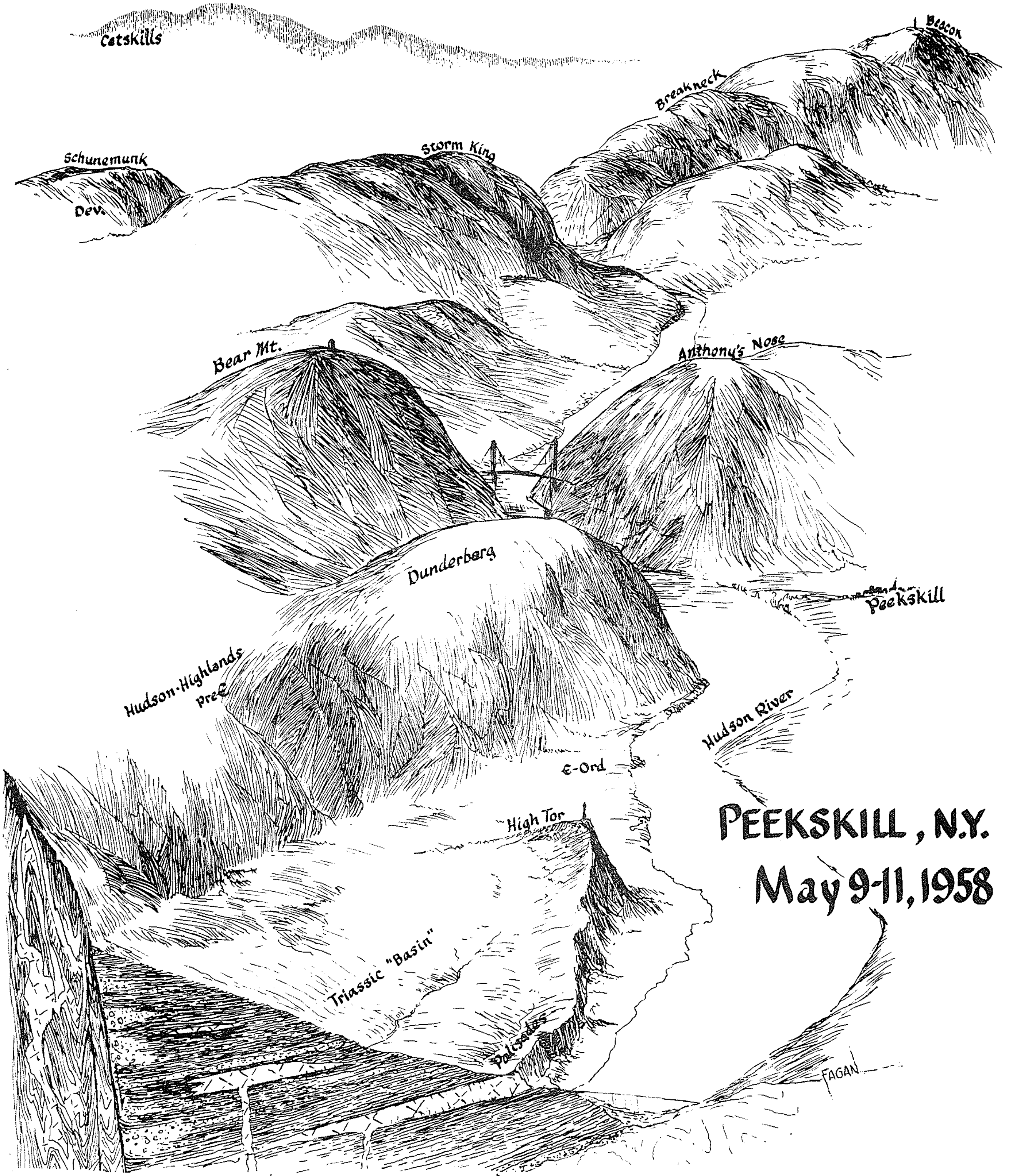
FIELD GUIDE BOOK



PEEKSKILL, N.Y.

May 9-11, 1958

NEW YORK STATE GEOLOGICAL ASSOCIATION · 30th Annual · Meeting

FIELD GUIDE BOOK

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NEW YORK STATE GEOLOGICAL ASSOCIATION

Thirtieth Annual Meeting

Peekskill, New York

May 9-11, 1958

HOST

Department of Geology
The City College
New York 31, N.Y.

Prepared

by

Authors of the Several Chapters

and

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TABLE OF CONTENTS

Acknowledgements

The COVER illustration is by John J. Fagan of Columbia University. It is intended to emphasize the ideal situation of Peekskill as a center of accessibility to a varied geological terrane.

The cooperation of the Palisades Interstate Park (Harriman Section), the New York Trap Rock Corporation, the Tidewater Oil Company and West Point Military Academy in facilitating arrangements for the field trips is gratefully acknowledged.

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Mrs. Sally R. Abrian, Secretary, Department of Chemical Engineering, The City College did the typing of the manuscript master copy.

LIST OF PLATES AND FIGURES

SCHEDULE OF EVENTS

Headquarters: Shustin's Locust Manor, Peekskill, New York
Tel.: PEeksill 7-1198 or 3452

(Location of all meeting activities including start and end of field trips)

NOTE: Trips 1, 2, 3 and 4 ($^1/_2$ day) will use private cars (filled to capacity).
Trips C and D (full day) will use buses exclusively.

Thursday, May 8

5:00 PM	Start of Registration
8:30 PM - 11:00 PM	Informal get-together

Friday, May 9

8:50 AM - 12:00 M	Trip 1-A (16 mi.) Paleozoic Inlier of the Peekskill Valley
	Trip 3-A (20 mi.) The Cortlandt Complex
12:30 PM	Lunch at Headquarters (if desired)
1:30 PM - 4:45 PM	Trip 1-B (same as Trip 1-A)
	Trip 2-B (30 mi.) The New York City Series in Westchester County
1:45 PM - 5:00 PM	Trip 3-B (same as Trip 3-A)
	Trip 4-B (30 mi.) Pleistocene Geology of Croton Point
8:30 PM - 11:00 PM	Complimentary Social Evening (Refreshments)

Saturday, May 10

8:30 AM - 5:00 PM	Trip D (Section 1) (60 mi.) Pre-Cambrian and Paleozoic Geology of the Hudson Highlands
9:00 AM - 5:30 PM	Trip D (Section 2) (same as Trip D, Section 1)
9:30 AM - 6:00 PM	Trip C (100 mi.) Northeastern Section of the Triassic (Newark) Basin in New York and New Jersey
7:00 PM - 8:00 PM	Annual Banquet
8:30 PM - 10:00 PM	Business Meeting and Discussion Period on the Geology of the Region
10:00 PM	Close of Registration

Sunday, May 11

8:45 AM - 12:00 M	Trip 1-E (same as Trip 1-A)
	Trip 2-E (same as Trip 2-B)
9:00 AM - 12:15 PM	Trip 3-E (same as Trip 3-A)
	Trip 4-E (same as Trip 4-B)

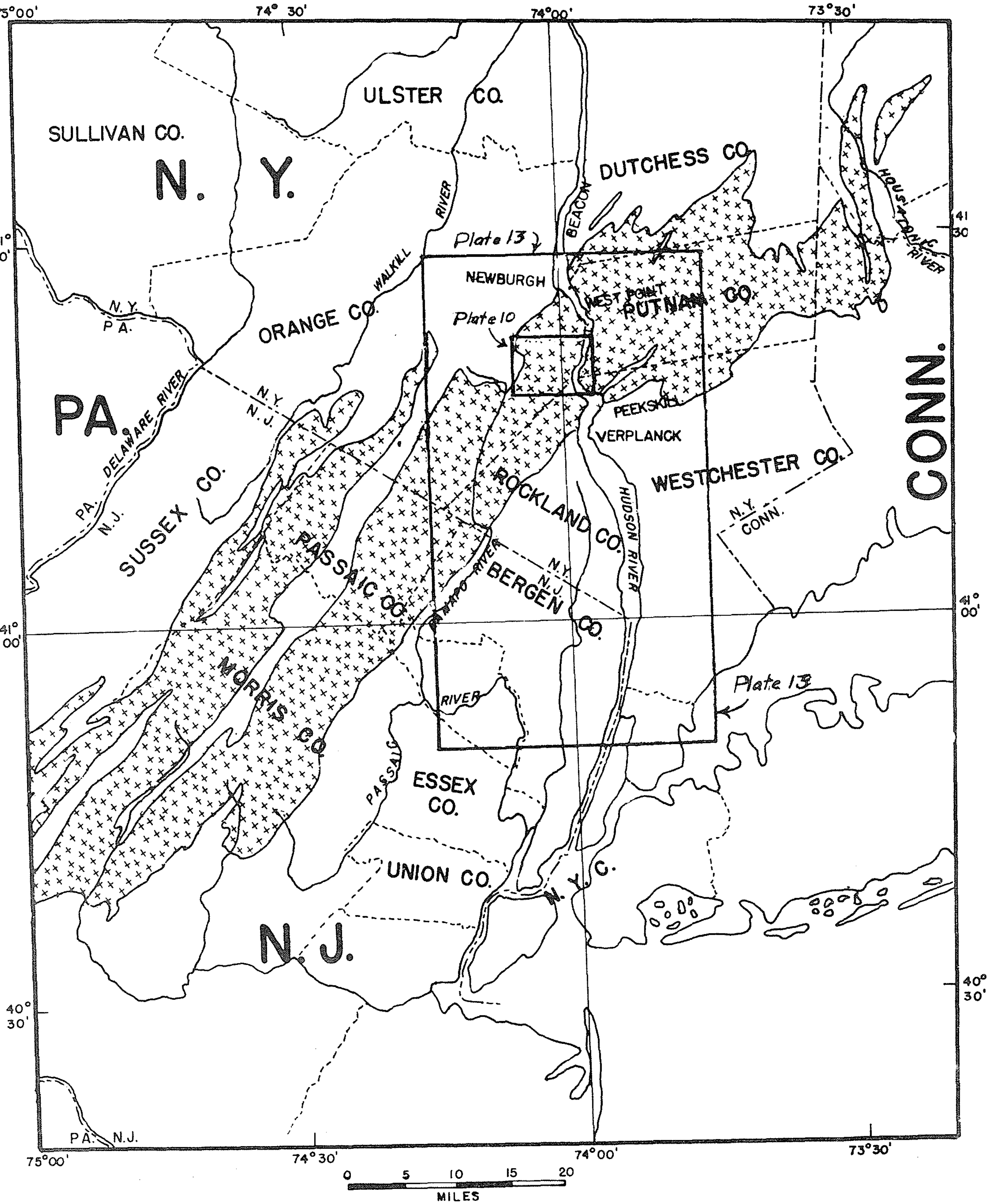

PLATE I: INDEX MAP

PALEOZOIC INLIER OF THE PEEKSKILL VALLEY

S. Schaffel
The City College

Trip 1-A, 1-B and 1-E

Introduction

The problem involved in the area covered by this trip is a stratigraphic-structural one. Portions of two valleys and a ridge which occur north of Peekskill comprise the problem area, (see Plate 13).

Peekskill Hollow, the southernmost valley is approximately 1/2 mile wide and trends in a northeasterly direction from the Hudson River for a length of 5 1/2 miles. Canopus Creek (formerly Sprout Brook) Valley trends in a north-northeast direction, is narrower but has a length equal to that of Peekskill Hollow. The two valleys are separated by Gallows Hill. Intersection of the two divergent directions of these two lows occurs at the Hudson River. The stream pattern is that of the letter "V" with the apex (developed as an inlet) pointing at the Hudson. The two lows as well as the central high are unquestionably an expression of the resistance of the lithologic units underlying the topography.

Lithology (in chronological sequence)

Highlands Gneisses:

There are many varieties of igneous and metamorphic rocks found within and composing the Hudson Highlands. This large group of Pre-Cambrian rocks is placed under the general heading of Highlands Complex. The reader is directed to the description of Trip D for treatment of these rocks.

Poughquag Quartzite:

The exposure seen on this trip (Stop 1-1) can be considered typical. The formation is up to 600 feet thick in this valley representing the maximum found in the region.

The rock is a dense, hard, fine to medium grained quartzite. Normal color ranges from white to tan and brown to red. The latter colors depend upon the concentration of limonite or hematite. Elsewhere in the Highlands and in the Paleozoic Great Valley to the north, other variations of this rock occur. A feldspathic type is commonly found as the basal member. Conglomeratic facies with distinctive blue pebbles have been reported.

The Poughquag is generally considered lower Cambrian in age. The formation unconformably overlies the Highlands crystallines and is in conformable contact with the Wappinger limestone above.

Wappinger Limestone:

The rock ranges in color from white to gray. Fresh exposures exhibit a bluish cast. Pure white and black colored members, although present, are rarely encountered. Grain size varies from fine to medium. Clay, silt and sand impurities generally determine the color. The amount of darkening is directly proportional to the impurities. The formation is sufficiently rich in magnesia locally to be called a dolomite.

At Peekskill the rock is massive in appearance and strata (where not deformed) range from two or three inches to approximately 18 inches in thickness. The only primary structures which can be observed are bedding planes. Fossils which are common in this limestone elsewhere have not been reported from this locality.

Intercalated shale and sandstone facies are found in this formation. These are not prominent and the individual thickness of the beds is quite small. At times, the Wappinger is sufficiently rich in impurities so that it can be described as a shaly or sandy limestone.

Although the apparent thickness of the Wappinger in Peekskill Hollow is on the order of 3000 + feet, it is the result of repetition of beds. The true thickness is normally taken as approximately 1000 feet in this region.

The Wappinger conformably overlies the Poughquag quartzite and is Cambro-Ordovician in age. It is conformably overlain by the Annsville phyllite (Hudson River pelite group).

Annsville Phyllite:

Gallows Hill lying between Peekskill Hollow and Canopus Greek Valley has been carved out of this formation (Stop 1-2).

The rock is generally dark bluish gray although it may be black upon rare occasions. Weathered pyrite crystals very often cause limonitic staining. Essential minerals appear to be simply muscovite and quartz as seen in thin section. Megascopically, the rock is fine-textured with the characteristic sheen on freshly broken foliated undulatory cleavage surfaces. Intercalated, discontinuous, augen-like stringers of quartz are common, probably representing thin sandy beds in the original shale. Ptygmatic folds as a consequence of plastic deformation of these beds can be observed. Original bedding planes appear to have been obliterated by metamorphism.

The true thickness of the formation at this location is uncertain, because the extent of isoclinal folding (which is undoubtedly present) is not known.

The Annsville phyllite is Cambro-Ordovician in age and conformably overlies the Wappinger limestone. It is the youngest rock unit of Paleozoic age preserved in the Peekskill valley.

Structure and Stratigraphy

Faults:

One major longitudinal and several cross faults have been mapped in the Peekskill valley (Berkey, 1919). Although the longitudinal fault is roughly parallel to the principal thrust faults in the Hudson Highlands to the north, it is a normal fault (Plate 2). It represents the continuation of the border fault southwest of the Hudson River where it separates the sedimentary red beds of the Triassic basin from the Pre-Cambrian crystallines of the Hudson and New Jersey Highlands (Plate 13 and Trip C, Stop 6). The fault crosses the Hudson River between Tomkins Cove and Peekskill, passes along the northwestern border of Gallows Hill and finally crosses over into the Peekskill Hollow valley continuing northeastward into the Highlands crystallines. Indirect evidence of its presence in the form of a limestone flow breccia may be seen at Stop 1-5.

The longitudinal fault is displaced by a number of high-angle cross faults which divide the inlier into several blocks (Plate 13).

The age of faulting is not known, but cannot be older than middle Ordovician.

Folding:

The fundamental structure of the inlier is interpreted as a large, tight synclinal fold overturned to the northwest (Plate 2). Gallows Hill marks the center of this fold with the trace of its axial plane parallel to the ridge crest. The position of the slaty cleavage in the Annsville roadcut (Stop 1-2) indicates the attitude of the axial plane.

The fault pattern and folded structure of these Paleozoic units are believed to have developed at the same time. The Paleozoic rocks must have existed at a higher level within this area, possibly covering the Highlands crystallines completely (Trip C, Stop 7) and were infolded and infaulted into the Highlands basement during one of the Paleozoic orogenies (possibly the Taconic).

The Paleozoic inlier at Peekskill is a classic example of the preservation of the younger rocks within an older terrane.

Fossil Record

The occurrence of fossils in the Paleozoic inliers here and elsewhere in the Highlands is negligible. Bucher has reported the presence of cystoid plates in the limestone in Canopus Creek. The author collected Scolithus erectus from the Poughquag quartzite in the northern part of the Highlands.

There is, however a rather good fossil record from the Paleozoic rocks in the Great Valley north of the Highlands with which the rocks of the Peekskill inlier are correlated.

Pleistocene Deposits

During and/or following the retreat of the ice these two valleys were flooded and active sedimentation in the form of glacial-fluvial deposition occurred. Typical glacial delta deposits (Stop 1-2) may be found on flanks of the valleys where they have provided a source of sand and gravel for road construction.

The following are controversial topics which bear upon the stratigraphy and structure of this inlier.

Controversey #1

The Age of the Limestone in Canopus Creek Valley

Berkey + Rice (1919) indicated Grenville age for this limestone belt. They based their conclusion upon the highly flow-deformed nature of the rock and the presence of serpentine, diopside, and graphite in many of the exposures along Canopus Creek.

The author would like to enumerate several arugments which tend to disagree with this interpretation.

1) The occurrence of this belt of Grenville limestone must be unique, if its dimensions are considered. It is approximately six miles long and varies from 500 to almost 2000 feet in width. There is no example of another pre-Cambrian limestone unit of this size or one even remotely approaching these dimensions that has been recorded in the Highlands of New York or New Jersey.

2) The normal sequence of Paleozoic rocks indicate that the Wappinger limestone should occur on both sides of the phyllite of Gallows Hill as it does at Stop 1-4. This would fit the structural picture of a syncline.

3) A discontinous fault is indicated by Berkey along the length of the Grenville body. There is good evidence for the existence of this fault (Stop 1-5). If the Wappinger limestone occupied the Canopus Creek Valley and if it had been involved in a major fault movement, it is entirely likely that the unit would have acquired the structural and mineralogical characteristics observed in the field.

Bucher reexamined the problem and came to some new conclusions (Plate 2, Fig. B). He does not apply the name Wappinger to the limestone occurring in either valley. The term Early Ordovician dolomite-limestone series is given to that part of the Wappinger which lies directly above the Poughquag quartzite. He then designates the upper portion of the Wappinger as Trenton.

Subdivision of the Wappinger in the Poughkeepsie Quadrangle was made by Gordon (1911). He assigned the lower portion of the unit to the Upper Cambrian (Potsdam). Beekmantown and Trenton age were given for the remaining upper part.

Bucher believes that the Trenton portion of the limestone was deposited upon an ancient Early Ordovician erosion surface developed on the Highlands crystallines and the Poughquag in the general vicinity of the present Canopus Creek. The transgressive sea then deposited limestone directly upon this surface enclosing crystalline rock talus. He refers to the resulting rock as a sedimentary breccia. The speific example which he cites is a critical outcrop on route 9 at Stop 1-5. Here all the rocks older than the limestone occur as inclusions within the limestone. The brecciated material ranges from fine silt to coarse boulders in an intensely flow-deformed calcareous matrix. He agrees that the plastic deformation must have been the result of later compression.

The author believes that the rock at Stop 1-5 can more readily be explained as a flow breccia in a fault zone. Since the fault cuts across both Paleozoic and Pre-Cambrian rocks, fragments representative of the several types would be expected to be present.

Controversey # 2

Correlation of the New York City Series (Manhattan-Inwood-Fordham formations) with the Cambro-Ordovician rocks (Poughquag-Wappinger-Hudson River Series)

Several attempts have been made at this particular correlation. One of the latest is by Paige (1956). The reader is referred to Plate 3 which summarizes this work in the form of a geologic map and two cross-sections.

