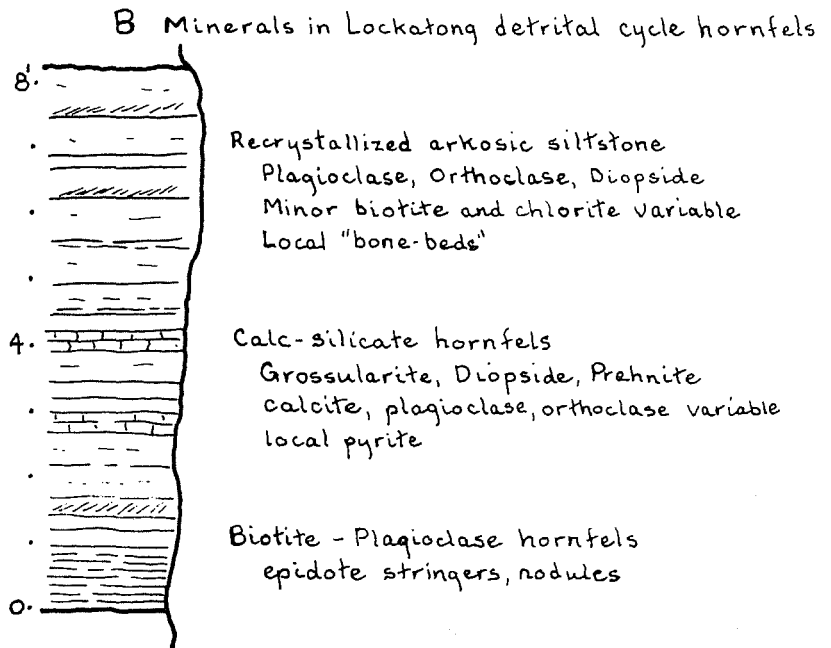
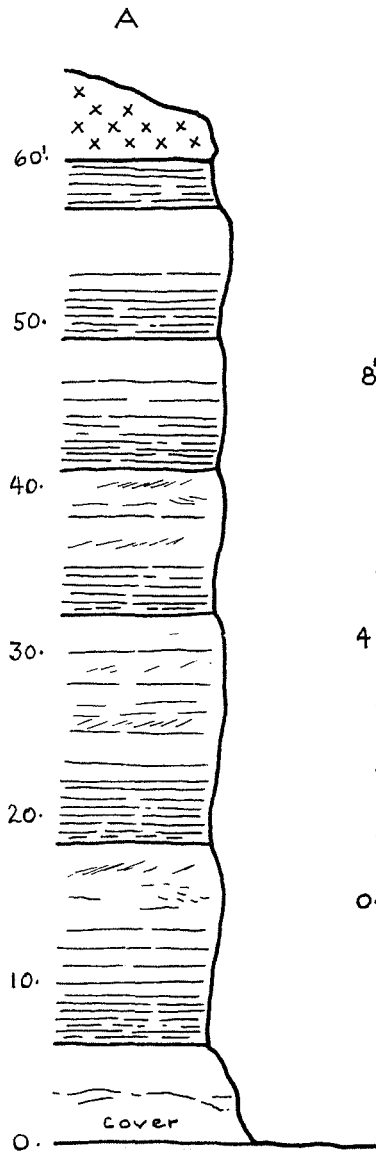
FIG. 21

CROSS-STRATIFICATION IN THE RED-BROWN AND BUFF FINELY BANDED FELDSPATHIC SANDSTONE ON THE NORTH SIDE OF CHERRY HILL, ROUTE 59 NEW YORK (STOP 6) ILLUSTRATING AVERAGE SIZE AND TYPICAL STRUCTURE OF THE CROSS-BEDS. (SKETCHED FROM A PHOTOGRAPH).

Figure 22. Locketong hornfels above Palisade Sill, STOP 8.

A. Succession of five complete detrital cycles, north end of upper level of Granton Quarry. See Figure 16B.

B. Model of hornfelsed Locketong detrital cycle.



- 68.2 0.7 Turn left onto Oak Tree Road at traffic light (J.J. Crowley Real Estate and State Line Restaurant).
- 68.9 0.9 Turn right (south) on NY 340.
- 69.8 9.8 Continue on NJ 501 south (Carter, Piermont, County, Huyter, Engle, Dean and Van Nostrand roads).
- 79.6 0.1 NJ 501 turns to left.
- 79.7 2.8 Turn right onto NJ 93 South (Grand Avenue).
- 82.5 0.8 Cross NJ 46. Continue south on NJ 935.
- 83.3 1.6 At traffic light (Connor Insurance Company) and traffic circle bear left then right to US 1 and 9 South (Bergen Turnpike and Tonnelle Avenue).
- 84.9 0.4 Hill of cross-bedded calcareous arkose on right (west). This sandstone with an interbedded 2-3 inch limestone unit (Kindle, 1944, p.4) overlies the Lockatong strata exposed in the Granton Quarry 1/2 mile to the south (see Figure 15A).
- 85.3 0.1 Diana Stores and knob of sill at Granton Quarry, North Bergen, on right.

STOP 8. Lockatong Hornfels and subsidiary sill.

Time here: 30 minutes.

- 85.4 0.1 Enter driveway at south end of Diana Stores property. Drive to rear, turn right and drive to north end of property and south face of escarpment (see Colbert, 1966, Figures 1,2).

About 60 feet of Lockatong hornfels lies between the top of the Palisade Sill to the east and a subsidiary sill at Granton Quarry, North Bergen (Figures 15A, 16B, 22). The excellent exposure at the north end of the Diana Stores parking area consists of five complete hornfelsed "detrital" cycles (Van Houten, 1964), two of which are exposed along the east wall of the lower quarry. In contrast to the "chemical" cycles in the River Road excavation (STOP 1) each of these is thicker, shows extensive evidence of burrowing as well as shrinkage cracking, and contains cross-bedded siltstone and very fine-grained arkose pervaded by diopside in the upper part. The presence of prehnite and recrystallized feldspathized arkose in the middle and upper part of each cycle suggest metamorphism in presence of water vapor.

The overlying subsidiary sill, more than 20 feet thick, has been reported to contain an arkose xenolith a maximum of 10 feet thick and 100 feet long (Lewis, 1908, p. 135).

In spite of the extensive hornfelsing of the Lockatong rocks they still yield fossils of reptiles, fish, estheriids and plants (Colbert, 1965, 1966).

- 85.5           Return to US1 and 9. Turn right (south) for Lincoln Tunnel; turn left (north) for George Washington Bridge.

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TRIP D: EXCURSION TO THE STERLING AND FRANKLIN AREA  
IN THE HIGHLANDS OF NEW JERSEY

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GEOLOGY ALONG THE ROAD BETWEEN LONG ISLAND AND THE HIGHLANDS OF NEW JERSEY

The geological trip to the Highlands of New Jersey starts at Queens College in Flushing and crosses the western part of Long Island in Queens County, the East River, Manhattan, the Hudson River, the Palisades, and the Lowlands of New Jersey.

Long Island.

Long Island forms the northernmost portion of the unsubmerged continental shelf, or the Coastal Plains of North America, stretching as far south as Florida, and west and southwest along the Gulf Coast to the Yucatan Peninsula.

The bedrock underlying the sedimentary sequence consists of undifferentiated metasedimentary rocks represented by schists and gneisses. Granodiorite occurs in the northwestern corner of Queens. Boreholes in Rockaway park revealed the presence of pegmatites and granite without signs of metamorphism (Perlmutter, 1949) and are probably of a Lower Paleozoic age. It appears that some of the gneisses can be correlated with the Precambrian Fordham Gneiss in Manhattan and the Bronx. The dolomitic limestone is apparently equivalent to the Inwood Marble, while the mica schist is similar to Manhattan Schist. So far the basement rocks are of very limited economic interest as a source of water which is of poor quality and insufficient quantity (Perlmutter, 1949). The bedrock crops out at the surface near Long Island City and Astoria in Queens County and dips at 80 feet per mile to the southeast where it is at 1100 feet below sea level at the Queens-Nassau boundary. The sedimentary sequence covering the metamorphic basement of Long Island is about 1200 feet thick in the southeastern part of Queens. It consists of Upper Cretaceous Raritan and presumably Upper Cretaceous Magothy Formations. The Raritan Formation contains the Lloyd Sand Member which is an aquifer. The Magothy Formation contains thin water-bearing zones yielding water for domestic purposes. The Cretaceous sediments are overlain by Jameco Gravel and Gardiners Clay of Pleistocene age. Jameco Gravel is an aquifer tapped in southern Queens by many wells. Gardiners Clay is covered by Upper Pleistocene deposits usually correlated with the Illinoian and Wisconsin stages of glaciation. The topography of Long Island features two terminal moraines, the Ronkonkoma moraine passing from east to west under the Queens College campus, and the younger Harbor Hill moraine. The Harbor Hill moraine forms a chain of hummocks north of Hillside Avenue in Queens reaching to elevations of 200 feet above sea level. The Long Island Expressway crosses the Ronkonkoma moraine west of Queens College.

Queens Midtown Tunnel.

Long Island is separated from Manhattan by the East River which is not a

river in a pure sense, but a salt water channel connecting Long Island Sound with Upper New York Bay. The channel of the East River was excavated along the north-striking outcrops of limestone formations. The Queens Midtown vehicular tunnel crosses the East River from Brooklyn to Second Avenue and 36th Street in Manhattan. The ground for the project was broken on October 2, 1936, by President F. D. Roosevelt, and the regular operations of the tunnel started on November 15, 1940. The maximum annual capacity of the tunnel is 16,000,000 vehicles. The construction was preceded by drilling exploratory boreholes along the river crossing at 200-foot intervals. The tunnel was shield driven and includes two cast-iron-lined tubes, about 31 feet in diameter, and each 6000 feet long. The depth of the top of the tube below river bottom at the Manhattan pierhead is 55 feet (Singstad, 1944). The tunnel was excavated partly through Fordham Gneiss, Inwood Marble, and Manhattan Schist, which form ridges along the river channel filled with overburden (Berkey, 1948).

#### Manhattan.

Manhattan is crossed along the 34th street to the entrance to Lincoln tunnel. The island of Manhattan is underlain by Precambrian Fordham Gneiss which is overlain unconformably by presumably Lower Paleozoic Inwood Marble and Manhattan Schist. Schist injected with granite forms the west side of Manhattan along the Hudson River. The entire rock complex represents the southernmost part of the Manhattan prong. The age of metamorphism of the Manhattan Schist was dated by the potassium / argon method as 360 million years (Long and Kulp, 1956, 1962). Relict ages as old as 480 million years suggest Cambrian or later age. According to the fossils (Pelmatozoa) found in a bed of marble at the base of the Manhattan Schist north of New York City, the Manhattan Schist is tentatively correlated with the Middle Ordovician Trenton Formation (Ratcliffe and Knowles, 1968).

#### Lincoln Tunnel.

The Lincoln vehicular tunnel crosses the Hudson River to New Jersey from 39th Street in Manhattan. The tunnel consists of three tubes which are respectively 8215, 7400, and 8008 feet long from portal to portal, the length of the underwater portion being 4600 feet in each case. The main sections of the tunnel were shield driven under compressed air. Work on the first tube started in 1934. The second tube was completed in 1937, and the third tube has been added recently, making accommodations for six lanes of traffic in all tubes. Cast iron segments were used for lining. The tunnel was excavated in Recent river silts and sands at depths ranging from 50 to 75 feet below the river bed. The depth of water in the Hudson River above the tunnel reaches 55 feet. The river sediments are underlain by Manhattan Schist and the Triassic sedimentary Newark series, separated by an unconformity approximately at the middle of the tunnel (Fluhr, 1941).

#### The Triassic Basin of New Jersey.

The cliff of the Palisades on the western bank of the Hudson River consists of the Upper Triassic diabase sill. It has chilled zones along the hanging wall and along the footwall. An olivine layer with magnetite and chromite formed above the chilled zone in the lower part of the sill as the result of gravitational settling of minerals which crystallized first (Widmer, 1964). The sill is about 1000 feet thick and dips at approximately  $15^{\circ}$  to the northwest. It is followed higher in sequence

by red continental Triassic shales, sandstones, and argillites underlying the lowlands forming part of the mid-New Jersey Piedmont. The youngest sediments in this area contain varved clays formed in the Hackensack and Passaic glacial lakes (Lewis and Kummel, 1940). Farther west, along Route 3 near Rutherford, harder Triassic sandstone forms higher elevations. The Triassic sediments are intercalated with three basaltic lava flows featuring columnar jointing and pillow structure. The lava flows cover an area of over 500 square miles and attain a thickness of 800 feet. Potassium/argon measurements on the Palisades diabase and associated basalts indicate their age as 190 million years (Erickson and Kulp, 1960). The diabase and basalt are quarried extensively as traprock and contribute substantially to the economy of the State of New Jersey. The openings and veins in traprock contain some sixty low-temperature minerals, including ten zeolite minerals (Mason, 1960). Excellent specimens of zeolites from New Jersey are on display at the American Museum of Natural History in New York. Copper desposits connected genetically with diabase and basalt were mined in this area between 1693 and 1810 (Widmer, 1964). The thickness of Triassic rocks reaches at least 10,000 feet at the border fault near Boonton. The accumulation of the wedge-shaped body of Triassic sediments was contemporaneous with faulting and represents a taphrogeosyncline (Kay, 1951).

### The Highlands of New Jersey.

The Highlands are part of the Reading prong of the New England physiographic province and extend in a northeastern direction across southeastern Sussex and Warren, and northwestern Passaic, Morris, and Hunterdon counties. They are 10 to 25 miles wide and form elevations up to 1000 feet above sea level. The climate in the Highlands is cooler than in the rest of New Jersey. In the south of the State the growing season is almost 8 weeks longer than in the Highlands (Widmer, 1964).

The Highlands consist of parallel ridges formed by Precambrian metamorphic rocks. The absolute age of pegmatites cutting these rocks is about 1100 million years (Long and Kulp, 1962). Therefore, the metamorphic formations are older than the pegmatites. Lower Paleozoic sediments occur in the Highlands in grabens and along faults. There are some 24 mappable rock units among the Precambrian formations such as marble, quartzite, skarn, pegmatites, quartz diorite, four kinds of granite, and 15 kinds of gneisses including several granite gneisses (Widmer, 1964). The thickness of the Precambrian sequence is over 6000 feet. The older group of Precambrian rocks is represented by metamorphically altered shales, sandstones, calcareous sands, and volcanics. The younger group of formations includes Franklin Marble with the world-famous deposits of zinc and manganese.

Iron was produced in the Highlands as early as 1710. The operations continued through the Revolutionary War contributing to the victory of the American forces. The number of magnetite mines grew until 1880 when 136 mines were operating. However, the last mines in the Dover area closed down recently, mainly because of conflict with labor unions. The magnetite ore bodies have the shape of laths or pods parallel to the linear structure and bedding in gneisses (Buddington, 1966). The magnetite ores in gneisses and amphibolites predominantly occur on the flanks of anticlines, the cores of which are commonly quartz-oligoclase gneiss. The ore bodies average 2 to 20 feet in width with the largest reaching 75 feet. Vertically the ore bodies range from 200 to 450 feet. The deepest mine reached the depth of 2000

feet below the surface (Widmer, 1964). The content of iron in ore bodies ranges from 35 to 60 percent. Recently the region started to attract attention because of the established existence of several deposits containing yttrium- and rare-earth-bearing minerals (monazite, allanite, spencite, xenotime, gadolinite, doverite, and others) associated with the iron deposits. Yttrium is used in the electronics industry and was recently sold at prices ranging from \$250 to \$390 per pound. The deposits examined do not contain sufficient quantities of yttrium and the rare earth elements to be recoverable under present economic conditions (Williams, 1967).

Buddington (1966) reviews attempts to explain the origin of magnetite ores which are expressed in hypotheses advocating the metasedimentary origin, hypogene replacement, leaching and reconstruction of country rocks as a source for iron, iron concentration in pegmatitic solutions, concentration of iron in solutions during the development of alaskite magma, structural and microstructural controls in localization of ore bodies, and the hypothesis of metasedimentary beds modified by hypogene solutions. Sims (1958) suggested that all of the iron was derived from granite magma. Hagner (1966) pointed out that the host rocks could be a source for magnetite ore during regional metamorphism. Buddington (1966) indicates that the hypothesis of origin by direct contributions, and emplacement by magmatic emanations, has the most support. However, he points out that it is not precluded that the magnetite deposits in the gneisses are metasedimentary beds modified by hypogene solutions. The last point of view seems to be the best founded. It is noteworthy that the banded magnetite-bearing gneiss contains layers and thin bands rich in magnetite alternating with those containing only small amounts of magnetite. This phenomenon is peculiar to the sedimentary rocks in which the iron mineral is of primary sedimentary origin.

#### THE STERLING-FRANKLIN AREA IN NEW JERSEY.

The deposits of zinc and manganese at Sterling Hill and Franklin in Sussex County are the main point of interest of this excursion. The region has been the most important producer of zinc east of the Mississippi River. The two ore deposits are 3 miles apart. Pinger (1948) refers to some evidence that the Dutch miners prospected the Sterling ore outcrops in 1640 for hemimorphite,  $Zn_4(Si_2O_7)(OH)_2 \cdot H_2O$ , for the making of brass. The red color of zincite ( $ZnO$ ) deceived the early prospectors who mistook it for cuprite ( $Cu_2O$ ). However, in 1812 zincite was used to make paint. Metallic zinc was first recovered from zincite ore in 1838. Franklinite,  $(Fe, Zn, Mn)(Fe, Mn)_2O_4$ , was used in 1854 to produce zinc oxide, and willemite ( $Zn_2SiO_4$ ) became the source of zinc in 1866. The ore body at Franklin was worked out and abandoned in 1954. The Sterling Hill ore body has been worked since 1870 (Widmer, 1964). Manganese and iron present in the ore are used to make spiegeleisen (an alloy of iron and manganese).

#### General Geology.

The ore bodies of Sterling Hill and Franklin are in Precambrian Franklin Limestone known also as the "White Limestone." The width of the outcrop of this limestone ranges from one half to two miles and extends from Ogdensburg in a north-eastern direction to Big Island in New York State. A fault east of the ore deposit is parallel to the strike of folded Franklin Limestone. It brings the Cambro-Ordovician Kittatinny Limestone, known also as "Blue Limestone," in contact with Franklin Limestone.

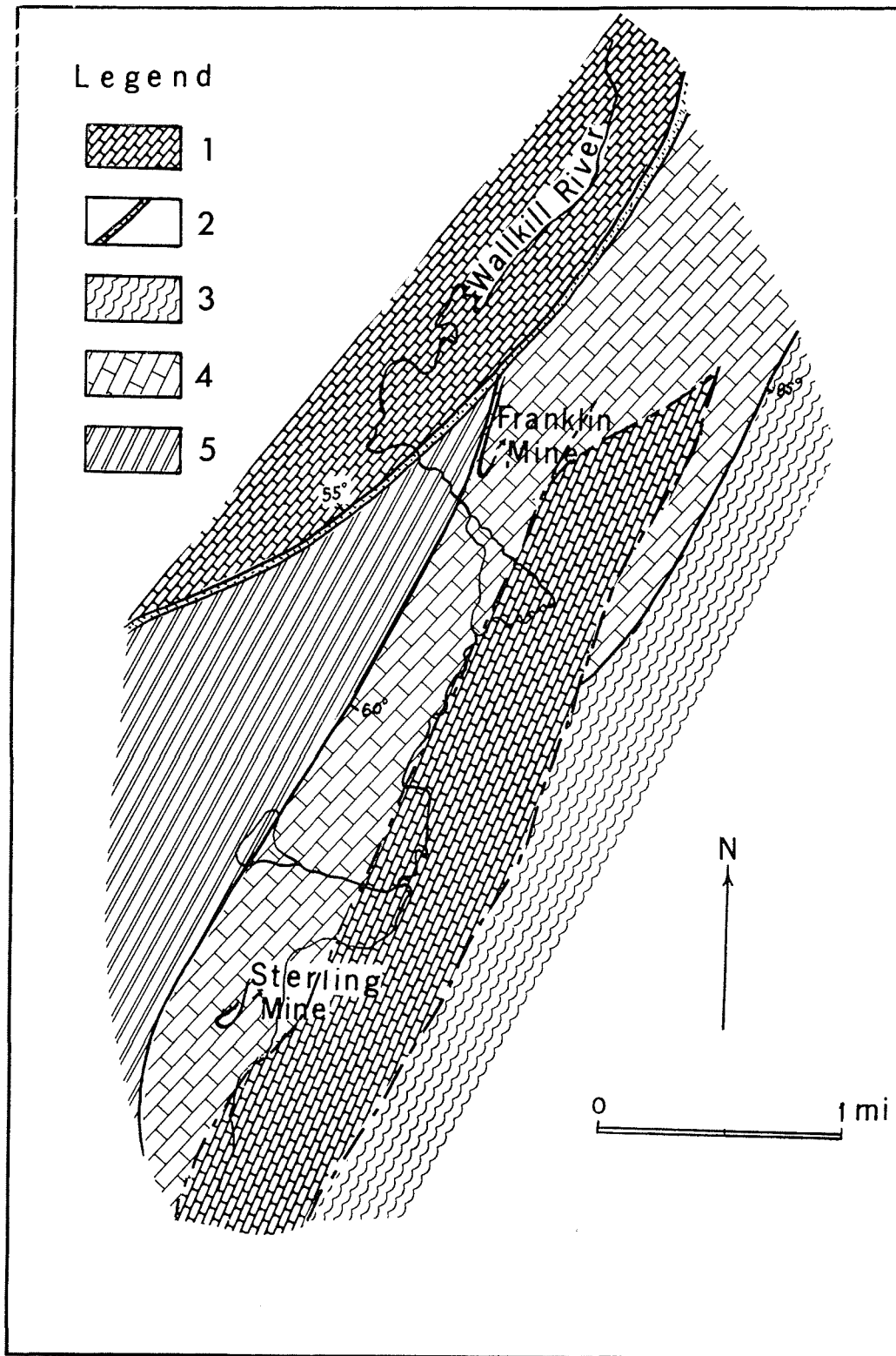


FIG. 1. GEOLOGIC MAP OF FRANKLIN-STERLING AREA.  
(AFTER PALACHE)

1. CAMBRO-ORDOVICIAN KITTATINNY LIMESTONE;
2. CAMBRIAN HARDYSTON QUARTZITE;
3. PRECAMBRIAN BYRAM GNEISS;
4. PRECAMBRIAN FRANKLIN LIMESTONE;
5. PRECAMBRIAN POCHUCK GNEISS.

follows: franklinite 40 percent, willemite 23 percent, zincite less than one percent, gangue silicates 11 percent, carbonates (calcite) 25 percent. Wilkerson (1962) indicates that in some places the ore consists entirely of franklinite with calcite, in other places it consists of willemite with franklinite and calcite, and still in other places it consists of willemite, zincite, and franklinite in calcite. It is difficult to establish zones characterized by definite mineral assemblages. However, it appears that zincite is typical of the lower part of the ore body. Metsger *et al.* (1958) point out that in the paragenetic sequence willemite is first and is followed in an undetermined order by tephroite, zincite, and franklinite.

The total number of minerals reported by mineral collectors from Franklin and Sterling mines is 194. In 1935 Palache described 148 of these minerals in detail, and in 1962 Wilkerson described 42 minerals. About thirty of these minerals are fluorescent. The most common fluorescent minerals are calcite and willemite. Calcite fluoresces because it contains manganese and traces of lead. It is claimed that 26 of the Sterling and Franklin minerals have not been found anywhere else in the world. Many of these minerals continue to be found in the operating Sterling Hill Mine of the New Jersey Zinc Company and in two open pits in Franklin, the Buckwheat open cut and the Trotter Mine. Both open pits are operated commercially. The minerals found in the area are displayed at the Franklin Mineral Museum, Inc., on Evans St. and at the Gerstman Private Museum on Walsh Road in Franklin.

Metsger (1962) points out that marble associated with the ore contains about 2.5 percent manganese. Oxidation of manganese as the result of exposure results in light brownish stain. A diffusion halo of zinc exists around the Sterling ore body and there appears to be a spectrographic lead halo present in the surrounding rocks.

The origin of the ore was explained in several ways. Opinions were expressed that the ore bodies are metasedimentary, that they were formed as the result of magmatic emanations, that they are pyrometasomatic, that they represent an ore magma of sulfides altered by metamorphism, that they have been deposited as sulfides and carbonates which weathered to oxides and hydroxides subsequently metamorphosed, and that they are high-temperature replacement deposits. Palache (1935) suggested the metasomatic origin for these deposits of hydrous zinc and iron minerals, and probably for the carbonates of zinc and manganese. The depositing solution is believed to have derived its metals from the products of oxidation of an older sulfide deposit. As the result of regional metamorphism these minerals were changed to their present composition. More recrystallization occurred after the formation of pegmatites and more minerals were deposited during subsequent hydrothermal activity. Minerals typical of the surface oxidation conditions formed when the ore bodies were stripped of overburden by erosion. Pinger (1948) is critical of Palache's hypothesis because in his opinion it fails to explain the lack of segregation of zinc and iron upon oxidation of mixed sulfides as it is common of many other deposits. Pinger indicates also that solution effects accompanying metasomatic deposits are lacking in New Jersey. Referring to the deposition by hot brines at the bottom of the Red Sea of sediments containing 56 percent  $\text{Fe}_2\text{O}_3$ , more than 6 percent  $\text{ZnO}$ , and 1.3 percent  $\text{MnO}$ , Callahan (1966) suggests that the controversial stratiform zinc and manganese deposits of New Jersey are of volcanic-sedimentary origin. Takahashi and Myers (1961) used a thermodynamic approach to the determination of temperature at which the minerals formed as we find them today. The absence of wollastnite indicates a maximum temperature of formation of  $680^\circ\text{C}$ . The occurrence of tephroite indicates the minimum temperature of  $530^\circ\text{C}$ . The absence of rhodochrosite and occurrence of calcite indicate that the

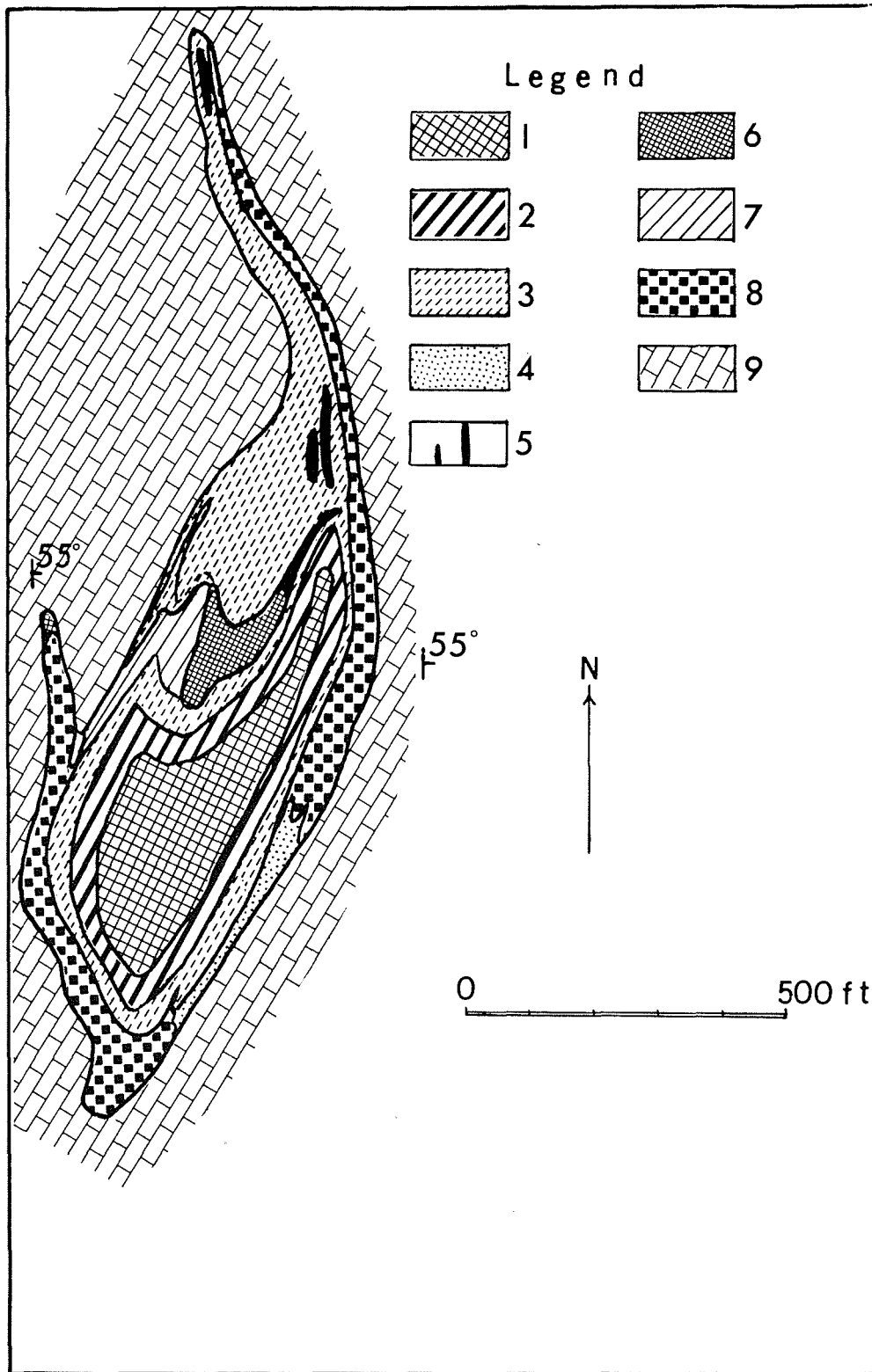


FIG. 2. GEOLOGIC MAP OF STERLING HILL ORE BODY.  
(AFTER METSGER)

- |                        |                        |
|------------------------|------------------------|
| 1. MUD ZONE;           | 6. BLACK WILLEMITE;    |
| 2. GNEISS;             | 7. CENTRAL ZINCITE;    |
| 3. PYROXENE LIMESTONE; | 8. OUTER ZINCITE;      |
| 4. FRANKLINITE ZONE;   | 9. FRANKLIN LIMESTONE. |
| 5. BROWN WILLEMITE;    |                        |



Farther east a second fault cuts the Kittatiny Limestone along the strike bringing it in contact with Precambrian Byram Gneiss. In such a manner the Kittatiny Limestone fills a graben in the Precambrian formations. On the western side the Franklin Limestone formation overlaps the Precambrian Pochuck Gneiss. The eroded surface of both Pochuck Gneiss and Franklin Limestone is covered unconformably by Cambrian Hardystone Quartzite dipping at  $55^{\circ}$  to the northwest.

The Franklin Limestone is coarsely crystalline and contains bands of gneiss. It is also characterized by steeply dipping bands of disseminated tremolite, chondrodite, phlogopite, and graphite (Metsger, 1962). These bands are parallel to each other and to the contact with the underlying Pochuck Gneiss, inferring inheritance of original sedimentary bedding (Pinger, 1948). Pinger indicates that the western side of the limestone belt is calcitic and low in silica. It has been mined for blast furnace flux, lime, and cement. On the eastern side, the limestone is more siliceous. It is interesting that folds occur in the Franklin Limestone which are not reflected in the underlying Pochuck Gneiss. This is probably the result of the capacity of limestone to flow and form secondary folds between more rigid formations. Dikes of basic traprock apparently of Upper Paleozoic or possibly Triassic age cut across the limestone.

#### Geology and Mineralogy of Ore Bodies.

The ore bodies of Franklin and Sterling Hill in Ogdensburg are both in the Franklin Limestone. Despite an intensive program of exploration no other ore bodies were found, so far, in the area. Both ore bodies form synclines or pitching troughs, as defined by Wilkerson (1962). The Franklin ore body plunges north-northeast at  $25^{\circ}$  and that of Sterling Hill plunges  $45^{\circ}$  to the east-northeast, terminating against a fault at a depth of 2500 feet below the surface.

The ore was exposed and partially eroded as long ago as before the deposition of Paleozoic rocks. This is indicated by the presence of detrital franklinite in the Cambrian Hardyston Quartzite. More erosion occurred during the Mesozoic and Cenozoic eras, especially during the Pleistocene glaciation. Two depressions in the Franklin Limestone are filled with zincy mud. One of them occupies the core of Sterling Hill syncline. It is 300 feet long, 200 feet wide, and 675 feet deep. The zincy mud is the result of the alteration of the limestone (Metsger, 1962; Anonymous, 1966). It is possible that these depressions formed during the long period of weathering preceding the Pleistocene glaciation. Glacial boulders of franklinite were found 10 miles to the south at Sparta.

The ore bodies range in thickness from 10 to 100 feet. At Franklin Mine the ore in the western limb of the syncline was exposed for a distance of about 2500 feet, while the eastern limb was exposed for a distance of about 600 feet. At Sterling Mine the ore in the western limb of the syncline was exposed for some 700 feet, while the east limb was 1600 feet long. The two ore bodies have similar host rock, similar tabular folded structure, and similar mineralogic composition. However, the Franklin ore body is close to the footwall, while the Sterling ore body is 1000 feet above the footwall. The Franklin ore body contained more rare minerals than the Sterling Hill ore body because of association with pegmatites.

According to Pinger (1948) the approximate composition of the ore is as

partial pressure of CO<sub>2</sub> was at a maximum of about 1000 atm. These figures, of course, indicate the conditions which existed during the process of metamorphism over 1.16 billion years ago, as indicated by a pegmatite cutting the ore body at Franklin (Long and Kulp, 1962).

It is obvious that the unique ore deposits of Franklin and Sterling Hill are a product of several geological processes. The primary ore was altered by regional metamorphism and locally by a pegmatite. Hydrothermal processes were superposed over the metamorphically altered ore. The presence of a lead halo around the ore bodies may be the result of this process. The source of metals remains not entirely clear. The volcanic-sedimentary source suggested by Callahan appears to be very plausible. Of particular interest is the presence of 2.5 percent manganese in the country rock. This manganiferous limestone has a sharp boundary with limestone containing only 0.1 percent manganese (Metsger, 1962). The country rock contains graphitic gneiss wrapping the core of the Sterling Hill syncline. Graphite from this gneiss is biogenic, as indicated by the C<sup>12</sup> to C<sup>13</sup> ratio (Pinger, 1948). All this evidence seems to point to the sedimentary nature of the country rock and the syngenetic nature of manganese in limestone, and appears not to preclude the syngenetic origin of the ore itself.

#### Mining Operations in the Sterling Ore Deposit.

According to the information issued by the New Jersey Zinc Company (Anonymous, 1966) the principal mine openings extending to the surface are the new main shaft inclined at 52° and bottoming at 2065 feet below the lower yard level, the old main shaft bottoming at the 1850 foot level, and the safety exit. Underground development includes a winze, bottoming at the 2670 foot level below the adit level, raises, drifts, and crosscuts. Levels are cut at 180 feet, 340 feet, 430 feet, 500 feet below the adit level, and at 100 foot intervals down to the 1600 foot level. There is a level at 1680 feet, one at 1750 feet, one at 1850 feet, and a crusher station level at 1920 feet in the main shaft. The winze is connected to levels cut at 100 foot intervals down to the 2550 foot level. Mining of 3 to 4 foot beds of ore up to a maximum of 15 to 25 feet is accomplished with longitudinal stopes for the full widths of the bed. Where the ore body thickness exceeds the 15 to 25 foot range, stoping is done by means of transverse stopes, carried in a hanging-wall-to-footwall direction, leaving pillars. The ore in the pillars is mined by means of square-set stopes. The past zinc production together with the available reserves exceeds 1,000,000 short tons.

#### GEOLOGY ALONG THE ROUTE BETWEEN THE HIGHLANDS AND LONG ISLAND VIA GEORGE WASHINGTON AND WHITESTONE BRIDGES

Route 23 crosses the Highlands in a southeasterly direction. The Oak Ridge Reservoir marks the northwestern border of a graben in Precambrian gneisses filled with Silurian and Devonian rocks. The Silurian Green Pond Conglomerate forms a ridge crossing the road between Newfoundland and the Charlottesville Reservoir which is underlain by Devonian shale and sandstone. The southeastern border of the graben is southeast of Charlottesville where the rocks are Precambrian gneisses.

The fault line separating the Precambrian Highlands from the Triassic basin is crossed at Riverdale. The diabase sill forming the Palisades is crossed

for the second time at the western approach to the George Washington Bridge.

The suspension-type George Washington Bridge across the Hudson River has a span from support to support of 3500 feet and is 204 feet above the surface of the water. The zinc used on the cables weighs 1,700,000 pounds and was produced from ore of the Franklin mine. The second deck of the bridge was opened in 1962.

The northern tip of Manhattan is underlain by Inwood Marble and Manhattan Schist and is featuring canoe valleys formed in the Inwood Marble. East of the Harlem River excellent outcrops of banded Fordham Gneiss can be seen in the road cut.

The East River is crossed over the Whitestone Bridge which was constructed in 1939. The main span of the bridge is 2300 feet long and 135 feet above the water surface. The solid rock on the Bronx side is at a depth of 98 feet below the surface and on the Queens side it is at 150 feet below the surface.

#### ROAD LOG

<u>Mileage.</u>		Some of the participants of the excursion will board the bus at the Sheraton Tenney Hotel at 90 Street and Ditmars Boulevard in Queens.
0.0	0.0	Queens College. Main gate on Kissena Boulevard. The bus will be boarded by the rest of participants of the excursion. Proceed north to Long Island Expressway. Turn left on the service road to the entrance to the expressway.
0.3	0.3	Entrance to L.I. Expressway.
1.1	0.8	Crossing the Ronkonkoma terminal moraine.
1.6	0.5	Grounds of the 1964-1965 New York World's Fair. Science Museum. The outwash deposits of Wisconsin age underlie the area between the terminal moraine and the East River.
8.2	6.6	Entrance to the Midtown Tunnel under the East River. The tunnel crosses ridges formed by Fordham Gneiss and Manhattan Schist, and depressions between the ridges eroded in Inwood Marble. The depressions are filled with Recent overburden.
9.6	1.4	Exit from Midtown Tunnel. Crossing Manhattan along 34th St., the underlying formations are mainly Manhattan Schist.
11.6	2.0	Entrance to Lincoln Tunnel under the Hudson River excavated in Recent sediments.
12.3	0.7	Boundary between the States of New York and New Jersey. The western part of the tunnel crosses the Upper Triassic continental sedimentary sequence underlying the diabase sill.
13.0	0.7	Exit from Lincoln Tunnel.

- 13.6 0.6 Crossing the escarpment of the diabase sill.
- 13.8 0.2 Fault in the diabase sill (a narrow valley developed along this fault north of the road).
- 14.7 0.9 Leaving the diabase sill. The area is underlain by Upper Triassic shales, sandstones, and argillites. Turn northwest on Route 3 crossing the Hackensack Meadows. The land rises at the entrance to Rutherford because of the appearance of harder sandstones.
- 19.7 5.0
- 26.5 6.8 Joining Route 46.
- 26.6 0.1 First Watchung Mountains formed by Triassic lava.
- 27.0 0.4 Lava with columnar jointing on the left side of the road.
- 27.4 0.4 Pillow lava structure on the left side of the road.
- 29.4 2.0 Triassic lava of the Second Watchung Mountains.
- 35.5 6.1 Triassic lava of Hook Mountain near Pine Brook. Third Watchung Mountains.
- 41.4 5.9 Escarpment formed by the fault zone between the Precambrian Highlands and the Triassic basin (mantled by glacial till).
- 53.0 11.6 Entering Dover. Outcrops of Precambrian gneiss.
- 54.3 1.3 Turning north on Route 15. Crossing an inlier of Silurian rocks north of Dover.
- 66.4 12.1 Turning on Route 517 in Sparta.
- 70.5 4.1 Ogdensburg. Turn left on Passaic Avenue. After 0.6 miles turn left on Plant Street.
- 71.3 0.8 Sterling Hill Mine office of the New Jersey Zinc Co. Visit to the mining property.
- 73.6 2.3 Franklin, N.J. LUNCH.
- 74.9 1.3 Gerstmann's Private Museum of Franklin and Sterling Hill minerals, 14 Walsh Road, Franklin, N.J.
- 76.2 1.3 Junction of Routes 23 and 517. Proceed southeast on Route 23 to New York.
- 84.1 7.9 Oak Ridge Reservoir. Northwestern border of graben in Precambrian gneiss -- inlier of Silurian and Devonian rocks. Southeast of Charlottesville the rocks are Precambrian. The fault line separating the Highlands from the Triassic basin is crossed at Riverdale.

- 103.6 19.5 Junction of Routes 23 and 46.
- 107.5 3.9 Junction of Routes 46 and 3. Continue on Route 46.
- 122.0 14.5 Triassic diabase sill.
- 124.2 2.2 George Washington Bridge.
- 125.8 1.6 Outcrop of Fordham Gneiss.
- 131.7 5.9 Whitestone Bridge. Cross Island Expressway.
- 139.3 7.6 Junction of the Cross Island Parkway and Long Island Expressway. Turn west on the expressway. The hills at the junction are formed at the terminal moraine.
- 142.7 3.4 Exit to Kissena Boulevard.
- 143.4 0.7 Queens College. After a short stop the bus continues to the Sheraton-Tenney Hotel.

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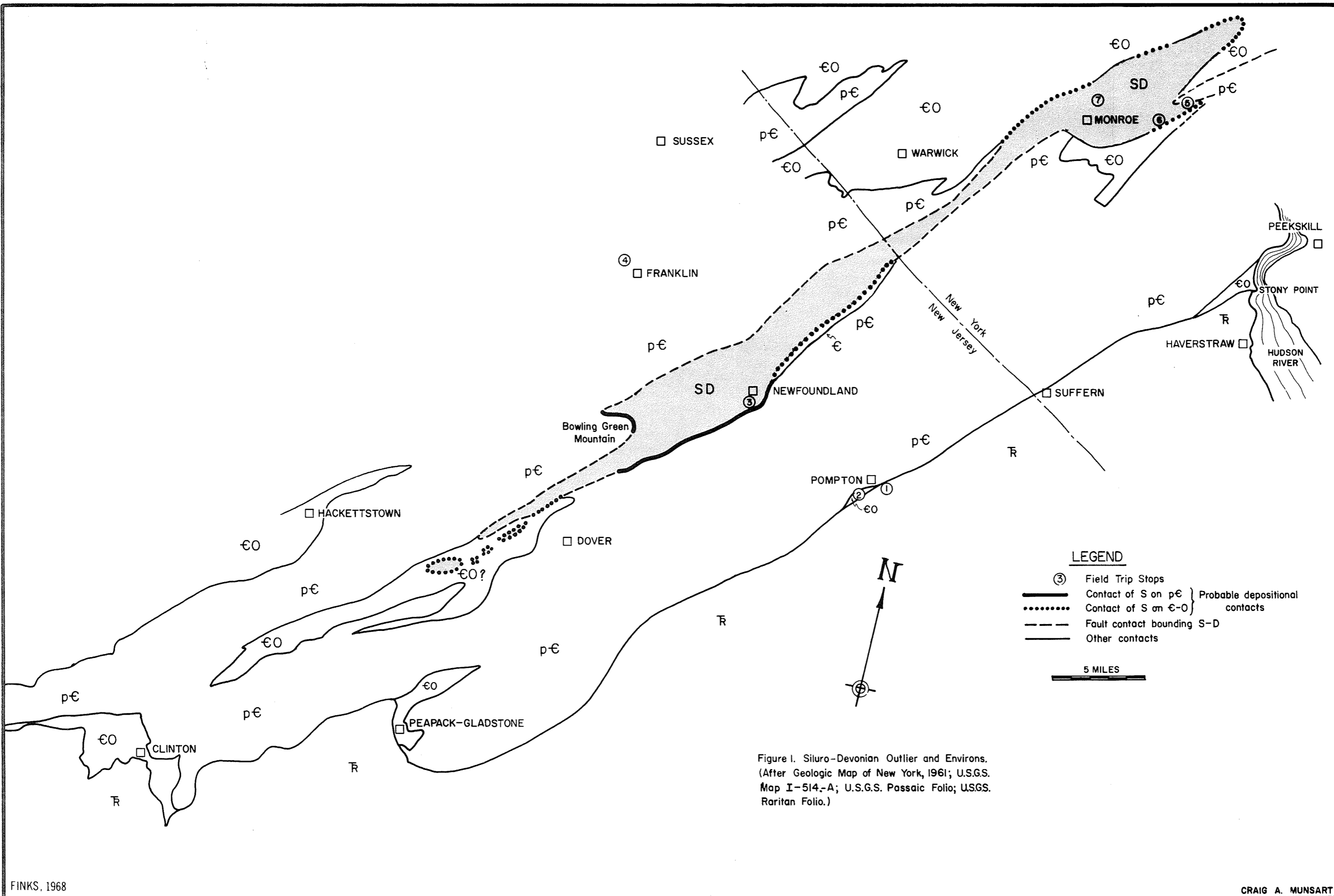


Figure 1. Siluro-Devonian Outlier and Environs.  
 (After Geologic Map of New York, 1961; U.S.G.S.  
 Map I-514.-A; U.S.G.S. Passaic Folio; USGS.  
 Raritan Folio.)



