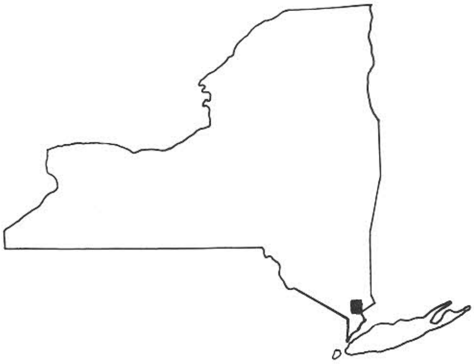

BEDROCK GEOLOGY OF THE OSSINING QUADRANGLE, NEW YORK

by George C. Wissig, Jr.

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ABSTRACT

The Ossining, New York, 7½-minute quadrangle is located on the east side of the Hudson River in Westchester County about 42 km north of New York City, in the Manhattan Prong of the New England Upland Appalachian province. The stratigraphic sequence within the quadrangle listed from oldest to youngest follows:

Fordham Gneiss
- Fordham unit A—subdivisions in order of abundance are: (1) interlayered pyroxene-hornblende gneiss, garnet-feldspar-biotite-quartz gneiss, quartz veins and pods, pegmatite, and amphibolite; (2) more homogeneous feldspar-biotite-quartz schistose gneiss; and (3) garnet-sillimanite-K-feldspar-plagioclase-biotite-quartz schist.
- Fordham unit B—garnet-biotite-hornblende-feldspar-quartz gneiss and amphibolite.
- Fordham unit C—pink granitic gneiss, white quartz-plagioclase gneiss, dark gray biotite-plagioclase gneiss, dark gray biotite-plagioclase-quartz gneiss, and amphibolite.

Lowerre Quartzite—vitreous quartzite and feldspathic quartzite.

Inwood Marble
- Inwood unit A—white dolomite marble.
- Inwood unit B—interlayered dolomite marble, calcite marble, and biotite-feldspar-quartz schist.
- Inwood unit C—white dolomite marble.
- Inwood unit D—interlayered white dolomite marble and gray calcite marble with mica, feldspar, tremolite, pyrite, and serpentine.
- Inwood unit E—tan-weathering calcite marble.

Manhattan Formation
- Manhattan unit A—fissile garnet-sillimanite-plagioclase-muscovite-quartz-biotite schist with a pyroxene-hornblende-K-feldspar-biotite-plagioclase-quartz schistose gneiss and interlayered calcitic marble-schistose gneiss locally present at base.
- Manhattan unit C—muscovite-biotite-plagioclase-quartz gneiss or schistose gneiss.

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In the northwestern part of the quadrangle, the Manhattan Formation has been intruded by the mafic Cortlandt Complex.

Metamorphic grade in the quadrangle ranges from sillimanite-garnet-muscovite subfacies (muscovite-sillimanite zone) to the sillimanite-garnet-orthoclase subfacies (K-feldspar-sillimanite zone). Maximum metamorphic temperatures are inferred to have been between 625° and 670°C, and pressures between 5.5 and 6.5 kb.

Carbonate assemblages (dolomite + quartz in the central part of marble belts and diopside and tremilite near the margins) indicate a decrease in P_{CO_2} with a concomitant increase in P_{H_2O} from the center to the margins of the belts.

Reactions between the aluminous Manhattan unit A schist and the Inwood Marble have produced a calc-silicate mineral assemblage at the Inwood-Manhattan contact. Net movement of K, Al, and H_2O from schist toward marble, and of Ca, Mg, and CO_2 from marble toward schist is inferred in response to activity (~concentration) gradients across the schist-marble contact.

All units have been deformed by passive folding into a series of elongate, northeast-trending anticlines and synclines.

Introduction

LOCATION AND GEOLOGICAL SETTING

The Ossining, New York, 7½-minute quadrangle is located on the east shore of the Hudson River in Westchester County about 42 km north of New York City (Figure 1). The quadrangle includes the towns of Ossining, Chappaqua, and Pleasantville.

The entire quadrangle (Plate 1) has been subjected to regional metamorphism of the upper-amphibolite facies and lies within the sillimanite zone. Contact metamorphism is restricted to a 50–100 m wide aureole surrounding the intrusive Cortlandt Complex in the northwestern corner of the quadrangle. Reaction between the Cortlandt Complex and the aluminous schists of the Manhattan Formation has resulted in the development of emery which is presently being mined within the quadrangle. The rocks of the area have been deformed into a parallel series of folds trending about N40°E. Folds plunge toward the southwest in the southern part of the quadrangle and toward the northeast in the northern part. This structural pattern is expressed in a series of doubly plunging anticlines and synclines.

Maximum topographic relief within the quadrangle is 252 m. Most hills and valleys trend northeast. Schist and, particularly, gneiss underly the hills and ridges whereas the valleys are commonly underlain by marble. Linear escarpments usually mark the gneiss-marble and schist-marble contacts. Glacial drift is most abundant in the valleys; on the hills glacial drift is rare, and bedrock exposures generally are excellent.

The stratigraphic sequence within the quadrangle consists of the basal Fordham Gneiss overlain by the Lowerre Quartzite, Inwood Marble, and Manhattan Formation. A younger mafic igneous complex, the Cortlandt Complex, discordantly intrudes the Manhattan Formation. The Yonkers Gneiss, which occurs to the south, has not been found within the Ossining quadrangle.

SCOPE AND OBJECTIVES

The Ossining, New York, 7½-minute quadrangle was mapped at a scale of 1:12,000 during the summers of 1966, 1967, and 1968. Approximately nine months were spent in the field, and correlative laboratory work was done at Syracuse University during 1968 and 1969. Analytical methods are described in Wissig (1970).

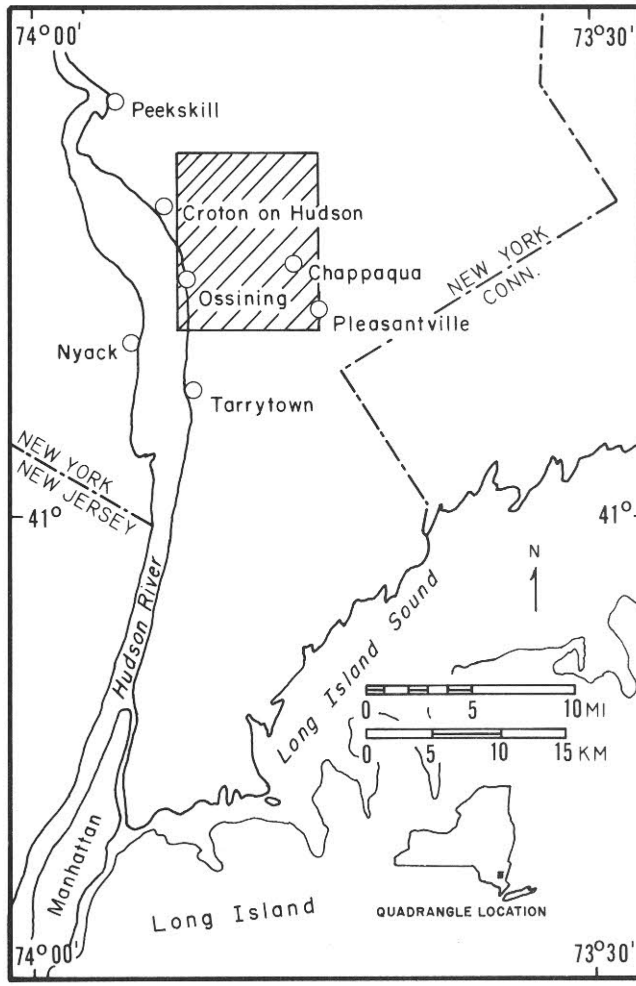

Figure 1 Index map showing location of Ossining quadrangle.

The principal objectives in studying the Ossining quadrangle were the following:

1. To map and subdivide each of the formations within the quadrangle using field criteria.
2. To provide field and petrographic descriptions of each stratigraphic unit; and
3. To work out the stratigraphic, structural, and metamorphic history of the area.

ACKNOWLEDGMENTS

John J. Prucha suggested this study of the Ossining quadrangle and guided the work. Field trips and informal discussions with Professors Leo M. Hall and Nicholas Ratcliffe, as well as discussions with Yngvar Isachsen have contributed to my understanding of the geologic relationships within and around the Ossining quadrangle. Professor Gary M. Boone instructed me on the laboratory techniques used in this study.

Leo M. Hall and Y. W. Isachsen critically reviewed the manuscript.

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Stratigraphy

GENERAL STATEMENT

The major stratigraphic units in the Ossining quadrangle are the Fordham Gneiss, Lowerre Quartzite, Inwood Marble, and Manhattan Formation. These formations can be subdivided into seven units recognized on the basis of rock type, stratigraphic position, and mineralogical composition. Hall (1968b,d) recognized 15 units within the White Plains quadrangle directly south of the Ossining quadrangle. In the Ossining quadrangle, the Fordham Gneiss has been subdivided into three units, the Lowerre Quartzite has not been subdivided, the Inwood Marble has been subdivided into five units, and the Manhattan Formation has been subdivided into two units. In contrast, Hall (1968b,d) recognized five Fordham Gneiss units, five Inwood Marble units, and three units in the Manhattan Formation in addition to Lowerre Quartzite and Yonkers Gneiss. In the Haverstraw quadrangle, adjacent to the Ossining quadrangle to the west, Ratcliffe (1968) mapped three units in the Fordham Gneiss and two units in the Manhattan Formation.

On the basis of the position of the Fordham Gneiss at the center of antiforms, it is inferred that this formation is the oldest in the quadrangle. The Fordham Gneiss includes layers of schist, amphibolite, and marble as well as gneiss. Fordham Gneiss subdivisions used in the present study correspond to units mapped by Hall (1966, oral communication and 1968d) in the White Plains quadrangle directly to the south. Unit E mapped by Hall in the White Plains quadrangle does not appear to be present in the Ossining quadrangle. Hall's unit D is present in the southern part of the Ossining quadrangle; however, it is not mappable.

Lacking evidence to the contrary in the Ossining quadrangle, the geological age assignments adopted by Fisher and others (1971) on the Geologic Map of New York are used here: Fordham Gneiss, Proterozoic; Lowerre Quartzite, Cambrian; Inwood Marble, Cambrian-Ordovician; Manhattan Formation, Ordovician and/or Cambrian.

FORDHAM GNEISS

Fordham Unit A

Fordham unit A occurs as a lens within Fordham unit C, and is characterized by its heterogeneity, slabby appearance in outcrop, and rusty or brown weathered surface. The unit tends to break along compositional contacts thereby accentuating the inherent heterogeneity.

Interlayering of rock types on a scale of a few millimeters to several meters is common in some sections of unit A; in other sections, composition is more uniform. These differences within the unit do not appear to have persistent stratigraphic significance. Rock types comprising the interlayered sequence include rare pyroxene-hornblende-bearing gneisses, garnet-feldspar-biotite-quartz gneisses, quartz veins and pods, pegmatite, and amphibolite. This interlayered sequence is highly deformed, with many folds and boudins present.

Foliation is poorly developed within much of the gneiss, and the rock has a granulose texture. Gneisses of the layered sequences within unit A which have a marked foliation are characterized by mineral segregations resulting in quartz-feldspar layers and biotite-bearing layers. The biotite commonly enwraps coarse quartz-feldspar pods. Where biotite segregations occur, the gneiss is schistose.

On the weathered surface, unit A has a yellow or orange chalky appearance and is very crumbly. A rusty or brown weathered surface is a common distinguishing characteristic.

Pegmatitic pods and layers are common throughout the unit; they are most abundant (particularly when present as distinct layers) in the interlayered sequence of unit A. The pegmatitic layers contain coarse (2 mm–2 cm) feldspar and quartz with minor amounts of biotite and garnet. Where biotite is present in the pegmatite, a coarse foliation exists which parallels the compositional layering of the sequence in general. Pegmatite pods from less than a centimeter to over a meter diameter commonly cut across foliation. Pegmatite is also common in the dilatant zones of boudinage structures throughout the interlayered sequence.

Some vein quartz exists within the interlayered sequence as layers crosscutting the foliation and as 1–20 cm diameter pods of varying orientation.

Amphibolite layers appear fresh, as do amphibolites throughout the entire stratigraphic sequence, and no apparent foliation exists within the layers. Although the amphibolite appears fresh and little weathered on the surface, it occupies the low areas in outcrop and thus apparently is the most easily eroded rock type in this heterogeneous sequence.

Fordham unit A is also characterized by more homogeneous areas where distinct compositional layering is not prominent. The rock type in such areas is a slabby, schistose gneiss containing quartz, feldspar, and biotite with lesser amounts of diopside and hornblende. Foliation, formed by the parallel orientation of the biotite, controls the parting of the rock into slabs a few centimeters thick. Some quartz-rich layers and pods, amphibolite layers, and white quartz-feldspar pegmatite layers and pods are also found. The weathered surface has a rusty or dark brown coloration which is present on closely spaced schistose planes, and pervasive weathering is characteristic of this rock.

Another distinct rock type of unit A is an aluminous schist closely resembling much of Manhattan unit A. This subdivision is rarely exposed and is limited to three outcrops within the quadrangle, located south of Tompkins Corners and 2,000 feet west of hill 651. This schist may represent a distinct unit underlying unit A; however, its limited exposure and close association with rocks clearly belonging to unit A indicate that it most likely represents highly aluminous sediments essentially contemporaneous with the deposition of unit A as a whole. This schist is similar to a distinct unit mapped by Hall (personal communication, 1967) in the White Plains quadrangle where it is in a stratigraphically different position from the schist here considered to be part of unit A in the Ossining quadrangle, and, therefore, the two units are not correlative. The Fordham unit A schist contains biotite, quartz, feldspar, sillimanite, lavender garnet, and magnetite. The weathered surface is characterized by decomposition and a rusty or yellow color.

The general trend of compositional layering and foliation of unit A parallels the contact with unit B.

Fordham unit B

Fordham unit B, overlying unit A, is a thin and perhaps discontinuous unit. Outcrops are not common, and, in many places, the unit may be absent. Unit B consists of a hard, massive, garnet-biotite-hornblende-quartz-plagioclase gneiss and amphibolite with accessory magnetite. Separate delineation of the gneiss and amphibolite has not been generally possible, and, thus, they have been combined into one map unit. Some narrow (about 2 mm thick) quartz-feldspar layers are present, giving the rock a marked foliation. A few randomly oriented quartz pods (generally about 1 cm in diameter) are also present. Foliation within the gneiss is also formed by the alternation of hornblende-rich layers with biotite-rich layers and by preferred orientation of biotite and hornblende parallel to the compositional layering. This compositional layering is generally on the order of a few millimeters thick. Foliation within the amphibolite is not common, and a granulose texture is characteristic. Foliation within unit B, when present, parallels the contacts of unit B. Except for porphyroblastic garnets, the dark gneiss is fine to medium grained. The fine-grained zones are very dense and massive without marked foliation. Amphibolite layers are medium-grained with approximately equal-sized and randomly distributed hornblende and feldspar grains. The fresh appearance and lack of brown or rusty coloration on the weathered surfaces of the amphibolite and gneiss are helpful field criteria for distinguishing individual outcrops of unit B from those of unit A.

Fordham unit C

Fordham unit C is by far the most widespread unit within the Fordham Gneiss and also the best exposed. In general, it consists of a pink granitic gneiss, a white quartz-plagioclase gneiss, a dark gray quartz-biotite-plagioclase gneiss, and amphibolite. These rock types are often found separately in individual outcrops or closely associated in outcrop, and the rock types do not appear to have persistent stratigraphic significance within the unit.

The pink granitic gneiss often is gradational with the white plagioclase-rich gneiss, with the color being dependent upon the amount of K-feldspar present. As the percentage of K-feldspar increases, the rock becomes more pink. In outcrop, recognizable minerals in the pink granitic gneiss include K-feldspar, plagioclase, quartz, biotite, and occasionally hornblende. Foliation is formed by the parallel orientation of biotite and by compositional layering of biotite-bearing layers and biotite-free layers of less than one centimeter to several centimeters thickness. Compositional layering and mineralogical foliation are parallel to one another. Some pink, K-feldspar-bearing pegmatite and white, K-feldspar-free pegmatite cut across the primary foliation. A few randomly oriented quartz pods also occur. In general, the pink gneiss is medium-grained; however, occasionally large (up to about ½ cm in diameter) K-feldspar grains are present.

The white gneiss, abundant in unit C, is a massive, medium-grained rock generally lacking a well-developed foliation. In the field, recognizable minerals include quartz, white feldspar, and biotite, with garnet and hornblende commonly present. In the absence of disseminated hornblende, distinct amphibolite layers are often present. These amphibolite layers have sharp contacts with the surrounding gneiss without any apparent compositional gradation between the two rock types. Biotite, where disseminated throughout the rock, forms a weakly developed foliation by virtue of its parallel orientation. Where biotite is concentrated into layers a distinct foliation is present with biotite grains parallel to the compositional layering. Competent amphibolite layers have been attenuated and broken during deformation, and amphibolite boudins are common. The less competent gneiss flowed into the zones of necking and separation formed by amphibolite attenuation. These amphibolite layers and boudins are similar to those previously described in other Fordham Gneiss units.

The dark gray or steel gray gneiss of Fordham unit C differs from the white gneiss in that it contains a higher percentage of hornblende and/or biotite. Minerals recognizable in the field include biotite, hornblende, feldspar, quartz, and locally garnet. Foliation is commonly formed by alternating layers of white gneiss and gray gneiss less than one centimeter thick. Preferred orientation of biotite and hornblende parallels and accentuates this foliation. White and pink granitic pegmatite layers and pods as well as occasional quartz pods both parallel and crosscut this foliation.

All rock types within Fordham unit C are present as both distinct layers in sharp contact with one another and as gradational rock types. Where distinct lithologic layering can be recognized, layers generally range in thickness from less than a centimeter to about 10 meters.

The general trend of foliation within Fordham unit C parallels the contact of the unit with the overlying Lowerre Quartzite or Inwood Marble. Contacts between units within the Fordham Gneiss, in general, parallel the contact between the Fordham Gneiss and overlying formations. Some divergence from this parallelism is evident. This divergence is probably the result of varying ductilities and anisotropies within the heterogeneous sequence of rock types that comprise the stratigraphic section. Fordham unit C is the only Fordham Gneiss unit in the Ossining quadrangle that is in contact with the overlying formations. In the White Plains quadrangle, Hall (1968a, b, c, d,) mapped units within the Fordham Gneiss which are truncated unconformably at the Fordham Gneiss-Inwood Marble contact. In the Ossining quadrangle, however, there is a general parallelism between Fordham units with the Fordham-Inwood contact.

LOWERRE QUARTZITE

The Lowerre Quartzite overlies the Fordham Gneiss. In the Ossining quadrangle, as elsewhere within the Manhattan Prong, this formation has a very limited distribution. Generally, the Fordham Gneiss is in direct contact with the overlying Inwood Marble. Since the name Lowerre Quartzite was first introduced by Merrill (1896), there has been a debate about the validity of the Lowerre Quartzite as a distinct formation. Berkey (1907) considered it to be a part of the Fordham Gneiss; later Berkey and Rice (1921) considered the Lowerre Quartzite to be a valid formation. Prucha (1956) studied all of the Lowerre Quartzite localities then known and came to the conclusion that the Lowerre Quartzite outcrops are "strongly sheared phases of the Fordham Gneiss and associated granite sheets" (1956, p. 683). Norton (1959) came to the conclusion that the Lowerre Quartzite is a valid formation. More recent mapping by Hall (1966, 1968a, b, c, d), Ratcliffe (1968), and I indicates that the Lowerre Quartzite is a distinct rock type of constant stratigraphic position within and adjacent to the Ossining quadrangle. On this basis the designation of the Lowerre Quartzite as a distinct formation will be retained for the Ossining quadrangle.

Within the Ossining quadrangle, the Lowerre Quartzite crops out in three localities. One of these localities, Sparta Landing, was previously described by several authors (Mather, 1843; Merrill, 1896; Berkey, 1907; Prucha, 1956; Norton and Giese, 1957; Norton, 1959). The other two localities had not been located prior to the present study. Berkey (1907) mentioned an outcrop of Lowerre Quartzite about 1 mile north of Chappaqua along the Harlem division of the New York Central railroad. Prucha (1956) was unable to locate this outcrop, nor was I.

The two new Lowerre Quartzite localities are in the northwestern quarter of the Ossining quadrangle on an anticline herein called the Teatown Anticline. One of these two outcrops is located on the nose of the northeast plunging anticline in a small north-south stream valley about ½ mile northeast of Teatown Lake. The quartzite in this area is 5 to 10 meters thick. It is a slabby, white, medium-grained quartzite of variable quartz content. Some layers or areas within the outcrop appear to be composed totally of quartz while other layers contain abundant feldspar and mica in addition to the predominant quartz. In the layers rich in feldspar and mica, foliation is well-developed; in the pure quartzite it is not. Where present, the foliation is parallel to foliation within the adjacent Fordham Gneiss and to the Fordham-Lowerre and Lowerre-Inwood contact.

The other previously unreported outcrop of Lowerre Quartzite is a very small one located on the southern limb of the Teatown Anticline at 73°50′15″W longitude and 41°12′10″ latitude. It is lithologically identical to the Lowerre outcrop previously described.

The Sparta Landing outcrop of Lowerre Quartzite is situated on the nose of an anticline which, at Sparta, plunges to the southwest. A feldspathic quartzite with minor amounts of biotite crops out along the railroad tracks and along Sparta Brook. The rock at this locality tends to be more crumbly and more highly weathered and rust-colored than either of the other two Lowerre Quartzite localities within the quadrangle. On the south side of the Sparta Brook valley, the quartzite is very slabby and highly sheared with abundant slickensides that strike 85° and plunge 45° east. This area may represent a zone of faulting, and as Prucha (1956) has suggested, this faulting may be responsible for the general lack of Inwood Marble along this contact in this area.

INWOOD MARBLE

On the basis of mapping in the Nyack, White Plains, and Glenville quadrangles, Hall (1968b,c,d) subdivided the Inwood Marble into five units, all of which are represented in the Ossining Marble outcrops within the Ossining quadrangle (Plate 1). These subunits could not be extrapolated as separate map units.

Within the Ossining quadrangle, the Inwood Marble is composed of relatively pure white dolomite marbles, calcite marbles, dolomite-calcite marbles, and calcitic marbles containing abundant mica, clinopyroxene, and quartz. Some layers containing calc-silicate minerals are also found. Dolomite and quartz coexist away from the Inwood-Manhattan contact, but, as this contact is approached, the pair dolomite-quartz is replaced by diopside. The dolomite-quartz reaction will be discussed in greater detail later.

Near the Fordham-Inwood contact, the Inwood consists of a coarse- to medium-grained white dolomite with some calcite, mica, and quartz (Inwood unit A). Within a few centimeters of the Fordham Gneiss, dolomite is absent owing to reaction during metamorphism of the Inwood A dolomite with quartz from underlying Fordham Gneiss. Recognizable foliation is lacking in Inwood unit A, and the rock tends to be massive.

Inwood unit B, although commonly exposed in the White Plains area (Hall, 1968d, p. 120), is poorly exposed in the Ossining quadrangle. It consists of white dolomite marble layers, red-brown quartz-biotite-feldspar layers, and calcite-dolomite marble which may develop a tan weathered surface. Quartz is rare in the marble layers of this unit.

Inwood unit C is well exposed south of the town of Ossining particularly on and around the grounds of Sing Sing prison. This rock is a medium- to coarse-grained, white dolomitic marble which is commonly nearly pure dolomite. Adjacent quartz and dolomite coexist without any evidence of reaction between the two. Accessory minerals include pyrite and mica. Layering is commonly massive, but layers ranging from less than 1 cm to several meters in thickness are also common. In the absence of layering visible foliation does not exist.