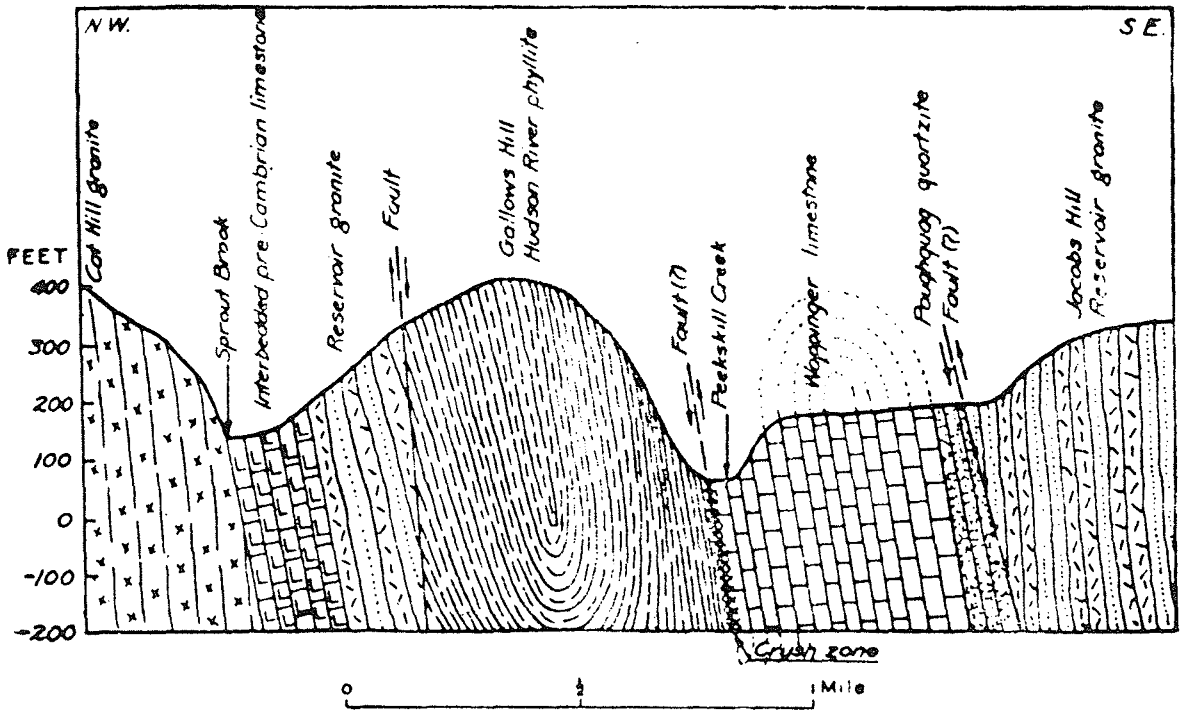

FIG. A PEEKSKILL HOLLOW SECTION
(AFTER C. P. BERKEY, 1933)

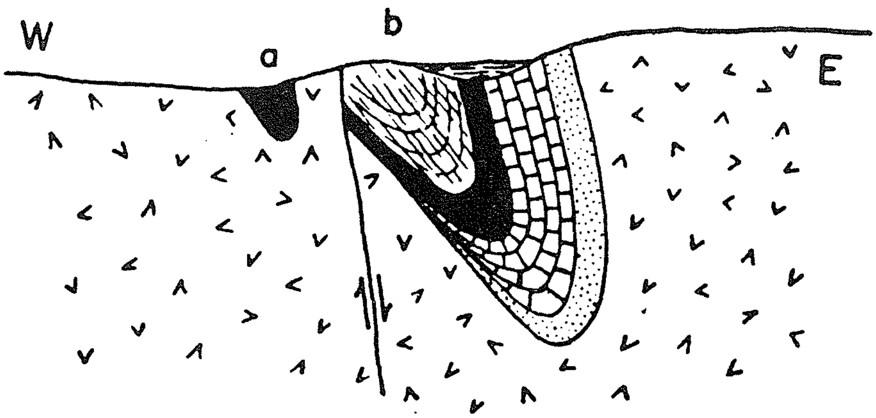

FIGURE B —DIAGRAMMATIC CROSS SECTION OF THE PALEOZOIC SEDIMENTS INFOLDED IN THE PRE-CAMBRIAN GNEISS NORTHWEST OF PEEKSKILL

Shows the westward overlap of the young Trentonian limestone and shales (eroded on left) onto the gneiss. At "a", US-9 roadcut, Stop 1-5 ; at "b", the Annsville cut. Poughquag ss., dotted; E-O dol.-ls. series, cross bars; Trenton ls., black; black sh. in center of syncline. (AFTER W. H. BUCHER, 1957)

Paige attempts this correlation between the Cambro-Ordovican sequence present in the inlier at Peeksill Hollow with the New York City Series at Verplanck Point. The Poughquag quartzite and Fordham gneiss are omitted from consideration. The series at Verplanck Point is then correlated with the Cambro-Ordovician Wappinger limestone at Tomkins Cove quarry on the west side of the Hudson River.

A single large anticline is indicated with the trace of its axial plane passing through Peekskill Hollow west of the Inwood Marble at Verplanck Point and thence to the Wappinger at Tomkins Cove. Compare discussion of this problem in connection with Trip 2 (Stop 2-3).

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Berkey, C.P. (1911) Geology of the New York City (Catskill) aqueduct, N.Y. State Mus., Bull. 146.

_______ and Rice, Marion (1919) Geology of the West Point quadrangle, N.Y. State Mus., Bull. 225-226.

_______ and Colony, C.P. (1933) Structural geology between New York and Schunemunk Mountain, Int. Geol. Congress, guidebook No. 9, New York City and Vicinity, p 40-41.

Bucher, W.H. (1957) Taconic klippe: A stratigraphic-structural problem, Geol. Soc. Am., vol. 68, p 657-674.

Gordon, C. E. (1911) Geology of the Poughkeepsie quadrangle, N.Y. State Mus., Bull. 148.

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PALEOZOIC INLIER OF THE PEEKSKILL VALLEY

Trips 1-A, 1-B and 1-E

Route Description

Mileage

0 Shustin's Locust Manor (headquarters) - left (N) on Locust Ave.

.9 left (SW) on Oregon Rd.

2.2 pass under Bear Mt. Pkwy.

2.3 right (W) on Pemart Ave.

2.5 park cars along Pemart Ave. near intersection with Highlands Ave.

STOP No. 1-1:

Walk right (N) on Highlands Ave. and right (E) on approach road to Bear Mt. Pkwy. (approx. 500 ft.). Outcrop of Poughquag quartzite (Cambro-Ordovician) in unconformable contact with Highlands gneiss (Pre-Cambrian). Dips of bedding and foliation are nearly vertical. This relation is considered typical of that between Paleozoic sediments and Pre-Cambrian crystallines along the southside of the Peekskill inlier.

2.5 right (N) on Highlands Ave. passing under Bear Mt. Pkwy.

2.9 right (NE) on Dogwood Rd. - park cars on lot along left (N) side of road.

STOP No. 1-2:

Southwest extension of Gallows Hill underlain by Annsville phyllite (Cambro-Ordovician Hudson River pelite group) and mantled by Pleistocene delta deposits. Interesting consolidation and solifluction structures have been collected at base of hill. Walk through US-9 roadcut following left (W) side of cut only. Take care to stay OFF roadway. Observe prominent slaty cleavage (axial plane type), diagonal shear planes, flow folding of quartzite bands and later quartz veins.

2.9 continue (NE) on Dogwood Rd.

3.9 right (SE) on Pump House Rd. crossing bridge over Peekskill Hollow Creek

4.0 park cars beyond bridge

STOP No. 1-3:

Wappinger limestone (Cambro-Ordovician) outcrops on north side of west abutment of bridge. Observe gradational contact with Annsville phyllite outcropping along steep west bank of creek. Specimens from this transition zone are identical with those from the Wappinger limestone outcrop at stop 1-4.

4.0 continue (SE) uphill on Pump House Rd.

4.2 left (NE) on Oregon Rd. (traffic light)

6.2 Putnam Valley - left (N) on Oscawanna Lake Rd. (traffic light at right side of road)

6.4 straight (N) at 2nd traffic light

6.6 park cars at right (E) - entrance to Putnam Valley Lodge

STOP No. 1-4:

Outcrops along left (W) side of road, Cambro-Ordovician sequence exposed from S to N (dipping east)

Annsville phyllite (approx. 100 ft.)

Wappinger limestone (10 - 15 ft.) is dark gray, fine-granular transition facies (same as in contact zone at Stop No. 1-3)

Poughquag quartzite, coarse granular (only a few inches exposed), in contact with granite pegmatite (Highlands crystallines). Is this an intrusive or unconformable contact?

Pre-Cambrian Highlands gneisses outcrop intermittently from this point northward.

Berkey (1919), on his geologic map of the West Point quadrangle
(1) shows the northern border fault of the Peekskill inlier passing between the Annsville phyllite and the Poughquag quartzite at this point;
(2) fails to indicate the presence of Wappinger limestone;
(3) indicates an unconformable contact between Poughquag quartzite and the Highlands crystallines.

This critical exposure does not yield clear evidence of faulting either within the sediments or between them and the crystallines. An orderly sequence of Cambro-Ordovician sediments appears to be present here lending support to the concept of the synclinal structure of the inlier (Plate 2). The much reduced thicknesses of the Poughquag and Wappinger support the interpretation of Bucher (1957) (Plate 2, Fig. B).

6.6 return (S) on the Oscawanna Lake Rd. through Putnam Valley

7.0 right (SW) on Oregon Rd.

9.0 pass Locust Ave. - continue on Oregon Rd.

10.3 pass under Bear Mt. Pkwy.

10.4 right (W) on Pemart Ave.

10.6 right (N) on Highlands Ave.

11.1 roadcut through Gallows Hill (earlier stop No. 1-2)

11.4 pass under US-9 and turn sharp left on approach road to US-9

11.5 straight (W) on US-9

11.9 park cars along right (N) side of road past roadcut and curve

STOP No. 1-5:

South side of roadcut shows Annsville phyllite and Highlands gneiss with intervening limestone flow breccia (relations are somewhat obscured by grading). Breccia appears to be tectonic and represents the continuation of highly deformed and metamorphosed marbles along Canopus Creek (to NE) called Grenville by Berkey (1919). Its stratigraphic position, however, makes its correlation with the Wappinger limestone a likely alternative. In that case, the Canopus Creek carbonate belt may be infolded and infaulted Cambro-Ordovician rather than Pre-Cambrian marble.

11.9 continue (SW) on US-9

12.4 left (SE) on US-6-202 crossing bridge to S-side of Peekskill Hollow Creek

12.7 left (NE) on Bear Mt. Pkwy.

15.6 leave Pkwy. at US-6 exit (right) turning left (NE) on US-6

15.9 left (N) on Locust Ave.

16.1 left at headquarters.

THE NEW YORK CITY SERIES

K. E. Lowe and S. Schaffel
The City College

Trips 2-B and 2-E

Introduction

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

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

Lithology

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Structure

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

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

Age Relations

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

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

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

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

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

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

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

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

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

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

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

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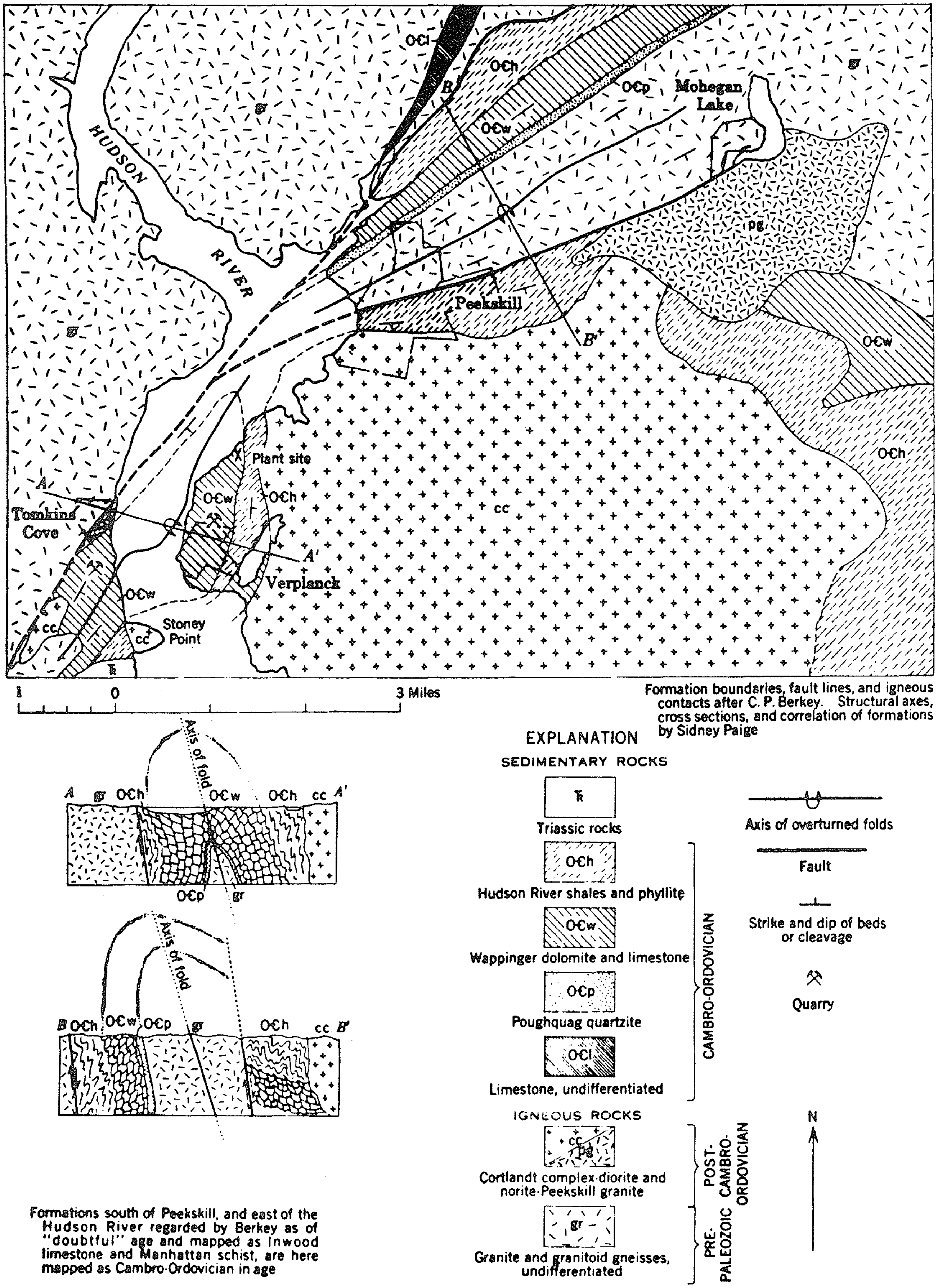

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THE NEW YORK CITY SERIES IN WESTCHESTER COUNTY

Trips 2-B and 2-E

Route Description

Mileage

0 Shustin's Locust Manor - right (S) on Locust Ave.

.2 right (W) on US-6

.4 pass under Bear Mt. Pkway. and turn right onto Parkway heading east.

1.6 US-202 and NY-35 join Parkway from right (W); continue straight (E)

3.5 keep left at Y-fork on approach to Taconic Parkway

4.5 enter Taconic Parkway heading south

9.1 NY-129 joins Pkway. from right (W); follow left (E) curve of Pkway.

9.5 Pkway. turns right (S) across Croton reservoir bridge

13.5 right turn off Parkway; exit to NY-100

13.6 left (NE) on NY-100 passing under Pkway.

13.8 right (SE) on NY-133

14.0 STOP No. 2-1:

Quarry behind transformer station at left (N), now used by N. Y. State for gravel and road machinery storage. Typical Fordham gneiss, the oldest formation of the New York City series.

14.0 continue (E) on NY-133

14.2 250 ft. beyond Millwood Railroad Station turn left (N) on NY-120 (Granite House Rd.)

14.4 intersection of NY-120 (Granite House Rd.) with NY-100

STOP No. 2-2:

The 3 formations of the New York City series outcrop in close proximity, although actual contacts are not exposed. Manhattan schist (garnetiferous muscovite schist) NW of the intersection along a side road; Inwood marble (medium grained, crystalline marble, here containing accessory graphite) in road cut on both sides of Granite House Rd.; Fordham gneiss (banded biotite gneiss) a short distance SE along cut-and-cover portion of Catskill Aqueduct. Formations appear conformable with nearly vertical dips. These rocks were traced continuously from the New York City line to this locality by Fluhr (1940). The thickness of the Inwood marble here is much reduced compared with that prevailing in New York City (approx. 750 ft.), a feature which is rather common in Westchester County. It has been explained by "squeezing-out" of the highly plastic rock and by faulting.

14.4 left (SW) on NY-100

15.0 pass under Taconic State Pkway.

15.2 right (W) on NY-133; Manhattan schist exposures for the next 3 miles

17.2 pass under NY-9A (Briarcliff-Peekskill Pkway.)

18.2 NY-134 joins NY-133 from right (NE)

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

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

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

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

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

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

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

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

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

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

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

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

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

THE CORTLANDT COMPLEX

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N. Y. City Department of Public Works

Trips 3-A, 3-B and 3E.

Introduction

The Cortlandt complex is a funnel-like mass of basic igneous rocks (mostly orthopyroxene gabbro or norite) outcropping in roughly oval shape principally in Cortlandt township south of Peekskill (Plate 13). That it is younger than the Inwood marble and Manhattan schists, which it intrudes, is known. But the age of these formations is itself a controversial matter, although they are certainly not younger than early Paleozoic.

The Cortlandt complex has attracted the attention of geologists for many years because of its unusually interesting petrologic and structural problems and because of the economic and mineralogic importance of its emery ores. A brief review of the history of investigation of the Cortlandt complex is a good illustrative example of how a geologic problem may be studied by the application of different methods, each contributing its part to a final picture.

Historical Summary

James Dana, in 1880, was the first to study the rocks as a whole and to recognize their genetic relationships to each other. It is to him that we owe the name Cortlandt series. Because of certain contact phenomena and locally pronounced banding he erroneously classified the rocks as metasediments. This hypothesis was abandoned by him in 1884 when additional field evidence led to the recognition of the true igneous nature of the complex.

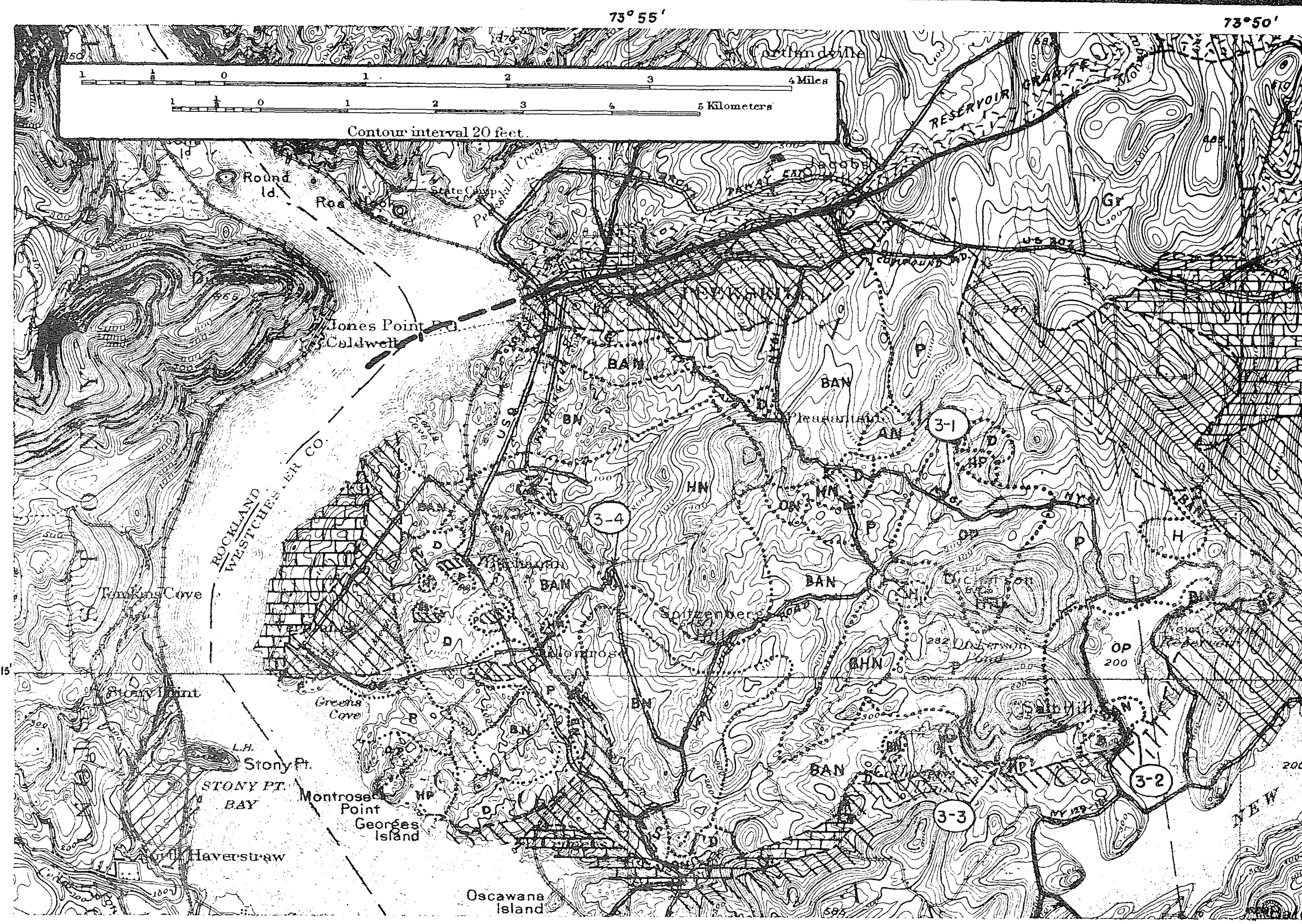
G. H. Williams (1884 to 1888) published the results of very detailed petrologic work. Several species each of peridotite, norite, gabbro, diorite and mica diorite-all intimately related by transition - are described. Williams considered the more basic types to have been intruded first, followed by successive intrusions of more and more acidic magma. Unfortunately, Williams studies did not cover the entire outcrop area of the Cortlandt intrusive.