## TRIP E: TACONIAN ISLANDS AND THE SHORES OF APPALACHIA

By Robert M. Finks, Queens College of the City University of New York

### INTRODUCTION

Within the Precambrian Highlands of northern New Jersey and adjacent New York are several infolded and unfaulted belts of Paleozoic sediments. The easternmost of these belts, the Green Pond - Schunemunk outlier, preserves Silurian and Devonian rocks as well as Cambrian and Ordovician. The mid-Paleozoic sediments lie some 25 miles farther southeast than the main outcrop belt of the miogeosyncline, and represent a sampling of material deposited approximately that much nearer the source. They provide a record of those tectonic events and geographic conditions in the source area whose influence did not spread far enough to become manifest farther west.

### TACONIAN ISLANDS AND RELATED MATTERS

A glance at the map (Figures 1 and 2) will show that the Silurian is in contact with the Precambrian in some places and with the Cambro-Ordovician in others. Some contacts with the Precambrian lie along the traces of high-angle faults that cut across the strike of the beds. The remaining Silurian-Precambrian contacts are parallel to the strike of the Silurian. It is possible that they are also faults, for the actual contacts are nowhere observable in the field, although outcrops are continuously exposed within a few feet of them (STOP 3). In certain places, as at the north end of Bowling Green Mountain (see Figure 1) the contact wraps around the nose of a fold and is parallel to Silurian beds of rather gentle dip (less than  $45^{\circ}$ ). It is unlikely that a single thrust, much less a composite of separate faults, would be consistently parallel to a gneiss-conglomerate contact. It is more likely that this is an unconformable sedimentary contact.

The area in which the Silurian rests on the Precambrian is quite circumscribed. Its precise outlines and limits cannot be completely determined because the outcrops of the Siluro-Precambrian contact are confined to a few narrow belts parallel to the axis of the present inlier. Direct evidence for the northern and southern limits are preserved near Newfoundland and Dover, New Jersey, respectively (Figure 2) but the eastern and western limits are somewhere outside the outlier. Nevertheless, we can establish the western limit as east of the Walkill Valley, for there the complete Cambro-Ordovician sequence rests on the Precambrian (STOP 4). East of the outlier, along the Triassic border fault, the Cambro-Ordovician is exposed intermittently: the complete unmetamorphosed sequence at Clinton, and a partial one at Peapack-Gladstone, New Jersey; Ordovician phyllite at Pompton, New Jersey, (STOP 2); phyllite and marble at Stony Point, New York (Trip H). Elsewhere, Cambro-Ordovician carbonate cobbles are abundant in the Triassic border conglomerates, as at Pompton Lakes, New Jersey (STOP 1) and in Rockland County, New York (Trip D) revealing that they were extensively exposed immediately west of the border fault as late as Triassic time. Thus we can establish that the local area of exposed Precambrian during the early Silurian was confined within this perimeter.

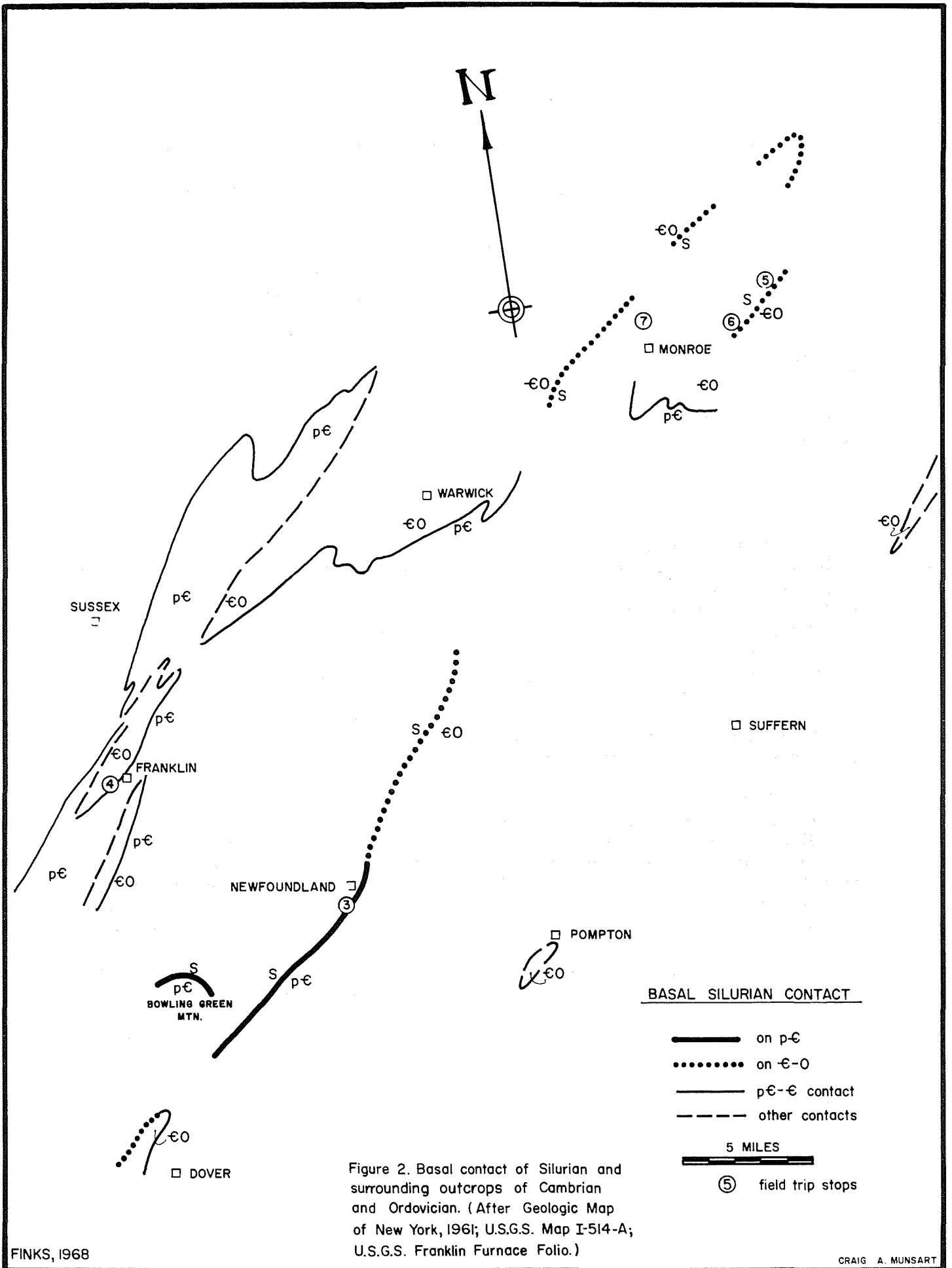
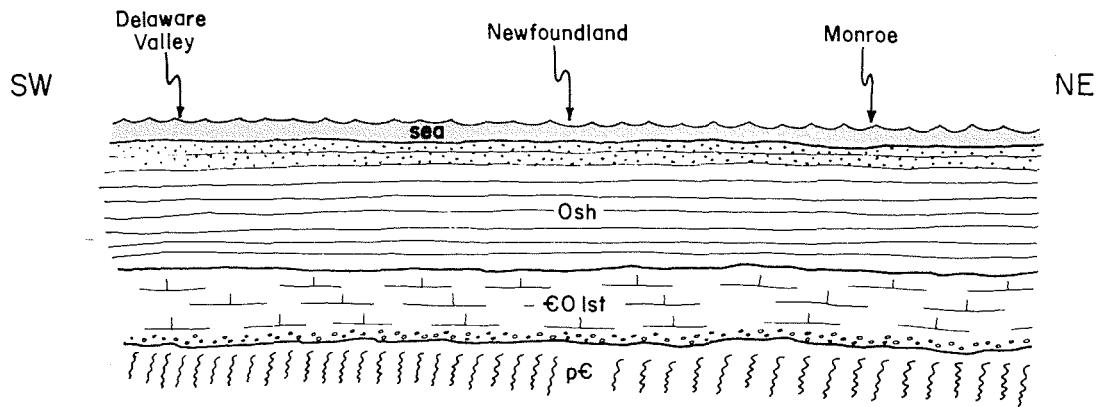
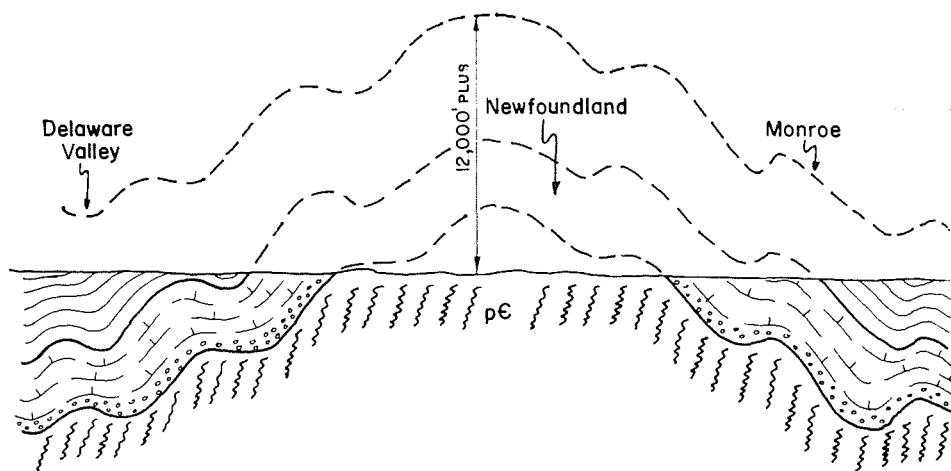


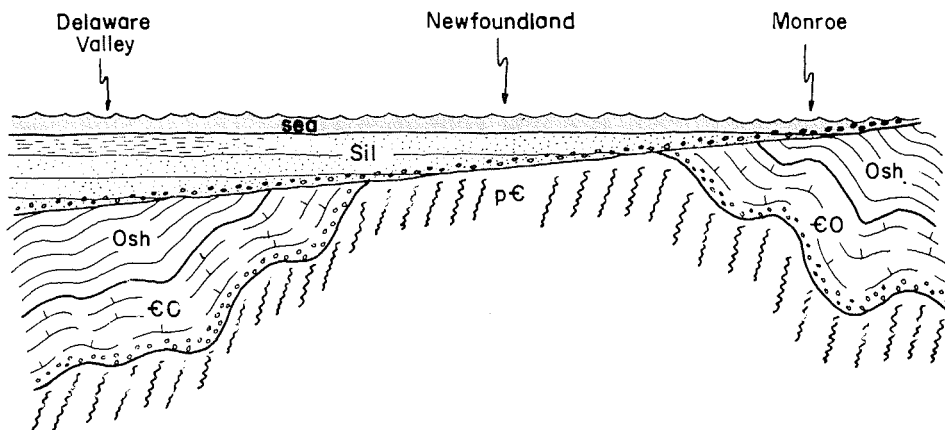
Figure 2. Basal contact of Silurian and surrounding outcrops of Cambrian and Ordovician. (After Geologic Map of New York, 1961; U.S.G.S. Map I-514-A; U.S.G.S. Franklin Furnace Folio.)



A- About 12,000 feet of sedimentary cover on pre-ε at end of Snake Hill (Trenton) time. Pre-Trentonian unconformity omitted.



B - Removal of more than 12,000 feet of cover before Shawangunk - Green Pond (Niagaran) time.



C- Condition during Later Silurian (Cayugan) time after Shawangunk - Green Pond deposition.

Vertical scale: 1"=10,000' Exaggeration approximately x6

The Silurian area of exposed Precambrian was almost certainly once covered with the full Lower Cambrian through Trentonian sequence. This sequence is essentially uniform in its stratigraphy on all sides of our area, and shows no signs of any uplift within the area in the form of a terrigenous clastic aureole. There is one rather widespread unconformity within the sequence, namely that at the base of the Trentonian (Balmville-Jacksonburg Limestones), but its very widespread nature indicates that it has no special significance for the local area. The strongest indication of this unconformity within our region can be seen to the northeast of Warwick, New York, where the Trentonian sequence oversteps rocks as low as the Upper Cambrian Pine Plains Formation (Offield, 1967). This amounts to the removal of about 1000 feet of section out of the entire 12,000 foot Cambro-Ordovician sequence (thickness from Offield, 1967). Consequently the remaining 11,000 feet or so was removed after the Trentonian and before the deposition of the Green Pond Formation by an uplift of this amount. As to the nature of the uplift, simple anticlinal folding might produce it, as shown in Figure 3, but thrust faulting would not be inconsistent with the style of Taconian deformation.

Because the entire Cambro-Ordovician sequence, completely surrounding the uplifted area, is wholly marine, the uplift may have risen as an island, or islands, out of the post-Trentonian sea. If so, its total area initially cannot have been much greater than the area of exposed Precambrian beneath the Silurian, a few tens of miles in greatest dimension. Ultimately it may have become joined to a larger Taconian landmass before being buried under Silurian sediment. Alternatively, it may have formed a mountain range in the Late Ordovician landscape, being uplifted only after the general emergence of the area from the sea. In either case, we must account for the widespread preservation of Trentonian and older rocks by assuming a protective cover of Late Ordovician sediment, subsequently removed, or else by assuming minimal uplift above sea level of the surrounding area.

#### THE SHORES OF APPALACHIA

Appalachia isn't dead, it's just gone to Africa. This paraphrase of Anna Russell's remark about vaudeville and England may serve to sum up more than a century of discussion concerning the source of eastward-coarsening terrigenous clastics in the Appalachian miogeosyncline. Whatever one considers Appalachia to have been, there is no doubt that it has manifested something of its geographic and tectonic nature in the sediments that it shed westward into the neighboring geosynclinal area. Major tectonic events have spread clastic debris even onto the craton, as for example the Catskill Delta. Lesser events have spread their influence more modestly. The Siluro-Devonian outlier of northern New Jersey and southeastern New York offers a unique opportunity to "take the pulse" of Appalachia, for it is nearer to this enigmatic body than the main Siluro-Devonian outcrop belt by about 25 miles.

### Tectonism.

True to this prediction, the Silurian and Devonian of the outlier do record, in the form of pulses of highly feldspathic sediments, periods of increased erosion of crystalline rocks not recorded elsewhere. The first of these is represented by the Middle Arkose Member of the Green Pond Formation. It consists of coarse, hematitic arkose containing fresh cleavage fragments of feldspar up to 1/2 inch across. The unit can be identified at the northeast end (STOP 5) and southwest end (STOP 6-A and Figure 4) of Pine Hill on the east side of the outlier and has been recognized in outcrops on the west side of the outlier to the west of Schunemunk Mountain (Coates, 1948). The member does not seem to be present to the south, at Newfoundland (STOP 3). This tongue of feldspathic material is conspicuous by contrast with the underlying beds of conglomerate which consist of pebbles of chemically-stable material such as milky quartz, quartzite and chert. The lower conglomerates represent the initial erosion products of the deeply-weathered Taconian landmass, and the angularity of the lowermost cobbles imply a nearby source (STOP 3 and Plate 1, figure 2). The feldspathic tongue represents the beginning of rapid mechanical erosion of fresh crystalline rock, and requires an essentially contemporaneous, nearby uplift, in late Niagaran or early Cayugan time. The presence of hematite indicates that the source area was simultaneously undergoing chemical weathering, probably on the interfluves in the manner of Krynine's interpretation of the Newark Series (Krynine, 1950).

The second episode of uplift in the source area is represented by the Lower Arkose Member of the Longwood Formation, shown on Figure 4 and described in the measured section at the south end of Pine Hill, Table I (STOP 6-A). This unit can also be recognized at Newfoundland (STOP 3). It is a medium-grained, red sandstone, with abundant light-colored feldspar grains. Similar, but somewhat less feldspathic, red sandstone beds are intercalated in the immediately underlying upper beds of the Green Pond Formation (Table I). This feldspathic sequence is separated from the Middle Arkose Member of the Green Pond by the clean quartz sands of the Upper Quartzite Member. It undoubtedly represents a renewal of strong mechanical erosion of a crystalline source, though by now the source is either lower or farther away. Conceivably it might be explained by increased rainfall, but a second pulse of uplift is at least as likely. This pulse would have taken place in middle to late Cayugan time.

Feldspar disappears from the section following this unit, and indeed, terrigenous detritus of any kind almost entirely drops out in the uppermost Silurian (STOP 6-A and Figure 4) and lowermost Devonian. In the presumably upper Helderbergian Central Valley Sandstone feldspar reappears in limited quantity, and continues, after an interruption by the Oriskanian Connelly Conglomerate (STOP 6-B) throughout the Onesquethawan sequence of Highland Mills Sandstone to Woodbury Creek Sandstone (STOP 6-C). Thus there is a third pulse of uplift in late Lower Devonian time, more or less centering on the Esopus Formation and its equivalents. These beds, of subgreywacke type, are not very coarse, though partly near-shore, and the source may have been relatively distant.

The late Onesquethawan Kanouse Sandstone is again a clean, non-feldspathic sediment, and is followed by the black Cornwall or Pequannock Shale. Beginning with the Bellvale Sandstone, (STOP 7), we have an increasingly coarse and lithic-fragment-rich, flysch sequence of Hamilton age, that represents the prograding Catskill Delta and the classic Acadian Orogeny. The initial beds are marine greywackes carrying Hamilton fossils (Mucrospirifer and Spinocyrtia) and grade up through subgreywackes and shales

with wood fragments to the hematitic coarse conglomerates of the Skunnemunk Formation. Because this outlier is closer to the source than any other preserved part of the Catskill Delta the definite Hamilton age of the initial greywacke beds provides a terminus post quem for the onset of the classic Acadian orogeny.

In summary, there are three minor pulses of uplift of the source area recorded in the outlier between the Taconian orogeny and the classic Acadian orogeny of the middle Devonian. The first, strongest at the northeast end of the outlier, is represented by the middle arkose tongue of the Green Pond. If the Green Pond is the transgressing sourceward feather edge of the Shawangunk, then Niagaran eurypterids in the Shawangunk due west of the outlier, at Otisville, date the pulse as slightly later, perhaps late Niagaran or even early Cayugan (Wenlock or early Ludlow). The second pulse is represented by the Lower Arkose Member of the Longwood, of probable Cayugan (Ludlow) age. The third, represented by the Central Valley through Esopus interval, was late Helderbergian through early Onesquethawan (Siegenian and Emsian). These three pulses might be considered faint echoes of the Caledonian orogeny, perhaps less physically distant than once thought. The major Acadian orogeny begins in the Hamilton (Givetian).

#### Shorelines.

It is not clear whether the initial beds of the Green Pond Formation represent a transgressing shoreline or piedmont alluvium. The lowermost beds at Newfoundland (STOP 3) have coarser and more angular clasts than higher in the section, and they contain a higher proportion of pebbles other than milky-quartz. Such pebbles include green and red chert, quartz-hematite phyllonite, quartzite, and shale. None of them have any obvious relation to the underlying Precambrian gneiss. They could represent a local weathering residue from Cambro-Ordovician sediments, reworked in the shore zone of an advancing sea. Their angularity favors such a local source, but the difficulty of matching them to anything from the immediately surrounding Cambro-Ordovician, except for the lighter cherts and the shale, argues against it. The eugeosynclinal Taconic sequence to the east might provide a suitable source, and swift, relatively short, streams might bring them in and deposit them without altering their angularity. The higher conglomerate beds of the Green Pond resemble the undoubtedly continental Skunnemunk Formation, and the Middle Arkose Member resembles typical continental red-beds. Thus it is quite possible that the entire lower part of the Green Pond is alluvial rather than marine. The prominent cross-bedding and "fining-upward" cycles (Plate 1, figure 3) is consistent with fluvial deposition. It may be therefore that the first marine shoreline does not appear in the Silurian section of the outlier until the Upper Quartzite Member of the Green Pond.

The Middle Arkose Member of the Green Pond in the Schunemunk area, however, need not have been continental. Because of the coarse, fresh feldspar clasts, it must have been derived from nearby exposed crystallines, but the situation could have been analogous to the Pennsylvanian and Permian marine arkoses that formed a narrow aureole around the "Ancestral Rockies" uplifts of Colorado. Unfortunately no fossils are known.

The same may be true of the Lower Arkose Member of the Longwood. The Upper Shale Member appears to be marine, for marine fossils have been reported from it (Hartnagel, 1907). Its uniform nature, and occasional mud-cracked surfaces, suggest a lagoonal or tidal mud-flat environment. The overlying "Binnewater" sandstone unit may be a beach or barrier bar, and the "Waterlime" unit, with its mud-cracks, intraformational conglomerates and stromatolitic structures, is almost certainly an intertidal flat, differing from the Longwood perhaps by a lesser influx of terrigenous sediment.

The Skyline Calcarenite Member of the Decker Ferry Formation (see Road Log, STOP 6-A, for formal description) consists of cross-bedded, coarse bioclastic debris of marine animals partly replaced by hematite. It has quartz-sandstone interbeds. It may represent a barrier-bar environment, similar to the "Binnewater" but under conditions of lower influx of terrigenous material. Alternatively, it may have been a more offshore shell-bank, but in any case in shallow water of high wave-energy. The intergradational nature of the "Binnewater", "Waterlime" and Skyline Calcarenite Units of the Decker Ferry (Figure 4 and STOP 6-A) indicate they are part of a single system of shifting environments. Indeed, the strong hematite content of the Skyline links it to the underlying Longwood and Green Pond Formations.

Limestones and calcareous shales with Lower Helderberg fossils ("Manlius," "Coeymans," and "New Scotland") are exposed at the north end of the outlier, at Cornwall (Hartnagel, 1907). These represent completely marine, and relatively off-shore conditions, for the first time in the sequence.

The Central Valley Sandstone may still be relatively offshore, though receiving much more terrigenous clastics. With the Connelly Conglomerate (STOP 6-B) there is a definite recession of the sea. This Oriskanian deposit, with its uniformly-sized, well-rounded quartz pebbles, and its abraded shells, (Boucot, 1959) was almost certainly a pebble beach. The distinctive nature of its typically Oriskany fauna (Costispirifer arenosus, Hipparionyx proximus and Rensellaeria ovata) make it possible to correlate it with more distant deposits. At Port Jervis, 25 miles due west, the same fauna occurs in an argillaceous limestone. At Kingston, 40 miles to the north, the type Connelly Conglomerate, occurs succeeded gradationally by the Glenerie Limestone carrying the same fauna. It is difficult to construct a paleogeography from three points, but the Schunemunk area would seem to have lain upon the Oriskanian shore.

The succeeding Esopus sequence (STOP 6-C) represents deeper water and presents a beautiful and classic example of the Cruziana-facies and the Zoophycos-facies of Seilacher (1964) alternating with one another. The Cruziana-facies represents a littoral to sublittoral environment above wave-base, the Zoophycos-facies a sublittoral to bathyal environment below wave-base. The shore of Appalachia at this time lay somewhere to the east, though in view of the good development of shallow-water features (see Road Log under STOP 6-C) probably not too far to the east.

The Kanouse Sandstone is another pebbly to sandy beach or near-shore environment, lithologically very similar to the Connelly. It is less pebbly, the fauna is much richer including many solitary rugose corals, and the shells are not abraded. It is likely to have been somewhat off-shore but probably close to it. It has been variously correlated with the Onondaga (Kindle & Eidman, 1955) or Schoharie (Rickard, 1964). In either case it is much richer in terrigenous detritus than its equivalent to the north and west.

The last shoreline recorded in our outlier differs from the rest in being the prograding shore of a delta. The Bellvale Sandstone (STOP 7 and Table II) begins with evenly-laminated greywacke and siltstone units representing a prodelta environment. They are succeeded by beds with "pillow-structures" (once referred to as "storm-rollers") and cut-and-fill structures, marking the beginning of the deltaic environment proper. The beds still contain marine fossils, but a possible wood fragment has also been found as well as zones of floating pebbles. These beds are succeeded by coarser, cross-bedded subgreywackes with shale chips and plant fragments. The higher sandstones become coarser, and more lithic-fragment-rich. A long succession of massively cross-bedded subgreywacke sandstones alternating with mudstones, and ending with coarse pebble-beds,

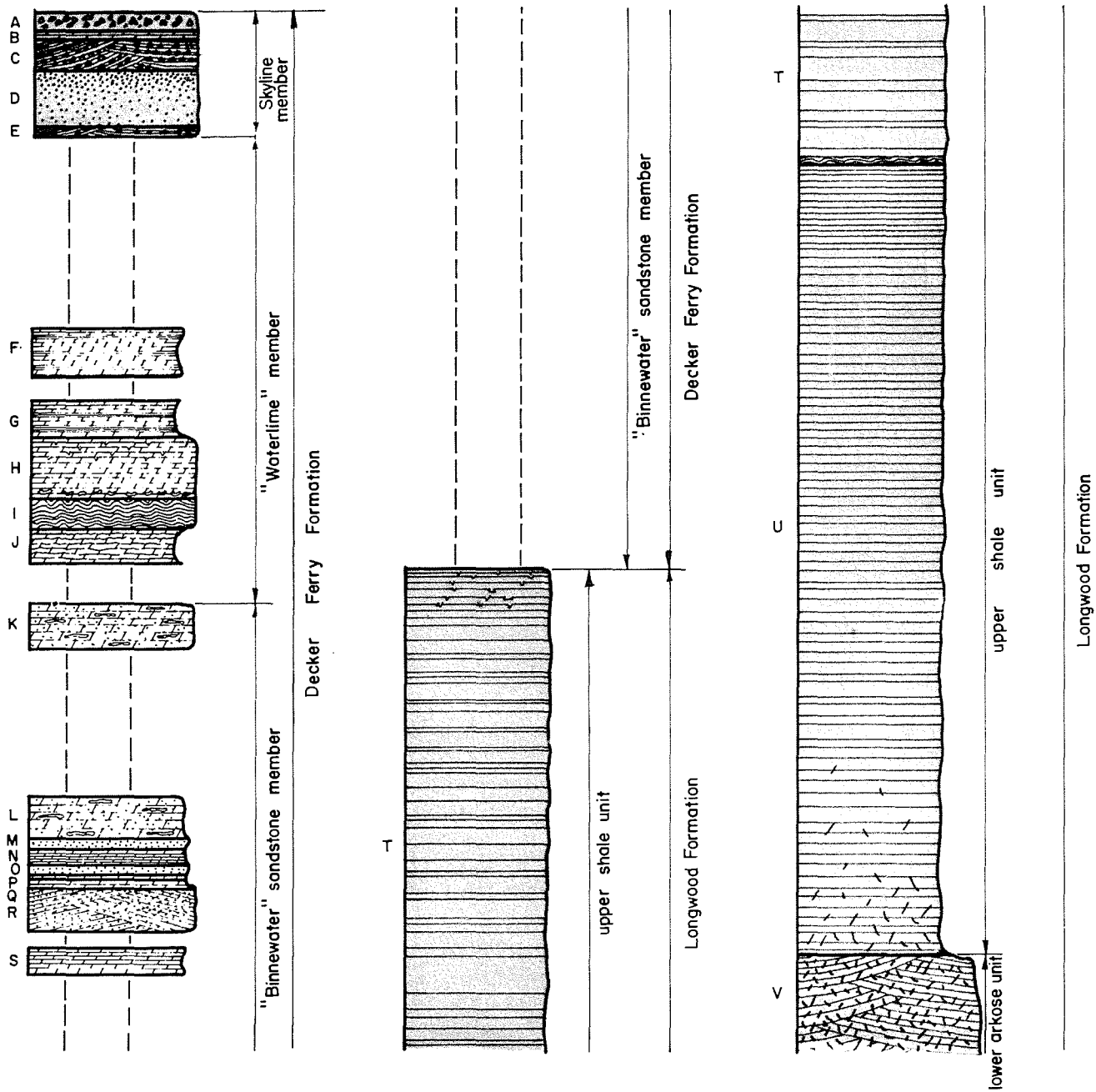
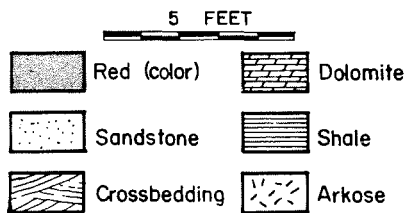


Figure 4. Silurian Section at the South End of Pine Hill. Page 1 of 3.





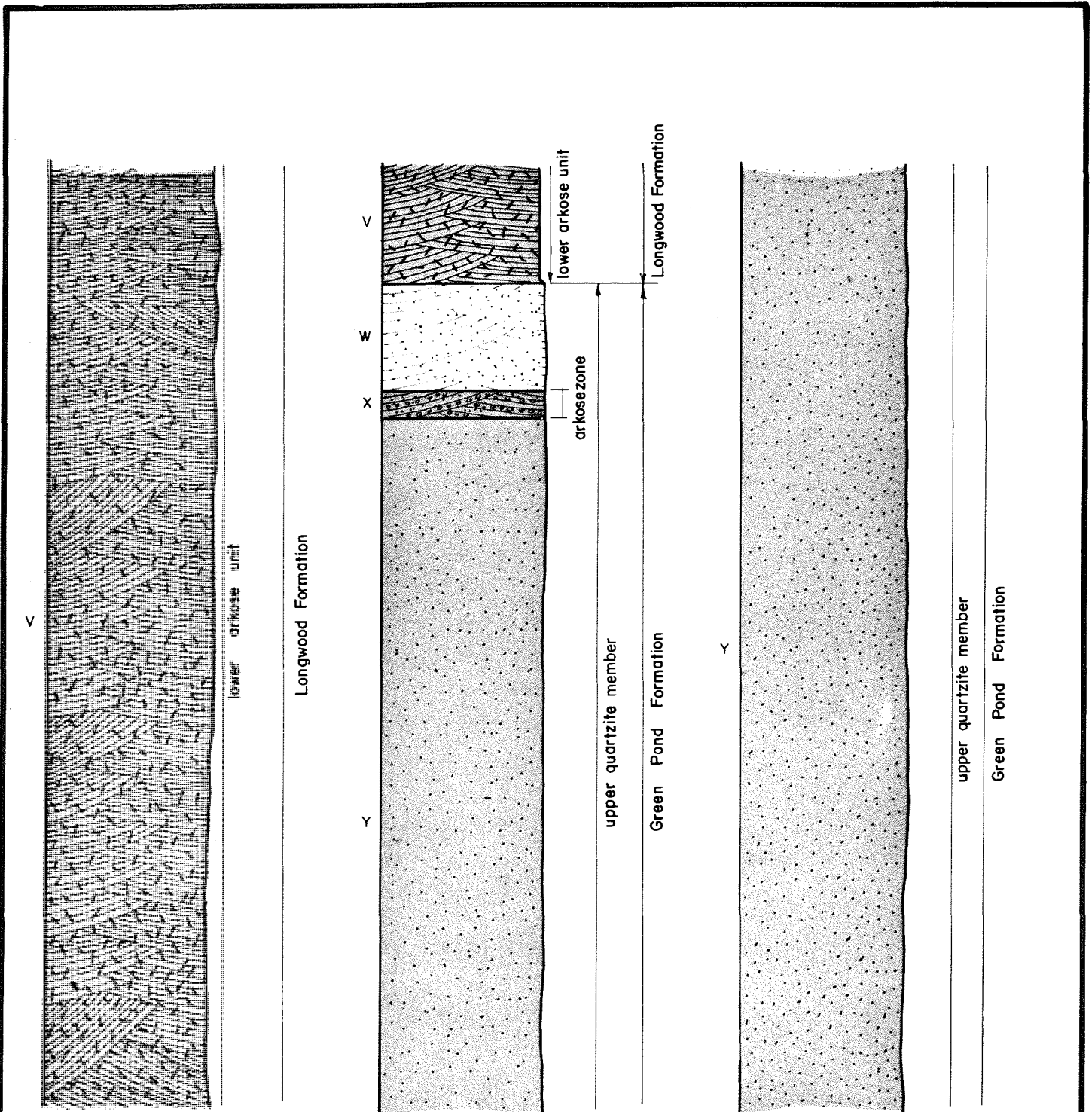


Figure 4. Silurian Section at the South End of Pine Hill. Page 2 of 3

5 FEET

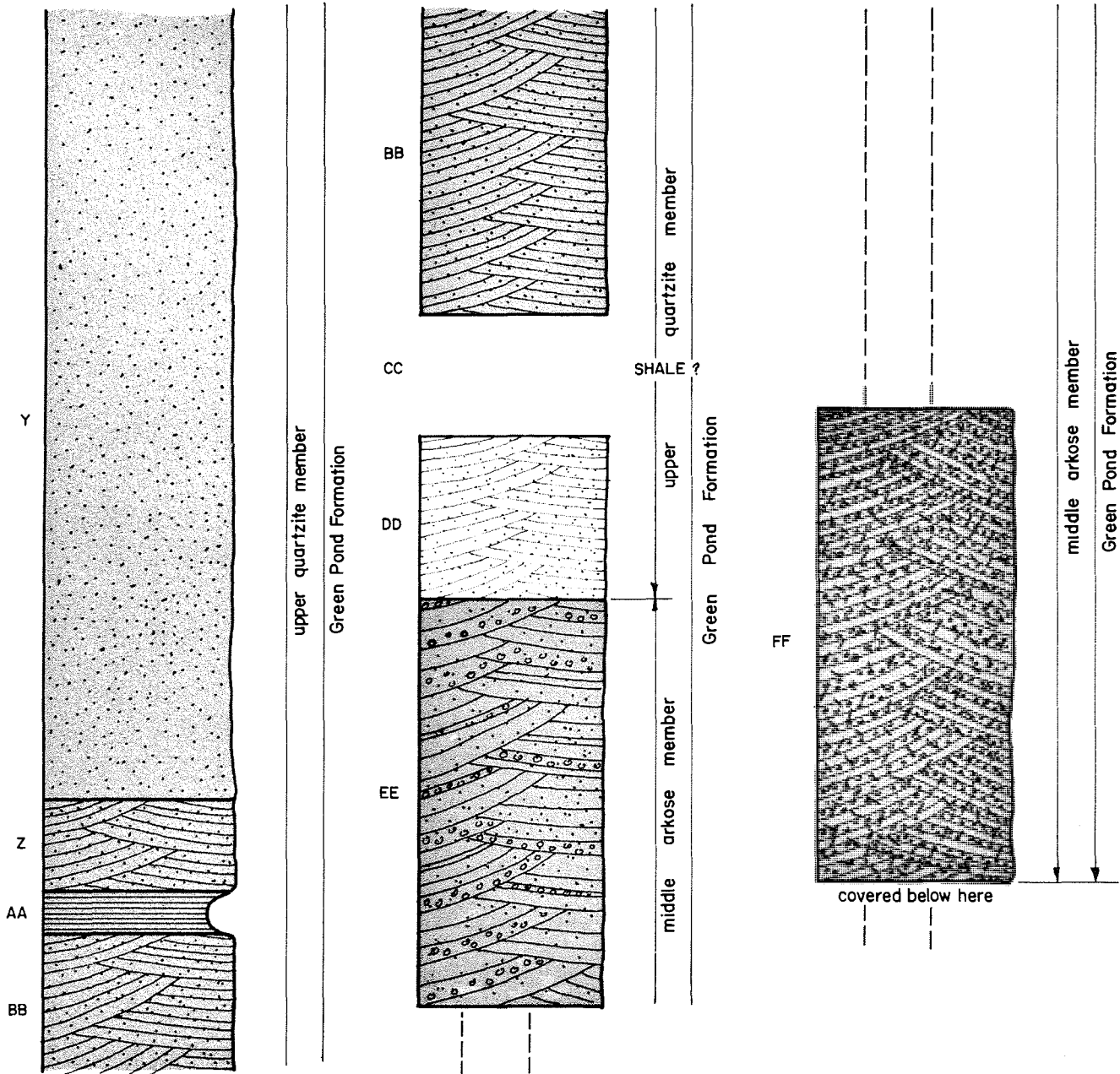


Figure 4. Silurian Section at the South End of Pine Hill. Page 3 of 3.

5 FEET

Table 1. Section of Silurian measured at S.W. end of Pine Hill Highland Mills, Orange Co., N.Y., S. E. across strike from north end of shale quarry east of Skyline Road just north of intersection with Pine Hill Road. Measured by R. M. Finks and F. H. Wind (Figure 4).

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<u>Unit</u>	<u>Thickness</u>	<u>Description</u>
		Top of section.
		<u>Decker Ferry Formation.</u>
		<u>Skyline Member:</u>
A	1' 1"	Calcarenite, gray-blue to red, weathers red, massive; crinoid clasts, 1 to 3 mm modal diameter, form matrix enclosing numerous large, frequently unbroken, fossils: 3 or more spp. of brachiopods, strap-like bryozoa ( <u>Ptilodictya</u> ), hemispherical massive bryozoan, fragmental 1 inch across ( <u>Monotrypa</u> ?), hemispherical <u>Favosites</u> , small horn coral; much hematite in pellets (?) 1-2 mm in diameter, and replacing crinoid debris.
B	0' 7"	Silty shaly dolomite, buff, weathers buff-gray, 1/8 to 1/4-inch beds, no fossils observed.
C	1' 10"	Calcarenite, gray-blue to red, weathers darker red, massive but with cross-bedded sheets 1 to 2 inches thick outlined by concentrations of hematite and/or red shale; clasts 1 to 3 mm modal diameter, fossils less obvious than in Unit A but similar.
D	3' 6"	Quartz-sandstone, speckled gray, yellow, buff, weathers buff; more massive at base, ranging from 3-inch beds at base to 1/4-inch beds at top; modal diameter of quartz sand about 1/2 mm, fine laminae 1/8 inch or so thick outlined by fine dark partings, vertical tension fractures 1/4 to 1/2 inch apart filled with similar dark partings.
E	0' 8"	Calcarenite as in C above.
		<u>"Waterlime" Member:</u>
	11' 10"	Covered interval.
F	3' 10"	Dolomitic siltstone or silty dolomite, argillaceous, gray, weathering buff, shaly-bedded in 1/4 to 1/2-inch beds, no fossils observed.
	1' 6"	Covered interval.
G	2' 4"	Same as Unit F.

- |   |    |     |   |
|---|----|-----|---|
| H | 3' | 9"  | Dolomite, aphanitic, medium-gray, weathering buff, massive with shallow, irregular, filled mudcracks. Obscure bedding planes from 2 inches to 1/4 inch, with finer laminae down to 1/32 inch. Bedding surfaces mud-cracked: polygons mostly 2 to 3 inches across, locally polygons in top bed as much as 5 inches across; larger cracks filled with quartz sand grains 1/2 mm across; conspicuous 1/2 inch diameter angular to rounded clasts (?) weather bright buff, forming depressions on weathered surface; Basal half-foot of this unit a coarse quartz sandstone (rounded grains, modal diameter about 1/2 mm) containing large angular clasts, up to 2 inches diameter, of unit below (Unit I). |
| I | 1' | 10" | Dolomite, aphanitic, algal (?), wavy-bedded; light dove-gray, weathering light buff, beds 1/2 to 1/4 inch thick with much finer laminae; length of waves 5 to 10 inches, amplitude 21 inches; many quartz-sandy partings, 1/8 to 1/4 inch thick, associated with breakage and reworking of algal laminae; upper surface of unit truncated by edgewise conglomerate (see above).   |
| J | 2' | 0"  | Dolomite, aphanitic, light greenish-gray, weathering buff in half-inch somewhat rubbly beds.  |
|   | 2' | 6"  | Covered interval.   |
|   |    |     | <u>"Binnewater" Member:</u>   |
| K | 2' | 8"  | Quartz-sandy dolomite, slightly blue-green-gray, weathers buff, with rounded quartz grains up to 1 mm in diameter; unit mud-cracked, polygons 4 to 6 inches in diameter, extending through 6 inches vertically; laminar algal interbeds and intraformational conglomerate with lighter-weathering clasts 1/8 to 1/4 inch across; entire unit massive with obscure half-foot bedding.  |
|   | 9' | 2"  | Covered interval.   |
| L | 2' | 7"  | Quartz-sandy dolomite with algal interbeds as above.  |
| M | 0' | 7"  | Quartz-sandstone, calcareous, gray, weathering buff, rounded quartz grains, modal diameter 1/2 mm.  |
| N | 1' | 0"  | Dolomite, greenish-grey, weathers buff, weathers shaly in 1/8 to 1/4-inch beds, irregular; sandy with rounded quartz grains 1/2 mm diameter.  |

O	0'	8"	Quartz-sandstone, lens-like, pinches to 4 inches surrounded by N lithology; pink-buff, quartz grains rounded, diameter approximately 1/2 mm.
P	0'	2"	Dolomite as in Unit N.
Q	0'	7"	Quartz-sandy dolomite, pink and gray.
R	2'	8"	Quartz-sandstone, gray with rusty banding, weathering red-buff, 2 to 6-inch beds, cross-laminated, quartz grains 1/2 to 1 mm in diameter and well-rounded.
	0'	10"	Covered interval.
S	1'	8"	Dolomite, laminated, as in Unit N.
	40' approx.		Covered interval.

Longwood Formation.

Upper Shale Member:

T	39'	2"	Shale, red, silty, hematitic slightly micaceous, breaking in 1-inch to 4-foot beds. Bedding surfaces mudcracked. Mud-cracks and (gas?) pits (1-6 inches in diameter) on bedding planes near top of exposed section, along with possible obscure fossils (fish plates?); 4-inch zone of contorted bedding at base. Base of unit is large bedding plane forming east wall of quarry to top of hill.
U	49'	0"	Red shale, east from brink of cliff above quarry; partly covered, transitional to unit below. (Unit U and underlying remainder of section measured east from brink of cliff across top of Pine Hill.)

Lower Arkose Member:

V	80' (approx.)		Arkose, red, feldspathic, fine-grained in 1/2-inch beds, cross-bedded in 6-inch to one-foot units; chips of shale, 1/4 to 2 inches across, are abundant in some beds; intermittent exposure, mostly covered.
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Green Pond Formation.

Upper Quartzite Member:

W	7'	4"	Quartz-sandstone, gray with pink spots, massive in 1 to 2-foot beds, cross-bedded in persistent 1/2-foot units, quartz rounded to subrounded, scattered hematitic staining and pebbles; local thin quartzites.
---	----	----	--

X	1'	10"	Quartz-sandstone, sub-arkosic, hematitic, cross-bedded in 1/2 to 1-foot units; subrounded medium quartz-sand with scattered pebble-layers and isolated pebbles of subrounded white quartz up to one inch in diameter; some beds with shale chips as in Unit U above.
Y	161'		Quartz-sandstone, quartzitic, prominent quartz-filled fractures, <u>not</u> cross-bedded, color ranges from dark red to cream-white in alternate bands; rather even 2 to 3-inch beds with finer laminations, medium-grained.
Z	5'	8"	Cross-bedded pink sandstone as in Unit W.
AA	2'	8"	Red shale.
BB	27'	2"	Red cross-bedded sandstone as in Unit W; mud-cracks (?) at base.
CC	7'	3"	Covered interval (shale?).
DD	10' approx.		Sandstone as in Unit W.

