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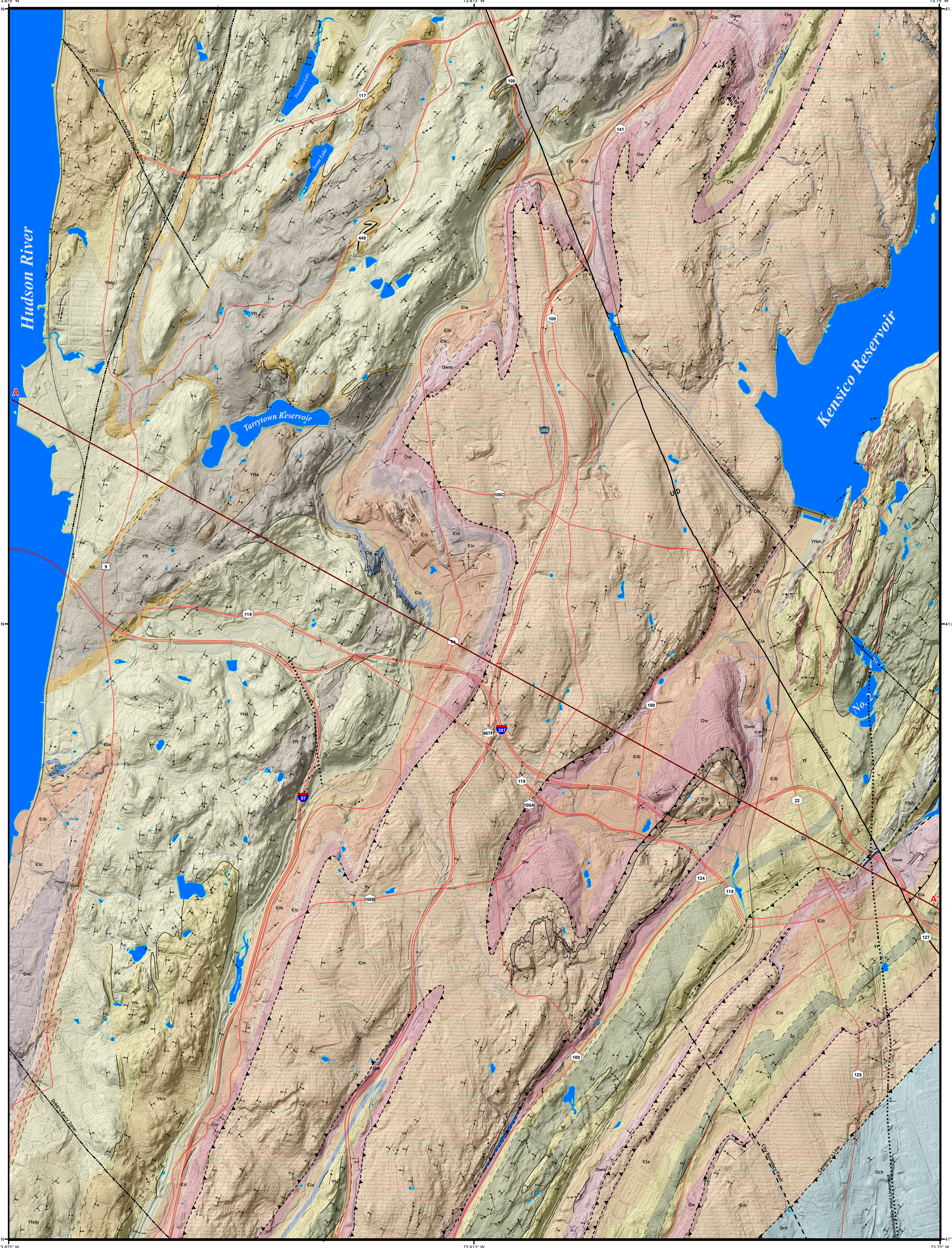
*Dr. Andrew L. Kozlowski, Mapping Program Director*




Universal Transverse Mercator, Zone 18 N, North American Datum of 1983

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Magnetic declination from the NOAA online Declination Calculator: (http://www.ngdc.noaa.gov/geomag-web/#declination)

Field map, notes and draft maps available through the NYSGS Open File: (https://www.nysm.nysed.gov/research-collections/geology/collections/open-file)

SCALE 1:24,000

1 0.5 0 KILOMETERS 1 2
1000 500 0 METERS 1000 2000
1 0.5 0 MILES 1
1000 500 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 FEET

CONTOUR INTERVAL: 10 FEET

Geologic mapping by L. Hall, 1981-1984
Digital data and cartography: J. Manchester, B. Bird and K. Backhaus, 2011, 2016, 2023-2024

MN GN 12° 47' 227 MILS 0° 47' 14 MILS

UTM GRID AND 2023 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

# BEDROCK GEOLOGY OF THE WHITE PLAINS 7.5-MINUTE QUADRANGLE, WESTCHESTER COUNTY, NEW YORK

Leo M. Hall
2024

# BEDROCK GEOLOGY OF THE WHITE PLAINS 7.5-MINUTE QUADRANGLE, WESTCHESTER COUNTY, NEW YORK

*prepared by*
Leo M. Hall, Janet Manchester, Brian C. Bird and Karl J. Backhaus

Supported in part by the U.S Geological Survey's
National Cooperative Geologic Mapping Program STATEMAP Award Number G22AC00366

## DESCRIPTION OF MAP UNITS

### *Autochthonous Rocks*

ORDOVICIAN — Walloomsac Formation

**Ow** — **Walloomsac Formation (Ow)**
Gray or dark gray, fissile, sillimanite-garnet-muscovite-biotite schist that is commonly rusty-weathering due to the presence of sulfides; it is locally interbedded with calcite marble near the base, and calcite-bearing dark gray schist is locally present.

**Owm** — **Phlogopitic Marble Member (Owm)**
Tan-weathering, gray, white, or blue-gray calcite marble that is commonly phlogopitic and is locally present at the base of the formation.

***Unconformity***

CAMBRIAN — Inwood Marble

**€id** — **Inwood Marble (Member D)**
Interbedded gray dolomite marble, gray calcite marble, calcite-dolomite marble, and some calc-schist.

**€ic** — **Inwood Marble (Member C)**
Thick-bedded, gray or blue-gray, and clean dolomite marble.

**€ib** — **Inwood Marble (Member B)**
Interbedded gray, buff, pinkish tan, or cream dolomite marble, tan or reddish-brown calc-schist, purplish brown or tan siliceous calc-schist and granulites, tan quartzite, and calcite-dolomite marble are the dominant rock types; bedding 0.5 to 4 feet thick is prominent.

**€ia** — **Inwood Marble (Member A)**
Well-bedded white, gray, or blue-gray dolomite marble.

Lowerre Quartzite

**€lg / €l** — **Lowerre Quartzite (€l & €lg)**
Tan- or buff-weathering, feldspathic quartzite or quartz-rich granulite, vitreous quartzite, and micaceous quartzite are typical; brownish- and locally rusty-weathering granulites and schists that commonly contain sillimanite are present locally at the base, particularly in the east. Clg is gray granulite shown separately on the northeast side of Beaver Hill.

***Unconformity***

NEOPROTEROZOIC — Yonkers Gneiss

**Zy** — **Yonkers Gneiss (Zy)**
Pink, pale orange, or pale purplish-blue, well-foliated, biotite-hornblende-quartz-plagioclase-microcline gneiss; ferrohastingsite with 2V of 10° to 20° the typical amphibole; garnet, ilmenite, magnetite, fluorite, and pyrite (which is commonly altered to goethite) are locally present as accessory minerals; black or dark greenish-black amphibolite is often observed but constitutes less than 5 percent of the entire rock unit.

***Discontinuity of Uncertain Nature***

MESOPROTEROZOIC — Fordham Gneiss

**Yfcv** — **Childrens Village Unit (Yfcv)**
Gray biotite and/or hornblende-quartz-feldspar gneiss with local garnet, brown-weathering garnet-biotite-quartz-feldspar gneiss, and amphibolites constitute the main rock types in this member; graphite is a common accessory mineral in many of the rocks to the southwest.

**Yfh** — **Harriman Road Reservoir Unit (Yfh)**
Gray garnet-biotite-quartz-feldspar gneiss with local sillimanite and abundant amphibolite characterize this unit; deformed poikilitic garnets up to 6 inches in the long dimension are present in the garnetiferous gneisses; pyroxene that is rimmed by amphibole is common in the southwest and, although not indicated on the map, amphibolite can be mapped separately in the vicinity of the Harriman Road Reservoir.

**Yfei / Yfeip** — **East Irvington Unit (Yfei &Yfeip)**
Gray or dark-gray biotite- and/or hornblende-quartz-feldspar gneiss, commonly with epidote and with minor amounts of calcite locally; the gneiss typically contains numerous white or pink quartz-feldspar layers and lenses; amphibolite is present in many exposures but is subordinate; Yfeip consists of pink hornblende-biotite-quartz-feldspar layers and lenses, commonly migmatitic, that are abundant in places and are common at or near the upper and lower contacts of Yfei but not restricted to these positions.

**Yfi** — **Interchange 9 Unit (Yfi)**
Rusty-weathering sillimanite-garnet-biotite-quartz-feldspar schist or schistose gneiss with characteristic lavender garnet typifies this member; interbedded siliceous biotite gneiss or quartzite and local calcite and/or dolomite marble are also present. The marbles are known primarily in the vicinity of Gore Brook.

**Yft** — **Tarrytown Reservoir Unit (Yft)**
Interbedded gray garnet-biotite-quartz-feldspar gneisses with local quartz, gray biotite-rich quartz-feldspar gneiss, gray hornblende-biotite-quartz-feldspar gneiss, brown- to rusty-weathering biotite-quartz-feldspar gneiss, and brown amphibolite characterize this unit; locally sillimanite is prominently abundant in the gneisses.

**Yfta** — **Tarrytown Reservoir Unit (Yfta)**
Gray biotite-quartz-feldspar gneiss with local garnet, bearing granular feldspar augen up to 1 inch in the long dimension; present locally at the base of Yft.

AGE UNCERTAIN

**Yfbh / Yf / Yfg** — **Fordham Gneiss (Yf, Yfg & Yfbh)**
The eastern outcrop area is largely undivided stratigraphically but two lithic units are mapped separately. Light gray- to dark gray-weathering biotite-quartz-feldspar gneisses with hornblende and/or garnet are the most abundant rock types. Local brown- and rusty-weathering gneisses also occur and amphibolite is fairly common. These rock types are interlayered and layering is common to the unit in general. Yfg is a garnetiferous biotite-quartz-feldspar gneiss and Yfbh is a gray biotite-hornblende-quartz-feldspar gneiss.

### *Allochthonous Rocks*

ORDOVICIAN

**Och** — **Hartland Formation (Och)**
Interbedded schists, schistose gneisses, granulites, and amphibolites. These rocks are brown-, gray-, or rusty-weathering, and many of the micaceous rocks have a spangled appearance as viewed on the foliation. Pegmatites are relatively common in this unit.

CAMBRIAN

**€m** — **Manhattan Schist (€m)**
Predominately brown-weathering, feldspathic, sillimanite-garnet-muscovite-biotite schist or schistose gneiss and minor amphibolite; sillimanite nodules are locally common in the pelitic rocks; magnetite is a typical accessory mineral and rocks in many exposures attract a magnet strongly; although siliceous beds are prominent locally, bedding is not commonly clearly defined.

**€mcp** — **Manhattan Schist (Central Park Avenue Amphibolite Member)**
Discontinuous amphibolite and minor schist common at or near the base of Cm.

### *Intrusive Rocks*

AGE UNCERTAIN

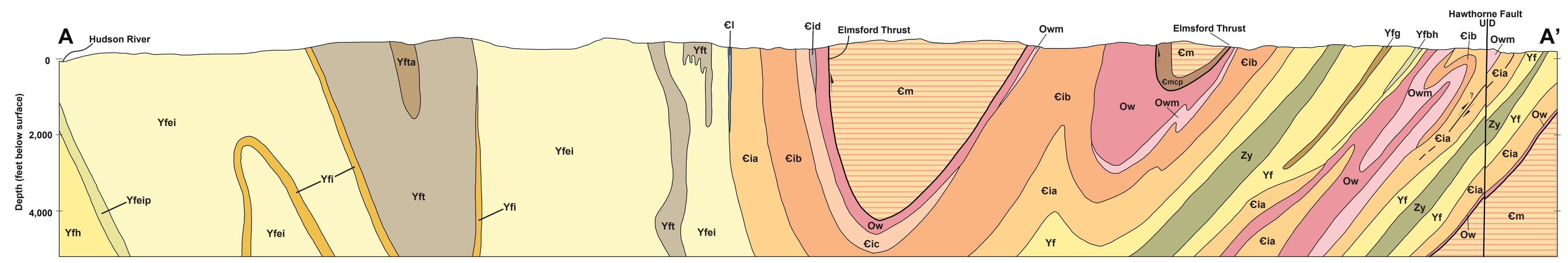
**Z?pg** — **Pegmatite (Z?pg)**
Light gray pegmatite in the vicinity of the White Plains Reservoirs; very coarse pegmatite with feldspar up to 3 feet long and coarse-grained quartz; also contains biotite, garnet, and hornblende; intrusive into the Yonkers Gneiss and may be Paleozoic.

**Zg** — **Pegmatite (Zg)**
Pale pink to pinkish-gray or gray granitic gneiss in the North White Plains region, perhaps related to the Yonkers Gneiss.

## SYMBOLS

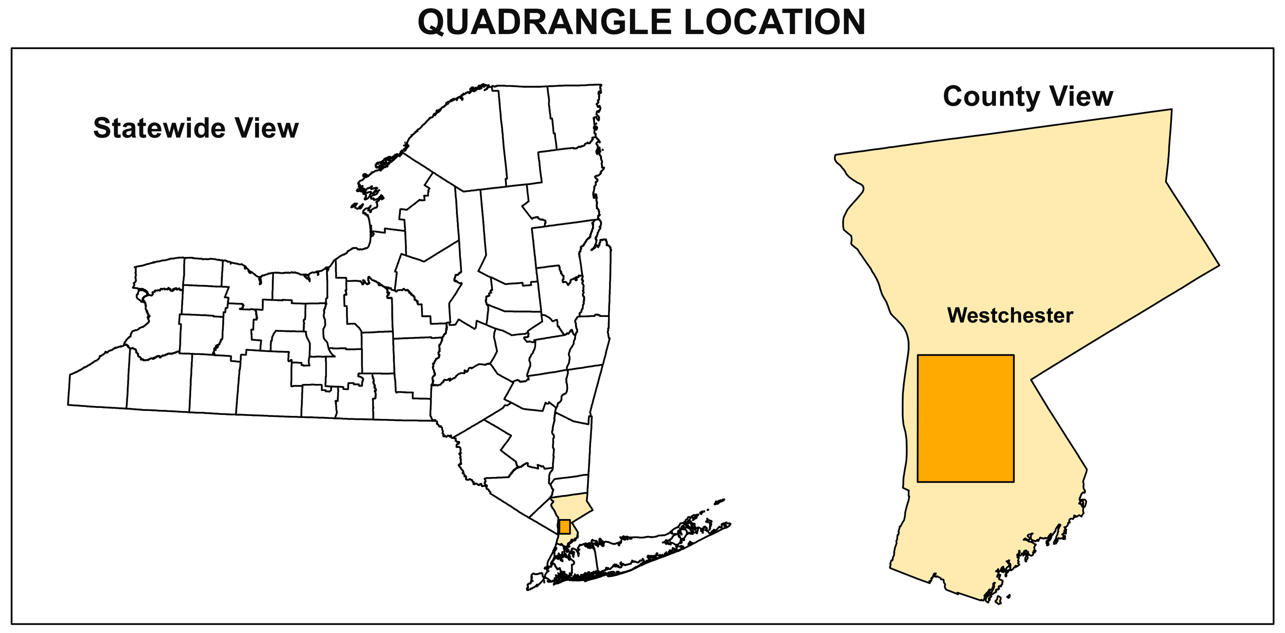
- Highway
- Railroad
- Water Body
- Stream
- Contour
- Waterline
- Contact, Position Definite
- Contact, Position Approximate
- Contact, Position Inferred
- Fault, Position Definite
- Fault, Position Approximate
- Fault, Position Inferred
- Thrust Fault, Position Approximate
- Thrust Fault, Position Inferred
- Fracture Zone
- Topographic Lineament
- Horizontal Fold Axis
- Fold Axis Lineation
- Bedding
- Overturned Bedding
- Lineation
- Foliation
- Vertical Foliation

## CROSS-SECTION A-A'

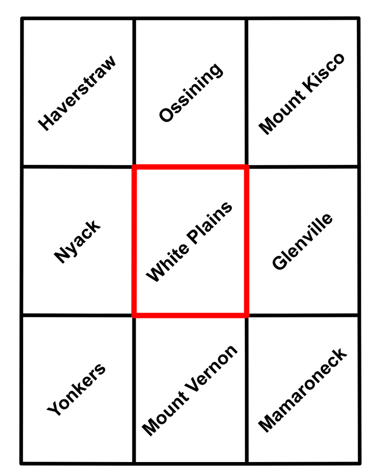



Scale: 1:24,000; No Vertical Exaggeration

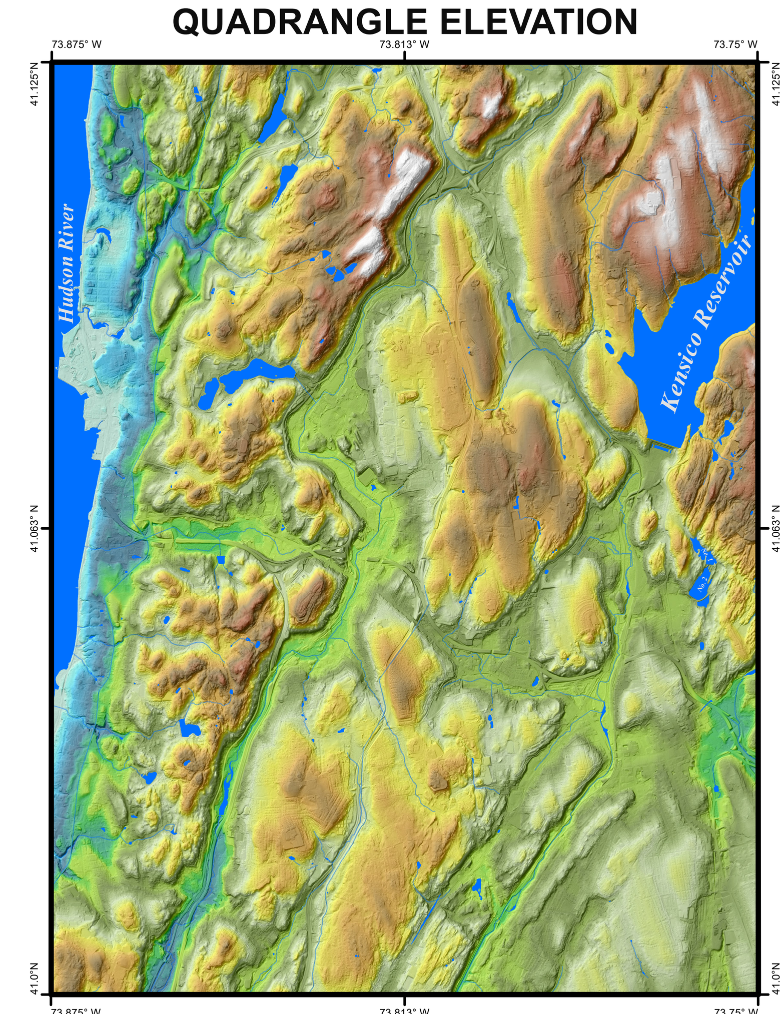
## QUADRANGLE LOCATION




## ADJOINING QUADRANGLES




## QUADRANGLE ELEVATION




1:75,000 scale; 2x vertical exaggeration

Feet-amsl
730 1380

Shaded relief generated from 2019 FEMA 1m lidar data set.