Berkey (1907) was the first to map the complete boundaries of the pluton and the first to suggest the possibility of a genetic relationship between certain granites outcropping immediately to the northeast (Peekskill granite) and the Cortlandt series proper. Such a relationship was not confirmed by Butler (1936, p. 542).

An important contribution was made by Rogers (1911) after intensive study of the entire area. The Cortlandt intrusive was divided into a large number of closely related types. Included among them were gabbro, several varieties of norite, peridotite, diorite, hornblendite and various species of pyroxenite (Plate 4). He had great difficulty in explaining their mutual relationships and magmatic history, although he believed the basic intrusions were followed by more acid magma.

New light was shed on the problem with the publication of Balk's (1927) classic structural study. Balk systematically mapped the dip and strike of

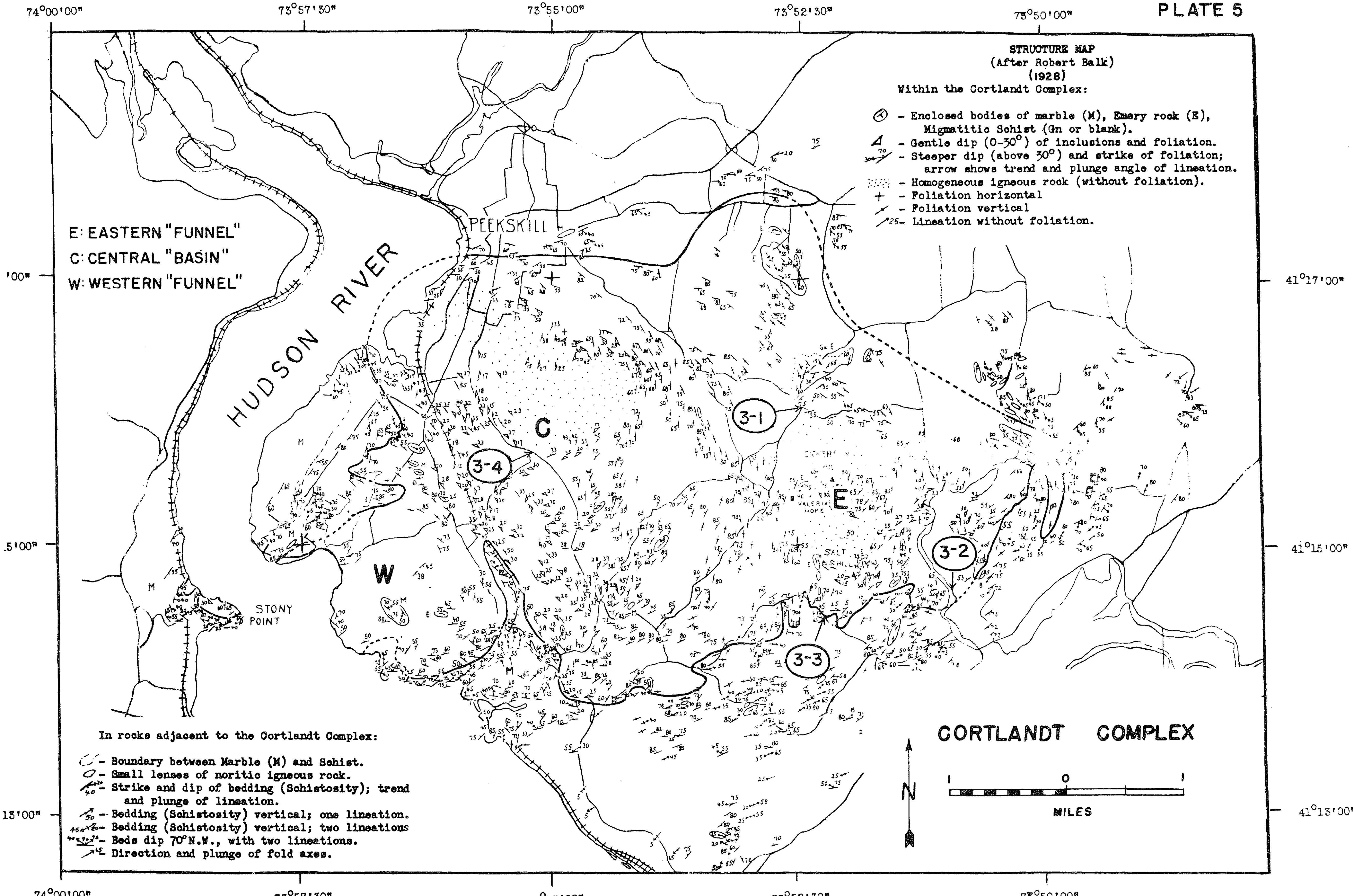
MAP OF THE CORTLANDT SERIES



AFTER G.S. ROGERS (1910)

Gr	GRANITE	H	HORNBLENDITE	BN	BIOTITE NORITE	ON	OLIVINE NORITE
S	SYENITE	P	PYROXENITE	AN	AUGITE NORITE	QN	QUARTZ NORITE
SS	SODALITE SYENITE	HP	HNB. PYROXENITE	BAN	BIOT. AUG. NORITE		MANHATTAN SCHIST
D	DIORITE	OP	OLIV. PYROXENITE	HN	HNB. NORITE		INWOOD LIMESTONE
G	GABBRO	BP	BIOT. PERIDOTITE	BHN	BIOT. HNB. NORITE		FORDHAM GNEISS

PLATE 5



MODIFIED FROM GEOL. SOC. AM., GUIDEBOOK OF EXCURSIONS, NOV. 1948

the banding, which is nearly always present (but not always prominent) in the Cortlandt complex (Plate 5). The bands are alternately light and dark, reflecting changes in mineral composition, although differences in grain size are sometimes more important distinguishing features than composition (Shand, 1942, p. 414).

Balk's map shows two oval areas within which the banding dips towards structureless focal "lows". At the first (Dickerson Hill; E of Plate 5) dips are steep on three sides but flatten to the south. The second and largest, running southeast from Peekskill (C of Plate 5), is asymmetric having steep dips on the east side but shallower dips to the west. On the southwest side of this second low a long reentrant seems to mark off a third area to the west (W of Plate 5). This is also suggested by a reentrant along the western Cortlandt-Manhattan contact.

On the basis of structure, Balk pictured the complex as the upper part of a funnel shaped magma chamber in which masses of early crystallized rock, rich in olivine, pyroxene or hornblende, floated upward. Around these "knots" wrapped the banding and schlieren, which he measured. Balk estimated the depth of the synclinal lows at from 3000 to 5000 feet with the funnel as a whole reaching depths of 3.75 to 6.8 miles.

Impressed by the complete lack of correlation between Rogers' petrologic and Balk's structural maps, Shand (1942) was led to a complete reexamination of the petrology of the Cortlandt complex. Noting the probability of Balk's structural funnels being channels by which the magma ascended and appreciating the strong evidence of all the main rock types belonging to a single period of intrusion, he became convinced there ought to be a rude concentric outcropping of different rock types around the funnels. Roger's map failed to show any such outcrop pattern.

In evaluating Rogers' work, Shand criticized the subjective character of his rock classification with its arbitrary boundaries. It is difficult, for example, to draw the line between biotite-hornblende norite and hornblende-biotite norite. In addition, Rogers failed to recognize the importance of compositional changes related to banding. Thus one outcrop can contain two or three different rock types. Finally it is remarked that Rogers made too few thin sections and relied too much on hand specimen identification.

In place of Rogers' "species petrology", Shand (1942) proposed "phase petrology". He defined critical phase to mean "... any phase which is restricted either to a particular part of the eruptive complex or to a particular period in the cooling history of the magma, and which may in consequence yield information about the chemical and physical changes that accompanied the freezing of the system" (p. 415). The most important phase is hornblende. This occurs in two forms (1) primary and (2) as a poikilitic replacement surrounding inclusions of plagioclase and pyroxene in norite. The first is confined to marginal zones (Plate 6) whereas the second coincides with Balk's central funnel (C of Plate 5) southeast of Peekskill.

Another critical phase is that of olivine in pyroxenite. This phase outcrops in a large eastern area and a smaller western area generally agreeing with Balk's eastern (Dickerson Hill) and western funnels. Each of these areas is surrounded by pyroxene without olivine. Although Shand questions the independence of the Dickerson Hill funnel, there seems to be no doubt as to the existence of a large, general Cortlandt complex funnel.

In discussing the history of crystallization of the magma, Shand concludes the the norite and pyroxenite were part of the same magma, but that the pyroxenite and peridotite were formed by the settling of crystals from the norite magma He postulates that the higher parts of the pluton, now eroded away, contained a greater proportion of norite. The steeply dipping, parallel bands are accounted for by subsidence of the partially differentiated mixture of crystals and liquid in the center of the funnel. The poikilitic hornblende was then formed by steam rising through the central funnel from hot, deeper portions of the magma chamber. This was in turn followed by local introduction of pegmatite and granite veins bringing crystallization to a close.

Woollard and Steenland (1948) conducted a gravimetric and magnetic survey of the area. Keeping in mind that such data are always open to several interpretations, it can be said that the gravity readings show anomalies roughly coinciding with the eastern and western peridotite-pyroxenite masses (Plate 7). Depths arrived at by assuming the masses to be funnels compare favorably with those of Balk. The central area, however, cannot be deeper than 1300 to 1800 feet. The magnetic readings show anomalies on the margins of the intrusive reflecting contact metamorphic, disseminated magnetite in emery ore. It is interesting to note that 3 of the prominent magnetic "highs" (Plate 8) fall <u>within</u> the present surface boundaries of the complex. This would suggest that the contact surfaces of the intrusive are, indeed, sloping inward in the form of a large funnel.

Bucher (1948) tried to weld all the facts into one interpretation (Insert on Plate 5). He concludes that the pluton must have become involved in the folding of the surrounding rocks while still quite fluid. In support of this concept are: the general presence of bent plagioclase twin lamellae, folding and faulting of marginal dikes, the general turbulence of the Cortlandt banding and the close accordance between this banding and the foliation in the Manhattan schist country rock. Also noted is the general parallelism of trend of the long axis of the Cortlandt complex with the regional fold trend (N 55^0 E). The liquid magma mushroomed around earlier crystallized viscous masses of olivine-pyroxene, wedging in between surrounding layers of country rock to form flange-like margins.

It seems well to remember that plagioclase crystals can be bent by jostling as they float upward during magmatic differentiation and that flow banding and schlieren are ordinarily expected to be roughly parallel to the contacts with the country rock. Also ascending plutons often accommodate themselves to surrounding wall rocks and can even cause marginal thrusting and folding as well as metamorphism during emplacement. It is possible to believe that the Cortlandt pluton may have been intruded after the main period of metamorphism but before all orogenic forces had subsided.

Genesis of the Emery

The genesis of the emery ores, which have been quarried for many years in the Cortlandt locality, is an interesting mineralogical problem. Quoting Friedman (1956, p. 7), "Emery is essentially an aggregate of corundum and magnetite, but many emery bodies also contain abundant spinel, while ilmenite is likewise common. Among the accessory minerals may be mentioned hematite, hoegbomite, pyrite, sillimanite, cordierite, andalusite, staurolite and garnet."

Emery is used as a commercial abrasive. Two types are recognized: (1) spinel bearing or black emery (no longer mined) and (2) gray or cordierite-sillimanite-sapphirine emery, now the only type quarried in Cortlandt township.

Through the years several theories have been proposed to account for the origin of the emery. A detailed discussion is not attempted here.

Rogers (1911) offered a theory of absorption of the Manhattan schist by Cortlandt magma with resultant aluminous segregations. He cited experiments in artificial production of corundum by Morozewicz.

Gillson and Kania (1930) gave deuteric contact metamorphism as the reason for emery formation. The gaseous or liquid emanations welled up through the already solid border of the igneous mass and into the schist. In support of this are: (1) emery and associated rocks contain common contact minerals, (2) emery occurs only with endomorphosed igneous rocks, and (3) quartz and corundum occur in the same rocks when they should have combined to form aluminum silicates, if absorption of schist had taken place.

A modification of the theory was made by Butler (1936). Contact metamorphism took place during the early liquid-magmatic stage of the basic Cortlandt intrusion. The emery was formed by emanations travelling in advance of the main magma into the country rock. He points out that emery deposits in norite are mineralized xenoliths engulfed by the magma. The emery was formed before solidification of the endomorphosed norite because norite cross-cuts emery lenses and encloses emery fragments.

Friedman (1956), after an exhaustive study of the entire problem of emery formation both in the United States and abroad, came to the conclusion that the spinel emery is a result of reaction between granitic emanations and pyroxene-rich basic rocks. Hornblende and biotite are formed and Fe, Mg and Al ions are released as a byproduct to form the emery. The emery occurs as irregular lenticular bodies replacing the basic rock. The ions that pass into the adjoining schists combine with silica to form a zoned hornfels and contact aureole. The influence of granitic material is evidenced by structural relations between the basic rocks and emery deposits, by typical mineral suites and by characteristic metasomatic changes in the basic rocks normally ascribed to granites.

In the case of the Cortlandt complex, such granitic emanations would come from the Peekskill granite outcropping to the northeast. This is the same granite that was thought to be an acidic differentiate of the Cortlandt series by Berkey and Rogers.

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THE CORTLANDT COMPLEX

Trips 3-A, 3-B, and 3-E

Route Description

Mileage

0	Shustin's Locust Manor (headquarters) - right (S) on Locust Ave.
.2	right (W) on US-6
.45	pass under Bear Mt. Parkway
.7	left (S) on Conklin Ave.
1.0	right on US-202 (Crompound Rd.)
2.0	sharp left (up-hill) on Arch St. and continuing on Boulevard
2.35	right on Riverview Ave.
2.5	cross Longview Ave. Pause: View of southeastern gateway of the Hudson gorge - on west side of River (from left to right): Dunderberg, West Mtn. and Bear Mtn. (with tower).
2.6	left on Maple Ave. heading southeast
3.20	hill at right with outcrops of Cortlandt complex augite norite
3.6) 3.7)	norite outcrops along both sides of road
5.3	intersection with Furnace Dock Road STOP No. 3-1 Olivine pyroxenite near northwest margin of "Eastern Funnel" (E on Plates 4 to 8) and "Olivine Region" (Plate 6). Typical spheroidal weathering similar to that of olivine zone in the Palisades. Dickerson Hill (center of "funnel") to the southeast. Banding mapped by Balk (Plate 5) is difficult to distinguish in this exposure. Discussion of structural and petrologic features of the Cortlandt complex.
5.3	continue (E) on Maple Ave.
6.5	end of Maple Ave.; right (S) on Croton Ave. - DRIVE CAREFULLY - steep hill down to Croton Reservoir
7.2	sharp right turn along reservoir following Croton Ave. - do not drive straight ahead on Baptist Church Rd.
7.6) 8.0)	Outcrops of pyroxenite at right (E)
8.4 to 8.55	STOP No. 3-2 Old quarry dumps on both sides of road. Collect samples of pyroxenite (with and without olivine) and augite norite. Note indistinct banding and quartz-pegmatite veins cutting pyroxenite and norite.
8.55	continue on Croton Ave. (S) along reservoir
8.65	Pause: Passing over contact of Cortlandt complex with Manhattan schist (country rock); schist outcrops on both sides of road. keep right after next curve in road

9.0 bear right (W) on NY-129 (Yorktown Rd.) - schist outcrops at right

9.55 right (N) on Mt. Airy Rd.

9.6 sharp right on Colabaugh Pond Rd. - Colabaugh Pond at left

10.1 STOP No. 3-3: Kingston Emery Quarry (operated by Colbate Emery Co., Peekskill, N.Y.) presently the only operating emery quarry in the Cortlandt complex. Note the following:

(1) In quarry, down near the working face, excellent rectangular jointing. Rocks are highly magnetic. South quarry wall shows crusts of quartz and calcite, and quartz veins in the pyroxenite.

(2) Walking up cut leading out of main excavation observe the pyroxenite grading into more banded augen schist which becomes a normal schist at the quarry entrance (Colabaugh Rd.). This zone of transition represents the Cortlandt complex - Manhattan Schist contact. The country rock shows evidence of having been mobilized by the Cortlandt pluton during intrusion. The contact effects are also well shown in the schist outcrops near the construction shacks. The quarry has only been in operation since 1942. The contact shown on Plates 4 to 8 is not quite accurate and should be shifted southwestward close to Colabaugh Pond Road.

(3) Emery ore (samples on dump at quarry entrance) is dark blue-gray with an occasional pinkish hue and massive. Quarrying operation has followed ore vein down-dip.

10.1 continue (W) on Colabaugh Pond Rd.

11.75 straight ahead (W) on Mt. Airy Rd.

12.1 sharp right (N) on Furnace Dock Rd.

12.4 left fork into Washington St.

13.0 intersection with Watch Hill Rd (blinker light) - continue straight (N) on Washington St.

14.6 intersection with Montrose Station Rd.

STOP No. 3-4:

Hornblende norite with poikilitic hornblende near western margin of central "basin" (C of Plates 4 to 8). Platy structure of hornblende crystals can be observed.

14.6 continue (N) on Washington St.

15.5 cross Welcher Av.

16.85 right (E) on South St. (traffic light) continuing on Division St.

17.0 left (N) on South Division St. proceeding to top of hill (monument)

17.35 left fork in front of monument into Highlands Ave.

17.9 right on approach road to Bear Mt. Pkway (ahead of underpass)

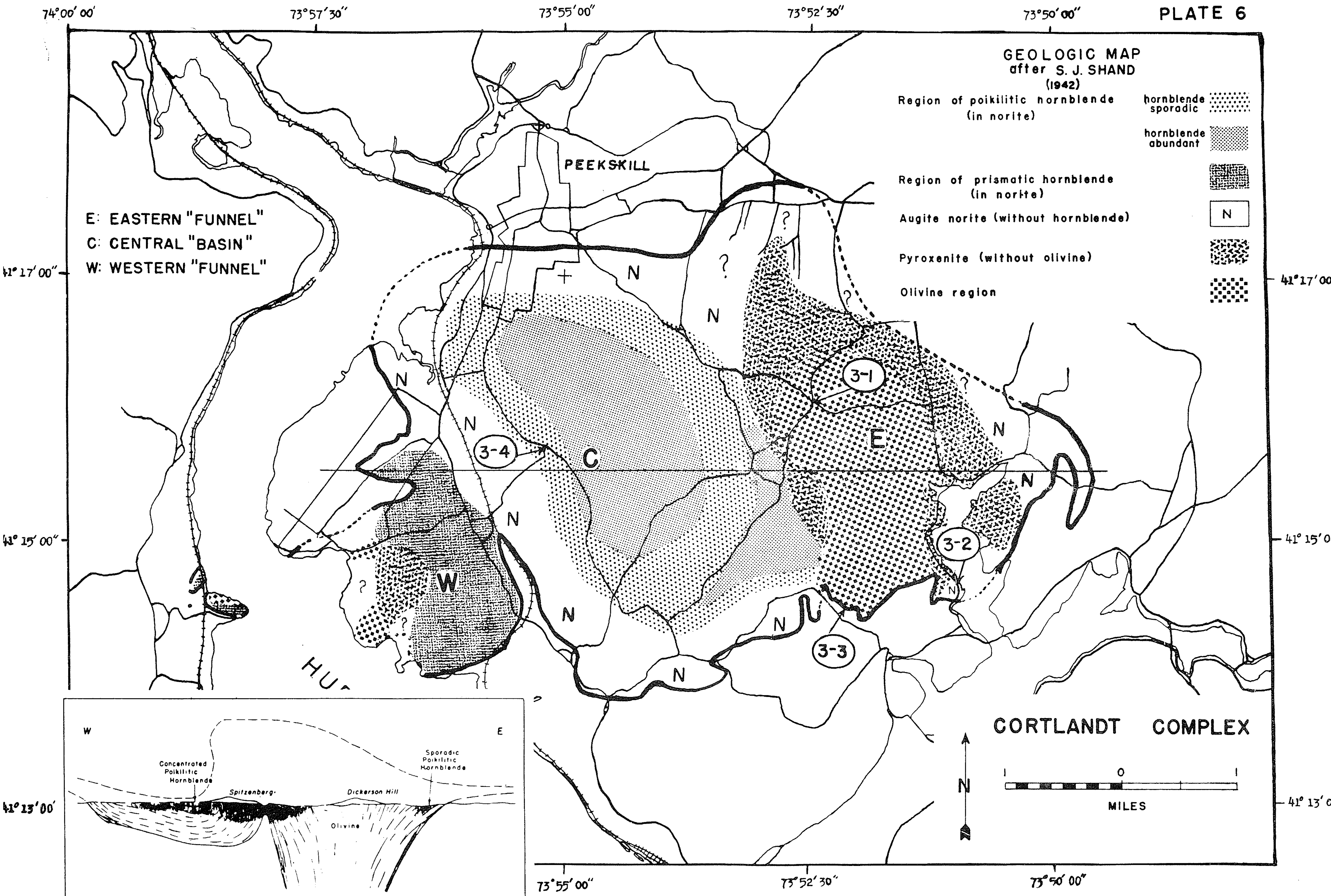
18.0 Pause: Poughquag quartzite (Cambro-Ordovician) in unconformable contact with Highlands gneisses (Pre-Cambrian) at right (S). Dips are nearly vertical.

