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

Nicholas M. Ratcliffe
City College of New York

## INTRODUCTION AND PURPOSE OF TRIP

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

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

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

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

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

## STATEMENT OF THE PROBLEM

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

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

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

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

## RESULTS OF PRESENT INVESTIGATION

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

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

# STRATIGRAPHY

## Basement Rocks (Fordham Gneiss).

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

> Pinkish-gray, poorly-foliated, K-feldspar-quartz biotite gneiss, granitic gneiss or granulite
>
> Layered, biotite-plagioclase-quartz gneiss
>
> Massive, hornblende-biotite-plagioclase gneiss and related layered hornblende gneisses and amphibolites.

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

## Lowerre quartzite.

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

## Inwood formation.

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

> Unit A. White to gray crystalline dolostone or dolomitic marble, without sandy or argillaceous impurities (15-100 feet ?). Probably correlative of Unit A of the Stockbridge Formation.
>
> Unit B. Gray to dark-gray, layered dolostone with thin, orange-weathering quartzite in one-inch beds, and numerous phyllitic partings. Beige weathered surfaces are typical. Minor 3 to 5-foot-thick quartzites occur along with biotitic, mottled, calc-dolostone. Probably correlative with Unit B, and perhaps with part of Unit C, of the Stockbridge Formation.
>
> Unit C. White, crystalline, dolomitic marble, locally sandy at the base, grading up into massive crystalline dolostone with minor, sandy, white to gray dolostone, with tremolite-rich bed near the top at Crugers. Probably correlative with Unit C and perhaps with Unit D of the Stockbridge Formation.

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

Manhattan Formation (of Scotford, 1956).

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

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

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

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

Upper Triassic.

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

## UNCONFORMITIES

### Lower Cambrian.

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

### Middle Ordovician.

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

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

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

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

(1) the result of squeezing out of the Inwood Marble (Lowe, 1958; Baskerville, 1967).

(2) interbedded relations between Fordham Gneiss, Inwood Marble, and Manhattan Formation (Prucha, 1956; Scotford, 1956), and

(3) the Manhattan unconformably overlying the lower rocks (Hall, this volume). Bucher (1951, 1957) used this argument for limestones at the base of the Annsville Phyllite in the Peekskill Valley.

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

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

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

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

## STRUCTURAL TERMINOLOGY

Planar Features.

| | |
|---|---|
| $S_0$ | Bedding. |
| $S_1$ | Foliation (here a regional axial surface of the major $F_1$ Verplanck Point - Tomkins Cove - Crugers anticline). |
| $S_2$ | Late crenulation cleavage or foliation related to $F_2$ folds. |
| $S_3$ | A crenulation cleavage cutting $S_2$ (related to $F_3$ folds) locally developed. |

Fold systems.

| | |
|---|---|
| $F_1$ | Major anticlinal structure now refolded (Verplanck - Tomkins Cove - Crugers anticline). |
| $F_2$ | Second generation structures at each outcrop ($F_2$ folds vary in attitude around the perimeter of the Cortlandt Complex). |
| $F_3$ | Very local structures not recognized everywhere. |

## REGIONAL STRUCTURE

All stops on this field trip are on the flanks of the same large refolded structure, the Verplanck - Tomkins Cove - Crugers anticline. The closure of this fold is mapped south of the Cortlandt intrusives between Prickly Pear Hill and Furnace Brook Pond (Figures 1 and 3). Structures in the cover rocks (Lowerre Quartzite, Inwood Formation, and Manhattan Formation) indicate steep to moderate northeast plunges for the $F_1$ fold axes. Later $F_2$ folding with nearly vertical axial planes plunge at low angles to the east.

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

## STRUCTURAL RELATIONS

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

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

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

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

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

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

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

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

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

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

## ROAD LOG

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

Mileage.