NOTICE

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*New York State Museum Map & Chart No. 153*

*ISSN:0097-3793 ; ISBN:978-1-55557-407-9*

New York State Museum & Science Service
*Jennifer Saunders, Director*

NYSGS NEW YORK State Museum

New York State Geological Survey
*Dr. Andrew L. Kozlowski, Mapping Program Director*

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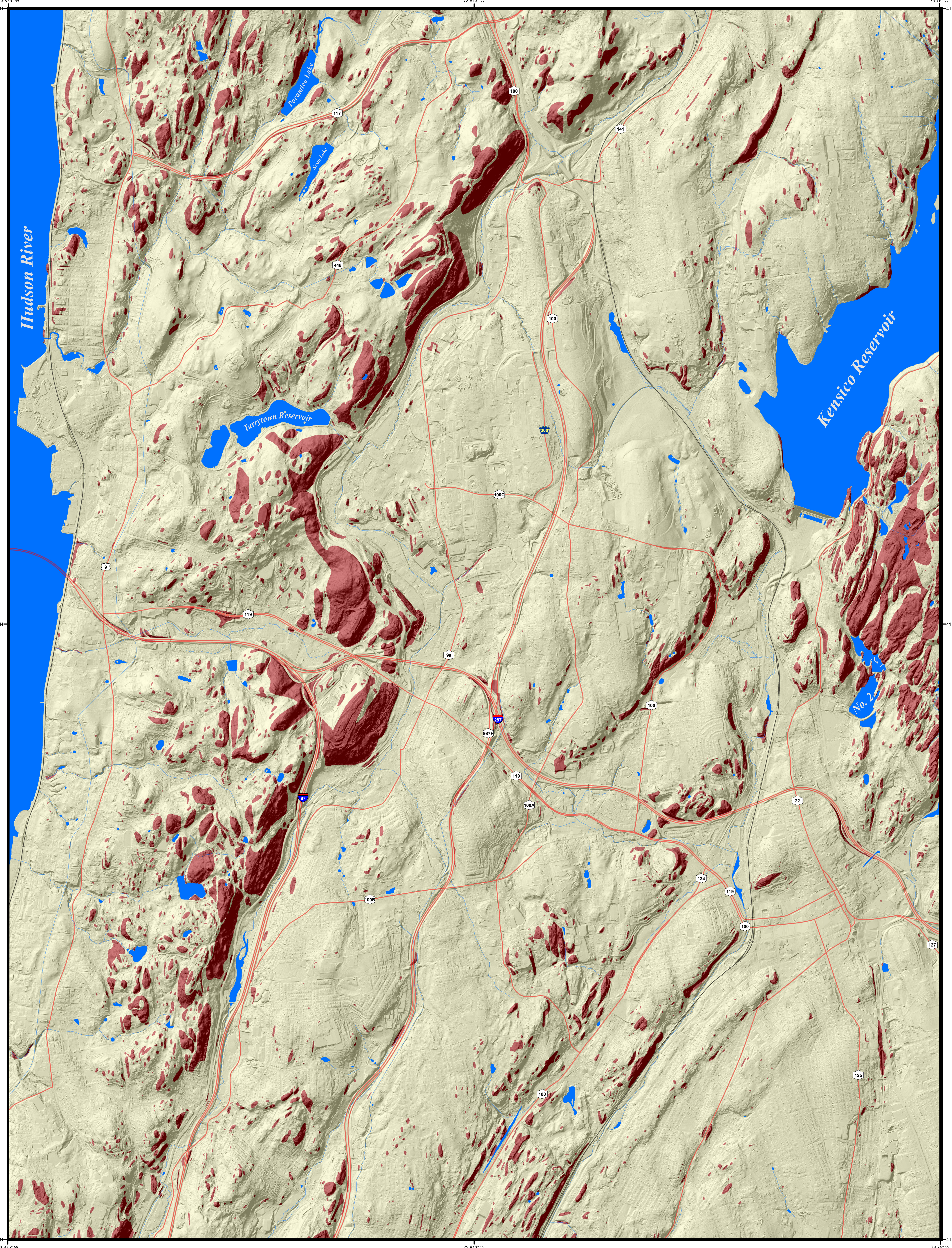


Universal Transverse Mercator, Zone 18 N, North American Datum of 1983

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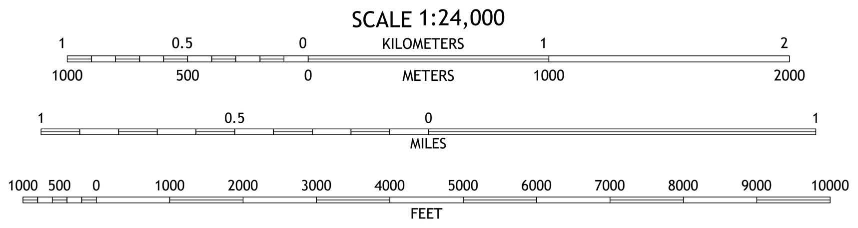
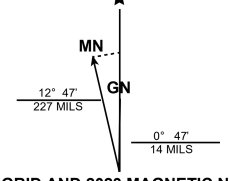



Geologic mapping by L. Hall, 1981-1984
Digital data and cartography, J. Manchester, B. Bird and K. Backhaus, 2011, 2016, 2023-2024




UTM GRID AND 2023 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

## SYMBOLS

Highway — Railroad — Water Body — Stream

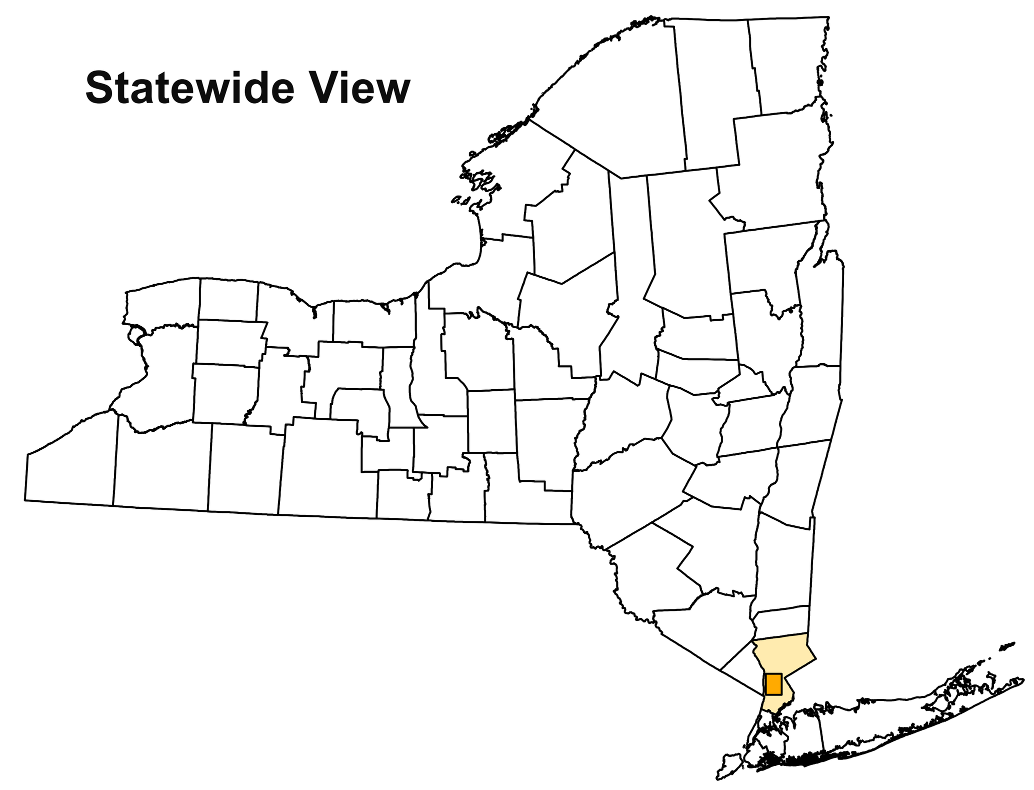
## DESCRIPTION OF MAP UNITS

**Br** — **Bedrock Outcrop (Br)**
Metamorphic rock that can range from Mesoproterozoic to Ordovician in age. May be covered by one meter or less of Quaternary-aged glacially and non-glacially derived sediment.

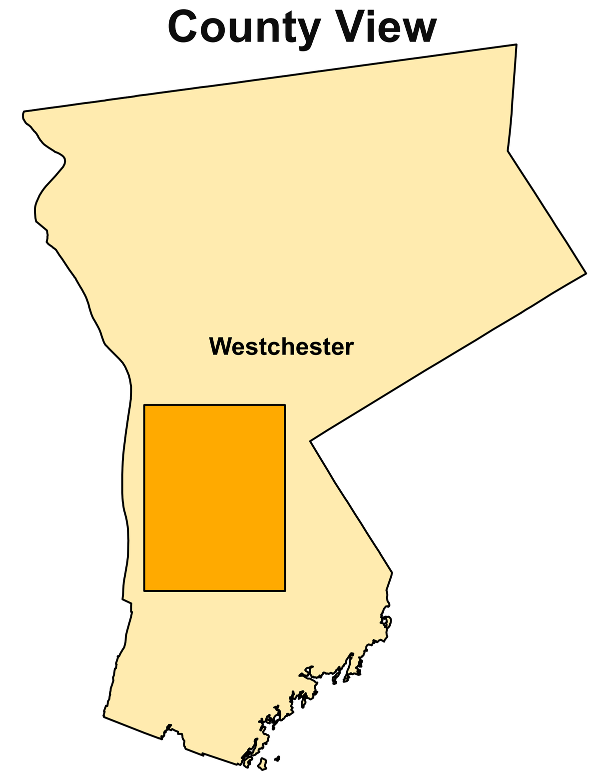
**Qc** — **Quaternary Cover (Qc)**
Glacially or non-glacially derived sediment of varying thicknesses overlying older metamorphic rock (Br).

## QUADRANGLE LOCATION

Statewide View



County View

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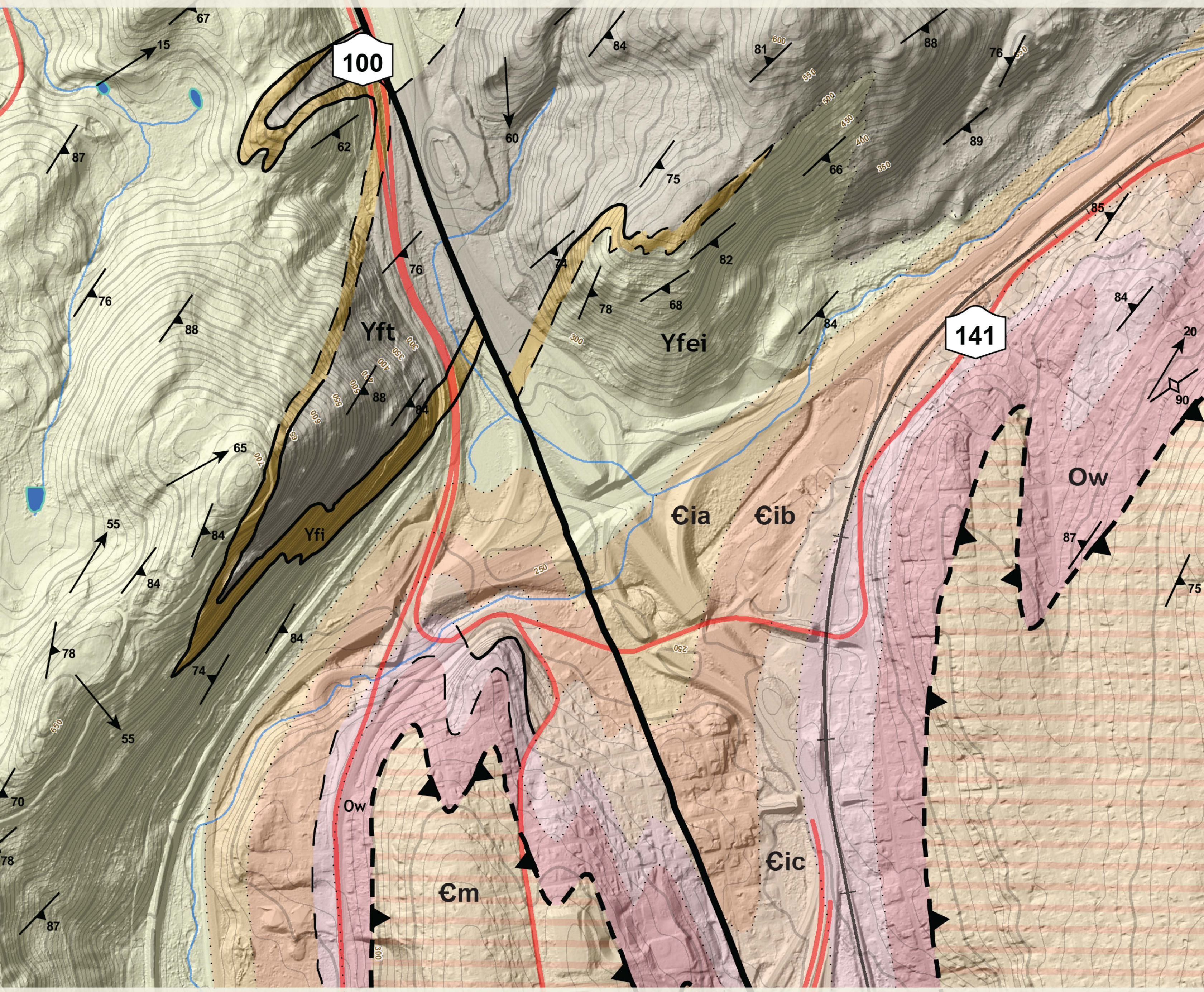


# Bedrock Geology of the White Plains Quadrangle

## Hudson Highlands Region, New York

Leo M. Hall, 1982

Map and Chart Series 153 • New York State Museum - Geological Survey • 2025

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NEW YORK STATE MUSEUM AND SCIENCE SERVICE
MAP AND CHART SERIES NUMBER 153
2025

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

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Edited by H.M. Forgeng

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# CONTENTS

## CAVEATS OF A LEGACY PUBLICATION

*Crucial Notes from the Reviewers and the Editor*

**From the Reviewers**

This bulletin is based on extensive field work in White Plains and adjacent quadrangles in Westchester County, New York, completed by Leo Hall before his untimely death in 1985. Leo Hall began his work in the White Plains area in 1961 with support from the New York State Geological Survey and continued it through 1964. In this effort Hall produced a series of publications that summarized his major conclusions about the stratigraphy, age, and structural history of this complexly deformed and poorly understood area. Hall's work on age and stratigraphy is now the standard for our understanding of the rocks of the Manhattan Prong. This report presents the details of the geology that were central to Hall's interpretations.

In 1981 and 1982, Hall was employed by the U.S. Geological Survey to conduct a brittle study of deformation of the largely plastically deformed rocks, as part of a program looking into the origin and cause of seismicity in the New York City area. The results of this study are melded here into a single report.

At the time of Hall's death, he had finished most of this manuscript, except for the discussion of structural geology and tectonic synthesis. The final version of this report was completed by Peter Robinson, Thomas Spinek, and Peter Panish of the University of Massachusetts and Nicholas Ratcliffe of the U.S. Geological Survey. In completing Hall's paper, we paraphrased some of his earlier papers and used unpublished notes and drawings in his possession. In all of this work we have tried to follow as completely as possible that we believe to have been Hall's ideas and have avoided rewriting and excessive editing of the text and maps.

*Peter Panish, Nicholas Ratcliffe, Peter Robinson, Thomas Spinek*
**1986**

**From the Editor**

Dr. Leo Hall's report entitled *Bedrock Geology of the White Plains Quadrangle* has waited four decades for publication. It has undergone multiple phases of review, punctuated by lengthy stints tucked carefully into a drawer while the world got on with itself in new and exciting ways. The city of White Plains must look entirely different now than it did at the time of Hall's study—which makes this work still more valuable, a time capsule for outcrops that might have been obscured as urban and suburban development continued. We are thrilled for this detailed contribution to see the light of day at last.

Across the breadth of forty years, however, certain crucial aspects have been lost. Most tangible are the casualties of several tables and figures to a forgotten desk drawer in another decade. Most tragic, and most impactful, is the missing ability to confer closely with the author in preparing his work to be published. As the reviewers have taken care to preserve Hall's geologic interpretations, I have proceeded with the preservation of his science and his voice held paramount.

In consequence, when the meaning of a claim was unclear to me, I left the words entirely untouched for the reader to interpret. In addition, reorganization or regrouping of ideas has been impossible to undertake without the author to advise (thus you will find two sections called *Thrust faults*). Nonetheless the trove of information that follows is worth its salt; the geology is presented as intended and without unwarranted modification, and the influential geologist who was Leo Hall has his latest publication in the books.

*Hailey M. Forgeng*
**2025**

## LIST OF FIGURES



## LIST OF TABLES



[Editor's Note] *Mineral names on all available copies of Tables 10 and 11 are truncated and some cannot be reliably distinguished. For a partial reconstruction of these tables, see Appendix 2.*

# INTRODUCTION

## Location and geography

The White Plains 7 1/2-minute quadrangle is located in Westchester County in southeastern New York State. It falls between west longitudes 73°45' and 73°52'30" and north latitudes 41°00' and 41°07'30" (Figure 1, Plate 1). Approximately two-thirds of the western boundary of the quadrangle is in the Hudson River, and an arm of the Kensico Reservoir extends into the northeastern portion of the quadrangle.

The city of White Plains, the county seat of Westchester County, is in the southeastern part of the quadrangle; other major population centers partially or entirely within the quadrangle are Scarsdale, Hartsdale, Ardsley-on-Hudson, Dobbs Ferry, Irvington, Fairview, Elmsford, Tarrytown, Valhalla, Hawthorne, and Thornwood (Plate 1). The remainder of the area is largely residential developments, watershed areas, privately owned woodlands, and county parks. There is industrial and commercial activity in some of the population centers, particularly White Plains, Tarrytown, and Elmsford, but many of the residents commute to jobs in New York City.