18.0 proceed (E) on Bear Mt. Pkway.

20.1 leave Parkway at US-6 exit (right) and then left (E) on US-6 passing under Parkway

20.25 left (N) on Locust Ave.

20.45 left into headquarters.



A possible interpretation of the subsurface extension of the Cortlandt complex. AFTER BUCHER (1948)

MODIFIED FROM GEOL. SOC. AM., GUIDEBOOK OF EXCURSIONS, NOV. 1948

PLATE 7

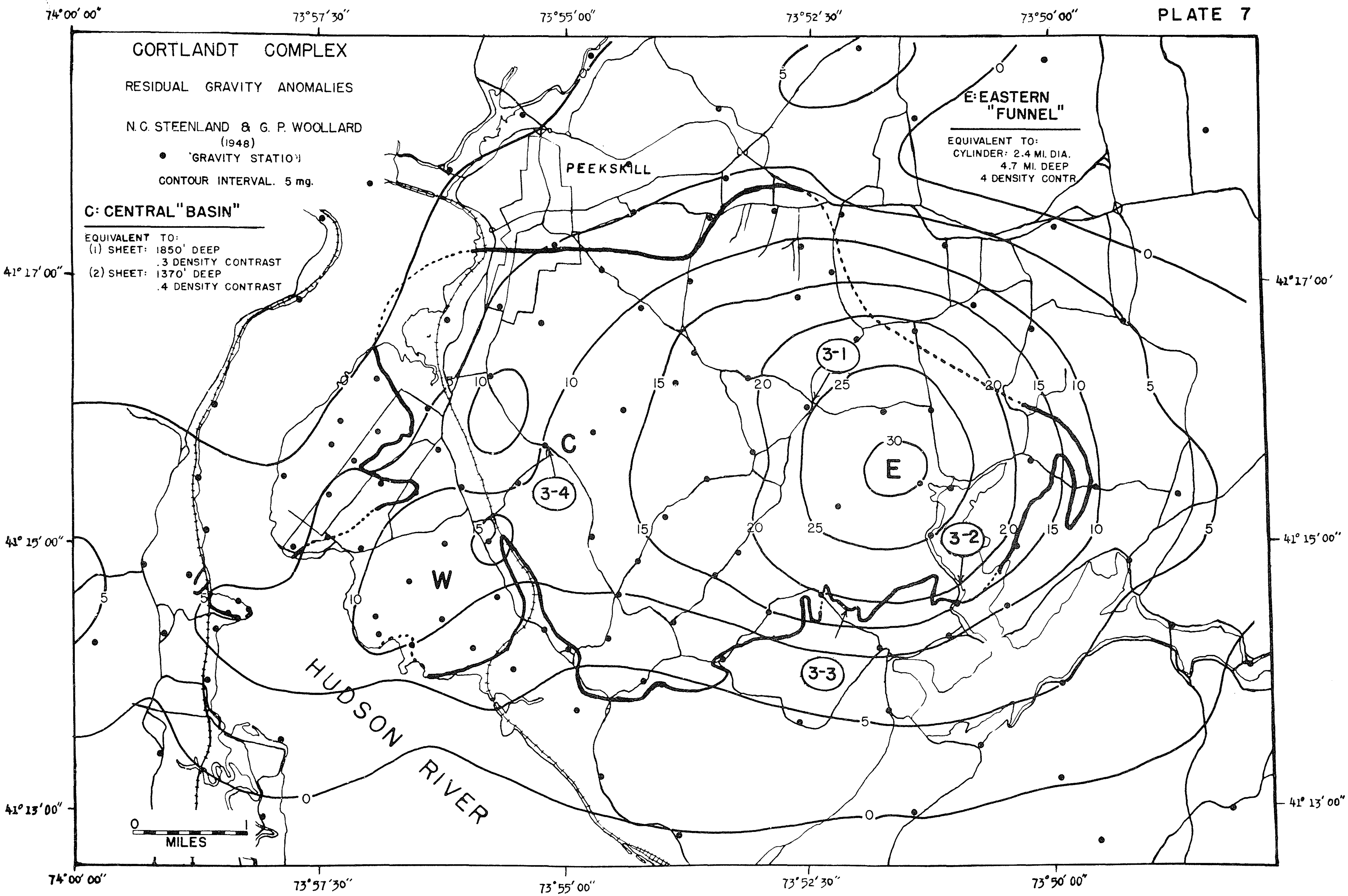


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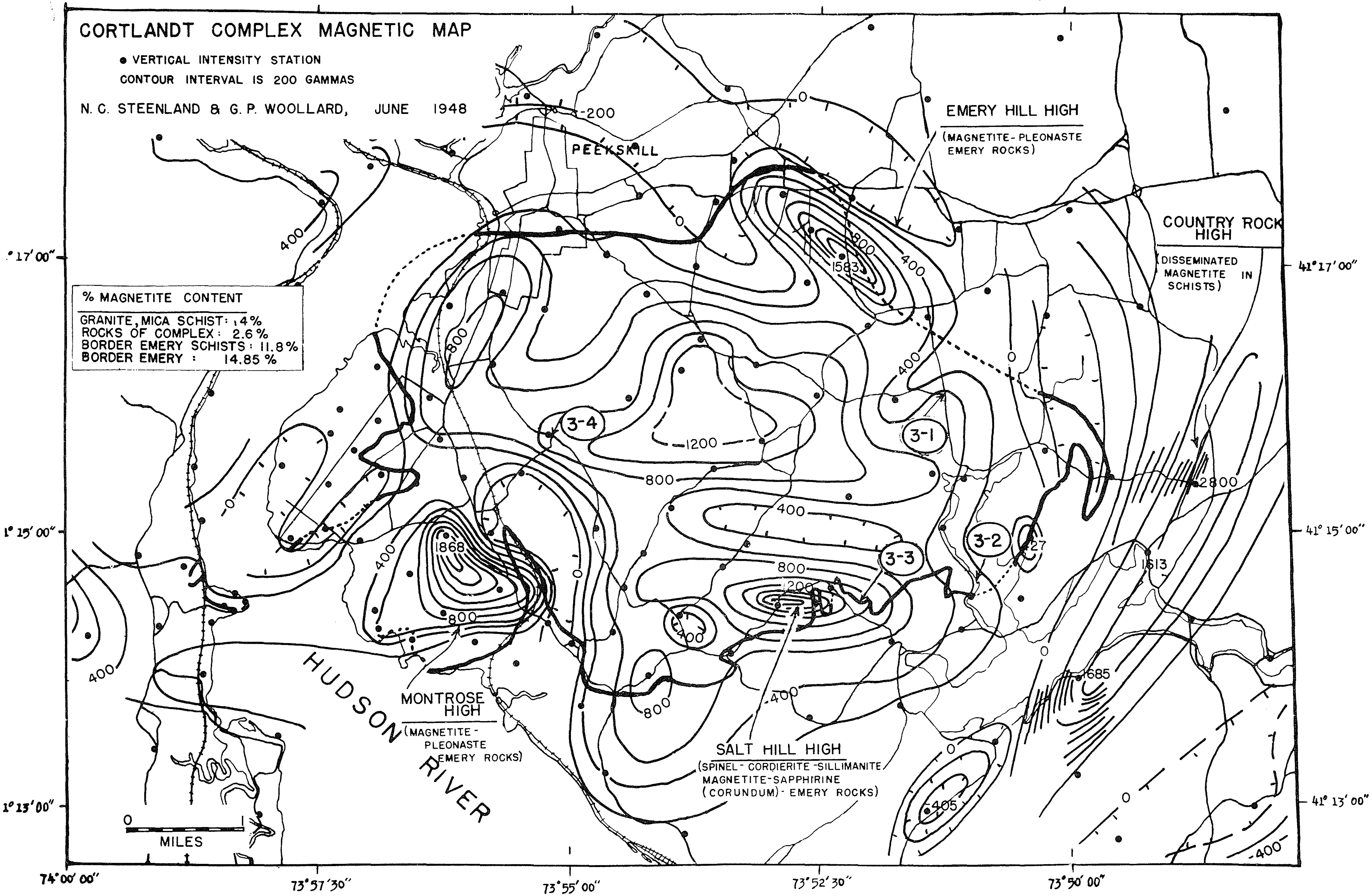
PLATE 8



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PLEISTOCENE GEOLOGY OF CROTON POINT

Cecil H. Kindle
The City College

Trips 4-B and 4E.

Route Description and Comments

Mileage

0 Shustin's Locust Manor (headquarters) - right (S) on Locust Ave.

.2 right (S) on US-6

.4 left on approach to Bear Mt. Parkway (heading W)

3.3 bear left on US-9 at intersection with US-6-202

3.9 pass under US-202 (Main St.) - continue S on US-9

5.9 Buchanan

11.9 NY-129 enters US-9 from left
If one had chanced to come along route NY-129, one would have observed the gravel and silt deposits of the former Croton River delta on the left (S) just before reaching US-9.
Continuing along US-9 we rise up onto this former delta surface
12.5 and find a traffic light ahead. Let us turn right (S) here on Croton Pt. Ave. and proceed to the Harmon railroad station (Fig. 1) Here we notice the wide cut made for the railroad and its shops. We continue west beyond the station on the viaduct over the tracks and skirt the south-side of a remnant of the old delta. If one took time to walk along the seaward (N) side, it would be possible to see where waves have exposed varved clay and slit at the base of these deltaic sands and gravels.

We do not stop now, but continue, observing a former tidal swamp, now filled with rubbish, on our left. Soon the delta remnant is behind us and we travel on a tombolo (bathing beach on our right and former swamp on our left) to the outer portion
15.2 of Croton Point. We proceed to the large parking field at its southern end.

Ahead of us we see a sand pit which furnishes the material used to cover the rubbish in the former swamp. Let us examine this exposure. Here we find another remnant of the old Croton delta with sand and fine gravel resting on varved silty clay. Occasional concretions may be seen in the latter. Some of the silty clay layers are disturbed with horizontal layers above them. Are they the result of slumping or disturbance by floating ice?

Let us now walk S along the shore. We see numerous bricks, castoffs from the days when bricks were manufactured here. Behind some swimming rafts parked above the reach of the tide we see a cattail (freshwater) swamp which marks the source of clay used in brick manufacture.

As we proceed beyond the swamp we see delta sands, and 100 yards or so further we observe these varved clays resting on glacial till containing boulders of various sizes in a reddish matrix. Now we realize the source of the boulders among which we have been threading our way along the beach. The surface of this moraine is uneven and appears to be dropping below sealevel for a distance

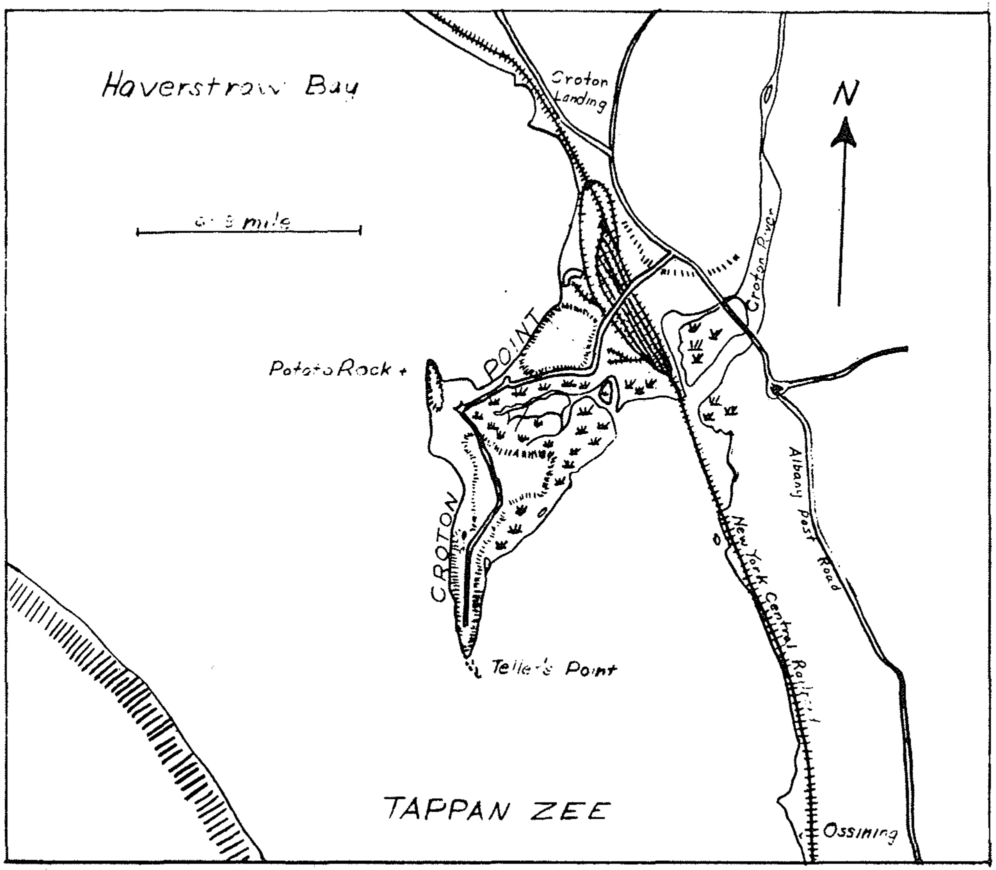

Fig. 1 Map of Croton Point, N.Y

before rising to 40 or 50 feet above sealevel at Teller's Point (Fig. 1). A boulder bar extending south of Teller's Point marks its further continuation.

As we return to our cars we realize the preservation of the outer remnant of the Croton delta from wave erosion must be credited to this moraine.

We can now drive to the north end of the parking area and examine the north tip of the outer part of Croton Point. The weather and the state of the tide will determine whether we walk along the outer side of the point (more boulders) or the inner side (shorter). Woodchuck holes indicate that the top of the southern end of this point is deltaic sand. At the north end are glacial till and Indian shell beds.

Erosion appears to be rapid at all points along the shore. Waves have certainly cut down the size of the Indian campsite (at the point) considerably since the oyster beds were laid there. Was sealevel lower a short time ago? Does the (now buried) tidal swamp south of the tombolo indicate that sealevel was lower when that portion of the old delta was eroded?

Return to cars and drive back to headquarters following the same route as taken at the start of the trip. Compare route description of Trip 2-B between mileages 20.9 to 25.8 and 30.6 to 36.4.

35.5 Arrive at headquarters.

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THE GEOLOGY OF THE TRIASSIC LOWLAND OF SOUTHEASTERN NEW YORK AND NORTHERN NEW JERSEY

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Trip C

Location

The area covered by the Triassic Field Trip is the northeastern part of the largest Triassic basin in the United States. The route follows the sides of a triangle. Starting near Peekskill it crosses the Hudson valley over the Bear Mt. bridge and follows the west shore of the Hudson to the vicinity of the George Washington Bridge at New York City. From here the route is northwesterly as far as Suffern, N. Y., where it turns northeast toward Stony Point, N. Y. on the Hudson and thence back to Peekskill. (Plate 9, Fig. A and Plate 13).

Geologic History

The Pre-Newark Peneplane

For practical purposes, the history begins with the broad beveling of a pre-Triassic complex following the Appalachian revolution at the close of the Paleozoic Era. The evidence for this beveling can be seen on the east shore of the Hudson estuary south of Peekskill. Here the line of hill summits rises from the estuary level at an angle varying between 10 and 15 degrees until it reaches the upland level. This region is interpreted by Sharp (1929) and others as an exhumed portion of the Pre-Newark peneplane for the following reasons: (1) the slope approximates the present dip of the Newark sediments across the estuary, (2) the intersection of the surface with the estuary level is a smooth line, indicating that the basement of the Newark sediments was an even surface. The single major projection along thisshoreline is interpreted as a residual on the erosion surface. This projection is utilized as the foundation for the eastern pier of the George Washington Bridge.

The Newark Series

The episode of erosion which produced the pre-Newark peneplane eventually changed to one of deposition for reasons which are conjectural. The nature of the material in the lower part of the Newark series indicates a source to the southeast from still-ungraded areas of the Appalachian orogenic belt. Fossils indicate an Upper Triassic age.

The STOCKTON formation at the base consists chiefly of light-colored arkosic sandstones and conglomerates with interbedded red sandstone and shale. Total thickness is as much as 3000 feet. A single phytosaur skeleton (Rutiodon manhattenensis) has been collected from the base of the Palisades a short distance south of the George Washington Bridge.

The succeeding LOCKATONG formation consists of black shales, hard massive dark argillites, flagstones and in a few places very impure, thin limestone layers. Thickness estimates range up to 3500 feet. The Lockatong has yielded a few species of fish (related to the lung-fish), a small crustacean (Estheria ovata) and a few remains of land plants. The formation thins northward and is not mapped in the area visited. However, similar rocks and fossils have been found below and above the Palisades sill.

The uppermost BRUNSWICK formation consists chiefly of soft red shales and interbedded sandstones, the latter being more abundant and coarser toward the northeast. Thickness estimates range up to 8000 feet. The formation underlies the widest area of the Lowland but is often under heavy glacial cover in this locality. Massive conglomerates occur at various points along the northwestern border adjoining the Highlands, and replace beds of the previous division at various horizons.

The aspect of all these sediments is continental. This is inferred from both physical and fossil evidence. Physically, mudcracks, raindrop impressions, channel fillings, rapid variations in texture, fanglomerates indicate stream, lake, or estuarine deposits. Dinosaur foot-prints, plant remains, crocodile-like dinosaurs and ancient fresh-water fish suggest non-marine deposition but, at times, possibly affected by estuarine waters. The Newark series was probably spread over a broad piedmont plain in the form of nearly flat coalescing alluvial fans by vigorous streams that washed sediment down from the uplifted crystalline foreland. During Locatong time estuarine embayments may have covered parts of the piedmont plain to produce the even-bedded laminations of the fish-bearing argillites.

Climatic Conditions

The sediments and their fossil contents have been used to infer the climatic conditions under which they were deposited. The occurrence of fresh feldspar in the arkose and the predominently red color in the shales and sandstones together with frequent mudcracks led early workers to the conclusion that the climate was of the warm, arid type. Recent work on sediments has shown that both arkoses and red beds may be produced under a variety of climatic conditions, including warm and humid. Such features have limited value as climatic indicators.

Animals such as dinosaurs and fish may have lived in or near water bodies, i.e., along streams or in deltaic or estuarine areas. Since such water bodies may be located in either arid or humid regions, the evidence for their existence affords little clue to the climatic conditions of the broader area of deposition. (cf. the Nile River). It appears then that the only conclusion that may be drawn is that the climate was probably warm.

Igneous Activity in Newark Time

Basic lava flows are intercalated with the beds of the Brunswick formation. Three distinct flows are now recognized in the Watchung region near Paterson, N.J. Occasional volcanic plugs appear along the northwest border fault. Deeper intrusives include the major sill of the Palisades which, as it is followed north of Nyack, N.Y. becomes a distinctly curved dike cutting across the strike of westward dipping Newark beds. The Palisades sill shows distinct baking effects in the surrounding sediments and occasional xenoliths near the lower contact. The sill itself is strongly differentiated as to texture and composition. (Walker, 1940 and discussion at Stop C-3).

Deformation of the Newark Series and Associated Igneous Rocks

In the continental basin that received the Newark sediments the floor must have sloped gently westward permitting low initial dips of the sediments. These dips have been generally increased by tectonic movements so that in this region they are about 15 degrees northwest. Some of this increase is probably due to subsequent basining or downwarping as suggested by the concentric curves of the Watchung trap ridges farther south. The axial region of the downwarp lies east of and parallel to the western margin of the basin. Since the present margin lies along a major fault, it is possible that the downwarping of the basin gave way to faulting. In this region the maximum displacement along the fault is near the center of the downwarp and diminishes northeastward so that the Triassic beds are no longer present east of the Hudson.

Between the northermost lava flow near Pompton Lakes, N. J. and the extension of the Palisades near Haverstraw, N. Y. the westward dipping Newark beds strike oblique to the border fault-line, indicating either pre-fault basining as suggested above or the increase of low initial dips by the rotational element of the fault. The individual effects of these two possibilities are difficult to evaluate.

Certainly faulting near the close of Newark sedimentation produced an escarpment facing southeast. From the upthrown block on the northwest, streams cut through early Paleozoic limestones and quartzites, deploying on the downthrown block to produce a set of alluvial fans or cones made of coarse, sometimes angular to semi-rounded, blocks of these materials. The faulting is pictured as part of a general program of isostatic uplift of an orogenic belt in which the general stretching effect produced not only uplift but gravity faults. At this time this elevated region was no longer receiving sediments except along fault scarps and was now subject to erosion to a new base level.