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

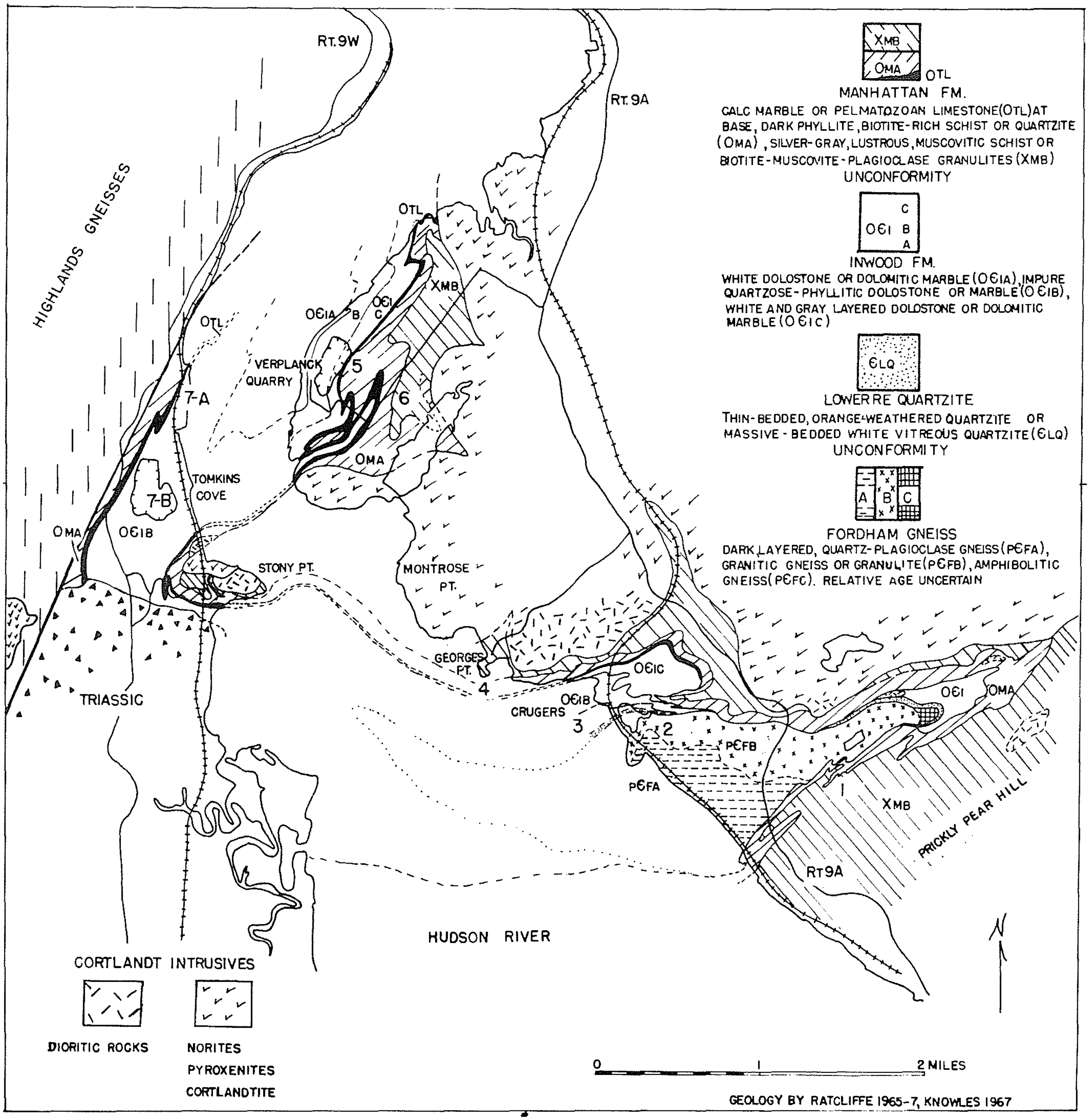


Figure 1. Geologic map of the western edge of the Cortlandt intrusives, showing location of field trip STOPS 1 - 7. Map includes portions of the Haverstraw and Peekskill, N.Y., 7-1/2 minute quadrangles.

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

*In this report all four sections are correlated and named similarly. Subdivisions of the Inwood formation are tentative only, but conform to the usage of Hall (this volume).
**Correlation indicated. Name not used.