Inwood unit D consists of interlayered white dolomitic marble and white or gray calcitic marble. Individual layers generally are a few centimeters to several meters in thickness. Mica, feldspar, tremolite, pyrite, and serpentine are commonly present in addition to calcite and dolomite. Foliation is marked by light and dark banding within the calcitic layers and by alternating dolomite and calcite layers. Hall (1968d) recognized a calc-schist associated with these interlayered dolomitic and calcitic marbles; however, in the Ossining quadrangle this schist was not seen.

Inwood unit E is a white, medium-grained calcitic marble. In addition to calcite, minor amounts of feldspar, quartz, pyroxene, and mica can be recognized in outcrop. A poorly developed foliation is formed by the parallel orientation of widely scattered mica flakes. Inwood unit E weathers to a tan color.

Hall (1968d, p. 120) indicated that some units within the Inwood Marble are commonly present as lenses which were not deposited in some areas. Similar lensing appears to be present in the Ossining quadrangle where, from the distribution of rock types, units apparently are commonly missing.

Hall (1968d, p. 122) indicated that there is an angular unconformity between the Manhattan Formation and the underlying Inwood Marble. The basis for this interpretation is that he finds basal Manhattan schist in contact with each member of the Inwood Marble and also with the Fordham Gneiss. Hall (1968d, p. 122) indicated that marble which commonly interlayered with schist at what was previously considered the Inwood-Manhattan contact is, in actuality, marble beds within the Manhattan Formation and, therefore, above the proposed unconformity. The sparseness of Inwood outcrops within the Ossining quadrangle does not permit a clear interpretation as to the presence or absence of an unconformity between the Inwood and Manhattan Formations in the Ossining quadrangle. Although the absence of Inwood Marble in many areas of the Ossining quadrangle may be indicative of an unconformity, it may instead be due to tectonic squeezing of the very ductile marble.

FORDHAM-INWOOD CONTACT ZONE

Where the Lowerre Quartzite is absent, the Fordham Gneiss is in contact with the Inwood Marble. Interlayering of gneiss and marble at the Fordham-Inwood contact can be seen in three different areas within the Ossining quadrangle. In two of these areas infolding is clearly responsible for the interlayering; in the third area, infolding is an important mechanism responsible for the interlayering, but it cannot be the only mechanism. The first locality of infolding of marble and gneiss is located about 182 m southwest of Echo Lake. Here a 0.6-meter-thick layer of marble, containing calcite, dolomite, and serpentine, is enclosed by Fordham unit C. Contacts between the gneiss and marble are sharp, with no apparent compositional gradation between the two rock types. Mirror repetition of rock types exists on either side of the fold axis. This outcrop is on strike with the Fordham-Inwood contact as established directly north of Echo Lake. The marble-gneiss outcrop is contiguous with Fordham unit C to the east and is 30 m from outcrops of the basal Manhattan unit perpendicular to strike to the west. This stratigraphic position, together with lithologic similarity of the marble with known Inwood Marble outcrops, strongly suggests that the marble is in fact Inwood Marble and not a marble layer within the Fordham Gneiss. The second outcrop of gneiss-marble infolding is located along a road cut 45 m west of the State Game Refuge in the central part of the quadrangle. The relationships here are very similar to those just described for the outcrop southwest of Echo Lake, and the outcrop is interpreted as another example of Inwood-Fordham infolding. The third area where the interlayered gneiss-marble is exposed near or at the Fordham-Inwood contact is in the town of Chappaqua. This interlayering can be traced parallel to strike from Chappaqua, along the railroad and Saw Mill River Parkway, into the Mount Kisco quadrangle for a distance of about 4 km. An excellent outcrop of this interlayered sequence, which provides both plan and cross-sectional views, is exposed at the northbound entrance ramp to the Saw Mill River Parkway at Chappaqua (Figures 2, 3). Isoclinal folding of this sequence is evident within the outcrop. From Figure 3 and Table 1, it is apparent that on the basis of symmetry, isoclinal folding can also be inferred where fold closures cannot be seen in outcrop. Consistent mirror symmetry does not, however, persist across the entire sequence, as can be seen in Figures 2 and 3.

Table 1

Rock sequence at the Chappaqua outcrop of the Fordham Gneiss-Inwood Marble contact zone. Rock types and layer designations correspond to those used in Figure 3.

Rock Type	Layer Designation	Thickness, m
cover		
interlayered biotite gneiss and quartz-feldspar gneiss	A	165
white quartz-feldspar gneiss	B	45
interlayered biotite gneiss and quartz-feldspar gneiss	A	23
white quartz-feldspar gneiss with 12.5 cm by 60 cm pod of white calcite marble	B with C	50
rusty, feldspar-quartz gneiss	D	15
white-gray calcite marble with diopside	E	30
rusty, feldspar-quartz gneiss	D	2.5
white-gray calcite marble with diopside	E	2.5
white quartz-feldspar gneiss	B	15
white-gray calcite marble with diopside	E	0–15
white quartz-feldspar gneiss	B	18
white-gray calcite marble with diopside	E	10
white quartz-feldspar gneiss	B	15
amphibolite	F	60
white quartz-feldspar gneiss	B	15
amphibolite	F	30
cover		

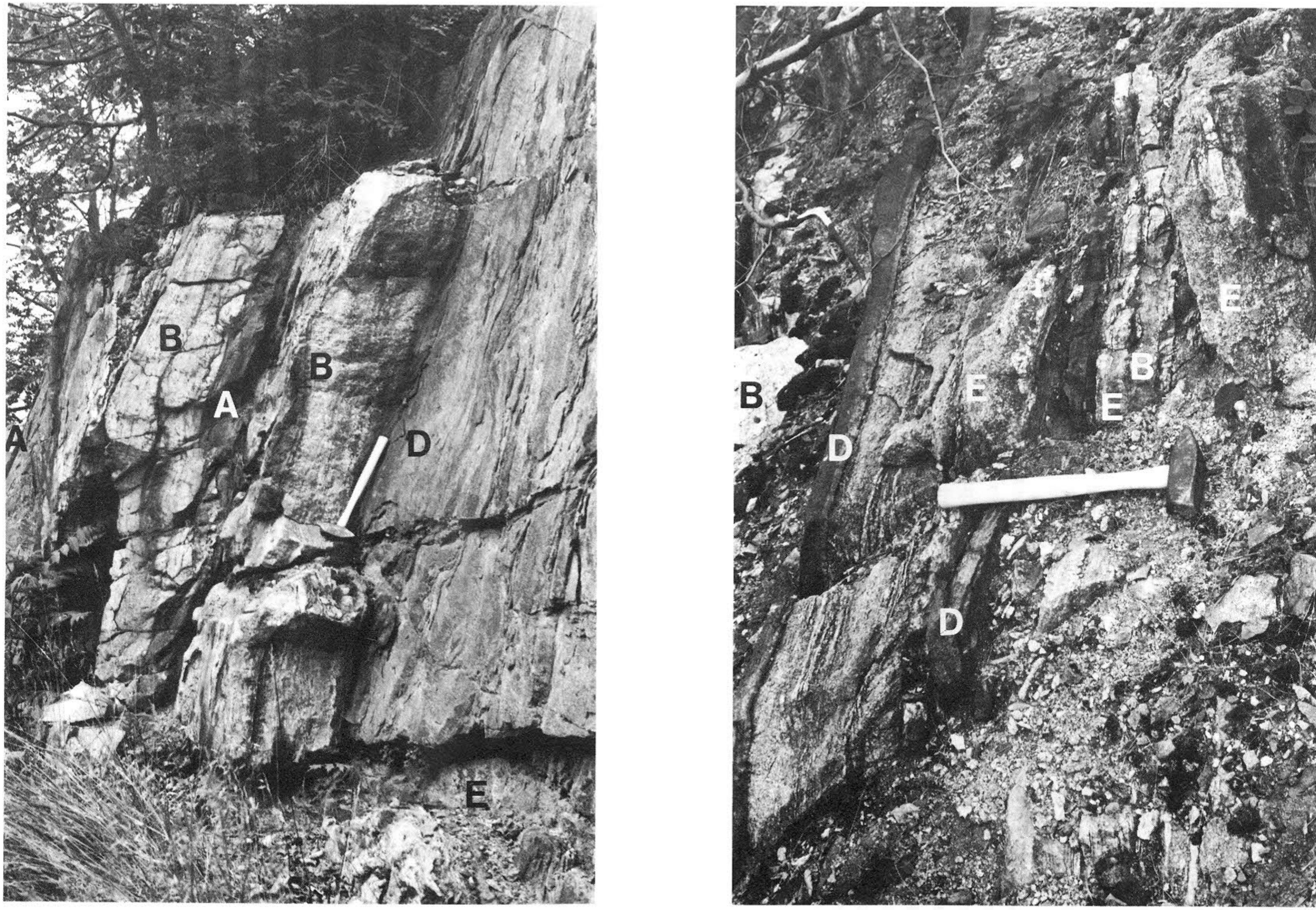


Figure 2 Fordham-Inwood contact zone as exposed along the Saw Mill River Parkway north-bound entrance ramp at Chappaqua, New York. Layer designations correspond to those used in Table 1 and Figure 3.

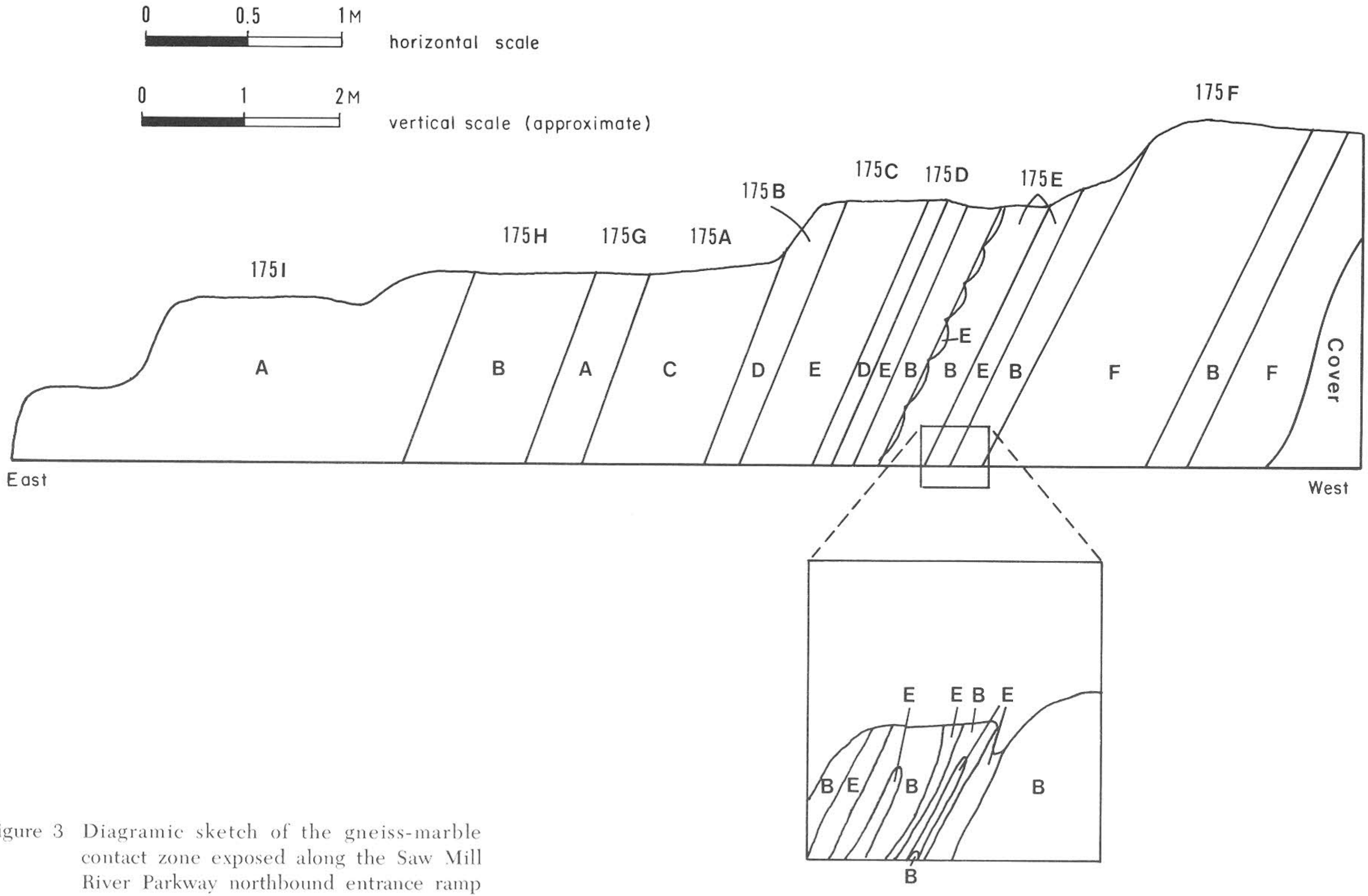


Figure 3 Diagramic sketch of the gneiss-marble contact zone exposed along the Saw Mill River Parkway northbound entrance ramp in Chappaqua, New York. Layer descriptions are listed in Table 1, and petrographic data are presented in Table 22.

MANHATTAN FORMATION

Manhattan unit A

The Manhattan Formation overlies the Inwood Marble. The interlayered marble and schist which exists near or at the base of the Manhattan Formation is a part of the Manhattan Formation (Hall, 1968d). The Manhattan Formation within the Ossining quadrangle consists of two units: (1) a fissile schist with calc-silicate rock or interlayered marble and calc-silicate rock locally present at the base, and (2) a feldspar-rich gneiss or schistose gneiss which overlies the fissile schist. Unit designations for the Manhattan Formation correspond to those of Hall (1968d, p. 120). Manhattan unit A will be used to designate the lower Manhattan unit and Manhattan unit C will be used for the upper Manhattan unit of the Ossining quadrangle. Hall's unit B, an amphibolite, is absent in the Ossining quadrangle and apparently also in the Haverstraw quadrangle (Ratcliffe, 1968, p. 200). Amphibolite layers occur within the Manhattan Formation of the Ossining quadrangle, but only as thin and discontinuous layers within both the upper and lower Manhattan units.

Manhattan unit A of the Ossining quadrangle is a fissile garnet-sillimanite-feldspar-muscovite-quartz-biotite schist (Oma in Plate 1) with a pyroxene-hornblende-biotite-quartz-feldspar schist or schistose gneiss (Omab in Plate 1) and interlayered calcitic marble-schistose gneiss locally present at the base.

?Omab

The basal, pyroxene-hornblende, bearing schistose gneiss is present more commonly in the central and northwestern portions of the quadrangle than in the southeastern portion. It ranges from a hard, rusty, slabby schistose gneiss to a more granulose rock with very little rust or brown coloration on the weathered surface. Commonly these two rock types are interlayered with layers 1 to 5 cm thick. Granitic pegmatite layers and quartz layers are common and range in thickness from less than a centimeter to several meters. The rusty, slabby schistose gneiss is dark blue-gray or black on fresh surfaces and has a well-developed foliation due to the parallel orientation of biotite. Where the schistose gneiss is interlayered with the granulose layers a compositional layering foliation is present. Both types of foliation parallel the general trend of the Manhattan-Inwood contact. In the field, minerals that can be recognized within the slabby schist or schistose gneiss include biotite, feldspar, quartz, pyroxene, hornblende, and occasionally calcite, garnet, and muscovite. The more granulose layers and zones do not have a well-defined foliation. The granulose zones contain more pyroxene and hornblende and less biotite and garnet than do the slabby, schistose gneiss zones. Calcitic marble layers (generally less than 1 m thick) are commonly interlayered with the schistose gneiss. These marble layers contain calcite, feldspar, quartz, mica, pyroxene, and hornblende. No dolomite is recognized.

The schistose gneiss and interlayered schistose gneiss-marble present at the base of the Manhattan Formation are local in their distribution, and many areas within the quadrangle exist where the fissile schist typical of Manhattan unit A is in direct contact with the underlying Inwood Marble.

?Oma

This is the most abundant rock type within Manhattan unit A. It is a fissile, aluminous schist easily identified within the Ossining quadrangle by its high mica content and very rough, irregular, weathered surface.

This unit has the largest number of mineral phases of any unit within the Ossining quadrangle; those recognizable in the field include biotite, muscovite, garnet, quartz, feldspar, sillimanite, magnetite, and rarely tourmaline and chlorite. Magnetite is locally abundant near the base of Manhattan unit A, and, in a few areas, makes it impossible to take accurate compass readings.

Compositional layering is commonly produced by feldspar-quartz-rich layers and mica-rich layers. Where present, it parallels both foliation and unit contacts.

Grain size within the schist is quite variable. Spherical to euhedral garnet grains and platy mica grains commonly are less than a millimeter in diameter, but locally exceed one centimeter. Sillimanite is generally fibrous, and ranges in length from less than a millimeter to several centimeters where present as small pods in the schist. The remaining mineral phases are fine- to medium-grained. Pink and white pegmatite pods and layers of greatly varying size are abundant throughout Manhattan unit A. They consist of quartz, feldspar, muscovite, biotite, and garnet, with subordinate tourmaline and sillimanite. Pegmatite pods as well as the commonly present quartz pods occur both concordantly and discordantly to the foliation. Pegmatite layers parallel the foliation.

?Omaa

Thin, discontinuous amphibolite lenses that are rarely more than a few meters thick and several meters in length occur within Manhattan unit A. The largest of these lenses is located on the southern limb of the Teatown Anticline where a 2-meter-thick lens can be traced for about 1.5 km along strike. Manhattan unit A amphibolite is very similar to amphibolite in other formations. It is dark gray to black and is composed of hornblende, plagioclase, and minor quartz. All amphibolites are concordant with the foliation of the surrounding schist, but the amphibolites themselves lack visible foliation.

Manhattan unit C

The contact between Manhattan unit A and Manhattan unit C in the Ossining quadrangle is gradational. Manhattan unit A rock type a few centimeters thick is interlayered with Manhattan unit C rock type of about the same thickness. This contact zone is limited to a few meters in width; however, schist layers similar to Manhattan unit A are occasionally found well within Manhattan unit C.

Manhattan unit C stratigraphically is the highest unit in the Ossining quadrangle. Manhattan unit C is fine- to medium-grained and composed of feldspar, quartz, biotite, and muscovite with minor amounts of garnet and magnetite and occasionally sillimanite. Quartz and feldspar are the dominant minerals; hence, the rock is gneissic in character. Compositional layering of quartz-feldspar layers and biotite layers (a few millimeters thick), as well as the parallel orientation of biotite and occasionally muscovite, give the rock a well-defined foliation. The preferred orientation of mica is parallel to compositional layering. In general the outcrop surfaces appear to be rather massive, but close examination reveals that the foliation is also expressed by small-scale preferential weathering out of the thin mica layers.

Amphibolite layers containing feldspar, hornblende, and biotite are locally found within Manhattan unit C. In some layers the hornblende grains have parallel orientation, in others preferred orientation is lacking.

CORTLANDT COMPLEX

A younger, mafic, igneous complex, the Cortlandt Complex, discordantly intrudes the Manhattan Formation. Other than to map the boundary between the Cortlandt Complex and the intruded Manhattan Formation, only a brief reconnaissance of the Cortlandt Complex was made for the present study. The Complex has been mapped by Rogers (1911), Balk (1927), and Shand (1942). Additional studies include those of Dana (1880), Williams (1884, 1886, 1887a,b, 1888a,b), Steenland and Woolard (1952), and Long (1961), The subdivisions are those used on the State Geologic Map of Fisher and others (1971).

Emery deposits, presently being mined at one locality within the Ossining quadrangle, are associated with the Cortlandt Complex. These were studied by Williams (1888b), Rogers (1911), Larsen (1928), Gillson and Kania (1930), Butler (1936) and Friedman (1956). They were most recently investigated by Barker (1964) who concluded that the emery formed by reaction of the pelitic Manhattan schist with the mafic Cortlandt Complex.

Petrography

GENERAL STATEMENT

Few studies have been made of the petrology of the Fordham-Manhattan stratigraphic sequence. Fettke (1914) studied the Manhattan Formation, and more recently Scotford (1956), Langer (1966), and Lessing (1967) have made petrographic studies of the above sequence.

During field work in the Ossining quadrangle, more than 300 samples were collected, and from these, 171 thin sections were made and studied. Modal analyses were made of 74 thin sections, and all were stained for either feldspar or calcite. The analyses, along with mineral identifications for all the 171 thin sections, are presented in Tables 18–27. Sample locations are shown on Plate 2. All modal analyses were made using 2,000 counts per thin section. The reliability of each point count analyses was determined by the method of Kalsbeek (1969), and the results are given as ± values for each modal percentage in Tables 18–27.

Thirty-two minerals have been identified from rocks of the Ossining quadrangle, exclusive of the Cortlandt Complex and that part of the Manhattan Formation which was metamorphosed by the intrusion of the Complex. Quartz and plagioclase are the most abundant. Other minerals are biotite, magnetite, hematite, pyrite, muscovite, zircon, apatite, sillimanite, garnet, sphene, allanite, tourmaline, staurolite, microcline, orthoclase, clinopyroxene, hornblende, scapolite, sericite, chlorite, serpentine, calcite, dolomite, phlogopite, olivine, tremolite, and clinozoisite. Microperthite, microantiperthite, and myrmekitic intergrowths of quartz and Na-plagioclase are also present in a few samples.

Determinative techniques other than microscopic were used only when two conditions were met: 1) the composition of the mineral in question could not be readily determined by flat stage techniques (*e.g.*, solid solution series such as the feldspar) and 2) knowledge of the composition was necessary for determining mineralogical paragenesis.

FORDHAM GNEISS

Fordham unit A

Fordham unit A is characterized by a variety of rock types, and a comparison of the mineral content of the samples listed in Table 18 reflects this variety. Hornblende, scapolite, and pyroxene are common in a few layers, but are rare or absent in the remainder of the unit. Sillimanite and muscovite are most common in the schist whereas perthite is limited to pegmatite. Variety of rock type is also reflected in the plagioclase compositions (Table 2). Anorthite content ranges from An_{16} to An_{39}.

Table 2. Fordham unit A plagioclase compositions

Sample #	An Mol %
15-II	16
70-II	22
57	25
70-I	29
117	29
27	32
65-II	34
120	34
65-I	39
114	39

Within Fordham unit A, as well as throughout the entire stratigraphic sequence, plagioclase composition reflects bulk rock composition rather than metamorphic grade. Those layers rich in aluminum and calcium contain plagioclase with a high anorthite content. Those poor in calcium, though often high in aluminum, have plagioclase with low anorthite content. The hornblende-scapolite-pyroxene-rich layers of Fordham unit A and the basal Manhattan unit A, as well as amphibolites throughout the stratigraphic sequence, are characterized by andesine and labradorite.

The granitic and aluminous units contain oligoclase as the most common plagioclase. In all samples of Fordham unit A except amphibolite, quartz is the dominant mineral, and quartz along with plagioclase and biotite constitute the bulk of all samples.

The schist in Fordham unit A (70-I and 70-II) is similar to the Manhattan unit A rock type. Sillimanite, biotite, garnet, and some K-feldspar (Or_{88}-Or_{90}) coexist. Thus, within the Fordham Gneiss, sillimanite, K-feldspar, and quartz represent a stable mineral assemblage.

The other rock types which constitute Fordham unit A are also not unique to this unit. Layers within Fordham unit A which contain abundant pyroxene, hornblende, scapolite, and calcic plagioclase closely resemble layers near the base of the Manhattan Formation, and the biotite-plagioclase-quartz gneisses of Fordham unit A are similar to some gneisses from Fordham unit C and Manhattan unit C. Such similarity of rock types exist throughout the stratigraphic sequence.