A dense network of roads pervades the White Plains quadrangle. Construction of many of the roads, particularly the New York Thruway (I-87), the Cross Westchester Expressway (I-287), and the Sprain Brook Parkway, has produced a number of marvelous rock cuts. The Taconic State, Saw Mill River, and Bronx River Parkways are also major limited-access highways in the quadrangle. Where these and other major highways extend northeast-southwest in the area, they have generally been constructed in valleys underlain by marble. In fact, the regional geologic trends stand out fairly clearly on most highway maps of Westchester County.

## Topography and drainage

There are three broad varieties of land surfaces in the White Plains quadrangle, and each is related to the general type of underlying bedrock. Areas that are moderately rugged and topographically highest are underlain by the Fordham and Yonkers Gneisses. Smooth, rolling topography at intermediate to high elevations is underlain by the Manhattan Schist and Walloomsac Formation. The valleys, generally narrow, are underlain mainly by the Inwood Marble and the Phlogopitic Marble Unit of the Walloomsac Formation, and to a much lesser extent by the Lowerre Quartzite.

The highest point in the quadrangle is approximately 215 meters (m) (~705 feet) above sea level at the top of Buttermilk Hill, which is 1.6 kilometers (km) (~1 mile) south of the north-central edge of the map. Sea level, at the bank of the Hudson River, is the lowest land elevation in the quadrangle, so the maximum relief is about 215 m. The maximum local relief is approximately 135 m (~443 feet) along the eastern side of Buttermilk Hill.

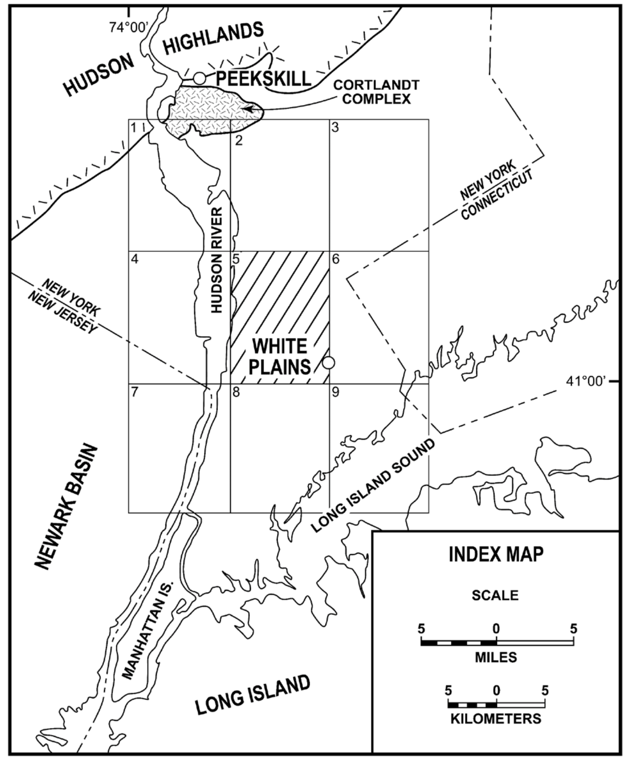


**Figure 1.** Index map of the White Plains quadrangle, New York: 1. Haverstraw quadrangle, 2. Ossining quadrangle, 3. Mt. Kisco quadrangle, 4. Nyack quadrangle, 5. White Plains quadrangle, 6. Glenville quadrangle, 7. Yonkers quadrangle, 8. Mt. Vernon quadrangle, and 9. Mamaroneck quadrangle.

In addition to the Hudson River, the Bronx and Saw Mill Rivers are major streams in the White Plains quadrangle. Sprain Brook originates in the south-central part of the quadrangle south of Dobbs Ferry Road and drains southwesterly. The outflow from Silver Lake forms the Mamaroneck River, which drains southeasterly out of the quadrangle.

Except at the headwaters of the Bronx River between Hawthorne and Valhalla (Plate 1), both the Bronx and Saw Mill Rivers drain southwesterly, following the general trend of the bedrock in the region. In addition to the larger streams, many small streams and works of man drain the area well. The only swampy area of any extent is near Sheldon Brook north of the New York Thruway in the west-central part of the quadrangle.

## Geologic setting

Physiographically, the White Plains quadrangle lies in the part of the New England Upland (Fenneman, 1938) that extends southwestward into New York State. This section of the New England Upland, commonly called the Manhattan Prong (Lobeck, 1950), is bordered to the south by the Coastal Plain, to the west by the "Triassic" Lowland (Newark Basin), and to the northwest by the Reading Prong (Hudson Highlands) (Figure 1). The Coastal Plain is underlain by unconsolidated clays, silts, and gravels. The

Newark Basin is composed of Triassic and Jurassic mafic igneous rocks and mudstones, siltstones, sandstones, and conglomerates that are predominately red. The Hudson Highlands sit upon crystalline Precambrian (middle-Proterozoic) metamorphic rocks of sedimentary and igneous parentage.

The Manhattan Prong itself and the White Plains quadrangle in particular are underlain by metamorphosed sedimentary and igneous rocks that are middle Proterozoic, late Proterozoic, and Lower Paleozoic in age. They are gneisses, marbles, and schists, and the stratigraphy of the Manhattan Prong has classically been divided into a tripartite sequence based upon these generalized rock types. This sequence is locally intruded by mafic igneous plutons, of which the Cortlandt Complex south of Peekskill (Figure 1) is the best known. The Manhattan Prong has been glaciated, and most of the bedrock exposed at higher elevations has been scraped by ice erosion (see Plate 2 for bedrock exposures). Glacial grooves and striations can be observed upon many of these exposures. The areas in the White Plains quadrangle floored by gneiss are covered by very thin, patchy glacial till, while the areas underlain mainly by schist have a more continuous cover of thin till. Most of the major valleys underlain by marble are covered by glacial outwash deposits.

## STRATIGRAPHY

On the basis of local mapped relationships and regional considerations, the metamorphic rocks in the White Plains quadrangle are divided into basement gneisses (Fordham Gneiss and Yonkers Gneiss), autochthonous cover rocks (Lowerre Quartzite, Inwood Marble, and Walloomsac Formation), and allochthonous cover rocks (Manhattan Schist and Hartland Formation), as shown in the diagrammatically restored stratigraphic section (Figure 2).

Stratigraphic relations among these rocks, and their geologic ages, have been interpreted differently by numerous previous workers in southeastern New York. Some have considered the rocks to represent a continuous Precambrian depositional sequence (Berkey, 1907; Berkey and Rice, 1919) and others a continuous section that is Paleozoic or partly Precambrian and partly Paleozoic (Dana, 1881; Stevens, 1867; Fluhr, 1950; Scotford, 1956; Prucha, 1956, 1959; Prucha, et al. 1968). On the other hand, still others have concluded that an unconformity separates the gneisses, which are considered Precambrian basement, from Lower Paleozoic cover rocks (Merrill 1890, 1896; Merrill et al., 1902; Balk, 1936; Hall, 1966, 1968b; Ratcliffe, 1968a,b).

The weight of the evidence, in the form of mapped relationships and geochronologic data, indicates that both Precambrian and Paleozoic rocks are present in the section. Truncation of various members of the Fordham Gneiss along the basal contact with the Lowerre Quartzite or the Inwood Marble (Plate 1) signals an unconformity between the Fordham Gneiss and overlying strata. This unconformity is interpreted to separate Precambrian rocks from Lower Paleozoic rocks (Hall 1966, 1968).

Fossil pelmatozoan fragments have been collected from the basal marble unit of the Walloomsac Formation near Peekskill and Tompkins Cove, New York (Ratcliffe and Knowles 1968), proving that part of the section elsewhere in the Manhattan Prong is Paleozoic. Geochronologic data indicate that the Fordham Gneiss is Grenvillian basement (Grauert and Hall, 1973) or older (Mose, 1982), that the Yonkers Gneiss is Late Precambrian or Avalonian (Long, 1969; Grauert and Hall, 1973; Mose and Hayes, 1975), and that the Manhattan Schist is Cambrian (Mose and Hall, 1979; Mose et al., 1979). In addition, other map relations point to the presence of an unconformity at the base of the Walloomsac Formation, which is interpreted to represent an erosional hiatus during the Middle Ordovician. Major regional thrust faults are interpreted to separate the Manhattan Schist from the autochthonous cover rocks along the Elmsford thrust and to separate the Hartland Formation from the Manhattan Schist along Cameron's Line (Plate 1).

Thus, the geologic history represented by the bedrock in the White Plains quadrangle is complicated and the interpretation of that history is problematical, as demonstrated by the different ideas generated by previous work. The rock units will be described systematically in accordance with the three major divisions identified above: (1) basement gneisses, (2) autochthonous cover rocks, and (3) allochthonous cover rocks.

### Basement gneisses

The Fordham Gneiss and the Yonkers Gneiss are the major rock units that constitute the basement gneisses in the area. Metamorphosed sedimentary rocks, as well as a fraction of probable metavolcanics, predominantly compose the Fordham Gneiss. Also included are igneous rocks that were likely produced by local melting during metamorphism, yielding migmatite and small plutons. The Yonkers Gneiss, on the other hand, consists almost entirely of biotite granitic gneiss with hornblende and, in places, garnet. Geochronologic data indicate that the Yonkers Gneiss is the younger of these two major basement rock units, and, although its geologic relationship to the Fordham is not clearly defined, it seems likely that it is intrusive. Even assuming

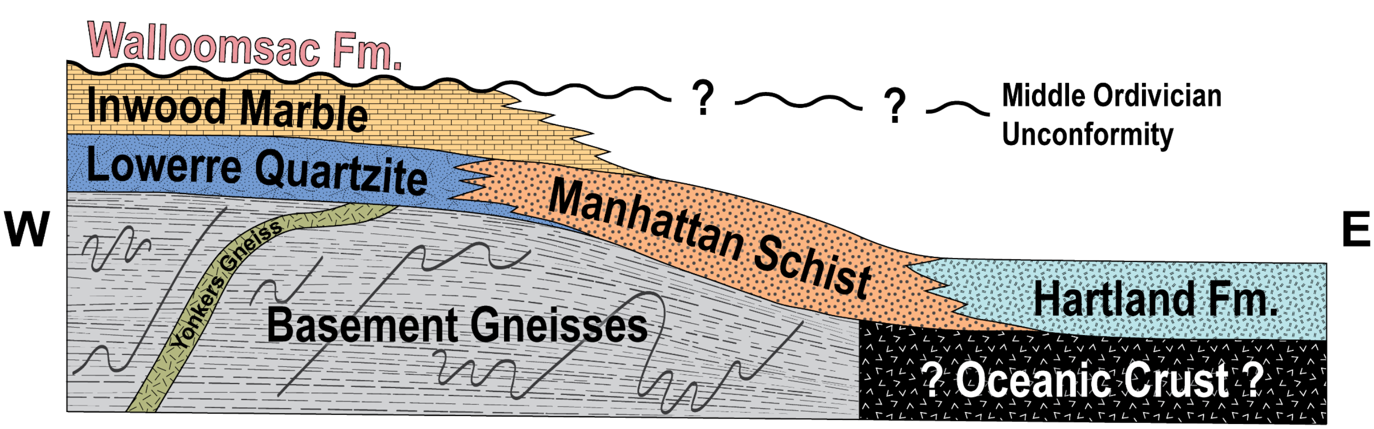


**Figure 2.** Diagrammatically restored stratigraphic section for southeastern New York and Connecticut.

that it is a metamorphosed intrusive igneous rock, it is known to lie within the Fordham Gneiss only in the White Plains quadrangle and thus is an integral part of the basement.

## *Fordham Gneiss*

Nearly all of the rocks within the Fordham Gneiss are gneisses of some kind. Various types are present, and it has been possible to group them into five mappable units in the western part of the quadrangle (Plate 1). The relative ages of these units are not known; they do occur in a sequential array, but the choice of oldest and youngest is essentially guesswork, so the sequence from oldest to youngest, as chosen, may be inverted. With this in mind, the five units in the assumed sequence from oldest to youngest are the Tarrytown Reservoir Unit, the Interchange 9 Unit, the East Irvington Unit, the Harriman Road Reservoir Unit, and the Childrens Village Unit.

Regions underlain by the Fordham elsewhere in the White Plains quadrangle are mapped simply as Fordham Gneiss. These parts of the Fordham are not divided into formal units, although lithic subdivisions are shown on the map (Plate 1). Unit names are not applied to these lithic subdivisions even though they are fairly extensive in the region north of the city of White Plains (Plate 1). The correlation of the rocks within terranes of stratigraphically undivided Fordham with the various units outlined above is uncertain.

### NAME

The term Fordham Gneiss was defined by Merrill (1890) to include all of the siliceous gneisses that are predominantly gray and typically exposed on the Fordham Heights in Bronx County, south of Westchester County. Merrill (1890) named the Fordham as a subdivision of the rocks that had previously been referred to as the Manhattan Group by Stevens (1867).

### DISTRIBUTION

Fordham Gneiss is the most widespread rock unit in the White Plains quadrangle, where it underlies five general regions (Plate 1). The most extensive terrane of Fordham, where it is subdivided into five units, is in the western part of the map area between the Saw Mill River Valley and the Hudson River. Two smaller zones of Fordham Gneiss occur near Thornwood and Greenville in the vicinity of the northern and southern edges of the quadrangle, respectively, with a third small area to the south between Central Park Avenue and the Bronx River Valley north of Edgemont High School. There is a fourth general locality in the southeast part of the White Plains quadrangle, where narrow linear zones of Fordham trend northeasterly into the Glenville quadrangle to the east. All of these regions of the Fordham Gneiss, excepting those in the vicinity of Thornwood and north of Edgemont High School, are continuous into the type locality in the Bronx.

### FORDHAM GNEISS, UNDIVIDED – (YF)

The Fordham Gneiss, undivided consists majorly of light gray to dark gray quartz-feldspar gneisses with numerous varietal minerals, of which biotite, hornblende, and garnet are most common. Most rocks are gray-weathering, with others brown- or rusty-weathering. These gneisses are typically bedded or layered, and in the places where layering is not obvious and the rocks appear compositionally massive, a foliation is well-displayed.

Lithic subdivisions are mappable within the “undivided” Fordham but have not yet been defined as formal units. These rocks are described here according to the general area in which they occur. Modes of selected samples of Fordham Gneiss, undivided are given in Tables 1 and 2 (a, b).

**Fordham Gneiss (Yf) SE of Central Park Avenue (Rte. 20)**

Exposures of Fordham Gneiss along the southeast side of Central Park Avenue near Hartsdale are characteristically well-layered and “slabby.” This belt of the Fordham Gneiss outcrops northwest of the Yonkers Gneiss and consists predominantly of gray to bluish-gray biotite-quartz-feldspar gneisses that locally contain graphite. Other rocks commonly present are dark gray to black biotite amphibolite (which is locally schistose or has a fissility apparently related to having been sheared); rusty-weathering, typically graphitic and pyritic(?) or pyrrhotitic(?) siliceous biotite gneiss, commonly with yellow sulfide staining on foliation surfaces; gray, siliceous biotite-feldspar-quartz gneiss or granulite (“quartzite”); relatively biotite-rich, fissile quartz-feldspar schist or schistose gneiss with graphite; gray biotite-hornblende gneiss; light gray to white granitic layers, typically with biotite and in variations that are locally pale pinkish in color; and pink granitic gneiss layers.

These rock types are interlayered with one another and with the predominant gray biotite-quartz-feldspar gneiss. The layers range typically between 2.5 cm to 0.6 m thick, but the most commonly observed thicknesses are 2.5 to 15 cm. All of the rocks are well-foliated as a result of preferred grain orientation and/or compositional layering related to biotite-rich and less-biotite-rich (dark and light) laminae. Locally there is a mylonitic foliation featuring prominent planar and linear alignment of mineral grains and an augen gneiss appearance with both euhedral and round white feldspar megacrysts in a dark gray to black (fine-grained?) biotite-rich matrix. Both of these types of mylonitic textures occur in thin zones parallel to the general foliation.

The slabbiness of the rocks in this area is due to a layering foliation related to differences in the abundance of biotite, as well as to the presence of 1 to 5 mm-thick white quartz-feldspar layers and to the repetition of rock types in thin layers. Layers of light gray to white granitic gneiss ranging from 1.3 to 15 cm in thickness, but typically 2.5 to 7.5 cm thick, also make the slabbiness and compositional layering particularly noticeable. This slabbiness is akin to textures in tectonic slides, and the local

**Table 1.** Estimated modes of rocks in the Fordham Gneiss, undivided in the vicinity of White Plains and Hartsdale.

| **General Location** | *Harrison to Scarsdale* | | | *Northwest of Silver Lake* | | | | *Northwest of the Bronx River Valley* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rock type** | Amphi-bolite | Calc-silicate rocks | | Gray layered gneiss | Biotite hornblende gneiss | | | Amphibolite | | | | | Biotite-quartz-feldspar gneiss | | Granite gneiss |
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
| Quartz | X | | 23 | 44 | 39 | 30 | 43 | 1 | 5 | X | 9 | X | 55 | 54 | 40 |
| Microcline | | 11 | 8 | | 3 | | | | X | | | | 6 | 8 | 26 |
| Plagioclase | 30 | 4 | 37 | 43 | 35 | 31 | 46 | 41 | 64 | 53 | 42 | 48 | 28 | 33[1] | 29 |
| Biotite | 1 | 19 | | 13 | X | X | 8 | | X | 15 | 2 | X | 10 | 4 | 1 |
| Garnet | | | | | | 4 | 1 | 1 | | | | | | | |
| Hornblende | 69 | 32 | 2 | | 17 | 34 | 1 | 46 | 28 | 32 | 47 | 52 | | | |
| Epidote | | | | | X | | X | | | | | X | | | |
| Diopside | | 34 | 29 | | | | | 8 | | | | | | | |
| Hypersthene | | | | | | | | 2 | | | | | | | |
| Muscovite[2] | | | | X | | | X | | | | | | 1 | 1 | 4 |
| Chlorite[2] | | | | X | 6 | X | 1 | | 3 | | | X | X | X | X |
| Calcite | | X | | | | X | X | | | | | | | | |
| Apatite | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| Sphene | X | | 1 | | X | | | | | X | X | X | | | |
| Allanite | | | | | | | | | | X | X | | X | X | |
| Zircon | X | X | X | X | X | X | X | | X | X | X | X | X | X | X |
| Tourmaline | | | X | | | | | | | | | | | | |
| Magnetite | X | | | | | | | | | | | | | | |
| Ilmenite | | | | | | | | | | | | X | | | |
| Pyrite | | X | X | | | | | | | | | | | | |
| Opaque | | | | X | | 1 | X | 1 | X | | X | | | | |
| An% of plagioclase determined by symmetrical extinction | $An_{48}$ | $An_{30}$ | $An_{36}$ | $An_{5}$ | $An_{39}$ | $An_{27}$ | $An_{37}$ | $An_{42}$ | $An_{30}$ | $An_{34}$ | $An_{37}$ | $An_{35}$ | $An_{25}$ | - | $An_{12}$ |

*Specimen descriptions can be found in Appendix 1.