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

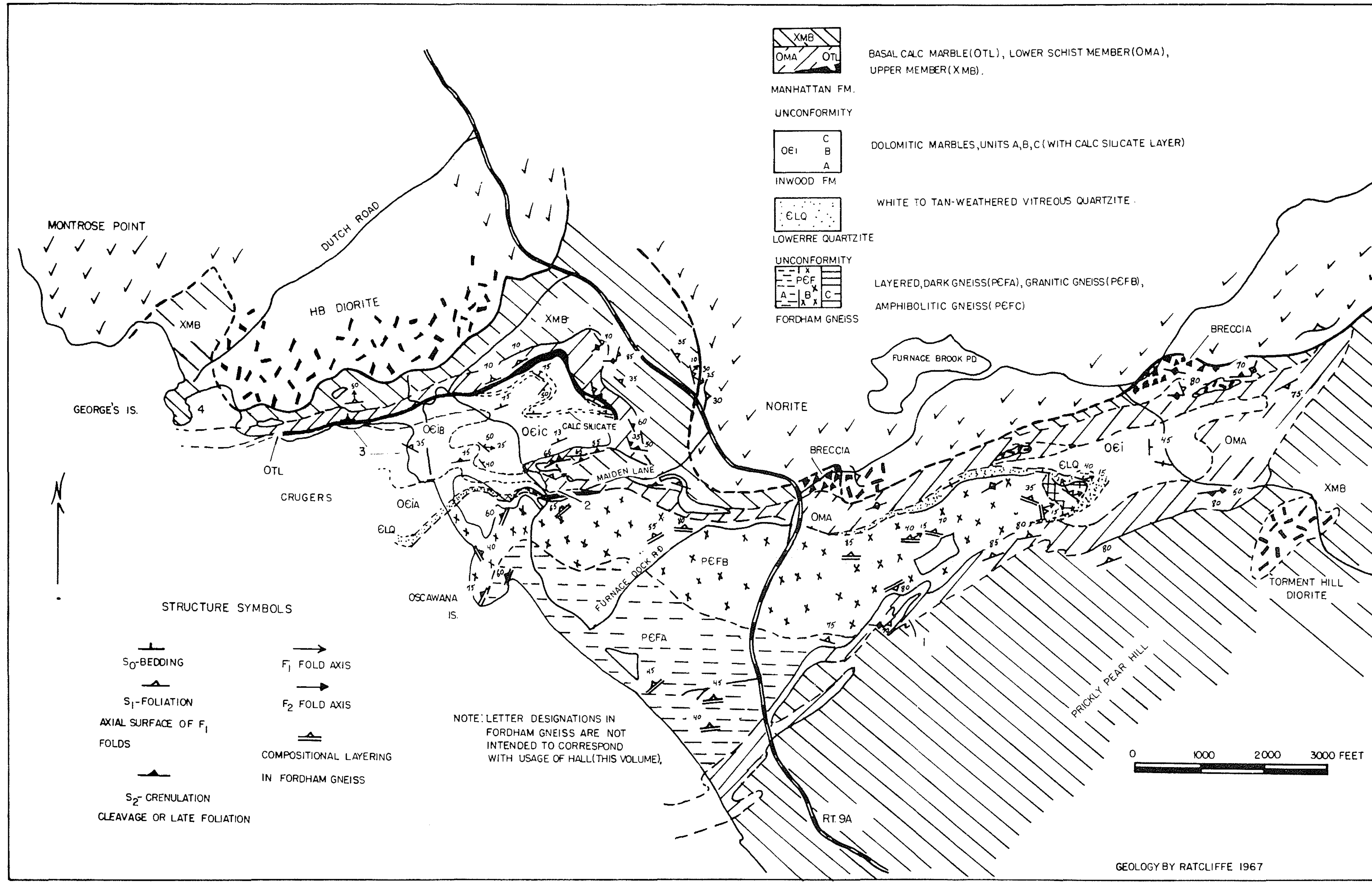


Figure 3. Geologic map of the Crugers area south of the Cortlandt intrusives showing the subdivisions of the Manhattan and Inwood formations. Location of field trip STOPS 1 - 4.

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

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

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

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

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

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

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

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

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

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

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

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

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

Leave Brinton Bird Sanctuary.

13.6 0.3 Turn right onto N. Y. 9A.

13.8 0.2 Overpass to Oscawanna on left (roadcut N. Y. 9) outcrops of layered gneisses of Fordham Gneiss dips are north at moderate angles. Granitic gneiss of Fordham can be seen at north end of cut. Underpass for N. Y. 9. Pass exposures on right (east) of layered norite. Continue north on N. Y. 9A.

14.6 0.8 Turn left on Maiden Lane. Pass outcrops of Manhattan (Xmb) in woods above road.

15.1 0.5 STOP 2. Maiden Lane Sand Pit.

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

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

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

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

Biotite-plagioclase-quartz-gneiss (Fordham)

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

Unit A Inwood white dolomitic marble 10-15 ft.