Middle Arkose Member:

EE	25'		Conglomeratic quartz-sandstone, subarkosic, red, with scattered, white quartz, subrounded pebbles up to one-inch diameter; cross-bedded in units up to 2 feet thick.
	28'	6"	Covered interval.
FF	29'		Conglomerate, arkosic, red to light gray, quartz pebbles angular to subrounded, up to 1-inch diameter; feldspar pebbles are angular cleavage-fragments up to 1/2-inch diameter, pebbles of feldspar may show imbrication; strongly cross-bedded in 1/2-foot to 1/3-foot units.

Base of exposed section.

Table 2. Section of Bellvale Sandstone measured along north side of Route 17, between Monroe-Washingtonville exit and a point 0.5 mile to the east, Orange Co., N. Y. Base of section is at the east end. Section measured by R. M. Finks and L. Mesticky.

---

<u>Unit</u>	<u>Thickness</u>	<u>Description</u>
		Top of section.
NN	20' 0"	Conglomerate and sand: sand festoon cross-bedded in 2-foot units, interbedded with conglomerate beds up to 2 feet thick, containing rounded pebbles of milky-quartz, quartzite, chert (minor), and shale or slate (minor); pebbles up to 3-inch diameter in sandy matrix, color dark-gray, weathering lighter gray.
covered	100' approx.	Covered interval is 200 feet along ground but beds at east end dip 55° NW and there is some indication that a similar dip is maintained through covered interval. Overlying Unit NN is nearly horizontal, dipping gently NE along plunge of syncline axis. Some faulting is possible at west end of covered interval.
MM	100'	Sand as below, massive, cross-bedded in 3 to 5-foot units.
LL	58'	Sand, as below, grades into mudstone at top; upper 13 feet of unit are mudstone; base of unit fills channel cut in underlying Unit KK.
KK	11'	Mudstone, cleaved.
JJ	61'	Sand, as below.
II	20'	Mudstone, cleaved.
HH	220'	Sand, with minor shale interbeds. At 140 feet above base of unit is a ten-foot thick probable channel fill; at 90 feet above base a zone of quartz-veins with slickensides, at 40 feet above base a small zone of quartz veins.
GG	25'	Mudstone, gray, weathers brown; cleaved.
FF	140'	Sand, massive, cross-bedded, contains shale chips.
EE	2'	Sheared sand with quartz veins.
DD	3'	Sand.
CC	31'	Mudstone, cleaved.

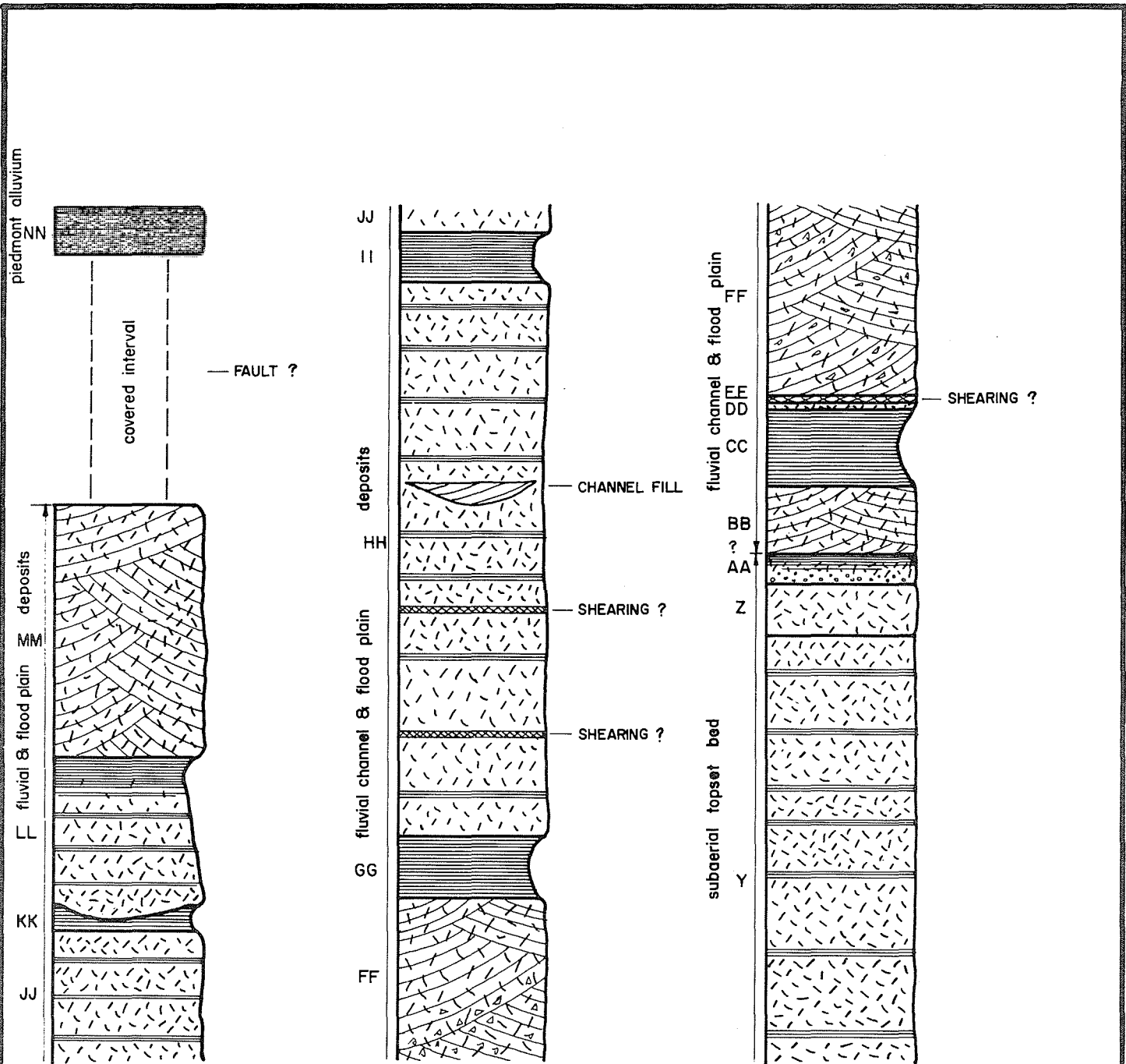









Figure 5. Section of Bellvale Sandstone on Route 17. Page 1 of 2.

50 FEET

LEGEND

- |   |              |   |             |
|---|--------------|---|-------------|
|  | Graywacke    |  | Siltstone   |
|  | Subgraywacke |  | Shale       |
|  | Crossbedding |  | Mudstone    |
|   |              |  | Coarse sand |



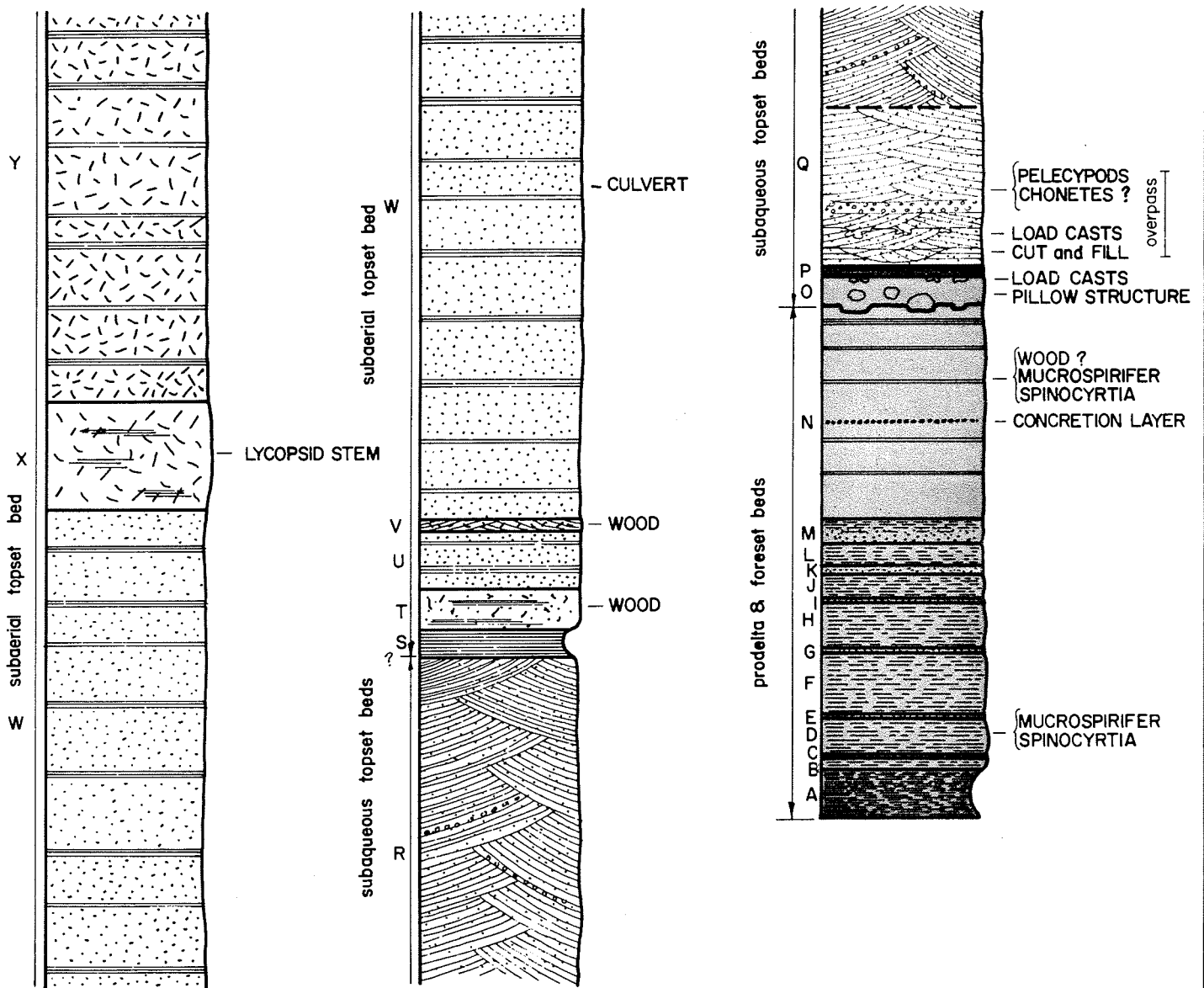


Figure 5. Section of Bellvale Sandstone on Route 17. Page 2 of 2

50 FEET

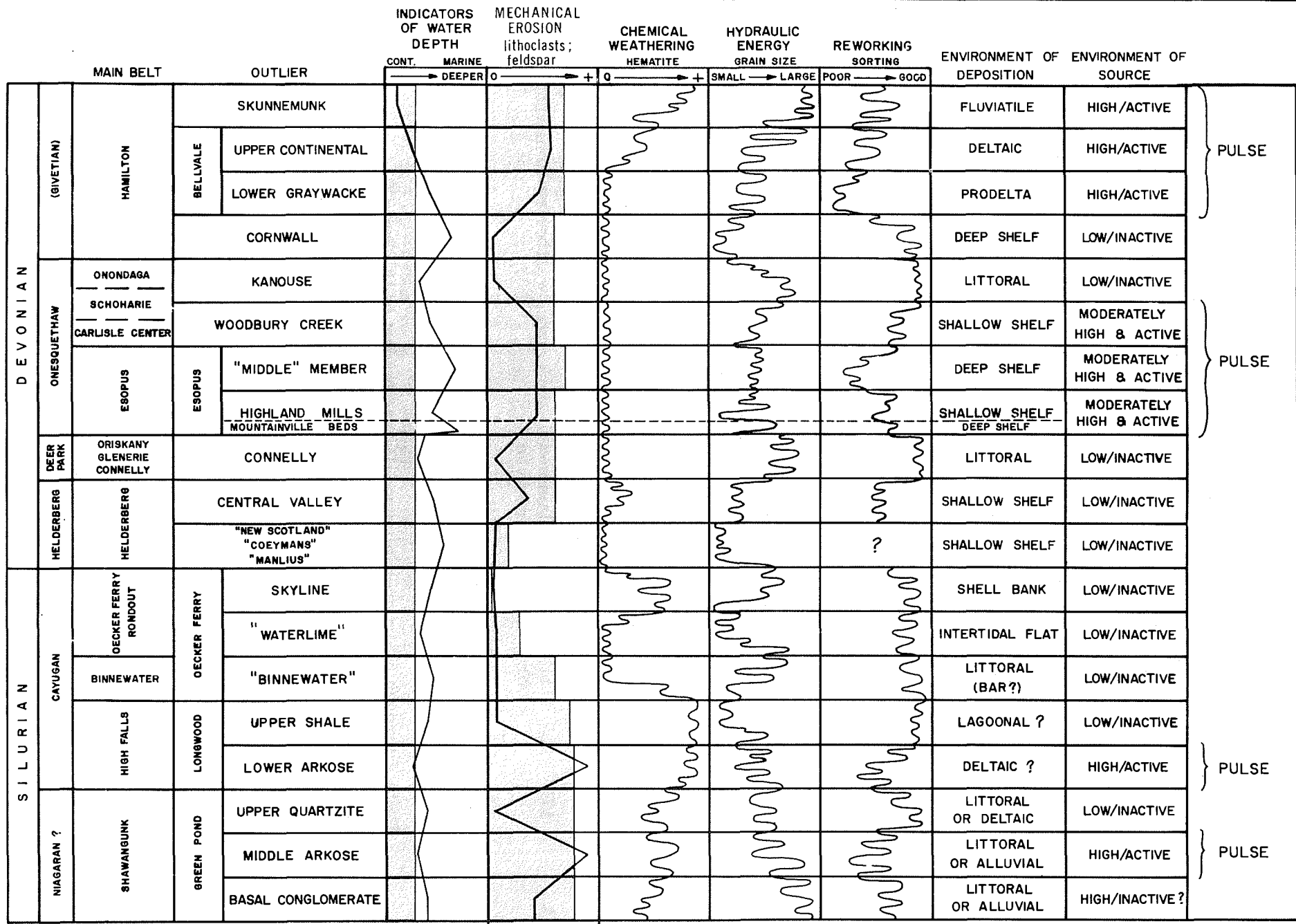
BB	27'	6"	Sand , massive, cross-bedded, light greenish-gray.
AA	11'		Sand with shale pebbles, fining upward.
Z	20'		Sand
Y	310'		Intermittently exposed sand and shale.
X	40'		Coarselithic-fragment-rich subgraywacke, light gray, weathers light brown; layers of black shale chips; contains lycopsid stems 1/4-inch in diameter. (Good glacial striae on outcrop surfaces.)
W	367'		Intermittently exposed subgraywacke with shale interbeds. (East side of culvert is at 125 feet above base of unit.)
V	4'		Sand , cross-bedded, coarse (grains up to 2 mm diameter) with shale chips. Possible lignite chip and wood impressions.
U	22'		Subgraywacke, with minor shale interbeds.
T	15'		Subgraywacke, highly lithoclastic and micaceous, coarse, with zones of dark-gray shale chips up to 2 inches in diameter; possible wood fragment.
S	10'		Shale, dark gray.
R	164'		Intermittent exposures of subgraywacke and shale as in Q (below), including at least one pebble bed.
Q	59'		Subgraywacke with minor shale interbeds, subgraywacke medium-gray, weathers light brown; coarser beds form cross-bedded lenses up to 2 feet thick; load-casts or ball and pillow structures present at intervals, especially in lower part of unit; at 36 feet from top of unit is a zone of well-rounded quartz and quartzite pebbles, up to 3/4-inch in diameter, floating in a matrix of subgraywacke; fossils in upper part of unit include pelecypods and, reportedly, brachiopods. Base of unit may be a channel fill cut into underlying Unit P. (Top of Unit Q is just west of overpass, remainder is mostly beneath overpass.)
P	3'	5"	Graywacke and shale interbedded in even 2 to 3-inch units. (This unit is just east of overpass.)
O	10'	3"	Massive graywacke with abundant ball and pillow structures (flow-rolls, "storm-rollers") 2 feet in diameter at base of unit, 2 inches in diameter at top of unit.
N	79'	5"	Graywacke and shale, dark-gray, weathering brown to orange, in graded units, each from 2 feet to 5 feet thick; at 35 feet from base of Unit N is a 1-inch concretionary layer.

M	8'	6"	Uncleaved sandy bed grading upwards through fine sandstone to 5 inches of shale with calcite laminae at top.
L	8'	0"	Fine sandstone as below.
K	2'	10"	Uncleaved medium graywacke somewhat gradational into overlying unit.
J	8'	8"	Fine sandstone as in Unit H.
I	1'	0"	Uncleaved sandy bed.
H	17'	7"	Fine sandstone as in Unit F below.
G	0'	5"	Uncleaved sandy bed.
F	23'	0"	Fine sandstone as in Unit B below but somewhat more massive.
E	0'	8"	Uncleaved sandy bed.
D	14'	0"	Fine sandstone as in Unit B below, frequently in 1-inch to 2-inch units showing concretionary structure; <u>Mucrospirifer</u> , <u>Spinocyrtia</u> , pelecypod ( <u>Grammysia?</u> ).
C	0'	2"	Uncleaved sandy bed.
B	4'	2"	Fine sandstone (graywacke) weathering with limonitic stain, bedding in 1-inch units; strongly cleaved; contains <u>Mucrospirifer</u> and <u>Chonetes</u> .
A	17'	8"	Siltstone, finely laminated, dark gray, weathering somewhat brownish; highly cleaved.

Base of section.

-----

Units A through N are probably prodelta and foreset beds, Units O through perhaps R are subaqueous topset beds, from Unit S or so, on up, probably subaerial topset beds grading up into river channel sands and flood-plain mudstones (such as Units BB through MM) to more piedmont type deposits as in Unit NN.



0 → +  
TERRIGENOUS  
DETRITUS  
(IN GRAY)

Figure 6. Siluro-Devonian Environmental History.

probably represents an alluvial environment. The pebbles are curiously similar to those of the Green Pond, including not only milky-quartz but also quartzite, chert, shale and phyllite. The Siluro-Devonian succession thus ends almost as it began.

In summary, the entire Siluro-Devonian sequence of the outlier contains three major types of shoreline. (1) The upper Silurian sequence, from at least the upper part of the Green Pond through the Decker Ferry, represents a transgressing shoreline in various stages of development, from the possible reworked regolith of the lower parts of the Green Pond, through the clean, possible shore sands of the upper Green Pond, to the intricate lagoon and barrier beach development of the Upper Longwood and Decker Ferry. (2) The Connelly and Kanouse Formations represent stable shorelines in which considerable reworking leaves a well-sorted, well-winnowed lag-concentrate of rounded quartz pebbles. (3) The Bellvale Formation represents the prograding shoreline of a delta, with a progression from prodelta and foreset beds through topset beds to alluvial plain and piedmont alluvium deposits.

Figure 6 presents a more complete summary of the Siluro-Devonian history of the outlier. Rough estimates of various environmental indicators are given. Water depth was based on evidence from fauna and primary structures. Sorting indicates degree of reworking and therefore tectonic stability. Grain size indicates hydraulic-energy conditions. Feldspar indicates rapidity of mechanical erosion, and therefore possibly relief of the source area. The proportion of terrigenous detritus to autochthonous sediment indicates general erosion rate and therefore also relief (or rainfall). Hematite suggests strength of chemical weathering in the source area, as well as oxidizing conditions in the sedimentary environment.

#### ACKNOWLEDGEMENTS

The late Professor Walter H. Bucher of Columbia University first introduced me to the section at Newfoundland, and Professor Cecil H. Kindle of City College and Professor Grace M. Carhart of Hunter College first told me of the outcrops at Highland Mills. Dean Herbert P. Woodward of Rutgers University introduced me to many other aspects of the local geology. It is impossible to thank individually all the many students I have taken to these localities during the past sixteen years, and whose eyes and wits have often been sharper than mine. Some contributions have been mentioned by name in the text and I hope the rest will accept this expression of my thanks. Mr. Frank H. Wind helped me measure the section at Pine Hill and Mr. Lubomir J. Mesticky that of the Bellvale at Monroe. Mr. Wind also identified some of the fossils of the Skyline Calcarenite, now being further studied by Miss Lillian Musich. Mr. Nicholas F. Avignone assisted in preparing the road log. The figures were drafted by Mr. Craig A. Munsart and the photographs prepared by Mr. Maurice W. Kalisky. I thank Mr. David P. Schwartz for petrographic consultation.

#### ROAD LOG

From the Hotel Sheraton-Tenney follow Astoria Boulevard to the Triboro Bridge, thence to the Major Deegan Expressway, to I-95 and across the George Washington Bridge.

Mileage.

0.0	0.0	George Washington Bridge Toll Plaza. Keep left and take I-80 express lane. Between 0.7 and 1.2 is a spectacular new cut in the Palisades Diabase. At the west end (1.2) overlying baked shales of the Newark Series may be seen, parallel to the top of the sill.
2.2	2.2	Meanders of the Hackensack River on its flood plain.
3.7	1.5	Cut in Newark sandstones.
11.3	7.6	Turn-off for Route 20.
12.2	0.9	On to Route 20 south. Road follows Passaic River flowing south.
13.6	1.4	On to Route 46 west.
16.8	3.2	Cut in First Watchung Basalt, an extrusive lava. Note curvicolunar jointing.
17.2	0.4	Fanned columnar jointing followed on LEFT by <u>pillow-lava</u> .
18.3	1.1	Passaic River flowing north in subsequent valley between First and Second Watchung ridges. This is upstream from where we last saw it. It crosses First Watchung Ridge at Paterson Falls.
18.5	0.2	Second Watchung Basalt.
19.9	1.4	Turn north (right) on Route 23.
21.8	1.9	Third Watchung (Hook Mountain) Basalt.
23.2	1.4	Wisconsin terminal moraine.
23.9	0.7	North (right) on Route 202.
26.4	2.5	Turn left to follow Route 202.
27.1	0.7	Turn right to follow Route 202.
27.3	0.2	Third Watchung (Hook Mountain) Basalt again. This has been bent around as part of a syncline in the Newark Series.
27.6	0.3	Turn left into Moyias Road and park. Walk across road (CARE!) and north <u>along grass</u> (STAY OFF PAVEMENT!) to outcrop.

STOP 1. Pompton Lakes. Triassic Border conglomerate.  
(Wanaque, N.J., 7 1/2 - minute Quadrangle.)

This outcrop provides a sampling of the exposed bedrock that lay immediately to the west of here during late Triassic time. Coarse conglomerates such as this are confined to the immediate vicinity of the Triassic border

fault and were apparently deposited as alluvial fans at the base of the fault scarp by east-flowing streams. No Precambrian pebbles can be recognized in this outcrop and presumably the Precambrian, now exposed in the hills immediately to the west, still lay covered beneath Paleozoic sediments. Large rounded cobbles, some more than a foot across, of a conglomerate of white quartz pebbles in a red quartzite matrix, closely resemble existing outcrops of the Silurian Green Pond Formation or the Devonian Skunnemunk Formation, both exposed in the outlier some ten miles west of here. Of more interest for the reconstruction of the paleogeography of the pre-Silurian uplift, is the abundance of white-weathering dolomite cobbles that could only have come from the Cambro-Ordovician carbonate sequence. These cobbles are sometimes less well rounded than the quartzite cobbles and must have been transported for no very great distance. The base of the Silurian rests directly on the Precambrian ten miles to the west. The Cambro-Ordovician carbonates were probably exposed somewhere between there and here in Triassic times and therefore could not have been removed during the pre-Silurian uplift. We will see at STOP 2 that the Trentonian phyllites are still preserved in this vicinity. These data place the eastern border of the pre-Silurian uplifted and eroded area as somewhere between here and STOP 3, only ten miles to the northwest.

- 28.1    0.5    Turn right at first traffic light.
- 28.6    0.5    Bear left at Y-intersection.
- 29.1    0.5    Park in lot of Riverdale Diner.

STOP 2. Riverdale - Pompton. Annsville Phyllite.  
(Pompton Plains, N.J., 7 1/2 - minute Quadrangle.)

After looking at the outcrop we will take a short REST STOP in the Riverdale Diner.

Walk east a little more than a block on the south side of the Hamburg Turnpike, crossing the bridge over the Wanaque River, and descend to the south side of the east abutment of the bridge. Here is exposed a small, but apparently genuine, outcrop of black phyllite; the outcrop is submerged at high water.

This outcrop was mapped as Hudson Schist in the USGS Passaic Folio (Darton, et al., 1908) a name applied to the rocks now called Manhattan Schist, as well as to the metamorphosed pelites of the upper Hudson Valley now referred to the Normanskill - Snake Hill sequence (Ordovician, Trentonian). I see no reason to question these correlations. This outcrop is called Annsville here because it occurs in the same structural position as the type Annsville at Peekskill, 30 miles to the northeast along the Triassic border fault, and because it resembles the type Annsville lithologically. It also resembles lithologically ( and structurally: refolded-foliation) the phyllitic phase of the Mount Merino Formation in Balk's classic area in Dutchess County, as at Noxon near Lagrangeville. Near Clinton, New Jersey, 40 miles to the southwest along the border fault,

a sizeable patch of the Cambro-Ordovician sequence is exposed between the Triassic and the Precambrian. The Ordovician pelites in it were mapped as Martinsburg Shale (Bayley *et al.*, 1914).

The present outcrop was interpreted in the Passaic Folio as a fault-slipper, or "horse," along the Triassic border fault. It is also possible that the pre-Triassic basement is generally much closer to the present surface along the border fault than usually reconstructed, and that much of the Triassic subsidence was taken up by faulting or warping farther east beneath the basin. The Cambro-Ordovician area near Clinton was mapped in the USGS Raritan Folio (Bayley *et al.*, 1914) as lying unconformably beneath the Triassic, and the present outcrop may have the same relationship.

Continue west on Hamburg Turnpike.

- |      |     |   |
|------|-----|---|
| 29.3 | 0.2 | Turn left at traffic light following sign to Route 23.                              |
| 30.0 | 0.7 | Turn right onto Route 23 north.   |
| 30.2 | 0.2 | Glacial lake delta on left. We have crossed Triassic border fault.                  |
| 30.6 | 0.4 | Outcrops of Precambrian gneiss.   |
| 31.4 | 0.8 | Cut in Wisconsin till on left.  |
| 37.8 | 6.4 | Cross Echo Lake Road.   |
| 38.1 | 0.3 | Park in grassy area on right between highway and abandoned segment of old Route 23. |

STOP 3. Newfoundland: South end of Kanouse Mountain.  
Green Pond Formation. (Newfoundland, N.J., 7 1/2 minute Quadrangle.)

Walk north across old highway to nearest outcrop on north side of road. These are the lower conglomerate beds of the Silurian Green Pond Formation dipping steeply northwest. The conglomerate occurs in rhythmically repeated, upwardly-fining, 2 or 3 foot, cross-bedded units. Most of the pebbles are rounded milky-quartz, but red chert, dark shale, and other rock types occur.

Walk uphill, northeastward into the woods, paralleling the base of the cliffs but keeping about 50 feet east of them. About 100 feet or so into the woods large talus blocks of the lowermost beds are passed. They are more coarsely conglomeratic, and contain many angular or sub-angular pebbles, a few inches across, of green chert, red chert, quartz-hematite phyllonite, quartzite, dark shale or slate, along with milky-quartz.



Another hundred feet or so further will bring you to the first outcrops of Precambrian Gneiss. An interval of 25 feet or so, covered with large talus blocks of Green Pond separates the nearest Precambrian outcrops from the exposures of Green Pond in the base of the cliffs. The contact is not exposed.

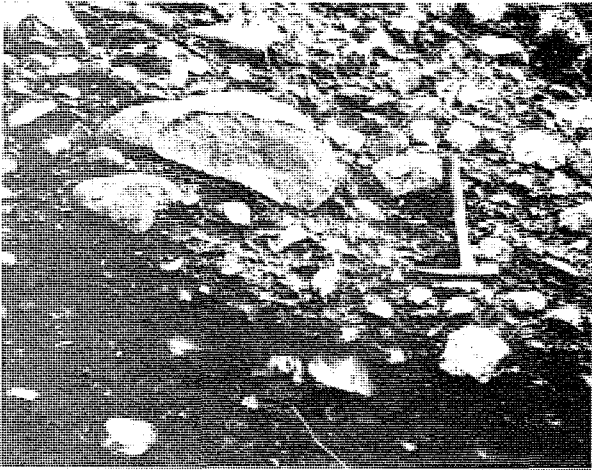
Return, following the base of the cliff as closely as talus and underbrush permit. At a point opposite the first ledges seen near the road, climb up to a broad rock surface on top of these ledges to observe spectacular Liesegang rings of hematite developed in the finer-grained layers of the rhythmic sequences. (WATCH YOUR STEP.)

Return to the road, cross the old highway and continue west across the grass plot to the main highway. Walk west along the shoulder (STAY OFF HIGHWAY! WATCH TRAFFIC!) to a cut in the Upper Quartzite Member of the Green Pond. The cut shows a small anticline and syncline parasitic upon the main synclinal structure (drag folds). A prominent thin pebble bed makes a convenient stratigraphic marker. Note well-developed quartz-filled gash-fractures along minor shear zones. At the westernmost end of the cut the lowermost red arkose beds of the Lower Arkose Member of the Longwood Formation are exposed in contact with the top of the Green Pond. These beds will be seen in the same stratigraphic position at Highland Mills (STOP 6-A).

Return along road to the bus.

(Note: A complete section between the basal beds and the Upper Quartzite Member is exposed in the woods along the south end of Kanouse Mountain, but we will not take the time to visit it. The Middle Arkose Member seen at the north end of the outlier (STOP 5) does not seem to be present here.)

- |      |     |  |
|------|-----|--|
| 41.9 | 3.8 | Oak Ridge Reservoir. Crossing high-angle fault between outlier and precambrian forming west boundary of outlier. Fault-line scarp visible to left along west shore of reservoir. |
| 42.5 | 0.6 | Flood plain of Pequannock River.   |
| 48.8 | 6.3 | Bear right, following Route 23. Entering small outlier of Cambro-Ordovician.   |
| 49.3 | 0.5 | Turn left at Franklin Diner.   |
| 49.4 | 0.1 | Outcrop on right of Cambro-Ordovician carbonate.   |
| 49.8 | 0.4 | Bear left.   |
| 49.9 | 0.1 | Dump of old Buckwheat zinc mine on right. Franklin minerals may be collected here (fee). Outcrops of Precambrian Franklin Marble.  |
| 50.3 | 0.4 | Turn left on Wildcat Road.   |



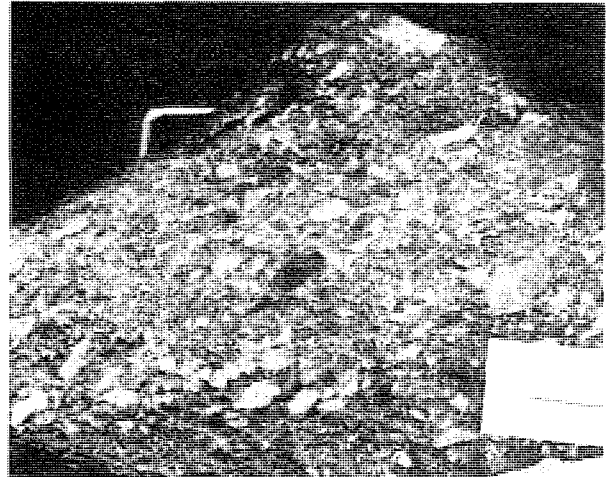
1



2



3



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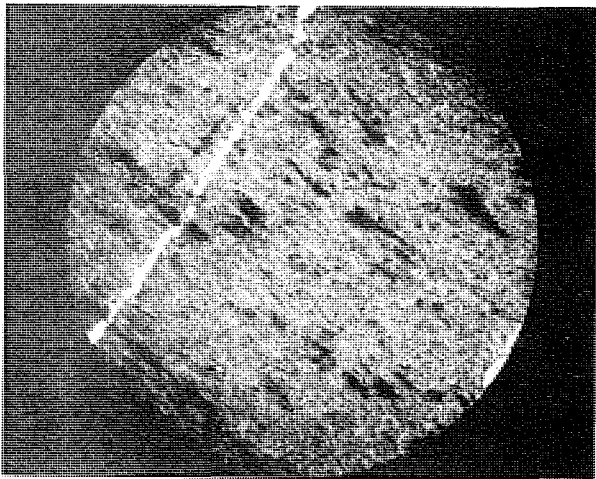
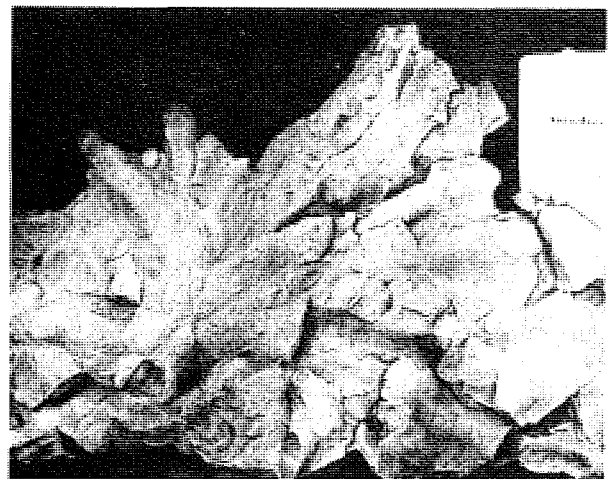


PLATE I

5



6

Plate 1.

Figure 1, Triassic border conglomerate at STOP 1. Largest cobble is probably Green Pond conglomerate, or else Skunnemunk Conglomerate. The white cobbles are Cambro-Ordovician dolomites.

Figure 2, Basal Green Pond conglomerate at STOP 3, showing large angular pebbles of chert and metaquartzite.

Figure 3, Basal Conglomerate Member of the Green Pond Formation at STOP 3, showing repeated graded units.

Figure 4, Hand specimen of Middle Arkose Member of Green Pond (base of Unit FF) from measured section (Table 2 and Figure 4) at southwest end of Pine Hill near STOP 6-A. White angular clasts are fresh cleavage fragments of feldspar. They show somewhat imbricate texture (bedding approximately horizontal). Scale in millimeters.

Figure 5, Photomicrograph (x100) of quartz-hematite phyllonite pebble from basal Green Pond at STOP 3. Dark mineral is hematite. Crossed-nicols. Photograph by David P. Schwartz.

Figure 6, *Phycodes* sp., ichnofossil from shaly layer in upper part of Highland Mills Sandstone member of Esopus Formation at STOP 6-C. Top of bed shown. Shaly layer was immediately above large ripple-marked surface and below lens of shells in sandstone. Millimeter scale.

- 50.5 0.2 Cut in Cambro-Ordovician carbonates on left.
- 50.9 0.4 Park in Metaltech Laboratories lot. Walk back (north) on Wildcat Road 0.1 mile to STOP 4.

STOP 4. Franklin. Hardyston - Precambrian Unconformity and Stissing Dolomite. (Franklin, N.J., 7 1/2 - minute Quadrangle.)

Walk east from Wildcat Road toward golf course just south of point where wooded ridge intersects road obliquely. Walk northeast along east base of ridge facing golf course about 25 feet to first outcrops. Here Lower Cambrian Hardyston Formation rests on light colored Precambrian gneiss. The Hardyston dips 55° NW. The basal five feet or so of the Hardyston contains pebbles of quartz and fresh feldspar up to an inch in diameter. About 20% of the pebbles are feldspar. PLEASE DO NOT HAMMER ON THIS OUTCROP. Exposures of the Cambrian - Precambrian unconformity are rare and should be preserved as an exhibit for students.

The type locality for the Hardyston is 2 miles to the northeast at Hardystonville along this same continuous outcrop belt. The Hardyston here is in one-foot beds that are internally cross-bedded in smaller units. The five feet or so of conglomerate grades upward into dark-gray, flaggy, quartz-sandy dolomite that underlies most of the ridge and totals about 100 feet in thickness. The dark-gray dolomite may represent the Lower Cambrian Stissing Dolomite.

Climb over the ridge across strike to Wildcat Road and walk north along the road past a covered swale to the next outcrops. These may be the base of the Upper Cambrian Pine Plains Formation. The light-weathering dolomite is interbedded with thin, ripple-marked beds of quartz-sandstone. Oscillation and interference ripples are beautifully displayed both on bedding surfaces and in cross-section. An extensive section of higher carbonate beds is exposed along the road for several hundred feet.

The base of the Hardyston represents a shore, but not a shore of Appalachia. The Early Cambrian sea transgressed westward onto the craton. The importance of this outcrop is to show that the Precambrian which was exposed at the surface at Newfoundland, during the Silurian, is still covered by the Cambrian at Franklin, only 10 miles to the west.

Return north on Wildcat Road.

- 51.5 0.6 Turn right (east).
- 51.8 0.3 Town Park. LUNCH.
- 52.5 0.7 Turn right (south) on Route 23.
- 52.6 0.1 Bear left following Route 23.

## NEW YORK STATE GEOLOGICAL ASSOCIATION GUIDEBOOK

MAY, 1968, MEETING AT QUEENS COLLEGE

ADDENDUM TO TRIP E: TACONIAN ISLANDS AND THE SHORES OF APPALACHIA.

Robert M. Finks, Queens College

After the description of this trip had gone to the printer, Dr. Stockton G. Barnett III, of the State University at Plattsburgh, informed me that he had recently completed a doctoral dissertation (Ohio State, 1966) on the Siluro-Devonian outlier, which is now in press. Dr. Barnett has completely remapped the New Jersey part of the outlier and has made a great many important new findings and interpretations, especially with regard to the stratigraphy of the late Silurian and Early Devonian. Dr. Barnett was unable to accept my invitation to be co-leader of this trip, but has kindly provided some of his new information. One of the most important results of his study is the discovery of an open-water marine facies of latest Silurian and Early Devonian age in the southern part of the outlier corresponding to the more lagoonal and intertidal facies both to the north and to the west! In collaboration with John Southard, he has also traced the Esopus Formation members, recognized by Boucot and Southard in the Highland Mills Area, into the southern part of the outlier.

In addition, Dr. Barnett kindly guided me to a classic locality that I had not visited before. This is of such interest that if time permits we will include this in our trip.

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ADDITION TO ROAD LOG

- |      |     |   |
|------|-----|---|
| 63.6 | 0.0 | Intersection of Union Valley Road and Route 23. Continue east on Route 23.                      |
| 65.0 | 1.4 | Turn left onto Echo Lake Road.  |
| 67.2 | 2.2 | Left turn.  |
| 67.6 | 0.4 | Left Fork.  |
| 68.1 | 0.5 | Turn left on Gould Road.  |
| 69.1 | 1.0 | Park opposite dirt road on left just after right-angle turn to the right (north) in Gould Road. |

STOP 4A. (If time permits.) Gould Quarry. Unconformity of Silurian on Cambrian. (Newfoundland, N.J., 7½-minute Quadrangle.)

Walk west into woods following old dirt road to abandoned and overgrown Gould limestone quarry. The first exposures are of Precambrian gneiss. A few feet of covered interval are succeeded by ledges of Hardyston Sandstone outcropping on the east side of a low ridge. The Hardyston dips steeply northwest and grades upward from a few feet of pebbly quartzite to a quartz-sandy dolomite, that forms the top of the ridge. Walcott (1893) found Olenellus in this dolomite a mile or so



to the north, and it is presumably the equivalent of the Lower Cambrian Stissing Dolomite of New York. Just over the crest of this ridge, on its western slope, and about 60 feet stratigraphically above the Hardyston Quartzite, the dolomite is succeeded abruptly by a coarse quartz-pebble conglomerate that rests on the irregular upper surface of the dolomite and includes clasts of dolomite just above the contact. This coarse conglomerate appears to be the base of the Green Pond Formation, for it is exposed intermittently from this point westward, across a narrow valley to the main mass of the formation in Kanouse Mountain. The upper surface of the dolomite, on which the Green Pond rests, is a karstic surface, for pockets of the same conglomerate appear in the basal part of the dolomite, on the east side of the ridge toward the south end of the old quarry, not far above the Hardyston Quartzite. Kummel and Weller (1902, p.7) were apparently the first to interpret these pockets as solution cavities filled from above. The pockets are lined with a thin layer of shaly sediment between the dolomite and the conglomerate. These solution fissures extended some 30 feet below the pre-Silurian surface.

This locality is about three miles north of STOP 3 where the Green Pond rested directly on the Precambrian. The Cambrian first appears beneath the Silurian a half-mile south of here at the north end of Echo Lake. The obvious unconformity here, barely 70 feet above the base of the Cambrian, is the strongest evidence for the unconformable nature of the less well exposed Silurian-Precambrian contact to the south. We are here on the northerly flank of the pre-Silurian uplift.

Dr. Barnett has discovered Ordovician shales on the west side of the outlier northwest of Bowling Green Mountain. Inasmuch as the Silurian rests directly on the Precambrian at Bowling Green Mountain, the northern limit of the exposed Precambrian lay just north of there. A line connecting that point with the corresponding contact at the north end of Echo Lake should be parallel to the axis of the pre-Silurian uplift. It has an ENE-WSW trend that is at variance with the axis of the outlier, though one that corresponds with late folds in the New York City group in Westchester County (see Trips A and H as well as Fisher et al., 1961.) This may be a late Taconian fold direction. It is also parallel with the Cambrian-Pre-Cambrian contact on either side of the outlier south of Monroe (see Figures 1 and 2.) Unfortunately the Silurian is faulted out of the outlier at that point so that the trend cannot be demonstrated to be pre-Silurian there.

Continue west on Gould Road to Union Valley Road at Postville.

70.4 1.3 Turn right (north) on Union Valley Road. This is mileage 66.9 on original road log.





## ADDITIONAL REFERENCES

Kummel, H.B., and Weller, S., 1902. The rocks of the Green Pond Mountain region, in Annual Report of the State Geologist for 1901, New Jersey Geological Survey, pp. 3-51.

Walcott, C.D., 1893, On the occurrence of Olenellus in the Green Pond Mountain Series of northern New Jersey, with a note on the conglomerates, Amer. Jour. Sci., ser. 3, v.47, p. 309-311.

4/22/68



- 63.6 11.0 Right on jughandle turn marked "To Greenwood Lake." Cross and turn left on Route 23 west then right (north) onto Union Valley Road (Route 513).
- 65.6 2.0 Outcrop of Cornwall (Pequannock) Shale (Middle Devonian). The road follows the strike of the Upper Silurian-Lower Devonian. On the right is the ridge of Green Pond Conglomerate, on the left the ridge of Bellvale Sandstone.
- 70.6 5.0 Left turn in West Milford, staying on Union Valley Road.
- 72.6 2.0 Bear right.
- 73.6 1.0 Turn left onto Lakeside Road.
- 74.6 1.0 To the right is Greenwood Lake. Beyond it to the east are hills of Precambrian forming the east boundary of the outlier. The Green Pond has been faulted out. To the left are nearly continuous outcrops of the lower beds of the Bellvale Sandstone (or the upper part of the Cornwall shale). The ridge to the left (west) is Bellvale Mountain, the type locality of the Bellvale Sandstone.
- 75.6 1.0 Entering New York. Road becomes Route 210.
- 79.6 4.0 Turn left following Route 210.
- 80.1 0.5 Bear left onto Route 17A, then bear right.
- 87.1 7.0 Bear right.
- 89.1 2.0 Bear right and follow road through Monroe business district.
- 89.6 0.5 Just past railroad station turn left through underpass, then right at stop sign.
- 90.6 1.0 Join Route 208 east.
- 94.6 4.0 Turn left (north) on Route 32 through Highland Mills.
- 95.6 1.0 Woodbury Falls, where railroad trestle crosses road. Marine beds of Bellvale sandstone in bed of Woodbury Creek on right, non-marine beds on left (west) side of road.
- 96.4 0.8 Turn right onto Smith's Clove Road. Precambrian hill on left (north) and Siluro-Devonian hill on right.
- 97.3 0.9 Turn right (south) at junction with Mineral Spring Road.