[1]An% not determined.

[2]Muscovite and chlorite occur as secondary minerals after feldspar and biotite respectively.

**Table 2a.** Estimated modes of rocks in the Fordham Gneiss southeast of Kensico Reservoir and along strike to the southwest.

| **Map unit** | *Bedded gneisses* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Rock type** | Gray garnet-biotite gneiss | | | | Gray sillimanite-garnet-biotite gneiss | | Rusty-weathering sillimanite gneiss | Rusty-weathering hornblende-biotite gneiss | Hornblende-biotite gneiss | Amphibolite |
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| Quartz | 36 | 49 | 34 | 28 | 49 | 25 | 39 | 49 | 28 | 1 |
| Orthoclase | | | X | 30[1] | X | | | | | |
| Plagioclase | 36 | 35 | 45 | 27 | 17 | 21 | 32 | 39 | 60 | 48 |
| Biotite | 28 | 16 | 21 | 15 | 21 | 34 | 28 | 4 | 10 | 4 |
| Garnet | X | X | X | X | 13 | 8 | X | 7 | | |
| Sillimanite | | | | | X | 12 | 1 | | | |
| Kyanite | | | | | X | X | | | | |
| Hornblende | | | | | | | | 1 | 2 | 47 |
| Cummingtonite | | | | | | | | X | | |
| Augite | | | | | | | | | | |
| Hypersthene | | | | | | | | | | |
| Muscovite[2] | | | X | X | | X | | X | | |
| Chlorite[2] | | X | | | | | | X | | X |
| Apatite | X | | X | X | | | X | X | X | X |
| Sphene | | | | | | | | | X | X |
| Allanite | | | | X | | | | X | | |
| Zircon | | X | X | X | X | X | X | X | X | X |
| Rutile | | | | | | | X | | | |
| Pyrite | | | | | | | X | | | |
| Magnetite | | | | | | | | | | |
| Opaque | X | | | X | X | X | | X | X | X |
| An% of plagioclase determined by symmetrical extinction | $An_{29}$ | $An_{28}$ | $An_{30}$ | $An_{33}$ | $An_{28}$ | $An_{25}$ | $An_{33}$ | $An_{55}$ | $An_{33}$ | $An_{35}$ |

*Specimen descriptions can be found in Appendix 1.
[1]Microcline that displays grid twinning.
[2]Muscovite and chlorite occur as secondary minerals after feldspar and biotite respectively.

**Table 2b.** Estimated modes of rocks in the Fordham Gneiss southeast of Kensico Reservoir and along strike to the southwest.

| **Map unit** | *Garnetiferous gneisses* | | | | | *Biotite-hornblende gneisses* | | |
|---|---|---|---|---|---|---|---|---|
| **Rock type** | Gray garnetiferous gneiss | | | | Garnet-biotite-hornblende gneiss | Biotite-hornblende gneiss | Hornblende-biotite gneiss | Biotite gneiss |
| **Specimen*** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| Quartz | 36 | 38 | 38 | 37 | X | 13 | 54 | 58 |
| Orthoclase | | X | | | | | X | 1[1] |
| Plagioclase | 59 | 48 | 33 | 33 | 53 | 30 | 28 | 24 |
| Biotite | 3 | 12 | 26 | 24 | 4 | X | 16 | 17 |
| Garnet | 2 | 2 | 3 | 6 | 15 | | | |
| Sillimanite | | | | | | | | |
| Kyanite | | | | | | | | |
| Hornblende | | | | | 19 | 57 | 2 | |
| Cummingtonite | | | | | 4 | | | |
| Augite | | | | | 3 | | | |
| Hypersthene | | | | | 2 | | | |
| Muscovite[2] | | | | | | | | |
| Chlorite[2] | | X | | | | | | |
| Apatite | X | X | | X | X | X | X | X |
| Sphene | | | | | | | | |
| Allanite | | | | | | | | |
| Zircon | X | X | X | X | X | | X | X |
| Rutile | | | | | | | | |
| Pyrite | | | | | | | | |
| Magnetite | X | | | | | | | |
| Opaque | | X | | | | | | |
| An% of plagioclase determined by symmetrical extinction | $An_{30}$ | $An_{30}$ | $An_{30}$ | $An_{36}$ | $An_{38}$ | $An_{50}$ | $An_{26}$ | $An_{22}$ |

*Specimen descriptions can be found in Appendix 1.

[1]Microcline that displays grid twinning.

[2]Muscovite and chlorite occur as secondary minerals after feldspar and biotite respectively.

mylonitic textures, as well as platy fissility in some lithologies, are also indicative of shearing. Thus the Fordham Gneiss along the southeast side of Central Park Avenue apparently was either highly sheared in a tectonic slide zone or deformed by a mechanism of shearing during at least some of the Paleozoic folding.

**Fordham Gneiss (Yf) on the NW side of the Bronx River Valley**

These gneisses, generally layered, lie between Yonkers Gneiss to the northwest and Inwood Marble in the Bronx River Valley to the southeast. Southeast of Fenimore Road, the rocks are predominately biotite-quartz-feldspar gneisses that are interlayered or bedded and light gray to gray or bluish-gray in color. Locally they contain garnet which is typically pinhead size, although at times coarser. These gneisses are generally very well-foliated due to dimensional orientation of grains, and to thin compositional layers or laminae that consist of light gray, quartz-feldspar-rich bands separating darker gray regimes of biotite, quartz, and feldspar. The laminae are often 1 cm or less in thickness and typically 2 to 3 cm thick, although some can be as thick as 4 cm. The relative thicknesses of the light gray to dark gray laminae differ from rock to rock and are apparently a function of the bulk composition of any given gneiss bed. Thus bedding is probably expressed by the overall shade of gray of any given biotite-quartz-feldspar gneiss, and that shade of gray is a function of the relative thickness and abundance of light versus dark laminae.

In this zone, biotite amphibolite (locally with garnet); gray siliceous biotite gneiss; and gray biotite-hornblende-quartz-feldspar gneiss are interbedded with one another and with the gray biotite-quartz-feldspar gneisses described above. In places, exposures of Fordham Gneiss are dominated by interbedded gray biotite-quartz-feldspar gneiss with or without garnet and biotite amphibolite, along with subordinate layers of light gray biotite granitic gneiss that are parallel to bedding. Beds or layers in all of these gneisses are typically from 2.5 cm to 0.6 m in thickness, but thicknesses of 5 to 20 cm are most common. Light gray and pinkish gray biotite granitic gneiss layers, typically 5 to 25 cm thick but up to 2.4 m thick, are common and are subparallel to the bedding and foliation in the other gneisses. Also observed are pink biotite granitic gneiss layers, 7.5 to 10 cm in thickness, that are parallel to foliation and bedding and have a very similar look to Yonkers Gneiss. Light gray pegmatites that locally display good intrusive relations are present, although other pegmatites occur in layers parallel to bedding and foliation and are well-foliated themselves, giving the appearance of being highly sheared.

Along the lower portion of the valley side, such as in the rock cuts in the vicinity of the parking lot for the former Conrail station near Fenimore Road (Plate 1), occur rusty-weathering siliceous biotite gneisses and schistose gneisses, some with garnet, that locally contain graphite and commonly display yellow sulfide stains on foliation surfaces. These gneisses are interbedded with gray, siliceous biotite gneiss, gray biotite-hornblende-quartz-feldspar gneiss, and biotite amphibolite.

Most of the exposures along Aqueduct Road and the Conrail tracks south of Fenimore Road reveal rusty-weathering rocks as above interbedded with brown-weathering biotite-quartz-feldspar granulite and schistose granulite. The brown-weathering rocks commonly contain muscovite, which may well be a retrograde metamorphic product. Along Aqueduct Road the rusty-weathering rocks also interlayer with hornblende-bearing gneisses and foliated granitic gneiss and are clearly part of the Fordham Gneiss. However, along the Conrail tracks, the rusty-weathering schistose gneiss is interbedded with biotite quartzite and quartzite in layers 12 to 20 cm thick.

Although they are mapped as Yf (Plate 1), identification of the latter exposures as Fordham Gneiss is problematical. This is due to the presence of muscovite in many of the brown-weathering granulites and schistose rocks, which is not characteristic of the Fordham, and also to the interlayering of quartzite. Lowerre Quartzite has been mapped along the west side of the Bronx River Valley in the Mt. Vernon quadrangle to the south (Merrill et al. 1902). The tan to gray biotite-quartz-feldspar granulites with muscovite, as well as the quartzites and biotite quartzites, look much like the Lowerre Quartzite. In fact, in the Mt. Vernon quadrangle, these rocks occur in a railroad rock cut north of the railroad bridge over the Bronx River, about 600 m south of the White Plains quadrangle boundary. The rest of this exposure is biotite-quartz-feldspar gneiss, siliceous biotite gneiss, schistose biotite gneiss, garnet-biotite gneiss, and white granitic gneiss with a mylonitic foliation. These are all clearly Fordham. Thus the Fordham-Lowerre contact may be present in this Mt. Vernon railroad cut, although in the whole exposure, both natural and artificial, most of the rocks are Fordham and the sooty brown rock surfaces lead to identification trouble besides. Whatever the case, the rocks along the Conrail tracks and Aqueduct Road in the White Plains quadrangle are interpreted to be Fordham Gneiss.

Many of the exposures of Fordham Gneiss along the northwest side of the Bronx River Valley have a slabby, laminated, and highly sheared appearance. Planar surfaces prevail; there is little in the way of folds, although some may be observed. In a few places where the rock has apparently experienced greater shear, it is weathered into loose or friable slabs or plates a few millimeters thick. There are also a number of spots where the gneisses are siliceous and have mylonitic textures. Thus, whether or not they are within a tectonic slide zone, the rocks in this area also provide evidence for shearing during deformation.

**Fordham Gneiss (Yf) from Harrison to Scarsdale**

This zone includes the exposures of Fordham Gneiss that occur on the northwest and southeast sides of the Yonkers Gneiss in the southeastern part of the White Plains quadrangle (Plate 1). While poorly exposed for the most part, the rocks in this region are mainly light gray to dark gray biotite-quartz-feldspar gneisses that locally contain garnet. Rusty-weathering biotite-quartz-feldspar gneiss, commonly with lavender garnet, is a distinctive rock type found in parts of this zone, and pinkish-gray to light gray granitic gneiss layers are observed in many exposures throughout. Amphibolite and biotite-hornblende-quartz-feldspar gneiss are also present, and calc-silicate rocks appear locally. All exposures display well-foliated rocks, with well-bedded or -layered rocks common. A rock cut made for an office building and parking lot west of Bloomingdale Pond (on the west side of Bloomingdale Road) is the best exposure of the Fordham Gneiss in this southeastern region. Here, a wollastonite-bearing calc-silicate rock occurs beside a siliceous gneiss with a reaction zone between. The Yonkers Gneiss is also exposed in this cut, and its contacts with the Fordham Gneiss on either side are observable.

**Fordham Gneiss (Yf, Yfbh, Yfg) NW of Silver Lake**

This subdivision includes rocks in the Fordham Gneiss that extend from the eastern edge of the quadrangle near Silver Lake southwestward to the Bronx River Valley, where they are continuous with the gneisses described above. In this region, four lithic types have been mapped in the Fordham; they will be described from northwest to southeast. The northwesternmost of these rock types shares a contact with the Yonkers Gneiss to its northwest and is continuous with the undivided Fordham (Yf) detailed previously, which lies along strike to the southwest (Plate 1). These rocks are similar to those that fall along strike on the northwest side of the Bronx River Valley but are not as slabby or so highly sheared in appearance. Most are gray biotite-quartz-feldspar gneiss and biotite amphibolite with some gray hornblende-biotite-quartz-feldspar gneiss and biotite-rich schistose gneiss layers. All of them are interbedded, and in many places the gray biotite-quartz-feldspar gneiss beds are very well-foliated as a result of preferred grain orientation and the prominent interlamination of 1 mm- to 3 cm-thick white quartz-feldspar and dark gray biotite-quartz-feldspar laminae. Whether these rocks are dark or light gray is dependent upon the thickness of the dark gray laminae relative to the white laminae.

There is a mappable garnetiferous gneiss horizon (Yfg) within the layered gneisses (Plate 1). The prominent rocks in Yfg are light gray, siliceous, garnetiferous biotite-quartz-feldspar gneiss and light gray to white, "splotchy-looking," garnetiferous gneiss. The splotchy or streaky appearance of outcrop surfaces has led to the informal descriptive name of "leopard rock." On these surfaces, irregularly-shaped deep red to lavender garnets up to 7.5 cm long and rimmed by biotite are set into a white to colorless quartz-rich matrix that has very little feldspar. Other rocks interbedded with the above include biotite amphibolite; a biotite-rich black rock with prominent red garnet megacrysts; dark gray biotite-quartz-feldspar schistose gneiss with elongate, lenticular, quartz-rich segregations 0.5 to 5 cm thick that stand out as ribs on the outcrop surface; and also some quartzite beds. As a lithic unit, Yfg could be generally described as quartz-rich and garnetiferous. Several outcrops of this rock unit were found along the northwest side of the Bronx River Valley. It is there inferred to pinch out against the Inwood Marble contact, which may be a shear zone that developed along the unconformity between them (Plate 1).

A lithic unit that consists largely of biotite-hornblende-quartz-feldspar gneiss and light gray granitic gneiss is the next mappable unit to the southeast (Plate 1, Yfbh). The rocks of Yfbh have various amounts of biotite relative to hornblende and contain local garnet. They are typically well-foliated due to grain orientation and the interleaving of white quartz-feldspar laminae 1 to 5 mm thick with somewhat thicker, dark gray biotite-hornblende-quartz-feldspar layers. Light gray granitic gneiss layers, commonly 1.2 to 2.5 cm in thickness, are locally present and parallel to the foliation. Despite a good foliation, these rocks appear massive because of their homogeneity. The consistency is interrupted in places by layers of biotite amphibolite and gray biotite-quartz-feldspar gneiss.

Light gray granitic gneiss sheets are present throughout Yfbh and in some cases are continuous enough to be mapped (not shown on Plate 1). These granitic gneisses are biotite-bearing, and their foliation is the result of aligned concentrations of biotite 1 to 2 mm thick as well as grain shape alignment. This foliation is folded, and a second, faint foliation in oriented biotite grains is parallel to the axial planes of these folds.

The contact between this lithic unit and the Lowerre Quartzite is interpreted to be unconformable in nature. The unconformity and the Lowerre Quartzite, in turn, are interpreted to be truncated by a thrust fault that brings the biotite hornblende gneisses into contact with the layered gneisses that lie to the southeast.

The name "gray layered gneiss" is appropriate for the rock unit along the hillside northwest of Silver Lake (Plate 1, Yf). It is an interlayered assemblage of light gray hornblende-biotite gneiss with sparse garnet, dark gray biotite-hornblende gneiss, light gray biotite-quartz-feldspar gneiss, and biotite amphibolite. Locally the light gray hornblende-biotite gneiss has a beautiful black and white laminated foliation, which gives the outcrop surface a striped appearance. The layers of each rock type are typically 5 to 15 cm thick. In addition, within this lithic unit there are instances of gray biotite-quartz-feldspar gneiss that has a "wispy" appearance on the outcrop surface. This quality is the result of white quartz-feldspar layers 1.3 to 5 cm thick that are separated by biotite concentrations and "pinch and swell" structures, as well as intricate folding.

The portion of this unit near its southeastern edge, physically above but unconformably below the Lowerre Quartzite, comprises brown- to orange-brown-weathering biotite-quartz-feldspar gneiss and granulitic gneiss as well as hornblende-biotite-quartz-feldspar gneiss. Although it might possibly be mapped separately, it has not been separated because it is of limited extent. It is interbedded with the physically overlying well-layered gneisses which form layers 7.5 to 45 cm thick. The southeast contact of this unit is an unconformity below the Lowerre Quartzite, which is itself truncated by the unconformity beneath the Walloomsac Formation (Plate 1).

**Fordham Gneiss (Yf) associated with the Yonkers Gneiss**

A zone of Fordham-type gneisses approximately 1.8 km in length and 100 m in width occurs within the map area of the Yonkers Gneiss in the south-central part of the quadrangle near Scarsdale Country Club, southeast of Central Park Avenue (Plate 1). The rocks within are largely biotite amphibolite, gray to white biotite-quartz-feldspar gneiss, and brownish-weathering biotite-quartz-feldspar gneiss. A series of interbedded amphibolites and light gray to white, siliceous, garnetiferous feldspar-quartz granulites and granulitic gneisses is present along the northwest edge of the exposure that extends southward from a fairway at the country club into the Greenville area (not labeled on Plate 1). The amphibolite and siliceous, garnetiferous gneiss in this exposure occur in beds approximately 1.3 to 13 cm in thickness. In places the quartz-rich garnetiferous granulite is exceptionally rich in garnet; in those places the garnets occur either as aggregates or irregular poikilitic grains 0.6 to 1.3 cm across. The largest portion of the exposure is biotite amphibolite that locally includes numerous irregular aggregates of white biotite-quartz-feldspar lenses that commonly contain scattered garnet. These lenticular aggregates are typically 0.6 to 1.3 cm thick and can be up to 4 cm thick. They lie in the foliation but are discontinuous and highly folded. Other white quartz-feldspar layers contain green clinopyroxene rimmed by black hornblende as well as garnet. This whole area of the exposure looks very similar to the rocks in the Harriman Road Reservoir Unit of the Fordham Gneiss and may be equivalent to part of it.

Many of the rocks throughout this zone mapped as Fordham are pinkish granitic gneisses very similar to Yonkers Gneiss in appearance. If they are in fact directly related to the Yonkers Gneiss, this implies an intimate relationship with the associated Fordham-type gneisses. Such a relationship may be explained by intrusive igneous activity; structural repetition by folding and/or faulting; or original depositional repetition of felsic volcanics, mafic volcanics (biotite amphibolites), and clastic sediments. Of these possible explanations an intrusive igneous relationship is the most appealing, and in fact the entire outcrop area of Fordham Gneiss in this region could be explained as a large inclusion. The hypothesis of structural repetition is less appealing, although the rocks are folded and minor shear zones subparallel to the foliation are present locally. The hypothesis of interbedding is possible, but the Fordham-type gneisses involved would need to be significantly younger than the Fordham Gneiss itself if radiometric data indicate the true geologic ages of the Fordham and Yonkers Gneisses.

Two small lenses of Fordham Gneiss (Yf) have also been mapped within the outcrop area of Yonkers Gneiss southeast of the White Plains Reservoirs (Plate 1). Most of the rocks in either lens are biotite amphibolites that locally contain sparse garnets. Also present are some light gray granitic gneiss layers and a very minor amount of gray biotite-hornblende-quartz-feldspar gneiss. Both lenses are mapped as Fordham Gneiss but are predominately amphibolite. Amphibolites exist to a minor degree throughout the Yonkers Gneiss in the White Plains quadrangle. Furthermore, there are small outcrop areas of amphibolite elsewhere in the vicinity of the White Plains Reservoirs. These are all interpreted to be part of the Yonkers Gneiss and are not shown separately on the geologic map (Plate 1).