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

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

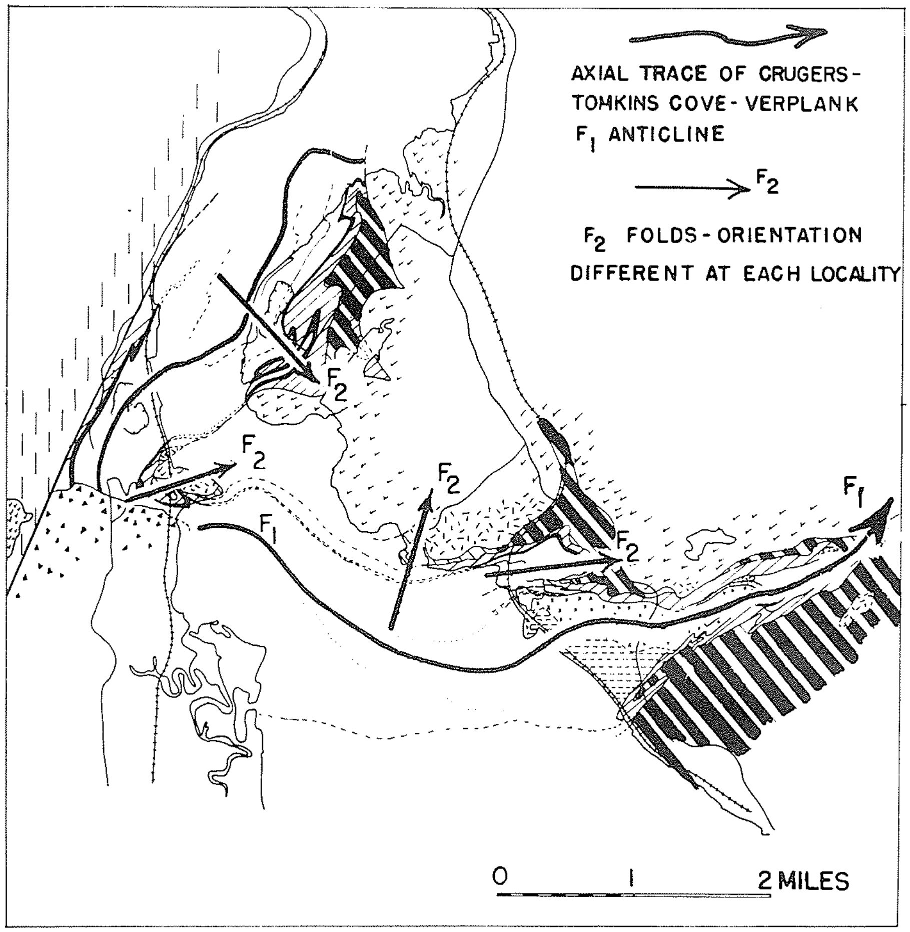


Figure 4. Generalized tectonic diagram showing axial trace of Verplanck - Tomkins Cove - Crugers anticline and orientation of late $F_2$ folds. $F_2$ folds vary in intensity and orientation from one locality to the next. The generalized orientation of $F_2$ folds within subareas in which they are consistent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