The Fall Zone Peneplane

Some time before Upper Cretaceous beds were deposited in nearby Long Island, the Triassic basin was reduced to a surface of low relief. The evidence for this surface is extended from the New England province to the Palisades sill. Only the area between Alpine, N. J. and Staten Island, N. Y. preserves a remnant of this surface. Elsewhere in the Triassic Basin the surface has been destroyed. The present account of subsequent developments follows Johnson (1931) in supposing that the Cretaceous cover extended inland beyond its present exposure to some distance northwest of the Triassic Basin.

The covered, peneplaned rock mass was tilted southeast along an axis roughly parallel to the strike of the Cretaceous beds in Long Island. This elevated the area of the Triassic basin and permitted consequent streams to develop on the exposed Cretaceous sediments. The only trace of this original consequent drainage in the area is the course of the Hudson through the Highlands, but this too has probably been modified in succeeding cycles.

The uplift that initiated the consequent drainage also began a cycle which ended in the production of the Schooley (Upland) peneplane.

The Schooley Cycle

During the Schooley Cycle consequent streams developed long subsequents in the Cretaceous cover mass over the site of the area studied. Johnson (1931) saw evidence for such a subsequent lowland in certain broad-floored wind gaps in the Palisades and the Watchung Mountains. He supposes that an ancestral Hudson became superposed on crystalline rocks of the Highlands but had been captured by a subsequent working headward from the southwest in a weak belt of the Cretaceous above the site of the Triassic basin. (This would be similar to a river like the present Susquehanna turning right at the present Fall Line). The subsequent thus established extended from the headwaters of the present Croton river to the vicinity of Summit, N. J. Later in the same cycle (according to Johnson) this subsequent became superposed on the Triassic sediments and associated igneous rocks.

At this time the ancestral Hudson is pictured as emerging from the Highlands along its present course, having undergone some adjustment since its southeast consequent direction was established. Actually, the Hudson gorge trends generally north-south following local weaknesses in rock structure, and emerges at the tip of the Triassic basin. Thompson (1936) on the basis of this adjustment has suggested an entirely different history, namely, that the river simply worked by headward erosion up the Triassic belt between the Palisades and the New York crystallines and kept going through the Highlands. The writer is willing to grant that the course of the Hudson through the Highlands was produced by headward erosion along weak belts in the crystallines, but only to modify a less favorable course of a stream superposed from the Cretaceous cover.

To resume the narrative, the adjusted Highlands course led into a superposed subsequent wandering broadly over the Triassic basin cutting across the strike of both sediments and igneous bodies. This ancestral Hudson was joined by the Croton river, also a superposed subsequent, but on various types of crystalline rocks.

The Harrisburg Cycle

Uplift initiated the Harrisburg cycle which reduced less-resistant rocks to a low relief surface. This surface is preserved in the ridge summits of the Newark series and in the floors of Sparkill, Paterson, Milburn and other wind gaps. The ancestral Hudson is pictured as still flowing over the Triassic basin during the Harrisburg cycle, becoming graded and meandering through broad water gaps in the igneous bodies. The present wind gap floors are roughly two miles wide (from north to south) and must have held meandering streams. Traces of the Harrisburg peneplane have also been recognized as rock terraces in the Hudson gorge at Bear Mt. Inn and at West Point. The elevation of this surface is now roughly 200 feet.

Post Harrisburg Erosion

During the Harrisburg cycle, the Cretaceous beds must have been eroded back to a point far south of Sparkill Gap, thus uncovering the Triassic belt between the Palisades and New York. Resequents draining the Fall Zone developed subsequents along this belt. By the time the present Long Island Sound valley was developed, one of these subsequents captured the ancestral Hudson at Sparkill Gap, diverting it to its present course. Since the diversion, the Hudson widened its valley below Sparkill until the floor attained a width of one mile. This is in sharp contrast to the two mile width of the Tappan Zee north of the Gap. This greater width may be explained by broad meandering during the Harrisburg Cycle when the course south of the Gap had not yet been developed.

Glaciation

In the area studied only evidence of the Wisconsin glacier is visible. Striae on the Palisades indicate that the glacier crossed the Fall Zone Section and the Hudson Valley from northwest to southeast. Elsewhere in the Lowland, the glacier moved essentially parallel to the strike of the tilted Triassic sediments. This is indicated in part by the festooning of the moraines farther south.

During glacial wastage, and partly during glacial advance, ridge-forming belts of the Triassic received a heavy cover of ground moraine so that bedrock outcrops are scarce. Ponding of water in front of the receding ice edge was wide-spread. The largest lake was south of the area visited between the Watchung Mtns. and the border fault (Lake Passaic). Other lakes were formed in the Hackensack valley and its tributaries. Farther north, smaller lakes

PLATE 9

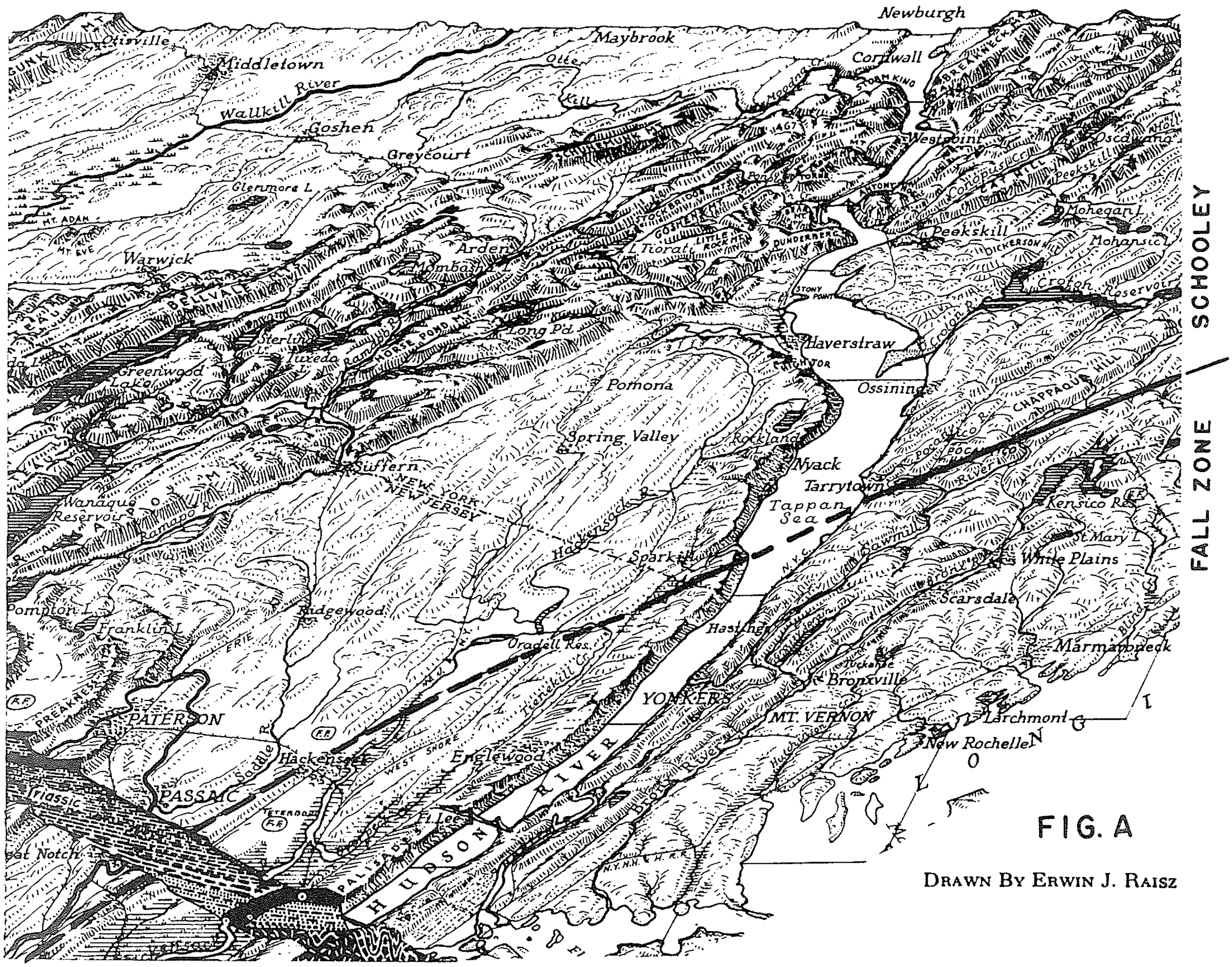

FIG. A

Drawn By Erwin J. Raisz

PHYSIOGRAPHIC DIAGRAM OF THE NEW YORK REGION

The Geographical Press,

Columbia University,

New York

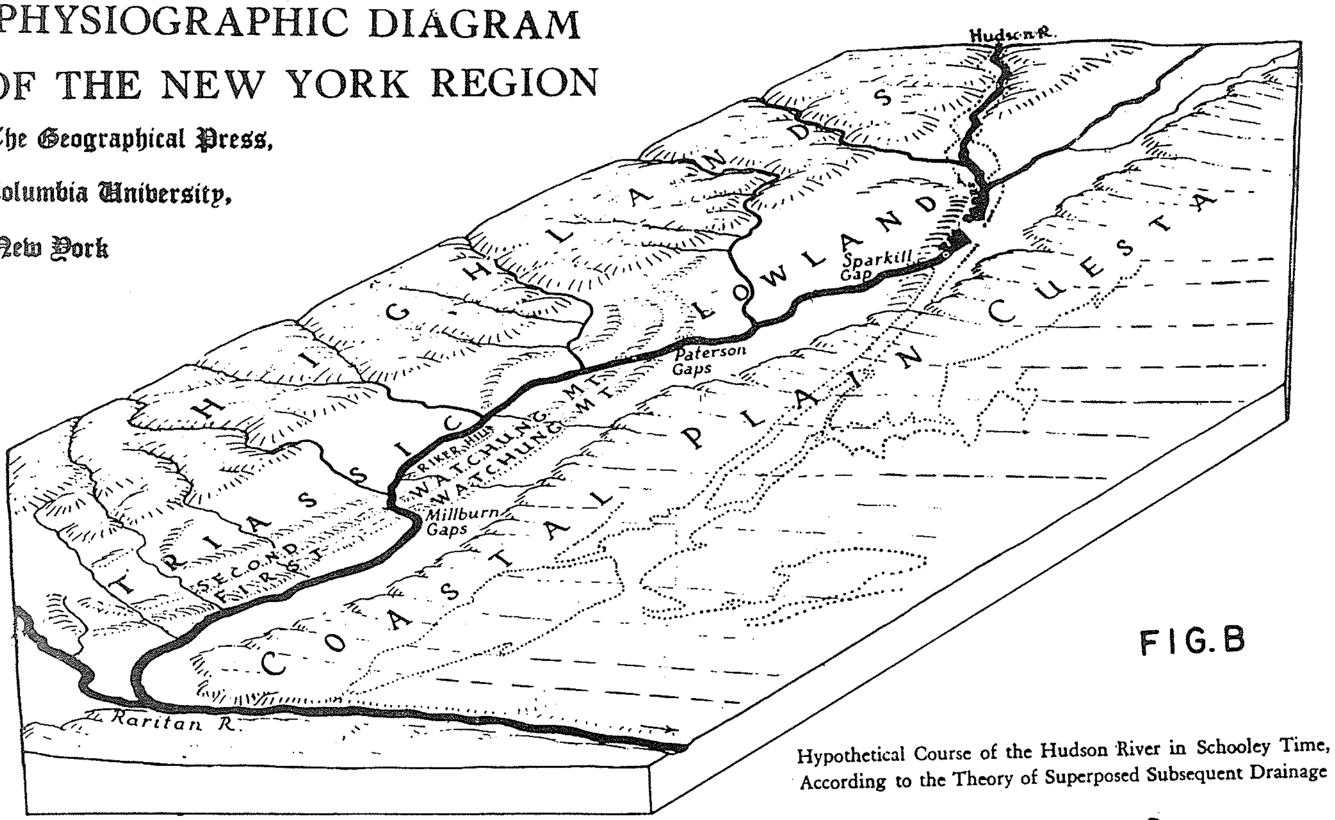

FIG. B

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)

produced deltas at the tip of the Palisades dike (Stop C-8). Complete removal of the glacier drained the lakes, and left the deltas as hills or terraces.. Since then, post-glacial stream erosion has modified the landscape but slightly.

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NORTHEASTERN SECTION OF THE TRIASSIC (NEWARK) BASIN IN NEW YORK AND NEW JERSEY

Trip C

Route Description

Mileage	Note: The first part of the trip (9.3 mi. to Bear Mt.) including Stop No. C-1 is the same as that of Trip D.
0	Shustin's Locust Manor (headquarters) -left (N) on Locust Ave.
.9	left (SW) on Oregon Rd.
2.2	pass under Bear Mt. Pkway.
2.3	right (W) on Pemart Ave.
2.5	right (N) on Highlands Ave. passing again under Bear Mt. Pkway.
3.0	roadcut through Gallows Hill; Annsville phyllite (Cambro-Ordovician Hudson River pelite group; see Trip 1, Stop 1-2).
3.3	pass under US-9 and turn sharp left (W) on approach road to US-9
3.4	straight (W) on US-9 following north shore of Peekskill Hollow Creek; note remnants of glacial deltas along both valley walls
4.3	right (N) on US-6-202
4.6	road starts climbing Highlands escarpment (fault line scarp); continuous exposures of Highlands crystallines (Pre-Cambrian gneisses, schists and granites) from here to Bear Mt. Bridge
7.4	Anthony's Nose lookout point STOP No. C-1: The Hudson River has cut a gorge through the Pre-Cambrian crystallines below the Schooley peneplane level, here shown by the hilltops. The rock bench on which the Bear Mt. Inn is located is interpreted as a remnant of the Harrisburg peneplane level formed by the Hudson River when it meandered at this level. Since Harrisburg time uplift permitted the stream to cut to lower levels before the valley floor was drowned. Glacial modification of the valley is indicated by its fiord-like walls and the shortcut east of Iona Island. The crystallines form an upthrown block of the fault associated with the Triassic Lowland to the south. See description of Trip D, Stop 1.
7.4	continue (N) on US-6-202
8.2	left (W) across Bear Mt. Bridge Excellent views crossing bridge: Left (S): Iona Island and southeastern gateway of Hudson gorge; prominent notch at Timp Pass (SW) where major thrust fault crosses Dunderberg-West Mtn. ridge crest Ahead (W): North side of bridge: Mouth of Popolopen Creek (drowned); Hell Hole fault notch between Bear Mtn. (left) and The Torne (right); Crown Ridge extending northeastward from The Torne; all these owe their topographic prominence to the Storm King granite Right (N): Southern portion of the Hudson gorge; Sugarloaf Hill on east shore (3 mi.) (Canada Hill granite phase); Livingstone Island (east shore, 1 mi.) and Cons Hook (west shore, 2 mi.) are separated from the shore by abandoned channels of the Hudson; bedrock terraces, particularly prominent on west shore.

Mileage

8.6 toll booths at west end of bridge

8.8 traffic circle; 3/4 around circle and then (S) on US-9W-202

9.3 pass under foot-bridge and bear left (do not turn right into road leading to Bear Mt. Inn)

10.3 Iona Island and abandoned river channel at left (E); Doodletown Brook (subsequent stream on Timp Pass-Hudson River thrust fault) at right (W); fault crosses road at this point

10.6 White, graphitic marble (Greenville ?) at right (W)

10.8 View of Hudson gorge and gateway to left (N)

11.8 Hudson River Reserve Fleet (ship "graveyard" of World War II) at left (E)

12.5 Verplanck Point quarry (Pre-Cambrian or early Paleozoic Inwood marble) across River at left (E)

13.4 Tomkins Cove quarry (Cambro-Ordovician Wappinger limestone) at left (E)

13.9 Wappinger limestone outcrop at left (E)

15.2 Stony Point traffic light; continue straight (S) on US-9W

15.3 cross bridge over Cedar Pond Creek; Triassic redbeds along both walls of gorge below

17.9 US-202 from right (traffic light); continue straight (S) on US-9W

18.2 traffic light; Haverstraw railroad station at left (E), Palisades (High Tor) at right (W)

19.4 right (SW) on NY-304 through deep roadcut in Palisades diabase

19.5 left (E) on road leading to Haverstraw quarry; bear right after leaving NY-304

19.8 level with crusher and loader at right (pick up Company guides)

STOP No. C-2: Haverstraw Quarry of the N.Y. Trap Rock Corp.

buses follow quarry road to left and take middle road (SE) at fork of roads; gentle uphill grade

20.1 Lower Quarry Level (appr. elevation 238 ft.):
The quarry, extending in a NW - SE direction, is in the intrusive diabase forming the northern arc of the Palisades. Here the strike of the diabase body is oblique to the strike of the Triassic sediments to the southwest indicating a cross-cutting relationship of the tabular igneous mass.

The prominent columnar structure of the diabase changes in attitude from nearly vertical (in the northeast quarry face) to easterly dips of 45^{0} to 50^{0} (in the northwest and southeast quarry faces). This feature suggests a rather abrupt change in the attitude of the intrusion with respect to the country rock from a gently dipping (15^{0} SW) sill-like body to a steeply dipping (45^{0} SW) dike. Preliminary results of recent extensive diamond core drilling on the Company's property bear out this contention (Fig. 2). It is not yet known whether the sill-like portion (Upper quarry level and Little Tor) is a true sill or a low-angle dike transgressing across the equally gently dipping Triassic sediments. The true thickness of the diabase intrusion appears to be approx. 700 ft.

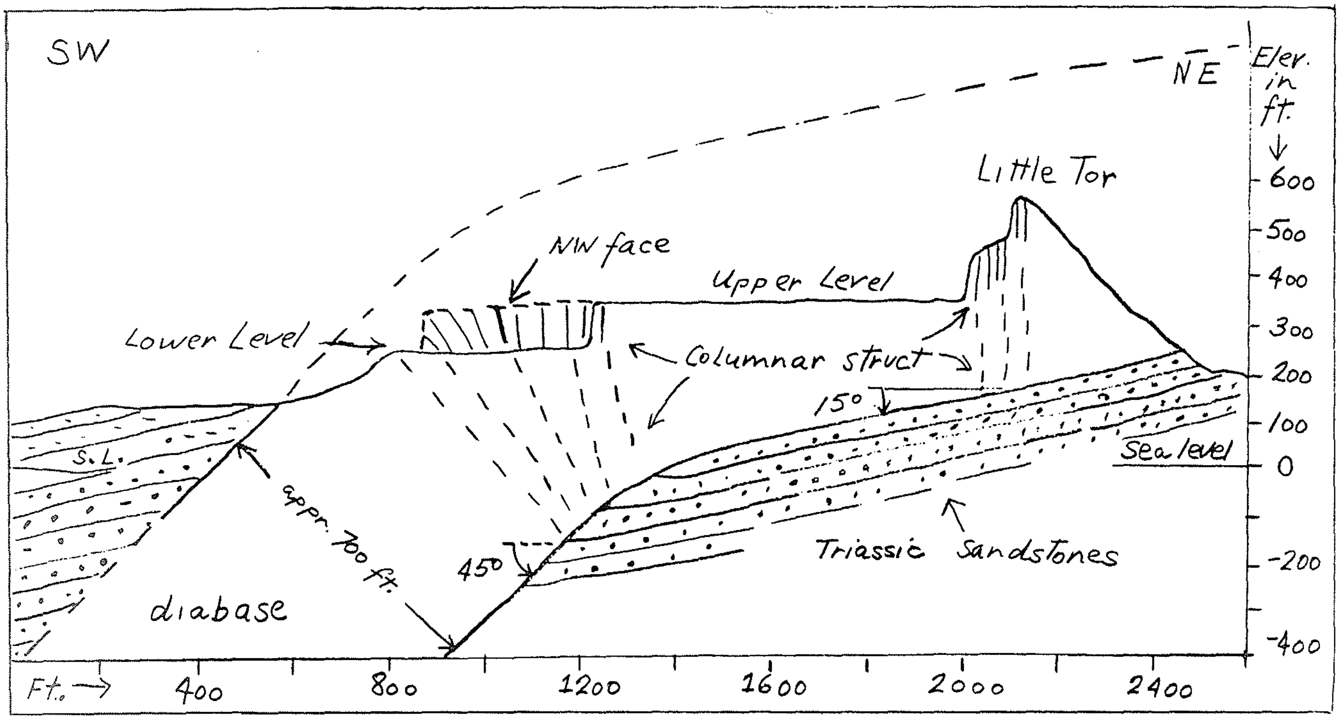

Fig. 2 Generalized Cross-section at Northwest End of Haverstraw Quarry

(New York Trap Rock Corp., K. E. Lowe, Geol. Consultant)

Farther south the upper contact of the steeply dipping diabase dike can be seen cross-cutting the Triassic sediments at the portal of the West Shore Railroad tunnel (mileage 22.7). No stop will be made at this locality.

Also observe occasional oblique shear planes with narrow zones of brecciation in the northeast quarry face.