**Fordham Gneiss SE of the Kensico Reservoir (Table 2a, b)**

Fordham Gneiss (Yf, Yfbh, Yfg) in this area extends from the eastern edge of the quadrangle southwestward to connect with the Fordham Gneiss, undivided (Yf) southeast of Central Park Avenue (Plate 1). Three main lithic types have been mapped in six separate zones in the Fordham between the Kensico River and the Yonkers Gneiss. In rough order of occurrence from southeast to northwest, the mapped zones are: biotite-hornblende-quartz-feldspar gneiss (Yfbh, two areas), bedded gneisses (Yf), garnetiferous gneiss (Yfg), a reoccurrence of bedded gneisses, and a reoccurrence of biotite-hornblende-quartz-feldspar gneiss. If each lithic type with multiple appearances in fact represents a single stratigraphic unit that is structurally repeated, the garnetiferous gneiss must lie in the core of an early fold and the other units must be mirrored in its opposing limbs.

The gray garnetiferous gneiss (Yfg) lies physically within the bedded gneisses but has been mapped separately because of its distinctive appearance. The rocks of Yfg are characteristically gray on fresh and weathered surfaces alike and are relatively resistant to erosion, presumably because of their siliceous nature, in that they typically hold up low ridges. Most are gray garnet-biotite-quartz-feldspar gneiss, granulitic gneiss, or granulite with various ratios of quartz to feldspar, although a majority are notably siliceous and some are quartzites. Amphibolites, gray hornblende-biotite-quartz-feldspar gneiss, and biotite-hornblende-quartz-feldspar gneiss are also present; each of them may contain garnet in places.

The gray garnetiferous rocks differ from one another primarily in relative abundances of biotite, garnet, and quartz. Such differences permit the identification of bedding in places, but the gross similarities of the rocks and the common presence of relatively thick (up to 1.5 m) beds render this feature somewhat vague and difficult to recognize. Bedding becomes more obvious where beds are less than one foot in thickness, and commonly 5 to 20 cm thick, as this is also where very different rocks such as amphibolite or biotite-hornblende-quartz-feldspar gneiss are locally present.

The typical well- to moderately-foliated gray garnet-biotite-quartz-feldspar gneiss of this unit contains garnets that are generally 5 mm to 1 cm across and some up to 2 cm across. Many of the garnets are poikiloblastic, and those that are larger show obvious deformation and are flat and elongate in the foliation. In looking down or directly at some foliation surfaces, one sees 1 to 4 cm long patches of elongate black biotite that surround deep red garnet and yield a streaky appearance. Foliation in this rock type is commonly the result of discontinuous laminae 1 to 2 mm thick that are rich in biotite and separate light gray to colorless quartz-feldspar portions of the rock.

The gray granulitic gneisses, granulites, and quartzites in this region are less well-foliated than the garnetiferous gneisses because they include less biotite. Their foliation arises from the dimensional alignment of inequidimensional grains of strained quartz, feldspar, and garnet. Quartz-rich knots and lenses stand up in relief on weathered surfaces of both the gneisses and the granulites but are more common in the gray, massive, and siliceous gneisses. Although some biotite amphibolite can be found interbedded with the gneisses and granulites on a scale of approximately 30 cm, it also occurs in thick zones greater than 3 m across.

Light gray to white granitic gneisses with biotite are found in places as layers in the garnetiferous gneisses. In addition, light gray granitic gneiss is locally extensive in this unit and is mappable at a larger scale than 1:24,000. This granitic gneiss is moderately well-foliated and contains biotite as well as occasional scattered hornblende grains. Magnetite is also commonly present in small amounts.

The two zones of bedded gneisses (Yf) underlie the gray garnetiferous gneisses (Yfg) on opposite sides. The zone on the northwest side is continuous with the Fordham Gneiss near Central Park Avenue to the southwest (Plate 1). Areas of these bedded gneisses are fairly extensively underlain by biotite-quartz-feldspar gneiss and gray hornblende-biotite-quartz-feldspar gneiss. Brown-weathering biotite-quartz-feldspar gneiss and granulitic gneiss, as well as rusty-weathering biotite-quartz-feldspar gneiss and schistose gneiss, are also important and characteristic of this unit. Despite the importance of these brown- and rusty-weathering rocks, they are not present in all areas of surface exposure of this map unit and thus are not diagnostic of it everywhere. In fact, attempts to map the rusty-weathering rocks separately on large-scale maps have met with some success. With thicknesses of 0.6 m or less, bedding or layering is ordinarily thin enough to be seen in an average rock exposure, but in some places the rocks are homogeneous over several feet so that the bedding may not be perceptible. Most of the rocks are well-foliated subparallel to the bedding. Light gray to white granitic gneiss, commonly with biotite, is widespread in layers commonly several centimeters thick but up to several tens of centimeters thick. These light gray granitic gneiss layers are subparallel to the bedding and foliation and enhance the appearance of the bedding or layering in outcrops. Biotite-hornblende-quartz-feldspar gneiss and amphibolite are also present within the bedded gneisses. Some of these rocks contain garnet, as, in places, do all of the other rock types in this unit.

Lavender garnet can be observed in some of the rusty-weathering gneisses, and graphite and sillimanite can also be found locally. These gneisses frequently have yellow sulfide-stained foliation surfaces and tend to be deeply weathered so that exposures of friable rocks are commonplace. They are thus removed relatively easily by erosion and are not as well-exposed as the other rock types in the bedded gneiss unit. They tend to underlie topographically low areas in the places where they are not protected by a more resistant rock that physically overlies them and thus makes a low cliff. The common mode of exposure for these rusty-weathering rocks is rock cuts made in construction projects, although there are numerous natural exposures as well. Biotite amphibolite beds up to 30 cm thick are associated with the rusty-weathering gneisses. Bedding is also observed due to the presence of more siliceous, locally quartzitic beds up to 25 cm thick and gneissic beds.

The bedded gneisses also include brown-weathering biotite-quartz-feldspar gneiss and granulitic gneiss that commonly host lavender garnet. Both rock types also display quartz knots and layers that stand out in relief as ribs on weathered surfaces. Brown-weathering, light gray to white biotite-quartz-feldspar gneiss with garnet and weathering-resistant sillimanite nodules (up to 7.5 cm long) is a very distinctive rock type that makes limited appearances within the bedded gneiss unit. While brown-weathering, these rocks also locally exhibit red or maroon streaky stains on the exposure surfaces. In some places, generally where the rock is more biotite-rich, this maroon stain covers the rock surface and extends several centimeters into the rock as well.

Biotite amphibolite, locally with garnet, is interbedded with the brown-weathering gneisses in places. Also interbedded are 1.3 to 2 cm thick quartz layers that might either be quartzite or veins parallel to bedding. Gray biotite-quartz-feldspar gneiss, with irregular foliation emphasized by biotite concentrated in layers up to 0.6 cm thick, is gray-weathering in some places and brown-weathering in others. Red or maroon stains are common on outcrop surfaces. The irregularity of the foliation arises from the biotite-rich layers or laminae that are molded around intervening light gray quartz-feldspar layers, which tend to “pinch and swell” and form lobed and cusped shapes that yield a “wispy” appearance on the surface. Folding of the foliation clearly adds to its irregularity as well.

Also found in the bedded gneiss unit are gray biotite-quartz-feldspar gneiss, gray hornblende-biotite-quartz-feldspar gneiss, and gray biotite-hornblende-quartz-feldspar gneiss, all of which contain garnet in parts. Along with amphibolite, these gray gneisses are interbedded on a scale ranging between a few centimeters to several tens of centimeters. They often contain prominent layers of light gray granitic gneiss a few centimeters to several tens of centimeters in thickness. Some surfaces of these granitic layers are selectively stained brown or tan, while the intervening gneiss is gray. Light gray garnet-biotite-quartz-feldspar gneiss is locally developed and extremely-well foliated due to thin (1 to 2 mm thick) smooth planar laminae of dark biotite, quartz, and feldspar that separate light quartz-feldspar laminae. Dark gray biotite-quartz-feldspar gneiss with fine, very sparse “pinhead” garnet (<1 mm diameter) is interbedded with the other rock types in beds typically 5 to 20 cm thick.

Pinkish granitic gneisses here assigned to the Yonkers Gneiss contain biotite and, in some places, hornblende. They occur throughout the bedded gneiss unit and in several areas are extensive enough to be mapped separately at the scale of the geologic map (Zg, Plate 1). These granitic rocks are typically homogeneous and well- to moderately-foliated. The foliation generally arises from biotite concentrations in continuous or discontinuous laminae <1 to 2 mm in thickness. The laminae are typified by smooth planar layers of dark biotite, quartz, and feldspar that separate light quartz-feldspar layers. In some places, the granitic gneiss is prominently foliated because of pronounced grain-shape orientation.

Some or all of these granitic gneisses (Zg) may be septae of the Yonkers Gneiss (Zy) and some are clearly intrusive. Many of them have a very similar appearance to the Yonkers, and they are spatially related to it, possibly as intrusive or tectonically repeated sheets. The intimate physical relationship between these granitic gneisses and the Fordham, and their apparent genetic relationship to the Yonkers, suggest strongly that the Yonkers Gneiss is itself intrusive (Figure 2).

A biotite-hornblende-quartz-feldspar gneiss unit (Yfbh) is recognized in three areas southeast of Kensico Reservoir. Garnet, magnetite, or both phases may be observed in this unit. In the two zones where these gneisses are in contact with the Yonkers Gneiss, they are generally homogeneous but well-foliated over extensive areas and form somewhat rounded, massive exposures that typically shape low ridges. Gray hornblende-biotite-quartz-feldspar gneiss, biotite-quartz-feldspar gneiss, and amphibolite are also present here, but the rock typically does not have a bedded appearance and thus is apparently very thick-bedded. Beds are likely on the order of 2.4 to 4.5 m. Fairly well-foliated, light gray or white granitic gneiss layers of a few centimeters to a few tens of centimeters in thickness are commonly observed in parallel to the foliation in the gray hornblendic gneisses.

The characteristic rock in the zone along the shore of Kensico Reservoir and its extension to the southwest is a bluish-gray, homogeneous biotite-hornblende-quartz-feldspar gneiss with local sparse garnet and occasional magnetite. This gneiss is ordinarily well-foliated due to grain shape alignment, as well as to discontinuous dark biotite and hornblende-rich laminae 1 to 2 mm thick that are spaced at 2 to 5 mm. Light gray to white granitic quartz-feldspar layers 0.6 to 5 cm in thickness are parallel to and enhance the foliation. The unit in this zone is well-layered in places, for example to the immediate southwest of Kensico Dam. There, gray biotite-quartz-feldspar gneiss; amphibolite; and light gray, granitic quartz-feldspar gneiss are interlayered in layers 2.5 to 20 cm thick. Hornblende-biotite-quartz-feldspar gneiss, amphibolite, and biotite-hornblende-quartz feldspar gneiss are also interbedded in places, and the ubiquitous granitic gneiss layers are subparallel to bedding and foliation and enhance their appearance.

**Fordham Gneiss (Yf) W of Greenville**

Two units are mapped in this area, the first of which is mapped in the basement. The second unit is a pinkish biotite-quartz-feldspar gneiss of granitic composition here mapped as Yonkers Gneiss (Zy). In a number of localities this granitic gneiss hosts scattered garnets, and layers of amphibolite 5 to 60 cm in thickness are also present with it. The rock looks generally similar to much of the Yonkers Gneiss but has not been mapped into areas of known Yonkers, and a correlation between the two based on appearance is highly tenuous.

Gray biotite-quartz-feldspar gneiss (Yf) is characteristic of the second lithic unit in this area. Garnet-biotite-quartz-feldspar gneiss and hornblende-biotite-quartz-feldspar gneiss can also be found here among other gneisses, commonly gray. Foliation is typically well-developed in these rocks and in many places thin layers are a prominent feature. White granitic gneiss layers are subparallel to the foliation and enhance the foliated and layered nature of the rock.

**Fordham Gneiss in Thornwood (Yf)**

The most abundant rock types in the Fordham at Thornwood are gray biotite-quartz-feldspar gneiss and light gray to dark gray biotite-hornblende-quartz-feldspar gneiss. These gneisses are commonly associated with pinkish or white granitic gneiss layers. Other notable rock types found here include pink to pinkish-gray biotite-quartz-feldspar gneiss, biotite amphibolite (locally with garnet), hornblende-biotite-quartz-feldspar gneiss, and garnetiferous biotite-quartz-feldspar gneiss.

## Subdivisions of the Fordham Gneiss

Five major units and two variations of these units have been mapped within the main belt of Fordham Gneiss on the western part of the map.

**Tarrytown Reservoir Unit (Yft, Yfta)**

The Tarrytown Reservoir Unit has previously been referred to as Member E of the Fordham Gneiss (Hall, 1968b) and is here named for typical exposures in the vicinity of the Tarrytown Reservoir (Plate 1). Rocks included within this unit underlie the region that extends northeastward from the Hudson River south of the Tappan Zee Bridge to the Tarrytown Reservoir and Eastview. They occupy the axial region of a complex refolded fold and thus follow an irregular map pattern from the reservoir area. One part extends northward beneath Kykuit Hill to Beech Hill Pond, and a second follows the eastern side of the Pocantico River Valley. A third part, disconnected from the others on the map, extends from the east side of Beaver Hill southwestward to the vicinity of East Irvington (Plate 1). A smaller zone underlain by this unit is found near the Saw Mill River Parkway and Route 119, and another reaches northeastward from the eastern side of Buttermilk Hill to the northern edge of the map.

A biotite-quartz-feldspar augen gneiss (Yfta) has been mapped separately as a lithic unit within this subdivision of the Fordham (Plate 1). This augen gneiss extends southwestward from the vicinity of the reservoir to end at the hill west of

Hackley School. Modes for selected samples from the Tarrytown Reservoir Unit are given in Table 3.

Layered or bedded gneisses are common within the Tarrytown Reservoir Unit. The most abundant rock types within this subdivision of the Fordham are gray biotite-quartz-feldspar gneiss, often with garnet; gray hornblende-biotite-quartz-feldspar gneiss; biotite-hornblende-quartz-feldspar gneiss; and biotite amphibolite. While garnet occurs with frequency in all of these rock types it is not found at every locality. The rocks of this unit are commonly brown-weathering. Outcrop surfaces are usually brown or gray, with red or maroon stains in places that might extend several inches into the rock. The staining makes mineral identification difficult.

Pinkish-gray, gray, or white granitic gneiss, typically bearing biotite and sometimes bearing hornblende, commonly occurs as layers several centimeters to several tens of centimeters thick within the other gneisses of this unit. A gray, siliceous, garnetiferous biotite-quartz-feldspar gneiss with "pinhead" garnets less than one millimeter in diameter can be found locally in zones several meters across. These gneisses have tannish-gray-weathering surfaces and commonly host light gray granitic gneiss layers a few centimeters in thickness. A sillimanite-rich garnet-biotite-quartz-feldspar gneiss is an unusual rock type that occurs in multiple exposures of the Tarrytown Reservoir Unit west of the New York Thruway and east of Taxter Road.

All of the rock types within the Tarrytown Reservoir Unit are generally well-foliated. The foliation arises from preferred shape alignment of grains and from interlayered compositional laminae that are dark gray or light gray depending on biotite and/or hornblende content. Some of the garnet-biotite gneisses have a "wispy" foliation resulting from dark, 2 to 3 mm-thick, irregular layers of biotite.

The biotite-quartz-feldspar augen gneiss (Yfta) is a relatively homogeneous gray, pinkish-gray, or pink gneiss with feldspar augen that are often 1 to 2.5 cm across. The augen are microcline or microperthite for the most part, although plagioclase porphyroblasts are also present to a lesser degree. A flaser texture is fairly commonplace, but many of the granular zones of augen have single crystal cores. Garnet is a typical phase within this gneiss, and muscovite has been identified in a number of places. Several small abandoned rock quarries are found in the area underlain by the augen gneiss, apparently a reflection of past attempts to use it as building stone. Although the rock is overall homogeneous, it does host layers of gray biotite-quartz-feldspar gneiss and lesser amphibolite. Estimated modes for samples of these augen gneisses are reported in Table 4.

**Interchange 9 Unit (Yfi)**

This unit of the Fordham Gneiss has previously been referred to as Member D (Hall, 1968b) and is here named for typical exposures in the vicinity of Interchange 9 on the New York Thruway, about 1 km southeast of the Tappan Zee Bridge (Plate 1). Other favorable and more readily-accessible exposures of this member occur within its outcrop area in Tarrytown along the streets 100 to 200 m east of Irving Junior High School. The Interchange 9 Unit has a complicated map pattern that outlines a large refolded fold in the Fordham Gneiss terrane in the western part of the quadrangle (Plate 1). It is found between the Tarrytown Reservoir and East Irvington Units of the Fordham Gneiss but is missing in places due to either non-deposition or tectonic thinning. It also outlines the fold that extends northeastward from the eastern side of Buttermilk Hill and occurs in a small zone between the Tarrytown Reservoir and East Irvington Units south of Beaver Hill.

Rusty-weathering biotite-quartz-feldspar gneiss and schistose gneiss are characteristic of the Interchange 9 Unit. Lavender garnet and sillimanite, the latter of which can occur as nodules, are common minerals in these rusty-weathering rocks. In places graphite is a prominent accessory mineral, and the rusty nature of the gneisses and schistose gneisses is presumed to result from the weathering of pyrrhotite. Biotite quartzite, feldspathic quartzite, and biotite-quartz-feldspar granulite, all of which may contain garnet, are commonly interbedded with the schistose gneisses. These rock types exhibit rusty staining along foliation and fracture surfaces. Outcrop surfaces of the rusty-weathering gneisses and, particularly, the schistose gneisses are reduced by the elements to loose, friable masses.

Gray garnet-biotite-quartz-feldspar gneiss is locally present in the Interchange 9 member of the Fordham, is are brown-weathering garnet-biotite-quartz-feldspar gneiss. In the roadcuts along Route 117 on the east side of Gory Brook, white calcite marble; brown-weathering, phlogopitic calcareous gneiss or "dirty" calcite marble; and very well-foliated, micaceous calcite marble that appears to be highly sheared are observed. The marbles are known only in the roadcut at this locality but may be present beneath Pleistocene or recent cover (Qc) elsewhere in the quadrangle. Table 5 lists modes of samples of various lithologies from the Interchange 9 Unit.

**East Irvington Unit (Yfei, Yfeip)**

This is the most widespread unit of the Fordham Gneiss in the western part of the White Plains quadrangle. It was formerly referred to as Member C (Hall, 1968b) and is here named for typical exposures in the vicinity of East Irvington. This unit is observed across a large area centered upon East Irvington. It is also present east of the Hudson River at Tarrytown, where it stretches along the complicated fold pattern northward and eastward to the hills on the western side of the Saw Mill River Valley.