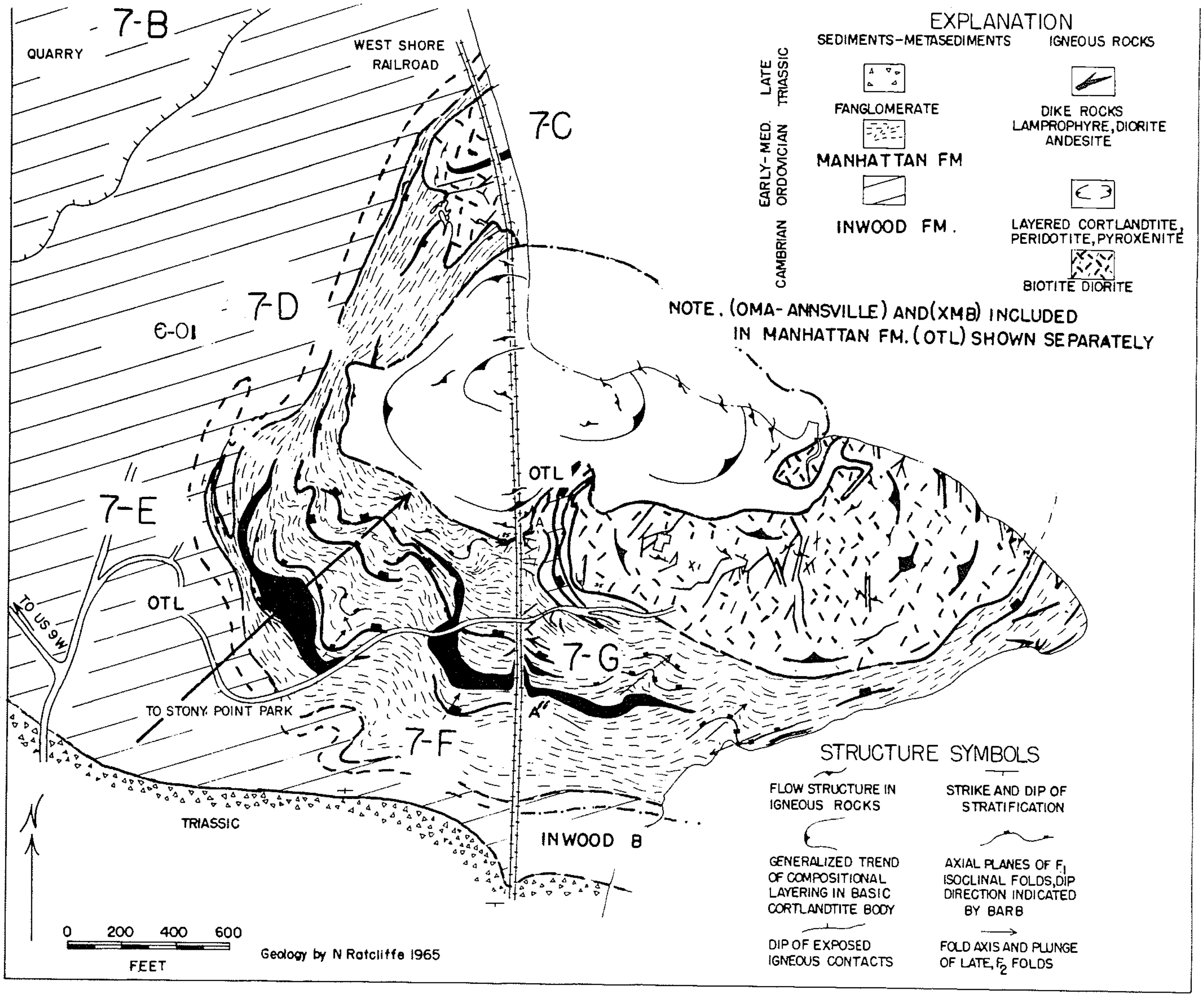


Figure 5. Geologic map of Stony Point area showing location of STOPS 7-B to 7-G. Subdivisions of Manhattan schist (Oma) and (Xmb) are present but not separately distinguished on this map. (Modified from Ratcliffe, in press.)