Fordham unit B

Field observations indicate that Fordham unit B consists principally of a dark quartz-feldspar gneiss and amphibolite. This character is reflected in the modes for the unit B samples (Table 19). The difference between the two unit B rock types is best reflected in the quartz/hornblende ratio. In amphibolites, the ratio is low, whereas in the dark gray gneiss the ratio is relatively high. The relatively subsilicic composition of this rock is evident from plagioclase compositions which range from An_{31} to An_{56} (Table 3). Biotite and occasionally clinopyroxene are abundant minerals in addition to quartz, plagioclase, and hornblende. Less abundant phases include zircon, unidentified opaque minerals, apatite, garnet and, in one sample, calcite.

In one sample from Fordham unit B, clinopyroxene constitutes 27.5% (volume) of the rock, but in general it does not exceed one or two percent. Clinopyroxene is green in hand sample, but colorless in thin section. It has excellent cleavage. Hornblende commonly occurs as rims around the pyroxene, but unrimmed pyroxene is also common. The optic angle N_y, and 2V were determined for 15 pyroxene samples from Fordham unit A, the Fordham-Inwood contact zone, Inwood Marble, and the base of Manhattan unit A as well as from Fordham unit B. From these data, pyroxene composition was inferred using a diagram presented by Tröger (1959, p. 62) (Figure 4). The pyroxene from Fordham unit B is salite.

The total number of mineral phases and the variability of mineral composition in Fordham unit B is smaller than in any other unit. This restricted compositional range suggests a very limited variability in the nature of the pre-metamorphic parent rock, and little if any interchange with the rocks above or below. Field studies support this conclusion in that contacts between unit B and the surrounding units are sharp. Such relationships, as well as the apparent absence of the unit in many places, are consistent with the possibility that unit B represents a mafic to intermediate volcanic rock.

Table 3. Fordham unit B plagioclase compositions

Sample #	An Mol %
63	31
7	32
94	34
52	35
72	35
69	36
93	36
28	40
35	40
76	56

Fordham unit C

Fordham unit C is quite variable in mineralogy, but, in all samples, quartz, feldspar, and biotite are dominant. Plagioclase is generally the dominant feldspar, but in some outcrops, particularly along the Teatown Anticline, K-feldspar dominates. In general, plagioclase and K-feldspar percentages vary inversely. Samples high in K-feldspar tend to be pink whereas those high in plagioclase are white to dark gray.

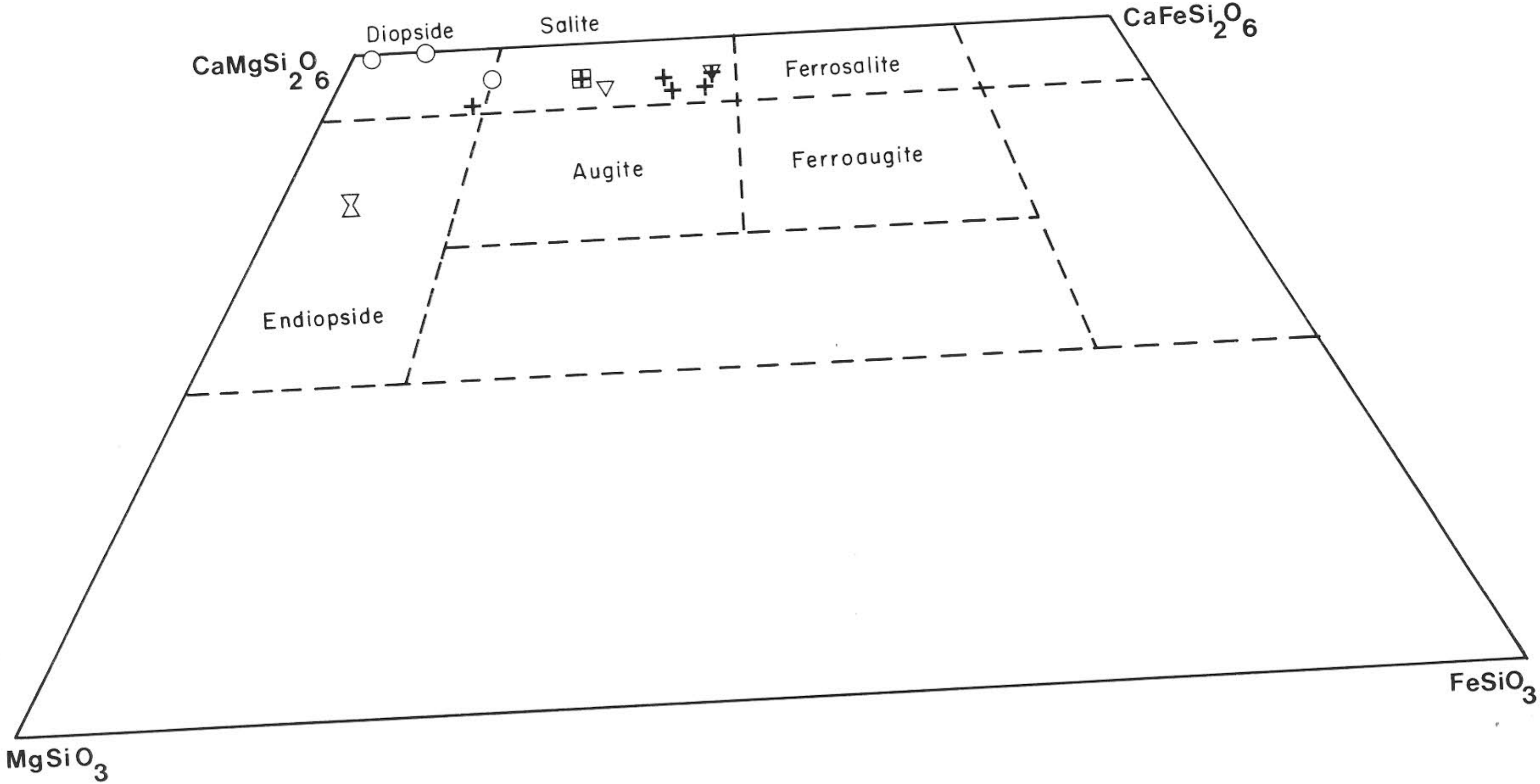
A study of structural state of the K-feldspar (Wissig, 1970) shows that of those samples which have a normal structural state, Fordham unit C and the Lowerre Quartzite have K-feldspars with a microcline structure. The Inwood Marble and the base of Manhattan unit A contain alkali feldspars that are quite variable in structural state. All of the alkali feldspars studied are K-rich, with little Na in solid solution. Values of K/K +Na for the K-feldspar range from 0.77 to 0.92 and average 0.88. No apparent relationship exists between stratigraphic position and composition of the K-feldspars. The petrogenetic significance of structural state and composition will be discussed later.

Table 4. Fordham unit C, K-feldspar compositions

Sample #	Composition
295A	Or_{88}
312-I	Or_{83}
317	Or_{86}
318	Or_{91}
319	Or_{88}

Plagioclase grains from Fordham unit C, particularly from the Teatown Anticline, locally have narrow, fresh borders surrounding a highly sericitized and twinned

Figure 4 Triangular plot of clinopyroxene compositions from the Ossining quadrangle. —Fordham unit A, —Fordham unit B, —Fordham-Inwood contact zone, —Inwood Marble, —Manhattan unit A (basal schistose gniess). Clinopyroxene classification based on Hess (1949).



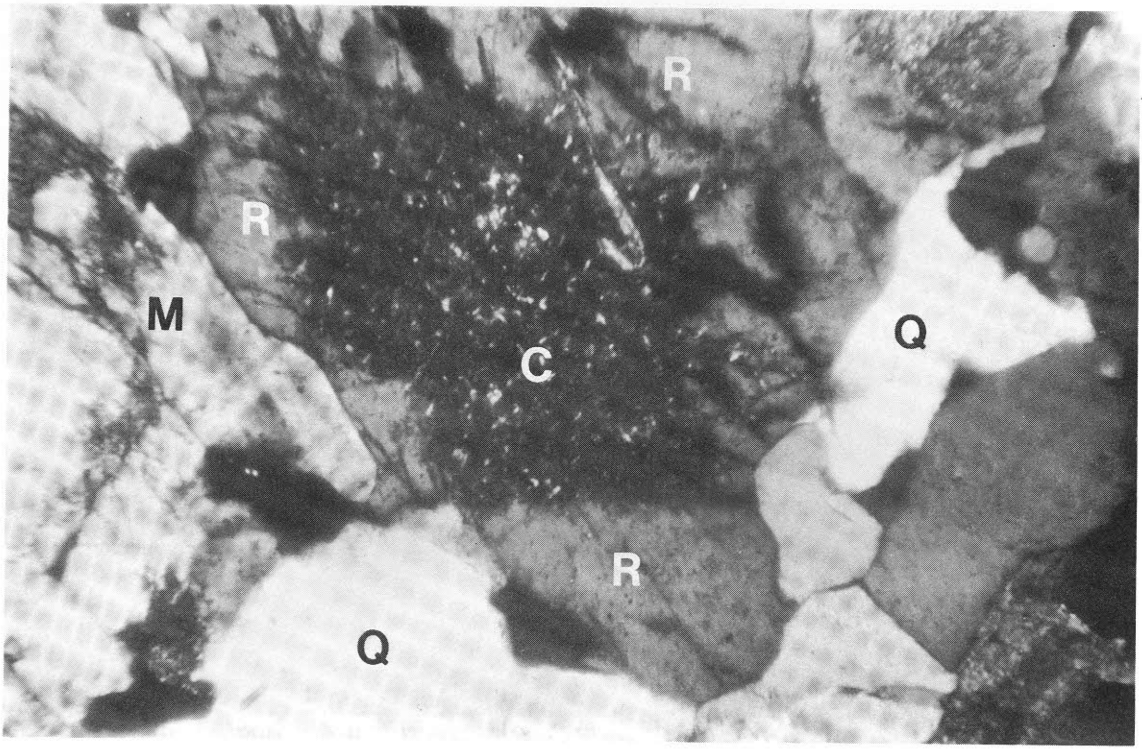


Figure 5 Photomicrographs of plagioclase with calcic core (C) (An_{14}) and sodic rim (R) (An_{11}). Quartz (Q), Microcline (M). Fordham unit C, sample 295-I. Crossed nicols.

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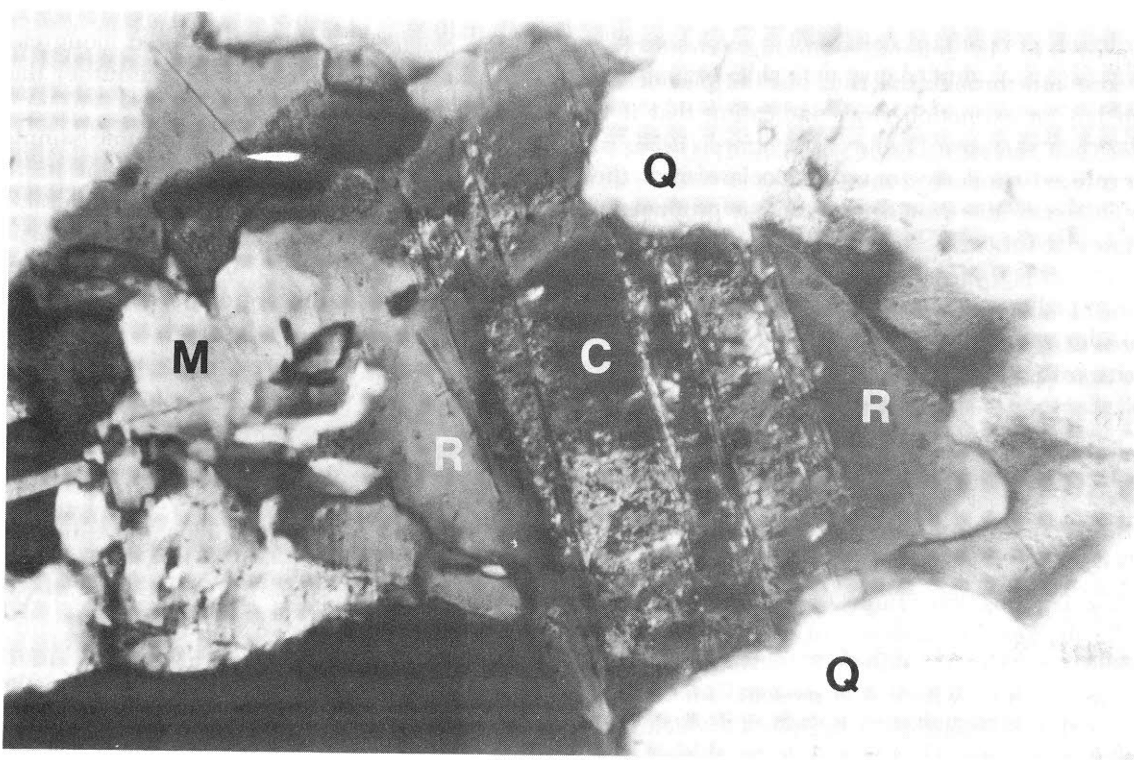

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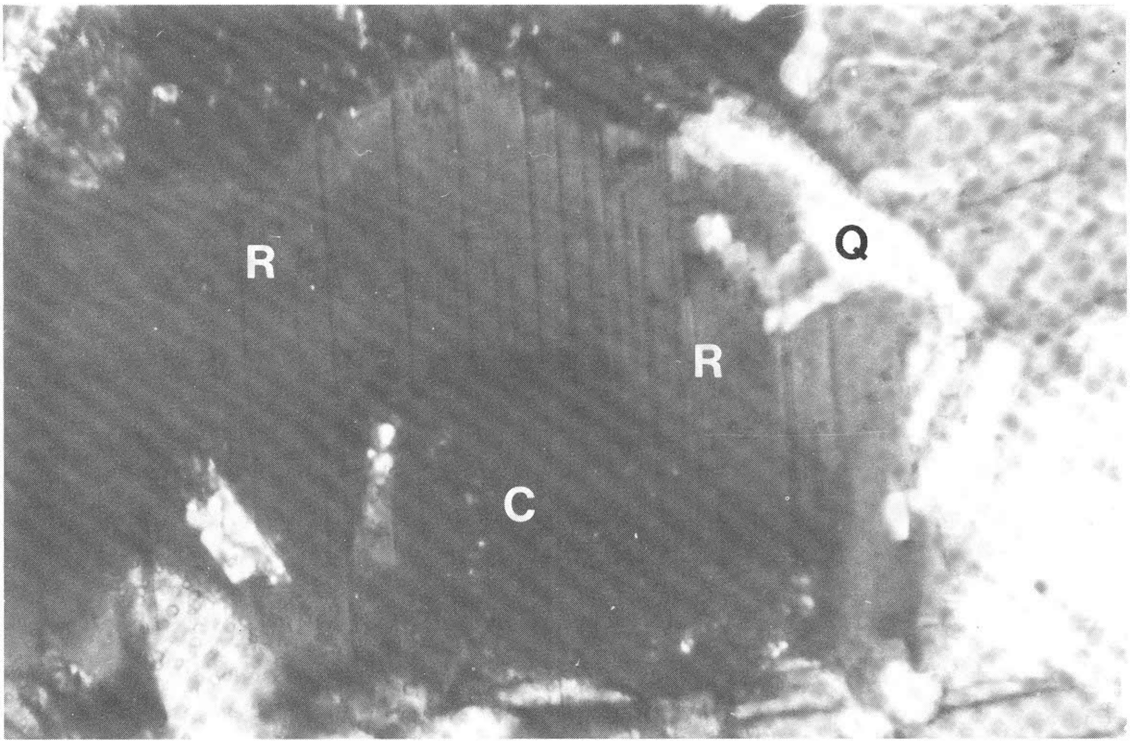


Figure 6 Photomicrograph of plagioclase with a calcic core (C) (An_{28}) and sodic rim (R) (An_{24}). Quartz (Q). Fordham unit C, sample 319. Crossed nicols.

core (Figures 5,6). In general, twinning extends beyond the core and through the rim, but the plagioclase in the rim has an extinction angle indicating that it is more sodic than the core (Table 5). Scotford (1956, p. 1173) interpreted similarly zoned plagioclase from the Fordham Gneiss of the Poundridge area as products of alkali metasomatism.

Table 5. Fordham unit C plagioclase compositions for rimmed plagioclase

Sample #	Core An Mol %	Rim An Mol %
295A	14	11
318	15	8
220	20	18
319	28	24

Plagioclase composition (Table 6) for the unit is related to the presence or absence of K-feldspar grains, varying from An_{26} to An_{36} where K-feldspar is absent and from An_{14} to An_{29} where it is present. An obvious exception to this relationship is sample 43 which contains K-feldspar and has a plagioclase of composition An_{43}. However, this sample differs from others in that the plagioclase is highly altered along cleavage traces, and the K-feldspar occurs there rather than as separate grains.

Hornblende is abundant in some samples and absent in others. Other minerals, present in trace amounts include an unidentified opaque mineral, zircon, muscovite, sericite, apatite, calcite, garnet, chlorite, clinozoisite, sphene, allanite, tourmaline, sillimanite, and myrmekitic intergrowths of quartz and plagioclase.

Table 6. Fordham unit C plagioclase compositions

Sample #	An Mol %	Sample #	An Mol %
312-I	14	105	26
312-II	14	110	26
313	15	112	27
260-II	16	107	28
309	16	119	28
111	18	317	29
86	19	96	32
Ch H	22	260-I	32
244	22	10	36
108	24	43	43
37	26		

Sphene is a common accessory mineral in the Fordham Gneiss of the Teatown Anticline where it frequently rims an unidentified opaque mineral. Lessing (1967, p. 23) described in the Poundridge area a similar occurrence of sphene surrounding pure ilmenite.

Bubble trains of unknown composition are common in some thin sections of both Fordham unit C and Manhattan unit C. Within any given thin section these bubble trains are parallel, and transverse to the foliation. Because the planes of inclusions commonly extend without deflection through adjacent quartz grains of different orientation, the orientation of these inclusions cannot be crystallographically controlled. Tuttle (1949) has pointed out that primary inclusions in quartz generally have either a random orientation or an orientation controlled by growth planes. Therefore, the bubble inclusions of those samples here studied are probably of secondary origin and may represent a late shearing direction transverse to the mineralogical foliation.

LOWERRE QUARTZITE

The Lowerre Quartzite is more distinctive in the field than in thin section. It is a feldspathic quartzite with a higher percentage of quartz than other units (Table 21). The generally high content of quartz (35% to 94%) readily distinguishes the unit from the underlying Fordham Gneiss and overlying Inwood Marble. Three K-feldspar determinations (Wissig, 1970) indicate that the K-feldspar structural state is close to that of microcline. K-feldspar compositions range from Or_{83} to Or_{84}. Plagioclase compositions of two samples are in the albite and oligoclase range (An_7 and An_{11}). Other minerals include biotite, muscovite, clinozoisite, zircon, apatite, tourmaline, sphene, and unidentified opaque minerals.

INWOOD MARBLE

The Inwood Marble is dominated by either dolomite or calcite in a given locality. Near the Inwood-Fordham contact and within the central part of the Inwood Marble, dolomite is common. Within the central part, dolomite coexists stably with quartz. Near the Inwood-Manhattan contact the dominant carbonate mineral is calcite, and the pair dolomite + quartz has been replaced by diopside. The single pyroxene identified from the Inwood Marble is an endiopside (Figure 4). Olivine occurs in some dolomitic marbles which are free of quartz. Olivine is commonly wholly or partially replaced by serpentine, and serpentine-rimmed olivine is common. Other minor constituents are phlogopite, K-feldspar, scapolite, and pyrite. K-feldspar has a variable structural state ranging from maximum microcline to intermediate between orthoclase and microcline (Wissig, 1970). K-feldspar composition is relatively constant, ranging from Or_{88} to Or_{92} (Table 7).

Table 7. Inwood Marble K-feldspar compositions

Sample #	Composition
131	Or_{88}
133	Or_{89}
336	Or_{91}
340-I	Or_{92}

The Inwood Marble as a whole contains approximately equal amounts of calcite and dolomite, with all other constituents being present in only minor amounts. However, large differences in calcite/dolomite ratio occur in individual samples as determined by staining. The same commonly applies to adjacent layers from the same outcrop. The total number of mineral phases within the Inwood Marble is relatively high (19); however, individual samples generally contain few phases, indicating that the number of components within any one part of the Inwood Marble is small.

In a few samples, well-rounded quartz grains occur, surrounded by a coarse, carbonate matrix. These grains are interpreted as detrital, presumably protected from deformation by the very ductile calcite and dolomite which surround them.

FORDHAM-INWOOD CONTACT ZONE

Figure 3 is a sketch of the Fordham-Inwood contact zone exposed along the Saw Mill River Parkway in Chappaqua. Pertinent petrographic data are presented in Table 22. Thin sections 175G and 175I were made from layer A; 175A, 175E, and 175H from layer B; 175B and 175D from layer D; 175C from layer E; and 175E from layer F. From these petrographic data, compositional distinctions between layers are obvious. Layer A is distinguished by its high biotite content, low hornblende content, and lack of K-feldspar. Layer B has a high K-feldspar content, low biotite content, and no hornblende. Layer D is distinguished on the basis of its physical appearance in outcrop, which is characterized by a rusty weathered surface. On the basis of petrographic data, layer D is similar in composition to layer B, and therefore, probably is a part of layer B. E is the only marble layer.

K-feldspar of layers B, D, and the amphibolite have similar structural states close to that of microcline

(Wissig, 1970). The pyroxene in layers D, E, and the amphibolite is entirely diopside (Figure 4).

Compositional similarities as determined from petrographic studies of the Fordham-Inwood contact zone indicate that infolding cannot, by itself, be the only mechanism. Layer A and the amphibolite are not correlative, and thus complete mirror symmetry is lacking. Faulting or more local shearing remains as a possible mechanism to account for the interlayering. With the available data from the Ossining quadrangle, conclusive explanation for the interlayering at the Inwood-Fordham contact is not possible.

MANHATTAN FORMATION

Manhattan unit A

Basal Schistose Gneiss: Locally, the base of Manhattan unit A is characterized by a schistose gneiss containing abundant calcsilicate minerals, plagioclase, and rarely K-feldspar. It is readily distinguished from the remaining lower Manhattan unit by the common occurrence of hornblende, pyroxene, scapolite, K-feldspar, sphene, calcite, and highly variable plagioclase compositions (An_{21} to An_{80}) (Table 8). With the exception of marble interlayers in which calcite is the dominant phase, all of the basal Manhattan zone contains plagioclase, quartz, and biotite as the dominant minerals. K-feldspar is found in the basal Manhattan Formation. However, none has been found in the upper part of Manhattan unit A, nor in Manhattan unit C. Other common minerals in the basal calc-silicate rock are quartz, biotite, opaque minerals; accessories include clinozoisite, zircon, apatite, myrmekitic intergrowths of quartz and plagioclase, garnet, tourmaline, sericite, chlorite, allanite, sillimanite, muscovite, and epidote. Both metamict and non-metamict allanite occur as trace constituents in a few samples, and allanite is commonly surrounded by clinozoisite. Metamict allanite is characterized by anastomosing cracks radiating from a central allanite grain into but not beyond the surrounding clinoziosite rim.

All pyroxenes studied from the base of the Manhattan Formation are monoclinic, ranging from Mg-rich to Fe-rich salite (Figure 4). K-feldspars from the basal Manhattan zone vary in both structural state and composition, with ranging from Or_{83} to Or_{92}, and structural state ranging between maximum microcline and orthoclase (Wissig, 1970). Three Na/K+Na values of muscovite (Na/K + Na = 13.0%, 13.0%, 22.3% for samples 236, 344, and 342-I, respectively) suggest high variability in muscovite compositions. Muscovite, K-feldspar, and plagioclase all have quite variable compositions within this zone. Hornblende rims around pyroxene are common.

Table 8. Basal Manhattan zone plagioclase compositions

Sample #	An Mol %	Sample #	An Mol %
212	21	210A	54
227	26	345-I	54
233	26	303	58
234(peg)	29	346-I	58
259-II	32	236	64
346-II	35	E10	68
222	41	126-III	68
344	41	180	70
211-I	45	224d	80
342-I	47	342-II	80

The number of phases in any one thin section is high; 9 or 10 phases commonly are present, but as many as 15 mineral phases coexist within one thin section. Similarly, the total number of phases present in the basal Manhattan zone is high (21). This variability reflects the existence and reaction between two very different bulk compositions: an aluminous assemblage and a carbonate-rich assemblage.