Although other rock types are widely represented, a homogeneous gray biotite-hornblende-quartz-plagioclase gneiss, commonly with pale green to yellowish epidote, is characteristic of the East Irvington Unit (Table 6). There is a tendency for these rocks to appear in massive exposures and also to form low cliffs, 3 to 9 m in height, where the foliation dips steeply. Above low cliffs and in areas of low relief, the exposures tend to be smooth and somewhat rounded, presumably the result of glacial scour.

**Table 3.** Estimated modes of rocks in the Tarrytown Reservoir Unit of the Fordham Gneiss.

| Rock type | Garnet-biotite gneisses | | | | Aluminosilicate-bearing gneisses | | | Amphibolite | | Hornblende and/or pyroxene gneisses | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
| Quartz | 39 | 32 | 39 | 23 | 53 | 52 | 49 | 3 | | 13 | 33 | 23 | 37 | 44 | 31 |
| Microcline | 29[1] | X | | | | | X | | | | | | | X | 7[2] |
| Plagioclase | 31 | 36 | 48 | 43 | 4 | 12 | 26 | 37 | 38 | 45 | 47 | 41 | 51 | 50 | 26 |
| Biotite | 30 | 1 | 11 | 25 | X | 34 | 19 | 8 | X | 22 | 10 | | | | 3 |
| Garnet | X | X | 2 | 9 | X | X | 5 | | X | | 1 | 9 | | X | 7 |
| Staurolite | | | | | X | | | | | | | | | | |
| Kyanite | | | | | 6 | | X | | | | | | | | |
| Sillimanite | | | | | 34 | 2 | | | | | | | | | |
| Hornblende | X | | | | | | | 45 | 14 | | 9 | 19 | 6 | 3 | 24 |
| Cummingtonite | | | | | | | | | 27 | 1 | | | | | |
| Epidote | | | X | | | | | | | | X | 5 | 1 | 3 | |
| Augite | | | | | | | | 7 | | | | 3 | 4 | | X |
| Hypersthene | | | | | | | | | | 19 | | | | | |
| Muscovite[3] | | 2 | | | X | X | | | | | | | | | |
| Chlorite[3] | | | | X | | | | | | | | | | | |
| Apatite | X | | X | X | X | | X | X | X | X | X | X | X | X | X |
| Sphene | | | | | | | | X | | | X | X | X | X | X |
| Allanite | X | | X | | | X | | X | | | X | | X | | X |
| Zircon | X | X | | X | X | X | X | X | | X | X | X | X | X | X |
| Ilmenite | | | | X | | | | | | | | X | | | X |
| Magnetite | | | | | 3 | | | | 1 | | | | 1 | | |
| Hematite | | | X | | | | | | | | | | | | X |
| Graphite | | | | | | | 1 | | | | | | | | |
| Pyrite | | | | | | | | | X | | | | X | | |
| Pyrrhotite | | | | | | | X | | | | | | | | |
| Opaque | X | | | | | | | | | | | | | | |
| An% of plagioclase determined by symmetrical extinction | $An_{43}$ | $An_{19}$ | $An_{32}$ | $An_{44}$ | $An_{24}$ | $An_{26}$ | $An_{43}$ | $An_{34}$ | $An_{55}$ | $An_{48}$ | $An_{34}$ | $An_{48}$ | $An_{34}$ | $An_{27}$ | $An_{33}$ |

*Specimen descriptions can be found in Appendix 1.
[1]Perthite.
[2]Orthoclase that is perthitic.
[3]Muscovite and chlorite occur as secondary minerals.

Pink to pinkish-gray biotite-quartz-feldspar granitic gneiss is widespread in the East Irvington Unit and can be mapped separately in places (Yfeip), but a larger-scale map would be needed to do this successfully. At numerous localities, however, these granitic gneisses are too intimately associated with the other gneisses of the unit to be mapped separately. With their pinkish color, they are similar to the Yonkers Gneiss in appearance. A number of abandoned quarries are present in areas where the granitic gneisses are exposed; some of them are fairly large in size and attest to successful use of this rock as a building stone. Aleinikoff (1985) reports that euhedral zircons from biotite granite gneiss yield U-Pb upper intercept ages of 1170 Ma (million years). This age is regarded by Aleinikoff (1985) as a minimum age for the East Irvington Unit of the Fordham Gneiss.

In many places, thin layers of pinkish or light gray to white granitic gneiss with biotite and/or hornblende occur subparallel to foliation within the biotite-hornblende-quartz-plagioclase gneisses and constitute 20 to 30% of the rock. The rock is a good migmatite in such places, and certain exposures of this migmatite display very fine fold-interference patterns. The thin granitic layers also occur as lenses in small shear zones along the short limbs of asymmetrical folds in the migmatitic gneisses. The presence of mafic selvages along the edges of the granitic layers allows the inference that they developed as a result of local partial melting during metamorphism.

Black to greenish-black biotite amphibolites and bluish gray, light gray-weathering biotite-hornblende-quartz-plagioclase gneiss are very common in the East Irvington Unit of the Fordham, and gray biotite-quartz-feldspar gneiss is also observed in places. Additional rock types are unusual, although gray garnet-biotite-quartz-feldspar gneiss and brown- to rusty brown-weathering biotite-quartz-feldspar gneiss are sometimes encountered. Augite, typically rimmed by hornblende, has been identified in many of the biotite-hornblende-quartz-plagioclase gneisses. Sphene is another common phase and occurs as both rims on magnetite and as discrete grains. Apatite, also a typical accessory mineral, can be identified in certain hand specimens. Calcite manifests in some specimens as discrete grains and fine veins. The occurrence of calcic plagioclase, epidote, hornblende, augite, sphene, calcite, and apatite within the biotite-hornblende gneisses is an indication that they are relatively rich in calcium. It is inferred from this characteristic that the sedimentary parent rock was a calcareous graywacke of some kind.

**Harriman Road Reservoir Unit (Yfh)**

This unit has previously been referred to as Member B of the Fordham Gneiss (Hall, 1968b). It is here named the Harriman Road Reservoir Unit after typical exposures at the eastern end and to the south of this reservoir (Plate 1). It underlies areas on opposing limbs of a fold and extends south from the reservoir to the southern edge of the quadrangle. It apparently also extends northeastward from the Hudson River at Philipse Manor to the northern edge of the quadrangle, although the rocks here are not identical to those near the reservoir. Modes of samples from the Harriman Road Reservoir Unit are reported in Table 7.

Within the vicinity of the reservoir and to the south, the Harriman Road Reservoir Unit is characterized by gray, silicious, and garnetiferous gneisses and dark gray to black or greenish-black amphibolites. In the northern part of the quadrangle, brown-weathering garnetiferous gneisses, amphibolites, and calc-silicate rocks are common in this member of the Fordham.

**Table 4.** Estimated modes of augen gneisses in the Tarrytown Reservoir Unit of the Fordham Gneiss.

| Rock type | Augen gneiss unit shown separately on geologic map | | | | Other augen gneisses | |
|---|---|---|---|---|---|---|
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** |
| Quartz | 36 | 33 | 27 | 11 | 28 | 29 |
| Microcline | 24[1] | 23 | 27 | 44[1] | 28[1] | 19[1] |
| Plagioclase | 27 | 38 | 33[2] | 38 | 32 | 48 |
| Muscovite[3] | | X | | X | X | X |
| Biotite | 13 | 6 | 13 | 6 | 12 | 4 |
| Garnet | | | | 1 | | |
| Apatite | X | X | X | X | X | X |
| Sphene | | X | | | | |
| Allanite | X | X | | | X | |
| Zircon | X | X | X | X | X | X |
| An% of plagioclase determined by symmetrical extinction | $An_{24}$ | $An_{26}$ | - | $An_{18}$ | $An_{24}$ | $An_{24}$ |

*Specimen descriptions can be found in Appendix 1.
[1]Microcline grains are microperthitic.
[2]Oligoclase, estimated on the basis of optic sign and relief.
[3]Muscovite is secondary.

**Table 5.** Estimated modes of the Interchange 9 Unit of the Fordham Gneiss.

| **Rock type** | Rusty-weathering gneiss | | | | | | | Gray-weathering gneiss | | | Quartzite | Mylonitic schistose gneisses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| Quartz | 41 | 40 | 46 | 34 | 50 | 48 | 32 | 25 | 28 | 39 | 76 | 32 | 34 | 55 |
| Orthoclase | | 2[1] | 1[1] | | X | 2[2] | | | | 36[1,2] | | 1[1] | | |
| Plagioclase | 27 | 30 | 9 | 20 | 3 | 20 | 13 | 2 | 38 | 24 | 6 | | | 10[3] |
| Biotite | 29 | 22 | 23 | 23 | 10 | 26 | 46 | 40 | 17 | X | 1 | 56 | | |
| Garnet | 3 | 2 | 19 | 23 | X | X | 9 | | 14 | | | 6 | 1 | X |
| Sillimanite | X | 3 | 2 | X[4] | 2 | 4 | X[4] | X[4] | X | X | 17 | 4 | X[5] | |
| Muscovite[6] | | | | | 35 | X | X | 33 | | 1 | X | 1 | 52 | 35 |
| Chlorite[6] | | | | | | | | | | | | | 13 | |
| Sphene | | X | | | | | | | | | | | | |
| Tourmaline | | X | | | X | | | | | | | X | | |
| Apatite | | | | X | X | | X | | X | | | X | X | X |
| Zircon | X | | X | X | X | X | X | X | X | X | X | X | X | X |
| Graphite | X | | X | | X | | X | X | | | | | X | |
| Magnetite | | | | | | | | | 3 | | | | | |
| Hematite | X | | X | | | | | | X | | | | | |
| Ilmenite | | | | | | | | | | | | | X | |
| Pyrite | | | | | | | | | | X | | | | |
| Pyrrhotite | X | | X | | | X | | | | | | | | |
| Opaque | | | | X | | | | | | X | | | | |
| An% of plagioclase determined by symmetrical extinction | $An_{30}$ | $An_{29}$ | $An_{47}$ | $An_{33}$ | $An_{31}$ | $An_{23}$ | $An_{28}$ | $An_{37}$ | $An_{50}$ | $An_{28}$ | $An_{33}$ | - | - | - |

*Specimen descriptions can be found in Appendix 1.
[1]Microperthitic.
[2]Potassium feldspar is microcline.
[3]Highly altered.
[4]Fibrolite.
[5]Retrograded to fine white mica.
[6]Muscovite and chlorite are secondary.

**Table 6.** Estimated modes of rocks in the East Irvington Unit of the Fordham Gneiss.

| **Rock type** | Biotite-hornblende gneiss | | | | | | | | | | Pyroxene-biotite hornblende gneiss | | | Amphibolite | Granitic gneisses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
| Quartz | 17 | 16 | 47 | 4 | 8 | 2 | 8 | 28 | 32 | 26 | 19 | 20 | 20 | 3 | 39 | 20 | 38 |
| Microcline | | 6 | | | | | | X[1] | 2 | | 8[1,2] | X[1] | 31[1,2] | | 31 | 40[1] | 37 |
| Plagioclase | 40 | 68[3] | 31 | 53 | 79 | 73 | 60 | 54 | 46 | 48 | 60 | 41 | 36 | 45 | 21 | 38 | 21[4] |
| Biotite | | 7 | 3 | 5 | 1 | 4 | 4 | 8 | 9 | 15 | 4 | 17 | 1 | | 9 | 2 | 4 |
| Garnet | | | 2 | 2 | | | | | | | | | | | | | |
| Hornblende | 15 | 3 | 17 | 36 | 12 | 21 | 28 | 10 | 10 | 8 | 9 | 21 | 1 | 52 | | | |
| Augite | | | | | | | | | | | X[5] | 1[5] | 11[6] | | | | |
| Hypersthene | | | | | | | | | | | | | X | | | | |
| Epidote | 20 | X | | | X | | X | X | 1 | 3 | X | | | | | | |
| Muscovite[7] | | | | | | | | | | | | | | | | X | |
| Chlorite[7] | | | | | | | | | | | | | | X | X | | |
| Calcite | | | | | | | | | X | | | X | | | | | X |
| Sphene | 2 | X | X | | X | X | X | X | X | X | X | X | | | X | X | X |
| Apatite | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Allanite | | | | | | | X | | | | | X | | | X | | X |
| Zircon | | X | X | X | | X | | X | X | | | X | X | | X | X | X |
| Magnetite | 6 | | | | X | | | | | | | | X | | | X | |
| Ilmenite | | | X | | | X | X | | | | | | | | X | | |
| Opaque | | | | X | | | | | | | X | | | X | | | X |
| An% of plagioclase determined by symmetrical extinction | $An_{46}$ | - | $An_{43}$ | $An_{30}$ | $An_{28}$ | $An_{32}$ | $An_{31}$ | $An_{29}$ | $An_{25}$ | $An_{31}$ | $An_{20}$ | $An_{26}$ | $An_{23}$ | $An_{42}$ | $An_{15}$ | $An_{19}$ | - |

*Specimen descriptions can be found in Appendix 1.
[1]Orthoclase is the potassium feldspar.
[2]Perthitic.
[3]An% not determined due to alteration.
[4]Estimated to be oligoclase by relief.
[5]Rimmed by hornblende.
[6]Has metamorphic exsolution lamellae.
[7]Muscovite and chlorite are secondary minerals.

**Table 7.** Estimated modes of rocks in the Harriman Reservoir Road Unit of the Fordham Gneiss.

| **Rock type** | Garnetiferous gneisses | | | | | | Hornblende gneiss | Amphibolite | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
| Quartz | 12 | 24 | 52 | 51 | 2 | 58 | 2 | | X | 5 | 6 |
| Orthoclase | 18[1] | 12[1] | | | | | | | | | |
| Plagioclase | 40 | 46 | 39 | 30 | 11 | 29 | 61 | 27 | 39 | 30[2] | 53 |
| Biotite | 22 | 16 | 9 | 17 | 16 | 11 | | X | X | | |
| Garnet | 8 | 2 | X | 2 | 63 | 2 | 16 | | | | 4 |
| Sillimanite | | | | | 8 | | | | | | |
| Muscovite[3] | | | X | X | X | X | | | | | |
| Chlorite[3] | | | X | X | X | | | | 10 | X | |
| Hornblende | | | | | | | 12 | 43 | 51 | 62 | 36 |
| Augite | | | | | | | 9 | 30 | | 1 | X |
| Epidote | | | | | | | | X | X | 2 | X |
| Calcite | | | | | | | | | | X | |
| Apatite | X | X | X | X | X | | X | X | X | X | X |
| Sphene | | | X | | | | X | X | X | | X |
| Allanite | | | | | | | | | X | | |
| Zircon | X | X | X | X | X | X | | | X | | |
| Ilmenite | | | | | | | X | | | | 1 |
| Magnetite | | | | | X | X | | | | X | |
| Opaque | | X | X | X | | | | | | | |
| An% of plagioclase determined by symmetrical extinction | $An_{30}$ | $An_{30}$ | $An_{28}$ | $An_{31}$ | $An_{35}$ | $An_{30}$ | $An_{37}$ | $An_{38}$ | $An_{31}$ | $An_{71}$ | $An_{43}$ |

*Specimen descriptions can be found in Appendix 1.
[1]Microperthite.
[2]Huttenlocher intergrowths present.
[3]Muscovite and chlorite are secondary.

While the gray, siliceous, and garnetiferous gneisses are varied in modal mineral abundances, they are typically exposed in rounded outcrops that have been molded by glacial erosion. Some of these gneisses display eye-catching poikilitic garnets that measure up to 15 cm in the long dimension, many of which have evidently been flattened and elongated parallel to the plane of prominent foliation. Quartz is the most common inclusion within these garnets, but biotite, sillimanite, and opaque minerals are included as well. Garnets also occur as segregations in quartz-feldspar zones that partially or completely surround them. The garnet here is typically rimmed by biotite. Some quartz-feldspar zones, however, do not contain garnet at all, at least not to be observed upon the two-dimensional outcrop surface. Many of the quartz-feldspar zones occur as layers parallel to the prominent foliation and may well reflect initial compositional differences related to bedding. The layers rich in quartz and feldspar range between 15 cm to 0.9 m thick and are interlayered with gray garnet-biotite-quartz-feldspar gneiss that has disseminated garnet. Both the quartz-feldspar layers and gray gneisses may contain hornblende and pyroxene. Apparently as a result of a retrograde hydration reaction, many of the pyroxene grains are rimmed by hornblende.

Light gray to gray, moderately well-foliated biotite-quartz feldspar gneiss and gray, siliceous garnet-biotite-quartz-feldspar gneiss locally contain muscovite-rich aggregates or knots that stand out in relief upon weathered outcrop surfaces. These features are very likely representative of retrograded sillimanite nodules. Magnetite is present in some of the gray gneisses and was observed in grains and clots up to 2 cm across. Quartzites and quartz-rich garnet-biotite-feldspar granulites are also found within this unit, as well as gray to dark gray biotite-quartz-feldspar gneiss. The latter hosts some garnet, and exhibits prominent quartz knots, segregations, and lenses that attain positive relief on weathered surfaces. The lenses, which stand out as ribs on a weathered outcrop, are typically 3 to 6 mm thick and 0.3 to 0.6 m long.

The gray, siliceous garnet-biotite-quartz-feldspar gneiss is typically well-foliated due to parallel white quartz-feldspar-rich laminae 3 mm to 1 cm thick and gray, siliceous, garnet-bearing layers 2 mm to 2 cm thick. A wavy foliation has developed in some of the coarse garnet-bearing gneisses and results from the distortion of garnets and associated biotite, which partially rims the garnets. Bedding is fairly well displayed by these gray gneisses. Beds are commonly from 5 cm to 1.2 m thick and are brought out by differences in the abundance of biotite, garnet, and quartz.

Well-foliated, dark gray to greenish-black biotite amphibolites are prominent in the Harriman Road Reservoir Unit and can locally be mapped separately, as in the vicinity of the Harriman Road Reservoir (Hall, 1968b). However, since these mappable horizons apparently do not persist throughout the area, they are not defined on the geologic map (Plate 1). Some of the amphibolites may represent metamorphosed calcareous rocks, and others metamorphosed volcanics. Clinopyroxene can be found in many of these amphibolites, and orthopyroxene, garnet, and epidote in certain examples.

Homogeneous, well-foliated pyroxene-biotite amphibolites and biotite amphibolites occur in layers up to 3 m in thickness and contain blotchy segregations rich in coarse black hornblende, with some clinopyroxene. The hornblende-rich blotches may be concentrations resulting from the removal of felsic minerals by local partial melting. Most of these amphibolites are composed primarily of clinopyroxenes, epidote, biotite, hornblende, and plagioclase, although the abundances of each mineral differs and compositional layering has resulted at numerous localities.