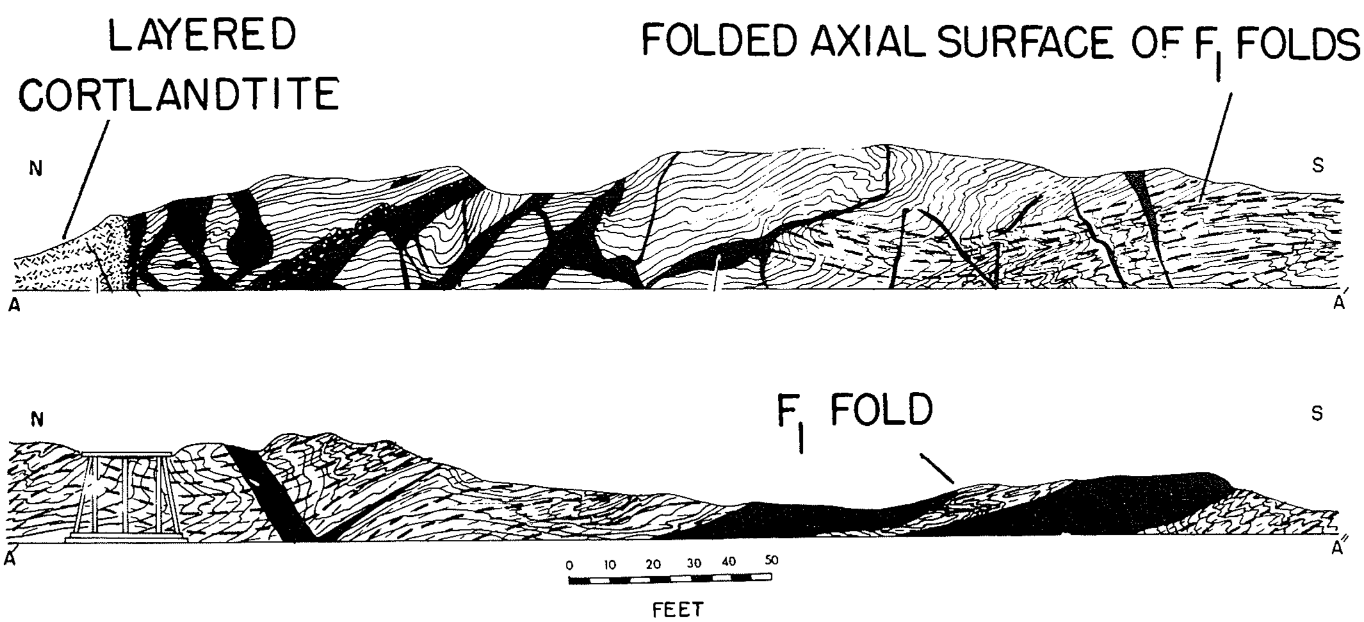


Figure 6. North-south cross-section along West Shore Railroad at Stony Point (facing east). Shows undeformed dikes of diorite and lamprophyre cross-cutting $F_1$ and $F_2$ folds in (Xmb). Intrusive contact of Cortlandtite pluton exposed at north end.

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

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

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

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

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

15.2 0.1 Exposures of Unit C of the Inwood formation at top of hill.

15.4 0.2 Continue north on Crugers Station Road.

15.7 0.3 Bus stops at overpass - unload, walk over railroad to STOP 3.

STOP 3. Crugers.

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

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

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

Here is an excellent exposure of the Inwood formation and Lower Manhattan (Oma) contact. Note the lithic characteristics diagnostic of Lower Manhattan seen on STOPS 1 and 2. A thin 2 to 3 inch coarsely crystalline calcareous marble occurs at the contact with the schist. Beneath this a zone of interlayered gray and white, crystalline, calcitic dolostone and calcite marble is exposed before massive, beige-weathered dolostones at the waters edge. Thin orange quartzites in the beige-weathered dolostones suggest this is Unit B. A thick section (200-300 ft.) of Unit C mapped to the east is not present here.

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

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

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

Return to bus.

Continue on Crugers Station Road to east.

Intersection Crugers Station Road and Rt. 9A.

16.2 0.5 Turn left (north).

16.7 0.5 Turn left on Dutch Road entrance to George's Island State Park.

17.8 1.1 <u>STOP 4. George's Point.</u>

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

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

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

18.9 1.1 Turn left on 9A.

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

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

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

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

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

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

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

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

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

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

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

LUNCH STOP

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

22.9 0.3 Turn left onto 13th Street.

23.1 0.2 <u>STOP 6</u> (end of road). (Beware of dogs.)

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

23.3 0.2 Turn right (north) on Broadway.

24.3 1.0 Turn right on Bleakley Avenue.

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

24.9 0.2 Head north on N.Y. 9.

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

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

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

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

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

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

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

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

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

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

G. Railroad cut in Upper Manhattan (Unit B). Shown here are dikes cross-cutting $F_1$ and $F_2$ folds. The contact with Cortlandtite pluton is exposed at the north end. Follow cross-section, Figure 6, for location on east wall. If a train comes, you will be warned. Please move promptly to the west side of the cut where there is plenty of room. Don't panic!

Continue north to see near vertical contact of the Cortlandtite with the schist. Note contact zone with minor drags, indicating north-up rotation sense. The hornblendite zone seen at STOP 7-D passes into typical north-dipping layered Cortlandtite 20 feet from the contact. Immediately above to the east on the slopes (see light colored soil zone) are exposures of calc-silicates of the basal Manhattan, exposed in an $F_1$ isoclinal fold that is truncated by the Cortlandtite pluton. $F_2$ folds are E-W perpendicular to Cortlandtite contact. The type locality of Cortlandtite (Williams, 1886) is located on the north shore of Stony Point near the swimming pier.

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

Meet bus at Stony Point Park.