97.6 0.3 STOP 5. North end of Pine Hill. Green Pond Formation.  
(Popolopen Lake, N.Y., 7 1/2 - minute Quadrangle.)

Outcrops near the road, at turn-off of private dirt road, are of Lower Conglomerate Member, dipping steeply northwest. The pebbles are almost entirely milky-quartz.

Walk into the woods across strike. About 100 feet NNW are outcrops of the Middle Arkose Member. Fresh, angular, cleavage fragments of feldspar, up to 1/2 inch across, are common along with quartz pebbles in a fine reddish matrix. This unit can be recognized 2 1/2 miles to the southwest along strike near Highland Mills (Figure 4 and Table 1).

Continue 200 feet or so further northwest to the base of ledges that expose the Upper Quartzite Member. (Some care should be exercised to avoid Copperheads in climbing over these ledges.)

Beyond this the Longwood is poorly exposed on the top of the ridge. We will see a better section at the next stop.

Return to the road.

Continue south on Smith's Clove Road. Precambrian hills on left (east), ridge of Green Pond (Pine Hill) on right (west).

99.6 2.0 Turn right (west) on Pine Hill Road.

100.2 0.6 Park on grass just beyond intersection with Skyline Road. Bus will continue to old Highland Mills Station and wait to pick up party.

STOP 6-A. South end of Pine Hill. Green Pond - Longwood - Decker Ferry. (Popolopen Lake, N.Y., 7 1/2 - minute Quadrangle.)

Walk north along Skyline Drive from intersection with Pine Hill Road. The first outcrops on the right (east) side of road are of the Upper Quartzite Member of the Green Pond, with characteristic Liesegang rings of hematite, and quartz-filled fractures.

Farther on the Lower Arkose Member of the Longwood is exposed in poor outcrops. If time permits, climb the hill to the well-exposed ledges on top of the ridge. The lower part of the measured section (Figure 4 and Table 1) was made here, from the Lower Arkose Member of the Longwood down to the Middle Arkose Member of the Green Pond; the section in the Green Pond was measured with several jogs northeastward along strike to preserve continuity of section. The intergrading contact of the Green Pond and Longwood is well exposed here. Do not go further up-section (northwest) than the lower beds of the Lower Arkose Member of the Longwood: the ground slopes downward to the unprotected edge of a sheer 100-foot cliff that drops vertically into the shale quarry to the northwest. **STAY AWAY FROM THE EDGE OF THE CLIFF!**

Continue north on Skyline Drive to the entrance to the shale quarry and turn right into the quarry. Steeply northwest-dipping bedding planes of the Upper Shale Member of the Longwood form the southeast wall of the quarry, higher beds being exposed stepwise toward the north. A zone of contorted bedding is exposed just above the first large bedding plane. Mud-cracks and curious spheroidal pits one to six inches in diameter, are common on some of the higher bedding planes.

The remainder of the section was measured at the northeast end of the quarry, where the Decker Ferry Formation is exposed, separated from the highest beds of the Longwood by a 40-foot interval covered with red shale debris. Some of the Decker Ferry is covered by a few inches of soil, but can be exposed by digging with the hammer. The beds seem to be in place and were measured inch-by-inch with a tape. Most of the formation consists of interbedded quartz-sandstone and dolomite. Quartz-sandstone predominates in the lower beds and this part is here called informally the "Binnewater" Member because it is homotaxial with the type Binnewater of the High Falls area, 40 miles to the north. A prominent outcrop (Unit R) of this lower part of the Decker Ferry is exposed half-way up the slope at the northeast end of the quarry, to the right of a grassy embankment.

Higher in the section thinly laminated (stromatolitic?) mud-cracked, somewhat argillaceous dolomites predominate, with minor quartz-sandstone interbeds. Intraclasts are common. This part of the formation is designated informally as the "Waterlime" Member. It resembles lithologically the waterlimes of the Rondout Valley which lie above the Binnewater Sandstone at its type locality. Outcrops may be seen lower on the slope and towards the northwest.

The continuous alternation of the two rock types, sandstone and dolomite, with mud-cracks in the dolomite often being filled with quartz-sandstone, suggests that the two types of sediment were being deposited contemporaneously in adjacent, spatially shifting areas, perhaps sandy beach and tidal mud-flat. (Southard, 1960, mapped the "Binnewater" and "Waterlime" units together as his sandy-claystone unit, emphasizing their continuity.)

The highest beds of the Decker Ferry are lithologically quite distinct, though sandstone & dolomite interbeds indicate their relationship to the underlying units. This unit is separated as the Skyline Calcarenite Member of the Decker Ferry Formation (new name). It includes all the calcarenite beds exposed in the quarry, its type section (see measured section, Table I). Minor interbeds of sandstone and dolomite are present. The principal lithology is a red to blue-gray coarse crinoidal clastic limestone, full of whole shells (see faunal list), cross-bedded, and heavily charged with hematite, which frequently partially replaces some of the fossils. The fauna has not been completely studied but the following have been tentatively recognized:

Bryozoa:

Ptilodictya sp. cf. P. frondosa Weller  
massive trepostome, cf. Monotrypa corrugata Weller

Brachiopoda:

Atrypa 'reticularis'  
rhynchonellid, cf. Camarotoechia sp.

Coelenterata:

Favosites sp.  
horn coral

Arthropoda:

ostracode, cf. Dilbolbina sp.

Echinodermata:

pelmatozoan (Probably crinoid) columnals

This fauna is hardly diagnostic of age, but is consistent with the Decker Ferry of New Jersey (Weller, 1903). Neither the fauna nor the lithology are anything like either the Wilbur Limestone or the Glasco Limestone, which fall into this part of the section in the Rondout Valley. Neither is it like any of the higher limestones of the Helderberg Group. The Becraft is the closest lithologically, and probably environmentally, but the fauna is certainly not the same. This appears to represent a shallow-water shell-bank environment. The name of the member is derived from the nearby Skyline Road.

Thicknesses of the members recorded in this section are as follows:

Decker Ferry Formation

Skyline Member	7'	8"
"Waterlime" Member	28'	9"
"Binnewater" Member	22' plus.	

Longwood Formation

Upper Shale Member	88'	2"
Lower Arkose Member	80'	

Green Pond Formation

Upper Quartzite Member	222'	10"
Middle Arkose Member	82' plus.	

Walk back out of the quarry, south on Skyline Road and west on Pine Hill Road. At the bridge over the Thruway one can see the Lower Arkose Member of the Longwood exposed north of the east abutment. On the west side of the Thruway, the first visible outcrop is that of the Connelly Conglomerate. When the writer first visited this cut in 1954, just after it had been partly blasted through, a white-to-violet-mottled, friable, clayey, fine sandstone, with characteristic thin interlaminae of dark-gray shale crumpled to give the rock a "zebra-stripe" appearance, was exposed to, the south of the Connelly. It has since been grassed over. Boucot (1959) named this unit the Central Valley Sandstone, and this is its type locality. North of the Connelly, on both sides of the Thruway, is a nearly complete section of the Onesquethawan Series. Access to the Thruway cut is prohibited and the prohibition strictly enforced by State Police.

Continue west on Pine Hill Road to the first black-top road on the right and walk up this road to its dead end.

STOP 6-B. Connelly Conglomerate.

Low ledges on the east side of the road expose the rather well-sorted quartz-pebble conglomerate (2 to 6 mm clasts) of the Connelly. Oriskany fossils establish its age. It is equivalent to an argillaceous limestone 25 miles to the west and to a similar conglomerate followed by an argillaceous limestone 40 miles to the north. This represents a shoreline facies, a pebbly beach on the temporarily stable shore of Appalachia. Most of the fines have been winnowed out.

It may be possible to find Central Valley float on the ground to the south.

Walk back to Pine Hill Road and turn right. At the bend in the road is a stone fence made of Connelly boulders, resting on small outcrops of the Connelly. Where road bends sharply to the left, turn right on private road, then take short path down to railroad tracks opposite abandoned station. Turn right and walk to first outcrops on east side of tracks.

STOP 6-C. Highland Mills. Highland Mills Sandstone and "Middle Member" of the Esopus Formation. (Popolopen Lake 7 1/2 - minute Quadrangle.)

WATCH OUT AND LISTEN FOR TRAINS. DO NOT SIT ON TRACK OR PLACE OBJECTS ON TRACK. TRAINS COME THROUGH FAST AND WITHOUT WARNING. If a train comes stand well back; there is plenty of room on either side of the track.

This stop demonstrates near-shore and off-shore deposits under conditions of strong influx of terrigenous clastics. The series of beds at the south end of the cut are of the upper part of the Highland Mills Sandstone of Boucot (1959). These light-blue-gray, light-brown-weathering, subgraywackes are dominated by evidences of shallow-water deposition. A prominent set of bedding planes display oscillation ripples of various sizes. The ripples tend to be uniformly oriented, roughly NNW - SSE when rotated back to horizontal. (The beds here strike N 50° E and dip 60° NW.) Just north of the ripple-marked layers are lenses of closely packed, jumbled, disarticulated shells. The lenses pinch out within a few feet, from thicknesses of a foot or so. (Preservation on the weathered surfaces is in the form of molds; the most common fossil is Leptocoelia flabellites, but besides the many other brachiopods described by Boucot (1959) there occur gastropods, pelecypods, horn corals, trilobites and other fossils.) Associated with the shell-lenses are shaly beds packed with the ichnofossil Phycodes. All these features are characteristic of the Cruziana-facies of Seilacher (1964) representing shallow-water above wave-base, littoral or sub-littoral.

The "Middle Member" on the other hand, exposed farther north along the tracks, represents Seilacher's deeper-water, sublittoral to bathyal Zoophycos-facies. Bedding planes are covered with the ichnofossil Zoophycos (= Taonurus, = Spirophyton). The rock is massive-bedded and the bedding planes very even. (The rock weathers brown to orange, the fresh rock is almost black.) Although described in the literature as a mudstone, most beds are poorly-sorted graywacke sandstone with about 55% to 85% quartz-grains of fine-sand size, and the rest chiefly fine-grained matrix (data from Miss Janice Lumnitz and Mr. Maury Morgenstein). Fossils are sparsely scattered on the bedding surfaces, mainly the brachiopods Leptocoelia flabellites and Spirifer macra. On many bedding-planes concave-up valves outnumber concave-down valves (from Miss Janice Lumnitz) suggesting settling-out through water followed by rapid burial without further reworking. The unsorted nature of the sediment also points to rapid sedimentation and the sparseness of fossils suggests dilution by rapid influx of terrigenous material.

Feldspar may be less abundant here than in the underlying Highland Mills Member, but the whole Esopus sequence is strongly suggestive of a pulse of erosion of the source area (Appalachia).

The Esopus sequence starts with deep-water Zoophycos-bearing beds (the Mountainville Member of Southard, 1960). The upper part of the Highland Mills Member (restricted Highland Mills Member of Southard) is mostly shallow-water. The "Middle Member" is again mostly deeper-water. The Woodbury Creek Sandstone appears to be mostly shallower water again. It is more fossiliferous than the "Middle Member" (dominated by the pelecypod Cypricardinia and the brachiopod Schuchertella). The fossils are evenly spread on the bedding planes, rather than in lenses as in the Highland Mills Member, and ripple marks are not well-developed. Also Zoophycos has been observed on some beds. It would thus seem to be of a depth intermediate between that of the Highland Mills Member and that of the "Middle Member".

The succeeding Kanouse Sandstone, a clean, somewhat pebbly, ortho-quartzite, again marks a stable shoreline deposit, with a falling off of terrigenous influx permitting better sorting of the material. It appears to be the shoreward equivalent of limy deposits to the north and west (Schoharie and/or Onondaga).

- |       |     |   |
|-------|-----|---|
| 100.7 | 0.5 | Board bus at Highland Mills Station. Continue on Pine Hill Road west to Route 32.   |
| 101.1 | 0.4 | Turn left (south) on Route 32.  |
| 102.1 | 1.0 | Central Valley Diner. REST STOP.  |
| 103.1 | 1.0 | Turn right (west) on Route 17 (Quickway).   |
| 105.1 | 2.0 | Pull over to side just before second overpass. Bus will continue to Monroe-Washingtonville exit (0.5 mile further) to wait for party. |



STOP 7. Monroe. Bellvale Formation. (Monroe, N.Y., 7 1/2 - minute Quadrangle.)

Between here and the Monroe-Washingtonville exit are exposed about 2000 feet of the Bellvale Formation, essentially a complete section. Details of the section are given in the measured section, Table II and Figure 5.

The lowest beds at the east end of the outcrop are shaly siltstones that are close to the base of the Bellvale, if indeed they are not to be considered the highest beds of the underlying Cornwall Shale. The beds immediately above are graywackes that carry Mucrospirifer and Spinocyrtia, thereby demonstrating their Hamilton age and marine nature. A small Chonetes is also common. This entire lower part of the section here is identical, lithologically and faunally, to the section exposed in the bed of Woodbury Creek, at Woodbury Falls, north of Highland Mills, where the railroad trestle crosses Route 32.

As one goes up-section, intercalated beds of uncleaved sandstone increase in thickness and ultimately dominate the section by the time one reaches the abutment of the overpass. Up to here the beds are evenly laminated without any indication of large scale cross-bedding or channeling.

Just at the east side of the overpass is a zone of ball and pillow structures and load-casts. These structures are widely recognized in the Catskill Delta rocks as marking the transition-zone from marine to non-marine beds. The beds beneath the overpass are still marine, however, as brachiopods have been found in them. Nevertheless, the nature of the bedding changes from the preceding even lamination, to evidence of channeling, cut-and-fill structure, and cross-bedding. The rock becomes lighter and coarser, a subgraywacke. Load-casts are present intermittently, and at least one zone of pebbles scattered in subgraywacke is present. It would appear that we have passed from the evenly laminated prodelta and foreset beds to channeled and irregular topset beds.

West of the overpass the subgraywacke becomes still coarser and lighter. Thin interbeds of shale become more common and numerous shale chips appear in the sandstones. Many of the smaller grains appear to be shale clasts or perhaps phyllite. Obscure plant remains and possible wood-fragments appear. No marine fossils have been found, and these deposits may have been made on the subaerial part of the delta.

Beyond the culvert the rock becomes even coarser and more lithic. Here unmistakable plant fragments are present including pieces of branches of scale-trees or related lycopsids a half-inch or so in diameter and clearly showing the leaf scars and internal woody fibers. (The first such were found by Mr. Harvey Zeiss; I have since found others.) Note the well-developed glacial striae and chatter-marks on some of the outcrop surfaces.

Beyond this point is a long succession of massively cross-bedded subgraywacke sandstones with shale interbeds. There are also four prominent units of highly cleaved mudstone, decreasing in thickness from 31 feet for the first such unit, to 11 feet for the last. These are probably flood-plain muds. The last of these units is clearly channeled and filled by the succeeding sand , probably a stream-channel deposit.

The Bellvale section ends with coarse pebble beds at the center of the syncline, just at the Monroe-Washingtonville exit. These beds have the character of the overlying Skunnemunk Formation, except that they lack the red color characteristic of that formation. The pebbles include besides milky-quartz, rocks such as chert, quartzite and shale or slate, not too unlike the pebbles included in the base of the Green Pond at STOP 3. We are probably dealing here with Piedmont alluvial deposits.

Continue on Monroe-Washingtonville exit ramp to Route 208. Turn left, cross over Route 17, then left into entrance for Route 17 eastbound. Return to the hotel via Route 17, New York State Thruway, Major Deegan Expressway, Triboro Bridge, Astoria Boulevard.

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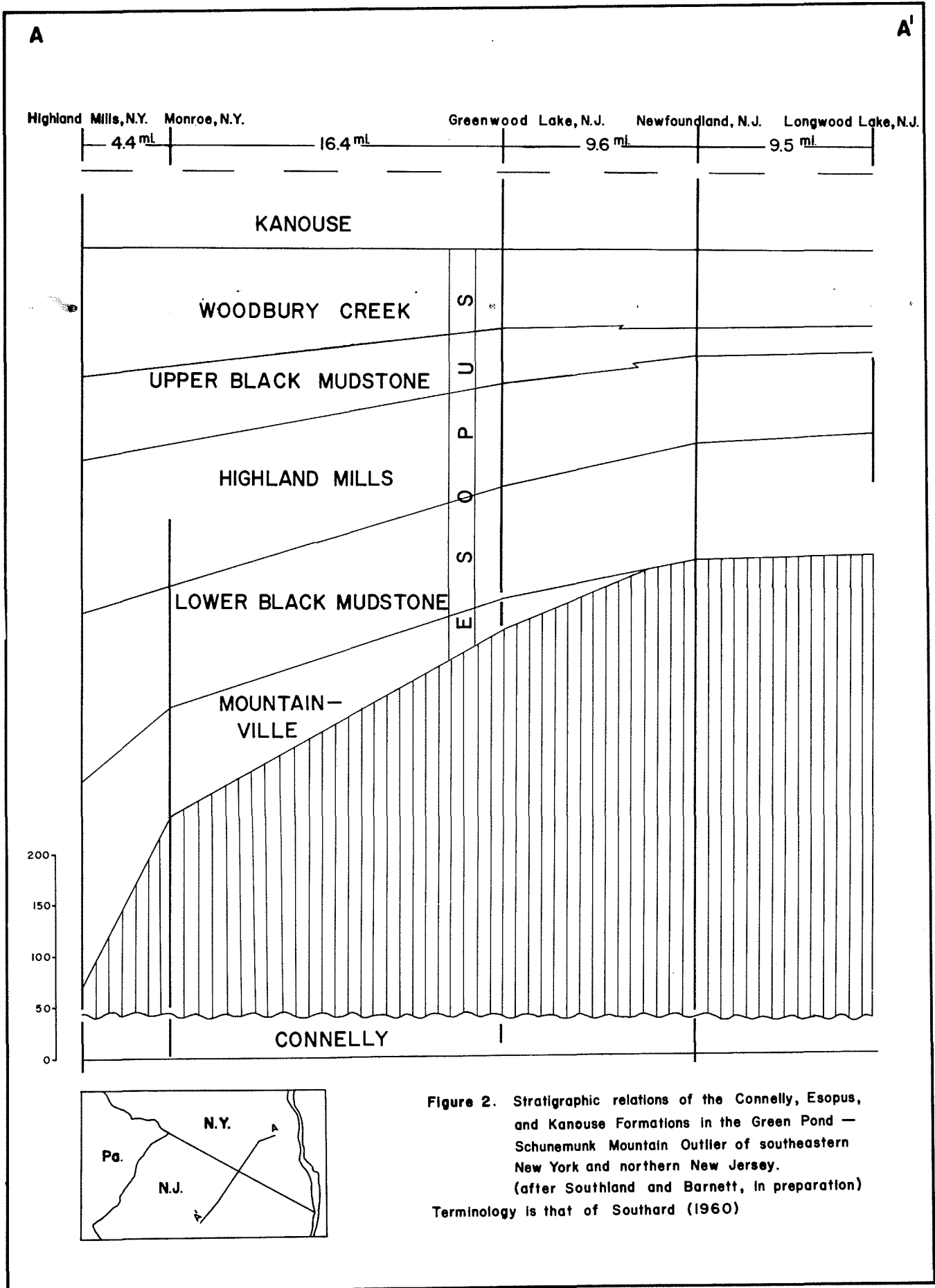


Field Mapping and study of stratigraphic sections in the Green Pond-Schunemunk Mountain Outlier and along the main Silurian-Devonian outcrop belt 25 miles to the northwest have resulted in alteration and refinement of regional stratigraphic relations of Late Cayugan and Helderbergian strata in southeastern New York and northern New Jersey (Fig. 1). Many well-established stratigraphic units of New York and eastern Pennsylvania can be recognized in the Outlier. Two new units in the Outlier will be proposed (Barnett, in preparation). A detailed statistical study of the evolutionary development of seven measurable characters of the conodont species Spathognathodus remscheidensis Ziegler has made precise intrabasinal time correlation possible. This technique relies upon the relationship between morphological evolution, environmental distribution, and environmental succession. A tentative paleoenvironmental analysis has resulted in the recognition of eight environmental facies: deltaic redbed, supratidal, intertidal lagoonal, subtidal lagoonal, biostromal reef, shallow neritic (crinoidal bank and sandstone), intermediate neritic, and deep neritic arranged in basinward order. Their approximate geographic distributions at twelve successive time horizons during the Late Cayugan and Helderbergian are shown on a series of lithofacies-paleoenvironmental maps (Barnett, in preparation). It can be inferred from these maps that the report area was situated on the eastern side of a generally deepening northern Appalachian basin. The north-south trending shoreline was predominantly located within the report area but at times receded to the west or advanced to the east. A sediment source was continually active in eastern Pennsylvania south of the main outcrop belt, whereas a source east of the northern portion of the Outlier was active only

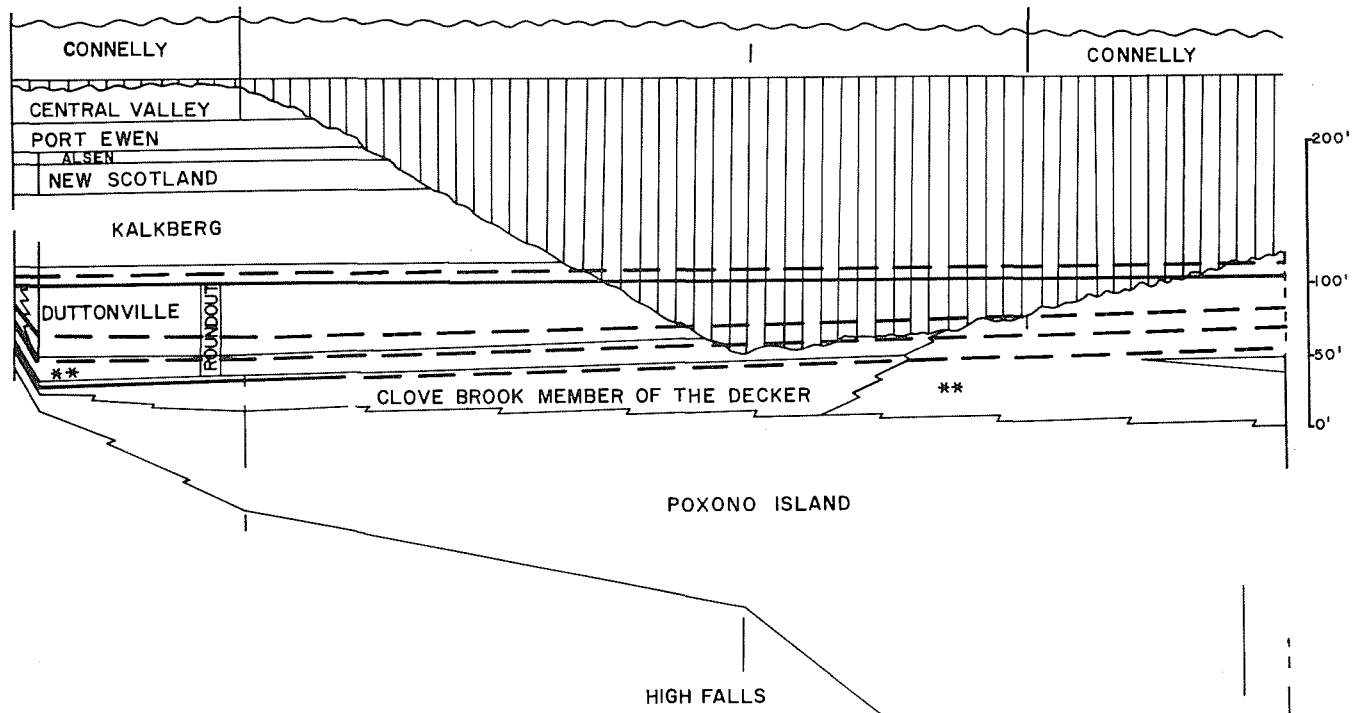
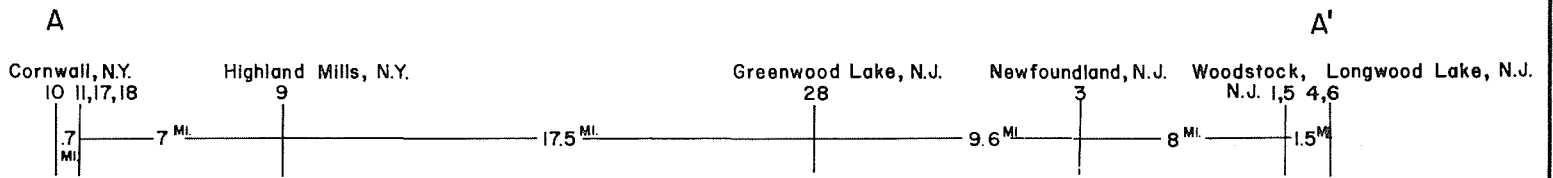
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during the late Helderbergian. Deposition in the southern part of the Outlier appears to have alternated between acting as a marine embayment connected to a marine sea located to the southeast and acting as a passageway which connected the northern Appalachian basin to this marine sea. The southern part of the Outlier was subjected to rather extensive pre-Oriskany (Deerparkian) erosion, whereas pre-Oriskany erosion in the northern Outlier was considerably less. On the other hand, deposition continued uninterrupted along the main outcrop belt throughout Late Cayugan, Helderbergian and Deerparkian time.

The stratigraphic relations in the Outlier of the Connelly, Esopus, and Kanouse Formations in ascending order are shown in figure 2.



DEVONIAN	HELDERBERGIAN	MUSTERIAN
	DEVONIAN	HELDERBERGIAN
SILURIAN	CAYUGAN	



CROSS SECTION OF LATE CAYUGAN AND HELDERBERGIAN ROCKS

— Time lines (Dashed where approximate)

\*\* = Name to be proposed

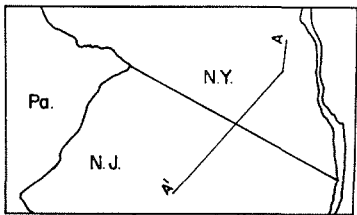


Figure 1. Stratigraphic relations of Late Cayugan and Helderbergian strata in the Green Pond — Schunemunk Mountain Outlier of southeastern New York and northern New Jersey. (after Barnett, in preparation)



## TRIP F: THE PLEISTOCENE GEOLOGY OF THE MONTAUK PENINSULA

By Walter S. Newman, David L. Thurber, David H. Krinsley,  
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## INTRODUCTION

Long Island is a long narrow island reaching east-northeastward from New York City to form a "fish-like" extension of New York State. The island lies south of and is approximately parallel to the Connecticut shore of New England and is separated from it by Long Island Sound. Long Island forms the north shore of an Atlantic Ocean reentrant known as the "New York Bight".

Although part of the Coastal Plain Physiographic Province, Long Island features a topography almost completely modified by glacial and proglacial processes. Two conspicuous end moraines extend from west to east along the axis of the island. The older Ronkonkoma moraine, probably Wisconsin in age, makes up a major portion of the Montauk Peninsula. The younger Harbor Hill moraine generally follows close to the north shore of Long Island east to Orient Point. The island abounds in other glacial and proglacial features such as the coalescing outwash fans and aprons which form much of the southern portion of the island.

## THE MONTAUK PENINSULA

The Montauk Peninsula, as here defined, extends east from the village of Easthampton to Montauk Point. Montauk Point is the eastern extremity of the Ronkonkoma Moraine which forms a ridge of coalescing hills traversing the area from west to east. It marks the maximum advance of an ice sheet during late Pleistocene time. East of Montauk village, the moraine appears to be composed principally of till but does include glaciofluvial material. Further to the west, the moraine contains increasing amounts of stratified drift. East of Montauk village, the moraine abuts the shoreline; however, west of this village the southern border of the moraine is found at an increasing distance from the south shore, from which it is separated by littoral and aeolian deposits. In the vicinity of Easthampton village, outwash is encountered in a limited area between the moraine and the south coast (Figure 1).

Much of the Montauk Peninsula is characterized by knob-and-kettle topography ranging in altitude from sea level to about 200 feet above sea level. However, the glacial drift has been extensively modified by littoral and aeolian processes. East of Montauk village, steep wave-cut bluffs rise abruptly from 30 to 80 feet above narrow boulder-strewn beaches. Fronting the ocean, from the village westward, are increasingly wide sandy beaches, backed from Hither Hills west, by extensive beach ridges. Littoral spits, bay-mouth beaches, and tombolos are common, especially along the north shore. Coastal sand dunes which have migrated inland for distances of up to 1.5 miles, cover most of the area behind the south-shore beaches from Hither Hills west to Easthampton.

## PLEISTOCENE STRATIGRAPHY

As summarized by Muller (1965), the Long Island sequence of glaciation was inferred by Fuller (1914) to commence with the deposition of the Manetto Gravel which Fuller interpreted as glaciofluvial in origin because of the relatively abundant granite pebbles and the occasional boulders up to two feet in diameter. The younger Jameco Gravel evidently is stratified drift, perhaps Illinoian in age. The fossiliferous (marine and lagoonal flora and fauna) Gardiners Clay is found at depths of fifty or more feet below sea level under the south shore of Long Island and is undoubtedly interglacial, quite possibly Sangamon in age.

Fuller considered the Manhasset Formation, including both the glaciofluvial (Herod and Hempstead Gravels) and glacial (Montauk Till) units, pre-Wisconsin in age. MacClintock and Richard (1936) questioned the validity of distinguishing the Montauk Till as a unit separate from the younger Ronkonkoma and Harbor Hill Till. Locally, the Jacob Sand, presumably of marine origin and post-Gardiners but pre-Manhasset in age, is exposed. The environmental significance and even the uniqueness of the Jacob Sand remains poorly defined.

We find that Fuller's (1914) mapping and description of eastern Long Island's Pleistocene terrane is largely unassailable although his interpretation of the areal geologic history requires extensive revision.

#### The Gardiners Clay Problem.

"The Gardiners Clay derives its name from Gardiners Island . . . on which several clay beds with included sands are well exposed at a number of points" (Fuller, 1914, p. 92). Fuller specifically restricted the term to interglacial clays. On western Long Island, the Gardiners Clay is consistently encountered under the south coast at depths of fifty or more feet below sea level. It yields marine and brackish water fossils similar to forms presently living along the Long Island littoral. According to Fuller (1914, p. 105-106), two localities on Gardiners Island contained fossils: (1) a locality just east of Cherry Hill Point, and (2) another unspecified locality. MacClintock and Richards (1936) visited the Cherry Hill Point locality and confirmed the presence of an interglacial fauna. However, Suter *et al.* (1949) although confirming the previous finding by MacClintock and Richards, found that the Gardiners Clay on Gardiners Island is, in large part, varved and, therefore, probably lacustrine in origin. Upson (1966) reported that many of the silt and clay exposures along the eastern portion of the north shore of Long Island are lacustrine rather than marine in origin and believes they are glacial rather than interglacial in age.

We sampled the "Gardiners Clay" at Montauk Point (STOP 1) and examined it for Foraminifera, diatoms, spores and pollen. Most samples were devoid of microfossils. However, several samples contained lean assemblages of cool Pleistocene flora including Pinus (pine), Picea (spruce) and Betula (birch) as well as reworked Cretaceous and Tertiary spores and pollen. The paucity of pollen grains suggest they were transported into the depositional site by both wind and glacial meltwaters. Certainly, the lack of marine microfossils and the cool Pleistocene flora suggests that the "Gardiners Clay" represents a diachronous diversity of depositional environments.

### The Montauk Till Problem.

In his attempt to fit Long Island stratigraphy into the classical four-fold divisions of the American mid-west, Fuller catalogued the Montauk Till as Illinoian in age. The inadequacy of Fuller's assignment has long since been corrected by MacClintock and Richards (1936). Nevertheless, the distinctive banding or lamination and compactness of the Montauk Till in its type area near Montauk Point (STOP 1) led both Woodworth and Wigglesworth (1934) and Kaye (1964) to correlate tills of similar aspect which they encountered on Martha's Vineyard with the Montauk Till of Long Island. Furthermore, they considered all these tills as Illinoian in age. We believe that till fabric, aspect, structure and stratification are an unsatisfactory basis for correlation. The intimate relationship of the Montauk Till with the Ronkonkoma Moraine indicates they are the stratigraphic and morphological representatives of a single glacial stade and are probably Wisconsin in age.

### Laminated Silt.

Upson (1966) believes that the deposits identified by Fuller as Gardiners Clay in eastern Long Island were locally deposited in shallow depressions on till and outwash from the glacier which deposited the Montauk Till. Upson suggested that these deposits, previously called Gardiners Clay, are of limited extent and do not underlie any appreciable part of Long Island. These deposits are probably ice-margin lacustrine deposits and are not the same as the marine and brackish water clays found at depths of 50 or more feet below sea level in western Long Island which Fuller also included in the Gardiners Clay.

These laminated sands, silts and clays are well-exposed at and near Montauk Point (STOPS 1 and 2) and our preliminary examinations support Upson's contention. The laminated deposits at Montauk Point contain varying proportions of Cretaceous and Tertiary as well as Pleistocene pollen and spores. The occurrence of rebedded pre-Quaternary pollen and spores in the region is by no means unique. Davis (1961) found that varved clay from Taunton, in southeastern Massachusetts, yielded Tertiary and Cretaceous pollen as did Groot and Groot (1964) in boring samples from the Texas Tower sites off New England. Sparse local vegetation and readily dispersed pollen from distant sources apparently made limited contributions to these ice-margin environments as did rebedded older pollen and spores. These data suggest that the periglacial landscape was nearly devoid of vegetation and that the tundra and boreal vegetation seres developed at some subsequent time (see Davis, 1965, 1967; and Sirkin, 1967) for further discussion of the late-glacial "tundra" problem).

### Loess

Fuller (1914, p. 166-167) noted that "Certain parts of the outwash plain have a thin superficial coating of dark-brownish loam, consisting in some places largely of sand, but in others of pebbles intermixed with a certain amount of finer silt. It is this finer material, which is oxidized, that gives the color to the deposits. The depth is in some places only a few inches and was nowhere seen to exceed 1 1/2 feet. No trace of lamination was noted in the deposits seen by the writer".

We find that most of the glacial drift on the Montauk Peninsula is blanketed by up to 10 feet of sandy silt. Furthermore, these silt deposits usually lie on a lag

gravel concentrate which occasionally yield ventifacts and, rarely, dreikanterers. Schafer and Hartshorn (1965) report that a similar mantle of aeolian material is nearly ubiquitous in much of southeastern New England. They suggest that the loess was derived mostly from areas of stratified drift during deglaciation before the surface was covered by vegetation. To our knowledge, loess has not previously been reported from Long Island.

#### HOLOCENE SHORELINE MODIFICATION

The shoreline configuration of the Montauk Peninsula has undergone significant change in Holocene times. Taney (1961) and Krinsley *et al.*, (1964) noted that the headlands of the Montauk Peninsula have been eroded and truncated by wave and littoral processes and the sediments so derived have generally moved towards the west. As the littoral sand moved westward, a narrow beach formed, abutting the headlands and sealing up small bays from the sea. The peninsula, which once extended for several miles to the south and east, has, owing to its exposure to the open sea, eroded back to its present location.

The Flandrian Transgression drowned swales in the Ronkonkoma Moraine separating portions of the peninsula into a series of islands in mid-Holocene time, some 2000 to 6000 years B. P. Presumably, Orient Point, Plum Island and the Gull Islands, off the north fluke of Long Island, (Figure 1) are a modern analogue of the ancestral Montauk Archipelago. Certainly, the Hither Hills area and the region east of Montauk village were islands separated from the Easthampton area. An additional strait may have trended north at Ditch Plains. Bluff erosion and longshore drift converted the archipelago into a peninsula by means of single and double tombolo construction during later Holocene time. The sequence and chronology of these events are still poorly known.

The conspicuous gap in the Ronkonkoma end moraine in the vicinity of Napeague Beach has been filled principally with sand derived from the high bluffs to the east (Taney, 1961; Krinsley *et al.*, 1964). Indeed, that reach extending from Montauk village west to Easthampton village and including the Napeague Beach beach-dune tombolo complex is unique in that it appears to be the only portion of Long Island's south shore which is currently prograding (Taney, 1961). Initially, the later Holocene dominant mode of shoreline modification was erosional as witnessed by the prominent bluffs, now isolated from the south shore, at Hither Hills State Park and along Bluff Road (STOP 8). Debris, principally sand, derived from these bluffs was transported by long-shore drift constructing a spit towards the northeast, marked by the Promised Land Chenier, while another spit built west from Hither Hills west towards Southampton. This latter spit, roughly following the present right-of-way of Route 27, eventually connected with the Easthampton area in the vicinity of Bluff Road and formed the initial Napeague Beach tombolo. The spit prograded and sand derived from the early tombolo formed dunes which advanced towards the north, first shoaling and eventually filling the lagoon or bay north of the tombolo. The development of the tidal marsh sere undoubtedly accelerated the shoaling process, still going on in the vicinity of Napeague Harbor.

The aeolian process is distinctive on the Napeague tombolo. The dunes are, for the most part, active and obviously moving inland from littoral source area irrespective of the prevailing winds. The "walking dunes" on the east side of Napeague Harbor are especially conspicuous in that these dunes have both covered and extinguished a Quercus velutina (Black Oak) forest moving on towards the southeast to cover and kill

additional portions of that forest while, at the same time, uncovering the now dead oak forest (STOP 7).

The south shore bluffs extending west from Montauk village to Hither Hills State Park erode only during times of exceptional storms such as the "Ash Wednesday" storm of March, 1962. Usually, these bluffs are separated from the shore by fringing beach and incipient dunes. The distinction of shoreline as contraposed to coastline is well defined along this coastal reach.

#### ABSOLUTE CHRONOLOGY

At the time of manuscript submission, we possess no radiocarbon dates bearing on the timing of the events noted in this guide. Suitable material has been secured from several localities and submitted for radiocarbon dating. However, the required laboratory procedures have yet to be completed.

For the moment, we suspect that the gross Wisconsin chronology probably follows that depicted by Schafer and Hartshorn (1965) for southern New England. Analyses of cores from the Reeves Bay tidal marsh at the mouth of the Peconic River near Riverhead, some 30 miles west of Easthampton, suggest that area supported a spruce-pine forest ('A' Pollen Zone) some 11,000 years ago (Newman, 1966). Other radiocarbon dates from the Reeves Bay site indicate that sea level was some 8 feet below its present level some 4000 years B. P. and rose to within 4 feet of contemporary sea level about 1000 years ago (Newman, 1966; Redfield, 1967).

Messrs. Eugene Foord and William Parrott, seniors at Franklin and Marshall College, have collected wood splinters from boring samples penetrating the Smithtown Clay (Lubke, 1964). The Smithtown Clay unit, almost certainly a proglacial lacustrine deposit, underlies the Smithtown Basin in western Suffolk County and appears to be post-Ronkonkoma but pre-Harbor Hill in age. The small amounts of wood secured by Foord and Parrott have been submitted for radiocarbon dating and we hope the results will date what will come to be called the "Smithtown Interstade".

#### ROAD LOG

Assembly Point: Sheraton Tenney Hotel Parking Lot, Grand Central Parkway at LaGuardia Field.

Departure time. 7:00 a.m. All travel by bus!

<u>Mileage.</u>		
0.0	0.0	Southeast on Ditmars Blvd.
1.0	1.0	Turn right (south) onto 108th Street.
2.0	1.0	Turn left (east) and enter Long Island Expressway.
2.5	0.5	Flushing Meadow-the site of the two New York World's Fairs. The geology of this swale has been described by Newman (1966).
4.0	1.5	To your right (south) the campus of Queens College of the City University of New York.

- 8.0 4.0 Alley Creek Valley - a drowned and then partially filled embayment of Long Island Sound.
- 10.0 2.0 Lake Success on your right (south). The lake has an area of 60 acres, a maximum depth of 72 feet, no surface outlet, and is one of the larger kettles on Long Island. Note the (both) Ronkonkoma and Harbor Hill morainal topography.
- 21.8 11.8 Plainview(!)-Here we descend for a short distance from the Ronkonkoma moraine onto the outwash plain. Note the relief contrast.
- 26.7 4.9 After crossing West Hills, one of several central Long Island areas where pre-Pleistocene strata rise considerably above sea level and approach the surface, we descend to the Huntington Plain which may be the site of a proglacial lake overlain by a thin veneer of outwash (Lubke, 1964).
- 28.7 2.0 We rise again into the Half Hollow and Dix Hills, areas similar in structure to West Hills. The Ronkonkoma End Moraine lies on the north flanks of these hills.
- 35.5 6.8 Sunken Meadow-Sagtikos State Parkways. Here we descend once again for a short time onto the outwash plain. Pilgrim State Hospital forms the large building complex on the right (south). We then once again mount the Ronkonkoma moraine.
- 38.6 3.1 Veterans Memorial Highway exit off Long Island Expressway. Turn east-southeast onto Veterans Memorial Highway. We descend almost immediately from the Ronkonkoma Moraine onto the outwash plain. Note the distinctive "pine barrens" vegetation of scrub-oak and pine. This area is underlain by a podzol soil having a bleached lower "A" horizon. This area of Long Island is devoid of agricultural potential because the outwash lacks the loess cover which is conspicuous in farming areas on outwash further east.
- 46.4 7.8 Intersection of Veterans Memorial Highway and Sunrise Highway. Turn left onto Sunrise Highway. Town of Patchogue. Continue east through "pine barrens" on outwash plain.
- 64.9 18.5 Eastport: temporary terminus of Sunrise Highway. Northeast on Route 51. Note farming activity on outwash plain. The surficial loess makes the difference! Route 51 climbs onto the Ronkonkoma moraine and then descends towards Riverhead and the pitted outwash plain between the Ronkonkoma and Harbor Hill End Moraines.
- 72.0 7.1 Riverhead: at the Peconic River mouth. Traffic circle-right (east) on route 24.
- 75.0 3.0 Reeves Bay on left (north).

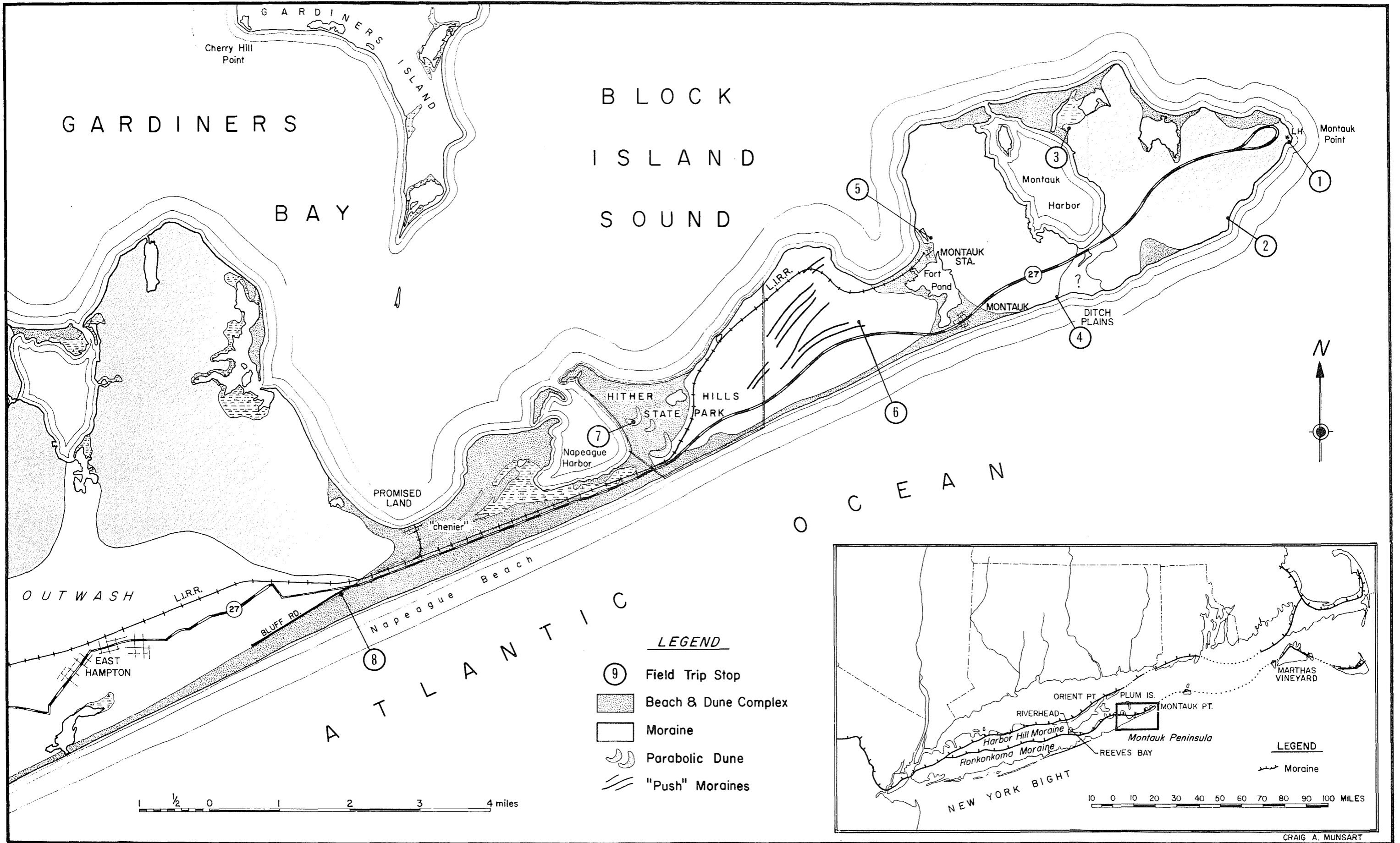


Figure 1. Outline map of the Montauk Peninsula. Inset map modified after Flint (1953).