Table 9. Basal Manhattan zone K-feldspar compositions

Sample #	Composition
E10	Or_{84}
224d	Or_{83}
303	Or_{88}
342-II	Or_{88}
345-I	Or_{89}
345-II	Or_{92}

Fissile Schist: In addition to the basal zone containing calc-silicate minerals, Manhattan unit A is characterized by a highly aluminous, fissile schist. Plagioclase, quartz, muscovite, sillimanite, and biotite account for the bulk of the rock, but garnet and magnetite are also common. Accessory minerals include tourmaline, staurolite, zircon, apatite, sericite, chlorite, K-feldspar, and myrmekitic intergrowths of quartz and plagioclase. Hornblende and clinozoisite are limited to amphibolite layers, where hornblende and plagioclase (An_{44}) are dominant, and quartz, zircon, magnetite, apatite, and sericite occur in lesser amounts. The staurolite is limited to the base of Manhattan unit A near the underlying marble and is not found in any other stratigraphic position within the quadrangle. Barth (1936, p. 788) reported that north of the Hudson Highlands, in the same stratigraphic sequence, staurolite is restricted to a narrow zone within

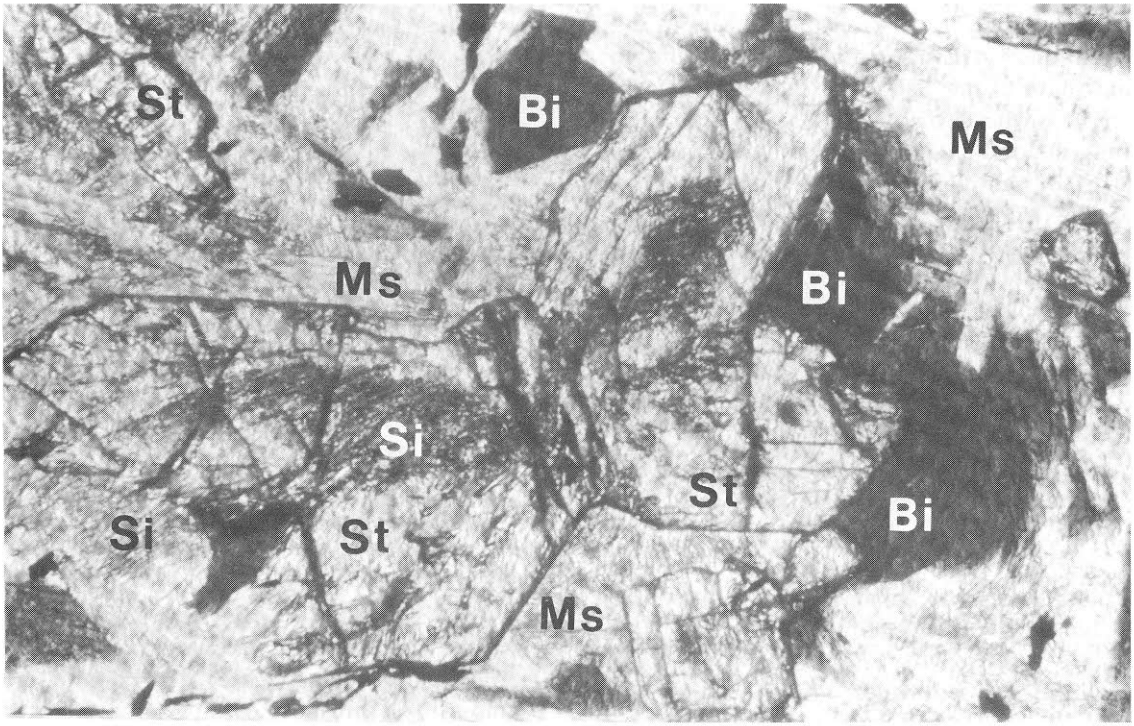


Figure 7 Photomicrograph of euhedral staurolite (St) with fibrous sillimanite (Si) inclusions. The sillimanite cuts across the staurolite grain boundary in the left side of the photomicrograph. Muscovite (Ms), biotite (Bi). Manhattan unit A, sample 308. Plane light.

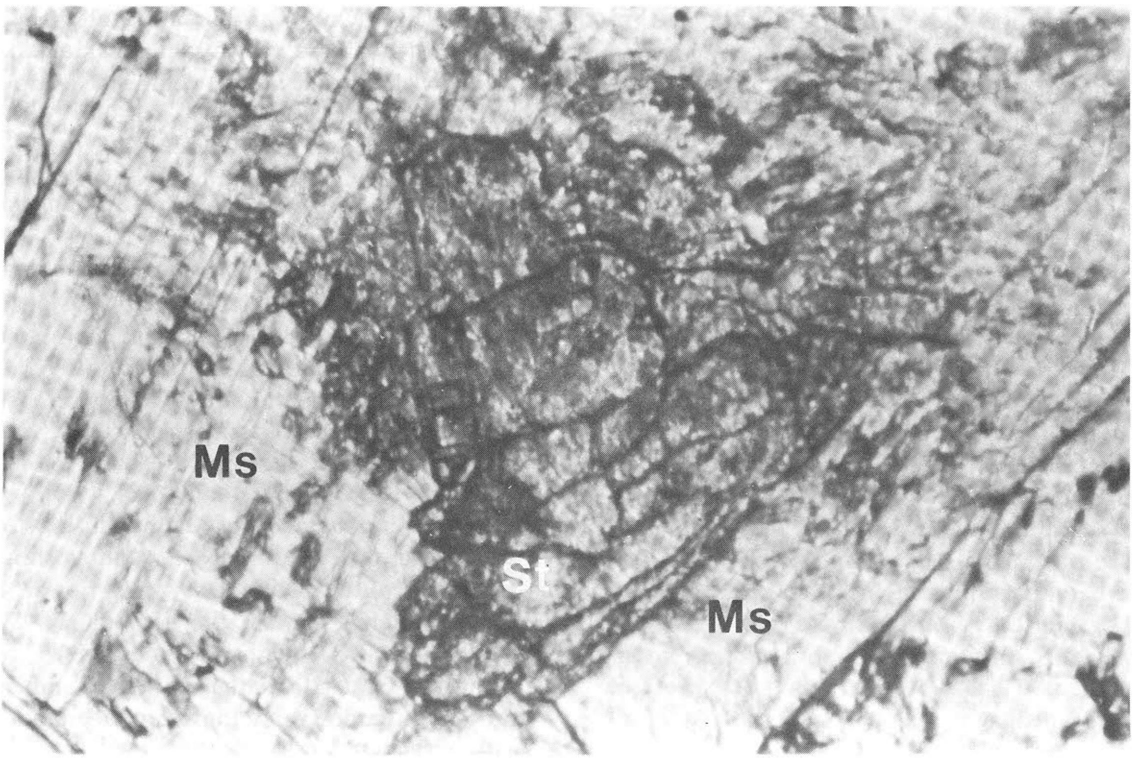


Figure 8 Photomicrograph of staurolite remnant (St) in muscovite (Ms). Manhattan unit A, sample 329. Plane light.

the schist near the contact between the schist and the marble. The similarity in occurrence of staurolite to the north and south of the Highlands may have significance in correlation between the two areas. Staurolite in the Ossining quadrangle occurs in both an unaltered state and in other samples partially replaced by rimming muscovite (Figure 8). Sillimanite, quartz, and muscovite coexist without any textural evidence suggesting reaction between the quartz and muscovite. Scotford (1956) reported that, in the Poundridge area, muscovite is limited to rocks containing sodic to intermediate plagioclase (An_{12-31}). This limitation does not apply to the Ossining quadrangle where plagioclase associated with muscovite ranges from An_{14} to An_{44} (Table 10). Using data from Evans and Guidotti (1966, p. 39), muscovite from Manhattan unit A was determined to have paragonite values ranging from 8 to 22% (Table 11). No regional or stratigraphic trends in muscovite composition are apparent in the Ossining quadrangle except for relatively high Na values (18–23% paragonite) of muscovite associated with staurolite. In staurolite-free assemblages, muscovite tends to be more K-rich. A similar trend was noted by Guidotti (1968) for rocks from the Rangeley area, Maine. Plagioclase compositions range from An_{14} to An_{39}, with most samples having values of about An_{25} (Table 10). K-feldspar is restricted to the base of the Manhattan Formation. Of the two K-feldspar samples for which structural state and composition were determined, one sample has an anomalous structural state; the other sample has an intermediate structural state and a composition of Or_{92}. No hornblende was found within either Manhattan unit A or Manhattan unit C except in amphibolites and near or at the Inwood-Manhattan contact.

Table 10. Manhattan unit A (fissile schist) plagioclase compositions

Sample #	An Mol %	Sample #	An Mol %
350	14	326	25
331	19	154	26
165	21	144-I	27
339	21	152	27
353	21	315	27
151A	22	320	27
307	22	329	27
258	24	210	31
265	24	332	31
302	24	347	34
E7	25	321	39
283	25	305(amp)	44

Table 11. Manhattan unit A (fissile schist) muscovite compositions expressed as percent paragonite (Pg)

Sample #	%Pg/Pg+Ms	Sample #	%Pg/Pg+Ms
197	8.3	165	13.7
315	10.0	349	16.1
151A	10.8	283	18.4
138	11.4	329	18.4
152	11.4	348	18.4
320	11.4	353	18.4
307	12.2	308	19.0
347	12.2	326	19.8
302	13.0	339	19.8
321	13.0	350	19.8
		E7	22.3

Manhattan unit C

Manhattan unit C, the stratigraphically highest unit within the Ossining quadrangle, is characterized by an abundance of plagioclase, quartz, and biotite, lesser amounts of muscovite, and an unidentified opaque mineral. Zircon, sillimanite, garnet, and apatite are common accessory minerals; allanite, clinozoisite, and sphene are rare accessories. Amphibolite layers contain abundant plagioclase and hornblende, with lesser amounts of biotite, quartz, and unidentified opaque mineral, and zircon. The mineralogical and modal composition of the schistose gneiss remains relatively constant, indicating a low degree of component variability throughout the unit. The Na/Na+K ratios of muscovite range from 9.0% to 20.8% (Table 12). Plagioclase compositions range from An_{21} to An_{32}, with most plagioclase samples being close to An_{27} (Table 13).

Within the Ossining quadrangle, four classes of metamorphic rocks can be recognized on the basis of their bulk chemical composition: aluminous, quartzofeldspathic, calcareous, and mafic. Of these, the aluminous assemblages are the most suitable for metamorphic facies classification. Thus, the aluminous Manhattan schist will form the basis for facies classification for the Ossining quadrangle.

The aluminous rocks of Manhattan unit A consist essentially of quartz, muscovite, biotite, sillimanite, garnet, staurolite, plagioclase, and minor K-feldspar. These minerals contain the components SiO_2, Al_2O_3, MgO, FeO, K_2O, Na_2O, CaO, and H_2O. Since quartz is present in all Manhattan unit A assemblages, SiO_2 is present in excess and therefore need not be graphically considered as a compositional variable. H_2O will be assumed to be a mobile component and must, therefore, be considered in terms of its chemical potential which is externally controlled. Hence, H_2O is not considered as a component in terms of the phase rule, but it must be considered as an intensive variable (*i.e.*, in addition to temperature and total pressure). With the elimination of H_2O and SiO_2 as variable components, Manhattan unit A fissile schist can be described in terms of the six components Al_2O_3, MgO, FeO, K_2O, Na_2O, and CaO. Both the AFM diagram (Thompson, 1957) and the CaO-Na_2O-K_2O-Al_2O_3 tetrahedron (Guidotti, 1963 and Evans and Guidotti, 1966) will be used for the present study in evaluating possible reaction pairs and stable assemblages.

Minerals in the AFM projection which are found in the aluminous schist of Manhattan unit A include biotite, sillimanite, garnet, and staurolite (along with quartz and muscovite). Examination of Table 25 reveals that assemblages containing only one or two of these minerals are rare, but three- and four-phase assemblages are common. Observed AFM mineral assemblages are as follows (all, also, contain quartz and muscovite):

1. Biotite
2. Biotite + sillimanite
3. Biotite + garnet
4. Biotite + sillimanite + garnet
5. Biotite + sillimanite + garnet + staurolite

These assemblages are plotted in Figure 10. Staurolite is found only near the base of Manhattan unit A, close to the contact of Manhattan unit A with the underlying Inwood Marble. The three-phase assemblages, sillimanite-garnet-biotite, is a stable assemblage in all but the lowest part of the Manhattan unit A.

Several possibilities exist to explain the presence of an additional phase in assemblage 5 over the theoretical maximum of three:

1) Equilibrium may not have been maintained during the progressive metamorphism of the Manhattan Formation;

2) Garnet, biotite, and staurolite may have different essential components (Fe^{+3}, $Ti^{+3,+4}$ in biotite; Zn^{+2} in staurolite; Mn^{+2} in garnet) which would remove one or more of these phases from the plane of the projection. In the absence of compositional control of these phases, this possibility cannot be evaluated fully. The rare occurrence of staurolite + magnetite rims around garnet suggests a compositional control of staurolite stability by the reaction:

Almandine + O_2 + $H_2O \rightarrow$ Staurolite + magnetite + quartz;

3) A decrease in the number of independent variables would stabilize an additional phase. A discontinuous reaction resulting in the addition of another phase can occur only on a specific surface in P, T,/μH_2O space, and the intersection of this surface with the earth's surface is a line (an isograd). Within the Ossining quadrangle, the distribution of the four-phase assemblage biotite + sillimanite + garnet + staurolite defines a stratigraphically controlled line near the base of the Manhattan Formation. If this distribution of phases represents an isograd in the Ossining quadrangle, only the isograd and the prograde assemblage biotite-garnet-sillimanite are represented. Muscovite from the staurolite-bearing assemblage is more sodic (Pg/Pg+Ms = 18–21%) than muscovite from staurolite-free assemblages (Pg/Pg+Ms = 8–17%). On the basis of data from Evans and Guidotti (1966), muscovite can be expected to become less sodic and plagioclase more sodic with increasing metamorphic grade. Although muscovite is more sodic in the presence of staurolite, plagioclase is not less sodic at or near a supposed staurolite isograd. Therefore, on the basis of muscovite-plagioclase equilibria there is no basis for inferring an isograd in a gradient of one or more intensive variables; and

4) Retrograde reactions may have been responsible for the addition of staurolite to the assemblage: biotite + sillimanite + garnet. Textural relationships in this regard are inconclusive. Euhedral staurolite occurs in part within sillimanite masses, in part including fibrolite. Sillimanite trains within the staurolite commonly are continuations of sillimanite fibers adjacent to the staurolite crystals (Figure 7). These textural relationships between sillimanite and staurolite could be the result of either prograde or retrograde reactions. Recrystallization of muscovite and partial replacement of staurolite by muscovite is suggested by the presence of small corroded relict staurolite and remnants of sillimanite swarms in large muscovite plates (Figure 8). These replacement textures occur in the same stratigraphic position within the Manhattan Formation as does alkali feldspar which is inferred to be the result of reaction between muscovite and calcite (p. 68). Experimental studies (Ganguly, 1968, p. 289) and observational evidence (Fyfe, Turner, and Verhoogen, 1958, p. 229) indicate that K-feldspar and staurolite are incompatible. The reaction of muscovite and calcite, therefore, would not be expected to form K-feldspar with staurolite in Manhattan unit A, but, rather, would be expected to alter the aluminum silicates (*i.e.*, staurolite) and reprecipitate muscovite. The alkali source for the alteration of staurolite to late-stage muscovite in the Ossining quadrangle is therefore inferred to be the reaction between preexisting muscovite and calcite.

In one sample of the fissile schist from the base of Manhattan unit A, fine-grained muscovite rims euhe-

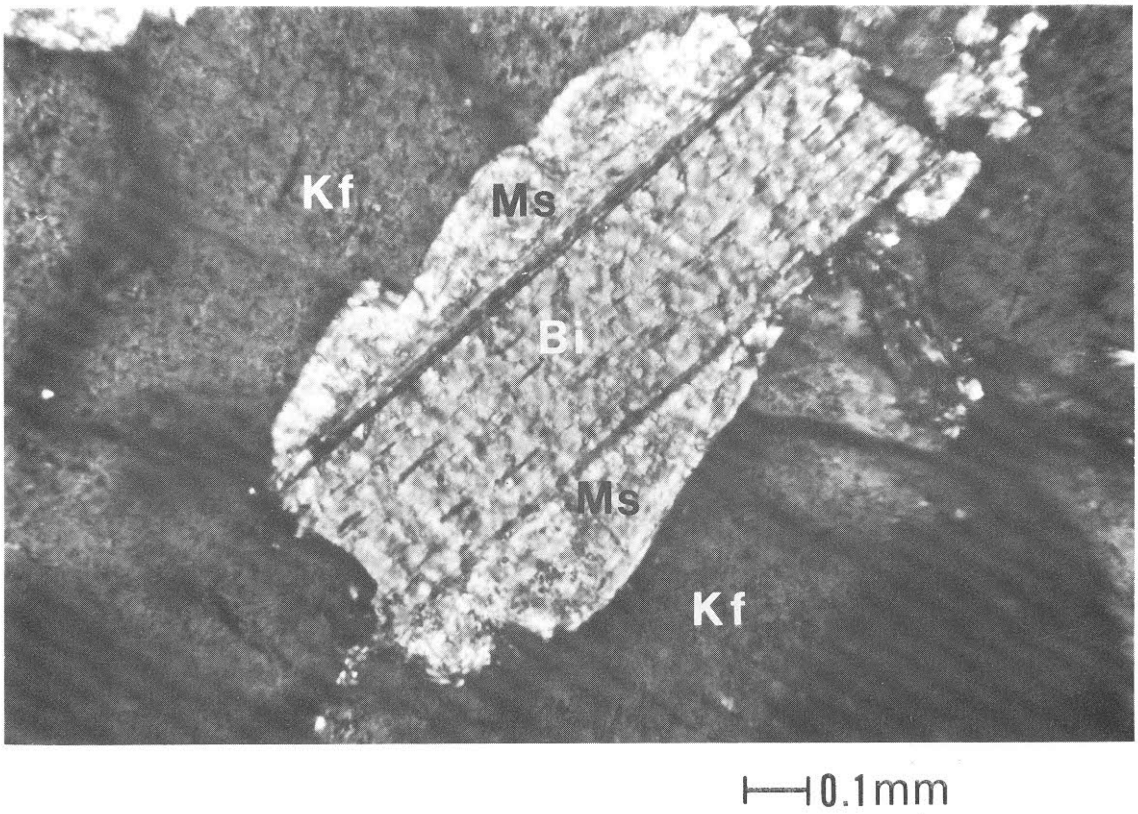
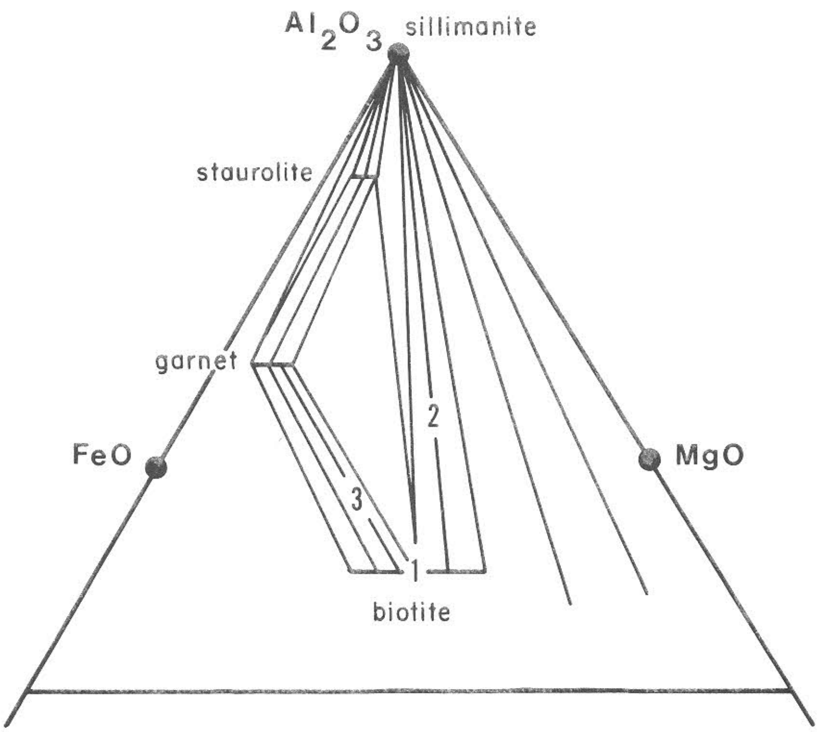


Figure 9 Photomicrograph of biotite (Bi) with a muscovite (Ms) rim. K-feldspar (Kf) surrounds the biotite and muscovite. Manhattan unit A, sample 265. Crossed nicols.

Figure 10 AFM diagram for Manhattan unit A of the Ossining quadrangle. Metamorphic assemblages are listed on page 23 and are numerically indicated in the diagram.



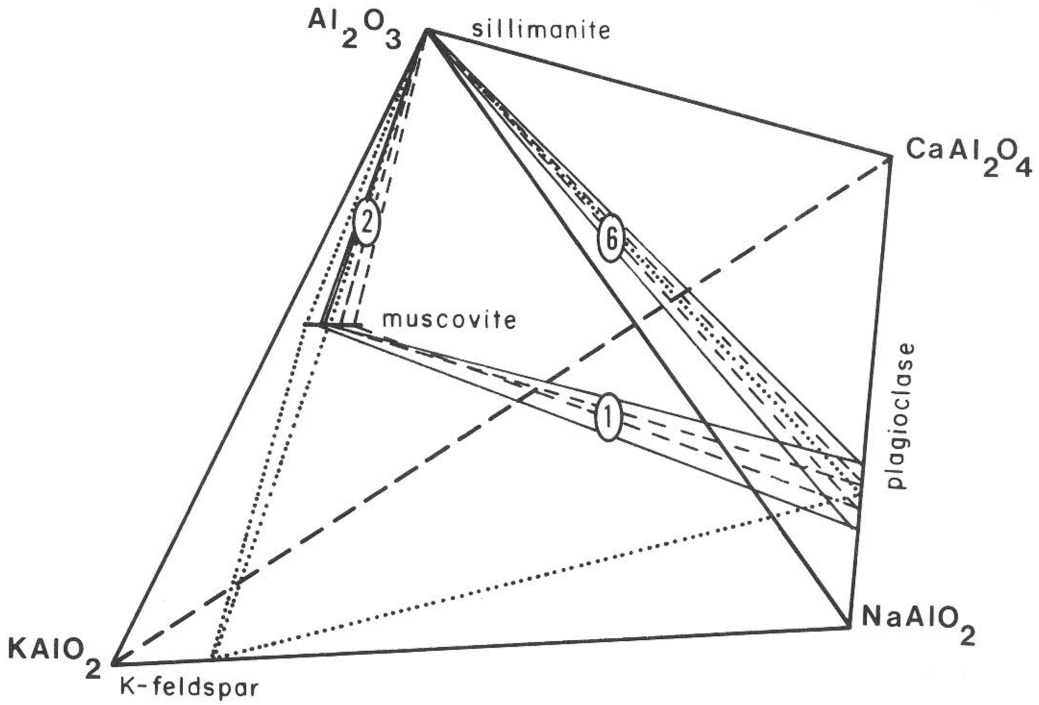


Figure 11 Al_2O_3-$KAlO_2$-$NaAlO_2$-$CaAl_2O_4$ tetrahedron for Manhattan unit A. ——— represents assemblage 3, — — — — — assemblage 4, ... assemblage 5. Assemblages 1, 2, and 6 are numerically indicated in the diagram.

dral biotite plates (Figure 9). This muscovite is closely associated with K-feldspar and is inferred to be late-stage muscovite formed from a reaction between preexisting muscovite, calcite, and quartz at some time following the formation of biotite. The biotite presumably served as a nucleating agent for the precipitation of muscovite.