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

## REFERENCES

Balk, R., 1927, Die primäre Struktur des Noritmassive von Peekskille am Hudson, nördlich New York: Neues Jahrb. Min., Beilageband 57, p. 249-303.

_______, 1936, Structural and petrologic studies in Dutchess County, New York. Part 1, Geologic structure of sedimentary rocks: Geol. Soc. America Bull., v. 47, p. 685-774.

Baskerville, C. A., 1965, Preliminary field study of the gneiss terrane of southeastern Westchester and Bronx Counties, New York (Abstract): Geol. Soc. America Program for Northeastern Section Meeting, Boston, p. 13.

Berkey, C. P. and Rice, Marion, 1919, Geology of the West Point quadrangle, New York: New York State Museum Bull. 225-226, 152 p.

Bucher, W. H., 1951, Infolded mid-Ordovician limestone on Precambrian north of Peekskill, N. Y., and its bearing on the region's orogeny (Abstract): Geol. Soc. America Bull., v. 62, p. 1426-1427.

________, 1957, Taconic klippe - a stratigraphic-structural problem: Geol. Soc. America Bull., v. 68, p. 657-674.

Fisher, D. W., Isachsen, Y. W., Rickard, L. V., Broughton, J. G., and Offield, T. W., Compilers and Editors, 1961, Geologic Map of New York: N. Y. State Geol. Survey, 5 sheets, scale 1:250,000.

Hall, L. M., 1965, Some stratigraphic relationships within the New York City Group in Westchester County, New York (Abstract): Geol. Soc. America Program for annual meeting, Kansas City, p. 69.

Long, L., and Kulp, J. L., 1962, Isotopic age study of the metamorphic history of the Manhattan and Reading prongs: Geol. Soc. America Bull., v. 73., p. 969-998.

Lowe, K. E., 1958, Editor, Field Guide Book: New York State Geological Association Thirtieth Ann. Meeting, Peekskill, New York, 52 p.

**Paige, S., 1956,** Cambro-Ordovician age of the "Inwood" limestone and "Manhattan" schist near Peekskill, New York: Geol. Soc. America Bull., v. 67, p. 391-394,

Prucha, J. J., 1956, Stratigraphic relationships of the metamorphic rocks in south-eastern New York: Am. Jour. Sci., v. 254, p. 672-684.

Rastall, R. H., 1910, The Skiddaw Granite and its metamorphism: Quart. Jour. Geol. Soc. London, v. 66, p. 116-161.

Ratcliffe, N. M., 1967, Paleozoic post-tectonic plutonism at Stony Point, N. Y. (Abstract): Geol. Soc. America Program for Northeastern Section Meeting, Boston, p. 51.

________, in press, Contact relations of the Cortlandt Complex at Stony Point, New York, and their regional implications (Short Note): Geol. Soc. America Bull.

________, and Knowles, R. R., 1968, Fossil evidence from the "Manhattan Schist - Inwood Marble" sequence at Verplanck, New York (Abstract): Geol. Soc. America Program for Northeastern Section Meeting, Washington, D. C., p. 48.

Rogers, G. S., 1911, Geology of the Cortlandt series and its emery deposits: N. Y. Acad. Sci., Ann., v. 21, p. 11-86.

Scotford, D. M., 1956, Metamorphism and axial plane folding in the Pound Ridge area, New York: Geol. Soc. America Bull., v. 67, p. 1155-1198.

Shand, S. J., 1942, Phase petrology in the Cortlandt Complex, New York: Geol. Soc., America Bull., v. 53, p. 409-428.

Williams, G. H., 1886, The peridotites of the Cortlandt series on the Hudson River near Peekskill, New York: Am. Jour. Sci., 3d ser., v. 31, p. 26-31.

Winkler, H. G. F., 1965, Petrogenesis of Metamorphic Rocks: Springer - Verlag Inc., New York, N. Y., 220p.

Zen, E-an, 1966, Stockbridge Formation, p. 30, _in_ Cohee, G. V., and West, W. S., Changes in stratigraphic nomenclature by the U. S. Geological Survey, 1965: U. S. Geol. Survey Bull. 1244-A, 60 p.

_______, and Hartshorn, J. H., 1966, Geologic map of the Bashbish Falls quadrangle, Massachusetts, Connecticut and New York: U. S. Geol. Survey Geol. Quad. Map, GQ-507, 7 p. explanatory text.