- 79.0 4.0 Turn left (east onto route 27.
- 81.0 2.0 Cross Shinnecock Canal. We mount the Ronkonkoma Moraine once again.
- 99.0 18.0 Easthampton village.
- 99.3 0.3 Right turn at flagpole onto Dunemere Lane.
- 99.9 0.6 Dunemere Lane becomes Further Lane.
- 101.9 2.0 Right turn onto Indian Wells Highway.
- 102.2 0.3 Left turn onto Bluff Road. Bluff Road marks the crest of an abandoned wave-cut marine cliff cut into Ronkonkoma outwash. Progradation due to the construction of the Napeague Tombolo has separated the bluff from the sea for distances of up to 1.5 miles.
- 103.8 1.6 Half-right turn onto route 27. We descend from the bluff, now on our left onto the Napeague beach-and-dune-complex Tombolo.
- 109.0 5.2 Intersection of Old and New Montauk Highways. Note the abandoned wave-cut bluff on left as well as the dunes on glacial drift. Drive half-left onto the New Montauk Highway mounting the Ronkonkoma Moraine at Hither Hills.
- 114.6 5.6 The village of Montauk built, for the most part, on a double tombolo.
- 121.6 7.0 STOP 1. Montauk Point State Park, Montauk Point. 45 minutes. REST ROOMS ARE IMMEDIATELY ADJACENT TO THE PARKING LOT ENTRANCE.

Montauk Lighthouse was built in the years 1795-1797 about 300 feet from mean high water. It is now only about 60 feet from the water's edge. Following the field trip leaders, walk southeast crossing the road (WATCH OUT FOR TRAFFIC!) and follow the trail which commences at the lighthouse reservation entrance and skirts the south boundary down to the water's edge. To your left, towards the lighthouse is the section sketched by Fuller (1914, fig. 159, p. 144) which probably includes the type Montauk Till section. Starting from the base, Fuller identified the units in the bluff as "(a) Till phase of Montauk till member; (b) boulder pocket; (c) sand and clay phase of Montauk member; (d) clayey sand phase of Hempstead gravel member; (e) normal sandy phase of Hempstead gravel member". We interpret this section as consisting of Ronkonkoma (=Montauk) Till; a lag concentrate; laminated, probably lacustrine, silt, sand and clay; grading upwards into eolian silt and sand. Over towards the northeast, the section includes some stratified



drift. The laminated unit appears to occupy a swale (kettle?) in the till. Listen (sic!) to the geomorphology and sedimentology. Returning to the busses, climb the bluff and look southwest. The bluffs are usually fringed by steep shingle-beaches and extend four miles southwestward to Ditch Plains.

Leave the parking lot and turn west on route 27.

- 122.6 1.0 Left turn into Montauk Air Force Station. Stop! We are now under military jurisdiction and supervision. Proceed under Air Force direction to south shore.

STOP 2. 1 hour. Leave the buses and enter upon the south shore beach. Immediately to the west is a mass of laminated silt and fine sand which Fuller considered "possibly" Gardiners. We believe this unit represents a proglacial lacustrine deposit. Walk southwest for 0.5 mile. Here we find the exciting section described by Perlmutter and DeLuca (1963). The major unit is the Montauk Till forming a 0.5 mile long open anticline. The Montauk Till overlies stratified drift consisting of interbedded gray and brown clay, laminated green and gray silt and clay, and some thin lenses of fine brown sand. Perlmutter and DeLuca found neither forams nor diatoms in the lower stratified drift which represents the oldest unit we will view on this trip. Immediately above the Montauk Till is stratified drift which ranges in thickness from a featheredge to about 30 feet and is composed chiefly of beds and lenses of brown and gray silt, fine to medium sand, and clayey sand. We interpret this unit as likely to be proglacial lacustrine in origin. Perlmutter and DeLuca report 5 to 20-foot-thick till unit on top of the upper stratified drift. However, Newman fails to note it. Occasional pockets of loess cap the section. Return to buses. Leave Montauk Air Force Station and turn left (west) onto Route 27.

- 124.6 2.0 Right turn (north) onto East Lake Drive. Note the morainal topography and surface erratics on right.

- 126.6 2.0 Right turn into borrow pit.

STOP 3. Montauk Airport Archeological Site. 30 minutes.

Geologically, this site includes a medley of till and ice-contact deposits including lenses of red-brown clay, silt and fine sand which Fuller would have referred to as Gardiners Clay. Overlying the drift is a lag concentrate, including occasional ventifacts, while the entire section is capped by loess. Pelecypod valves, including Crassostrea virginica, Venus mercenaria and Pecten irradians, form a "shell midden" associated with the upper portion of the loess blanket. The absence of artifacts suggests the midden dates from the "Archaic Stage" of aboriginal development and is thus some 4000 to 6000 years old. These aborigines probably harvested

the lagoon or bay that existed immediately to the north of the site which has since been filled by the tidal marsh sere and then covered with sand dunes.

LUNCH STOP! Perhaps. It depends upon the wind direction. If conditions are unfavorable here, we'll eat at STOP 4.

Backtrack on East Lake Drive.

- |       |     |   |
|-------|-----|---|
| 128.6 | 2.0 | Intersection with Route 27. Right (west) on Route 27. |
| 129.5 | 0.9 | Left turn onto Ditch Plains Road.                     |
| 129.9 | 0.4 | Parking Lot behind south shore beach.                 |

STOP 4. Ditch Plains Stratigraphic Section. 45 minutes.

Enter upon the beach and walk west 0.2 mile. At this point, the bluff presents a rather simple section consisting of the Montauk Till, a lag concentrate, with loess on top. However, further to the east, additional units are found beneath the loess. These new units of stratified drift appear to have an easterly dip component. At the east edge of the bluff, accentuated by a morphological reentrant at the back of the beach, the stratified drift clearly takes on the aspect of a delta built into a standing body of water. However, this critical exposure is frequently obscured by slump from the still younger unit, aeolian sand comprising dunes, found above the loess. At about this point, the Montauk Till surface dips below the beach and two additional units are found which outcrop near the upper edge of the beach. The lower unit is composed of laminated silt, clay and fine sand. The upper unit is a peat. Both of these units can be traced for about 0.4 mile towards the east although occasionally interrupted by drift, mostly till, cropping out at beach level. Still further towards the east, the bluffs, composed for the most part of Montauk Till, reappear.

Rooted stumps are occasionally found on the peat layer. About a mile to the northeast, adjacent to East Lake Drive and Montauk Harbor, the U. S. Geological Survey notes 98 feet of clay commencing at elevation 0 (Well S010041). The evidence so far developed suggests the entire Montauk Harbor swale was at one time a lake basin. A pollen section from the beach exposure worked up by Maurice Kalisky, one of our graduate students, indicates the sampled section straddles the B (pine) and C-1 (oak-hemlock) Pollen Zones. In this and other aspects, this pollen section resembles that of Donner's (1964) site 2 section from a bluff 0.3 mile west-northwest of Montauk Point. Apparently, a proglacial lake developed a bog sere in postglacial times which was terminated by the Flandrian transgression. The rise in sea level breached the basin rim and littoral and aeolian sand encroached upon portions of the original basin.

Return to Route 27. FULL STOP!



Plate 1

Plate 1. Vertical aerial photograph of a portion of Hither Hills, Montauk Peninsula. Long Island's south shore showing fringing dunes adjacent to wave-cut bluffs appear in the lower portion of the picture. STOP 6 is the excavation in the upper right portion of the photo. The east-northeast-striking lineaments are "push" or "thrust" moraines.

- 130.4 0.5 Left (west) on Route 27.
- 131.7 1.3 TRAFFIC CIRCLE. Right (north) onto Edgemere Road. Fort Pond on your left is dammed on both its north and south side by tombolos.
- 132.8 1.1 Montauk Station: eastern terminus of the Long Island Railroad. Bear right onto Flamingo Road.
- 132.9 0.1 Left into Sand Pit.

STOP 5. 30 minutes.

This excavation illustrates the internal structure of a morphologically well-defined ice-contact kame. Till is exposed at the north side of the pit while a lag concentrate and loess overlie the glacial drift.

- 134.1 1.2 Return to Route 27 at traffic circle. Montauk Village Traffic Circle. Turn right (west) onto Route 27.
- 134.7 0.6 Intersection with Old Montauk Highway. Stay right on Route 27 (New Montauk Highway).
- 135.9 1.2 Right turn onto access road into Montauk Sanitary Landfill Project. Park in designated area.
- 136.5 0.6 STOP 6. 30 minutes.

Both the topographic maps and aerial photographs (see Plate 1) of the Hither Hills area feature several dozen northeast striking ridges. Fuller (1914, p.48), referring to the swales between these ridges, called them "inner-fosse channels". He considered them to be erosion channels which were outlets for waters issuing from the ice margin at successive halts and escaping parallel to the ice front. The structure of the stratified drift exposed in this excavation, however, suggests these ridges are ice-thrust moraines. On the west side of the excavation access road, coarser stratified drift, a lag concentrate, and loess are exposed.

- 137.1 0.6 Return to Route 27. Turn right (west) on Route 27.
- 139.2 2.1 In clear weather, the view towards the west gives an excellent view of the Ronkonkoma moraine as well as many grosser shoreline features.
- 140.7 1.5 Intersection of New and Old Montauk Highways. Continuing west along Route 27, note the wave-cut bluff to your right (north) now isolated from the sea by a prograding shore. The bluff section consists of stratified drift overlain by dune sand now cascading down onto the Long Island Railroad right-of-way. These dunes appear to have migrated in from the north shore.

- 141.4 0.7 Intersection of Route 27 with "Four Wheel Drive". Dismount buses. Walk north 0.9 mile north on "Four Wheel Drive". Note the dune topography of the east end of the Napeague Tombolo. At the terminus of the paved road, follow path to top of "Walking Dune".

STOP 7. "Walking Dune". 30 minutes.

These magnificent parabolic dunes are the present result of a series of morphological developments. Initially, a spit was built westward out from the north shore of Hither Hills. Foredunes were then built behind the beach associated with the spit. Meanwhile, a tidal marsh sere developed in the lagoon behind the spit and the dunes encroached upon and, in large measure, covered the tidal marsh. An oak forest sere developed within the dune swales but were subsequently covered and still later exhumed. Note the dune slip faces currently burying the existing forest.

Return to buses. Continue west on Route 27.

- 146.3 4.9 Right turn onto Napeague Meadow Road.
- 146.4 0.1 UNGUARDED RAILROAD CROSSING-CAREFUL!  
Crossing Napeague Meadows, a ditched tidal marsh.
- 147.7 1.3 Left turn onto Cranberry Hole Road.
- 147.9 0.2 Roadcut through Promised Land Chenier.
- 148.8 0.9 Promised Land fish-rendering plant on right; chenier on left (south). The road parallels the chenier for 1.5 miles.
- 150.3 1.5 "Cross Road" intersection. Continue on Cranberry Hole Road. The chenier ties into the Ronkonkoma Moraine at the east end of the wave-cut bluff marked by Bluff Road. Presumably, the chenier marks the location of a former spit built eastward at the time the sea was eroding along the line of bluff road.
- 151.2 0.9 CAREFUL! NARROW BRIDGE over Long Island Railroad.
- 151.4 0.2 STOP! DANGEROUS CROSSROAD! Cross Route 27 obliquely onto Bluff Road. Bluff Road follows the crest of a wave-cut cliff cut into outwash. Some might suggest that the flat below the bluff represents a mid-Holocene three-meter terrace in the sense of Fairbridge. However, it is more likely that the flat is due to prograding Atlantic shore in this vicinity. The present shore cuts the bluff out at Easthampton village.
- 152.2 0.8 STOP 8. Bluff Road. 30 minutes.

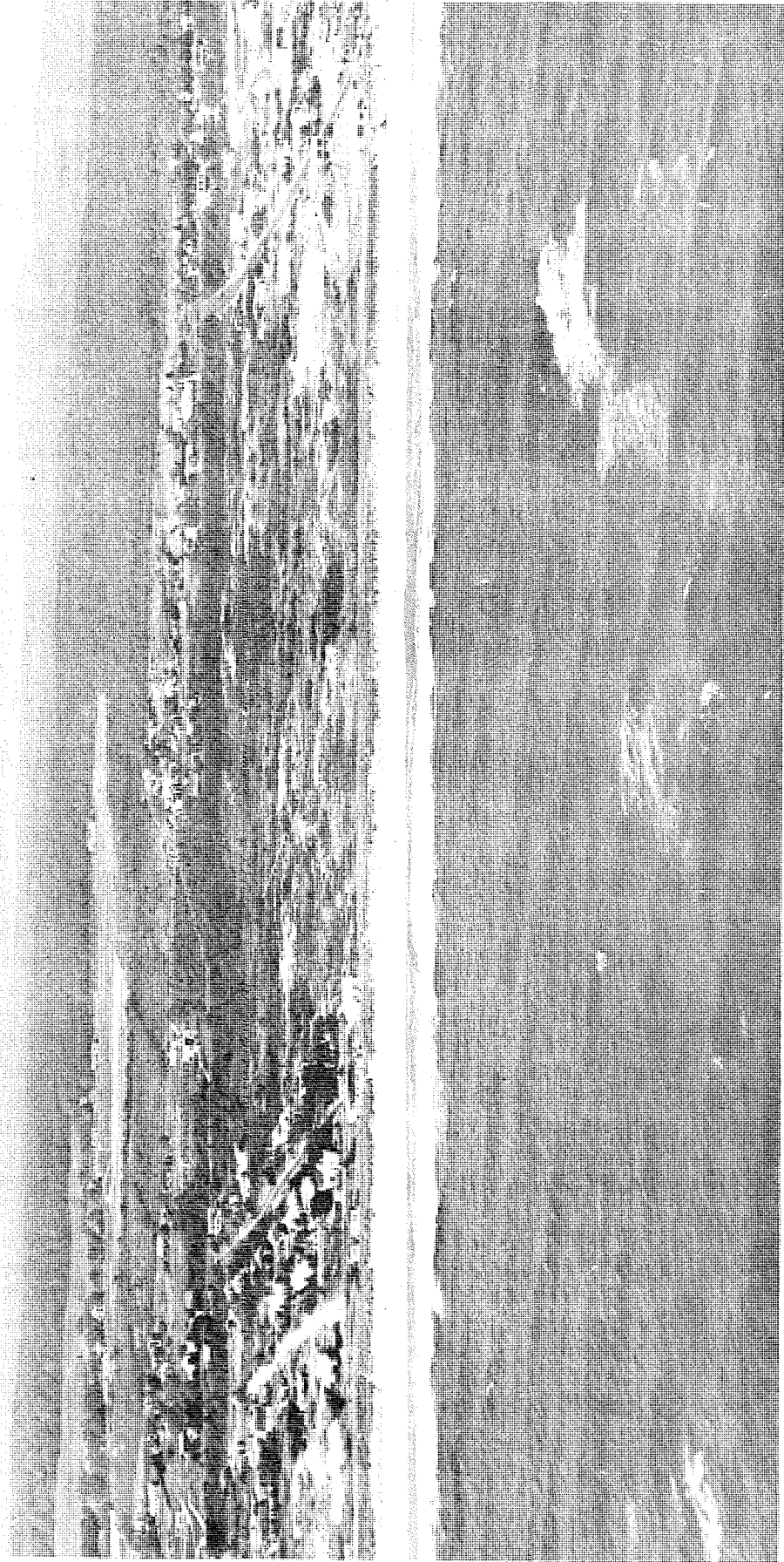


Plate 2

Plate 2. High oblique aerial photograph viewing STOP 8 and vicinity towards north. From the Atlantic Ocean north, note Napeague Beach, the extreme west end of the Napeague beach-dune tombolo complex, the Bluff Road wave-cut cliff, outwash apron (cultivated fields), the Ronkonkoma Moraine (wooded area), and Gardiners Bay in the distance. Photo by Ernest Filep, USNR.



Plate 2 depicts the morphological relationships of the locality. Time permitting, we will walk the 0.4 mile to the Atlantic shore beach. Mount buses for return trip to Sheraton Tenney Inn.

- 153.0 0.8 Right turn onto Indian Wells Highway.  
 153.3 0.3 Left onto Further Lane.  
 155.9 2.6 Intersection with Route 27 at flagpole. Retrace route back to NYSGA Headquarters.  
 255.2 99.3 Sheraton Tenney Inn.

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## TRIP G: STRUCTURE AND PETROLOGY OF PELHAM BAY PARK

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and David J. Leveson, Department of Geology, Brooklyn College.

## 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.

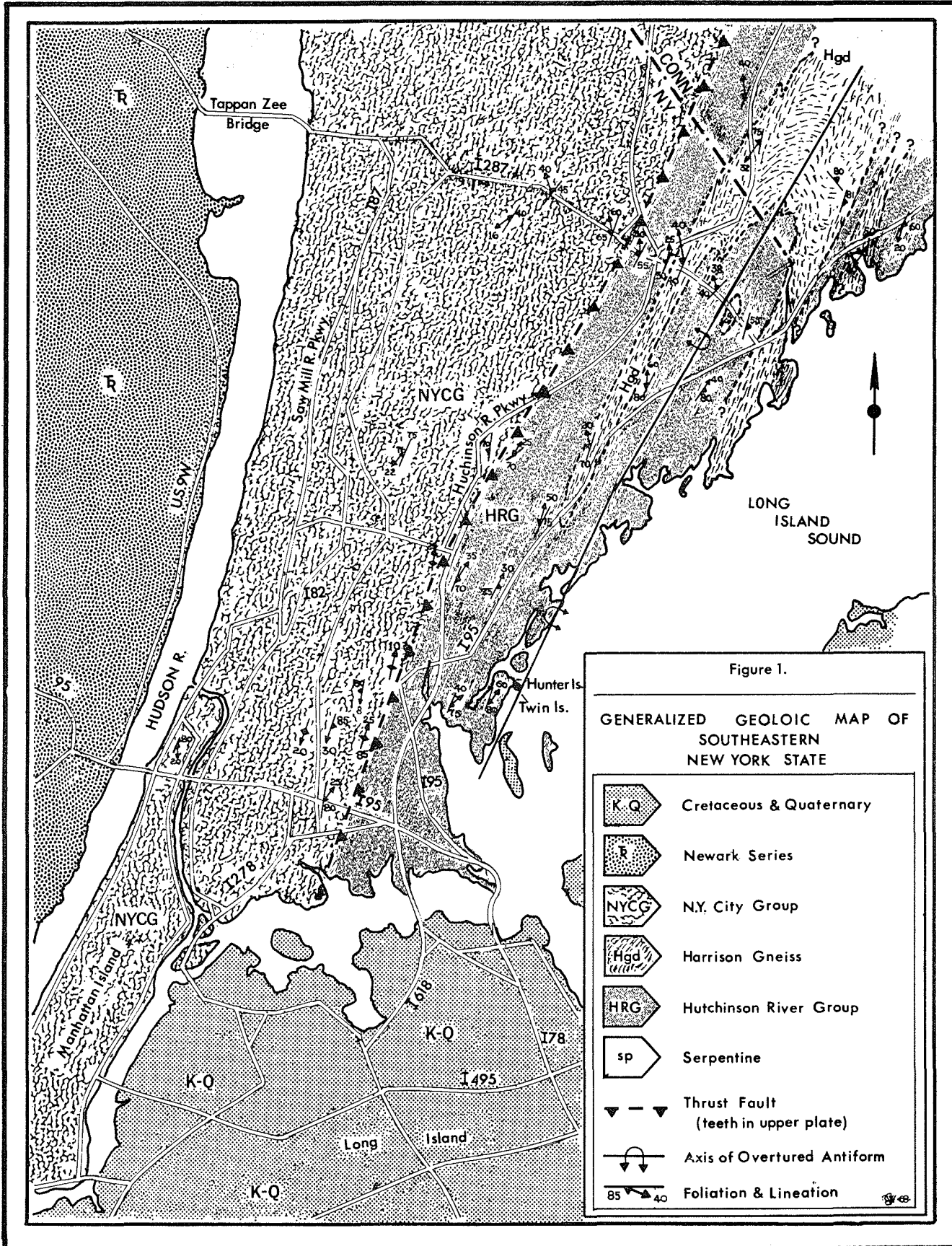











Figure 1.

GENERALIZED GEOLOGIC MAP OF  
SOUTHEASTERN  
NEW YORK STATE

-  Cretaceous & Quaternary
-  Newark Series
-  N.Y. City Group
-  Harrison Gneiss
-  Hutchinson River Group
-  Serpentine
-  Thrust Fault  
(teeth in upper plate)
-  Axis of Overtured Antiform
-  Foliation & Lineation

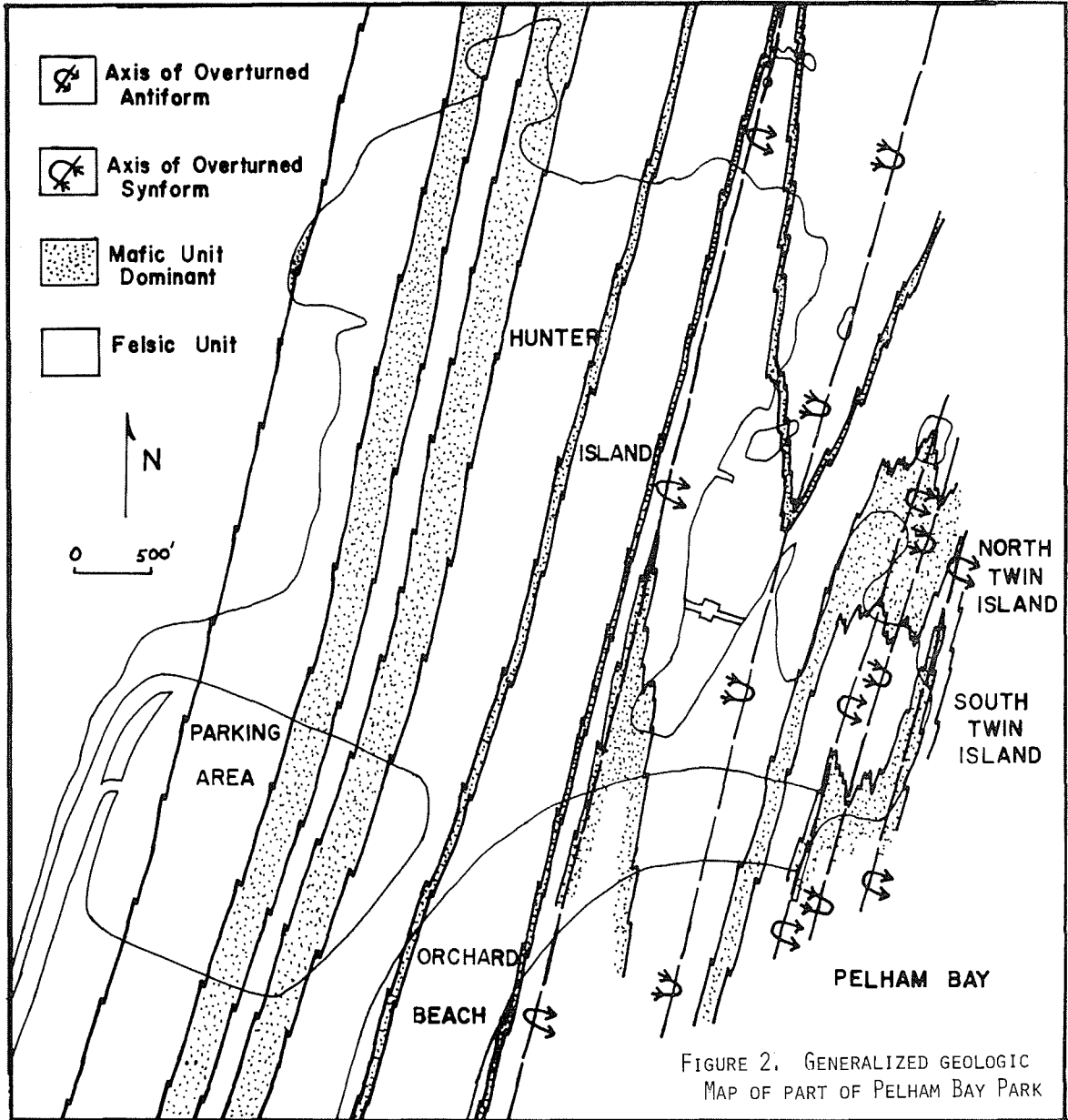


FIGURE 2. GENERALIZED GEOLOGIC MAP OF PART OF PELHAM BAY PARK

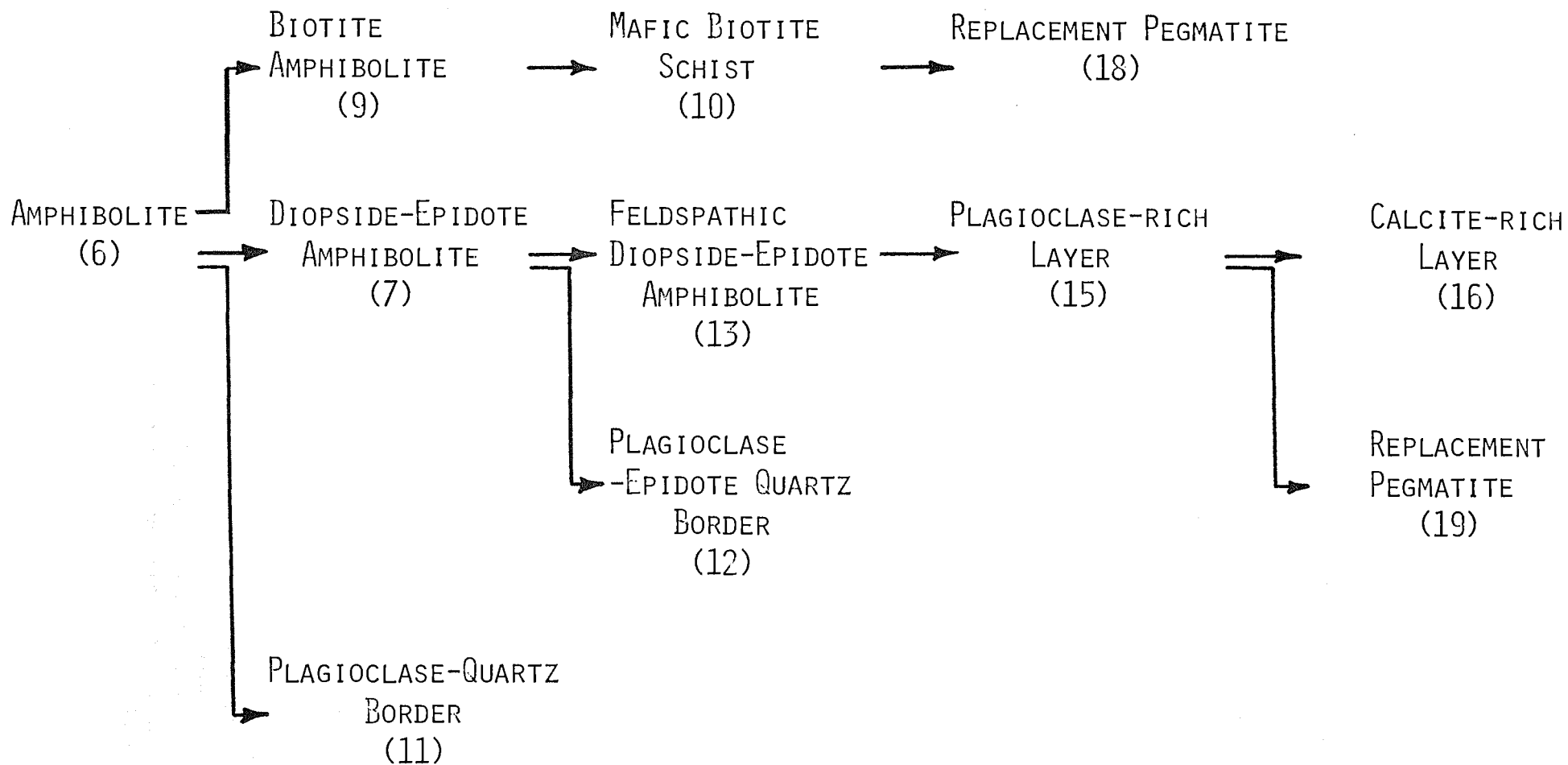


FIGURE 3. CHANGES IN ROCK TYPES PRODUCED BY METASOMATISM DURING THE THIRD PHASE OF DEFORMATION. INDEX NUMBERS FOR SAMPLES IN TABLE 2 ARE INDICATED IN PARENTHESES.



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

Index Number	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
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 <sub>2</sub>	72.2	64.2	63.8	48.1	58.1	48.1	48.4	49.2	47.1
TiO <sub>2</sub>	0.8	0.5	1.1	1.7	0.7	0.8	1.2	0.2	1.2
Al <sub>2</sub> O <sub>3</sub>	11.4	14.1	13.9	23.1	15.4	14.7	13.8	14.8	15.3
Fe <sub>2</sub> O <sub>3</sub>	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 <sub>2</sub> O	2.8	3.4	3.1	2.3	1.3	2.4	2.2	2.5	2.2
K <sub>2</sub> O	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	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>
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 <sub>2</sub>	41.0	68.7	55.7	53.7	50.7	56.5	16.9	60.8	70.6
TiO <sub>2</sub>	1.8	0.8	0.7	1.2	1.6	0.6	0.3	0.4	0.5
Al <sub>2</sub> O <sub>3</sub>	18.0	17.1	24.7	16.7	20.3	20.0	5.1	21.2	14.1
Fe <sub>2</sub> O <sub>3</sub>	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 <sub>2</sub> O	1.9	0.9	4.9	5.6	5.1	6.9	1.3	5.7	3.7
K <sub>2</sub> O	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<sub>2</sub>

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<sub>37</sub>), iron-bearing diopside (salite), and epidote, with minor apatite, sphene, quartz, magnetite, scapolite, calcite, biotite, and garnet (Table 1, number 7). Foliation (S<sub>1</sub>) 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<sub>1</sub>) foliation within adjacent diopside-epidote amphibolites. Plagioclase in the borders is more calcic (An<sub>48</sub> to An<sub>78</sub>) than that in the adjacent diopside-epidote amphibolite (which has An<sub>37</sub>). 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 it 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.

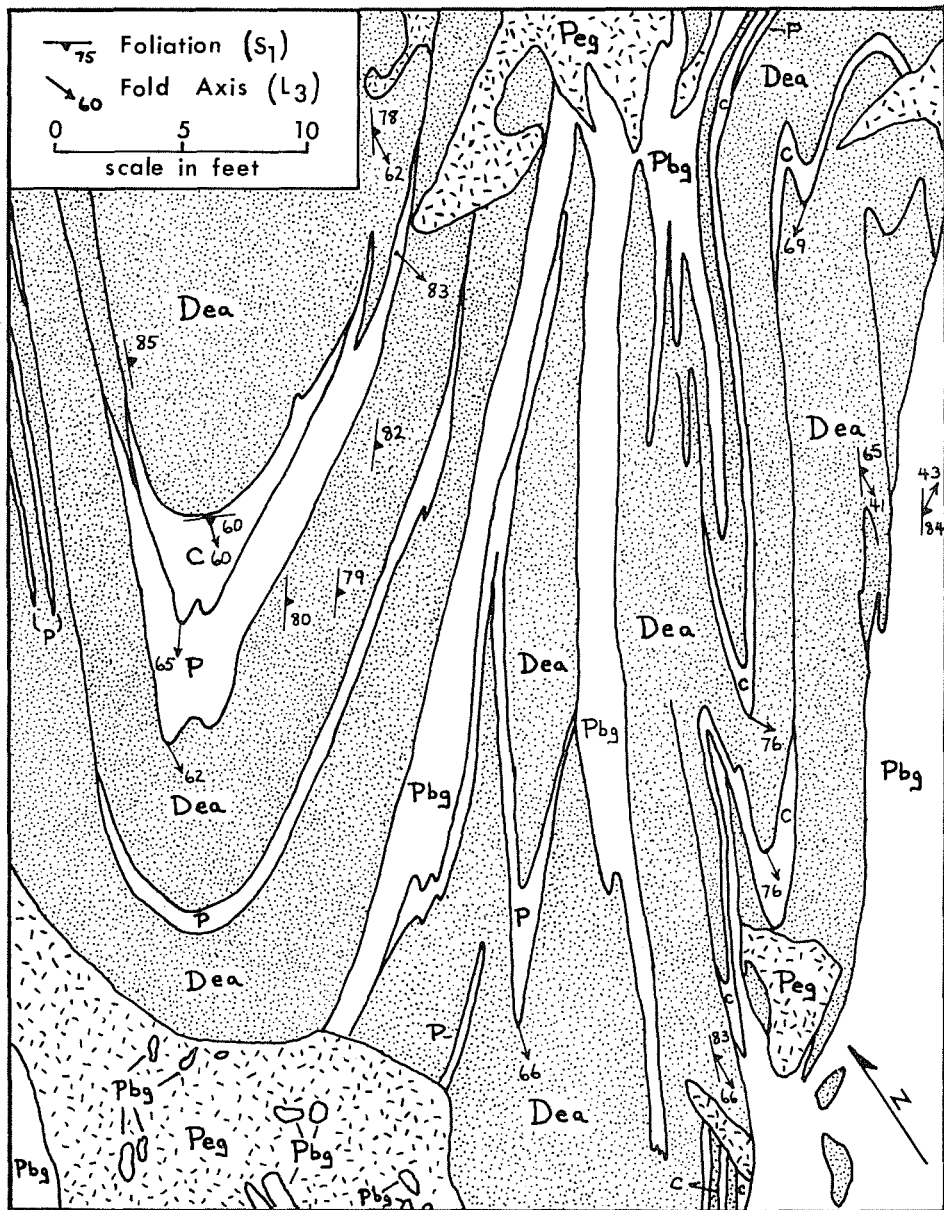


FIGURE 4. LAYERING WITHIN DIOPSIDE-EPIDOTE AMPHIBOLITE, NORTH TWIN ISLAND (STOP 8).  
 Pbg = PLAGIOCLASE-BIOTITE GNEISS;  
 P = PLAGIOCLASE-RICH LAYER;  
 C = CALCITE-RICH LAYER;  
 Dea = DIOPSIDE-EPIDOTE AMPHIBOLITE;  
 Peg = REPLACEMENT PEGMATITE

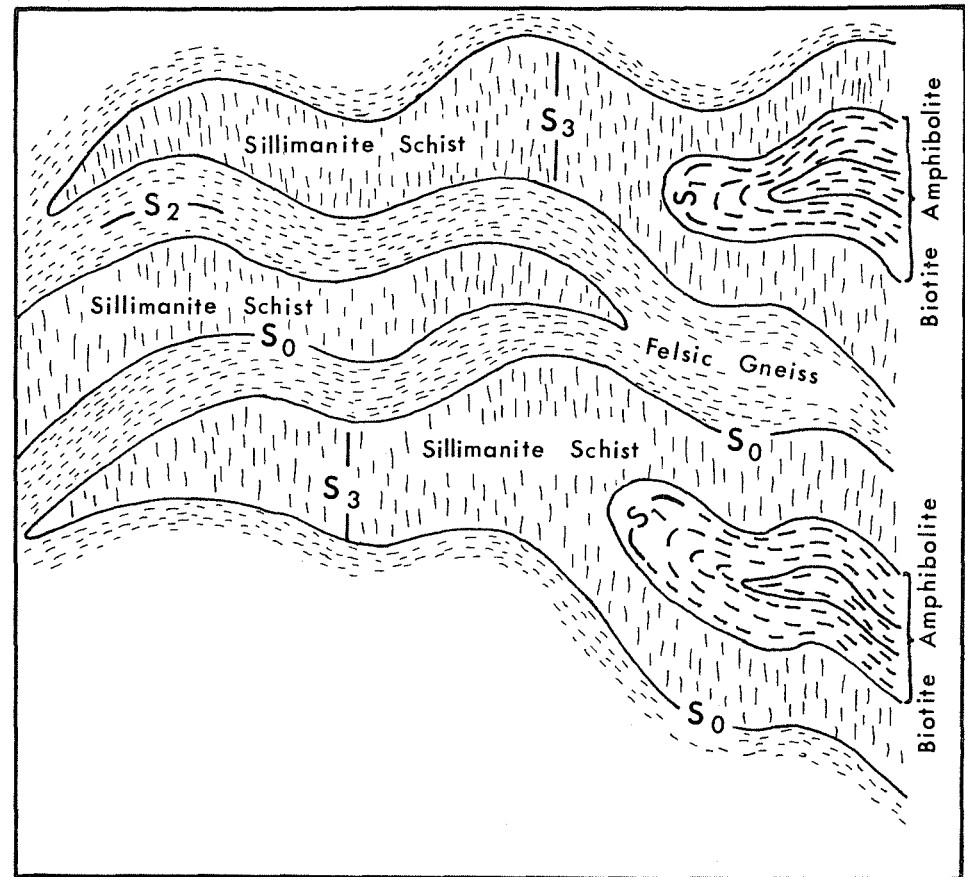


FIGURE 5. DIAGRAMMATIC SKETCH OF THE RELATION BETWEEN FOLDS AND FOLIATION AT STOP 11.  
 $S_0$  = BEDDING;  $S_1$  = EARLY FOLIATION;  
 $S_2$  = AXIAL PLANE FOLIATION OF FOLDS PRODUCED DURING THE SECOND PHASE OF DEFORMATION;  $S_3$  = AXIAL PLANE FOLIATION OF FOLDS PRODUCED DURING THE THIRD PHASE OF 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<sup>0</sup> foliation ( $S_1$ ) has been folded about  $L_2$  fold axes. A second axial plane foliation was produced<sup>1</sup> 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  $15^\circ$  to  $60^\circ$  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 hornblende 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.

Reconnaissance 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 Manhattan 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).

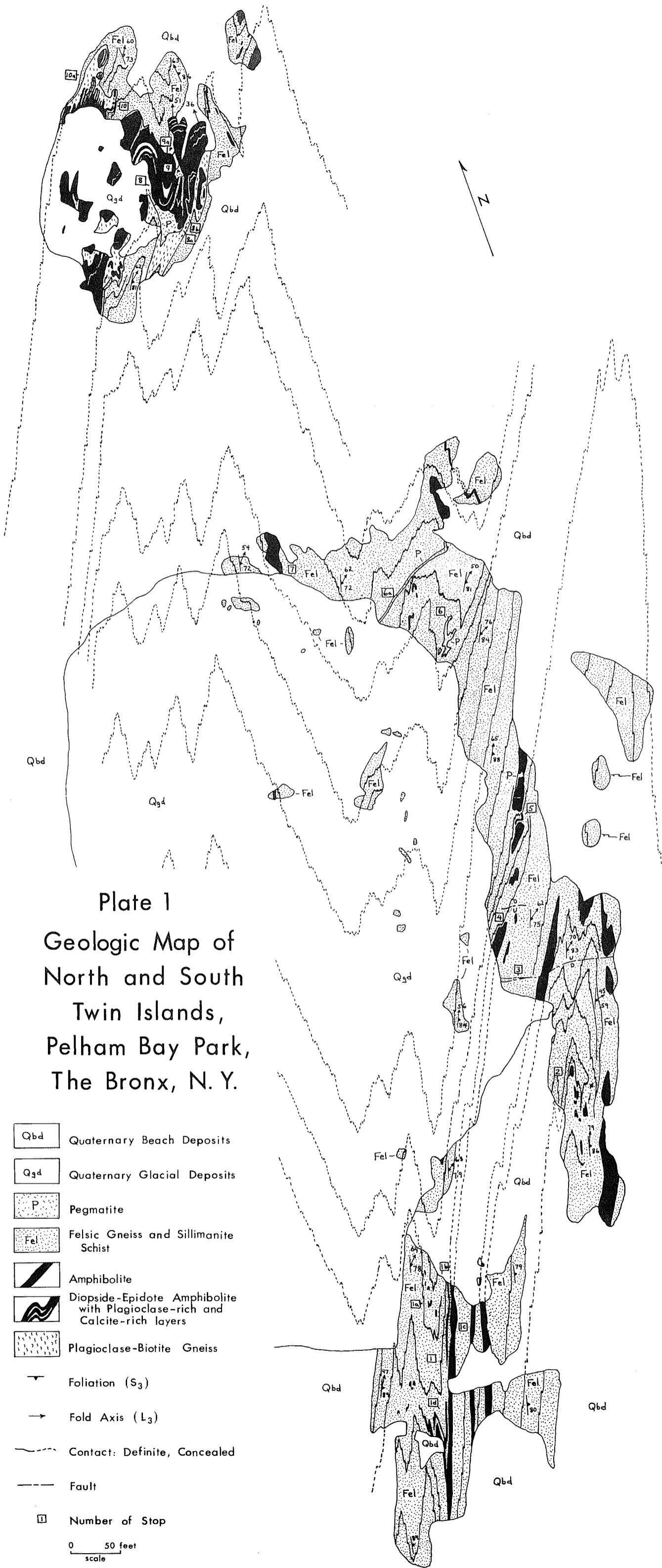


Plate 1  
 Geologic Map of  
 North and South  
 Twin Islands,  
 Pelham Bay Park,  
 The Bronx, N. Y.

- Qbd Quaternary Beach Deposits
- Qgd Quaternary Glacial Deposits
- P Pegmatite
- Fel Felsic Gneiss and Sillimanite Schist
- / Amphibolite
- / Diopside-Epidote Amphibolite with Plagioclase-rich and Calcite-rich layers
- / Plagioclase-Biotite Gneiss
- ▼ Foliation ( $S_3$ )
- Fold Axis ( $L_3$ )
- Contact: Definite, Concealed
- Fault
- Number of Stop

0 50 feet  
 scale

- 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<sub>3</sub>) of the latest set of folds (F<sub>3</sub>).

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 erratics 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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TRIP H: STRATIGRAPHIC AND STRUCTURAL RELATIONS ALONG THE  
WESTERN BORDER OF THE CORTLANDT INTRUSIVES

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INTRODUCTION AND PURPOSE OF TRIP

The New York State Geological Association as recently as 1958 dealt specifically with the problem and areas outlined in this discussion. Recent discoveries by Hall (1965, and this volume), however, have brought the stratigraphic problems of the New York City Group much more clearly to light and have encouraged re-evaluation of the field evidence in this critical area.