Some instances of this compositional layering are very likely related to metamorphic differentiation, and some to bedding. An example of the latter manifests in varied feldspar and clinopyroxene content, relatively higher abundances of which impart a light gray or greenish hue respectively upon the amphibolite. Locally, rocks containing a profusion of green clinopyroxene are interlayered with light gray clinopyroxene-feldspar granulites that are probably metamorphosed sedimentary rocks. Dark gray biotite-hornblende gneiss is also associated with the amphibolites, and these rock types can be subjectively distinguished in the field by the greater abundance of hornblende in the amphibolite. White feldspar-rich segregations, some of which are coarse-grained, are present in lenses parallel to foliation and contain prominent garnet and hornblende-rimmed clinopyroxene. In some segregations, clinopyroxene- and hornblende-rimmed orthopyroxene is also observed. The various amphibolitic rocks are interbedded, and the thickness of beds ranges between 7 cm to 3 m. The gray siliceous garnet-biotite gneisses, amphibolites with local garnet and/or clinopyroxene, and biotite-hornblende gneisses are frequently layered together as well. Thus, for all of these characteristics, the original sedimentary rocks were evidently compositionally gradational.

In the northwestern portion of the map, brown- and rusty-weathering rocks are conspicuous in the Harriman Road Reservoir Unit, but various gray gneisses and dark gray amphibolites are also observed. The interlayering of these varied rock types makes bedding apparent in many exposures. Blue-gray to gray garnet-biotite-quartz-feldspar gneiss and gray biotite-quartz-feldspar gneiss are common in this portion of the unit. Many exposures display brown- or rusty-weathering surfaces, although gray-weathering surfaces are also present. The garnets in some of these gneisses are flat and elongate in the foliation (up to 5 cm in the long dimension) and are very coarse in places. In other gneisses the garnets are fine and disseminated. Also within this unit are rusty-weathering garnet-biotite-quartz-feldspar ± sillimanite gneisses and schistose gneisses that present prominent yellow sulfide-stained foliation surfaces.

Dark gray biotite amphibolite that contains local pyroxene and garnet is another common rock type within the Harriman Reservoir Road Unit, and these lithologies also display brown- to rusty-weathering outcrop surfaces or streaky-brown outcrop surfaces in places. Gray biotite-quartz-feldspar gneiss, gray biotite-hornblende-quartz-feldspar gneiss, and light gray to white garnet-feldspar quartz granulite to quartzite are also present in this unit. Although this assemblage of rock types is not identical as a whole to the Harriman Road Reservoir Unit to the south, many rocks within are quite similar. This similarity, in addition to their position relative to the Interchange 9 Unit and Irvington Unit, has led to the conclusion that they represent a repetition of the Harriman Road Reservoir Unit.

The Harriman Road Reservoir Unit north of Pocantico Lake contains fairly well-layered amphibolites, biotite-hornblende-quartz-feldspar gneiss with local garnet, and light gray biotite-hornblende-quartz-feldspar granitic gneiss. The layers or beds are a few centimeters to approximately one meter in thickness. Pinkish biotite-bearing granitic gneisses and light gray biotite-quartz-feldspar granitic gneisses are fairly abundant in this region. Again, these rocks are not typical of the Harriman Road Reservoir Unit but are mapped as such for continuity.

**Childrens Village Unit (Yfcv)**

This rock unit has been previously referred to as Member A of the Fordham Gneiss (Hall, 1968b) and is here named the Childrens Village Unit after its exposures in Dobbs Ferry (Plate 1). Typical exposures are designated along the ridge about 5 m west of Woodlands Lake and about 3.2 km north of Childrens Village. Unfortunately there is no convenient place name for this ridge on the map. The Childrens Village Unit underlies that region from the southern edge of the map northward, nearly to the southern extent of the Harriman Road Reservoir, and also the area immediately east of the Hudson River in the northwest portion of the quadrangle. Modes for selected samples from the Childrens Village Unit are reported in Table 8.

Well-bedded gneisses are common within this unit. They consist of a variety of interbedded rock types: Graphitic biotite-quartz-feldspar gneiss, gray garnet-biotite-quartz-feldspar gneiss, white quartz-feldspar gneiss, brown-weathering amphibole (cummingtonite?)-bearing calc-silicate rocks, punky-weathering calc-silicate rocks with diopside, dark gray biotite amphibolite, and gray quartzite with some white feldspar. Bedding can range in thickness from several centimeters to several meters. Beds of gray biotite-quartz-feldspar gneiss with sparse garnet occur at thicknesses between 0.3 to 1.2 m and manifest a well-developed foliation. This foliation is the result of preferred dimensional orientation of grains, as well as the concentration of biotite in layers 2 to 12 mm thick. The biotite-rich layers commonly stand out in relief on weathered surfaces and have a characteristic “wispy” appearance due to “pinch and swell” features, among other irregularities. Some of the gray garnet-biotite-quartz-feldspar gneisses concentrate biotite in lenticular aggregates 0.2 to 2.5 cm long, these aligned in the axial-planar orientation of minor folds that deform the bedding and early foliation that is subparallel to bedding.

Brown- to reddish brown-weathering, graphitic biotite-hornblende-quartz-feldspar schistose gneiss is also present within this unit. This lithology contains 1.2 cm thick quartz-rich layers, which have positive relief on weathered surfaces, along with dark gray biotite amphibolite. Other rocks interbedded with the schistose gneiss are light gray quartz-feldspar gneiss (beds 1.2 to 5 cm thick), gray quartzite with white feldspar (beds 10 cm to 0.9 m thick), and gray biotite-hornblende-quartz-feldspar gneiss. The latter is burgundy-red-weathering, with the reddish stain locally extending as much as 1.0 cm into the rock. There is a transitional contact with the Harriman Road Reservoir Unit, in which rocks in both units are similar while the contact between is fairly sharp.

Various gray gneisses are found in the Childrens Village Unit. A dark, bluish-gray, siliceous biotite-quartz-feldspar gneiss ± graphite is mostly gray-weathering, although some outcrop surfaces also display brown weathering stains. There is a well-developed compositional foliation related to alternating light gray quartz-feldspar-rich layers and dark gray biotite-rich layers, all of which are typically less than 1.3 cm thick. Light gray quartzite layers up to 5 cm in thickness are also observed subparallel to the foliation. Other gray biotite-quartz-feldspar gneisses with local graphite have “wispy” biotite segregations and are light, medium, or dark gray depending on the relative abundance of biotite. Thus these different shades of gray are a function of mineral composition and are believed to reflect bedding, which is several centimeters to approximately one meter in thickness. The light gray gneisses tend to have biotite distributed in “wispy” concentrations whereas their darker counterparts typically have the mineral distributed throughout, and apparently in greater abundance.

Light gray biotite-hornblende-quartz-feldspar gneiss is another variety of gray gneiss in the Childrens Village Unit. Garnet with hornblende rims is locally present in this rock type. The gneiss is well-foliated, with foliation arising from the dimensional orientation of minerals as well as the concentration of hornblende in thin layers. Bedding is also evidenced by 5 cm to 0.6 m thick layers of white quartz-feldspar gneiss with scattered hornblende.

A well-foliated, massive or compositionally homogeneous gray biotite-quartz-feldspar gneiss is a distinctive rock type in the unit due to local white quartz-feldspar knots that attain positive relief on weathered surfaces. It occurs in massive outcrops that stand topographically high and locally form cliffs. Although most exposures of this rock are gray-weathering, local red weathering stains have been noted. Another gray gneiss, this with the assemblage garnet-biotite-quartz-feldspar, hosts sillimanite nodules that also stand in relief on outcrop surfaces. These are locally present but not common.

Additional brownish- and rusty-weathering gneisses are prominent in the Childrens Village Unit. Among these is graphitic garnet-biotite-quartz-feldspar gneiss in beds that are 1.8 m or greater in thickness. This graphitic gneiss is well-foliated due to dimensional orientation of mineral grains and thin lenticular segregations of quartz and feldspar. Rusty-weathering, graphite-rich garnet-biotite-quartz-feldspar schist and schistose gneiss with

**Table 8.** Estimated modes of rocks in the Childrens Village Unit of the Fordham Gneiss.

| **Rock type** | Graphitic schistose gneiss | Graphitic amphibole schist | | Quartz-feldspar gneiss | Garnetiferous, hornblende-quartz-feldspar gneiss | | | | Biotite-hornblende gneiss | | | Hornblende gneiss | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| Quartz | 2 | 29 | 50 | 43 | 23 | 46 | 24 | 16 | 26 | 40 | 47 | 8 | X |
| Microcline | 27 | | X[1] | 6 | | | | | | | | | |
| Plagioclase | 13[2] | 21 | 45 | 49 | 45 | 38 | 54 | 56 | 46 | 32 | 19 | 5 | 9 |
| Biotite | 38 | 31 | 2 | 1 | | X | 5 | X | 9 | 3 | 10 | | 11 |
| Garnet | | | 3 | X | 8 | 2 | X | X | | | | | |
| Muscovite[3] | 20 | | X | 1 | | | | | | | | | |
| Chlorite[3] | | | X | | | X | X | | | X | | 1 | X |
| Hornblende | | 3[4] | X | | 23 | 14 | 16 | 28 | 19 | 25 | 23 | 81[4] | 80 |
| Cummingtonite | | 16[4] | | | | | | | | | | 5[4] | |
| Augite | | | | | 1 | | | | | | | | |
| Epidote | | | | | X | | 1 | | X | X | X | | X |
| Calcite | | | | | | | | | | | X | | |
| Apatite | | | X | | X | X | X | X | X | X | X | | |
| Sphene | | | | | | | | | | | 1 | | |
| Allanite | | | | | | | | | X | | | | |
| Zircon | X | X | X | X | | X | | | X | X | X | | X |
| Graphite | X | X | X | | | | | | | | | | |
| Pyrrhotite | | X | | | | | | | | | | | |
| Ilmenite | | | | | X | | | | | | | | |
| Magnetite | | | | | | | | X | X | | | | |
| Opaque | | | | | | X | | | | X | X | | |
| An% of plagioclase determined by symmetrical extinction | - | $An_{40}$ | $An_{44}$ | $An_{12}$ | $An_{41}$ | $An_{34}$ | $An_{43}$ | $An_{53}$ | $An_{41}$ | $An_{44}$ | $An_{32}$ | - | $An_{3}$† |

*Specimen descriptions can be found in Appendix 1.
[1]Orthoclase.
[2]An% not known.
[3]Muscovite and chlorite are secondary minerals.
[4]Has exsolution lamellae.

†*This entry appears truncated on all available copies. The An% value might fall between $An_{30}$ and $An_{39}$. Interpret with caution.* —Ed.

yellow sulfide-stained foliation surfaces are locally conspicuous and are typically deeply weathered. Also found in this unit is a red- to brown-weathering biotite-quartz-feldspar gneiss with "wispy" biotite concentrations. This rock type is interlayered with 2.5 to 7.5 cm thick layers and lenses of garnet-quartz-feldspar gneiss that stand in positive relief upon weathered outcrop surfaces.

Within the northwestern part of the White Plains quadrangle, common rock types in the Childrens Village Unit include gray biotite-hornblende-quartz-feldspar gneiss ± garnet, biotite-quartz-feldspar gneiss ± garnet, and biotite amphibolite (locally with garnet). Also observed in this region is an abundance of foliated, very coarse-grained pegmatites. Hornblende-bearing gneisses are featured quite conspicuously in much of the area, with the ratio of hornblende to biotite varying between <1 to >1 in different gneisses (Table 8). This variation, in conjunction with the presence of additional rock types, produces a layering or bedding that is often visible and can be recognized by differing shades of gray that are related to the mineralogy. Magnetite is another mineral with local prominence in these biotite-hornblende gneisses.

Many exposures of the Childrens Village Unit in the northwestern part of the quadrangle are similar to some of those seen in the East Irvington Unit, although the rocks in the Childrens Village can be distinguished by their display of bedding and common garnet. Thus, the rocks here are interpreted to be akin to the Childrens Village Unit even though they do not include a significant proportion of its characteristic brownish-weathering rocks.

### *Yonkers Gneiss*

The Yonkers Gneiss (Zy) consists of pinkish, orange, or purplish-blue biotite and/or hornblende granitic gneisses. Its constituent rock types are relatively resistant to erosion and thus have a tendency to uphold ridges, and to be fairly well-exposed. Resistance to weathering and a pleasing appearance make some of the gneisses in the Yonkers ideal for building stone. Known commercially as "Westchester Granite," they have been quarried for this purpose for many years.

#### Name

The name Yonkers Gneiss was originally assigned by Merrill (1890, p. 388) to rocks he referred to as "reddish gneiss," "arkosic gneiss," and "red gneiss" which are typically exposed in Yonkers, New York, a city nearly 6 km south of the White Plains quadrangle. Merrill (1890) originally interpreted the Yonkers Gneiss to be the oldest unit in the stratigraphy of Westchester County. Later he revised that interpretation and described the Yonkers Gneiss as a metamorphosed granite that is intrusive into the Fordham Gneiss (Merrill, 1896, p. 29). He further suggested that the Yonkers may have come from a source common with the pegmatite dikes that intrude the marbles and schists at many places in Westchester County (Merrill, 1896, p. 30).

#### Distribution

The Yonkers Gneiss is well-exposed in the southeastern and east-central parts of the White Plains quadrangle (Plate 1, Zy). It occupies the core of the ridge that extends through Hartsdale (Plate 1) and can be traced continuously along the extension of this ridge through the Mt. Vernon quadrangle to the type locality in Yonkers (see geologic map of the Harlem quadrangle, Merrill et al., 1902). From Battle Hill, a site on this ridge within the White Plains quadrangle, the Yonkers extends northeastward across the Bronx River to the east-central part of the quadrangle. There it is exceptionally well-exposed in the area known as Quarry Heights (Plate 1). Rock quarried here was used in construction of the Kensico Dam, located a short distance to the west.

There is also a narrow zone of Yonkers Gneiss in Scarsdale at the southern boundary of the map (Plate 1), not far to the west of White Plains Post Road (Rte. 22). From there, it extends northeasterly to the vicinity of East White Plains at the eastern boundary of the quadrangle. This zone of the Yonkers Gneiss has been traced continuously through the western part of the Glenville quadrangle and into the Yonkers found at Quarry Heights. Rocks similar in appearance to the Yonkers are also present near the south-central edge of the quadrangle, west of the Sprain Brook Expressway, as well as in the southwestern corner of the quadrangle. These rocks are mapped as Fordham Gneiss rather than Yonkers Gneiss because they are not traceable to the type locality, and they were not designated as Yonkers Gneiss by Merrill where they extend into the Mt. Vernon quadrangle (Merrill et al., 1902).

#### Lithology

Pinkish, orange, or purplish-blue biotite- and/or hornblende-quartz-plagioclase-microcline gneisses constitute approximately 90% of the Yonkers Gneiss. Amphibolite layers and lenses are common and comprise most of the remainder of the rocks grouped into the Yonkers. Gray biotite-quartz-feldspar gneiss is also present. In addition, pegmatites are commonly found intrusive into the Yonkers. (*This unit is not to be confused with rocks of similar lithology mapped as the "Fordham Gneiss (Yf) west of Greenville."* —Rev.)

All of the pinkish gneisses in the Yonkers Gneiss are mineralogically similar in that they contain quartz, plagioclase (commonly oligoclase), and microcline, and most assemblages include biotite and hornblende (Table 9). The gneisses are in general granitic but range through quartz monzonite and granodiorite in composition.

The hornblende in the Yonkers Gneiss is unusual, and is characteristic of this rock unit in the White Plains quadrangle in that every hornblende-bearing rock studied in thin section contains the same variety of hornblende. It has a small 2V and is dark bluish-green with the general pleochroic scheme being

**Table 9.** Modal analyses of the Yonkers Gneiss.

| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Number of points if counted** | 1000 | Est. | 1500 | 1500 | 1500 | Est. | 1000 | 1000 | 500 | 2400 | 1500 | 1000 | 100 |
| Quartz | 36 | 32 | 41 | 17 | 21 | 44 | 32 | 28 | 16 | 15 | 40 | 16 | 23 |
| Microcline | 30 | 9 | 31 | 36 | 34 | 28 | 27 | 16 | 41 | 40 | 33 | 39 | 38 |
| Plagioclase | 32 | 52 | 22 | 26 | 32 | 27 | 18 | 32 | 26 | 25 | 25 | 28 | 23 |
| Hornblende (ferrohastingsite) | X | | 3 | 11 | 5 | X | 14 | 15 | 16 | 20 | | 14 | 11 |
| Biotite | 2 | 7 | 3 | 10 | 8 | 1 | 9 | 2 | 1 | | 1 | 3 | 5 |
| Garnet | | | | X | | | X | 7 | X | | X | X | X |
| Muscovite | X | X | | | | | | | | | | | |
| Chlorite | | X | | | | X | | | | | | | |
| Zircon | | X | X | X | X | | X | X | X | X | X | X | X |
| Xenotime (?) | | X | X | X | X | X | | X | X | X | X | X | X |
| Apatite | | | | X | X | | X | X | X | X | | X | X |
| Sphene | | X | X | X | X | | X | | X | | | X | |
| Epidote | | | X | X | X | | | | | | | | |
| Calcite | | | | | | | X | | | | | | |
| Fluorite | | | | | | X | | | | | 1 | | |
| Hematite | | X | | | | | | X | | | | | |
| Opaques | X | X | | X | X | | X | X | X | | X | X | X |
| An% of plagioclase; α index given where determined, otherwise by symmetrical extinction | $An_{15}$ | $An_{14}$ α = 1.535 | $An_{14}$ α = 1.535 | $An_{17}$ α = 1.537 | $An_{12}$ | $An_{21}$ | $An_{10}$ α = 1.533 | $An_{17}$ α = 1.537 | $An_{14}$ α = 1.535 | $An_{14}$ α = 1.535 | $An_{33}$ | $An_{27}$ | $An_{18}$ |

*Specimen descriptions can be found in Appendix 1.

X = yellowish-green, Y = dark green, Z = dark bluish-green (very dark). The characteristically small 2V was estimated in each thin section and was never found to be greater than approximately 20°. It is commonly 10° to 15° and as low as 5° in one thin section. Indices of refraction were determined on a flat stage with white light for grains from specimen WP-3385 (Table 9, No. 10) and are as follows: $\alpha$ = 1.704, $\beta$ = 1.725, and $\gamma$ = 1.727. Together, these optical properties lead to the identification of this mineral as ferrohastingsite.

Biotite in most specimens is dark reddish-brown, although in some specimens it is greenish. Plagioclase is in the oligoclase range, as determined from the index of refraction for most specimens and from symmetrical extinction for the remainder (Table 9). Some of the plagioclase grains are weakly zoned, while others exhibit no perceptible zoning at all. Antiperthite is locally present in several of the thin sections studied. Where it occurs in zoned grains, the interior of the grain is antiperthitic and the outer portion is clear. Myrmekitic intergrowths of plagioclase with quartz are also locally observed. Microcline grains are typically clear, but some are microperthitic. Microcline augen are rare in the Yonkers Gneiss but have been observed locally up to 2.5 centimeters across.

While most accessory minerals within the Yonkers Gneiss are typical (e.g. zircon, apatite, sphene; Table 9), one somewhat unusual phase has been tentatively identified as xenotime. This mineral is pleochroic and fairly striking, with zonation prominently displayed by varied colors including red, rose, plum, pale brown, yellow, and nearly colorless. Twinned grains of xenotime (?) are common and conspicuous. Fluorite is present in two of the thin sections studied (Table 9), and it has also been reported as an accessory mineral in specimens of Yonkers Gneiss collected in a quarry in the city of Yonkers (Long, 1969). Magnetite was identified megascopically at multiple outcrops but it is not abundant. At several localities in the Quarry Heights region, magnetite occurs with biotite and hornblende in aggregates up to 2.5 cm across.