Minerals in the tetrahedron sillimanite-anorthite-albite-K-feldspar which are found in the aluminous schist of Manhattan unit A include sillimanite, muscovite, plagioclase, and K-feldspar (along with excess SiO_2 as quartz). Examination of Table 25 reveals that assemblages with only one of these phases are nonexistent, two-phase assemblages are rare, but three-phase assemblages are common. Four-phase assemblages are rare. Observed mineral assemblages which plot within this tetrahedron are as follows:

1. Muscovite + plagioclase
2. Muscovite + sillimanite
3. Muscovite + sillimanite + plagioclase
4. Muscovite + sillimanite + plagioclase + staurolite
5. Muscovite + sillimanite + plagioclase + K-feldspar
6. Sillimanite + plagioclase

Clearly, assemblages 3 and 4 are the same assemblage with regard to the sillimanite-K-feldspar-Ab-An tetrahedron, but, as pointed out earlier, textural evidence suggests that the muscovite associated with staurolite was formed late in the metamorphic history of the rock. No such evidence exists for the other assemblages listed above; hence, assemblage 4 has been considered as an assemblage distinct from assemblage 3. In addition to textural consideration, a cursory examination of muscovite compositions in Table 11 indicates that 3 and 4 should probably not be considered a part of the same assemblage. The above assemblages are plotted in Figure 11. Only the compositionally limiting values have been plotted on this figure in order to avoid confusion with too much data.

Within each assemblage, compositions exist between the values as plotted in Figure 11. Two samples (321 and 353) from assemblage 3 and one sample from assemblage 4 (350) have not been used in this study. Mineral compositions determined from these samples are not in agreement with the remaining samples in their respective assemblages. The reasons for their great variance is not known; however, even if these samples are considered as valid, they do not change relationships either within or between assemblages.

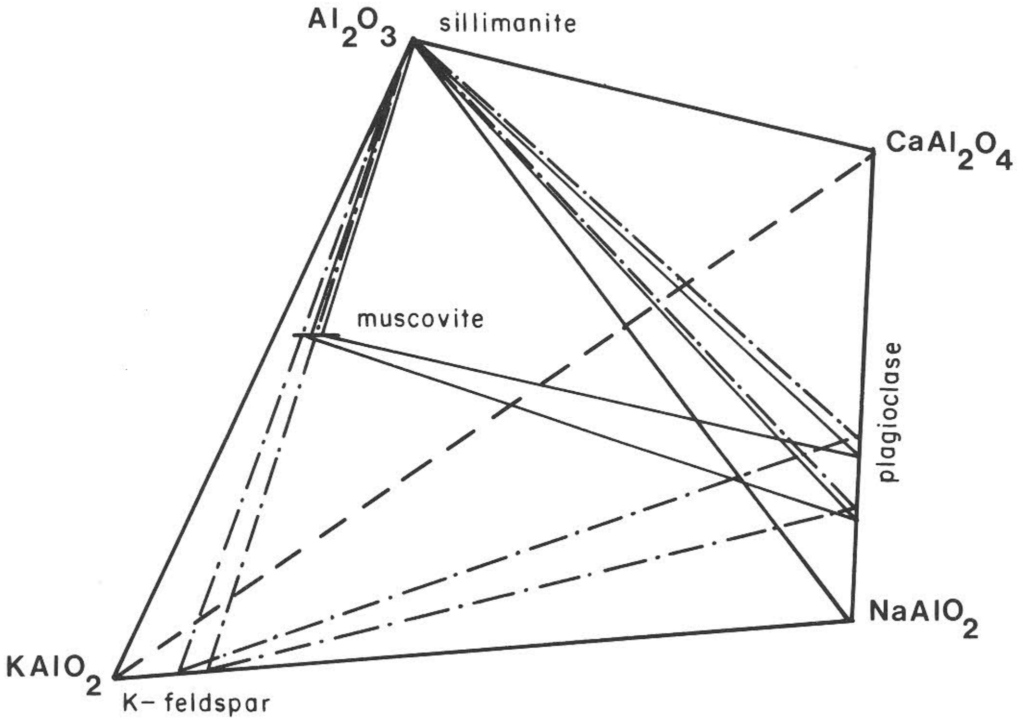


Figure 12 Al_2O_3-$KAlO_2$-$NaAlO_2$-$CaAl_2O_4$ tetrahedron for Fordham unit A (schist) and Manhattan unit A. — · — · — · represents Fordham unit A and ———— represents Manhattan unit A.

Figure 11 does not reveal any evidence for disequilibrium within individual assemblages; in all assemblages the number of phases is either equal to or less than the number of components. Local equilibrium is possibly present within and between assemblages. The amount of K^+ in plagioclase, reflecting local K^+ concentrations, may be responsible for crossing of muscovite-plagioclase tie lines (Boone, 1969, personal communication). The triangle for assemblage 4 cuts the component triangle for assemblage 3. The wedge representing phase assemblage 5 cuts assemblages 1, 3, 4, and 6. Previously, it was suggested that the muscovite of assemblage 4 and the K-feldspar of Manhattan unit A were formed by the reaction between preexisting muscovite and calcite. K-feldspar and Na-rich muscovite within Manhattan unit A are restricted to the base of Manhattan unit A, near the contact with the underlying Inwood Marble. Hewitt and Orville (1968) studied muscovite-calcite-quartz stability and found that the reaction $KAl_3Si_3O_{10}(OH)_2 + CaCO_3 + 2SiO_2 \rightarrow KAlSi_3O_8 + CaAl_2Si_2O_8 + H_2O + CO_2$ has a maximum equilibrium temperature of 463 ± 3°C at 1000 bars, 492 ± 3°C at 2000 bars, and 548 ± 5°C at 4000 bars. Extrapolation of these data to higher pressures and temperatures (Figure 13) indicates that under metamorphic conditions inferred for the Ossining quadrangle (p. 76) the above reaction should proceed to the right. The introduction of $CaCO_3$ from the underlying marble is thus proposed to explain the lack of equilibrium between assemblages within the sillimanite-Or-Ab-K-feldspar tetrahedron. The introduction of $CaCO_3$ may also explain why K^+ concentration differences exist (Boone, 1969, personal communication). In the absence of K-feldspar, the stable assemblage within this tetrahedron is sillimanite-muscovite-plagioclase. The two- or three-phase assemblage consisting of sillimanite and/or muscovite and/or plagioclase is considered to be the equilibrium phase assemblage within all but the base of the aluminous Manhattan unit A of the Ossining quadrangle.

By eliminating from consideration those rocks near the base of the Manhattan Formation, the following minerals represent stable phases within Manhattan unit A: biotite, sillimanite, garnet, plagioclase, muscovite, and quartz. These minerals indicate that the Manhattan unit A is within the muscovite-sillimanite zone, and belongs to the sillimanite-almandine-muscovite subfacies of the amphibolite facies.

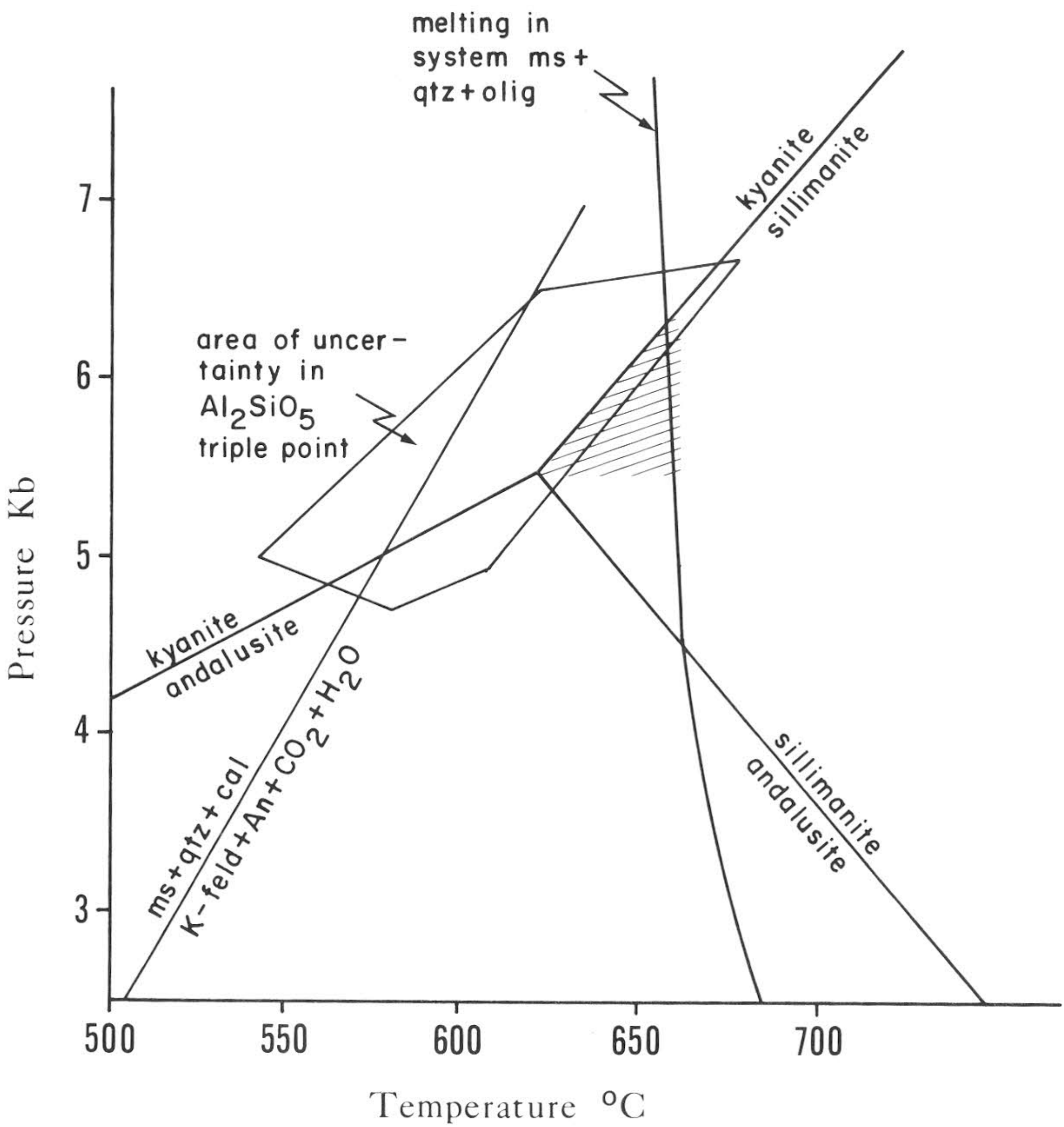


Figure 13 Experimental mineral equilibria and inferred physical conditions of metamorphism for the Ossining quadrangle; hachures indicate the inferred maximum range of pressure and temperature. Aluminum silicate curves and area of uncertainty for the Al_2SiO_5 triple point from Richardson, *et al.*, (1969). Curve for melting of muscovite (ms), quartz (qtz), and oligoclase (olig) from von Platen and Höller (1966). Curve for reaction of muscovite (ms) + (qtz) + calcite (cal) to form K-feldspar (K-feld) + anorthite (An) + CO_2 + H_2O, from Hewitt and Orville (1968).

Table 12. Manhattan unit C muscovite compositions expressed as percent paragonite (Pg)

Sample #	%Pg/Pg+Ms
304	9.0
335	9.0
314	10.8
284	12.2
324	12.2
333	12.2
286	14.4
325	14.4
328	16.8
279	20.8

Table 13. Manhattan unit C plagioclase compositions

Sample #	An Mol %
327-I	21
279	23
284-I	24
286	26
275	27
304	27
314	27
292	29
324	29
335	29
357	29
280	30
316	30
325	31
333	31
287	32

Petrology

INTERNAL EQUILIBRIUM AND METAMORPHIC FACIES CLASSIFICATION

If equilibrium has been established either locally or over wide areas within the Ossining quadrangle, the mineral assemblages must conform to the requirements of the phase rule (Goldschmidt, 1911; Korzhinsky, 1936, 1950, 1965).

The establishment of internal equilibrium is dependent on the scale or size of the system under consideration. Although mutually incompatible assemblages within the system are indicative of disequilibrium, Thompson (1959) pointed out that local equilibrium may be established within such a system if the incompatible phases are not in contact with one another. For the present discussion, the limits of each system will be defined as the boundaries between stratigraphic units, and, therefore, each unit defines a system.

Although local equilibrium is established for most phases within the Ossining quadrangle, some local discontinuities do exist. Textural evidence of local (grain boundary) disequilibrium include hornblende rims on pyroxene (Fordham unit B, samples 72 and 94; basal schistose gneiss of Manhattan unit A, samples E10, 35, 180, 211-II, 303), biotite rims on hornblende (Fordham unit B, samples 28 and 76; Fordham unit C, samples 112 and 260-III; Fordham unit A, sample 115), fresh sodic rims on altered calcic plagioclase (Fordham unit A, sample 115; Fordham unit C, samples 220, 295-I, 318, 319; Fordham-Inwood contact zone, sample 175A; Table 16, Figures 5, 6); muscovite plates rimming staurolite (Manhattan unit A, sample 329; Figure 8), and muscovite rimming biotite (Manhattan unit A, sample 265; Figure 9).

The occurrence of fresh sodic plagioclase rims on altered calcic plagioclase (Figures 5, 6) is most common in Fordham unit C of the Teatown Anticline. The highest concentrations of microcline in the quadrangle also occur here, and the sodic plagioclase is restricted to the boundaries between Ca-rich plagioclase and K-feldspar. Tuttle (1952) studied secondary albite in six granites, and found that nearly all of the secondary albite is located at K-feldspar-plagioclase boundaries. Tuttle concluded that despite the absence of perthite, unmixing of alkali feldspars is the most probable source for the K-feldspar and "late stage" albite. Within the Ossining quadrangle, minor amounts of microperthite are found in three of the six samples from Fordham unit C containing sodic plagioclase rims on calcic plagioclase cores (295-I, 318, 319), suggesting exsolution as the cause.

Throughout the stratigraphic sequence, the plagioclase is uniformly of low temperature-intermediate structural state (Wissig, 1970). In contrast, the K-feldspar structural state is quite variable, indicating a disequilibrium within stratigraphic units. Temperature, water pressure, and bulk composition all affect the K-feldspar structural state, and studies by Dietrich (1962) indicate that composition of the feldspar is also an important factor. It is interesting to note that, in the Ossining quadrangle, the unit with the greatest variation in K-feldspar structural state (Manhattan unit A) is also the unit with the greatest variation in composition of the K-feldspar. In addition to structural state, disequilibrium relations in the Manhattan unit A fissile schist (p. 65–69) indicate that assemblages containing K-feldspar are in disequilibrium.

The only aluminous schist of the Fordham Gneiss occurs within Fordham unit A. This schist contains the following coexisting minerals: plagioclase (An_{22-29}), biotite, garnet, sillimanite, and K-feldspar (Or_{88-90}). This assemblage differs from that for Manhattan unit A in the absence of muscovite and the presence of a K-feldspar close to orthoclase in structural state. The two different assemblages are plotted on the sillimanite-An-Ab-Or tetrahedron in Figure 12. Clearly, the difference between these cannot be attributed to differences in the bulk composition, and the crossing tie lines are best attributed to a difference in metamorphic grade. The Fordham unit A assemblage represents a slightly higher metamorphic grade than that of the Manhattan unit A. The assemblage in Fordham unit A belongs to the K-feldspar-sillimanite zone and the sillimanite-garnet-orthoclase subfacies of the amphibolite facies. From the relative stratigraphic position of the two units, this difference in metamorphic grade suggests a slight increase in grade of metamorphism with stratigraphic depth. An alternative explanation is that the Fordham Gneiss has undergone a high grade metamorphic event prior to the deposition of the Manhattan Formation and the assemblage sillimanite-garnet-orthoclase in Fordham unit A records this early event. Definitive evidence regarding these choices is lacking.

On the basis of mineral phases present within all the other units of the quadrangle, it is concluded that the metamorphic terrane of the quadrangle lies wholly with the amphibolite facies. The grade of metamorphism ranges from the sillimanite-garnet-orthoclase subfacies (K-feldspar-sillimanite zone) to the sillimanite-garnet-muscovite subfacies (muscovite-sillimanite zone) of the amphibolite facies.

PHYSICAL CONDITIONS OF METAMORPHISM

Mineral stabilities as shown on PT diagram are only approximate unless the variables controlling mineral stability are known. For the rocks from the Ossining quadrangle, many of these variables are not known, and, therefore, any inferences regarding temperature and pressure are somewhat speculative.

Within the Manhattan Formation, the stable phases most useful in determining maximum temperature and pressure include sillimanite, muscovite, quartz, and oligoclase. Within Fordham unit A, the presence of K-feldspar, sillimanite, and oligoclase and the absence of muscovite are helpful for determining metamorphic environment. The stability fields defined by these minerals are plotted in Figure 13.

The stability fields of the Al_2SiO_5 polymorphs have been extensively studied with quite divergent results (Zen, 1969, presents an excellent summary of these studies). For the present study, the experimental results of Richardson, *et al.*, (1969) have been plotted in Figure 13. In addition to their univariant lines, the region of uncertainty for the triple point as determined by Richardson, *et al.*, has been includes in Figure 13. The univariant lines kyanite-sillimanite and sillimanite-andalusite define the lower temperature stability field of the metamorphic terrane within the quadrangle as well as both the upper and lower pressure stability field. Within the Manhattan Formation, muscovite, quartz, sillimanite, and oligoclase coexist in apparent stable equilibrium. Except near the Manhattan-Inwood contact, K-feldspar is lacking. This suggests that metamorphic conditions were below the temperature and pressure necessary for formation of sillimanite and K-feldspar from the pair muscovite + quartz, but above the temperature and pressure necessary for the formation of K-feldspar from muscovite + quartz + calcite. The muscovite-quartz-oligoclase assemblage also suggests that the maximum metamorphic temperature within the Manhattan Formation was below that necessary for anatectic melting. The reaction marking the onset of such melting is:

> muscovite + quartz + plagioclase → K-feldspar-plagioclase-quartz components in the melt and An-richer plagioclase + sillimanite + H_2O (von Platen and Höller, 1966)

Pegmatite layers within the Ossining quadrangle may be the result of anatectic melting; compositional data were not obtained. On the basis of the univariant curves sillimanite-kyanite and sillimanite-andalusite, and anatectic melting of quartz-muscovite-oligoclase, the temperature and pressure at the time of metamorphism of the Manhattan Formation can be bracketed between 625° and 665°C and 4.5 and 6.4 kb, respectively.

Fettke (1914) and Ratcliffe (1968) found abundant staurolite and kyanite in the Manhattan Formation of the Haverstraw quadrangle directly west of the Ossining quadrangle.

Staurolite and kyanite indicate a decrease in metamorphic grade to the west, with pressure above that at which andalusite is stable. The sequence kyanite → sillimanite without intermediate andalusite suggests that metamorphic pressure within the Ossining quadrangle was above 5.5 kb (Figure 13) thereby further restricting the possible range of metamorphic conditions.

Within Fordham unit A, sillimanite coexists with K-feldspar and oligoclase suggesting that the stability range for muscovite + quartz has been exceeded.

However, biotite + sillimanite + quartz coexist. Although no experimental studies on the reaction biotite + sillimanite + quartz→ K-feldspar + almandine + H_2O have been made, Winkler (1967, p. 212) suggested that such a reaction should take place at slightly higher temperatures than the anatectic melting of muscovite + quartz. Therefore, within Fordham unit A, metamorphic temperature was probably only slightly higher than that necessary for anatectic melting of muscovite + quartz. This suggests a temperature of about 670°C and pressure between 5.5 and 6.5 kb.

In Figure 13, the inferred range of possible temperature/pressure conditions is indicated by hachures. Temperature is inferred to have been between 625° and about 670°C with pressures between 5.5 and 6.5 kb.

FORDHAM AND MANHATTAN METAMORPHISM

If the Fordham Gneiss has undergone a metamorphic event prior to the deposition of the cover rocks as suggested by Hall (1968d), this event might be recorded in the resulting mineral assemblages. As pointed out earlier (p. 71), Fordham unit A represents a slightly higher metamorphic grade than does Manhattan unit A; however, this difference in metamorphic grade may reflect slight differences in metamorphic environment (T, P, μH_2O, etc.) within the same metamorphic event.

Smith and Yoder (1956) studied the structural state of plagioclase from various petrologic environments and found that plagioclase structural state is dependent on composition and thermal history. Thus, by comparing plagioclase of similar compositions, variations in structural state should reflect variations in the thermal history of the plagioclase. The structural state of plagioclase from the Ossining quadrangle was studied (Wissig, 1970) using the method of Bambauer, *et al.*, (1967).

The data from this study indicate that plagioclase from both the Fordham Gneiss and Manhattan Formation has a low temperature-intermediate structural state. A variation in plagioclase structural state would indicate a variation in the thermal history of the plagioclase, but similar structural states do not necessarily indicate similar thermal histories. An alternative explanation for the resultant similarity in plagioclase structural state is the possibility that a subsequent metamorphic event has been of sufficient intensity to change the Al-Si-ordering arrangement. In such a case, the plagioclase structural state reflects only the subsequent thermal event and not the entire thermal history of the plagioclase. It thus appears that the question of multiple periods of metamorphism within the Ossining quadrangle cannot be resolved on the basis of plagioclase structural state.

CARBONATE PETROLOGY

Although facies designation is not easily determined using carbonate rocks because of the added variable of P_{CO_2}, a number of varying assemblages occur in the Inwood Marble which are helpful in determining the thermodynamic conditions at the time of metamorphism.

The assemblages plotted in the SiO_2-CaO-MgO triangle (Figure 14) include calcite, dolomite, quartz, olivine, tremolite, and endiopside, the latter being based on a single determination. Although variations in pyroxene composition are possible, they would not change relationships within or between assemblages as inferred from the SiO_2-CaO-MgO composition triangle. Examination of Table 23 reveals that SiO_2-CaO-MgO-CO_2-H_2O assemblages containing one phase are rare, but two- and three-phase assemblages are common;

1. Calcite
2. Calcite + dolomite
3. Calcite + quartz
4. Dolomite + quartz
5. Calcite + quartz + clinopyroxene
6. Calcite + quartz + dolomite
7. Calcite + dolomite + tremolite
8. Calcite + dolomite + olivine

phlogopite,
± K-feldspar,
scapolite

Noncrossing tie lines *within* individual assemblages indicate local equilibrium, but crossing tie lines *between* assemblages suggest that equilibrium has not been established within the Inwood Marble as a whole. Although compositional variables may be responsible for the apparent disequilibrium, the distribution for these assemblages within the Inwood Marble (Table 23 and Plate 2) suggests that the most probable variable responsible for the lack of internal equilibrium within the Inwood Marble is the partial pressure of CO_2. Those assemblages indicating a high P_{CO_2} (*i.e.* dolomite + quartz and calcite + dolomite + quartz) are found in the central part of the Inwood Marble belts whereas toward the outer margins of the marble belts dolomite and quartz have reacted to produce pyroxene and tremolite. These relationships suggest a decrease in P_{CO_2} with a concomitant increase in P_{H_2O} going outward from the central part of the marble belts.

Experimental studies in the system CaO-MgO-SiO_2-CO_2-H_2O have been restricted to studies at pressures of 2000 bars or less (summarized by Winkler, 1967). Hence, the only conclusion which can be drawn from the experimental data is that P_{CO_2} exceeded 2 kb.