The stratigraphic age and correlation of the rocks surrounding the western edge of the Cortlandt intrusives has been clouded by the personal prejudices of individual workers for many years. Because definitive evidence of a stratigraphic kind is difficult to come by in an area as complexly deformed as this, this correlation problem of regional importance is not resolved at the present time.

This trip will focus on one major problem: are the rocks called Manhattan Schist and Inwood Marble south of the Cortlandt intrusives correlative with fossiliferous rocks at Tomkins Cove and Verplanck Point? Lithic and structural arguments will be presented to support this correlation. As in all metamorphosed areas, we must rely primarily on lithic characteristics and stratigraphic succession as well as on structural continuity to solve this kind of problem. The answer is to be found in the rocks; all we must do is look for it.

The purpose of this field trip is to present new stratigraphic and structural data from the western border of the Cortlandt intrusives. This area is critical because it is the locality where correlation of Manhattan Schist and Inwood Marble with the low-rank carbonate rocks and phyllites at Tomkins Cove can best be accomplished. Bucher (1951) demonstrated the lower Paleozoic age of the Tomkins Cove section on the basis of pelmatozoan fragments in a calcareous zone at the base of the phyllite section there (STOP 7-A).

A similar fossiliferous zone rich in pelmatozoan remains has been discovered at Verplanck Point Quarry, on the east side of the Hudson River, demonstrating a Lower Paleozoic age for these rocks (Ratcliffe and Knowles, 1968) (STOP 5). A very similar "crinoidal" limestone is interbedded with the base of the type Annsville Phyllite in the Peekskill Hollow Creek at Van Cortlandtville 1-3/4 miles north of Peekskill. Identifiable fragments of pelmatozoan columnals were found in this rock by participants in the NYSGA excursion of 1958, thus supporting the correlation of Annsville Phyllite with the phyllites at Tomkins Cove proposed on lithic grounds by Bucher (1951). It is here suggested that the lower unit of the Manhattan formation is correlative with the combined Balmville Limestone and Annsville Phyllite and that both are Mid-Ordovician in age.

## STATEMENT OF THE PROBLEM

Despite the gross lithic similarities between the Manhattan Schist - Inwood Marble section (at Verplanck) and the Tomkins Cove section, correlation was opposed by Berkey and Rice (1919) on the basis of the greater metamorphic rank and crystallinity on the east side of the river. Paige (1956) countered this argument by noting the lithic similarity between the Verplanck Quarry section and Tomkins Cove and presented a structural section relating the two localities. The difference in crystallinity of the Verplanck rocks was attributed to the effects of the Cortlandt intrusion.

The correlation of Paige (1956) has been widely accepted despite lack of conclusive evidence. Lowe and Schaffel (in Lowe, 1958) did not accept this correlation, objecting principally to the short distance (1-1/2 miles) across strike that the metamorphic change from phyllite to biotite-muscovite-garnet schist took place. They suggested the Manhattan Schist and Inwood Marble here are older than the rock at Tomkins Cove and have been thrust westward along a post-metamorphic low angle thrust, placing the two sections in close proximity.

Ratcliffe and Knowles (1968) reported pelmatozoan fragments in the basal Manhattan Schist (STOP 5) and compared this zone with a similar fossiliferous zone at Tomkins Cove (STOP 7-A). These workers conclude that Paige's correlation was justified and provide firm evidence supporting Paige's correlation. What metamorphic differences exist (discussed at STOP 5), probably can be explained by a combination of normal prograde regional metamorphism and superposed contact effects.

Correlation of these sections with type Manhattan Schist - Inwood Marble south of the Cortlandt complex has been hindered by the lack of detailed structural and stratigraphic data. The detailed mapping in this area by Balk (1927) was primarily concerned with the Cortlandt Complex and did not contribute to the solution of this stratigraphic problem. Paige's map (1956, pl. 1) did not show the relation of Tomkins Cove and Stony Point rocks to the Manhattan Schist south of the Cortlandt intrusives on the east side of the Hudson River.

## RESULTS OF PRESENT INVESTIGATION

Detailed mapping at a scale of 1 inch/1,000 feet has demonstrated a mappable stratigraphy within the Manhattan Schist - Inwood Marble sequence south of the Cortlandt Complex. The same stratigraphy is present in the sections to the north and west (at Tomkins Cove and Verplanck) thought to belong to the Wappinger - Hudson River sequence.

The detailed tracing of units, taken together with new fossil evidence from the limestones at Verplanck Point Quarry, suggests strongly the Lower Paleozoic age of the Manhattan Schist-Inwood Marble Sequence. Correlation with the Tomkins Cove and Verplanck sections is supported on lithic as well as on structural grounds. All sections above are exposed on the limbs of the same major  $F_1$  structure (see Figure 1). Stratigraphic, fossil, and structural evidence presented here and elsewhere (Paige, 1957; Bucher, 1951; Ratcliffe and Knowles, 1968; and Ratcliffe, in press) strongly supports the correlation of these three sections. The actual age of the Manhattan and Inwood Formations, however, cannot be finally proved until diagnostic fossils are found in rocks directly traceable to the type locality.

## STRATIGRAPHY

Basement Rocks (Fordham Gneiss).

Within the present map area (Figure 1) several gneisses and granulites make up the Fordham Gneiss, including:

Pinkish-gray, poorly-foliated, K-feldspar-quartz biotite gneiss, granitic gneiss or granulite

Layered, biotite-plagioclase-quartz gneiss

Massive, hornblende-biotite-plagioclase gneiss and related layered hornblende gneisses and amphibolites.

Outcrop areas underlain predominantly by these rock types are outlined in Figure 1. The letter designations are not intended to correlate with the subdivisions of the Fordham Gneiss proposed by Hall (1965, and this volume).

Lowerre quartzite.

Massive, white, vitreous quartzite in beds 1 to 5 feet thick, or thin-bedded tan to pinkish-tan-weathered quartzite, is exposed at five different localities. At two localities a possible basal conglomerate is present closest to the contact with the underlying Fordham Gneiss. Fragments of gneiss are included in a very impure quartzo-feldspathic matrix. No actual contact with the Fordham Gneiss has been seen. However, the contact can be located within several feet at several localities.

Inwood formation.

Owing to varying degrees of metamorphic recrystallization, the Inwood Formation differs in gross characteristics, such as color and crystallinity, from place to place. Despite these differences, certain distinctive original lithic characteristics have been recognized and a tentative stratigraphy mapped. General correlations with units of the Stockbridge Formation (Zen, 1966) are suggested.

Unit A. White to gray crystalline dolostone or dolomitic marble, without sandy or argillaceous impurities (15-100 feet?). Probably correlative of Unit A of the Stockbridge Formation.

Unit B. Gray to dark-gray, layered dolostone with thin, orange-weathering quartzite in one-inch beds, and numerous phyllitic partings. Beige weathered surfaces are typical. Minor 3 to 5-foot-thick quartzites occur along with biotitic, mottled, calc-dolostone. Probably correlative with Unit B, and perhaps with part of Unit C, of the Stockbridge Formation.

Unit C. White, crystalline, dolomitic marble, locally sandy at the base, grading up into massive crystalline dolostone with minor, sandy, white to gray dolostone, with tremolite-rich bed near the top at Crugers. Probably correlative with Unit C and perhaps with Unit D of the Stockbridge Formation.

If the correlations with the Stockbridge Formation are correct, the Inwood Marble exposed here ranges from Lower Cambrian to Upper Cambrian or lowermost Ordovician in age. Calcitic units have been reported in the upper part of the Inwood Marble by Hall (this volume). These units do not appear to be present here.

#### Manhattan Formation (of Scotford, 1956).

A calcareous zone at the base carries pelmatozoan fragments in a dark to light-bluish-gray, crystalline limestone or marble. This unit is probably a correlative of the Balmville Limestone of Trenton age. This basal limy phase is not present everywhere, and is notably absent or very thin where the Manhattan Formation is exposed close to the Fordham Gneiss.

The Lower Manhattan (Oma) is basically a dark colored "graphitic" biotite-rich phyllite or schist, marked by black calcitic quartzites 1 to 3 inches thick and by interbedded calcareous phyllite and phyllitic marbles. Rusty-weathered, sooty-black schists are common in zones close to the base. Minor calcareous graywackes are abundant near the base. Excellent exposures of Oma can be seen at Verplanck Point Quarry (STOP 5), Crugers (STOPS 2 and 3), and Tomkins Cove (STOP 7). On the basis of similar fossil content (pelmatozoans in basal limestone) and lithic characteristics, Unit A of the Manhattan Formation is correlated with the Annsville Phyllite of the Peekskill Valley.

The Upper Manhattan (XMb) is well exposed at the new road cut in Prickly Pear Hill on Route 9 (STOP 1), above Maiden Lane (STOP 2), and at George's Point (STOP 4). The unit as a whole is characterized by a lighter colored, silvery-gray sheen on the foliation surfaces, produced by coarse-grained muscovite plates. Large garnets and coarser-grained phyllosilicates give this rock a markedly different appearance from Unit A. Thin milky white to granular crystalline quartz layers occur throughout and represent isolated layers in a predominantly schistose matrix. Very distinctive biotite-muscovite-quartz-plagioclase granulites are common, for example at George's Point (STOP 4), and account for a considerable thickness of Unit B. Unit B here corresponds in usage to Unit C of the Manhattan according to Hall (this volume).

A correlation chart, Figure 2, shows the age assignments by previous workers for the rocks at Tomkins Cove, Verplanck, and Crugers. In the present report all three sections are correlated and a single name is used for all correlatives, despite the degree of crystallinity or intensity of metamorphism. Because of the variation from phyllite to schist and limestone or dolostone to marble within the same units in different parts of the area, the names Manhattan Formation (Scotford, 1956) and Inwood Formation are used.

#### Upper Triassic.

The basal limestone conglomerate overlies Inwood Marble south of Stony Point. This contact, for reasons discussed at STOP 7-F, probably is not a normal fault contact as illustrated on the New York State Map (Fisher, et al., 1961) but an unconformity.

## UNCONFORMITIES

Lower Cambrian.

In the crestal area of the major  $F_1$  structure, mapped contacts within the basement gneisses trend at high angles to the contacts with both the Manhattan Formation and the Lowerre Quartzite (see Figure 1). This strongly suggests unconformable relations. The presence of a basal conglomerate at the base of the Lowerre Quartzite, containing fragments of the underlying amphibolite and granite gneisses at this locality further substantiates the argument for a pre-Lowerre unconformity. Folds in the gneisses trend at nearly  $90^\circ$  to the cover rocks in the area of closure of the  $F_1$  anticline.

Middle Ordovician.

On a broader scale (Figure 1) it can be seen that various rock units within the Fordham Gneiss as well as the Lowerre Quartzite and the Inwood Marble are in contact with the Manhattan Formation. These relations are taken as indication of a second unconformity in pre-Manhattan (Middle Ordovician) and post-Inwood time (Lower Ordovician). No exposure within the mapped area proves this point, however, as no actual angular discordance has been observed.

The Manhattan Formation rests at different localities on widely different rocks. Various units of the Fordham Gneiss, the Lowerre Quartzite, and individual units of the Inwood Marble are truncated by this contact. The parallelism of Unit A of the Manhattan Formation to this contact and the folded irregular map pattern suggest that this contact is either a low angle thrust contact or an unconformity.

The basal limy unit of the schist carries pelmatozoan fragments at Verplanck Point Quarry and Tomkins Cove. On the basis of the lithic similarity, fossil content, and similar stratigraphic position, this zone is correlated with the Balmville Limestone of Trenton age. The base of the Balmville Limestone elsewhere marks a major mid-Ordovician unconformity north and west of the Hudson Highlands and in western Massachusetts (Bucher, 1957; Zen and Hartshorn, 1966). For these reasons the base of the Manhattan schist south of the Cortlandt Complex is interpreted as an unconformity. Hall (this volume) presents similar evidence in support of a mid-Ordovician unconformity beneath the Manhattan Formation.

The proximity of the Manhattan with various underlying units has been observed before and interpreted as:

- (1) the result of squeezing out of the Inwood Marble (Lowe, 1958; Baskerville, 1967).
- (2) interbedded relations between Fordham Gneiss, Inwood Marble, and Manhattan Formation (Prucha, 1956; Scotford, 1956), and
- (3) the Manhattan unconformably overlying the lower rocks (Hall, this volume). Bucher (1951, 1957) used this argument for limestones at the base of the Annsville Phyllite in the Peekskill Valley.

The first argument can be largely dismissed on the basis of evidence seen

at the sand pit on Maiden Lane (STOP 2). In this contact zone basal Manhattan rests on Unit B of the Inwood (here only 15 feet thick). The upper part of Unit B (at least 200 to 300 feet thick) and Unit C (also several hundred feet thick) are absent. These units are present on the northern limb of the same east-west syncline on which the sand pit is located. There is no particular reason why squeezing out should have selectively removed only the upper part of the section.

Inasmuch as a definite carbonate stratigraphy can be mapped here, and interbedding with the underlying gneiss is not indicated (*i. e.*, the Lowerre inter-venes) explanation 2 fails to explain the field relations.

Interpretation 3, for reasons outlined above, seems the remaining choice. The overall map relations strongly support the hypothesis of Hall (this volume) that the lower part of the Manhattan Formation rests with unconformity on the lower rocks.

Map relations seen on Figure 1 show lower Manhattan truncating all units down to the Precambrian (cutting the Lowerre - Precambrian contact) along the perimeter of the single anticlinal structure.

#### STRUCTURAL TERMINOLOGY

##### Planar Features.

- |                |   |
|----------------|---|
| S <sub>0</sub> | Bedding.  |
| S <sub>1</sub> | Foliation (here a regional axial surface of the major F <sub>1</sub> Verplanck Point - Tomkins Cove - Crugers anticline). |
| S <sub>2</sub> | Late crenulation cleavage or foliation related to F <sub>2</sub> folds.   |
| S <sub>3</sub> | A crenulation cleavage cutting S <sub>2</sub> (related to F <sub>3</sub> folds) locally developed.                        |

##### Fold systems.

- |                |   |
|----------------|---|
| F <sub>1</sub> | Major anticlinal structure now refolded (Verplanck - Tomkins Cove - Crugers anticline).   |
| F <sub>2</sub> | Second generation structures at each outcrop (F <sub>2</sub> folds vary in attitude around the perimeter of the Cortlandt Complex). |
| F <sub>3</sub> | Very local structures not recognized everywhere.  |

#### REGIONAL STRUCTURE

All stops on this field trip are on the flanks of the same large refolded structure, the Verplanck - Tomkins Cove - Crugers anticline. The closure of this fold is mapped south of the Cortlandt intrusives between Prickly Pear Hill and Furnace Brook Pond (Figures 1 and 3). Structures in the cover rocks (Lowerre Quartzite, Inwood Formation, and Manhattan Formation) indicate steep to moderate northeast plunges for the F<sub>1</sub> fold axes. Later F<sub>2</sub> folding with nearly vertical axial planes plunge at low angles to the east.

Verplanck Point (STOP 5), Stony Point (STOP 7-D-F), Crugers (STOP 3), and Maiden Lane (STOP 2) all lie on the right-side-up limb, whereas Prickly Pear Hill (STOP 1) and Tomkins Cove Quarry (STOP 7-A) expose the vertical or over-turned limb. Structural relations are obscured south of Stony Point by the unconformable Upper Triassic cover.

### STRUCTURAL RELATIONS

Obvious evidence of multiple deformation is seen in nearly every exposure of the cover rocks. The major structural trends are portrayed in Figure 4. The large  $F_1$  anticline is folded about a late  $F_2$  axis, having a  $N70^\circ E$  direction. Stony Point is located in the axial region of the late fold system.

The  $F_1$  fold system is characterized by passive flow folding in the schists and phyllites and by flexural flow in the carbonate rocks. A prominent axial plane cleavage is developed in the Manhattan Formation that is clearly related to the earliest fold system. This axial surface is folded by the later  $F_2$  fold system and  $F_3$  that produced kink bands or slip cleavage.

Detailed study of macro-structures from various localities demonstrates that the late  $F_2$  structures vary in intensity and attitude around the perimeter of the late structure (see Figure 4). For example, there is a definite late  $F_2$  folding in the Crugers area in a  $N70^\circ E$  direction that is responsible for the rotation of  $F_1$  axial surfaces in that area. However, unfolded  $F_1$  axes have the same trend to the east, in this area, as the  $F_2$  axes.  $F_1$  axial surfaces are extremely folded (STOP 2), whereas  $F_2$  surfaces have  $N65^\circ-85^\circ E$  strikes and dip at high angles to the south or north.  $F_2$  fold axes developed on the  $F_1$  axial surfaces plunge at moderate angles to the east.

The local attitudes of  $F_2$  folds, for example STOPS 4, 5, and 7-D-F, may be directly related to the struggle for space between separate but coalescing intrusions. Data at Stony Point (Ratcliffe, in press) and preliminary data at Montrose and Crugers suggest that the Cortlandt intrusion is composed of several separate stock-like plutons with wedges of metasediment trapped between them. Shand's map (1942) greatly simplified the structural relations and compositional variations of these separate plutons (for example, at Stony Point). Ironically, Rogers' 1911 map showing the lithic variations within the pluton may provide the approach necessary to understand the intrusive history of the Cortlandt Complex. Investigations are in progress to try to determine whether multiple intrusion of separate magmas was significant in the Cortlandt Complex as a whole. Preliminary data suggest a dioritic phase is not restricted to a border facies of the norite but occurs as separate mappable plutons within as well as adjacent to the Cortlandt Complex (see Figure 1). Note the Torment Hill diorite body and small bodies within the schist along the north limb of the Verplanck - Tomkins Cove - Crugers anticline east of Crugers (Figure 3), as well as the diorites at Stony Point and Crugers (Figure 1).

If separate plutons can be recognized, then many of the late  $F_2$  structures seen on the map (Figure 4) might be the result of interference between igneous masses. The late structures at George's Island (STOP 3) trend  $N25^\circ-20^\circ E$  and plunge at moderate angles to the northeast. These folds could have been produced by being trapped between the dioritic mass (at the FDR Hospital) on the east and

the pyroxenite-noritic mass exposed to the northwest at Montrose Point. This problem must be studied further.

Contacts of the early  $F_1$  folds having axial plane foliation or schistosity are truncated in map scale at Verplanck, Stony Point, and east of Crugers by the Cortlandt Complex. Late dikes from the Cortlandtite pluton at Stony Point cut the late  $F_2$  folds in the railroad cut at Stony Point (STOP 7-D).

Very fractured, boudinaged, and recrystallized schists of the Manhattan Formation are common at the borders of the noritic portions of the complex, particularly within 100 feet of the norite contacts (see Figure 3). These brecciated zones are characterized by a lack of pervasive cleavage and by rotation of separate blocks having  $F_1$  foliation. A very thin brecciated zone (2 to 3 feet thick) is present at Stony Point between the Cortlandtite and the Manhattan schist but is not developed at the contact with the diorite pluton. The exact relation of  $F_2$  folds to this brecciated zone has not been determined as yet.

Quartz-K-feldspar-garnet veinlets fill the  $F_2$  axial planes in outcrops close to the norite contacts. Mineralization in these fractures and in other unfolded veinlets increases as the complex is approached. Excellent exposures showing these relations can be seen in the Upper Manhattan (Xmb) on the ridge west of Lake Meahagh on Verplanck Point (STOP 6).

These relations indicate the Cortlandt intrusives were intruded late in the tectonic cycle and after the development of a regional foliation ( $F_1$  axial surface).

The map relations at Stony Point (Ratcliffe, in press) and STOP 7-D-E indicate the intrusive phase was synchronous with or later than  $F_2$ . If the ages available for the Cortlandt Complex are reliable (Biotite-K/Ar: 435 m. y., Long and Kulp, 1962), then the major  $F_1$  fold and the refolding by  $F_2$  probably are both Taconic in age. The fossils found in the basal Manhattan, if indicative of a Trenton age, as proposed here, limits the regional deformation producing  $F_1$  and  $F_2$  folds as post mid-Ordovician and pre-Devonian.

#### ROAD LOG

Leave Hotel Sheraton-Tenney, 90th St. and Ditmars Boulevard, reaching Major Deegan Expressway by way of Triboro Bridge. Follow Major Deegan Expressway north to N. Y. State Thruway (I87), and follow N. Y. State Thruway north to intersection of I287 and Tappan Zee Bridge approach. Exit onto N. Y. 9 before toll booth, turn south on N. Y. 9. Assembly point at Howard Johnson's Restaurant 0.1 mile south of turn onto N. Y. 9 and on east side of N. Y. 9.

#### Mileage.

0.0	0.0	Leave Howard Johnson Parking Lot heading north on N. Y. 9. Follow N. Y. 9 north through Tarrytown and past Sing-Sing Prison.
9.0	9.0	Follow dual highway N. Y. 9. Note large outcrops of Yonkers-type gneiss with large apparently folded pegmatites.
11.0	2.0	Turn off N. Y. 9 to 9A north at Senaque Rd. Turn left on 9A.



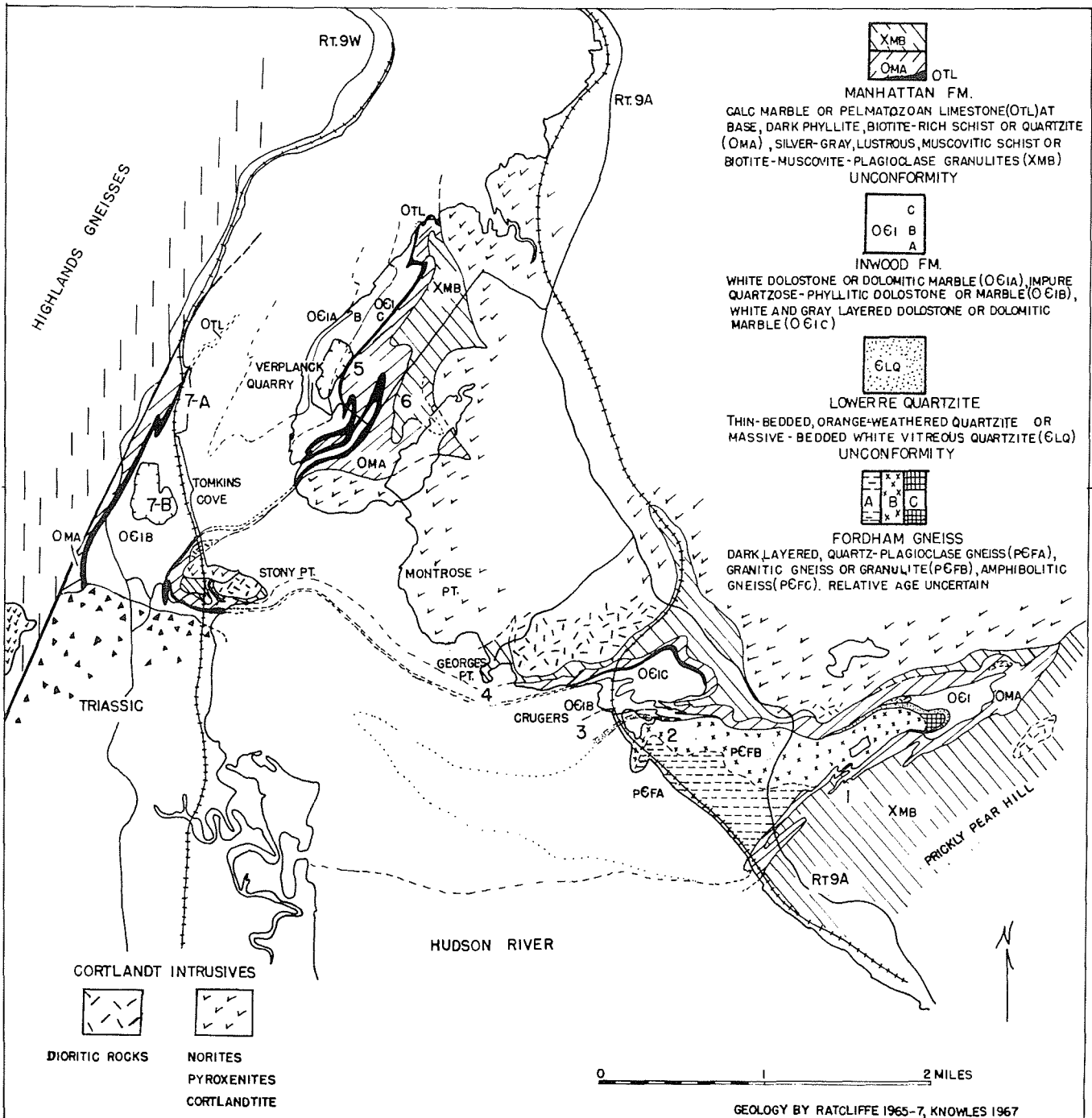


Figure 1. Geologic map of the western edge of the Cortlandt intrusives, showing location of field trip STOPS 1 - 7. Map includes portions of the Haverstraw and Peekskill, N. Y., 7-1/2 minute quadrangles.

Age	Berkey & Rice, 1919		Bucher, 1951, 1957	Paige, 1956	Fisher et al., 1961 N. Y. State Geologic Map			*This report
	Tomkins Cove	Verplanck	Tomkins Cove	Verplanck Tomkins Cove Stony Point	Tomkins Cove Stony Point	Verplanck	Crugers	Verplanck Tomkins Cove Stony Pt. Crugers
Age Uncertain							Manhattan Schist Inwood Marble	Xmb
Middle Ordovician	Hudson River Shales		**Annsville Phyllite  Trenton Limestone Unconformity	Hudson River Shales	Normanskill Formation	Berkshire Schist		Oma  Trenton Limestone Unconformity
Early Ordovician	Wappinger Limestone		Cambro-Ord. Dolostone	Wappinger Limestone	Stockbridge Limestone	Stockbridge Limestone		C B A
Cambrian	Not Exposed		Not Exposed	Not Exposed	Not Exposed	Not Exposed		Lowerre Quartzite Unconformity
Precambrian		Manhattan Schist Inwood Marble					Fordham Gneiss	Fordham Gneiss

\*In this report all four sections are correlated and named similarly. Subdivisions of the Inwood formation are tentative only, but conform to the usage of Hall (this volume).

\*\*Correlation indicated. Name not used.

Figure 2. Correlation chart showing terminology used by various authors for the Verplanck, Tomkins Cove, Stony Point, and Crugers sections.

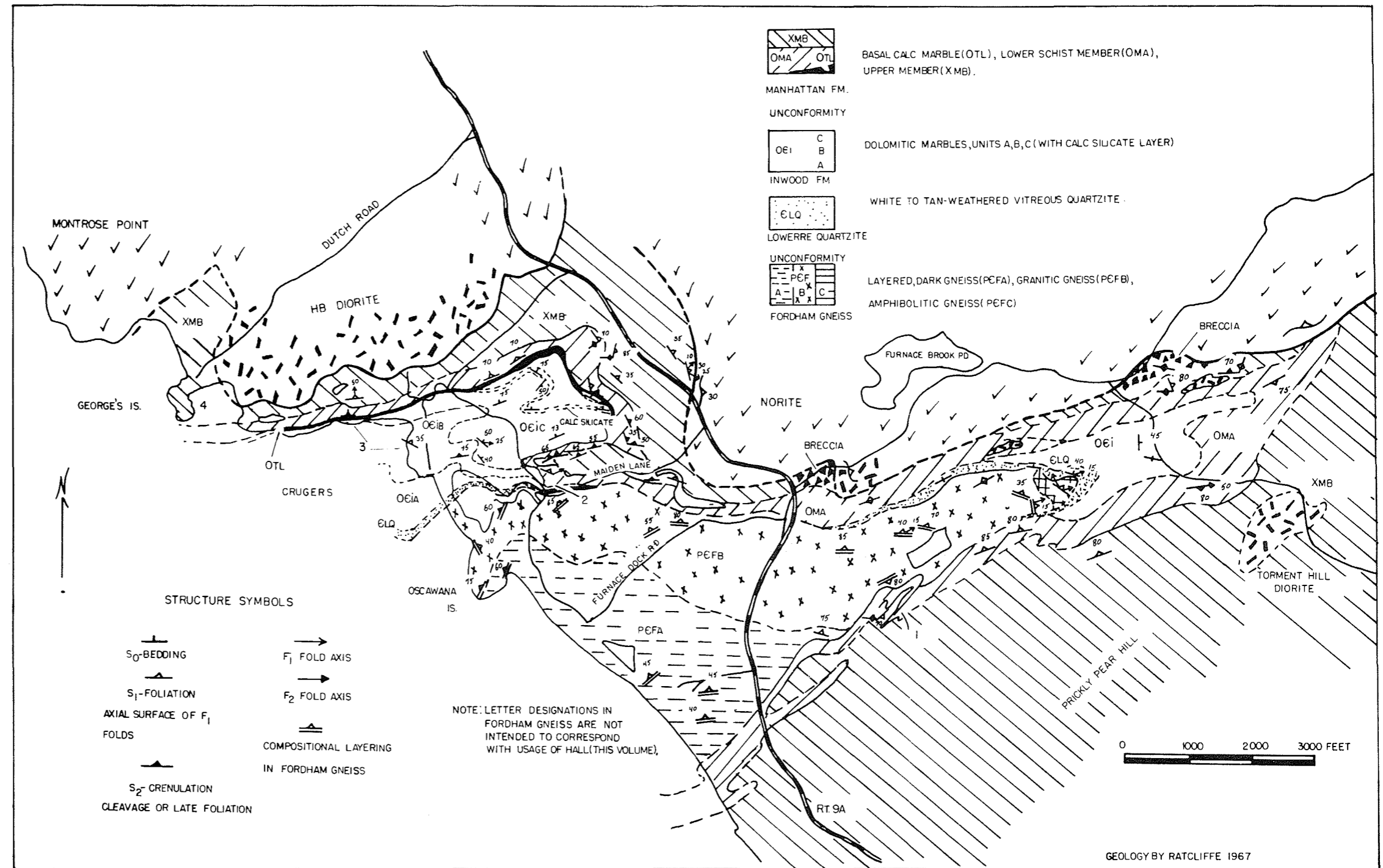


Figure 3. Geologic map of the Crugers area south of the Cortlandt intrusives showing the subdivisions of the Manhattan and Inwood formations. Location of field trip STOPS 1 - 4.

Continue north along 9A around west end of Prickly Pear Hill. Numerous exposures of Xma (Upper Manhattan, here staurolite grade). Just entering map, Figure 1.

13.0 2.0 Turn right on private road marked to Brinton Bird Sanctuary.

13.3 0.3 STOP 1. Brinton Bird Sanctuary. North flank Prickly Pear Hill, NE 1/9 Haverstraw Quad.

This stop is located on the southeast flank of the Tomkins Cove Crugers  $F_1$  anticline (Figures 1 and 3), and exposes granitic gneisses of the Fordham Gneiss in near contact with the Lower Manhattan (Oma).

Walk northeast up the path into the bird sanctuary approximately 800 feet to large glaciated exposure of Manhattan schist.

Garnet-quartz-biotite-muscovite-schist and garnet-biotite-muscovite-plagioclase-quartz granulites are the dominant lithologies. Staurolite is a diagnostic mineral in much of Unit B of the Manhattan in this area. This is typical of the Upper Manhattan exposed to the southeast on Prickly Pear Hill and resembles the type Manhattan of New York City despite the lower metamorphic grade.

Closures of  $F_1$  folds may be seen in the outcrop with the  $F_1$  axial surfaces (with bedding parallel in most cases) trending  $N45^\circ-50^\circ E$  and dipping steeply to the east. Late  $F_2$  folds with a related crenulation cleavage trend  $S75^\circ-80^\circ E$  and have near vertical axial planes and fold the  $F_1$  axial surfaces.

An  $F_3$  fold system is weakly developed in the north-central portion of the outcrop with axial planes trending  $S45^\circ-50^\circ E$ .

Note the several generations of quartz veins, parallel to  $S_1$ ,  $S_2$ , and  $S_3$ .  $S_3$  quartz is located in short gash-like fractures, suggesting the brittle behavior of the late  $F_3$  structure.

Note the habit of the large post-kinematic metacrysts of biotite (plates are not oriented in  $S_1$ ,  $S_2$ , or  $S_3$ ).  $S_1$  foliation is developed largely by the orientation of the white mica and lenticular quartz grains.

Walk north into open field to small outcrops of Lower Manhattan. Black, sooty appearance is typical of the Lower Manhattan. Minor dark siliceous layers are common.

Continue north across field noting scattered small outcrops of Lower Manhattan.

Near the edge of the field to north and by stone wall are outcrops of granitic gneiss of the Fordham. Foliation having the orientation

of  $S_1$  in the schist is present in the gneiss. Compositional layering is difficult to see in the gneiss at this locality, but it commonly is not parallel to  $S_1$  (i.e.,  $S_1$  is superposed on an earlier, probably Precambrian, foliation in the gneiss). There is little room here for the Inwood formation. This gneiss - Lower Manhattan contact has been mapped along the north side of Prickly Pear Hill to a point east of the lake where compositional layering in the gneiss demonstrates the anticlinal closure (see Figure 3).

Leave Brinton Bird Sanctuary.

- 13.6    0.3    Turn right onto N. Y. 9A.
- 13.8    0.2    Overpass to Oscawanna on left (roadcut N. Y. 9) outcrops of layered gneisses of Fordham Gneiss dips are north at moderate angles. Granitic gneiss of Fordham can be seen at north end of cut. Underpass for N. Y. 9. Pass exposures on right (east) of layered norite. Continue north on N. Y. 9A.
- 14.6    0.8    Turn left on Maiden Lane. Pass outcrops of Manhattan (Xmb) in woods above road.
- 15.1    0.5    STOP 2. Maiden Lane Sand Pit.

This stop is located on the opposite (north) limb of the major  $F_1$  fold from STOP 1 (Figure 3). Walk into the sand pit starting from the intersection of Maiden Lane and Cortlandt Street.

Layered biotite, plagioclase gneiss is exposed at corner. Foliation and compositional layering dip steeply to the north. Granitic gneiss of the Fordham is exposed in stream bed and on the hill to the south of the stream.

Enter sand pit east of house. The sand pit exposes a section that is a maximum of 50 feet thick, from Fordham Gneiss to the base of the Manhattan Formation.

Walking north into pit, one encounters the various rock units.

Biotite-plagioclase-quartz-gneiss (Fordham)

Lowerre quartzite (right-side-up) 15 ft.

Unit A Inwood white dolomitic marble 10-15 ft.

Unit B Inwood - impure siliceous dolostone with phyllitic layers 20 ft.

Manhattan (Oma) - calcareous, siliceous black meta-graywacke, biotite-quartz-plagioclase schist, and lustrous garnet-staurolite-muscovite, biotite quartz schist.

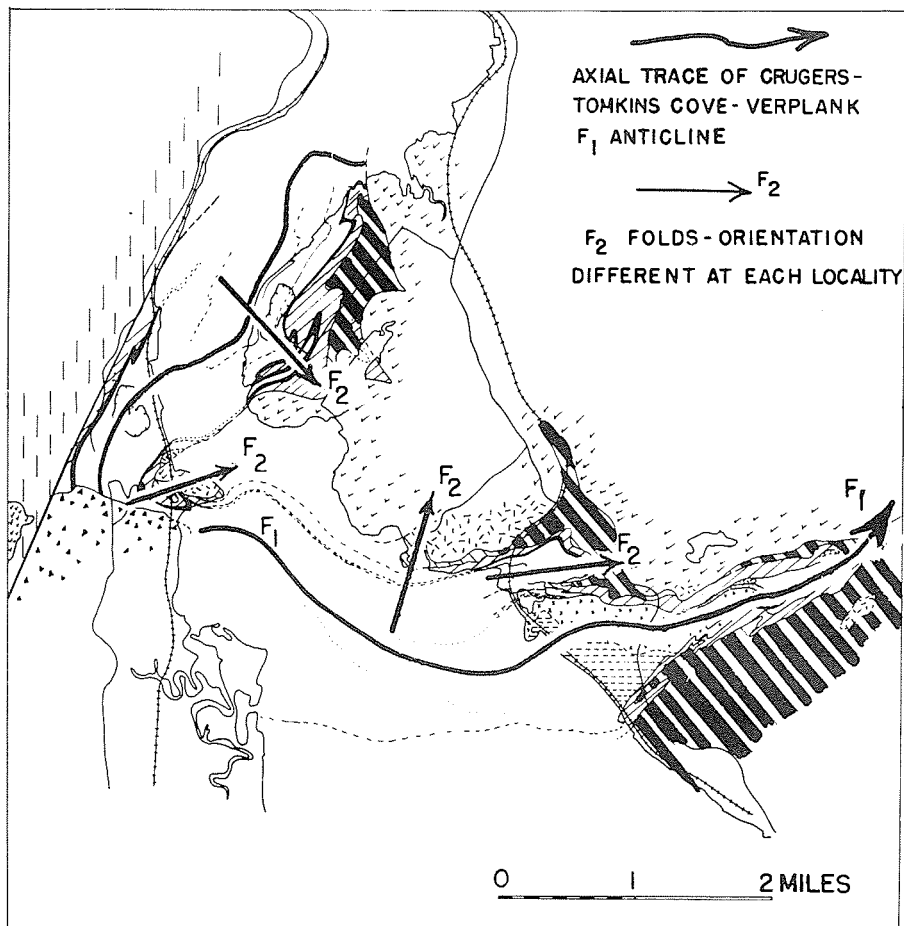


Figure 4. Generalized tectonic diagram showing axial trace of Verplanck - Tomkins Cove - Crugers anticline and orientation of late  $F_2$  folds.  $F_2$  folds vary in intensity and orientation from one locality to the next. The generalized orientation of  $F_2$  folds within subareas in which they are consistent in orientation is indicated. These late structures seem to be genetically related to the intrusion of the Cortlandt plutons. Indeed,  $F_2$  structures may have resulted from interference between separate small 'mushrooming' plutons.

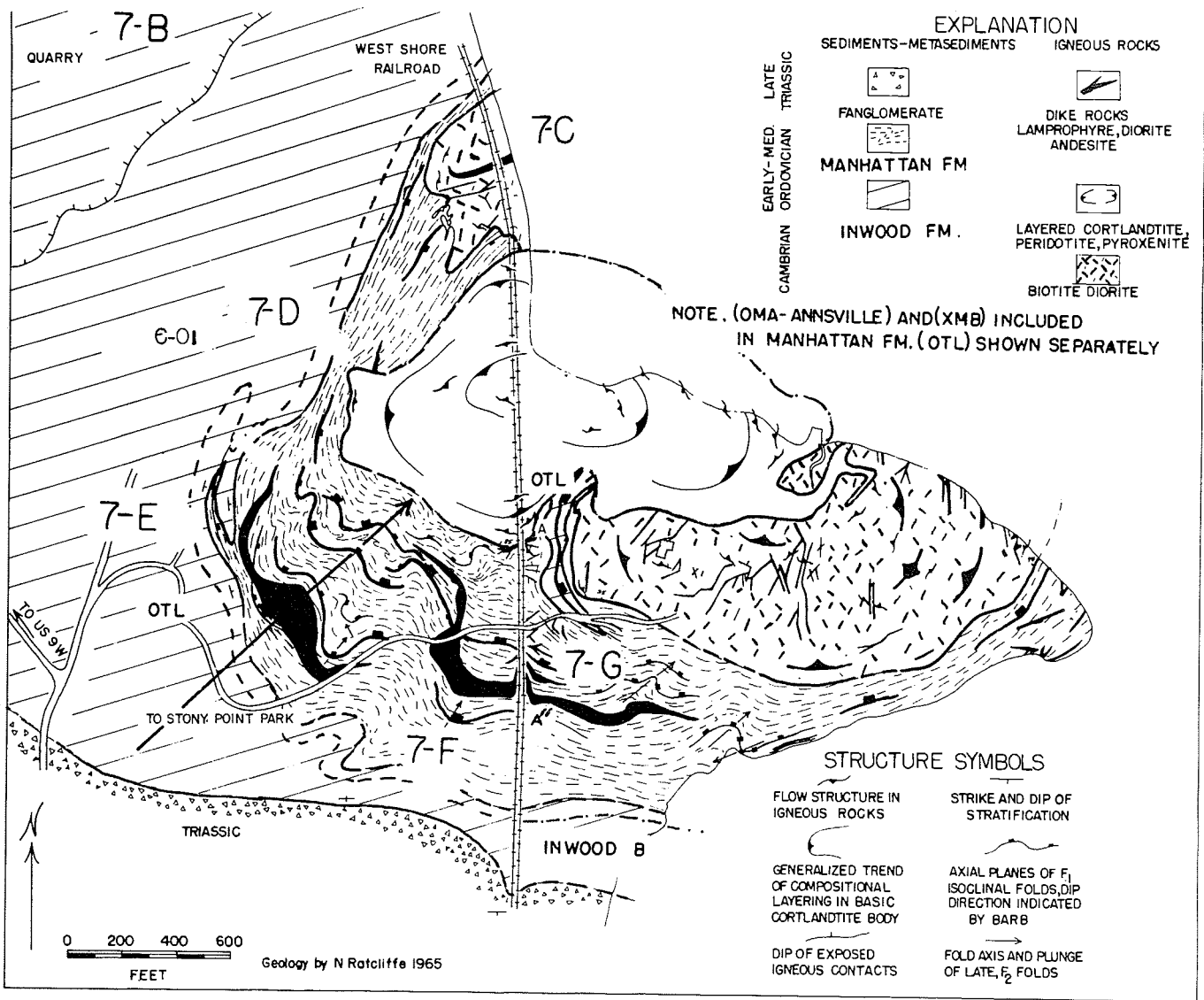


Figure 5. Geologic map of Stony Point area showing location of STOPS 7-B to 7-G. Subdivisions of Manhattan schist (Oma) and (Xmb) are present but not separately distinguished on this map. (Modified from Ratcliffe, in press.)

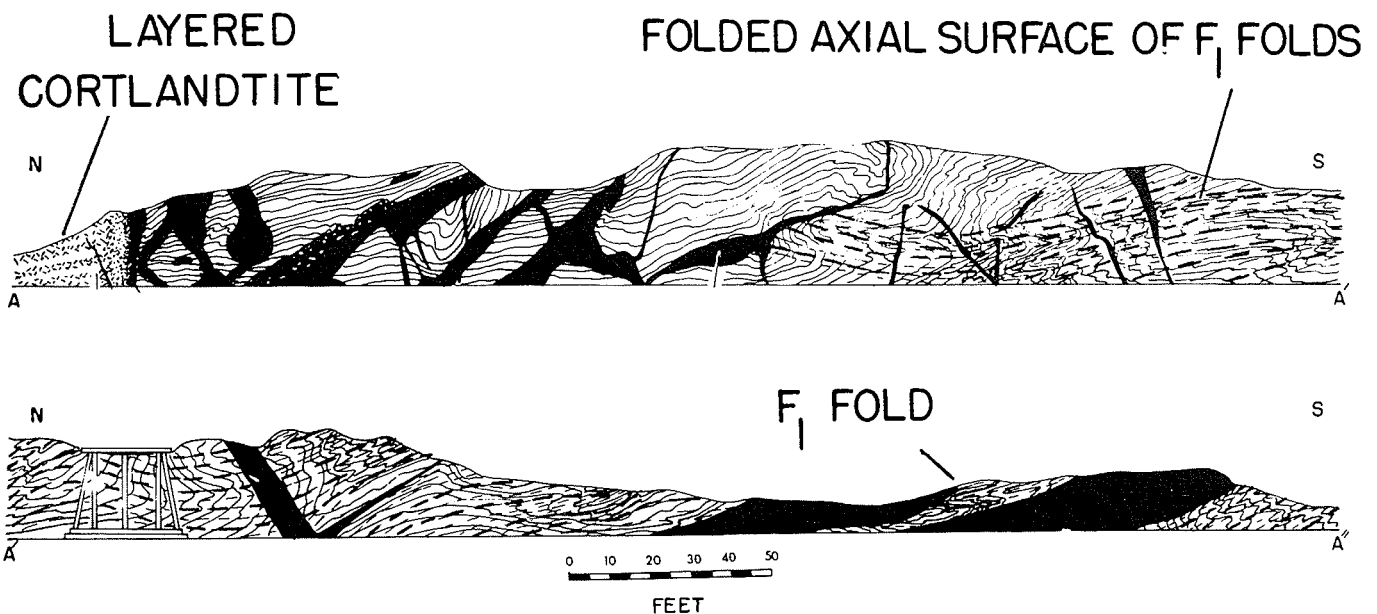


Figure 6. North-south cross-section along West Shore Railroad at Stony Point (facing east). Shows undeformed dikes of diorite and lamprophyre cross-cutting  $F_1$  and  $F_2$  folds in (Xmb). Intrusive contact of Cortlandtite pluton exposed at north end.