20.2 return (NW) to crusher level

20.5 sharp right (SE) turn on road leading to upper quarry level; steep grade

20.9 Upper Quarry Level (appr. elevation 340 ft.):
On a clear day, a fine view of the Triassic Lowland shows the low sandstone ridges striking toward the observer and oblique to the diabase dike. The ridge line at the back of the quarry extends southward for several miles showing the mature dissection characteristic of the Schooley peneplane remnants. In the far distance (S) the even summit area of the Palisades is characteristic of the early mature dissection of the Fall Zone peneplane remnants. Sparkill Gap near the boundary of the two surfaces is hidden from view. The headwaters of the Hackensack River have been impounded to form the Lake DeForest reservoir seen directly south.
Turning toward the impressive northeast quarry face, osbserve extensive mass wasting aided by the near-vertical columnar structure and joint (shear) planes dipping toward the quarry floor. A 50 ft.

Mileage	
	wide bench at approx. 430 ft. elevation, indicating the earliest quarry level, has been almost buried under weathered debris. This represents one of the hazards of quarry operation, overcome in part by leaving ever wider benches on successively lower levels (thus reducing the rock volume that can be quarried).
20.9	return (NW) to crusher level
21.3	sharp left (SE) and then right (SW) road (downhill) at fork
21.6	left (SE) on macadam road
21.8	left (E) at intersection
22.4	right (SW) on US-9W; unusually well-developed, polygonal columnar structure at left (SE)
22.7	passing over West Shore Railroad tunnel; portal at right (S) below road shows steep upper contact of diabase dike cross-cutting the Triassic sediments
23.0	intersection with NY-303; straight (SE) on US-9W
24.8	cross Lake Rd. at Congers, N.Y.
26.9	roadcut through Palisades diabase
28.8	Nyack, N.Y.; left (E) at 2nd traffic light onto NY-59 (Main St.)
29.3	right (S) on Broadway
30.2	sharp left (E) on Cornelison Ave.
30.3	right (S) on Piermont Ave.
30.7	pass under N.Y. Thruway
30.9	Triassic redbeds (arkose of the Stockton formation) dipping gently NW (into cliff) at right (W) (behind bottling plant); top of outcrop approx. 150 ft. above sea level; Tappan Zee at left (E)
33.1	center of Piermont, N.Y. (Ash St.)
33.2	cross railroad tracks
33.3	buses turn right on Piermont Ave. and park

STOP No. C-3: Sparkill Gap

Note: Take your belongings, because the party will not return to buses until after lunch (approx. $1^1/_2$ hrs.)

As the Gap is approached from the north along the Hudson River several outcrops of the Stockton formation (mileage 30.9) extend up the valley wall to about 150 ft. above sea level. The contact with the diabase is not visible at these localities, but must be above 150 ft. elevation.

Walk across bridge into Tallman Mt. Section of the Palisades Interstate Park. Follow shore road southward. Here the diabase is first seen extending to sea level. Although the contact is not exposed at this point, its position can be estimated from the location of the olivine zone about 30 ft. above sea level. Elsewhere, this zone is known to lie about the same distance above visible contacts. It is interpreted as the result of magmatic differentiation by gravitative settling of early olivine crystals in the still fluid diabase magma. The olivine concentration in the zone is up to 25%.

Continuing along the shoreline past the swimming pool, an outcrop of arkose holds up a low terrace a few feet above sea level. A ledge at the back of the terrace is indurated arkose near the igneous contact, which is not exposed. The higher slopes expose fine-grained diabase and farther up the olivine zone.

Farther south, at a place not to be visited, the contact rises to over 10 ft. above sea level. It is evident, therefore, that there is a sag in the base of the sill at Sparkill Gap which may be associated with faulting. That a thickening of the diabase is not involved, is indicated by a distinct narrowing of the width of outcrop at the Gap.

We now walk back up the automobile road to the level of the Gap floor (some 200 ft. above sea level). Here coarser diabase outcrops nearer the interior of the sill. We are close to the north side of the Gap which extends southward for about 2 miles before the slopes rise to the summit at 500 ft. elevation (see mileage 36.1 to 36.7).

To the north, we look down on the water gap of the Sparkill. An offset of the diabase on the west side of the gap indicates that this creek follows a cross fault. It is the only stream cutting through the Palisades for its entire length from Haverstraw, N.Y. to Bayonne, N.J. On the other (N) side of the Sparkill the diabase slopes rise to rounded hills reaching heights of 700 ft. Care must be taken to distinguish between the actual water gap of the Sparkill and the interpreted earlier wind gap of broader dimensions and greater height (Plate 9, Fig. A).

Johnson (1931) interpreted the wind gap as a part of the former course of the Hudson River established as a superposed subsequent during the Schooley cycle. Later the river cut a water gap through the Palisades sill during the Harrisburg cycle. This water gap was abandoned when capture diverted the Hudson into its present course southward. At this time a reversal of drainage through the gap established the Sparkill as a tributary to the Hudson along the fault line mentioned above. (Plate 9, Fig. B).

Lunch in picnic grounds at north end of Tallman Mt. State Park return to buses via the same route

33.3	board buses and continue (SW) on Piermont Ave.
34.1	left (S) on Valentine St.
34.2	straight on Union Ave.
34.3	left (W) on US-9W sign
34.5	straight (S) on US-9W
35.8	cross road leading to Lamont Geological Observatory of Columbia University (left -E)
36.1	US-9W climbs south wall of Sparkill Gap
36.7	cross New York - New Jersey border
37.0	pass under Palisades Interstate Pkway.
40.0	pass Alpine Rd. (underpass at left - E)
40.7	intersection with NJ-201; continue straight (S) on US-9W
45.2	turn off road to right in front of large (burnt-out) road house Pause (if time permits): Discussion of Fall Zone peneplane level
45.7	cross NJ-503; straight (S) on US-9W
47.2	right (SW) on US-9W

Mileage	
47.9	right (W) at Turnpike sign on overpass; keep right (N) on US-4
49.0	right)NE) before reaching overpass
49.1	left (W) over bridge (overpass spanning US-4)
49.2	park at right beyond bridge; buses will make U-turn facing east

STOP No. C-4: Flatrock Brook, N. J.

The outcrop of diabase near the road is close to the upper contact of the Palisades sill. It is fine-grained and cut by thin acidic dikes. The hill-slope down toward the Brook approximates the dip-slope of the upper contact. The contact zone appears in the Brook as the diabase gives way to light-colored baked shales with low northwesterly dips. The actual line of contact is obscured by cover. Similar baked shales are found at the lower contact near Edgewater, N. J. but of much darker hue. The baked shales of the upper contact continue south along the strike of the sill. Their most impressive exposure is in Granton Quarry at North Bergen, N. J. where they underlie a subsidiary sill of diabase. Fossil fish (coelacanths) and a small crustacean (ostracod) have been collected from that locality. Both the lithology and fossil content of these beds strongly suggest the Locatong formation, although they occur many miles north of the main outcrop area of this formation.

Looking east from the road outcrop, one sees US-4 descending a valley which runs oblique to the upper contact in a northerly direction. The valley follows a fault line of the gravity type with downthrow on the east. The vertical displacement is approx. 100 ft. and appears to be related to adjustments connected with the emplacement of the magma.

Looking west, one sees the drowned valley of Overpeck Creek and beyond, the low sandstone ridges of the Brunswick formation, approx. at the Harrisburg level. The skyline ridge is the First Watchung Mountain, a lava flow (fissure type) approximating the Schooley level. It should be possible to make out the Paterson wind gap which is similar in form and origin to the Sparkill Gap.

49.2	re-cross bridge (E)
49.3	right (S)(downhill)
49.4	right (NE) on US-4
55.7	right on approach road to NJ-17
55.8	straight (NW) on NJ-17
60.0	cross Linwood Ave. (traffic light) and turn right (NE) on Van Emburgh Ave. keeping straight ahead at blinker light
61.4	straight (E) on Washington Ave. (traffic light)
62.1	follow curve to left
62.5	straight (N) on Woodcliff Heights Rd. (uphill) paralleling the Garden State Pkway. (right -E)
62.7	park buses near top of hill

STOP No. C-5: Woodcliff Lake area - Brunswick Formation

Construction of the Garden State Pkway. below produced this new road and outcrop. These are rather typical sandy beds of the Brunswick formation. The shaly beds are usually found in the valleys. The brown sandstones here contain a few pebble beds which could be stream channel deposits. Conglomerate cobbles similar to those found near the border fault (Stop C-6) in alluvial fan deposits suggest a westerly source. This outcrop is about 8 miles from the border fault.

63.5 left (W) on Saddle River Rd.

63.7 left on Chestnut Ridge Rd.

64.0 left into Woodcliff Lake Rd.

64.7 straight ahead, crossing Chestnut Ridge Rd.

65.0 left on E. Allendale Rd. (downhill)

65.6 cross bridge over Saddle River

66.3 right (N) at traffic light on NJ-17

69.0 straight (N) on NJ-507 (Franklin Turnpike)

71.7 US-202 from left (underpass); continue straight (N)

71.8 right (NE) at road fork on Washington Ave., Suffern, N.Y.

72.3 cross Lafayette Ave. (traffic light)

72.4 cross railroad tracks

72.7 right at stop sign under N.Y. Thruway onto US-202

72.8 park at right (on US-202); outcrop along road (uphill) at left (NW)

STOP No. C-6: Triassic Border Fault (Suffern, N.Y.)
The outcrop consists of badly sheared, Pre-Cambrian (granite) gneisses. Many slickensided surfaces are parallel to the surface of the border fault. The lineation (fault striae) approximates the direction of relative motion along the fault. While this is not considered to be the actual fault plane (dipping steeply southeast with downthrow of Triassic sediments to the south), it is probably within the fault zone. From a high point one sees the escarpment (Ramapo Mts. of the Hudson Highlands) extending beyond the Thruway toward the southwest. This escarpment is the product of differential erosion along the fault whose relative motion dropped the Triassic beds down on the southeast in contact with the Pre-Cambrian crystallines. The whole mass was deeply eroded by the time the Schooley peneplane was produced. The escarpment was developed later as a consequence of regional uplift.
Looking southeastward toward the Triassic Lowland, a prominent hill just across the Thruway is an eroded plug-like intrusion of diabase (now being quarried for crushed rock).

73.3 US-202 swings away (S) from fault line proceeding on the rocks of the Triassic basin

75.2 Y-intersection with Viola Rd. (Antrim Playhouse sign); park in triangular plot at right of US-202; outcrops on both sides of road

STOP No. C-7: Triassic Border Conglomerate
These outcrops are about 1/4 mile east of fault line. Here the Mahwah River has etched a valley along the fault zone in Triassic beds. The outcrop at left (NW) side of road indicates former alluvial fan which was banked up against the original fault scarp. The presence of early Paleozoic cobbles, sometimes only slightly rounded, and the absence of the crystalline cobbles lead to several conclusions: (1) streams cutting into the upthrown block were relatively short, (2) the upthrown block was much higher than at present and contained a thick Paleozoic cover, (3) as the streams cut into this

cover they nowhere reached the Pre-Cambrian basement, and (4) the upper surface of the fan must have been higher than the present Schooley level.

What we see now are a few remnants of this fan showing typical torrential cross-bedding and rapid changes in grain size. Cobbles consist of Cambrian quartzite, Cambro-Ordovician limestones and Silurian-Devonian conglomerates. None of these rocks are now present on top or within the Pre-Cambrian crystallines of the Hudson Highlands directly to the northwest. Some have been preserved, however, as inliers to the west (along the New York-New Jersey border and in the New Jersey Highlands). They also outcrop abundantly in the Great Valley beyond the present Highlands to the north and northwest.
On the east (SE) side of the road, pebble beds decrease and a more normal Brunswick aspect appears, similar to that seen at Stop C-5.

75.2 continue (NE) on US-202

76.1 Lime Kiln Rd. at right (S); fine-grained diabase; intrusions of diabase outcropping intermittently along south (right) side of road for the next $1^1/_2$ miles are presumed to be one or more plug-like bodies or dikes; rare contact exposures show cross-cutting relationships.

76.4 coarse border conglomerate at right (S)

76.7 coarse border conglomerate on both sides of road

76.9 to 77.1 fine-grained diabase with columnar structure at right (S)

79.5 park at entrance of sand and gravel pit at left (N) side of road

STOP No. C-8: Mt. Ivy Glacial Delata
This appears to be a fairly normal delta deposited in a periglacial lake, with typical top and foreset beds. No varved clays are exposed. The elevation of the delta top is 400 + ft., which indicates that it was a local lake feature not connected with the Hudson River 4 miles to the east.

79.5 continue (E) on US-202

79.7 pass under Palisades Interstate Pkway.

82.3 View of Palisades ahead to right (E); westerly end of hook-shaped Palisades ridge (dike) rising from beneath Triassic sediments (Plate 13)

83.1 sharp left (NE) downhill on shortcut to US-9W (sign at right)

83.2 traffic light; left (N) on US-9W

85.3 cross bridge over Cedar Pond Brook (see mileage 15.3)

85.4 Stony Point, N.Y. traffic light; straight (N) on US-9W

86.0 right (NE) downhill at entrance to Stony Point Battlefield Reservation (Park Rd.)

86.2 Y intersection; park at right side of road

STOP No. C-9: Triassic Fanglomerate at Stony Point, N.Y.

This remarkable remnant of another alluvial fan consists almost entirely of semi-rounded Wappinger limestone (Cambro-Ordovician) pebbles poorly cemented by calcite and hematite.. The source formation can be seen in place along a road to the north (mileage 86.5) and has wide exposure in the Tomkins Cove quarry 1/2 mile to the north. The occurrence of the Cortlandt complex and some gneisses of dubious age at Stony Point to the east suggest some complicated step-faulting in the region.

86.2 take left fork at Y (Park Rd.)

86.3 sharp left (W) uphill

86.5 roadcut through folded Wappinger limestone (Cambro-Ordovician); this belt of limestone widens northward where it is quarried at Tomkins Cove (1/2 mile)

86.6 right (N) on US-9W

Note: Return trip from here to Peekskill headquarters follows the same route as taken in the morning (except Stops C-1, C-2 and C-3)

90.1 entrance to Hudson River Reserve Fleet at right; US-9W starts climbing Highlands escarpment (fault line)

91.1 View of Hudson gorge to right (N)

93.2 Bear Mt. bridge traffic circle; right (E) on US-6 and across bridge; turn right (S) at east end of bridge

97.7 left (NE) on US-9 along north shore of Peekskill Hollow Creek

98.6 right (SE) turn-off to Highlands Ave. and Annsville (Gallows Hill) roadcut

99.5 left (E) on Pemart Ave. after passing under Bear Mt. Pkway.

99.7 left (NE) on Oregon Rd. again passing under Pkway.

101.1 right (SE) on Locust Ave.

102.0 right at headquarters.

PRE-CAMBRIAN AND PALEOZOIC GEOLOGY OF THE HUDSON HIGHLANDS

Kurt E. Lowe
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Trip D

Introduction

The route of Trip D crosses the Hudson Highlands northwestward (perpendicular to the structural trend) affording opportunities of studying the petrology, structure and geomorphology of the Pre-Cambrian crystallines. It then turns northeastward to reach the northern gateway of the Hudson gorge at Cornwall-on-Hudson by following the belt of early Paleozoic sediments along the northwest border of the Highlands. These sediments and their structural relations to the Highlands crystallines are briefly examined in the field. The return leg of the trip again crosses the Highlands (this time oblique to the structure) along the west side of the Hudson gorge to Bear Mt., where it crosses the River to Peekskill.

The reader is referred to Lowe (1949, 1950) from which much of the following information has been extracted.

The Hudson Highlands

The Highlands are a chain of low, but rugged, mountain ranges extending about 140 miles from Reading, Pa. northeastward through northern New Jersey and southeastern New York into western Connecticut. They are mostly Pre-Cambrian crystallines, representing an ancient orogenic belt of Grenville (?) sediments which were folded, faulted, metamorphosed and invaded by several igneous phases (Plate 1).

The Hudson Highlands, a rather loose geographical term, refers to that portion of the mountain chain which lies athwart the Hudson River in New York State.

Geomorphology

Geomorphically the Highlands are known as the Reading Prong of the New England Upland.

In view of the long, continued exposure of the Highlands to subaerial erosion (perhaps since early Mesozoic times) present topographic features exhibit the effects of structural and lithologic control to a high degree. Hessian Lake, a glacially scoured depression along the contact of the resistant Storm King granite and the weaker metasediments (Stop D-2), and the prominent notch at Timp Pass where a major thrust fault crosses the ridge (seen from Stop D-3) are but two examples observed on this trip.

In some instances even minor internal rock structures (e.g. obscure platy flow structure in the Storm King granite) are emphasized by the development of subsequent erosional surfaces (Stop D-2 and Plate 12, west shore of Hessian Lake). Thus geomorphic expression is frequently used to interpret concealed or questionable subsurface structures.

The origin and development of the Hudson Rivergorge through the Highlands has been a source of controversy for many years. The reader is referred to the discussion of Trip C(and Stop C-1), written by a geomorphologist, for a brief resume of the salient features and arguments.

An unusual erosional feature in this Highlands terrane is the Natural Bridge at the southwest end of Popolopen Lake where a creek flowing into the lake has tunnelled through a thick bed of coarse (Paleozoic ?) marble.

Certain characteristic weathering phenomena also bear mentioning. The Storm King granite exhibits prominent sheeting or exfoliation parallel to existing topographic surfaces (Stops D-2 and D-3), which can best be explained by "unloading".

In localities where glaciation failed to remove the residual mantle this granite weathers to a characteristic "rubble". The elongate weathered fragments were produced by kaolinization of the feldspars and relative preservation of the parallel alignment (lineation) of the hornblende prisms (Stop D-3).

Huge talus boulders of Storm King granite (often parts of ancient landslides) are common along the steep flanks of Bear Mt. where they were derived by mechanical weathering of joint blocks produced by near-vertical longitudinal (SW-NE) and transverse (NW-SE) joints (Stop D-2; west shore of Hessian Lake).

Evidence of Wisconsin glaciation is abundant. Upland surfaces (Bear Mt., The Torne, etc.) show glacial polishing and chatter marks. Glacial striae, however, are relatively uncommon, because weathering and exfoliation on exposed granite ledges have effectively destroyed such markings. Glacial boulders are scattered over the entire region. Till and drift have accumulated to considerable depths in some of the valleys (e.g. Doodletown Brook valley, Popolopen Creek valley NE of lunch stop, etc.).

Regional Structures

The folded structure of the Highlands is clearly indicated by the topography of the Bear Mt. region (Plate 10). Ridges of resistant Storm King granite, which was intruded conformably with the structure of the country rocks, depart from their prominent northeasterly trend indicated by Cranberry Hill - Long Mt. - Holmans Hill. The trends of Turkey Hill - Summer Hill - West Mt. - The Timp - Dunderberg (the last two are not shown on Plate 10) describe a distinct arcuate pattern with Bear Mt. as the center. Field measurements proved the existence of a large, synclinal structure with a northeast plunge of 40^0 at Bear Mt., steepening rapidly to 50^0 and 60^0 at Fort Montgomery.

The major, probably Pre-Cambrian, faults strike northeast (parallel to the tectonic trend) and indicate overthrusting to the northwest. The more northerly strike of the Timp Pass- Hudson River fault (north of Doodletown Brook) suggests possibly Paleozoic (Taconic) origin. Overthrusting along this fault is believed to account for the absence of the eastern limb of the Bear Mt. syncline and for intense crumpling, shearing and overturning of minor folds in the Doodletown Brook valley (thrust sole).

Cross faults at Highland Brook, Popolopen Creek and Hell Hole are interpreted as high-angle tear faults with large vertical components of displacement (Plate 13).

The northwest and southeast borders of the Hudson Highlands are in fault contact with the younger sediments. Along the southern margin of the Highlands the Triassic sediments west of the Hudson have been down-dropped along a series of prominent normal faults (Ramapo fault between Suffern, N.Y. and Stony Point, N.Y. - Trip C, Stops 6, 7 and 9). A continuation of this fault east of the Hudson is partially responsible for the preservation of the Paleozoic Peekskill inlier (Trip 1). Along the northern border of the Highlands, the Pre-Cambrian crystallines have been thrust over the early Paleozoic sediments of the Great Valley along steeply southeast dipping fault planes. In some localities (as at Stop C-6) thrust slices have produced crystalline outliers.

HUDSON HIGHLANDS IN THE VICINITY OF BEAR MT., N.Y.

PLATE 10

THRUST FAULT (TO NW)

NORMAL FAULT

SYNCLINAL AXIS

1 0 1 2 3

MILES

STOPS: D-1, D-2, D-3, D-4, D-L

STORM KING GRANITE

LINEAR) FLOW STRUCTURE
PLATY)

Petrology

Highlands Complex

This term includes the entire sequence of Pre-Cambrian crystalline rocks older than the Storm King granite, which is the youngest of the Highlands granites and the only one which can be readily identified in the field.

The oldest components of the Complex appear to be meta-sediments of Grenville (?) age (according to Berkey and Rice, 1919) comprising quartzitic, micaceous and calcareous rocks which are characteristically layered and were intensely metamorphosed during several intervals of regional deformation and igneous invasions. A great variety of rock types resulted. At Bear Mt. where the Grenville (?) series constitutes the major part of the Complex, biotite, hornblende, epidote, and graphite schists and garnetiferous biotite gneisses are common. Some of these will be seen at Stops D-2 and D-3.