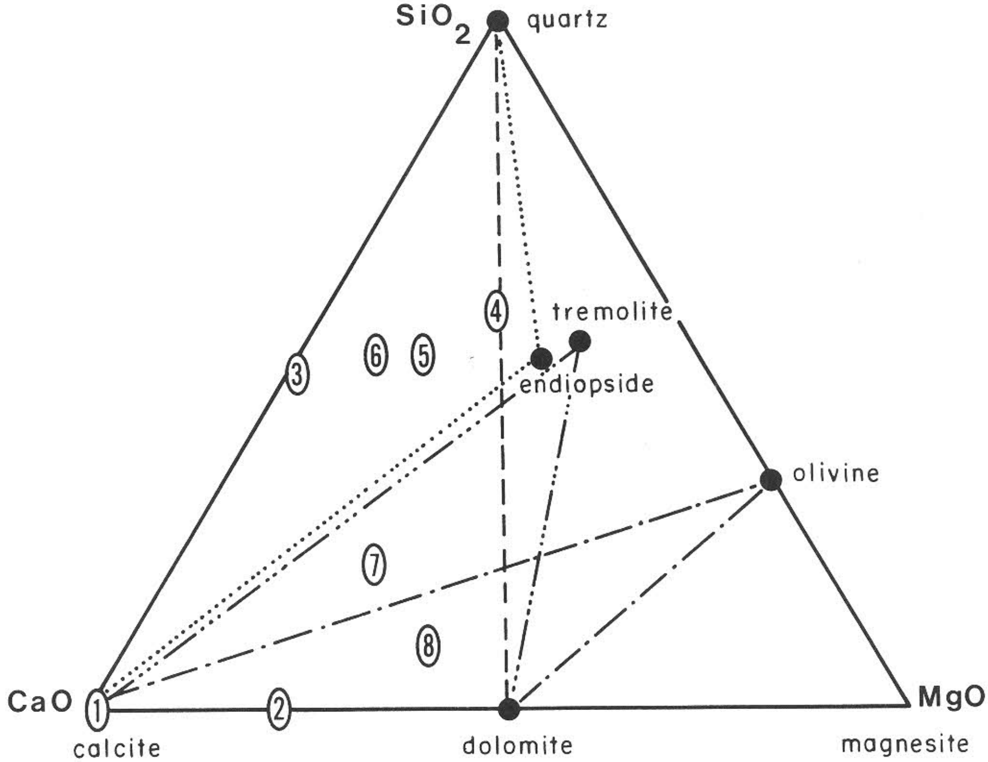


Figure 14 CaO-MgO-SiO_2 diagram for the Inwood Marble. — — — represents assemblage 4, · · · assemblage 5, — · · · — assemblage 7, and · — · — · assemblage 8.

INWOOD-MANHATTAN CONTACT ZONE

Reaction between the Inwood Marble and the fissile schist of Manhattan unit A resulted in the formation of a calc-silicate mineral assemblage not found elsewhere. This assemblage (basal schistose gneiss) occurs only locally along the contact, and appears to have a maximum thickness of about 300 meters. In many of the thickest parts of this zone, thin (2–10 cm) calcitic marbles are intercollated with schistose gneiss layers which are at least several meters thick.

The calc-silicate assemblage may represent a gradational depositional contact between a calcareous and aluminous sediment, a metasomatic reaction zone, or a combination of these two processes. On the basis of the mantling relationships previously described, metasomatic transfer of components appears to be the primary, if not the only, mechanism responsible for the observed assemblage. Such an interpretation, with transfer of components as shown in Table 14, is consistent with the model proposed by Vidale (1969).

Table 14. Mineral assemblages and inferred component transfer across the Inwood-Manhattan contact in the Ossining, New York quadrangle

Inwood Marble away from contact	Inwood Marble near contact	Manhattan A basal schistose gneiss	Manhattan A fissile schist
Dolomite			
Phlogopite	Phlogopite		
Calcite	Calcite	Calcite	
Scapolite	Scapolite	Scapolite	
Sphene	Sphene	Sphene	
Quartz	Quartz	Quartz	Quartz
	Tremolite		
	Diopside	Diopside-salite	
	K-feldspar	K-feldspar	
		Ca-rich plagioclase	
		Hornblende	
		Clinozoisite	
		Biotite	Biotite
		Garnet	Garnet
			Sillimanite
			Muscovite
	—CO_2→		Na-rich
	— Ca→		Plagioclase
	— Mg →		
	←H_2O —		
	← K —		
	← Al —		
	← Si? —		

Compositional control on many of the calc-silicate minerals is inadequate for determining phase equilibria within either individual assemblages or the calc-silicate zone as a whole.

Structural Geology

GENERAL RELATIONSHIPS

The Ossining quadrangle is located in the Manhattan Prong of the New England Upland. In southeastern New York, the Prong is bounded on the north by the Precambrian Hudson Highlands and on the west by the Triassic Newark Group. For additional information on the regional tectonic setting, the reader is referred to the generalized Tectonic-Metamorphic map of New York (Fisher *et al.*, 1971).

Within the Ossining quadrangle, stratigraphic units have been deformed into a series of northeast-trending isoclinal folds overturned to the northwest, with axial surfaces dipping steeply eastward (Plate 1). The folds plunge to the northeast in the northern and southeastern part of the quadrangle and to the southwest in the southwestern and western part of the quadrangle. The northeast trend of major folds and formational boundaries is characteristic of the Manhattan Prong from New York City through Westchester County and west-

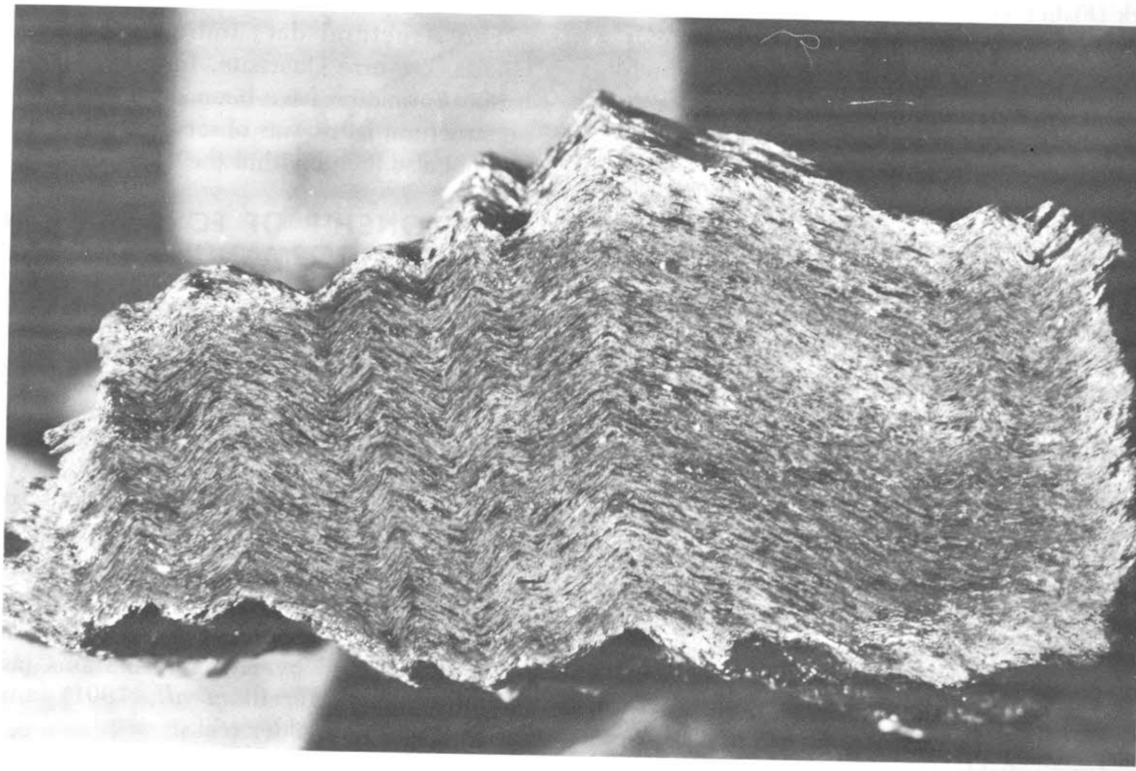


Figure 15 Small-scale chevron folds in the fissile schist of Manhattan unit A.

ern Connecticut, as can be seen on the Geologic Map of New York (Fisher *et al.*, 1971). In northern Westchester and Putman counties, the entire sequence is rotated into a series of isoclinal cross-folds which plunge to the northwest. Scotford (1956) and Prucha *et al.*, (1968) described these features as axial-plane folds.

Foliation is prominent in all formations of the Ossining quadrangle. The Fordham Gneiss is characterized by a compositional-layering foliation; the Manhattan Formation is characterized by a well-defined biotite and/or muscovite schistosity; and Lowerre Quartzite and Inwood Marble are characterized by poorly defined foliation formed by widely scattered parallel mica flakes. In a few areas, the schistosity of the Manhattan Formation is crinkled into a series of small-scale chevron folds (Figure 15). Foliation in all units is steeply dipping. The strike of the foliation parallels the map traces of the axial surfaces of major folds, and the foliation is interpreted to be axial-plane foliation.

Lineations (mineral lineations, small-scale fold axes, and crenulations) plunge southwest in the southwestern part of the quadrangle and northeast in the northern part. The sense of shear on small-scale parasitic folds is not consistent in any one area. Sinistral and dextral parasitic folds are, therefore, inferred to be the result of local stress fields, not reflecting movement on a regional scale.

Lineations parallel the general direction of plunge of the regional isoclinal folds. On the basis of direction and amount of plunge of small-scale fold axes, the regional folds are inferred to plunge about 35°SW in the southwestern and western part of the quadrangle and from 60° to 30°NE in eastern and central part of the quadrangle.

Deformation within the quadrangle has caused tectonic thickening and thinning of the more ductile units, particularly the Inwood Marble. The map breadth of the Inwood Marble is quite variable and ranges from zero to somewhat more than one mile. In general, the marble map breadth is narrow on the limbs of the major northeast-trending folds and wide in the hinge areas. In some areas, such as in the central portion of the quadrangle, tectonic thinning is interpreted to have removed the marble from the limbs of major folds at the present level of erosion, and Fordham unit C is in direct contact with Manhattan unit A.

No major faults have been recognized within the Ossining quadrangle. Slickensides are common in a few areas throughout the stratigraphic sequence, but these reflect only small-scale local movement. Deformation within all units is mainly the result of similar folding. Small-scale folds are often variable in fold style, but the generally constant northeast strike of foliation as well as thickening of units in hinge areas suggests regional deformation by passive (similar) folding.

The structural data indicate that the Fordham Gneiss, Lowerre Quartzite, Inwood Marble, and Manhattan Formation have been deformed simultaneously; no structural fabric was observed in one formation that was not also found within the other formations.

RELATIONSHIP OF FORDHAM GNEISS TO OVERLYING FORMATIONS

Fordham-Inwood Contact Zone

An aspect of the geological history of the Manhattan Prong which has received considerable attention in recent years is the question of whether or not an unconformity exists between the Fordham Gneiss and the overlying Lowerre Quartzite, Inwood Marble, and Manhattan Formation. Prucha (1955, 1956, 1959), Prucha, *et al.*, (1968), Scotford (1956), and Clarke (1968) concluded that the entire sequence is conformable. Hall (1966, 1968a,b,c,d) and Ratcliffe (1968) concluded that an unconformity exists between the Fordham Gneiss and overlying formations (as originally concluded by Merrill *et al.*, 1901), and between Manhattan-A and older rocks.

In three different areas of the Ossining quadrangle, the Fordham-Inwood contact is characterized by interlayering of gneiss and marble. These interlayers trend parallel to the Fordham-Inwood contact. Although much of the interlayering at the Fordham-Inwood contact within the quadrangle is the result of isoclinal folding, the absence of mirror repetition in some suggests that some of the interlayers may have another explanation. No conclusive evidence has been found in the quadrangle to either confirm or deny the possibility of shearing as an explanation, as proposed by Isachsen (1964) or the possibility of a continuous depositional sequence across the Fordham-Gneiss-Inwood Marble contact as suggested by Prucha (1956), Prucha, *et al.*, (1968), and Scotford (1956). There is no evidence that would indicate shearing or fracturing within the contact zone, but this does not exclude the possibility of faulting or a folded unconformity. No evidence was found in the Ossining quadrangle to support the suggestion by Hall (1968d) that the interlayering might result from sedimentary reworking. In sum, the data observed in the Ossining quadrangle neither prove nor disprove the existence of an unconformity between the Fordham Gneiss and overlying formations. Within the White Plains quadrangle directly to the south, however, Hall (1968d) has mapped an angular unconformity between the Fordham and overlying units. Also, in the Haverstraw quadrangle to the west, Ratcliffe (1968) has mapped a similar angular unconformity.

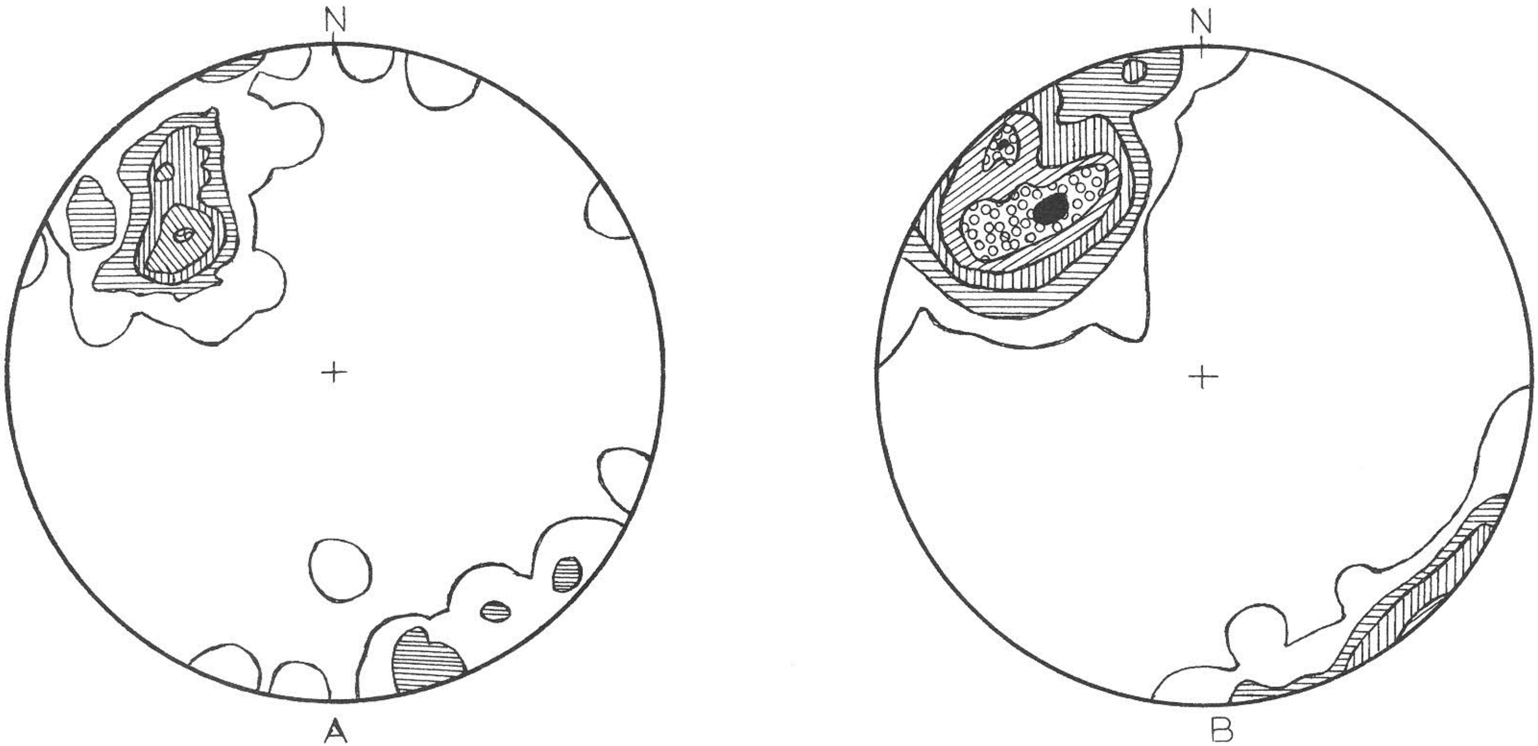


Figure 16 Foliation data for the Teatown Anticline. Lower hemisphere, equal-area projections. Plane of diagrams is horizontal. (A) 57 poles to foliation from Fordham unit C. Contours 1.8%, 5.3%, 8.8%, 12.3%, 15.8% per 1% area. (B) 146 poles to foliation from Manhattan unit A. Contours 0.7%, 2.1%, 4.1%, 6.2%, 8.2%, 10.3% per 1% area.

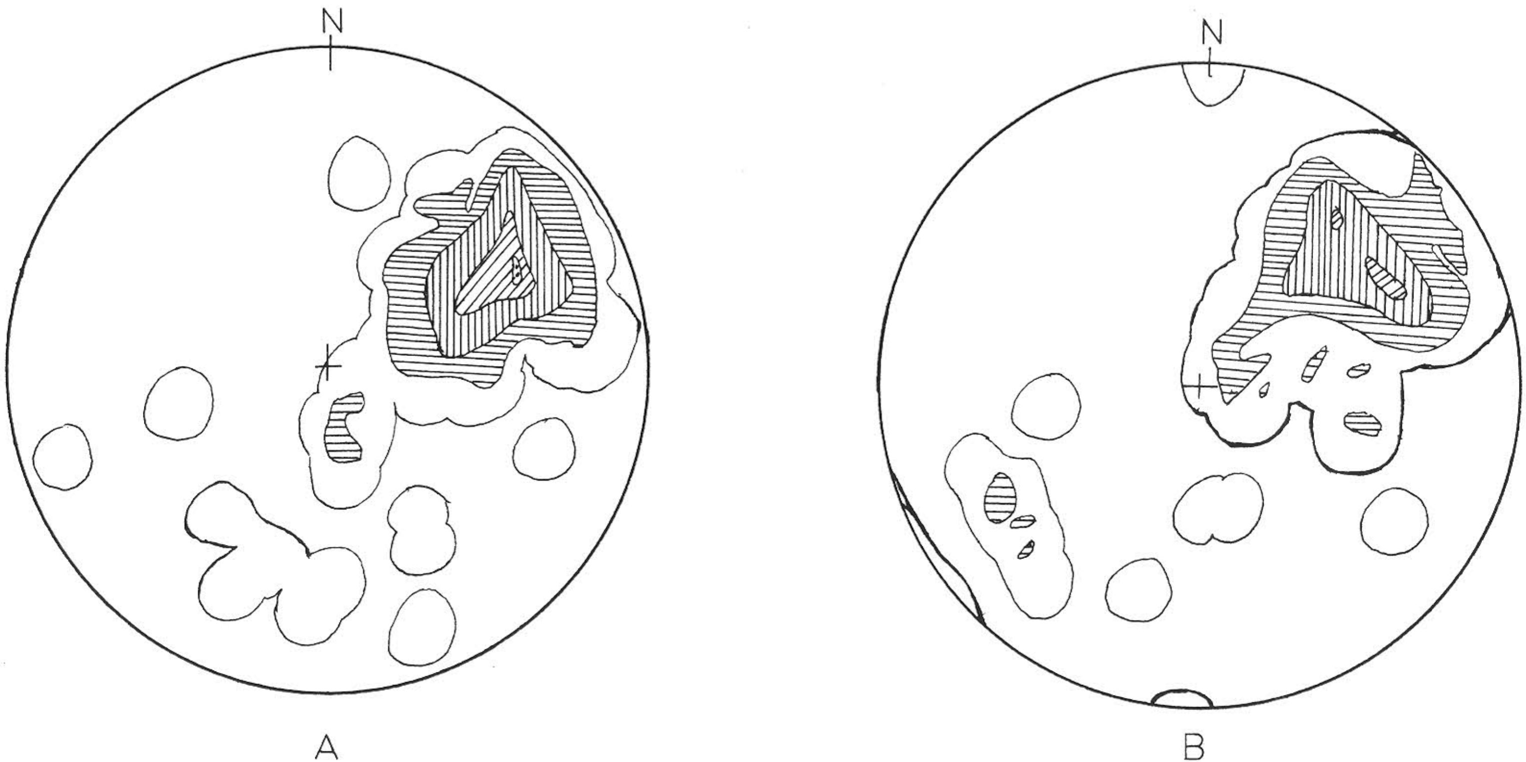


Figure 17 Lineation data for the Teatown Anticline. Lower hemisphere, equal-area projections. Plane of diagrams is horizontal. (A) 103 lineations from Fordham unit C. Contours 1%, 3%, 7%, 12%, 15% per 1% area. (B) 94 lineations from Manhattan unit A. Contours 1.1%, 3.2%, 7.4%, 11.7% per 1% area.

COMPARISON OF STRUCTURAL TRENDS IN THE FORDHAM AND MANHATTAN FORMATIONS

Although no angular relationship can be discussed between the Fordham and overlying units in the Ossining quadrangle, the possibility of a structural discontinuity can be tested in a large fold (the Teatown Anticline) within the Teatown Lake area of the Ossining quadrangle.

Poles to foliation from both the Fordham Gneiss and Manhattan unit A have been plotted and contoured using a circular counter on a lower hemisphere Schmidt (equal-area) net (Figure 16). Although the two projections differ in detail, both show the same strong pole concentration to the northwest, corresponding to a foliation trend striking about N40°E and dipping about 65° southeast.

Lineations from the same units have been similarly plotted and contoured (Figure 17). A strong northeast lineation direction is evident in both projections.

It is clear from Figures 16 and 17 that no structural discontinuity is discernable in the Teatown Anticline, and for this reason, an interpretation of a conformable sequence is favored for the Ossining quadrangle. However, in view of Hall's (1968d) evidence for an angular unconformity between these formations to the south, the similarity in structural orientation in the Ossining quadrangle may indicate either that both deformations were coaxial or that the later deformation obliterated evidence of an earlier event in the Fordham Gneiss.

The age designations adopted on the Geologic Map of New York (Fisher *et al.*, 1971) are used herein, but with the reservation explicit in the above paragraph.

MULTIPLE DEFORMATION WITHIN THE OSSINING QUADRANGLE

Recent structural studies in southeastern New York indicate that the rocks of the Manhattan Prong have undergone polyphase deformation. Scotford (1956) and Prucha *et al.*, (1968) recognized movement in two different directions. Bowes and Langer (1968) and Langer and Bowes (1969) indicated that the schists and amphibolite from the Bronx, New York have been subjected to three phases of deformation. Ratcliffe (1968) recognized three phases of folding in the Haverstraw quadrangle. Hall (1968d) described three varieties of folds in the Manhattan Formation as well as a tilting prior to the deposition of the Manhattan Formation and at least one period of deformation of the Fordham Gneiss prior to the deposition of the Inwood Marble.

On the basis of contoured equal-area projections discussed above, structural analysis of the Teatown Anticline can be undertaken without considering the Fordham Gneiss and Manhattan Formation separately. The Teatown Anticline is a large, northeast-plunging fold with an axis striking about N45°E. The plot of poles to foliation (Figure 18) shows an axial fabric corresponding to foliation striking N45°E and dipping 65°SE. The strike of the foliation as determined from the foliation pole-diagram (N40°E) is nearly parallel to the trace of the axial surface (N45°E).

Lineations from the Teatown Anticline have been plotted and contoured on an equal-area net (Figure 18). The axial lineation concentration lies on the foliation plane as determined by the foliation pole-diagram, and plunges about 45°NE. The lineations are inferred to be B-lineations parallel to the regional fold axis of the Teatown Anticline.