The lower units of Oma are characterized here by concentrations of pale green tourmaline with khaki green overgrowths. Similar zoned tourmalines are present in Oma at STOP 3 and again at Verplanck Quarry (STOP 5).

The dominant foliation  $S_1$ , sub-parallel to bedding, varies from  $N80^{\circ}-90^{\circ}E$  and dips  $70^{\circ}-80^{\circ}$  to the north.  $S_2$ , here a well developed foliation ( $N80^{\circ}E$ ,  $85^{\circ}S$ ), folds  $S_1$  producing east-plunging folds of  $S_1$  and  $S_0$ .

A locally well-developed  $S_3$  crenulation cleavage, ( $N45^{\circ}-50^{\circ}E$ ,  $90^{\circ}$ ) cuts  $S_2$  and  $S_1$  surfaces on a small exposure of Lower Manhattan above the sand pit.

Typical Upper Manhattan (Xmb) can be seen above the sand pit to the northeast. Note abundant refolded  $F_1$  folds; east plunging  $F_2$  folds dominate the structure. Staurolite-garnet-muscovite-biotite-quartz-plagioclase schists and typical garnet-muscovite-biotite-plagioclase-quartz granulites of the Upper Manhattan are exposed. Kyanite has been found with staurolite in exposures of this unit 300 feet east of this outcrop.

Leave Stop 2 - Maiden Lane. Turn north on Cortlandt Street.

- |      |     |   |
|------|-----|---|
| 15.2 | 0.1 | Exposures of Unit C of the Inwood formation at top of hill.   |
| 15.4 | 0.2 | Continue north on Crugers Station Road.                       |
| 15.7 | 0.3 | Bus stops at overpass - unload, walk over railroad to STOP 3. |

### STOP 3. Crugers.

The purpose of this stop is to visit excellent exposures of B type Inwood and to see the Manhattan - Inwood contact.

Begin by walking down to Hudson River behind houses to sandy dolostones of Unit B. Compound folding is common here. Thin orange-weathered quartzites are common in the dolostone. Rocks similar to this will be seen at Stony Point on STOP 7. Dolostones of Unit B are best exposed in the railroad cut.

Walk north to the FDR Hospital grounds and northwest along Hudson River to small point.

Here is an excellent exposure of the Inwood formation and Lower Manhattan (Oma) contact. Note the lithic characteristics diagnostic of Lower Manhattan seen on STOPS 1 and 2. A thin 2 to 3 inch coarsely crystalline calcareous marble occurs at the contact with the schist. Beneath this a zone of interlayered gray and white, crystalline, calcitic dolostone and calcite marble is exposed before massive, beige-weathered dolostones at the waters edge. Thin orange quartzites in



the beige-weathered dolostones suggest this is Unit B. A thick section (200-300 ft.) of Unit C mapped to the east is not present here.

Walk east along contact. Note minor transverse faults and tectonic breccias filling fault planes (late state effects of Cortlandt intrusions, perhaps). Isoclinal  $F_1$  folds are common along the contact zone to the east.

Walk up section to foot path. Note here black and white striped calcitic schists of Manhattan Unit A. This is a very distinctive lithology seen in many places just above the base of Unit A. An excellent exposure of this can be seen at the north end of a roadcut on new Route 9 at Prickly Pear Hill (NE 1/9 Haverstraw Quad.). Common mineral assemblages and texture in Oma at this locality are lepidoblastic muscovite and biotite (parallel to  $S_1$ )-quartz-plagioclase-calcite-garnet.

Upper Manhattan is exposed above on a hill. Note change in color of the rock and in bedding characteristics. Lepidoblastic biotite and muscovite are common along with garnet, quartz, and plagioclase. Staurolite is present in some layers.

Return to bus.

Continue on Crugers Station Road to east.

Intersection Crugers Station Road and Rt. 9A.

- |      |     |   |
|------|-----|---|
| 16.2 | 0.5 | Turn left (north).  |
| 16.7 | 0.5 | Turn left on Dutch Road entrance to George's Island State Park. |
| 17.8 | 1.1 | <u>STOP 4. George's Point.</u>                                  |

Excellent exposures of Upper Manhattan (Omb) granulites and schists.  $F_1$  folds are well exposed and dip steeply to the northeast and are mildly folded by late northeast plunging  $F_2$  folds.

This point is located between a large dioritic mass to the east and a pyroxenitic-noritic mass to the northwest (Montrose Point). The late  $F_2$  folds may be a result of shouldering aside of the country rocks by one or both plutons. These schists belonging to the Upper Manhattan will be seen at Verplanck on STOP 5 and again at Stony Point on STOP 7.

Garnet-biotite-muscovite-plagioclase-quartz is the common mineral association. No staurolite has been found here. Return to N. Y. 9A on Dutch Road.

- |      |     |                  |
|------|-----|------------------|
| 18.9 | 1.1 | Turn left on 9A. |
|------|-----|------------------|

- 20.9    2.0    Intersection 9A - Bleakley Street. Turn left at light (exposures of norite).
- 21.3    0.4    Follow Bleakley Street to light at intersection with Broadway. Turn left.
- 22.0    0.7    Turn right into Verplanck Quarry on unmarked dirt road opposite cemetery.
- 22.3    0.3    STOP 5. Verplanck Point Quarry (for location see Figure 1).

The contact between Unit A of the Manhattan Formation (compare with STOPS 1, 2, and 3) and the Inwood Formation is exposed in the east wall of the quarry.

Climb over the wall carefully, a few at a time. Pelmatozoan fragments are abundant in a blue-gray crystalline limestone at the base of the Manhattan. Abundant isoclinal ( $F_1$ ) folding repeats this zone several times. One excellent stem plate is preserved in the crest of a small  $S_1$  isocline beneath the overhang. NO HAMMERING PLEASE!  $F_1$  axial planes strike  $N35^\circ-40^\circ E$  and dip  $50^\circ-60^\circ SE$ .  $F_1$  plunges are moderately steep to the southwest.  $F_2$  crenulation cleavage is incipient and weakly folds the  $F_1$  axial planes. Axes of  $F_2$  plunge  $S25^\circ-30^\circ E$  at  $45^\circ-50^\circ$ .

The intensity of  $F_2$  folds increases toward the complex.

Note the distinctly phyllitic texture of the rock. Biotite-muscovite-quartz-calcite-plagioclase-garnet is the common assemblage. Biotite usually predominates over muscovite. Both are perfectly oriented in  $S_1$  and folded by  $S_2$ . An interesting bed two feet from the marble contains abundant red-brown biotite, garnet, and minor amounts of staurolite. Very distinctive green tourmaline with khaki overgrowths is an accessory mineral in most specimens of Oma here.

Walk north along rim. Excellently exposed  $F_1$  folds are shown by limy interbeds in the Lower Manhattan.

The north face of the quarry exposes white dolostone closest to the schist, assigned tentatively to Unit C of the Inwood Formation. The main layered dolostone in the quarry is characterized by dark dolostones with black phyllitic partings and thin quartzite stringers. Weathered surfaces are cream or beige. These rocks are assigned to Unit B of the Inwood Formation.

If time allows, we will walk west to the Hudson River down cliffs of sandy dolostones of Unit B to white crystalline dolostones exposed at the river's edge that probably belong to Unit A of the Inwood Formation.

A change from the staurolite-almandine subfacies of the almandine-amphibolite facies (at Verplanck quarry) to the quartz-albite-epidote-biotite subfacies of the greenschist facies (Tomkins Cove) takes place over a distance of 1.5 miles. This is a rather steep metamorphic gradient in regionally metamorphosed areas. For example, from biotite to staurolite isograds in Dutchess Co. is three miles (Balk, 1936).

Staurolite generally is ascribed to regional metamorphism because of the relatively high pressures thought to be necessary for its formation (Winkler, 1965). However, staurolite has been reported from the aureole of a shallow level granitic pluton (Rastall, 1910). Moreover, Winkler (1965, p. 109) believes staurolite with almandine might be expected in restricted areas bordering deep level plutons.

Metacrysts of staurolite and almandine in the Lower Manhattan Formation at Verplanck Point Quarry have textures indicative of post  $F_1$  crystallization and may have formed synchronous with or later than the  $F_2$  fold system. These observations are consistent with an hypothesis attributing the garnet and staurolite to contact effects induced by intrusion of the Cortlandt intrusives. Contact metamorphism under high confining pressure might be the cause of the steep metamorphic gradient seen here.

#### LUNCH STOP

22.6 0.3 Return to Broadway. Turn right (southwest).

22.9 0.3 Turn left onto 13th Street.

23.1 0.2 STOP 6 (end of road). (Beware of dogs.)

Small outcrop of Upper Manhattan (Omb) - typical granulites very similar to George's Point (STOP 4). Note folded  $F_1$  folds and strong development of  $F_2$  structures. Fracture fillings in  $S_2$  probably are related to increased grade of contact metamorphism as Cortlandt intrusives are approached. Compare intensity of  $F_2$  structures with STOP 5, and note the similar orientation.

23.3 0.2 Turn right (north) on Broadway.

24.3 1.0 Turn right on Bleakley Avenue.

24.7 0.4 Turn left on N. Y. 9A.

24.9 0.2 Head north on N. Y. 9.

27.0 2.1 Turn left on N. Y. 6-202

- 27.3 0.3 Traffic circle. Continue north on 6-202.
- 31.3 4.0 Bear Mt. Bridge.
- 31.5 0.2 Head south on 9W (270° around traffic circle).
- 37.8 6.3 Entrance to Tomkins Cove Quarry.
- 38.0 0.2 STOP 7. Tomkins Cove - Stony Point (see Figure 4 for location).

A. Railroad cut by Orange and Rockland plant north of quarry. Exposed on west wall is interbedded Lower Manhattan (Oma) and "crinoidal" limestone unit seen at STOP 5. Isoclinal  $F_1$  folding is common. Note refolded  $F_1$  fold and steep plunges of  $F_1$  folds.

B. Walk into main quarry. The contact of the "crinoidal" limestone unit with underlying (stratigraphically) white dolostones is exposed on the west slope of the quarry. Adventurous ones may climb up to see a truncation of  $S_0$  in the dolostone by the limestone. Is this sedimentary, or tectonic and the result of flowage? Be very careful of those following you; do not dislodge loose blocks.

From the quarry walk east to the railroad tracks and walk south toward Stony Point. Exposures of sandy dolostones, perhaps Unit B of the Inwood Formation (tops east?).

C. First outcrops are biotite diorite of the Cortlandt Complex. Climb up hill to exposure of contact with Lower Manhattan. Note discordant contact and nonfoliated igneous rock and apophyses.

D. Walk south along ridge toward Cortlandtite pluton to contact with Oma. Note brecciated rock close to Cortlandtite. Fragments of foliated biotite schist float now in a matrix of K-feldspar-sillimanite-garnet and quartz. This sillimanite zone is very thin, perhaps 10 feet thick. Closest to schist is a green hornblende-rich contact phase developed around the pluton at the contact with either diorite or schist.

E. Walk down to road to west. Follow road south. Note small outcrops of limestone. Exposures of calcitic marble and Lower Manhattan (Unit B) on slopes above pond. This is metamorphosed equivalent of the crinoidal zone exposed on the west flank of the anticline. The very distinctive Oma here is a biotite-muscovite-quartz-plagioclase phyllite.

F. Continue to the south to road. Cross swamp to base of ridge to south. Exposures of carbonate rock on hillside. Probably Unit B of the Inwood Formation. Note the position south of the intrusives and its relation to STOP 3 at Crugers. The carbonate rocks close around the south side of the Cortlandt rock at Stony Point.

Walk east along carbonate outcrop to railroad tracks. Then head north along railroad toward intrusives.

G. Railroad cut in Upper Manhattan (Unit B). Shown here are dikes cross-cutting F<sub>1</sub> and F<sub>2</sub> folds. The contact with Cortlandtite pluton is exposed at the north end. Follow cross-section, Figure 6, for location on east wall. If a train comes, you will be warned. Please move promptly to the west side of the cut where there is plenty of room. Don't panic!

Continue north to see near vertical contact of the Cortlandtite with the schist. Note contact zone with minor drags, indicating north-up rotation sense. The hornblendite zone seen at STOP 7-D passes into typical north-dipping layered Cortlandtite 20 feet from the contact. Immediately above to the east on the slopes (see light colored soil zone) are exposures of calc-silicates of the basal Manhattan, exposed in an F<sub>1</sub> isoclinal fold that is truncated by the Cortlandtite pluton. F<sub>2</sub> folds are E-W perpendicular to Cortlandtite contact. The type locality of Cortlandtite (Williams, 1886) is located on the north shore of Stony Point near the swimming pier.

In the time remaining feel free to wander into the Park where there are excellent exposures of the biotite diorite with late cross-cutting lamprophyres and still later aplitic dikes. Flow structure and xenoliths can be seen in the biotite diorite. No hammering on exposed surfaces in the Park, please.

Meet bus at Stony Point Park.

Bus will return to Sheraton-Tenney via N. Y. 9W, Tappan Zee Bridge and will make a brief stop at Howard Johnson's (Assembly Point) to discharge members who wish to meet rides home. Bus will then continue to hotel.

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TRIP I: DEEP-WELL INJECTION OF TREATED WASTE WATER--AN EXPERIMENT  
IN RE-USE OF GROUND-WATER IN WESTERN LONG ISLAND, N. Y.

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Work done in cooperation with the Nassau County Department of Public Works

### INTRODUCTION

The thick unconsolidated deposits beneath Long Island, which contain many thousands of billions of gallons of fresh water, constitute one of the most productive ground-water reservoirs in the world. The average daily withdrawal from the reservoir in 1966 was about 440 million gallons. About 70 percent of the total pumpage was for public-supply commercial, and industrial use in the three western counties of Long Island--Kings, Queens, and Nassau Counties (Figure 1).

The fresh ground water is bordered by and is hydraulically connected with salty ground water which in turn is hydraulically connected with bodies of salty surface water in estuaries, bays, Long Island Sound, and the Atlantic Ocean. The salty ground water is a near-term local threat to the continued withdrawal of fresh ground water because of its proximity to and movement toward some existing public-supply well fields. It poses a long-term regional threat also, because of its slow migration inland and replacement of fresh ground water in substantial portions of the ground-water reservoir.

The salty ground water of chief significance is a locally encroaching body in the Jameco and Magothy aquifers in southwestern Long Island (Figure 1), and is referred to in this paper as the main salt-water wedge. The Magothy aquifer is the source of most of the ground water used for public-supply purposes on Long Island and, in all likelihood, will be the principal source for many years to come.

The immediate objective of the artificial-recharge experiments now in progress at Bay Park (Figure 1) in southwestern Nassau County is to obtain information on the hydraulic and geochemical problems involved in injecting treated sewage effluent into the Magothy aquifer through a deep injection well. The results of the present experiments may be used, along with additional geologic and hydrologic data, to evaluate the feasibility of injecting water into the Magothy aquifer to create and maintain a hydraulic pressure barrier in Southern Nassau County to stabilize the main salt-water wedge or possibly retard its movement inland.

A summary of the hydrogeologic environment of western Long Island and the characteristics of the main salt-water wedge are given below as background for understanding the design and operation of the injection study and its possible relation to the problem of regional salt-water encroachment.



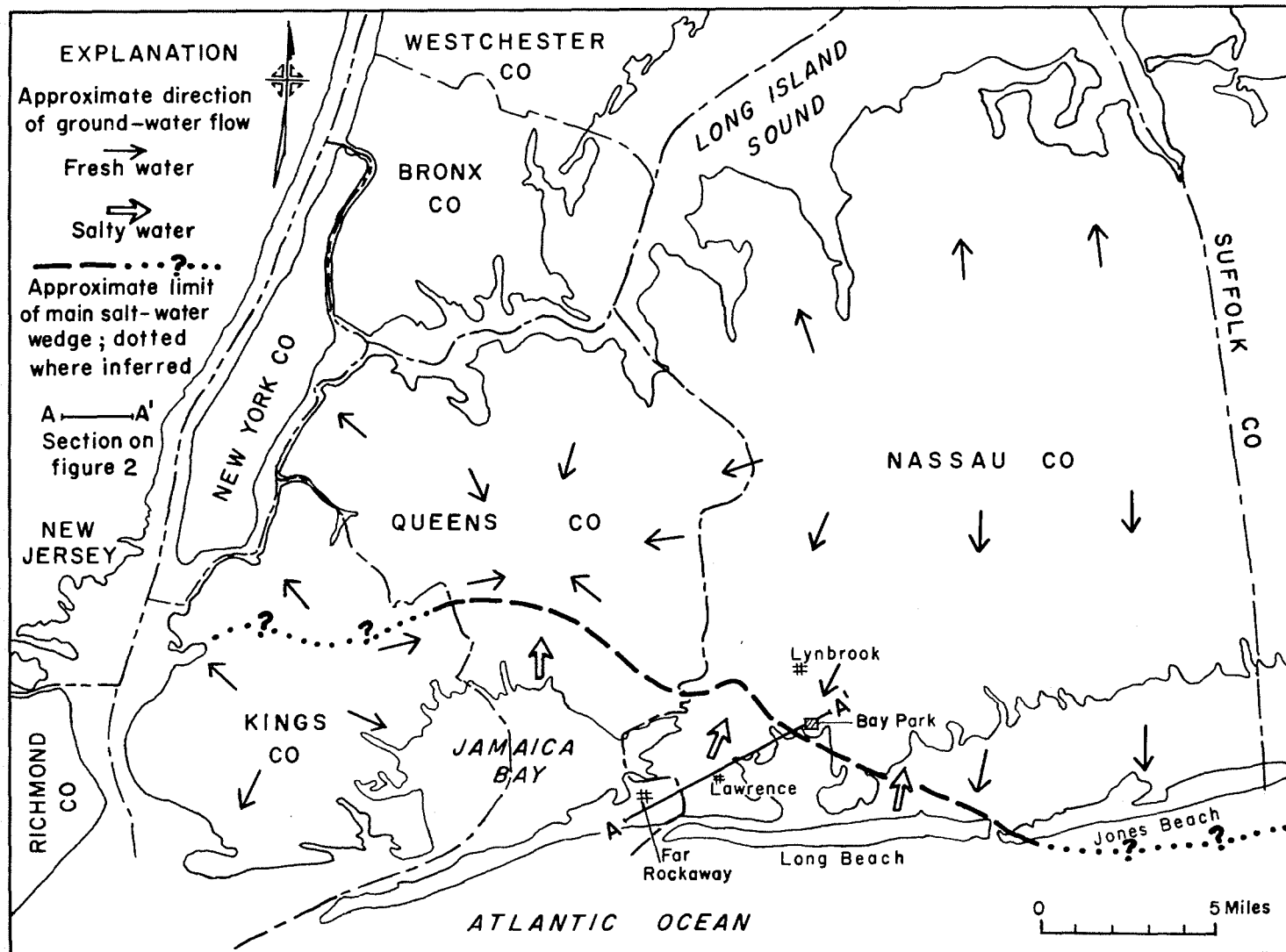


Figure 1. Approximate extent of salt-water encroachment in the Jameco and Magothy aquifers and the general direction of ground-water flow in western Long Island, N. Y.

## HYDROGEOLOGIC FEATURES

The ground-water reservoir of Long Island is composed of unconsolidated deposits of gravel, sand, silt, and clay of Late Cretaceous, Pleistocene, and Recent age. These deposits, which constitute a thick wedge resting on a southeasterly sloping surface of crystalline basement rock of Precambrian(?) age, range in thickness from less than a foot in northwestern Queens County to about 1700 feet in southeastern Nassau County.

The geologic units in the area have been divided into the following major hydrologic units (see Figure 2, for sequence and lithology): (a) the upper glacial aquifer (Pleistocene and Recent), (b) the Jameco aquifer (Pleistocene), (c) the Magothy aquifer (Late Cretaceous), and (d) the Lloyd aquifer (Late Cretaceous). The Gardiners Clay (Pleistocene), a major confining unit, separates the upper two aquifers in much of Kings and Queens Counties and in southern Nassau County. The Raritan clay (Late Cretaceous), another major confining unit, generally separates the lower two aquifers. The "20-foot clay", a local discontinuous confining unit in the upper glacial aquifer, is found mostly in southern Nassau County. The upper surface of the relatively impermeable bedrock forms the bottom of the ground-water reservoir.

In some parts of western Long Island, particularly in Kings and Queens Counties, deep channels were eroded partly or completely through the confining clays and the aquifers. The channels were back-filled with more permeable material and now constitute conduits for inland and vertical movement of salty ground water.

Fresh ground water in Long Island is derived entirely from local precipitation. About half of the total precipitation is lost--mostly by evapotranspiration but partly by overland runoff. The remainder percolates down to the water table, which generally is in the upper glacial aquifer. The water table is about 90 feet above sea level in east-central Nassau County; its lowest point is about 10 feet below sea level in central Queens County as a result of intensive pumping. The highest point on the water table in Kings County is about 7 feet above sea level.

The Jameco, Magothy, and Lloyd aquifers, which are confined by overlying or interbedded silts and clays (Figure 2), contain water under artesian pressure. The first two aquifers are recharged mostly by downward leakage from the upper glacial aquifer, and the Lloyd aquifer is recharged mainly by downward leakage from the Jameco and Magothy aquifers.

The regional pattern of movement of fresh water in the upper part of the ground-water reservoir is shown by the flow arrows in Figure 1. Ground water generally moves radially outward from interior areas of recharge, and discharges naturally at or near the shorelines by seepage into streams or as submarine outflow to adjacent bodies of salty surface water. A major distortion in the natural flow pattern occurs in central Queens County, however, where heavy pumping has created large cones of depression in the water table and in the piezometric surfaces of the deeper aquifers (J. Soren, U. S. Geological Survey, written communication). These depressions cause the ground water to flow radially inland toward the centers of pumping.

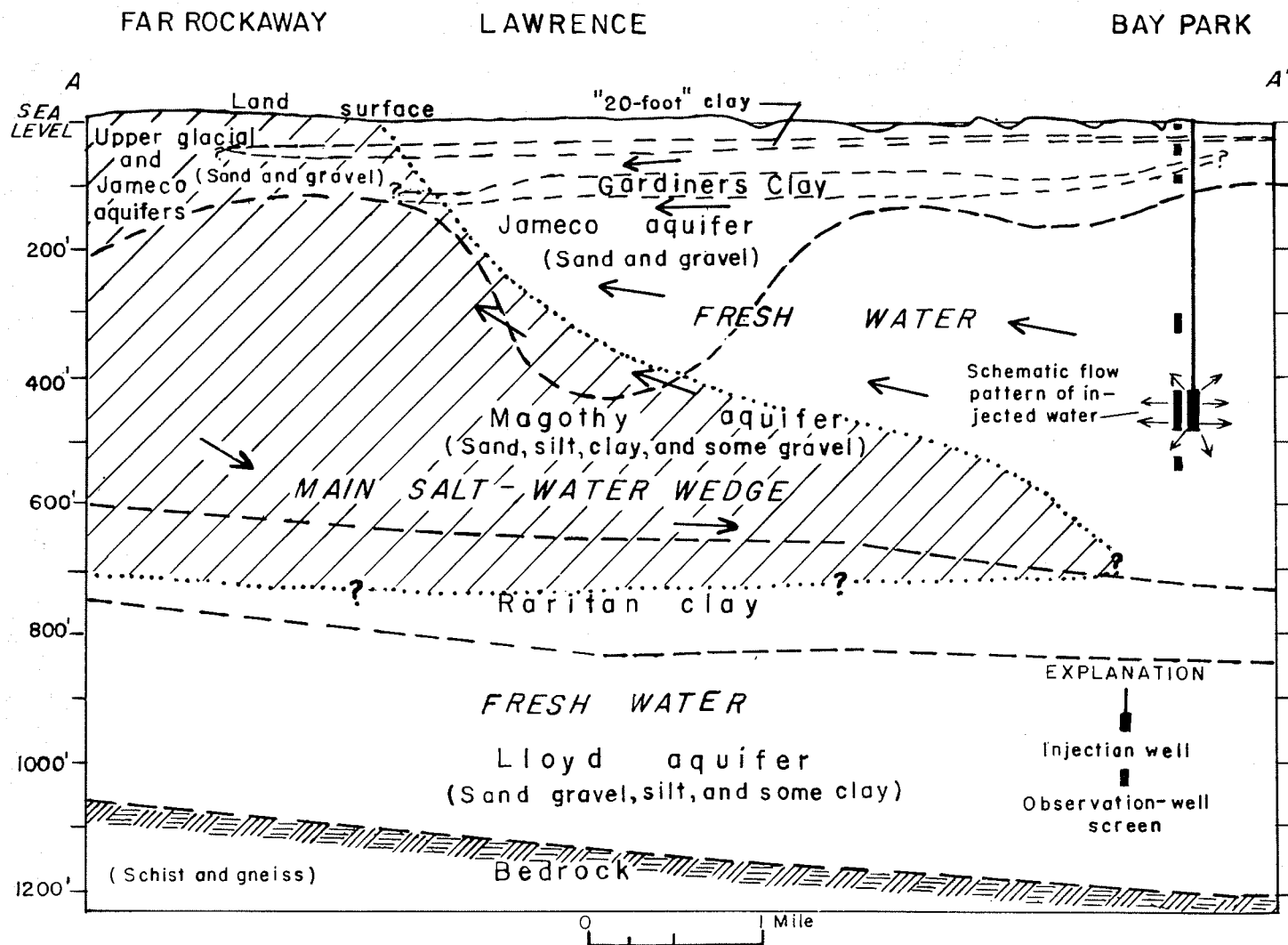


Figure 2. Hydrogeologic section showing the positions of the injection well at Bay Park and the main salt-water wedge. Arrows show component of flow in the plane of section. (Adapted in part from Lusczynski and Swarczewski, 1966, pl. 3A).

Another factor that has caused a regional lowering of the water table and artesian heads in Queens County and in southwestern Nassau County is the discharge of about 100 to 150 million gallons per day of used ground water to the sea through sewer systems (N. Y. State Water Resources Commission, 1966, written communication). This loss of natural fresh-water outflow has been a causative factor in the slow inland movement of the salty ground water described in the next section.

Water levels in wells tapping the upper glacial aquifer of eastern Nassau County, where most of the used water is returned to the ground-water reservoir by means of cesspools and seepage fields, generally have remained several feet higher than corresponding levels in the western area (Franke, 1968). It is likely, however, that the change in waste-water disposal planned for eastern Nassau County, from the use of cesspools to communal sewers, will cause some additional declines of water levels in the future, and consequently may accelerate salt-water encroachment in that area unless counter measures are taken.

#### DESCRIPTION OF THE MAIN SALT-WATER WEDGE

The experimental recharge site at Bay Park is near the landward limit of the main salt-water wedge whose leading edge (Figure 1) trends approximately from northwestern Kings County to Jones Beach in southeastern Nassau County. East of Jones Beach the leading edge extends offshore.

Detailed investigations of the extent and the hydraulic and chemical characteristics of the main salt-water wedge in southern Nassau and southeastern Queens County were made by the U. S. Geological Survey from 1952 to 1956 (Perlmutter and Geraghty, 1963) and from 1958 to 1961 (Luszczynski and Swarzenski, 1966). The extent of the salty ground water in Kings County and western Queens County is less well defined, and was inferred from various data obtained as a result of the long-term program of studies by the Geological Survey in cooperation with the New York State Water Resources Commission.

As shown in Figure 2, the main salt-water wedge is chiefly in the Jameco and Magothy aquifers. It thins and disappears along the top of the Raritan clay at depths as great as 600 feet below sea level. The wedge thickens seaward where it merges with other tongues and wedges of salty water that collectively occupy the entire ground-water reservoir. Chloride concentrations in the main salt-water wedge increase through a zone of diffusion from about 40 milligrams per liter (mg/l) at the fresh-water interface. The zone of diffusion which is as much as 500 feet thick and several miles wide is not shown in Figure 2.

The landward encroachment of the main salt-water wedge from its natural predevelopment position near the shoreline is believed to be due mainly to the activities of man, particularly large net withdrawals of ground water from the artesian aquifers in western Long Island, which have caused substantial declines in water levels and reduction in the amount of subsurface outflow of fresh water.

Following the cessation of heavy pumping for public supplies in Kings County in 1947 (Luszczynski, 1952), the formerly depressed water levels in that county recovered slowly from elevations as much as 35 feet below sea level to elevations above sea level in most of the area. Although active salt-water

encroachment may have virtually ceased in most of Kings County, chloride data from scattered wells suggest, however, that residual salty water, containing up to several thousand milligrams per liter of chloride or more probably occupies parts of the shallow and deep aquifers in that county.

Salt-water encroachment in the Jameco and Magothy aquifers and in part of the upper glacial aquifer is occurring in southern Queens and southwestern Nassau Counties, as indicated by increases in chloride concentrations and by the decline in water levels in selected-wells. Estimates made in 1961 of the rates of movement of the main salt-water wedge (Luszczynski and Swarzenski, 1966, p. 71) are about 160 feet per year in southern Queens County, about 300 feet per year in southwestern Nassau County, and about 10 feet per year in southcentral and southeastern Nassau County. The higher figures are for small areas near the leading edge that are relatively close to centers of heavy pumping, and the lowest figure represents the rate of movement over a broad segment of the leading edge, which is influenced mainly by regional withdrawals in inland areas.

It is significant to note that the position of the main salt-water wedge in southwestern Nassau County was established largely prior to the construction of sewers in that area from 1952 to 1964. The full impact of that construction on the position and movement of the main salt-water wedge in southern Nassau County may not be evident for some time to come, but several proposals to retard landward movement are under investigation now. One of these proposals is the subsurface injection of treated waste water described in the next section.

#### INJECTION STUDIES AND INSTRUMENTATION AT BAY PARK

The experimental recharge facility completed early in 1967 at the Bay Park Sewage Treatment Plant in southwestern Nassau County (Figure 1), was constructed cooperatively by the Nassau County Department of Public Works, the U. S. Geological Survey, and the Federal Water Pollution Control Administration. A series of injection experiments are in progress at the site under the direction of U. S. Geological Survey personnel to collect and evaluate information on techniques and problems connected with injecting treated sewage effluent into the Magothy aquifer through a deep recharge well. This information ultimately will be used to help evaluate the feasibility, and possibly the design, of a proposed line of recharge wells along the south shore of Nassau County to return about 30 million gallons per day or more of treated waste water to the Magothy aquifer. It has been conjectured that such recharge may permit increased withdrawals of fresh ground water and retard the rate of salt-water encroachment in southern Nassau County by maintaining submarine outflow at or above its present rate.

The primary features of the recharge facility are: (a) A tertiary sewage-treatment plant designed by private consultants that is capable of renovating about 400 gpm of effluent from the secondary sewage-treatment plant at Bay Park so that it meets drinking-water standards of the U. S. Public Health Service (1962), and (b) an injection plant (Figure 3). The injection plant includes: (a) a 50,000-gallon storage tank, for temporary retention of the treated water; (b) a vacuum-degasification tower, in which dissolved gases can be removed from the water prior to injection; (c) a supplementary chemical-treatment unit, now being used to adjust the pH of the water and to reduce residual oxidizing agents; (d) pumping and control equipment for maintaining injection either at a constant rate or under a constant

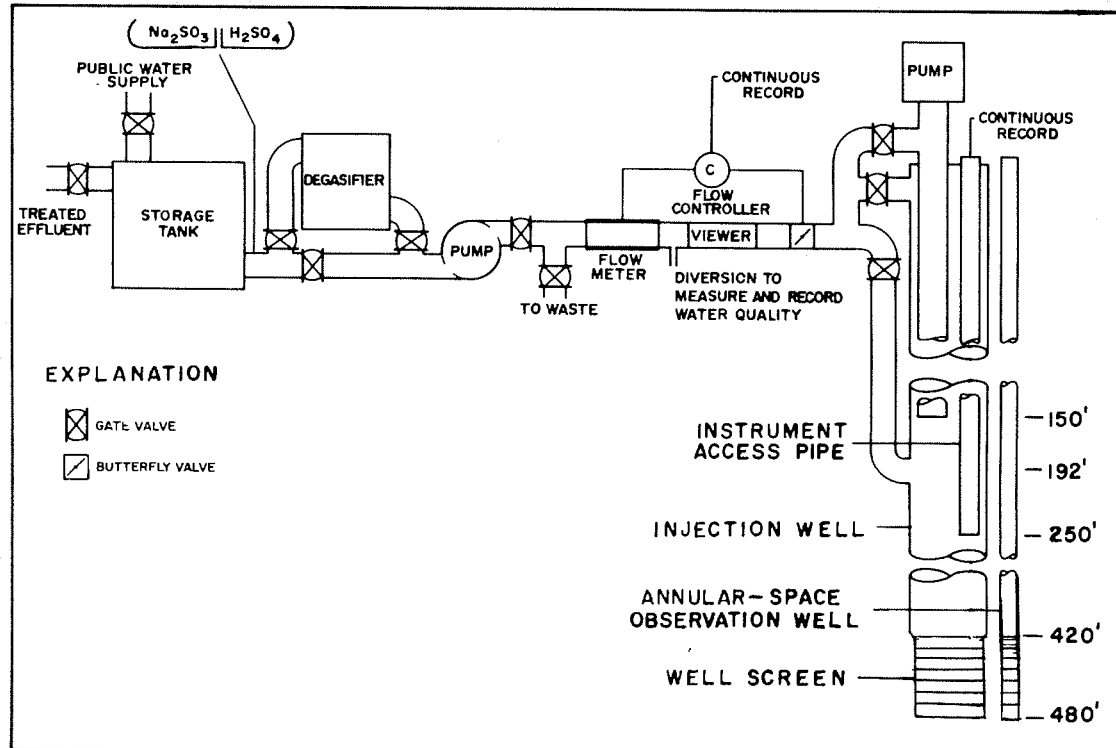


Figure 3. Schematic drawing of the injection plant at Bay Park. (Adapted from Cohen and Durfor, 1966b, fig. 4, p. 198).

pressure; (e) instrumentation for measuring and recording the injection rate, pressure and volume, and the pH, conductivity, residual chlorine content, oxidation-reduction potential, temperature, and turbidity of the injected water; (f) the main injection well; (g) an array of observation wells, at which the hydraulic and chemical effects of the recharge operation may be monitored; (h) pumping equipment for testing the main injection well and redeveloping it in the event of clogging; and (i) a small field laboratory for making partial chemical analyses of water samples.

The injection well is cased with 18-inch diameter non-corrosive fiber-glass pipe to a depth of 420 feet and a 16-inch diameter stainless-steel well screen is attached to the bottom of the casing from 420 feet to 480 feet. The well has been pumped at rates as high as 2,500 gallons per minute and has a specific capacity of about 35 gallons per minute per foot of draw-down (Cohen, and Durfor, 1966a, p. 257). Piezometer taps have been installed to permit head measurements within the injection well at land surface and at the top of the screen. The water to be injected enters the injection well under pressure and may be piped into the well either near the top, or may be routed through an injection pipe entering the main casing at a depth of 190 feet, or may be injected through the pump column and bowls of the redevelopment turbine pump (Figure 3).

An observation well has been installed in the same borehole as the injection well, and is screened in the filter pack surrounding the screen of the injection well to monitor potential clogging effects. Twelve other observation wells are installed at distances of 20 to 200 feet from the injection well at depths ranging from about 10 to 726 feet, to monitor changes in the head and quality of the water with time and distance from the injection zone. The vertical position of some of the nearby observation well screens are shown on Figure 2.

A number of injection experiments have begun starting with the injection of fresh ground water from a nearby public water-supply system at a rate of about 200-300 gallons per minute. Initially, this public-supply water was degasified and modified slightly for chemical compatibility. In later experiments, the injected water will receive progressively less treatment. Following the tests with public-supply water, a series of injection experiments will be made with the effluent from the tertiary sewage-treatment plant. Here again, the degree of treatment prior to injection will be progressively reduced in successive experiments. Throughout the experiments, the effects on the condition and performance of the injection well, and changes in the hydraulic head and in the chemical quality of the water at different depths in the Magothy aquifer will be studied. The results of these studies will be reported in appropriate technical publications at a later date.

#### GEOCHEMICAL ASPECTS OF THE INJECTION

The principal concern in regard to the geochemical aspects of the injection experiments are those that relate to potential clogging of the screen of the injection well and the adjacent aquifer materials. Such clogging would be indicated by a rise in pressure or head in the injection well for a constant rate of injection (equivalent to a decrease in the specific capacity of the well). Although clogging of other injection wells has been caused by several factors, including sediment accumulation and bacterial growth, the most likely potential causes of clogging in these experiments are: (1) the release of dissolved gases in the injected water, and (2) the formation of precipitates due to incompatibility of the native and injected waters (see Table 1 for comparative chemical

Table 1. --Anticipated quality of the native and injected water at Bay Park, 1965-67

	Dissolved material in milligrams per liter (mg/l)														
	Silica (SiO <sub>2</sub> )	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Total nitrogen as N	Total phosphate (PO <sub>4</sub> )	<sup>1/</sup> MBAS	Residue on evaporation at 180°C	pH
Composition of native water in the Magothy aquifer within 100 ft. vertically and 200 ft. horizontally of the injection well (average of 8 samples)	7.4	0.2	0.03	1.8	0.3	3.8	0.7	8	4.8	4.	0.1	0.01	<0.02	29	5.9
Composition of public-supply water at the injection plant (average of 2 samples)	8.3	.2	.03	16	.6	3.8	.4	47	6.2	4.2	.1	.07	<.02	64	8.0
Anticipated composition of sewage effluent after tertiary treatment <u>2/</u>	15	.1	.04	19	3	44	13	158	63	97	23	14	<.02	339	7.4

1/ Methylene blue-active substances which indicate the presence of detergent compounds.

2/ Preliminary data from experimental treatment unit of Nassau County Department of Public Works.



characteristics).

#### Dissolved Gases.

After the sewage effluent receives tertiary treatment including coagulation, filtration, carbon adsorption, and chlorination, residual gases such as carbon dioxide, chlorine, and oxygen may remain in the renovated water. Also, air may be picked up as a result of leaks in the system. The dissolved gases may be released from solution at bends in the piping, at valves, and at other places where the velocity increases abruptly during injection. The bubbles of the gases can partly block openings in the well screen or the pores in the filter pack around the screen and in the adjacent aquifer materials, and reduce their capacity to transmit water. The chief measure against the release of gases in the injection well is passage of the effluent through a vacuum degasifier (Figure 3).

#### Precipitated and Suspended Solids.

The second major potential cause of clogging of the injection well may be the formation of precipitates on the well screen or in the adjacent aquifer materials due to chemical reactions between the native and injected waters (Table 1).

In general, the water in the Magothy aquifer and the more mineralized renovated water (Table 1) appear to be reasonably compatible chemically. The remarkably low dissolved-solids content of the water in the Magothy aquifer is related in part to the quality of its source water, precipitation, and in part to the scarcity of soluble materials in the aquifer which consists chiefly of quartz and a small percentage of heavy minerals, muscovite, pyrite, and lignite. Feldspars and carbonates are rare to absent.

The precipitates most likely to develop during injection are compounds of iron such as hydroxides, oxides, or sulfides. Dissolved iron may be present in the formation water, in the injected water, or may be derived from the materials used in well construction. Regardless of the source of iron, changes in the pH or in the oxidation-reduction potential during the injection and mixing of the renovated and native waters may cause the iron to precipitate. The reduction in velocity as the injected water enters the aquifer from the well tends to encourage clogging by precipitates that form in and near the well, and by other suspended matter in the injected water.

Most of the wells in the Bay Park experiment were constructed with fiberglass and plastic casings and stainless-steel screens which should yield virtually no iron. Also, the aquifer and the injection waters contain only small quantities of iron in solution (Table 1). In the early experiments, however, the pH of the injected public-supply water will be reduced to that of the formation water by the addition of sulfuric acid, and any oxidizing substances which may be present such as dissolved oxygen or residual chlorine should be reduced by the addition of sodium sulfite. Thus, hopefully, iron precipitation can be prevented or subdued. In later experiments, the amount of chemical treatment will be reduced deliberately to determine the minimum chemical adjustment, required for satisfactory injection operations.

The composition of the renovated water to be injected in later experiments is not as similar to the native ground water as is the public-supply water (Table 1), but the renovated water will receive similar chemical adjustments. Another problem in regard to the composition of the renovated water could be suspended sediment. The tertiary treatment is designed, however, to sharply reduce or eliminate this sediment, as well as to bring the sanitary quality of the water (Table 1) up to drinking-water standards (U. S. Public Health Service, 1962).

#### CONCLUDING STATEMENT

It is hoped that the results of the present experiments at Bay Park will supplement the findings of similar recharge studies elsewhere in the United States, and will provide water managers with part of the data needed to formulate plans for deep-well injection not only in shoreline environment but in inland areas as well.

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GEOLOGY, GEOMORPHOLOGY, AND LATE-GLACIAL ENVIRONMENTS  
OF WESTERN LONG ISLAND, NEW YORK

OR

SUBURBAN PLEISTOCENE GEOLOGY: WHO BUILT A PARKWAY  
ON MY BOG?

By Leslie A. Sirkin, Adelphi University.

INTRODUCTION

The glacial geology and geomorphology of western Long Island were first studied in detail by Woodworth (1901) and Fuller (1914). Supplementary and more recent work has been contributed by de Laguna and Perlmutter (1949), Swarzenski (1963) and Perlmutter and Geraghty (1963), among others. The reconstruction of late-Wisconsin and postglacial environments in western Long Island is based mainly on the relationships between the glacial deposits, geomorphology, and radiocarbon dated pollen stratigraphy. The pollen stratigraphy and chronology for this region (Sirkin, 1965) show consistent similarities to the late-glacial and postglacial pollen stratigraphy and chronology of southern New England (Deevey, 1958) with notable exceptions: (1) a longer and presumably more nearly complete late-glacial record is found in the vicinity of the terminal moraine (i. e., near the southern limit of late-Wisconsin glaciation), (2) deglaciation began earlier in the terminal moraine region than to the north in New York and New England, (3) the pollen record begins with pollen spectra indicative of parktundra vegetation, rather than the high Arctic tundra suggested in southern New England (Leopold, 1956; Ogden, 1959), and (4) the pollen zones, at least through subzone B2 (pine, oak), begin earlier in western Long Island and are time transgressive into southern New England. Finally, correlation between the pollen record, glacial geology, and geomorphology provides a means of interpreting the late-glacial physical environment.

PRE-PLEISTOCENE GEOLOGY

The oldest stratigraphic units in western Long Island consist of metamorphic rock, probably of lower Paleozoic age, which crop out along the East River in Queens and are found at increasing depth below the much younger Mesozoic and Cenozoic deposits of the continental shelf-coastal plain sedimentary wedge to the east and south (Table 1). Along the northern shoreline of western Long Island and offshore in Long Island Sound, depth to the metamorphic basement varies between 50 feet and 250 feet below sea level.