In many localities (e. g. Doodletown Brook valley opposite Iona Island) intercalated lenticular beds of graphitic marble, showing intense plastic flow deformation are exposed. The calcareous and foliate facies of the Grenville series behaved as incompetent layers compared with the rocks more clearly associated with igneous activity (mainly granites, granite gneisses and pegmatites). Hence these beds appear most frequently distorted, crumped and drag-folded. They are also most readily affected by chemical weathering and are therefore differentially eroded to produce most of the topographic lows of the region (Hessian Lake, Stop D-2).

The oldest igneous representative distinguishable in the Hudson Highlands is of dioritic composition (Pochuck diorite) and almost always intimately associated with the Grenville metamorphics (Berkey and Rice, 1919). Exposures of the uncontaminated diorite parent rock are rare, but have been observed by the writer on the west shore of Lake Tiorati (7 miles SW of Bear Mt.) and by Colony (1921) in some of the old magnetite mines in this region. The writer, therefore, prefers to use the term Pochuck diorite phase.

In place of the Canada Hill, Reservoir and Mahopac granites described by Berkey and Rice (1919), the term Canada Hill granite phase includes all rocks representative of granitic igneous activity in the Hudson Highlands after the Pochuck diorite phase and earlier than the Storm King granite intrusion. Perhaps the most typical representative of the Canada Hill phase is a medium-grained, medium-gray biotite granite. The white and gray feldspars are principally albite-oligoclase and perthite with orthoclase and microcline sometimes present in appreciable amounts. Gray quartz is an essential constituent, and violet-red to dull-red garnet is an abundant accessory. Biotite flakes are characteristically oriented in layers which give the rock a faint to excellent foliation structure depending on the quantity of biotite present. The writer believes that metasomatism (granitization) is responsible for the formation of the granitic rocks of the Canada Hill phase.

An excellent example of selective replacement by fluids of the Canada Hill phase can be observed at Stop D-3. Below the Storm King granite contact, layers of granitic composition alternate with biotite schists and biotite-hornblende gneisses. The layers of different composition are sharply defined, have uniform thickness, and can be traced for more than 600 feet at this locality. The granitic layers are remarkably uniform, medium-grained quartz-feldspar rocks containing discontinuous stringers of coarser pegmatitic material invariably oriented parallel to the rock structure. There are no dikes or off-shoots from these granitic rocks into adjacent, thin, continuous layers of well-foliated and fissile biotite schist and hornblende gneiss. Under the microscope, intergrown aggregates of feldspar (microperthite, acid plagioclase and microcline) seem to have replaced the larger quartz grains, producing deeply embayed outlines and veinlike structures along visible fractures. The quartz is clear and has uniform extinction. Also most of the larger feldspar grains are not confined to a particular variety and contain a profusion of unoriented inclusions of all other types of feldspar.

All these features strongly suggest replacement and recrystallization of a pre-existing rock (possibly a rather pure arkosic sandstone) by hydrothermal solutions, rich in alkalies, from a magmatic source of perhaps granitic composition. The writer has suggested the term "pseudo-alaskite" to describe these igneous-looking rocks which are comparable in texture and composition to intrusive alaskites. It is interesting to note that where biotite appears in visible quantities, the rock becomes indistinguishable from an intrustive biotite granite such as the Canada Hill granite of Berkey and Rice (1919).

The Highlands Complex is cut by a variety of pegmatites which have not been studied in detail and are difficult to relate to a particular magmatic phase in the long and involved geologic history of the region. Frequent dikes of a coarse,pinkish quartz-microcline-hornblende pegmatite, however, can be recognized as off-shoots from Storm King granite intrusions (often not exposed in the vicinity).

Storm King Granite

The Storm King granite represents the last major invasion of magmatic origin in the Hudson Highlands. In contrast to the great variety of rock types in the Highlands Complex and their involved field relations, this granite occurs in large masses of rather uniform character. Hence, it is the most distinct lithologic unit encountered in the crystallines of the Hudson Highlands.

The typical Storm King granite (Berkey and Rice, 1919) is a medium-to coarse-grained rock which is dull gray on fresh exposures, sometimes with a greenish to pinkish-buff tinge and a somewhat greasy luster. Its characteristic streaky appearance, the result of linear alignment of the dark minerals, constitutes one of the most constant structural criteria for the recognition of this granite in the field.

More than 60% of the rock (by volume) is gray and reddish feldspar. Microcline, microcline-microperthite and perthite predominate. Orthoclase and albite-oligoclase occur in relatively minor amounts. The abundance of potash feldspars is perhaps the most characteristic petrographic feature. The quartz content ranges from practically none to about 30% by volume. Subhedral to euhedral hornblende is the important mafic mineral, but augite and biotite may be present. Common accessory minerals are zircon, apatite and magnetite. Allanite is present occasionally.

Certain distinct mineralogical changes occur in the granite near contacts with the Highlands Complex. Composition of this contact facies seems to be related to the lithology of the adjacent country rocks. Increasing quantities of biotite, plagioclase feldspars, garnet and graphite are usually present near contacts with basic Grenville gneisses and schists. Lack of dark constituents, increase of potash-soda feldspars (perthite) and abundance of quartz characterize contacts with rocks of the Canada Hill phase. Another rather unusual type of contact facies may be observed at Stop D-3 where intense chloritization along quartz fractures and feldspar cleavages imparts a dark-green color to the rock.

Brownish-green quartz has a decidedly greasy luster. Biotite partly altered to chlorite is the dark mineral.

Most of these contact features are undoubtedly the result of reaction between the Storm King magma and its wall rocks. Cross assimilation (reactive solution and precipitation) involving an exchange of certain components (Shand, 1943, p. 95) would account for the field evidence. The writer believes that local contact zones rich in chlorite and quartz can be explained more satisfactorily by the action of volatile end-stage products, escaping from the Storm King magma, upon the chilled borders of the intrusion.

Linear parallelism of prismatic hornblende crystals and crystal aggregates is characteristic and gives the rock a streaky, gneissoid appearance on most exposures. This linear structure has a constant orientation of N 40^{0} E, 40^{0}, or nearly parallel to the tectonic axis of the Bear Mt. syncline (Plate 11, Fig. B). In the marginal portions of the granite mass at Bear Mt., the linear hornblende elements commonly acquire an additional plane-parallel alignment. Such platy structure has invariably the same attitude as the nearest granite contact surface (Plate 11, Fig. B).

Petrofabric studies reveal that quartz grains in the interior of the Storm King granite mass have no clearly preferred space-lattice orientation. There is certainly no evidence of a tectonic pattern of orientation of the quartz c-axes.

At Bear Mt., this granite occupies the core of the syncline (maximum thickness: 3000 ft.) and extends in sheet-like fashion along its western limb, forming the continuous ridge crests of the Torne, Crown Ridge and Bare Rock (Plate 10). Contact exposures aggregating some 5000 ft. prove that the granite mass is entirely concordant with the structure of the Highlands Complex. Contacts are sharp and show no gradational transition. Xenoliths of the country rocks are found only in the near-contact portions of the granite. They generally maintain the same structural attitude as the adjacent parent rocks and exhibit sharp, angular borders without any evidence of fusion (Stop D-3).

Emplacement of the Storm King granite

The evidence cited appears to be in favor of magmatic intrusion of the Storm King granite in the form of a synclinal pluton following the pre-existing structure of the Highlands Complex. Linear and platy mineral structures are interpreted as the result of magmatic (laminar) flow of a viscous melt.

Postkinematic nature of the intrusion is indicated by complete absence of secondary foliation and lack of preferred (tectonic) orientation of quartz space-lattices. Since this sizable granite pluton was evidently the result of quiet intrusion at depth and under no great deformational stress, it is unlikely that it made room for itself by lifting the overlying country rocks. It is suggested, therefore, that gradual sagging of the synclinal structure under plastic conditions into the emptying magmatic chamber below created space in the more solid rocks above, which in turn was occupied by the rising magma. This concept of "exchange of space" was first proposed by Loewinson-Lessing (1933) to explain emplacement of large, gently dipping trap sheets in Siberia.

In the Hudson Highlands, field evidence proves that the Storm King granite is unquestionably younger than the Canada Hill granite phase. Recent potassium-argon age determinations on feldspars and mica from both granites by the Lamont Geological Observatory of Columbia University indicate that the Canada Hill phase is from 800 to 900 million years old while the age of the Storm King granite is between 600 and 700 million years.

About 12 miles southwest of Bear Mt. (Plate 13) the Storm King granite disappears as a recognizable intrusive unit and mixed granite gneisses take its place, suggesting formation by granitization rather than by magmatic intrusion. In the Highlands of New Jersey and Pennsylvania, the Byram and Losee gneisses which were correlated by Berkey and Rice (1919) with the Storm King and Canada Hill granites respectively, appear to be of nearly the same age, because they have been found cross-cutting each other.

This age discrepancy and somewhat different mode of formation of the principal granite phases in the continuous Highlands chain of mountains may be simply a function of the regional structure. The tectonic structure of the Highlands has a consistent northeast plunge. Thus the Hudson Highlands represent a younger stratigraphic horizon than those of New Jersey and Pennsylvania. Both granites probably originated from a single magmatic source, in view of their very similar chemical composition, which differs to any extent only in the potash-soda ratio.

In the southwestern Highlands, granites were formed at greatest depth, i.e. under greatest pressure and temperature. In such environment the magmatic fluid was probably very liquid, mobile and chemically active, because it still contained all its volatiles, and therefore was peculiarly well suited to act as "granitizing agent". The most volatile and reactive components (soda-rich in this case) then penetrated the upper rock horizons, causing formation of the Canada Hill granite phase by metasomatism. At the same time, the viscosity and chemical stability of the residual liquid gradually increased, with loss of volatiles, until a true magmatic melt had formed. With increasing viscosity, this (potash-rich) magma intruded ever more slowly into the higher levels of the crust to form the Storm King granite.

In conclusion, it might be suggested that the opposing camps of "granite makers" are not nearly as far apart as they would have us believe. It is quite plausible that granitization and magmatic intrusion are merely phases of one and the same process and depend largely upon the crustal horizon at which the formation of a granite takes place.

Dike Rocks

Basalt dikes cutting all the crystalline rocks are the only evidence of post-Storm King (Paleozoic or Mesozoic) magmatic activity in the Hudson Highlands. They appear in large numbers throughout the Highlands terrane and vary in composition from dioritic to camptonitic. Some acid varieties were described by Kemp (1888). The dike materials evidently chilled rapidly and were clearly guided by open fractures in the crystallines. Contacts are always sharp and evidence of contact effects is lacking, both in the dike and wall rocks.

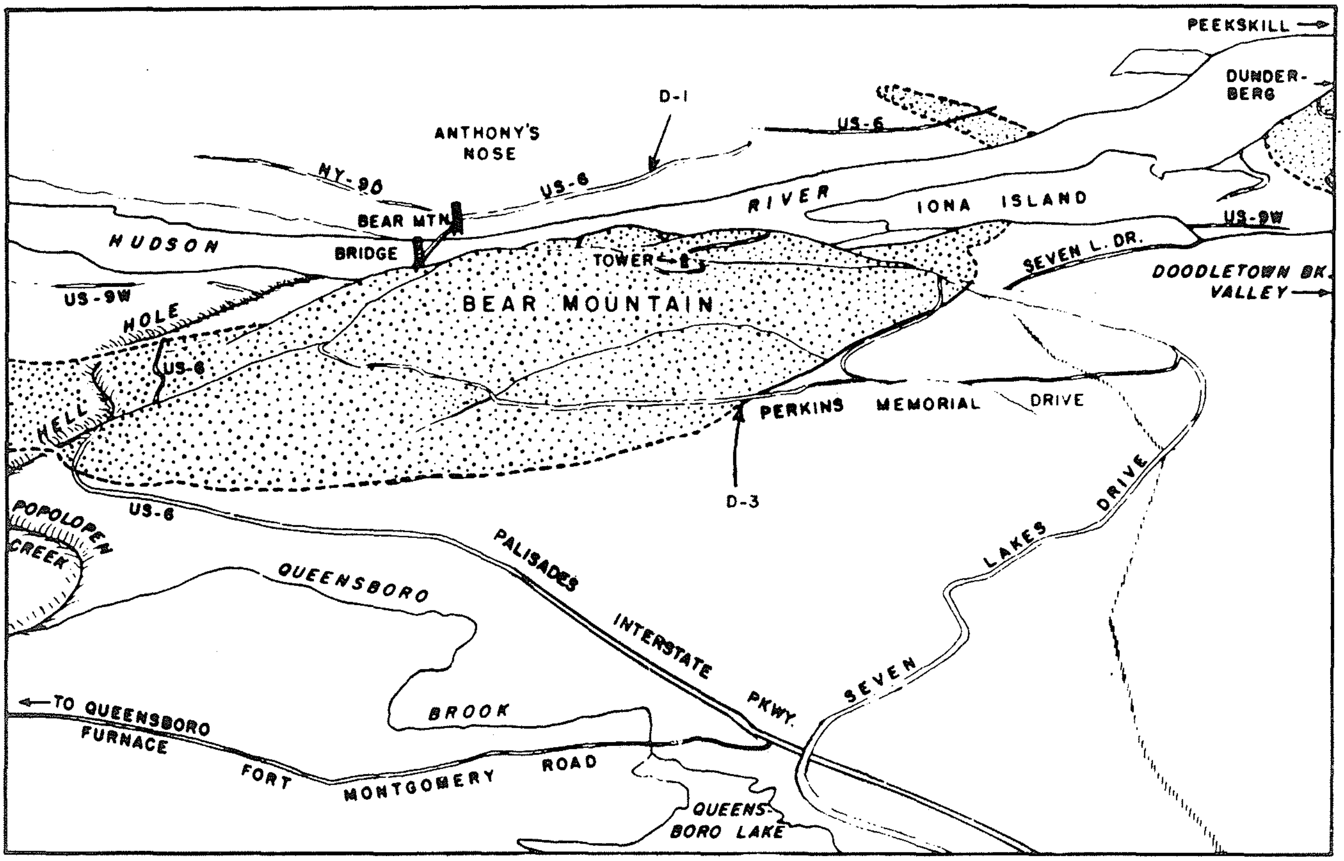
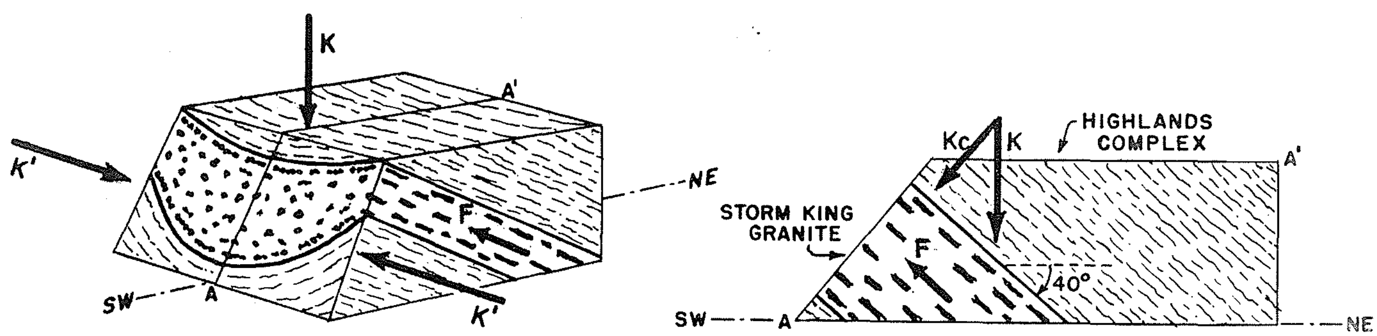


FIG. A VIEW OF BEAR MT., N.Y.

LOOKING EAST FROM 5000 FT.
STORM KING GRANITE STIPPLED



Perspective View

Section AA'

F- DIRECTION OF FLOW DURING INTRUSION

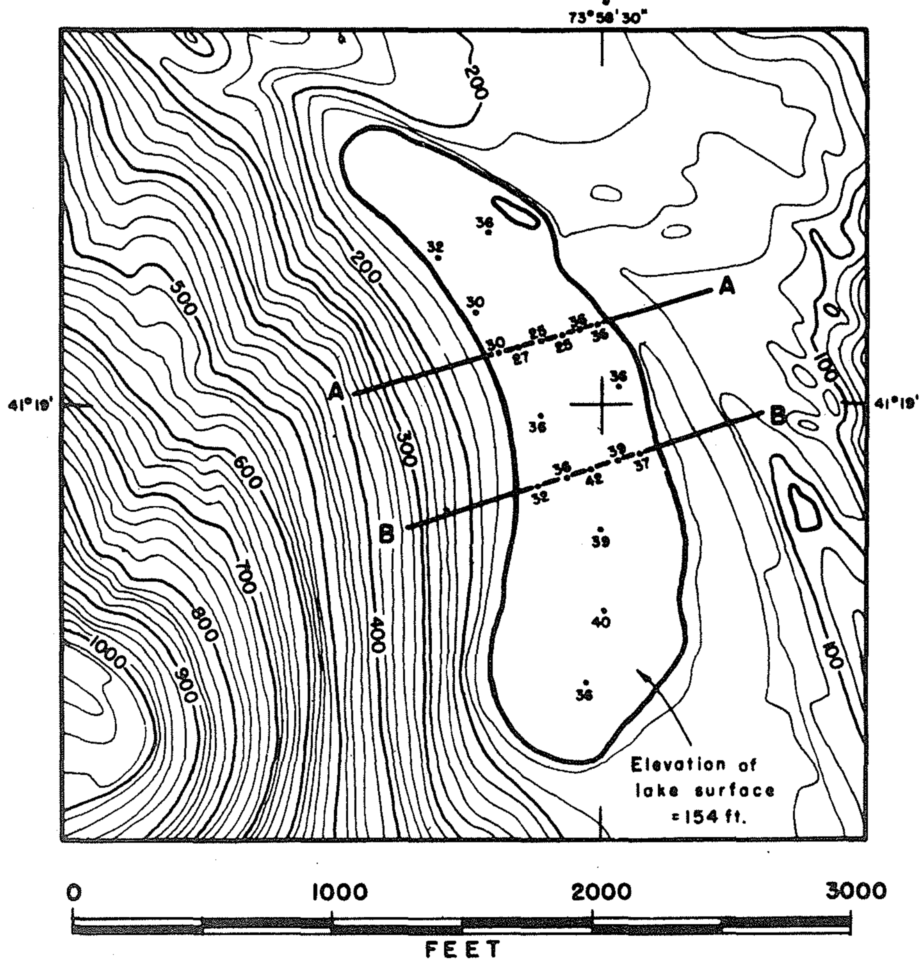
K- UNIFORM LOAD STRESS

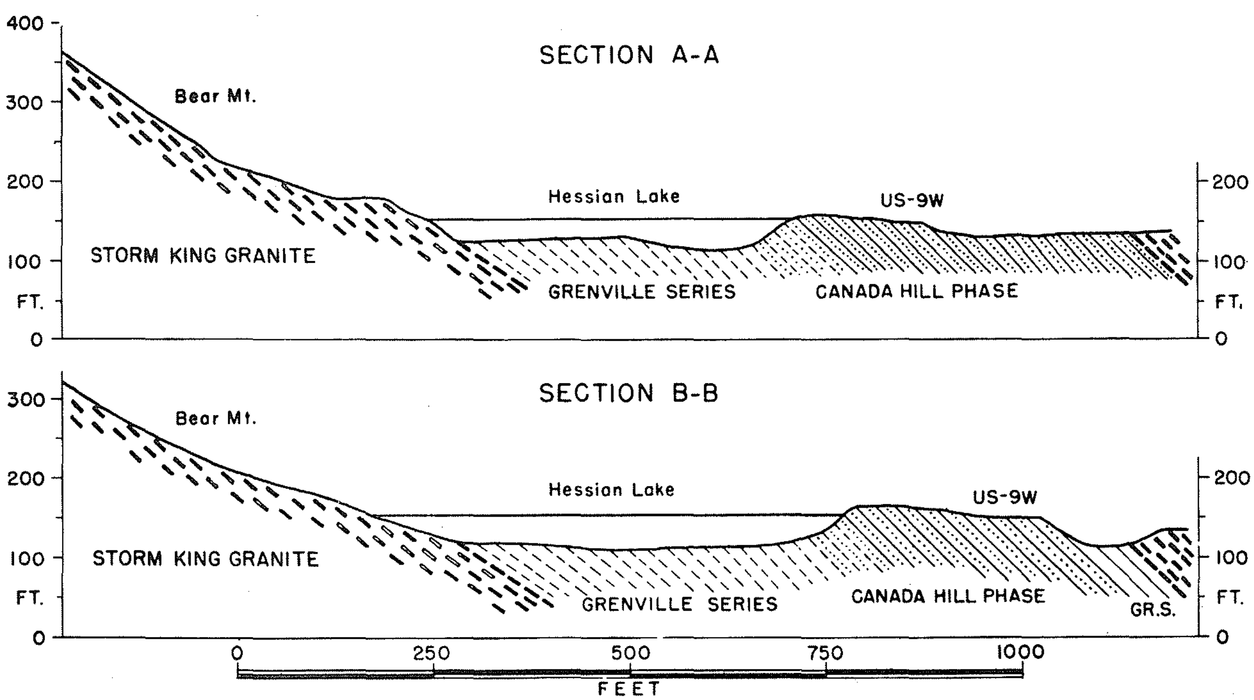
Kc-LOAD STRESS COMPONENT PERPENDICULAR TO FLOW DIRECTION

K'-DIFFERENTIAL OROGENIC STRESS PERPENDICULAR TO FLOW DIRECTION

FIG. B STRUCTURE OF THE BEAR MT. PLUTON

HESSIAN LAKE, N.Y.