The southwest extension of the Teatown Anticline is not exposed, and, thus, the data are not representative of the entire structure. The recorded data from the exposed part of the anticline record only one period of deformation. The map pattern and lineation data for the quadrangle as a whole indicate that structures plunge to the northeast in the northern and eastern part of the quadrangle and to the southwest in the southwestern part of the quadrangle. The structural data indicate that the foliation maintains a persistent northeast trend throughout the quadrangle. Stratigraphic units have been deformed into a series of elongate northeast folds, and foliation parallels this northeast trend. On the basis of a well-defined axial-plane foliation and thickening of units within hinge areas, these regional folds are inferred to be the result of similar folding. A late-stage deformation is recorded in some outcrops of Manhattan unit A (fissile schist). The axial-plane foliation (mica schistosity) of Manhattan unit A has been deformed into small-scale chevron folds (Figure 15) which are not related to the regional fold pattern.

Within the Ossining quadrangle, metamorphism and deformation were largely synchronous. Although a few phases may be the result of retrograde metamorphism (staurolite and late-stage muscovite), there is no indication of the relationship between these phases and the deformational history.

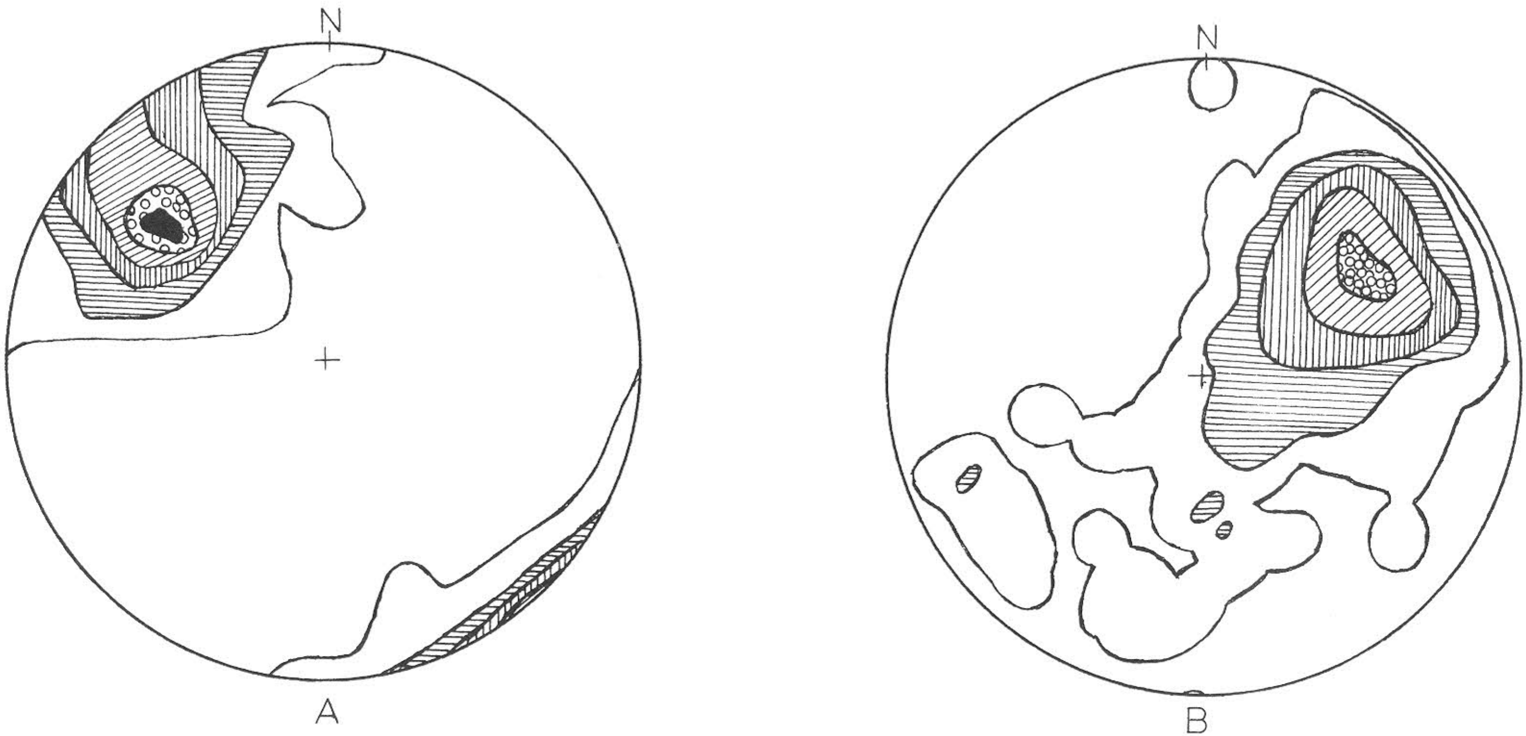


Figure 18 Foliation and lineation data for the Teatown Anticline. Lower hemisphere, equal-area projections. Plane of diagrams is horizontal. (A) 241 poles to foliations from Fordham unit C, Manhattan unit A, and Manhattan unit C. Contours 0.4%, 21.%, 4.1%, 6.2%, 8.3%, 10.4% per 1% area. (B) 288 lineations from Fordham unit C, Manhattan unit A, and Manhattan unit C. Contours 0.3%, 1.7%, 3.5%, 6.9%, 10.4% per 1% area.

Tables 15–27

Table 15. Compositions of plagioclase

Fordham unit A

Sample #	An Mol %
15-II	16
70-II	22
57	25
70-I	29
117	29
27	32
65-II	34
120	34
65-I	39
114	39

Fordham unit B

Sample #	An Mol %
63	31
7	32
94	34
52	35
72	35
69	36
93	36
28	40
35	40
76	56

Manhattan unit A (fissile schist)

Sample #	An Mol %
350	14
331	19
165	21
339	21
353	21
151A	22
307	22
258	24
265	24
302	24
E7	25
283	25
326	25
154	26
144-I	27
152	27
315	27
320	27
329	27
210	31
332	31
347	34
321	39
305(am)	44

Fordham unit C

Sample #	An Mol %
312-I	14
312-II	14
313	15
260-II	16
309	16
111	18
86	19
Ch H	22
244	22
108	24
37	26
105	26
110	26
112	27
107	28
119	28
317	29
96	32
260-I	32
10	36
43	43

Manhattan unit A—Cortlandt contact zone

Sample #	An Mol %
354	17
E9	24
352	27
351	29

Manhattan unit A (basal schistose gneiss)

Sample #	An Mol %
212	21
227	26
233	26
234(peg)	29
259-II	32
346-II	35
222	41
344	41
211-I	45
342-I	47
210A	54
345-I	54
303	58
346-I	58
236	64
E10	68
126-III	68
180	70
224d	80
342-II	80

Manhattan unit C (upper Manhattan)

Sample #	An Mol %
327-I(am)	21
279	23
284	24
286	26
275	27
304	27
314	27
292	29
324	29
335	29
357	29
280	30
316	30
325	31
333	31
287	32

Table 16. Compositions of rimmed plagioclase

Sample #	Formation	Core, An Mol %	Rim, An Mol %
115	Fordham A	73	52
295-I	Fordham C	14	11
318	Fordham C	15	8
220	Fordham C	20	18
319	Fordham C	28	24
175A	Fordham-Inwood contact	26	

Table 17. K-feldspar compositions

Sample #	Formational unit	Composition
70-I	Fordham A	Or_{88}
70-II	Fordham A	Or_{90}
15-I	Fordham A (pegmatite)	Or_{77}
Ch H	Fordham C	Or_{92}
295A	Fordham C	Or_{88}
312-I	Fordham C	Or_{83}
317	Fordham C	Or_{86}
318	Fordham C	Or_{91}
319	Fordham C	Or_{88}
237b	Lowerre	Or_{83}
310-I	Lowerre	Or_{84}
310-II	Lowerre	Or_{83}
175A	Fordham-Inwood contact zone	Or_{89}
175E	Fordham-Inwood contact zone	Or_{91}
131	Inwood	Or_{88}
133	Inwood	Or_{89}
336	Inwood	Or_{91}
340-I	Inwood	Or_{92}
E10	Manhattan A (basal zone)	Or_{84}
224d	Manhattan A (basal zone)	Or_{83}
303	Manhattan A (basal zone)	Or_{88}
342-II	Manhattan A (basal zone)	Or_{88}
345-I	Manhattan A (basal zone)	Or_{89}
345-II	Manhattan A (basal zone)	Or_{92}
323-III	Manhattan A (fissile schist)	Or_{92}

Table 18. Modes (volume percent) of Fordham unit A

Sample Number	15-I	15-II	27	57	65-I	65-II	70	70-II	114	115	117	120	Avg. of 4 (excluding schist)
Quartz	X	51±2	X	51±2	X	X	X	26±2	38±2	X	X	50	48
Plagioclase	X	14±2	X	34±2	X	X	X	25±2	21±2	X	X	33	26
Biotite	X	28±2	X	15±2	X	X	X	27±2	32±2	X	X	12	22
Garnet		6±1			X		X	2±1		X	X	4	3
Opaque		1	X	tr	X	X	X	5±1	8±1	X	X	1	3
Zircon		tr	X	tr			X	tr	tr	X	X		tr
Sericite	X		X		X	X		tr				tr	tr
Sillimanite			X				X	6±1					tr
K-feldspar				tr		X	X	8±1		X		tr	tr
Apatite					X				tr	X			tr
Sphene						X							tr
Muscovite	X												tr
Allanite									tr				tr
Hornblende										X			tr
Scapolite										X			tr
Pyroxene			X							X			tr
Perthite	X												tr
Chlorite	X												tr
Tourmaline									tr				tr
Plagioclase An%		16	32	25	39	34	29	22	39		29	34	

114 – Rusty weathered schistose gneiss
115 – Rusty weathered schistose gneiss
117 – Rusty weathered schistose gneiss
120 – Pegmatite layer in schistose gneiss
15-I – Pegmatite layer in dark gray gneiss
15-II – Dark gray garnetiferous gneiss
27 – White gneiss with biotite
57 – Dark gray gneiss
65-I – Dark gray gneiss
65-II – White, granitic gneiss
70 – Sillimanite-garnet schist
70-II – Sillimanite-garnet schist

Table 19. Modes (volume percent) of Fordham unit B

Sample Number	7	28	35	52	63	69	72	76	93	94	Avg. of 7
Quartz	30±2	X	tr	7±1	X	tr	6±1	43±2	X	3	13
Plagioclase	49±2	X	33±3	42±2	X	42±3	35±2	29±2	X	33±2	38
Biotite	tr	X	7±1	28±2	X	1	1	6±1	X	1	6
Hornblende	20±2	X	29±3	19±2		51±3	42±2	10±1	X	50±2	32
Zircon	tr			tr	X	tr	tr	tr		tr	tr
Opaque	tr	X	3±1	tr	X	tr	2±1	1	X	4±1	1
Apatite	tr	X		tr		tr	tr	tr	X	tr	tr
Pyroxene			25±2			5±1	4±1			7±1	6
Garnet			2	3±1			9±1	10±1		tr	3
Carbonate										1	tr
Plagioclase An%	32	40	40	35	31	36	35	56	36	34	

7 –Massive dark gray gneiss
28 –Massive dark gray gneiss
35 –Amphibolite
52 –Massive dark gray gneiss
63 –Interlayered light gray and black gneiss
69 –Amphibolite
72 –Massive dark gray, garnetiferous gneiss or amphibolite
76 –Massive dark gray, garnetiferous gneiss
93 –Massive dark gray gneiss
94 –Massive, fine-grained amphibolite

Table 20. Modes (volume percent) of Fordham unit C

Sample Number	Ch H	10	37	43	86	96	105	107	108	110	111	112	119	220
Quartz	22	X	22.±2	X	X	28.±2	X	X	X	X	23.±2	26±2	X	22±2
Plagioclase	20	X	51.±2	X	X	42.±2	X	X	X	X	42 ±2	39±2	X	44±2
Biotite	1	X	23 ±2	X	X	7 ±1	X	X	X	X	16 ±2	26±2	X	13±1
K-feldspar	56		tr	X	X		X	X	X	X	19 ±2		X	17±2
Opaque	tr	X	tr	X	X	tr	X			X	tr	1	X	tr
Hornblende		X	1	X		18 ±2		X	X	X		4±1		
Zircon	tr		1		X		X	X	X	X	tr	tr	X	tr
Myrmekite	tr										tr		X	2
Muscovite	tr						X							
Sericite		X		X	X		X							
Apatite		X	tr	X	X	tr	X	X	X		tr	tr	X	tr
Carbonate			1											
Garnet				X		3 ±1	X					2±1		
Chlorite						1		X						
Clinozoisite		X						X	X					
Sphene														
Allanite											tr			tr
Tourmaline														
Perthite														
Sillimanite														
Plagioclase An%	22	36	26	43	19	32	26	28	24	26	18	27	28	20(core) 18(rim)

Ch H – Interlayered white and gray gneiss
10 – Interlayered white and gray gneiss
37 – Gray biotite gneiss
43 – Interlayered white and gray gneiss
86 – White to light gray gneiss
96 – Massive, steel-gray hornblende gneiss
105 – Gray garnet-biotite gneiss
107 – Pink to gray granitic gneiss
108 – Gray biotite gneiss
111 – White to pink granitic gneiss
112 – White and gray layered gneiss
119 – White and gray layered gneiss
220 – Gray biotite gneiss
237-III – Gray biotite gneiss
244 – Interlayered white and gray gneiss
250 – Interlayered white and gray gneiss
260-I – Interlayered white and gray gneiss
260-II – Interlayered white and gray gneiss
260-III – Interlayered white and gray gneiss
295-I – Pink granitic gneiss
295-II – Pink granitic gneiss
309 – Pink granitic gneiss
312-I – Light gray and pink gneiss
312-II – Light gray and pink gneiss
313 – Pink granitic gneiss
317 – White to pink granitic gneiss
318 – Pink granitic gneiss
319 – Pink granitic gneiss

(cont'd)

Table 20 (cont'd)

237-III	244	250	260-I	260-II	260-III	295-I	295-II	309	312-I	312-II	313	317	318	319	Avg. of 11
X	33±2	X	X	24±2	X	X	X	X	X	20±2	X	50±2	8±1	X	25
X	60±2	X	X	63±2	X	X	X	X	X	36±2	X	24±2	27±2	X	41
X	4±1	X	X	5±1	X	X	X	X	X	17±2	X	1	11±1	X	11
X	2	X		1	X	X	X	X	X	17±2	X	23±2	37±2	X	16
	tr		X			X	X	X	X	tr		tr	tr		tr
	tr			6±1	X			X	X	3±1			7±1		4
	tr	X	X	tr	X	X	X	X	X		X	tr	1	X	tr
X						X	X	X	X	1	X		3±1	X	1
X						X	X					1			tr
							X								tr
X		X	X	tr	X	X	X	X		1	X		1	X	tr
						X									tr
															tr
			X			X	X	X	X			tr		X	tr
	tr								X	1	X		tr	X	tr
						X	X		X	2			2	X	tr
									X	tr	X		tr		tr
			X												tr
						X	X						2±1	X	tr
						X									tr
	22		32	16		14(core) 11(rim)		16	14	14	15	29	15(core) 8(rim)	28(core) 24(rim)	

Table 21. Modes (volume percent) of Lowerre Quartzite

Sample Number	237-I	237-II	306-I	306-III	310-I	310-II	Avg. of 4
Quartz	X	64±2	94±1	36±2	X	84±2	69
K-feldspar	X	31±2	2	19±2	X	14±2	17
Biotite	X	2		4±1		1	2
Plagioclase	X	1	1	37±2			10
Muscovite	X	tr	1	3±1	X	tr	1
Opaque	X	1	tr	tr		tr	tr
Clinozoisite	X						tr
Zircon	X	tr	tr	tr	X	tr	tr
Apatite	X	tr	tr				tr
Tourmaline			tr				tr
Sphene					?	?tr	tr

237-I – Feldspathic quartzite
237-II – Feldspathic quartzite
306-I – Vitreous quartzite
306-III – Feldspathic quartzite
310-I – Vitreous quartzite
310-II – Vitreous quartzite

Table 22. Modes (volume percent) of Fordham-Inwood Contact Zone

Sample Number	175A	175B	175C	175D	175E	175E	175F	175G	175H	175I	183-I	183-II	183-III	Avg. (excluding marble & amphibolite)	Avg. of three marble samples
K-feldspar	64±3	15±2	2±1	60±3	9±1	26			40±2		X	19±2		26	10
Plagioclase	13±2	29±2		7±1		13	27±2	37±2	30±2	45±2	X	10±1	66±2	30	3
Myrmekite	3±1	tr		2±1		tr						tr		1	tr
Quartz	19±2	42±2	10±2	15±2	11±2	33		37±2	25±2	35±2		2	20±2	28	8
Biotite	tr			tr			3±1	21±2	3±1	16±2	X		12±2	7	
Chlorite	tr			tr										tr	
Apatite	tr	1		tr	tr	tr	tr	tr	tr	tr	X	tr		tr	tr
Muscovite	tr							2	1					tr	
Opaque	tr	4±1	tr	tr		tr	1		tr	tr		1	tr	tr	tr
Zircon	tr	tr		tr		tr	tr	1	tr	tr			tr	tr	
Pyroxene		8±1	14±2	14±2	27±2	3					X	18±2		3	20
Sphene		tr	tr	tr	tr		tr					tr		tr	tr
Clinozoisite		tr												tr	
Allanite		tr												tr	
Calcite			72±3		48±3			1			X	48±2		tr	56
Serpentine			tr												tr
Scapolite			1±1		4±1	24						tr	1	3	2
Hornblende							68±2			3±1				tr	
Phlogopite												tr			tr

175A – White quartz-feldspar gneiss
175B – Rusty quartz-feldspar gneiss
175C – Light gray calcite marble
175D – Rusty quartz-feldspar gneiss
175E – Light gray calcite marble
175E – White quartz-feldspar gneiss
175F – Amphibolite
175 – White feldspar-quartz gneiss
175 – White feldspar-quartz gneiss
175 – White feldspar-quartz gneiss
183-I – Light gray calcite marble
183-II – Light gray calcite marble
183-III – White feldspar-quartz gneiss

Table 23. Modes (volume percent) of Inwood Marble

Sample Number	126-I	126-II	131	132a-II	132a-I	133	135	140	143	168	189	215	216	252	254	255-I
Calcite	57±3	11	X	X		98	X	X	14±2	X	X	X	23	X	X	X
Dolomite	tr	87	X	X			X	X	76±2	X	X	X	30	X	X	X
Quartz	1		X		X	tr				X						
Phlogopite	13±2			X					2	X						X
Pyroxene	17±2															?
K-feldspar	1	tr	X		X	tr			4±1							
Scapolite	8±1	2		X		1	X	X			X	X	2	X		X
Apatite	tr	tr														
Opaque	1	tr	X	X		tr	X	X	1		X	X		X		X
Sphene	tr				X	tr		?								
Zircon			X				?									
Plagioclase				X	X											
Sericite					X											
Sillimanite					X											
Biotite					X					X						
Olivine							X	X	3±1		X		1			
Serpentine							X	X		X	X		4		X	
Chlorite										X						
Tremolite														X	?	

126-I – Gray calcite marble
126-II – White dolomite marble
131 – White calcite marble
132a-II – White calcite marble
132a-I – Rusty quartz-feldspar gneiss
133 – White calcite marble
135 – White dolomite marble
140 – White calcite marble
143 – White dolomite marble
168 – Green calcite marble
189 – White calcite marble
215 – White calcite marble
216 – White calcite-dolomite marble
252 – White dolomite marble
254 – White dolomite marble
255-I – White dolomite marble
255-II – White dolomite marble
261 – White dolomite marble
301 – White dolomite marble
322-I – Green calcite marble
322-II – Green calcite marble
323-IV – Tan calcite marble
330-I – White calcite marble
330-II – White dolomite marble
336 – White calcite marble
338-I – White dolomite marble
338-II – White dolomite marble
340-I – White calcite marble
340-II – White calcite marble
358 – White calcite marble
359 – White calcite-dolomite marble

Sample Number	255-II	261	301	322-I	322-I	322-II	323-IV	330-I	330-II	336	338-I	338-II	340-I	340-II	358	359	Avg. of 11
Calcite	1		X	32±2	X	X	X	X	X	91	X	X	93	X	X	21±2	40
Dolomite	94	98±1	X	3±1	X	X			X		X	X		X	X	62±2	41
Quartz	tr	1	X				X	X	X	2			1	X			tr
Phlogopite	1		X							3							2
Pyroxene	tr				?	?	X										2
K-feldspar										3		5	X				1
Scapolite	2	tr	X				X		X		X	X	tr	X	X	6±1	2
Apatite	tr		?	tr						tr							tr
Opaque	tr	tr	X	1	X	X	X	X	X	tr	X	X	tr	X	X		tr
Sphene																	tr
Zircon					X	X	X			tr			tr				tr
Plagioclase														?			tr
Sericite																	tr
Sillimanite																	tr
Biotite																	tr
Olivine																2	tr
Serpentine															X	7±1	4
Chlorite				50±2	X	X	X		?						?		4
Tremolite				14±2							X						1

Table 24. Modes (volume percent) of Manhattan unit A (basal schistose gneiss)

Sample Number	E10	126-III	180	210A	211-I	211-II	212	222	224d	227	233	234	236
Plagioclase	26±2	33±2	X	X	X	X	X	X	33±2	X	X	X	X
Quartz	25±2	32±2	X	X	X	X	X	X	20±2	X	X	X	X
Hornblende	10±1		X			X			8±1	X			
Biotite	15±1	25±2		X	X		X	X	20±2	X	X	X	X
Pyroxene	1	tr	X			X							
Opaque	2	2±1	X	X	X	X	X	X	1	X	X		X
Scapolite	10±1					X							X
K-feldspar	7±1	1			X	X	X		14±1		X	X	
Sphene	tr	tr	X			X			1	X			
Clinozoisite	2±1					X		?		X			X
Zircon	tr	tr		X	X		X		tr	X	X	X	X
Apatite	tr	tr	X	X	X	X	X	X	tr	X		X	X
Myrmekite	tr	tr			X		X		tr		X	X	
Garnet		5±1		X			X				X		X
Tourmaline		tr		X		X							
Calcite		tr											X
Sericite			X	X				X			X		X
Chlorite			X	X		X						tr	
Allanite						X		X	2	X			X
Sillimanite							X				X		
Muscovite							X	X			X	X	X
Epidote													
Plagioclase An%	68	68	70	54	45		21	41	80	26	26	29	64

E10 – Rusty, slabby schistose gneiss
126-III – Dark gray garnetiferous gneiss
180 – Dark greenish gray gneiss
210A – Garnetiferous schistose gneiss
211-I – Dark gray schistose gneiss
211-II – Dark greenish gray gneiss
212 – Dark gray garnetiferous gneiss
222 – Dark gray schistose gneiss
224d – Rusty, slabby schistose gneiss
227 – Dark gray schistose gneiss
233 – Dark gray garnetiferous schist
234 – Pegmatite
236 – Dark gray schistose gneiss
259-I – Dark gray schistose gneiss
259-II – Rusty schistose gneiss
303 – Dark gray schistose gneiss
337-I – Rusty schistose gneiss
337-II – Rusty schistose gneiss
342-I – Slabby schistose gneiss
342-II – Slabby schistose gneiss
344 – Slabby schistose gneiss
345-I – Slabby schistose gneiss
345-II – Slabby schistose gneiss
345-III – Slabby schistose gneiss
346-I – Dark gray gneiss
346-II – Calcite-bearing dark gneiss

(cont'd)

Table 24 (cont'd)