Cretaceous and younger strata, including possible Tertiary marine sediments, late-glacial drift, and estuarine deposits, disconformably overlap the metamorphics. The oldest Cretaceous deposit in this region, the Lloyd Sand member of the Raritan Formation, is not found at the surface. Cretaceous variegated clays and sands of Raritan and/or Magothy age crop out in the base of bluffs along the north shore. These beds, which contain fragments or nodules of fossiliferous (mainly plant debris)

TIME UNITS: PERIOD	EPOCH	STAGE	SUBSTAGE	REVISED STRATIGRAPHIC UNITS FOR LONG ISLAND
QUATERNARY	HOLOCENE	RECENT	POSTGLACIAL	PEAT, SILT
	PLEISTOCENE	WISCONSIN	LATE-GLACIAL VALDERS TWO CREEKS PORT HURON CARY	LACUSTRINE AND MARINE SILT AND CLAY
			pre-CARY	HARBOR HILL DRIFT RONKONKOMA DRIFT  (may include the MANHASSET FORMATION HEMPSTEAD GRAVEL MONTAUK TILL HEROD GRAVEL)
			SANGAMON	JACOB SAND GARDINERS CLAY
			Pre-SANGAMON (?)	JAMECO GRAVEL unconformity MANETTO GRAVEL unconformity
CRETACEOUS	UPPER  CRETACEOUS	SANTONIAN  TO CENOMANIAN	MAGOTHY FM RARITAN FM. CLAY MB.  LLOYD SAND MB unconformity	
LOWER PALEOZOIC				CRYSTALLINE BASEMENT

TABLE 1: TENTATIVE REVISION OF THE STRATIGRAPHY OF WESTERN LONG ISLAND

siderite and red sandstone, iron oxide concretions and pipes, lignite lenses and marcasite nodules, are highly deformed and discontinuous units where they crop out. Due to glacial erosion and deformation and coastal slumping of large blocks, the exposed sections vary in the sedimentary units which they contain. In places, till rests directly on Cretaceous strata, while in other sections outwash and/or a white sand unit separate the till and the Cretaceous clays. (See Plate 2, figures 3 and 4). The regional dip of the pre-Pleistocene beds as projected from well cores is less than one degree to the southeast, but is sufficient to produce a northwest-facing cuesta.

A fine to medium grained, apparently unfossiliferous, and partially indurated white sand layer may be somewhat angularly unconformable to the underlying Cretaceous. This unit physically resembles certain upper Cretaceous and Tertiary units of the New Jersey and Massachusetts coastal plain.

### PLEISTOCENE GEOLOGY

Pleistocene deposition accounts for up to 150 feet of sediment mantling the former Cretaceous upland. Evidence of pre-Wisconsin glacial deposition in Long Island includes the Manetto Gravel, a bedded gravel containing erratic pebbles, and the Jameco Gravel, a diabase rich gravel. Both of these gravels are encountered in wells in western Long Island and at the surface in the Dix Hills area in central Long Island, and are considered to be outwash gravels (Table 1). The superposed tills and gravels in Block Island, Martha's Vineyard and Cape Cod, which have been described by Woodworth and Wigglesworth (1934) as representing two or more classical glacials, apparently have no correlative exposed in western Long Island.

A marine or lagoonal clay and sand unit, the Gardiners Clay-Jacobs Sand, mantles the gravels and has been placed in the Sangamon interglacial stage on the basis of microfossil flora, indicating a cold-warm-cold temperature sequence and consisting of diatoms and pollen (Donner, 1964), and on the basis of fauna (mollusks and foraminifera) correlating with the Cape May Formation in New Jersey (MacClintock and Richards, 1936).

In the classical study of Long Island geology by Fuller (1914), the lower Wisconsin is represented by the Manhasset Formation which comprises the Herod Gravel, Montauk Till, and Hempstead Gravel members. This sequence would reflect glacial advance and recession, if interpreted as a till bounded by outwash gravels. The Montauk Till member underlies younger drift in well-sections in western Long Island and in the sea cliffs of southeastern Long Island, a fact documented by the other workers in this area.

Another clay layer, apparently younger than the Gardiner's Clay, is the 20-Foot Clay. This deposit is found in south shore well-sections and in buried stream channels inland, but it is not found on the north shore (Perlmutter and Geraghty, 1963). This clay may be the result of a Wisconsin interstadial (Plum Point equivalent?) episode on Long Island.

The upper Wisconsin ice sheet is generally thought to have occupied its southernmost boundary in northeastern North America well before 18,000 B.P. (years before the present). Recession from this position began possibly before 17,000 B.P. as suggested by sea level curves (Fairbridge, 1961). The exact age

# FIGURE 1: LATE-PLEISTOCENE GEOLOGY

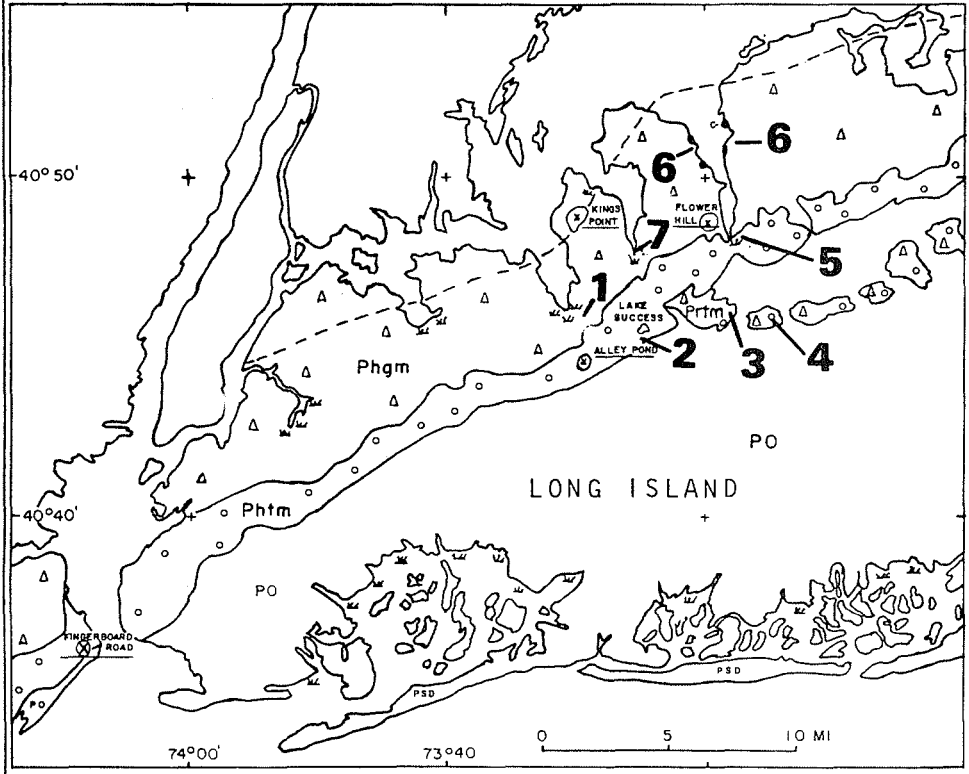
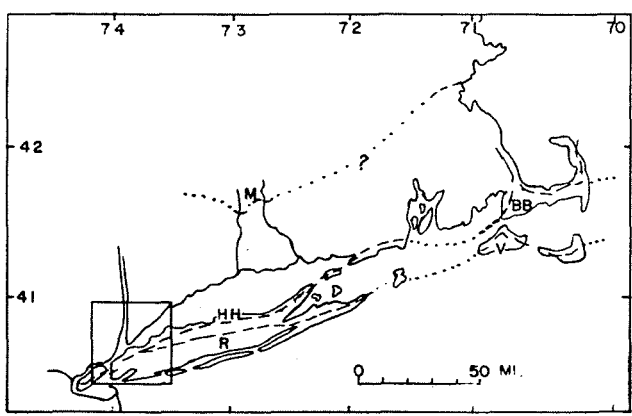
## WESTERN LONG ISLAND - EASTERN STATEN ISLAND, NEW YORK



(after Fuller, 1914; Swarzenski, 1963; Staten Island Surficial Geology Sheet, 1901)








### INSET (at left): GEOGRAPHIC CORRELATION OF MORAINES IN SOUTHERN NEW ENGLAND - NEW YORK

(after Flint, 1953, in Ogden, 1959)

M= MIDDLETOWN, HH= HARBOR HILL, BB= BUZZARDS BAY, R= RONKONKOMA, V= VINEYARD



- 
STUDY AREA ON INSET AT LEFT
  - 
BOGS STUDIED

FLOWER HILL  
ALLEY POND  
KINGS POINT  
FINGERBOARD ROAD
  - 
SHORELINE DEPOSITS  
MARSH and BEACH
  - 
UNDIFFERENTIATED OUTWASH
  - 
HARBOR HILL GROUND MORAINES  
and STRATIFIED DRIFT
  - 
HARBOR HILL TERMINAL MORAINES
  - 
RONKONKOMA TERMINAL MORAINES
  - 
PRE- PLEISTOCENE CLAY DEPOSITS
  - 
ICE STAND ON THE NECKS
- POST  
and  
LATE-  
GLACIAL

LATE-  
PLEISTOCENE

of the recession has, as yet, not been determined due to lack of success in finding, and/or determining, the age of the organic samples from the moraines or from the basal sediments of bogs lying on the moraines. The late-Wisconsin interval covers the time during which the terminal moraines and associated outwash were deposited in Long Island, and during which glacial erosion and deformation of the underlying sedimentary units occurred. The late-glacial interval encompasses the time of recession and minor fluctuations of the ice margin.

The moraines of western Long Island are the Ronkonkoma Moraine and the Harbor Hill Moraine (Figure 1). The Harbor Hill Moraine marks the terminal position of the late-Wisconsin ice sheet in western Long Island and generally is presumed to overlies the older Ronkonkoma Moraine, which according to well data (Swarzenski, 1963) trends west north-west under the Harbor Hill drift. The Ronkonkoma Moraine according to Fuller (1914) also overlies till and gravel of the Manhasset Formation.

However, inspection of new cuts in the Ronkonkoma and Harbor Hill Moraines has failed to reveal a complex situation involving more than 2 tills. It appears that the Ronkonkoma Moraine is composed of kame-like deposits which are underlain by a sandy gray-brown till (Montauk equivalent?) which grades southward into stratified drift (see Plate 1, figure 5 and Plate 2, figures 1 and 2). The stratified drift above this till varies considerably in grain size, ranging from coarse gravels to fine cross-bedded sands. There is also evidence that till of Harbor Hill age was deposited in places over the older drift so that the Ronkonkoma Moraine may be capped by this younger till. Plate 1, figure 5). The lower till, presumably the Montauk Till, may be traced northward below the outwash and has been described from north shore sand pits (Fuller, 1914) and, as previously mentioned, in north shore wells. The Harbor Hill Till (Plate 1, figure 1). is a less sandy and more oxidized till than the Montauk Till. Both contain a variety of lithologies, but the Harbor Hill Till appears to contain a wider range of sedimentary sizes - from clay to large erratics, and a more pronounced flow (or solifluction) structure.

In the Harbor Hill Moraine, the Harbor Hill Till, which varies in thickness up to 50 feet, overlies stratified drift which has been described as outwash deposited during the recession of the glacier from the Ronkonkoma terminus (Fuller, 1914). Woodworth (1901) also describes a boulder bed (which has subsequently been removed in quarrying) in the late-Pleistocene sequence in the Port Washington sand pits. This unit may have been a lag deposit formed during the same interval.

Both the Ronkonkoma and Harbor Hill Moraines, therefore, are composites of till and outwash and both attain their greatest relief over the former Cretaceous uplands. The Harbor Hill Moraine and the Ronkonkoma Moraine diverge east of Lake Success, a large kettle lake in western Long Island. The Ronkonkoma Moraine extends eastward to Montauk Point, and the Harbor Hill Moraine trends northeastward toward the north shore (Figure 1).

Recessional deposits formed during glacial recession north of the terminal moraine include late-glacial outwash sand and gravel, till or ground moraine intercalated with gray clay lenses, and delta and kame deposits. The till, which varies in thickness up to 20 feet, is exposed in the north shore sea cliff sections, railroad



SUBSTAGES AND CLIMATES		POLLEN ZONES		AGE B.P	SOUTHERN NEW ENGLAND	FLOWER HILL	ALLEY POND	KINGS POINT	
POST GLACIAL	SUBATLANTIC moist and cooler	OAK	C3b	1000	sp,pi rise	oak,ch,bi, ma	ch,bi,c-t	oak,bi,nap	
			C3a		oak,hem,ch	oak,pi,hic gr,sd,hol	oak,ch,bi, hol	bi,hem,nap, hol	
	SUBBOREAL warm,dry		C2	2000	oak, 2b hic, 1b	oak,hic,2b hem, 1b	oak,ch,hic, wil,pi, 1b	oak,bi, hem wil	
	ATLANTIC warm,moist		C1	5000	oak,hem	oak,hem,gr	oak,ch,hem	oak,ch	
	BOREAL warm,dry		B2	6000	pi,oak	pi,oak,gr	pi,bi,nap *9250±100	pi,oak,gr	
B1	pi,sp	pi,bi,c-t							
VALDERS	VALDERS cool	SPRUCE	A4	8500	sp returns	sp,pi,fir, sbi,gr	*10100±400 pi,sp,fir, gr	pi,sp,bi *11150±300	
TWO CREEKS	TWO CREEKS cool		A3		pi,sp,oak			sp,pi,bi	
PORT HURON	RECESSION cold		A2	12000	bi,sp	pi,sbi,nap	sp,pi	spi,bi,nap	
			A1		sp incr			sp,pi incr	
CARY	LATE-GLACIAL MIDDLETOWN GLACIAL	HERB	T3	13000	hi nap-pi, bi pk-tun	nap incr- gr,pi,sp	sp,spi, bi,gr	gr,pi,sp	
			T2		13500	sp pk-tun		sp,pi,bi	pi,sp, fir,bi
			T1	15000	13800	hi nap- pi tun	pi,sp,sbi, nap incr-gr	gr,wil, sbi	pi,gr, sbi
			W3		glaciated	pi,bi,sp	spi,nap, sbi	pi,sp,fir	
PRE-CARY	HARBOR HILL RECESSION	w2b	17000			hi nap, gr, bi wil,bi, gr,sd	glaciated	glaciated	
		w2a							

TABLE 2: CORRELATION OF WESTERN LONG ISLAND-EASTERN STATEN ISLAND POLLEN STRATIGRAPHY AND CHRONOLOGY WITH SOUTHERN NEW ENGLAND. (Southern New England pollen stratigraphy and chronology from Deevey, 1957. \*Radiocarbon dates in this study.)

KEY:

sp=spruce, pi=pine, spi=small pine, bi=birch, sbi,small birch, ma=maple, hol=holly, 1b-2b=beech maxima, wil=willow, hem=hemlock, ald=alder, ch=chestnut, hic=hickory, gr=grass, sd=sedge, pk=park, tun=tundra, c-t= cat-tail.

cuts, and sand borrow pits. The recessional till mantles the upland of northwestern Long Island where it overlies outwash sand and gravels. The outwash gravels also show evidence of flowage or folding, but as a competent unit, which might have occurred if this unit was frozen during deformation (Plate 2, Figure 5). Periglacial (permafrost or solifluction) features are also seen in excavations in the ground moraine of northwestern Long Island. Near the heads of the north-south valleys, kames are found, generally on the southeast side of the valley. These deposits are composed of sands and gravels with well developed ice contact features (Plate 2, Figure 6).

Other late-glacial deposits include aeolian, lacustrine, estuarine, and marine sediments formed on the surface of the drift or on pre-drift strata or in lakes and estuaries and in Long Island Sound. The postglacial interval is represented mainly by peat formed in bogs and in salt and fresh water marshes. It is from these units that the late-glacial and postglacial environments are being reconstructed.

### GEOMORPHOLOGY

Western Long Island is divided physiographically into two provinces, the "terminal moraine region" and the "outwash plain," both of which are oversimplifications. The northern half of the island is dominated by the Harbor Hill Moraine which forms the highest hills, for example, Harbor Hill in Roslyn and the major east-west divide across the island. North of the Harbor Hill Moraine, the upland is sculptured into low, semi-elliptical, partially flat-topped hills mantled by glacial drift. Major extensions of the upland northward into Long Island Sound form the so-called necks of the north shore, which are separated by steep walled partly silted-in troughs. The valleys open out northward to form bays of Long Island Sound. East-west through drainage valleys cut across the necks at their southern margins and also at about three-fourths the distance to the Sound (Figure 1). The necks are also divided into secondary north-south lobes which have drumlinoid shapes, but with oversteepened slopes overlooking Long Island Sound. Smaller drumlinoid hills, such as College Point, Fort Totten and Douglaston, as well as a small drumlin in the Manhasset valley, conform to the north-south axial trends.

The presence of the bays, which occupy the former glacial troughs, of drumlinoid hills, which are deformed Cretaceous and Wisconsin deposits marginal to the bays, and of kame deposits at the heads of the valleys, suggests that glacial erosion, deformation, and deposition were the dominant forces involved in the development of the valleys. Furthermore, the oversteepened north-facing bluffs indicate recent sapping of the cliffs and possible postglacial emergence.

The history of the troughs is more complicated. The alignment of the valleys with the bedrock valleys of southern New York and New England, the existence of aligned, buried drainage channels beneath glacial drift of Long Island, and the presence of topographic highs on the buried Cretaceous and Tertiary erosion surfaces may be evidence of well established pre-Pleistocene drainage across the coastal plain. The valleys may have been inherited from a former drainage pattern, which persisted not as antecedent streams, but as topographic lows during successive depositional episodes. Subsequent glacial activity has only accentuated the valley segments north of the moraines. The moraines have dammed-up the southeasterly flowing drainage.

## LATE - WISCONSIN EVENTS

The present surface of western Long Island may be interpreted as the result of continental glaciation during the late-Wisconsin, which deformed the existing deposits and deposited the drift. The following sequence of events is suggested, based on the glacial stratigraphy. The lower till unit of the Ronkonkoma Moraine, *viz.*, the Montauk Till, was deposited during the major glacial advance into the Long Island region, following the mid-Wisconsin interstadial, correlative in time with the Plum Point. A stationary ice front deposited the kame deposits over the till, prior to the recession of the ice front northward at least to the northern edge of Long Island. During this episode a thick sequence of outwash deposits was formed north of the Ronkonkoma terminus. Glacial meltwater was channeled eastward between the ice front and the moraine, breaching the moraine at numerous points.

Subsequently, the glacier readvanced over the post-Ronkonkoma deposits and on western Long Island over the Ronkonkoma Moraine, and deposited the Harbor Hill Till and contemporaneous outwash to the south. As suggested previously, these events occurred during pre-Cary time, possibly during the classical Tazewell substage of the Wisconsin. Radiocarbon ages obtained for pollen zones (see, Pollen Stratigraphy) in this area and in southern New York, also indicate a Tazewell age for this activity (Connally and Sirkin, 1967).

The Harbor Hill advance for which surficial trends can be examined appears to be the result of glacial lobes following the major drainage systems. The Harbor Hill Moraine on western Long Island, Staten Island and New Jersey, clearly represents the terminus of the Hudson River lobe. Further east on Long Island, the moraine may have originated in the Connecticut River lobe of the glacier. Lobate segments of the moraines in central Long Island may represent coalescence of lateral deposits of the two glacial lobes.

The events associated with the recession of the Harbor Hill ice may be incorporated within the framework of: (1) ablation of the glacier through regional downwasting, (2) recession of the glacial terminus to the northern edge of Long Island, followed by glacial stillstand and deposition of deltas in marginal lakes (Woodworth, 1901), (3) minor advance of the ice within the troughs, sculpturing the valleys and depositing kames and outwash in the valleys, and (4) final recession of the ice from Long Island, with this sequence of events possibly taking place during late Tazewell and early Cary time.

The problem of the origin of Long Island Sound, as it affects the geomorphic development of western Long Island, is made difficult by the lack of detailed study of deep cores and basement profiles in the Sound. Geologic cross sections of Long Island (Perlmutter and Geraghty, 1963) indicate a Cretaceous cuesta buried by late-glacial and postglacial estuarine deposits, underlying the present Sound. This evidence, in conjunction with the through-valley structure between southern New York and Long Island, suggests that the postulated pre-Pleistocene drainage network consisted of consequent north-south and subsequent east-west rivers, including a Long Island Sound River developing after regression of the Cretaceous sea. Pleistocene (at least late-Wisconsin) modification of this pattern occurred during glacial deposition and through the formation of marginal glacial lakes during glacial recession. The morainal barrier across the Hudson trough created proglacial lakes in New Jersey and probably in Long Island Sound (Newman, 1966). In addition, west to east meltwater drainage from the Hudson trough, running through the Sound valley, deepened the valley, and cut through the moraines to the east.

## POLLEN STRATIGRAPHY AND LATE GLACIAL ENVIRONMENTS

Evidence for interglacial or intraglacial vegetation and environments is at present lacking in western Long Island. The pollen record begins with lake sediments (i.e., clays and silts) deposited on Harbor Hill drift in conjunction with glacial recession from the Harbor Hill terminus. The late-glacial and postglacial pollen stratigraphy and chronology are summarized and correlated with that described by Deevey (1958) for southern New England (Table 2). The correlation indicates that the zonation in this study may be associated with a sequence of events that in part precedes the late-glacial record (the T zones) in southern New England. The pollen subzones of the Herb Pollen Zone (Davis, 1965) for this early interval in Long Island are designated (tentatively) by the letter W, and three subzones W2a, W2b, and W3, are recognized. The W1 subzone, which is not recognized in this study, is reserved for the interval following the deposition of the Ronkonkoma moraine.

The oldest subzone found here is W2a, represented in the Flower Hill section. The pollen assemblage of willow, large and small birch, large and small pine, grass, and sedge represents tundra-like vegetation where the characteristic plants are moss, grass, and shrubs (Table 2). Since the AP (arboreal pollen) represent over 50 per cent, a park-tundra, rather than a pure tundra vegetation is suggested. The large birch and pine pollen may indicate invasion of the outwash plain by these trees from the coastal plain to the south. The presence in the W and T subzones of deciduous-tree pollen, such as oak, chestnut, and beech, is regarded as either evidence for transport from the deciduous forests to the south of the moraine or (less likely) for redeposition of this pollen from the glacial sediments. At the time of subzone W2a, the glacier was receding from the Harbor Hill position.

The high percentages of NAP (Non-Arboreal Pollen) and large birch pollen in subzone W2b imply a continuation of the glacial environment and near-tundra vegetation of zone W2a and establishment of the vegetation indigenous to the bog. The NAP increase, mainly in grass, sedge, cat-tail, and Plumbaginaceae (cf. Armeria) and Polygoniaceae (cf. Polygonum), suggests a moist, cold climate resulting from the presence of ice on northwestern Long Island. It is significant that subzones W2a and W2b are identified in the Flower Hill section but not in the Kings Point section to the north. This sequence provides additional evidence of the northward recession of the glacial front and a stillstand just south of Kings Point in subzone W2b time. The first zone appearing in the Kings Point record is subzone W3, which correlates across the study area as a pine-spruce-fir-birch-NAP assemblage. The persistent relatively high percentage of grass pollen in this spectrum is good evidence of park or park tundra vegetation.

The glacial stand along the northern edge of Long Island was previously recognized by Woodworth (1901) as resulting in the formation of proglacial lakes and associated deposits, such as the Port Washington delta. Cutting of the east-west drainage lineation marginal to the ice on northwestern Long Island (Figure 1), also occurred at this time. It is suggested that the subzone W events occurred in pre-Cary time.

The T subzones of the Herb Pollen Zone reflect continued cold environments during glacial recession from the study area into southern New York and New England during subzone T1, based on a pollen spectrum of pine, spruce, shrub birch, and NAP, indicates a park-tundra in the study area, correlative with southern New England (Table 2).

Coupled with the glacial evidence (*i. e.*, erosion, deformation and deposition features) in the bays of northwestern Long Island, it appears that a minor readvance during the subzone W3 stillstand and prior to the subzone T1 recession sent ice tongues up the troughs, possible to the heads of the valleys. Following this last pulse western Long Island appears to have been ice-free during subzone T2 with the ice front receding into New England.

Subzone T2 represents evidently more of a parkland setting in which spruce, pine, and birch are dominant, accompanied by a decrease in the NAP. The climate in the study area is interpreted as warming, as glacial recession continued until the glacial front was north of the Middletown moraine site in central Connecticut. The pollen stratigraphy of subzone T3 is similar to that of subzone T1, including the increase in NAP, particularly grass, which at Kings Point amounts to nearly 50 per cent of the pollen. The return of a more open parkland is correlated with the presumed glacial readvance to the Middletown site in Connecticut during Cary time.

Glacial recession at the onset of the Spruce Pollen Zone (Davis, 1965) continued northward in Port Huron time. In the study area, subzone A1 of the Spruce Pollen Zone, with increasing proportions of spruce, grades upward into the pine, birch assemblage of subzone A2. The A3 and A4 subzones are not as clearly differentiated as in southern New England. In western Long Island subzone A3 grades upward into subzone A4, where the spruce increase occurs. Variations in pollen profiles are the result of the more southerly location than New England. For example, the increase in pine in subzone A4 indicates that the pine succession probably began in the Long Island area earlier than in southern New England as the ice front receded into northern Canada.

The A3 subzone in southern New England is correlated with the late-glacial Two Creeks Interstadial, which has a pine, spruce, oak pollen assemblage and a radiocarbon age of  $11,850 \pm 140$  years B.P. (Broecker and Farrand, 1963). Subzone A4 in the northeastern United States, with the rise of spruce, is correlated with the Valders glacial substage at the close of the late-glacial (Deevey, 1958). The radiocarbon ages of  $11,150 \pm 300$  years B.P. (L-738) for the A4 subzone at Kings Point, and  $10,100 \pm 400$  years B.P. (L-868D) for the A3-A4 subzone at Alley Pond fall within the range of the established ages of these zones.

The climatic amelioration that began toward the end of the Spruce Pollen Zone sequence prevailed during the Boreal substage of the postglacial. The designation of the Pine Pollen Zone or B subzone in this study is substantiated by the maximum percentage of large pine pollen and by the radiocarbon age of  $9,250 \pm 100$  years B.P. (L-868C). The warm and dry postglacial climate is reflected in the pollen record, along with later stages of bog development initiated by a lowering of the water table during drier conditions.

The rise of oak in the upper part of the Pine Pollen Zone marks the beginning of the succession of hardwood forests and the decline of the boreal vegetation. A radiocarbon date of 6,600 + 700 years B.P. (L-617) from a peat 16.5 meters below present sea level at Flushing Meadow, indicates that near the Oak Pollen Zone transition, sea level was about 16 meters below its present level. Increased atmospheric moisture and higher ground water levels resulting from the rise of sea level and closer proximity of the shore line are apparent in the Atlantic substages. The dominance of the oak-hemlock forest is characteristic of the vegetation of the C1 subzone throughout northeastern North America. Variations in the pollen record, including chestnut, and Sphagnum, are interpreted as indicating warmer and moister conditions with an increase in ground-water level and the development of standing water in the bogs. The eastern deciduous forest, which extends from southern New England through the Appalachian Mountain region, appeared in the study area during subzone C2, oak-hickory succession, typical of the Sub-Boreal climate.

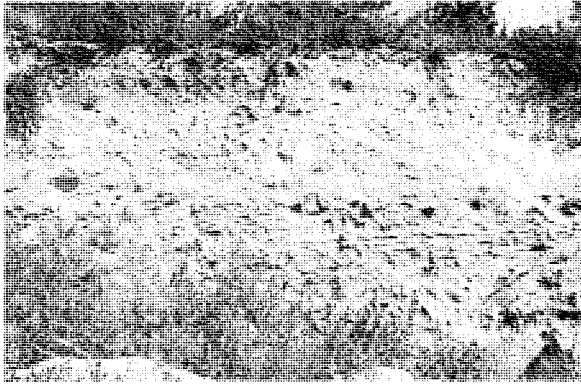
The NAP increases during subzone C3 began approximately 2000 years ago, according to a radiocarbon age of 2,025 + 250 years B.P. (1-510) for the base of C3a subzone in the Hackensack Marsh of northeastern New Jersey (Heusser, 1963). Subzone C3 is associated with the moist, cool environments of Sub-Atlantic time. The lower C3a subzone is characterized by an oak, hemlock, chestnut assemblage in southern New England. In Long Island oak declines and chestnut is not significant. The NAP rise is related to a rise in water table. The peak of holly in this subzone throughout this region and in northeastern New Jersey (Heusser, 1963) supports the inference of increased moisture.

In subzone C3b, oak again increases, but the spruce and pine increases recorded in southern New England are not seen here, although pine is present. Increase in birch and chestnut reflect the cool, moist climate, while the rise of the composites is seen as the direct result of settlement and clearing, which began about 400 years ago. The growth of peat and the invasion of the bog mats by arboreal vegetation occurred mainly during subzone C3 time.

#### SUMMARY

Correlation of the pollen stratigraphy from sedimentary sections located on or near the southern glacial margin in western Long Island, with the late-glacial drifts, aids in the reconstruction of geologic, climatic, and vegetational trends associated with glacial recession. The southern limit of this glaciation is represented by moraines presumed to be of pre-Cary age in southern New York. Glacial recession is represented by glacial drift of Cary and Port Huron age north of the glacial margin.

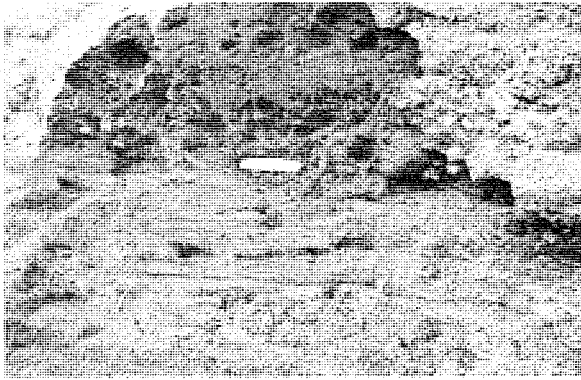
The late-glacial Herb Pollen Zone subzones (the W sequence) indicate the presence of park-tundra vegetation succeeded by tundra-like vegetation, in the vicinity of the moraine and following a recession, a minor readvance, and final recession from the terminal moraines. Tundra conditions are recorded in the T subzones in southern New England in Cary and early-Port Huron time, so that the Herb Pollen Zone appears to transgress late-glacial time. This zone is generally succeeded by the Spruce Pollen Zone, comprised of varying proportions of spruce and pine, as early as late-Cary time in the region of the terminal moraines.



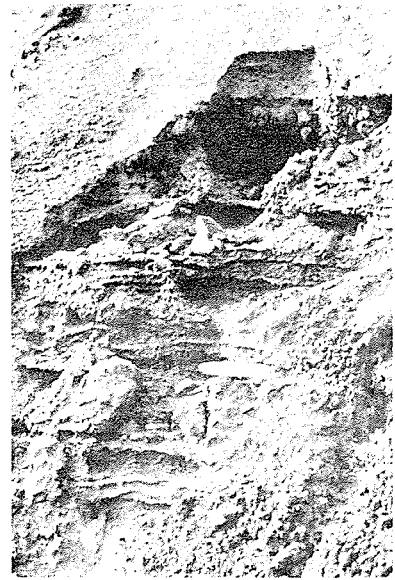
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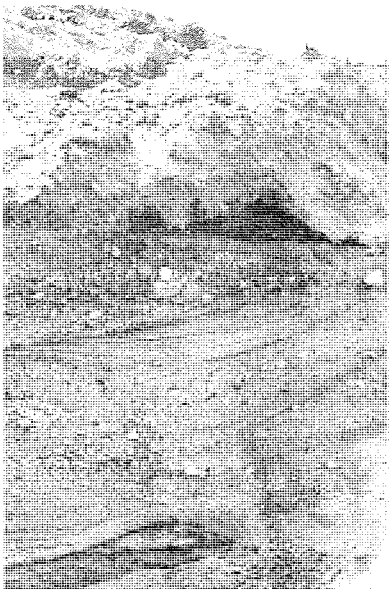
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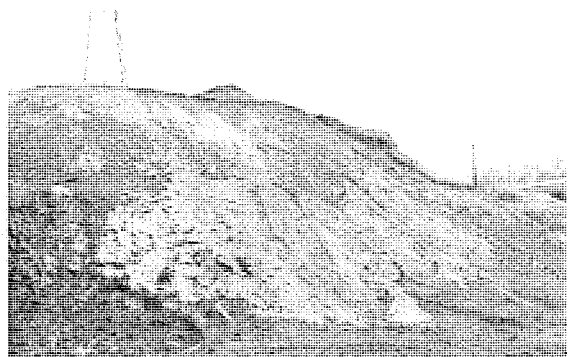
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**PLATE 1**

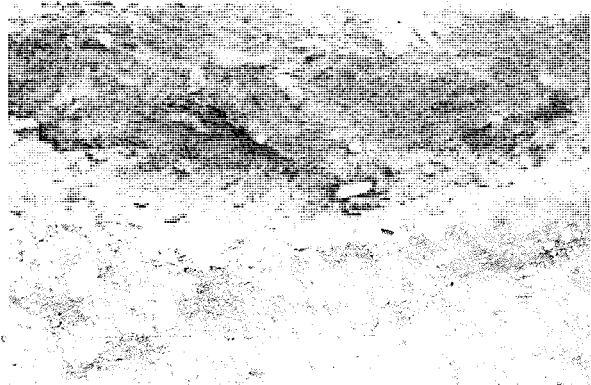
## Plate 1.

- Figure 1. Harbor Hill Till, Little Neck.
- Figure 2. Harbor Hill Till over thin bedded sand and clay, Lakeville Road - Northern State Parkway.
- Figure 3. Same. Contact of till and bedded sequence.
- Figure 4. Same. Detail, clay partings.
- Figure 5. Ronkonkoma Moraine. Till (cf. Harbor Hill) over cross bedded sand and gravel. Willis Avenue - Northern State Parkway.
- Figure 6. Harbor Hill Till over outwash; contact near break in slope, Harbor Hill, Roslyn.





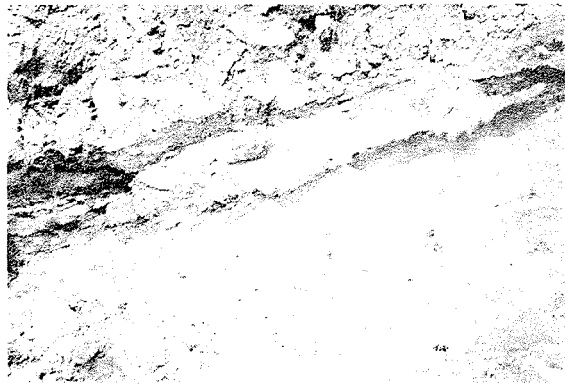
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PLATE 2

## Plate 2.

- Figure 1. Ronkonkoma Moraine. Coarse outwash over till (cf. Montauk Till). Roslyn Road - Northern State Parkway.
- Figure 2. Same. Detail of contact: outwash over till.
- Figure 3. Coastal slump blocks. Till over white sand. Garvies Point.
- Figure 4. Same. Detail of contact, till over white sand.
- Figure 5. Folded(?) outwash. Manhasset.
- Figure 6. Ice contact features. Kame, Manhasset Valley.

Dominance of spruce, pine, and birch occurs in the subzone A sequence while the ice front receded through New England. The Pine Pollen Zone or B subzone is identified by a pine maximum beginning earlier in the study area than in southern New England, according to radiocarbon ages. Variations between the Oak Pollen Zone (C subzones) in this study and those in New England result from local climatic and ecologic factors.

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### ROAD LOG

#### Mileage.

- |      |     |  |
|------|-----|--|
| 0.0  | 0.0 | Leave La Guardia vicinity. Follow 94th St. and then Junction Boulevard south to the Long Island Expressway (L.I.E.) eastbound.   |
| 2.6  | 2.6 | Follow L.I.E. eastbound: Note crossing Flushing Bay, a glacial trough which may be linked to the Bronx River valley on the Bronx side of the East River.   |
| 9.7  | 7.1 | Exit at Douglaston Parkway. Right (south) on Douglaston Parkway to Alley Pond Borrow Pit.  |
| 10.2 | 0.5 | <u>STOP 1.</u> Alley Pond Borrow Pit.<br>This exposure provides an opportunity to observe the lithology and structure of the Harbor Hill Moraine, (Plate 1, figure 1), the till (upper 5 + feet), the Little Neck Bay trough, and from the top of the cut, the New York skyline. Long axes of pebbles from the till point generally NNW. <u>Note:</u> The extension of Little Neck Bay with Eastchester Bay and the Hutchinson River in the Bronx to the north; the drumlinoid hills - Fort Totten on the west side and Douglaston on the east side of Little Neck Bay. Occasionally, the stratified drift below the till is exposed in gullies. A section is also exposed at the northeastern corner of the Korvette shopping center, below 251st St. North of the L.I.E. a small lobe projecting from the valley wall on the east side was dissected in construction. It may have been a small kame. Alley Pond bog is on top of the moraine on the west side of the valley. |
| 10.7 | 0.5 | Return to the L.I.E. via Douglaston Parkway.   |
| 13.0 | 2.3 | Follow the L.I.E. eastbound to Lakeville Road.   |
| 13.4 | 0.4 | <u>LOOK STOP.</u> Lake Success. A kettle lake about 0.4 miles across and about 75 feet deep; several small kettles are located on the west and south sides of Lake Success.  |

Follow Lakeville Road south to the Northern State Parkway. Stop on Lakeville Road just before Parkway.

- 0.3 STOP 2. Lakeville Road - Northern State Parkway. A recent cut for widening of the parkway has exposed a section of the Harbor Hill Moraine comprised of about 5 feet of Harbor Hill till overlying 20 + feet of stratified lacustrine sands with thin clay partings (Plate 1, figures 2, 3 and 4). A lake history is suggested since the results of examination for marine microfossils was negative. No other evidence for a high marine stand effecting deposition along the moraine has been found, other than the suggested wave cut cliff along the distal slope of the moraine (Woodworth, 1901). The kettle topography north and east of this site suggests that the stratified fine grained section was deposited in an ice dammed lake on the distal slope of the moraine at the junction of the outwash plain. Other large kettles developed on the pitted outwash just south of the moraine. This section is located near the junction of the Harbor Hill and Ronkonkoma moraines which may have some relationship to the stratigraphy if ice movement pivoted at this point, calving-off large ice blocks.

0.7 Return to L.I.E. eastbound.

3.3 Exit at Willis Avenue southbound (right turn). Proceed to Northern State Parkway. Stop on south side.

0.2 STOP 3. Willis Avenue - Northern State Parkway. In this cut, northeast of the intersection, a section of 4 to 8 feet of till overlies 10 + feet of cross bedded sands and gravels and very coarse cobbles. (Plate 1, figure 5) This section is in the Ronkonkoma moraine and demonstrates the superposed till (cf. the Harbor Hill Till) over outwash and the kamelike nature of the moraine.

0.2 Return to the L.I.E. eastbound service road.

0.5 Proceed to Roslyn Road.

South on Roslyn Road to Northern State Parkway. Stop on north side of parkway.

0.3 STOP 4. Roslyn Road - Northern State Parkway. Another cut into the Ronkonkoma Moraine, on the northeast side of the road, has exposed the lower till (cf. the Montauk Till). Approximately 10 to 15 feet of till are overlain by 25 to 30 feet of coarse cobbly, outwash (or Kame) deposits (Plate 2, figures 1 and 2). The till when exposed in a drainage trench appeared to grade downward and southward into sandy lenses.

Return north on Roslyn Road to Main Street, Roslyn, to old Route 25 A eastbound to Harbor Hill.

- 20.7 1.8 STOP 5. Harbor Hill, Roslyn. Harbor Hill is the type locality of the Harbor Hill Moraine and the Harbor Hill Till. The contact between the till and the outwash may be examined here (Plate 1, figure 6). The hillside just northeast of Route 25 A (on the east side of the bridge) is underlain by a kame (Swarzenski, 1963). Observe the Hempstead Harbor trough and the borrow pits along the west side of the Harbor in Port Washington. Flower Hill bog is above the borrow pits and is being cut into at this time.

Return to Main Street westbound to West Shore Drive.

- 21.0 0.3 North on West Shore Drive to the Police Rifle Range, passing on the way Bar Beach which was a mid-bay bar before construction of a town beach.

- 24.3 3.3 STOP 6. Police Rifle Range, Port Washington. A stratigraphic section, measured in detail by students of Dr. David Krinsley, Queens College (Dr. Krinsley, personal communication) include from the base: 14 feet 2 inches of poorly sorted, pebbly, medium grained sands, 40 feet 10 inches of white sands, which are often pebbly and streaked with iron and manganese oxide stain, and about 15.5 feet of alternating light and dark sands and gravels. The age of the "white sand" layer is questionable, since it is reportedly unfossiliferous (although Dr. Walter S. Newman reports one Cretaceous spore from this horizon).

Observe Mosquito Cove - Glen Cove Creek to the ENE across the Harbor. This inlet and the low break in the cliffs north of the Rifle Range constitute a portion of the east-west drainage along the glacial stillstand referred to in the text. The Cretaceous crops out at Garvies Point on Mosquito Cove and in the Morgan Park north of that site, but it is not exposed north of the borrow pit. The cliffs to the north in Sands Point are composed of 20 to 40 feet of outwash overlain by a thin layer (5+feet) ground moraine.

- (26.7) (2.4) ALTERNATE STOP 6. Garvies Point. (Described above and in text.) Six miles from Main Street, Roslyn, via Main Street - Bryant Road - Glenwood Road, East Shore Road (Sea Cliff), Prospect Avenue, Glen Avenue, Glen Cove Road and McLaughlin to Garvies Point Preserve. The Preserve, a Nassau County facility, is set aside for archaeological studies, and in addition to exposures of Cretaceous and Pleistocene deposits in the cliff sections, contains paleo-Indian shell middens and a possible Indian fishing site in the Cove. Typically, red, gray, and white clay with lignite lenses, marcasite nodules, and fossiliferous (plants) siderite nodules are exposed at the base of the cliffs. The plant fossils include woody fragments and leaves of fig and magnolia. Preliminary pollen and spore analysis of the clays indicates Raritan or possibly Magothy age. The clays are overlain by a white sand section and/or outwash and/or till (Harbor Hill ground moraine or recessional till) (Plate 2, figures 3 and 4). The attitude of the slump blocks is evident here.

Return to highway, turn left (west) on Beacon Hill Road, follow to Main Street, Port Washington, to Shore Road, south to Plandome Road, west and then south on Bayview Avenue, Manhasset, to Nassau County Department of Public Works parking lot. The route follows scenic Manhasset Bay.

- 29.9      5.6      STOP 7. Manhasset Valley Park - Nassau County Department of Public Works, Manhasset. At this stop, one, or possibly two, separate kames (or kame deltas) are found mantling the moraine consisting of thin till over outwash. The outwash is apparently folded or has flowed (Plate 2, figure 5) and is occasionally exposed in building excavations on Northern Boulevard (Route 25 A). The till is probably recessional or ground moraine of late-Harbor Hill age. The kames exhibit striking ice contact structures (Plate 2, figure 6) and indicate a late Harbor Hill glacial advance which sent tongues of ice up the troughs. This advance is supported by several lines of evidence:

- (1) the presence of kames at the valley heads.
- (2) sculpturing of peripheral deposits (i.e., the drumlinoid hills) and deformation of cliff sections (although the outwash may also have been deformed during the initial Harbor Hill advance).
- (3) Oscillation in the pollen record: The subzones W2 - W3 sequence indicating the stillstand and the return of cold indicators in subzone T1.
- (4) the stillstand evidence including the "deltas" of Woodworth (1901) and the E-W drainage lineation (Figure 1).

Tracing the deposits clockwise around the exposure, observe the kame, next (above the wall) outwash (thin till at top) and kame (fronting on 25 A behind gas station).

- 31.4      1.5      Return to L.I.E. via Community Drive. Note the drumlin (possible) south of lake on east side of road. Note cuts into the moraine while ascending the trough on the proximal slope of the Harbor Hill Moraine.
- 41.4      10.0      L.I.E. westbound to Junction Boulevard.
- 44.0      2.6      Junction Blvd. and 94th Street to La Guardia vicinity.

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NOTES

The first part of the report deals with the general principles of the theory of the structure of the atom. It is shown that the structure of the atom is determined by the laws of quantum mechanics. The second part of the report deals with the application of these principles to the structure of the atom. It is shown that the structure of the atom is determined by the laws of quantum mechanics.