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For references on the geomorphology of the Hudson gorge see Trip C.

PRE-CAMBRIAN AND PALEOZOIC GEOLOGY OF THE HUDSON HIGHLANDS

Trip D

Route Description

Mileage	
	Note: The first part of the trip (9.3 mi. to Bear Mt.) including Stop No. D-1 is the same as that of Trip C.
0	Shustin's Locust Manor (headquarters) - left (N) on Locust Ave.
.9	left (SW) on Oregon Road
2.0	pass under Bear Mt. Parkway
2.3	right (W) on Pemart Avenue
2.5	right (N) on Highlands Ave. passing again under Bear Mt. Parkway
3.0	road cut through Gallows Hill; Annsville phyllite (Cambro-Ordovician Hudson River pelite group; see Trip 1, Stop 1-2)
3.3	pass under US-9 and turn sharp left (W) on approach road to US-9
3.4	straight (W) on US-9 following north shore of Peekskill Hollow Creek; note remnants of glacial deltas along both valley walls
4.3	right (N) on US-6-202
4.6	road starts climbing Highlands escarpment (fault line scarp); continuous exposures of Highlands crystallines (Pre-Cambrian gneisses, schists and granites) from here to Bear Mt. Bridge
7.4	cross to left (W) side of road and lookout point

STOP No. D-1: Anthony's Nose Lookout (See Plates 10 and 11, Fig. B)

Lithology: Canada Hill phase of Highlands Complex (Canada Hill granite of Berkey, 1919) - biotite oligoclase granite with epidote pods; gneissoid structure not pronounced; interpreted as granitized meta-sediments

Hudson Gorge: Southeastern gateway of Hudson gorge; superposition versus progressive headward stream erosion of the Hudson River; Iona Island and abandoned River channel; significance of bedrock terrace at Bear Mt. Inn

Faulting: Timp Pass - Hudson River thrust fault; channel fault (?) at Dunderberg Mt.; Hell Hole tear fault (Popolopen Creek)

Regional Structure and Intrusive Plutons: Synclinal plutons of Storm King granite: Dunderberg and West Mts. (lower pluton) Bear Mt. - The Torne and Crown Ridge (upper pluton)

7.4 continue (N) on US-6-202

8.2 left (W) across Bear Mt. Bridge
Excellent views crossing bridge:

Left (S): Iona Island and Southeastern gateway - prominent notch at Timp Pass, where fault crosses West Mt. - Dunderberg ridge

Ahead (W): South of bridge: Bear Mt. terrace
North of bridge: Mouth of Popolopen Creek (drowned); Hell Hole fault notch between Bear Mt. (left) and The Torne right (N)

Right (N): Hudson gorge (southern portion); Sugarloaf Hill on E-shore (3 mi. NE) (Canada Hill granite phase); abandoned river channels at Livingston Island (1 mi. on E shore) and Cons Hook (2 mi. on W shore); bedrock terraces, particularly on W-side of river

Mileage

8.6 toll booths - W-end of bridge

8.8 traffic circle; $^3/_4$ around circle and left (S) on US-9W-202

9.3 passing under foot bridge and right (SW) on approach road to Bear Mt. Inn

9.35 straight on Seven Lakes Drive (do not turn right into circular drive leading to Inn and parking field)

9.6 Administration Building (rear) and entrance to SW parking field

STOP No. D-2: (on foot - 1 mi.) Bear Mt. Inn Terrace

Walk N along W-edge of playing field
glaciated and striated outcrops of pegmatitic Canada Hill granite phase (S of roller skating rink); outcrop of sillimanite-garnet-biotite gneiss and schist (metasediments of Highlands Complex) at SE corner of rink

Hessian Lake: Shallow, glacially scoured contact line depression in Grenville (?) metasediments (including marble bands); intrusive contact with Storm King granite pluton along S and W shores of lake; Canada Hill granite phase along NE shore (Plate 12).

Ancient landslides of large Storm King granite blocks (SW shore) from near vertical cliffs (obscured by trees) developed along major NE trending longitudinal joints in granite; prominent exfoliation of Storm King granite along W-shore; steep W-shore profile developed parallel to linear and platy structure of hornblende crystals in Storm King granite

9.9 exit of parking field - right (W) on Seven Lakes Drive

10.1 Bear Mt. traffic circle - continue on Seven Lakes Drive (right)

10.5 massive Storm King granite at right (N)

11.9 entrance to Perkins Memorial Drive (right) - park buses

STOP No. D-3: Storm King Granite Contact

This stop on SW flank of Bear Mt. will be reached on foot (.6 mi. from entrance), because buses are not permitted on the Perkins Drive. It is regrettable that the planned visit to the top of Bear Mt. had to be eliminated for the same reason.
Keep to the left side of the Drive facing traffic and watch for cars on this winding 2-lane, 2-way road.

Layered sequence of Highlands Complex rocks: Biotite and hornblende gneisses and schists with intercalated bands of pseudo-alaskite (Canada Hill granite phase); interpreted as the result of selective granitization of metasediments (micro-pegmatite bands parallel to structure; replacement of quartz by plagioclase feldspars and perthite in thin-section); biotite in places makes rock indistinguishable from Canada Hill granite of Berkey.

Lower contact of Storm King granite pluton (at nose of syncline) with metasediments; xenoliths near contact; dark-green, chloritized, quartz-rich contact phase of Storm King granite 500 ft. NW along road; prominent exfoliation of massive granite; typical "rubbly" weathering along linear hornblende structure; if time permits: visit to eclogite locality 100 feet below on abandoned road; metamorphic pyroxene (diallage) - garnet - graphite - quartz layer in Highlands Complex; source rock questionable.

return to Perkins Drive entrance

Mileage

11.9 continue on Seven Lakes Drive (W)

12.9 straight ahead on overpass over Palisades Parkway following road curving left (SW)

13.4 prominently banded metasediments (biotitic and graphitic gneisses and schists) at left along Palisades Parkway

13.7 traffic circle - keep right (W) on US-6 toward Central Valley

13.9 right into Brooks picnic grounds

LUNCH STOP: 1 Hour

14.0 continue uphill (W) on US-6

15.5 nearing top of Long Mt. ridge; view of Bear Mt. at right (E) (Plate 11, Fig. A)

16.5 old (drained) beaver swamp along right (N) side of road

17.2 passing between Lake TeAta (left -S) and Lake Massawippa (right -N); construction of dam (at N end of Lake Massawippa) across the Brooks Hollow Creek temporarily uncovered a striking coarse-grained marble (contact-metamorphosed by intrusive Storm King granite) consisting of pink calcite, pale-green diopside and brownish phlogopite (named the Brooks Hollow marble)

17.7 sharp right (NE) on NY-293 leaving the Palisades Interstate Park

19.7 left into parking field of Camp Natural Bridge (West Point Military Reservation)

STOP No. D-4: Popolopen Natural Bridge

Walk $^1/_4$ mile to SW end of Popolopen Lake
Natural Bridge across creek flowing into Popolopen Lake, developed through coarse, white, chondrodite-bearing marble; spinel dike on down-stream (lake-side) of bridge; curious dense, dark gray rock paralleling marble and creek on upstream side; thin-section study suggests a metamorphosed graywacke; both rock types along creek are completely different from known Pre-Cambrian metasediments in the Hudson Highlands; preliminary reconnaissance also indicates strong deformation of Highlands rocks along both sides of Popolopen Lake valley; rocks at this locality are, therefore, interpreted as infolded (and possibly infaulted) Paleozoic sediments(inlier)

return to buses at Camp Natural Bridge

20.0 right (SW) on NY-293

22.0 intersection with US-6; straight (SW) on US-6

23.2 top of NE-trending fault-line escarpment of crystalline Hudson Highlands; view of Central Valley (belt of early Paleozoic limestones)

23.3 to 23.4 brecciated zones in Highlands gneisses at right (only evidence of steeply SE dipping border thrust at base of escarpment)

23.6 last outcrop of Highlands crystallines (Pre-Cambrian)

24.4 passing over N.Y. Thruway; view (straight ahead) of Schunemunk Mt. (Devonian orthoquartzite and conglomerate)

30.0 Central Valley - right (N) on NY-32 (Albany Turnpike)

31.2 Highland Mills - right (E) on Park Ave.

31.5 Highland Mills Railroad Station

STOP No. D-5: Devonian Sediments

Cross railroad tracks to prominent outcrops along E-side of right of way Devonian shaly sandstones (Oriskany-Esopus-Schoharie horizons)

Fossils: Lower strata:
poorly preserved sponges of type Titusvillia (?)
Leptocoelia flabellites, Leptaena rhomboidalis and other brachiopods

Middle strata:
Spirophyton caudagalli (worm burrows or algal swish marks??)

Upper strata:
Cypricardinia (pelecypod)
Brachiopods (several genera)
Phacops and Dalmanites (trilobites) (confined to a single layer, hard to find)

Time will not permit to traverse across hill to E; in valley E of hill can be found (in descending stratigraphic order) Lower Devonian and Upper Silurian limestone (with corals), Silurian red shales (Longwood) followed by Lower Silurian conglomerate (Shawangunk) in Pine Hill beyond. Between Pine Hill and the Highlands escarpment to the E are beds of Wappinger limestone (Cambro-Ordovician). The exact structural relations between these stratigraphic sequences are not known with certainty. Westward across the valley of Woodbury Creek the shaly sandstones of the Highland Mills station appear to include the Hamilton group and are finally overlain by (Uppper ?) Devonian orthoquartzites and conglomerates of Schunemunk Mt. (a shallow syncline).

Approximately 1 mile to the north, along the E-side of the railroad, rocks of Oriskany lithology have been correlated with the Kanouse horizon (Onondaga) on good fossil evidence. (Eidman and Kindle, 1955)

31.6 return (W) on Park Ave.

31.9 right (N) on NY-32 (Albany Turnpike)

34.2 pass under N.Y. Thruway

34.5 Glacial delta deposits on both sides of narrow valley

39.2 right on NY 307

39.7 pass under US-9W

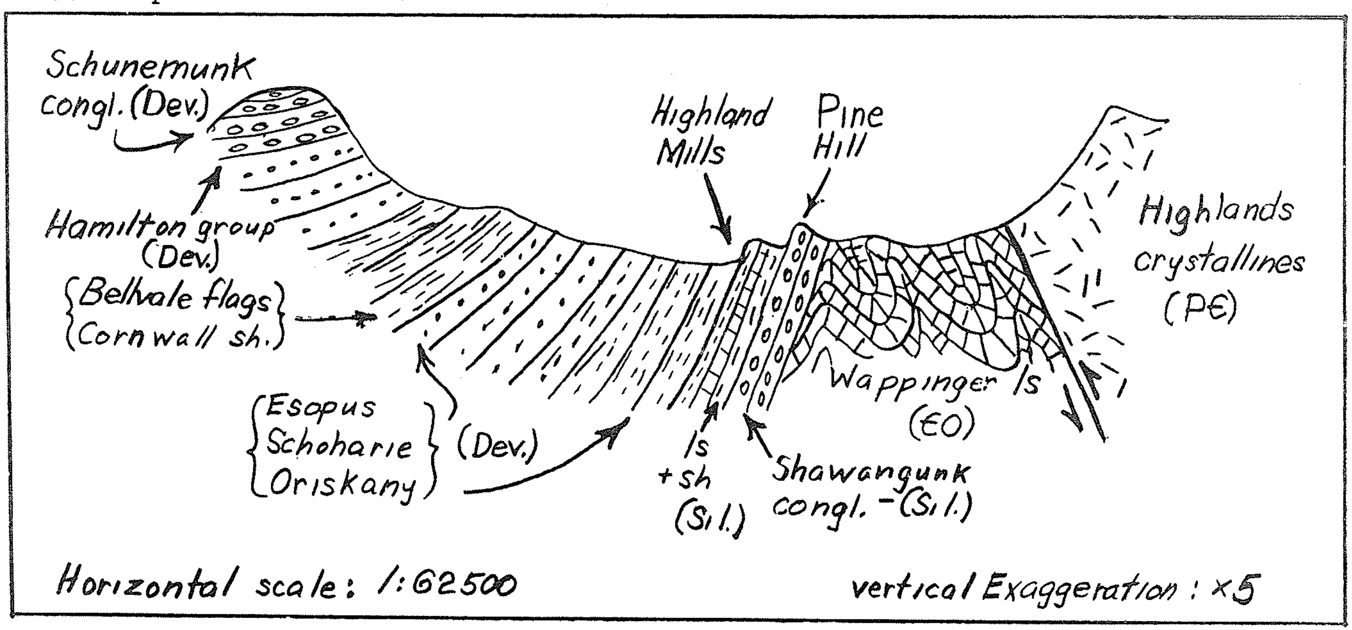


Fig. 3 Cross-Section at Highland Mills (generalized)

Mileage

40.1 Cornwall - bear left (NE) on Main St.

40.6 take right fork (E) at monument on NY-307

41.1 straight ahead at blinker light

41.4 right (SE) on Hudson St. (NY-218)

41.7 sharp right (S) on Lafayette St.

41.9 swing left (E) and park buses at intersection with Mountain Rd.

STOP No. D-6: Overthrust in Highlands Outlier
Walk S on Mountain road, crossing bridge to outcrop in hill at left (E) side of road (appr. 300 yds.)
Overthrust of Storm King granite (Pre-Cambrian) on intensely crumpled slaty shales of the Hudson River pelite group (Cambro-Ordovician). Thrust plane dips rather gently toward the southeast. Small hill appears to be an outlier, because Lower Paleozoic sediments have been found between it and the Highlands escarpment a short distance to the SE. Attitude of thrust plane here is atypical of Highlands border thrust which generally dips at high angles (70° in Delaware Aqueduct Tunnel E of Hudson River) to the SE.
Return to buses

41.9 left (N) on Mountain Road

42.0 left (W) on Hudson St. (NY-128); follow Hudson St. bearing left

43.2 left on Main St. (traffic light)

43.8 bear right to stay on NY-307

44.4 pass under US-9W and turn left (SE) on US-9W-south approach road; continue SE on US-9W

48.7 cross highway to left (through break in center mall) to Crow's Nest Lookout - dangerous crossing

STOP No. D-7: Crow's Nest Lookout
View of middle Hudson gorge; West Point Military Academy on rock terrace below; Constitution Island with abandoned river channel; similar to Iona Island (Stop No. D-1), but on E-side of valley; Schooley Upland level E of the Hudson

48.7 cross highway again heading south

49.3 to 49.9 large xenoliths of hornblende gneiss in pegmatite phase of Storm King granite at right (W)

55.7 Bear Mt. Bridge traffic circle; left (E) on US-6-202 to Bear Mt. Bridge

56.4 right (S) at E end of bridge

60.3 left (NE) on US-9 (do not cross bridge over Peekskill Hollow Creek)

61.1 right turn off US-9

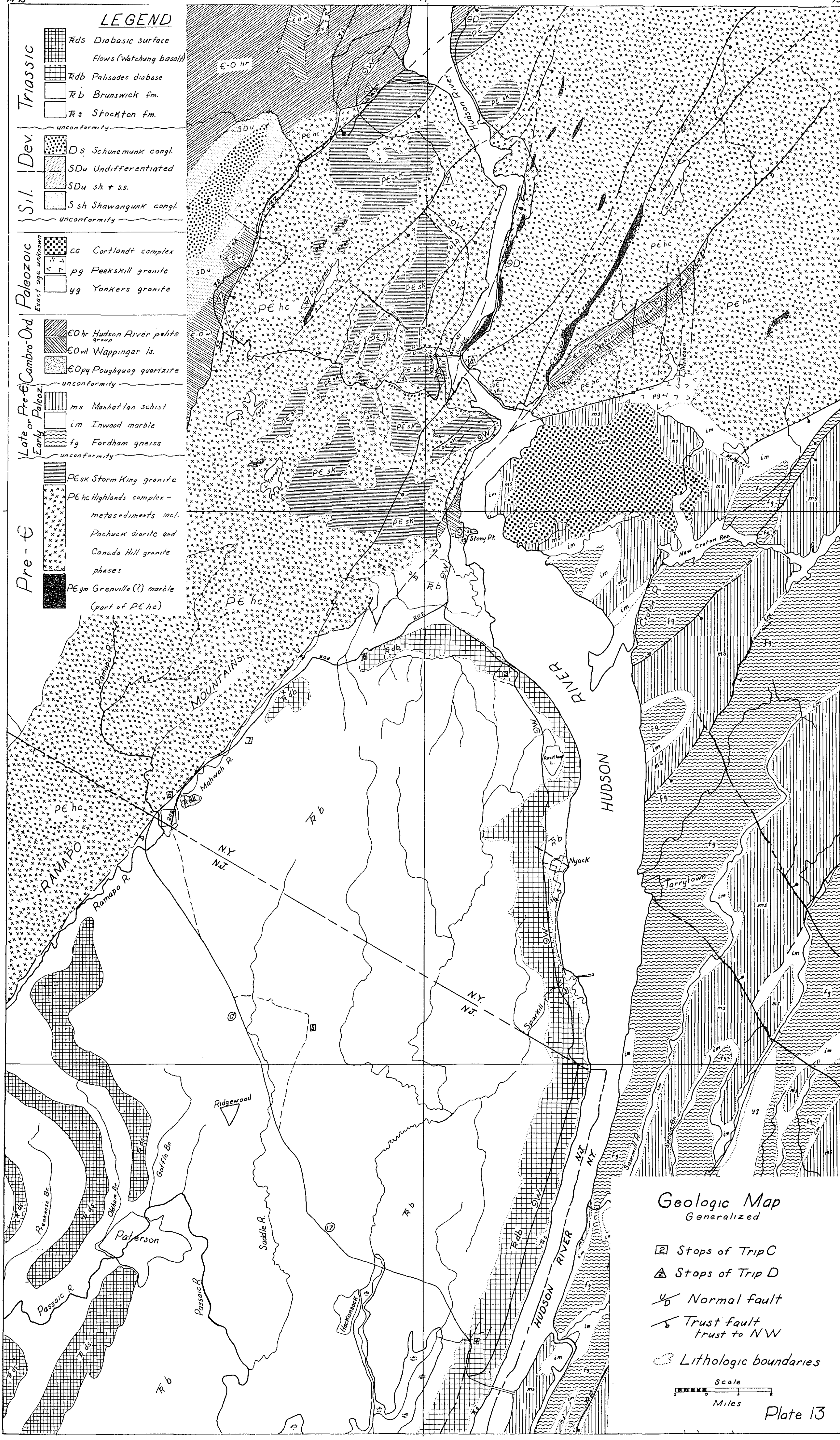
61.5 right (SE) on Highlands Ave. (through Annsville road cut)

62.0 left (E) on Pemart Ave. (after passing under Bear Mt. Parkway)

62.2 left (NE) on Oregon Rd.

63.6 right (SE) on Locust Ave.

64.5 right at headquarters



LEGEND
Triassic
Ꞧds Diabasic surface flows (Watchung basalt)
Ꞧdb Palisades diabase
Ꞧb Brunswick fm.
Ꞧs Stockton fm.
unconformity
Sil. Dev.
Ds Schunemunk congl.
SDu Undifferentiated
SDu sh. + ss.
S sh Shawangunk congl.
unconformity
Paleozoic
Exact age unknown
cc Cortlandt complex
pg Peekskill granite
yg Yonkers granite
Cambro-Ord.
€Ohr Hudson River pelite group
€Owl Wappinger ls.
€Opq Poughquag quartzite
unconformity
Late or Early Pre-€ Paleoz.
ms Manhattan schist
im Inwood marble
fg Fordham gneiss
unconformity
Pre-€
P€sk Storm King granite
P€hc Highlands complex - metasediments incl. Pochuck diorite and Canada Hill granite phases
P€gm Grenville (?) marble (part of P€hc)
Geologic Map
Generalized
Stops of Trip C
Stops of Trip D
Normal fault
Trust fault trust to NW
Lithologic boundaries
Scale
Miles
Plate 13
74°15'
74°00'
73°45'
41°15'
41°00'
40°50'
RAMAPO MOUNTAINS
Ramapo R.
Mahwah R.
HUDSON RIVER
Hudson River
Stony Pt.
Nyack
Sparkill
Tarrytown
New Croton Res.
Croton R.
Sawmill R.
Sprain Br.
Paterson
Passaic R.
Preakness Br.
Oldham Br.
Goffle Br.
Saddle R.
Ridgewood
Hackensack
N.Y.
N.J.