259-I	259-II	303	337-I	337-II	342-I	342-II	344	345-I	345-II	345-III	346-I	346-II	Avg. of 6
X	X	19±2	X	X	X	X	X	X			25±2	13±1	25
X	X	34±2	X	X	X	X	X	X	X	X	33±2	20±2	27
X		6±1	X	X		X							4
X	X	1	X	X	X	X	X	X	X	X	9±1	5±1	13
X		15±2	X	X		X		X	X	X			3
X	X	3±1	X	X	X		X	X	X	X	2	1	2
		11±1	X	X		X			X	X	10±1		5
X	X	6±1	X	X	tr	X		X	X	X	6±1		6
X		1	X	X		X		X			1	tr	tr
?			X	X		X				X			tr
	X	tr	X	X	X	X	X	X	X	X	tr	tr	tr
X		tr	X		?	X	X			X	tr	tr	tr
	X	tr		X							tr		tr
					X		X						1
	X				X		X	X			tr	tr	tr
			X	X		X			X	X	8±1	60±2	11
X			X										tr
									X	X			tr
		2	X	X		X				X	tr		tr
					X		X						tr
					X		X						tr
											3±1		tr
	32	58			47	80	41	54			58	35	

Table 25. Modes (volume percent) of Manhattan unit A (fissile schist)

Sample Number	E7	138	144-I	144-II	151A	152	154	165	197	210	258	265	283	302	305
Plagioclase	X		16±2	X	44±3	X	X	10±1	X	X	X	17±2	X	49±2	22±2
Quartz	X	X	25±2	X	11±2	X	X	37±2	X	X	X	23±2	X	17±2	10±1
Muscovite	X	X	tr	X	10±2	X		9±1	X	X	X	21±2	X	5±1	
Sillimanite	X	X	21±2	X	6±1	X	X	5±1			X	6±1	X	3±1	
Biotite	X	X	35±2	X	26±2	X	X	29±2	X	X	X	25±2	X	15±2	
Garnet	X		tr	X	tr	X	X	7±1		X	X	tr	X	8±1	
Tourmaline	X									X					
Staurolite	X												X		
Zircon	X		tr	X	tr	X	X	tr		X	X	tr		tr	1
Opaque	X	X	2±1	X	2±1	X	X	2	X		X	tr	X	1±1	5±1
Apatite	X			X						X	X	tr	X	tr	tr
Sericite									X	X		tr		tr	tr
Chlorite												tr			
Clinozoisite															1
K-feldspar												6±1			
Myrmekite												tr			
Hornblende															60±2
Plagioclase An%	25		27		22	27	26	21		31	24	24	25	24	44

Sample Number	307	308	315	320	321	323-III	326	329	331	332	339	347	348	349	350	353	Avg. of 11 Samples (excluding am)
Plagioclase	X	tr	21±2	X	X	tr	12±1	X	14±1	X	X	X	13±1	X	9±1	X	19
Quartz	X	9±1	29±2	X	X	X	29±2	X	8±1	X	X	X	28±2	X	18±2	X	21
Muscovite	X	36±2	17±2	X	X	tr	29±2	X	31±2	X	X	X	31±2	X	31±2	X	20
Sillimanite	X	11±1	8±1	X	tr	X	11±1	X	6±1			X	1		11±1	X	8
Biotite	X	26±2	22±2	X	X	X	14±1	X	31±2	X	X	X	18±2	X	24±2	X	24
Garnet	X	4±1		X	X	X	tr	X	8±1	X	X	X	7±1		3±1	X	3
Tourmaline	X	1		X			1	tr		X	X	X	tr	X	tr	X	tr
Staurolite	X	9±1					tr	X					tr		tr		tr
Zircon	X	tr	tr		X	X	tr	X	tr	X	X	X	tr		tr	X	tr
Opaque	X	2	tr	X	X	X	2±1	X	tr	X	X	X	tr	X	2		1
Apatite	X	tr		X	X	X	tr	X	tr	X		X			tr		tr
Sericite									tr								tr
Chlorite						X			tr								tr
Clinozoisite																	
K-feldspar			1			X											tr
Myrmekite			1														tr
Hornblende																	
Plagioclase An%	22		27	27	39		25	27	29	31	21	34			14	21	

E7 – Dark gray fissile schist
138 – Dark gray fissile schist
144-I – Dark gray fissile schist
144-II – Dark gray fissile schist
151A – Feldspar-rich fissile schist
152 – Feldspar-rich fissile schist
154 – Feldspar-rich fissile schist
165 – Garnetiferous fissile schist
197 – Feldspar-rich hard schist
210 – Feldspar-rich hard schist
258 – Feldspar-rich hard schist
265 – Feldspar-rich hard schist
283 – Feldspar-rich fissile schist
302 – Feldspar-rich hard schist
305 – Amphibolite
307 – Garnetiferous fissile schist
308 – Dark gray fissile schist
315 – Feldspar-rich hard schist
320 – Feldspar-rich fissile schist
321 – Feldspar-rich hard schist
323-III – Garnetiferous fissile schist
326 – Sillimanite-rich fissile schist
329 – Sillimanite-rich fissile schist
331 – Garnetiferous fissile schist
332 – Feldspar-rich hard schist
339 – Garnetiferous fissile schist
347 – Feldspar-rich hard schist
348 – Garnetiferous fissile schist
349 – Very fissile gray schist
350 – Garnetiferous fissile schist
353 – Garnetiferous fissile schist

Table 26. Modes (volume percent) of Manhattan unit A near Cortlandt Complex

Sample Number	E9	351	352	354	Avg. of 2
Plagioclase	X	11±1	X	15±1	13
Quartz	X	27±2	X	15±1	21
Muscovite	X		X	16±1	8
Biotite	X	23±2	X	13±1	18
K-feldspar	X	tr			tr
Opaque	X	1	X	8±1	5
Zircon	X	tr	X	tr	tr
Apatite	X		X	tr	tr
Garnet		10±1		1	6
Sillimanite		27±2	X	31±2	29
Tourmaline		tr		tr	tr

E9 – Hard feldspar-rich schistose gneiss
351 – Garnetiferous fissile schist
352 – Hard feldspar-rich schistose gneiss
354 – Sillimanite-rich fissile schist

Table 27. Modes (volume percent) of Manhattan unit C

Sample Number	275	279	280	284-I	284-II	286	287	292	304
Plagioclase	X	X	X	X	X	30±2	31±2	X	X
Quartz	X	X	X	X	X	42±2	35±2	X	X
Biotite	X	X	X	X	X	18±2	21±2	X	X
Muscovite	X	X	X	X	X	6±1	tr	X	X
Sillimanite	X							tr	tr
Garnet	X	X	X			tr	tr		
Opaque	X	X	X	X	X	3±1	1	X	X
Zircon	X	X	X	X	X	tr	tr	X	X
Apatite	X	X	X	X	X	tr	tr	X	X
Calcite (secondary)							10±1		
Sericite									
Allanite									
Sphene									
Hornblende									
Clinozoisite									
Plagioclase An%	27	23	30	24		26	32	29	27

Sample Number	314	316	324	325	327-I	327-II	328	333	335	357	Avg. of 5
Plagioclase	X	X	36±2	X	X	X	36±2	X	24±2	X	31
Quartz	X	X	31±2	X	X	X	41±2	X	37±2	X	37
Biotite	X	X	27±2	X	X	X	14±1	X	28±2	X	21
Muscovite	X	X	4±1	X			5±1	X	6±1	X	4
Sillimanite	tr								2±1		tr
Garnet							1		tr		tr
Opaque	X	X	1	X	X	X	1	X	2	X	2
Zircon	X	X	tr	X	X		tr	X	tr	X	tr
Apatite	X	X	tr	X			tr	X	tr	X	tr
Calcite (secondary)											
Sericite	X									X	tr
Allanite			tr	X							tr
Sphene				X							tr
Hornblende					X	X					tr
Clinozoisite				X							tr
Plagioclase An%	27	30	29	31	21			31	29	29	

275 – Gray, biotite-rich gneiss
279 – Hard, gray schistose gneiss
280 – Hard, steel gray gneiss
284-I – Hard, steel gray gneiss
284-II – Hard, steel gray gneiss
286 – Hard, steel gray gneiss
287 – Hard, dark gray gneiss
292 – Hard, steel gray gneiss
304 – Hard, steel gray gneiss
314 – Hard, steel gray gneiss
316 – Hard, steel gray gneiss
324 – Hard, steel gray gneiss
325 – Hard, steel gray gneiss
327-I – Amphibolite
327-II – Amphibolite
328 – Hard, steel gray gneiss
333 – Hard, steel gray gneiss
335 – Hard, dark gray gneiss
357 – Hard, steel gray gneiss

SUMMARY AND CONCLUSIONS

The stratigraphic sequence within the Ossining quadrangle has been divided into 11 units on the basis of rock type, stratigraphic position, and mineralogical composition.

With the exception of the Inwood Marble and the base of the Manhattan Formation, phase equilibria within units have been established. Only the aluminous Fordham unit A and Manhattan unit A are suitable for classification into the metamorphic facies classification. Within Fordham unit A, the stable mineral assemblage is biotite-sillimanite-garnet-plagioclase-K-feldspar-quartz; within Manhattan unit A, it is biotite-sillimanite-garnet-plagioclase-muscovite-quartz. The metamorphic grade for the Ossining quadrangle thus ranges within the amphibolite facies from the sillimanite-garnet-orthoclase subfacies (K-feldspar-sillimanite zone) to the sillimanite-garnet-muscovite subfacies (muscovite-sillimanite zone). Metamorphic temperatures are inferred to have been between 625° and 670°C, and pressures between 5.5 and 6.5 kb.

Within the Inwood Marble, phase equilibria have been established locally, but not for the unit as a whole. In the central part of the Inwood Marble belts, dolomite + quartz coexist whereas, toward the margins, dolomite + quartz have reacted to produce pyroxene and tremolite. The relationships suggest a high CO_2 pressure gradient, with P_{CO_2} decreasing from greater than 2.0 kb in the center of marble belts to almost 0 kb at the margins, with a concomitant increase in P_{H_2O}. The stable coexistence of dolomite + quartz within a few hundred meters of the Inwood-Fordham and Inwood-Manhattan contact indicates that the Inwood Marble acted as an efficient seal to CO_2 migration.

The base of the Manhattan Formation is locally characterized by a calc-silicate mineral assemblage which appears to have been formed by metasomatic reaction between the aluminous Manhattan unit A and the calcareous, basal Manhattan unit A and Inwood Marble. Net displacement of K, Al, H_2O, and possible Si from the schist toward the marble is inferred with concomitant displacement of Ca, Mg, and CO_2 from the marble toward the schist.

Structural data and the lithologic outcrop pattern indicate that the entire stratigraphic sequence of the Ossining quadrangle has been deformed by passive (similar) folding into a series of elongate, northeast-trending folds. Structural fabric studies failed to reveal any structural discontinuities between formations.

Hall (1966, 1968a, b, c, d) mapped an angular unconformity between the Fordham Gneiss and overlying formations in the White Plains quadrangle. In the Ossining quadrangle, however, such evidence is lacking. All units within the Fordham Gneiss parallel the Fordham-Inwood and Fordham-Lowerre contact and the small-scale interlayering of Fordham Gneiss and Inwood Marble is ambiguous. The structural fabric within the Fordham Gneiss is similar to that of the overlying units and plagioclase structural state and metamorphic grade are similar throughout the stratigraphic sequence. There is no unambiguous evidence to indicate metamorphism of the Fordham Gneiss prior to the deposition of the overlying units.

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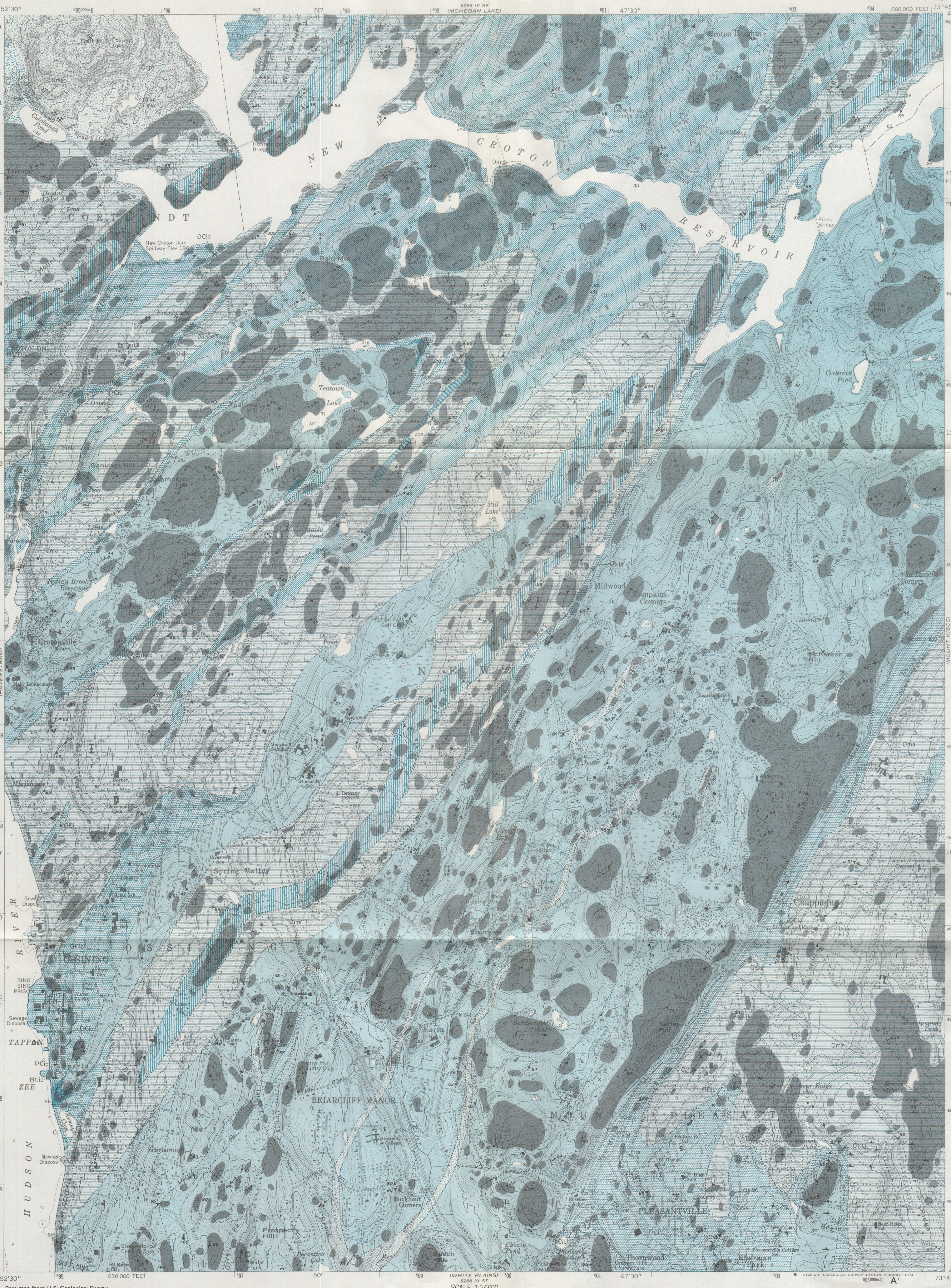
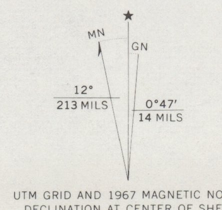
THE UNIVERSITY OF THE STATE OF NEW YORK
THE STATE EDUCATION DEPARTMENT

GEOLOGICAL SURVEY
Robert H. Fakundiny, State Geologist



Base map from U.S. Geological Survey,
1967 Ossining Quadrangle, 7½ Minute Series

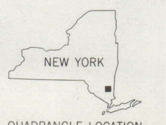


UTM GRID AND 1967 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1:24000

1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET



QUADRANGLE LOCATION

FIELD WORK DONE DURING
SUMMERS OF 1966, 1967, 1968

EXPLANATION

Cortlandt Mafic Complex

Oban - Biotite-augite norite
Oopx - Olivine pyroxenite, in part with poikilitic hornblende; local peridotite
Opx - Pyroxenite

Manhattan Formation

Omc - Light gray to nearly black muscovite-biotite-plagioclase-quartz gneiss and schist.
Omca - Amphibolite lens

Oma - Dark gray or black, fissile, garnet-sillimanite-plagioclase-muscovite-quartz-biotite schist with K-feldspar and staurolite present locally near base.
Omaa - Amphibolite lens.
Omab - Rusty-weathered pyroxene-hornblende-K-feldspar-biotite-plagioclase-quartz schistose gneiss and interlayered calcitic marble; schistose gneiss present locally at base.

Inwood Marble

O€i - Inwood marble, member uncertain.
O€ie - White, medium-grained calcitic marble.
O€id - White dolomitic marble interlayered with white or gray calcitic marble.
O€ic - White, medium- to coarse-grained dolomitic marble.
O€ib - White dolomitic marble interlayered with biotite-quartz-feldspar gneiss and tan-weathered calcite-dolomite marble.
O€ia - White, coarse- to medium-grained dolomitic marble

Lowerre Quartzite

€l - Tan, slabby, feldspathic quartzite interlayered with buff colored massive vitreous quartzite.

Fordham Gneiss

fc - Pink granitic gneiss, white biotite-quartz-plagioclase gneiss with amphibolite layers and boudin, and dark gray hornblende-biotite-quartz-plagioclase gneiss.
fb - Dark gray garnet-biotite-hornblende-plagioclase-quartz gneiss, and pyroxene-bearing amphibolite.
fa - Interlayered dark gray pyroxene-hornblende gneiss, rusty-weathered garnet-plagioclase-biotite-quartz gneiss, quartz pods, white or gray biotite-plagioclase-quartz pegmatite, and amphibolite. Includes a moderately homogeneous rusty-weathered plagioclase-biotite-quartz schistose gneiss and a rusty-weathered, lavender, garnet-sillimanite-K-feldspar-plagioclase-quartz-biotite schist.

SYMBOLS

Unit and formation contact: solid where observed, dashed where approximately located or inferred. Outcrops not mapped in Oopx.

Area of outcrop or closely-spaced outcrops; lone structural symbol or x locates isolated outcrop too small to designate otherwise.

Strike and dip of foliation

Strike of vertical foliation

Strike and dip of foliation showing plunge of lineation

Strike of vertical foliation showing plunge of lineation

Mineral lineation showing azimuth and plunge

Minor fold axis showing azimuth and plunge

Minor crenulation showing azimuth and plunge of axis

Vertical lineation

Operating mine or quarry

Abandoned mine or quarry

Sand pit

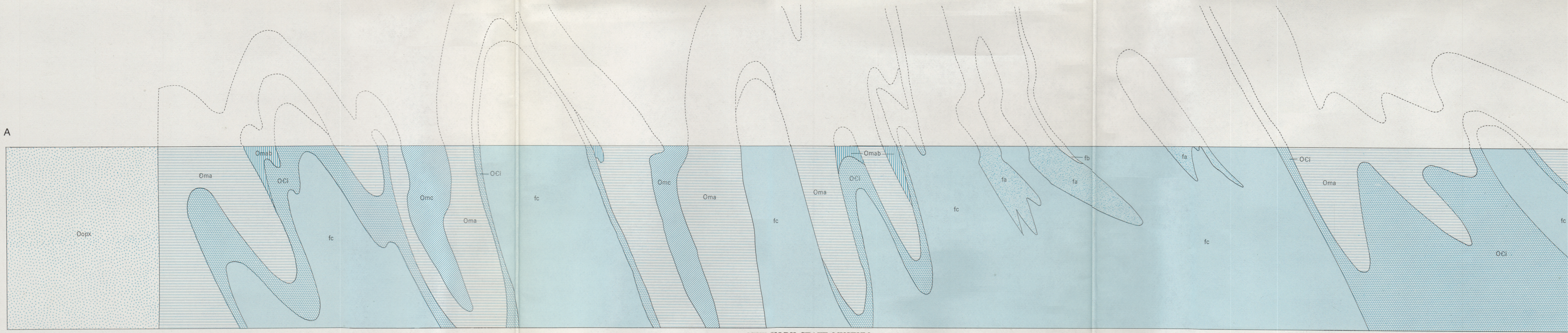


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PLATE 1. BEDROCK GEOLOGY AND STRUCTURE SECTION OF THE OSSINING QUADRANGLE, NEW YORK

George C. Wissig, Jr.

1979

Williams & Heintz Map Corporation, Washington

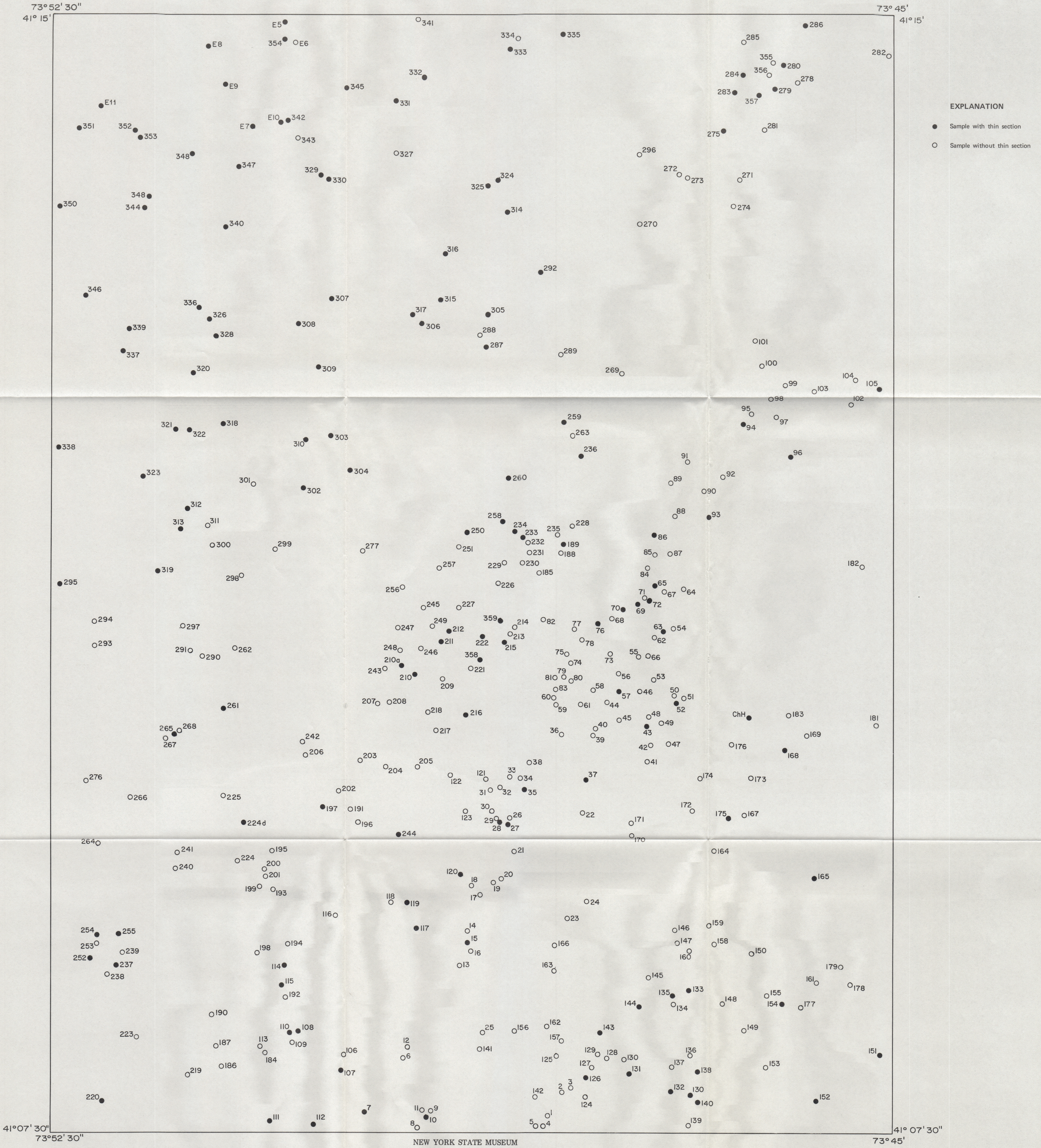

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PLATE 2. SAMPLE LOCATION MAP OF THE OSSINING QUADRANGLE, NEW YORK

George C. Wissig, Jr.

1979