Typical outcrops of pinkish Yonkers Gneiss do not display perceptible bedding or compositional layering. Lenses and layers of amphibolite are present, but they may represent metamorphosed dikes or sills rather than metamorphosed mafic volcanics or calcareous sediments. The lack of bedding notwithstanding, the pinkish gneisses are characteristically well-foliated. However in some places, for instance north of White Plains Reservoir No. 1, lineation predominates over foliation. Elsewhere, the rocks are massive so that it is difficult or impossible to accurately measure foliation attitudes. The gneiss is typically somewhat fine-grained and thinly laminated with alternate light-colored quartz- and feldspar-rich laminae and dark biotite- and hornblende-rich laminae. These fine-grained laminated gneisses locally approach in appearance a mylonitic texture megascopically. This suggests the possibility that the thin laminar foliation elsewhere is related to a mylonitic process that occurred during part of the deformation. Undulatory extinction in quartz is typical in thin sections of these gneisses, and its presence alongside warped twin lamellae in some plagioclase is permissive evidence for mylonitic deformation.

The foliation within the Yonkers Gneiss has been folded at a scale directly visible in outcrops, and, in places, open folds produce a characteristic wavy appearance. The gneiss commonly breaks at a slight angle to the prominent foliation, and the irregular intersection of the dark and light folia on these breaking surfaces yields a characteristic "tiger stripe" appearance. This striped appearance is one aspect of the gneiss that is pleasing to the eye and contributes to its use as a building stone.

Despite its general resistance to weathering, there are places within the Yonkers Gneiss where it is deeply weathered and friable. The most spectacular example is seen within an exposure of Yonkers Gneiss along the western edge of the Scarsdale Country Club near the access road, where the gneiss is friable to a depth of approximately 2 m. The reason for these more deeply weathered rocks is not clear, but it could be related to closely-spaced fractures and the exploitation of textures related to shearing.

The contact between the Yonkers and Fordham Gneisses is largely distinct and sharp. In some places, however, there arises a slight difficulty in identifying the contact. This is particularly true where there are granitic gneisses in the Fordham near the contact. It is somewhat ambiguous to speak of the Yonkers Gneiss in terms of thickness, because if it is a stratigraphic unit, whether volcanic or sedimentary, its top might not be exposed since it would lie in the keels of stratigraphic synclines that are truncated by an unconformity. Its contact with the Fordham Gneiss truncates stratigraphy in that unit and is either an unconformity, a fault, or an intrusive contact. If the Yonkers Gneiss is indeed a deformed sheetlike intrusive, the present thickness of the sheet is varied. With all of this in mind, the minimum present thickness of the Yonkers Gneiss is approximately 105 m. This figure has been calculated based upon the width of outcrop of the Yonkers Gneiss in the vicinity of White Plains-West New York Post Road (Rte. 22) and the White Plains city line in the southeastern part of the quadrangle (Plate 1). The dip in this zone is assumed to be 60° to the northwest, and the width of outcrop is approximately 120 m. The maximum thickness of the Yonkers in the White Plains quadrangle lies in the Quarry Heights region.

### Age

The Yonkers Gneiss, along with the Fordham Gneiss, is unconformably overlain by the Lowerre Quartzite as well as younger rocks (Hall, 1966) and has been interpreted as part of the Precambrian gneiss complex (Hall, 1968). Long (1969) analyzed specimens of the Yonkers Gneiss collected at a quarry in the city of Yonkers to determine a whole-rock Rb-Sr isochron that yields an age of 575 ± 30 Ma. He concluded that the most plausible interpretation is that this is the primary age of the Yonkers (Long, 1969, p. 2089). Borwin Grauert analyzed euhedral zircons from the Yonkers Gneiss, collected in the same quarry as those of Long (1969), and found them to have an apparent age of 525 Ma (Grauert and Hall, 1973). This is compatible with the Rb-Sr whole-rock date (Long, 1969) assuming a disturbance of the U-Pb or Rb-Sr systems during Paleozoic deformation and metamorphism.

All field evidence obtained to date from the White Plains quadrangle, and from the Glenville quadrangle to the east, indicates that the Yonkers Gneiss is part of the Precambrian gneiss complex and is unconformably overlain by the younger cover rocks. Consequently, the Yonkers is interpreted to be older than the cover rocks and younger than the Fordham Gneiss. Thus the Yonkers Gneiss could be intrusive into older gneisses, or it could be metamorphosed rhyolitic volcanics or sedimentary rocks which unconformably overlie older gneisses. Evidence implies that it is probably intrusive into the Fordham, but this is a problem that awaits a solution. Detailed large-scale mapping of the Yonkers-Fordham contact should be conducted to shed more light on the question.

The 575 ± 30 Ma age of the Yonkers Gneiss determined by Long (1969) and supported by Grauert and Hall (1973) seems firm. This suggests that the Yonkers is related to similarly-dated late Precambrian, or Avalonian, rocks elsewhere in the northern Appalachians (Rodgers, 1972; Naylor et al., 1973). It is interesting to note that the Dry Hill Gneiss from the Pelham Dome in Massachusetts, dated by Naylor at 575 ± 30 Ma (Naylor et al., 1973) looks somewhat similar to the Yonkers Gneiss megascopically and also contains hornblende with a small 2V of nearly 0° (Peter Robinson, personal communication, 1973).

## Autochthonous cover rocks

The Lowerre Quartzite, the Inwood Marble, and the Walloomsac Formation constitute the autochthonous cover rocks inside the White Plains quadrangle. A basal unconformity separates this succession from the underlying basement gneisses, and another unconformity occurs at the base of the Walloomsac Formation. The basal Lowerre Quartzite consists of the metamorphosed equivalents of clastic quartz sandstone, arkose, and shaly sandstone or siltstone. It is overlain by the metamorphosed equivalents of clean dolomitic limestone and some limestone and sandstone in the Inwood Marble. This is topped by the Walloomsac Formation, comprising the metamorphosed equivalents of black shale with some limestone interbeds, as well as limestone that is locally extensive enough to be mapped separately. These three units of cover rocks are interpreted to have been deposited during the Cambrian through the Middle Ordovician Periods, with a gap in the section represented by the unconformity at the base of the Walloomsac Formation.

### *Lowerre Quartzite*

The Lowerre Quartzite (€l, Plate 1) is a rock unit that is characterized by buff- or tan-weathering quartzite, feldspathic quartzite, and micaceous quartzite. Other rock types are also present. There has been debate over the origin (tectonic or sedimentary) of the Lowerre Quartzite and whether it, in fact, is a bona fide stratigraphic unit of regional extent (Berkey, 1907; Balk, 1936; Prucha, 1956, 1959; Norton and Geise, 1957; Norton, 1959; Prucha et al., 1968; Hall, 1968a).

#### Name

Merrill (1896, p. 26) proposed the name Lowerre Quartzite for the southernmost exposure of these rocks known to him. It was named for the vicinity of this exposure to the Lowerre Railroad Station in Yonkers, New York, and while the rocks there were briefly described by Merrill at an earlier time (Merrill, 1890), he did not name the unit until the later date (Merrill, 1896). The railroad station and tracks are gone now, but some exposures of the Lowerre remain and are yet to be totally destroyed and covered by the works of man (Norton and Geise, 1957; Hall, 1968b). Merrill subsequently referred to the Lowerre Quartzite as Poughquag Quartzite after concluding that these two units are correlative (Merrill et al., 1902). It is clear that the modifying term "quartzite" was used in naming this unit because siliceous rocks and some true quartzites are characteristic of the unit and not because pure quartzites make up the bulk of it.

#### Distribution

The Lowerre Quartzite is exposed at six known localities in the White Plains quadrangle and occurs between the Fordham Gneiss and Member A of the Inwood Marble at each of them (Plate 1). The localities are as follows: 1) in Irvington at Sunnyside, the former home of Washington Irving, which is located near the Hudson River to the north of Mathiessen Park; 2) near Thornwood, approximately 60 m west of the Saw Mill River Parkway; 3) northwest of Elmsford Center, on the northeast and east side of Beaver Hill, extending from the vicinity of the Saw Mill River Parkway to the bottom of the hill and including the rock cut behind the A&P warehouses described by Norton (1959); 4) along the Sprain Brook Valley east of Ardsley; 5) at Thornwood approximately 250 m north of the intersection of Columbus Avenue with Kensico Road and Nanny Hagen Road; and 6) in the vicinity of East White Plains along the northwest side of Silver Lake.

Due to the controversial nature of its extent and its stratigraphic significance, the Lowerre Quartzite has been mapped as extending only a few hundred meters along strike beyond the limits of known exposure in the White Plains quadrangle (Plate 1). Thus the Lowerre appears to be a highly discontinuous unit on the geologic map, but it may well be far more continuous than is shown. The sparseness of exposures of Lowerre may be due to its limited thickness and local non-deposition. It is also highly susceptible to weathering and erosion because of its well-layered and jointed nature and its position between two rock units of greatly disparate resistance to erosion.

### LITHOLOGY

The characteristic rock types that compose the Lowerre Quartzite are interbedded feldspathic quartzite, micaceous quartzite, biotite-quartz-feldspar granulite, and vitreous quartzite (Table 10), all of which typically weather buff or tan.

[Editor's Note] *Mineral names on all available copies of Table 10 are truncated and some cannot be reliably distinguished. A partial reconstruction of Table 10 is included in Appendix 2. Specimen descriptions remain available in Appendix 1.*

Gray feldspathic and micaceous granulites are also common. It should be noted that there are coarse-grained quartzite beds that are probably deformed coarse grit to fine conglomeratic beds in some of the exposures on the northeast slope of Beaver Hill, but conglomerate beds are yet to be positively identified in the Lowerre Quartzite in the White Plains quadrangle.

Brown- to rusty-weathering biotite-quartz-feldspar granulite and schistose gneiss with local sillimanite nodules are observed in a few localities near the base of the Lowerre, for example in places along the Saw Mill River Parkway on Beaver Hill. Elsewhere feldspathic quartzite and quartzite are present at the base of the unit. Vitreous quartzite is a characteristic rock type in the Lowerre, but it is subordinate in abundance to the more feldspathic and micaceous varieties. Gray feldspathic and micaceous granulites are also common and are abundant enough to be mapped separately along the northeast side of Beaver Hill (€lg, Plate 1). While the rocks mapped on the side of Beaver Hill have characteristic gray-weathering exposure surfaces, many are brownish to brownish-gray on a broken surface. They are well-bedded with 1 to 10 cm beds commonly seen as a result of darker biotite-rich layers, some with tourmaline, interlayered with lighter gray quartz-rich granulite layers.

The various rocks that compose the Lowerre Quartzite are similar mineralogically in that most consist largely of quartz and microcline with lesser amounts of plagioclase, biotite, and muscovite (Table 10). Chlorite is typically present in trace amounts as a retrograde product after biotite. In several of the thin sections studied some microcline grains are microperthitic, but the microcline is generally clear. Plagioclase grains are typically partially altered to fine white mica, making compositional determinations uncertain, but in most thin sections the index of refraction is greater than microcline and less than quartz. This property indicates that the plagioclase is sodic. In every thin section where it is present, biotite is pleochroic from reddish-brown to pale tan.

Accessory minerals are widespread in the Lowerre, with apatite, zircon, and opaques being the most common. The opaque grains are orange, yellowish-brown, and red in reflected light and are probably goethite. In some places the goethite occurs as coatings on black opaques that may be hematite but in at least one case are magnetite. The widely distributed orange and yellowish-brown opaques explain the buff- and tan-weathering rock surfaces that are typical of exposures of the Lowerre. Tourmaline is also among the more common accessory minerals identified in thin section and has been observed in abundance on some bedding surfaces. The Lowerre Quartzite is well-bedded, with beds ranging in thickness from approximately 5 cm to 2 m. Quartzite beds are commonly fractured at high angles to bedding, and where minor folds are present the fractures fan the folds in the manner common to fracture cleavage. Feldspathic and micaceous quartzite beds weather more deeply than the
vitreous quartzites and, in some places, are friable aggregates. Thus, interbeds of vitreous quartzite are broken up along fractures and are easily eroded where their interlayered support has weathered.

Gneisses immediately beneath the Lowerre are deeply weathered in the rock cut behind the A&P warehouses in Elmsford and may be similarly weathered elsewhere at this contact. This state of weathering could result from concentrations of ground water flowing along the boundary between two rocks of different permeabilities. The gneisses may have been rendered more susceptible to weathering by groundwater by minor post-metamorphic shearing along and near the contact. However, no direct evidence has been identified to support the idea of major shearing along the contact.

The sillimanite-bearing quartz-feldspar granulites and schistose gneisses that are locally present near the base of the Lowerre Quartzite suggest that an aluminum-enriched weathered zone developed on the pre-Lowerre gneiss surface. The scattered nature of the sillimanite-bearing rocks might then be explained by local preservation of the weathering profile, or at least by very little sedimentary transport of these materials from the site of weathering. Elsewhere, the weathering residue would have been completely removed by erosion so that arkosic, clayey, and clean sandstones could be unconformably deposited directly upon relatively fresh gneisses.

A maximum thickness of 220 m was determined for the Lowerre Quartzite on the basis of straight calculation from the folded pattern on the northeast slope of Beaver Hill, where the maximum outcrop width is about 300 m and the net plunge about 52°. This maximum value is probably greater than the true thickness. The average width of outcrop for the Lowerre on the northeast slope of Beaver Hill is approximately 100 m to yield an average thickness of 80 m, which is probably closer to the true thickness. The Lowerre is absent in many places in the quadrangle, but where it is exposed its average thickness ranges between 28 m to 58 m.

### AGE

No fossils have been discovered in the Lowerre Quartzite, but it is believed to be Cambrian in age on the basis of correlation with similar rocks that are known to be Cambrian and rest unconformably on Precambrian gneisses (Merrill et al., 1902; Balk, 1936; Hall, 1966, 1968a).

### *Inwood Marble*

The Inwood Marble consists predominately of clean dolomitic marbles with lesser calcitic marbles. While the unit is largely dolomitic in its lower parts, it is calcitic toward the top. Dolomite and calcite are present together in many of the marbles. For this reason, care must be taken when using acid in the field to distinguish rocks that are primarily dolomite but with moderate calcite from those that are truly calcite marbles. Schists, schistose marbles, quartzites, calcareous quartzites, and calc-silicate rocks are also observed in the Inwood. Four mappable subdivisions have been defined within this unit and are designated by letters, from oldest to youngest, as Members A, B, C, and D (Hall, 1968b). A fifth member, Member E, was also assigned previously (Hall, 1968b). However, later work indicates that the rocks within, as well as a portion formerly included at the top of Member D, occur above the unconformity at the base of the Walloomsac Formation and should thus be classified as Walloomsac. Inwood Members A and B have the most widespread occurrence in the White Plains quadrangle (€ia, €ib, Plate 1), presumably because the younger members of the unit were eroded prior to deposition of the Walloomsac.

#### Name

Merrill (1890) proposed the name Inwood limestone for the assemblage of carbonate rocks exposed in the New York City area and Westchester County. The assemblage has subsequently been referred to as Inwood Marble (Balk, 1936; Prucha, 1956). The type locality is Inwood, a section of New York City at the north end of Manhattan Island. Subsequent to defining the Inwood, Merrill referred to these rocks as Stockbridge dolomite (Merrill et al., 1902) and thus presumably believed the correlation of Inwood with Stockbridge to be reasonably certain. The name Inwood Marble is retained here because it is well-established in recent literature (Prucha, 1956, 1959; Scotford, 1956; Prucha et al. 1968; Fisher et al., 1970; Wissig, 1979).

#### Distribution

The Inwood Marble occurs in six general zones within the White Plains quadrangle. From west to east, these are in the following locations (Plate 1): (1) along the eastern shore of the Hudson River in the vicinities of Ardsley-on-Hudson and Dobbs Ferry; (2) along the Saw Mill River Valley from Chauncey at the southern edge of the map to Thornwood at the northern edge, where the unit also extends eastward as a result of being repeated by folding; (3) along Sprain Brook from the southern edge of the map to the latitude of Ridge Road County Park, outlining a fold pattern and extending southward along the narrow valley west of the Catskill Aqueduct; (4) from the Kensico Reservoir southwestward to the southern edge of the map where it extends along the valley occupied by Central Park Avenue; (5) outlining a fold pattern in White Plains and extending southwest to the edge of the map; and (6) in the southeastern corner of the map where it is presumed to underlie a zone extending from the vicinity of Fenway Golf Course northeastward toward Harrison.

#### Lithology

White dolomitic marble and gray dolomitic marble are the most widely-exposed rock types in the Inwood Marble, although various other lithologies are also observed. While most of the marbles are relatively pure carbonate rocks, additional minerals that have been identified within include phlogopite, bright green chlorite, tremolite, diopside, forsterite, quartz, microcline, plagioclase, scapolite, tourmaline, sphalerite, and pyrite. An internal stratigraphy has been defined by grouping the Inwood's constituent rock types together into members. The age sequence of the respective members was established with some difficulty due to the paucity of exposures. The sequence was developed by observation of several reasonably continuous sections across strike of the units and by projecting these units along strike in order to determine whether they fall above or below adjacent members.

**Member A (€ia)**

This member is characterized by white dolomitic marble that is gray- or white-weathering (€ia, Plate 1). Other common rock types are gray and blue-gray dolomitic marbles. These marbles are commonly bedded at thicknesses typically between 15 cm to 1.5 m but up to 2 m. The dolomitic marble is fetid in many places. Quartz segregations measuring from a few centimeters up to several tens of centimeters across are locally present within it. These segregations display reaction rims of tremolite and diopside, and they may represent metamorphosed chert nodules. A gray quartzite bed 0.5 m thick was observed at one locality, but such quartzites are not common. Blue-gray calcite marble occurs interbedded with the dolomite marble in many localities, and calcite-bearing dolomite marbles have also been recognized. Thus Member A is largely a fairly-pure white dolomite marble, and because of this it is quarried commercially at Thornwood (Plate 1).

**Member B (€ib)**

This unit is characterized by well-bedded gray-, buff-, tan-, and pinkish tan to cream-weathering dolomitic marbles (€ib, Plate 1). They are interbedded with brown-, reddish brown-, and tan-weathering phlogopitic calc-schists; tan or reddish brown to purplish siliceous calc-schists and quartzites; gray- to brown-weathering calcite-dolomite marble; and some schistose carbonate rocks that are deeply-weathered, spongy, and calcite-rich. Sphalerite is present locally in some of the tan-weathering dolomitic marbles. Member B is a very distinct unit in the Inwood Marble due to its well-bedded nature, with beds commonly 1 cm to 1 m thick, as well as to the variety of rocks present within it. It is the most well-exposed member of the Inwood in the White Plains quadrangle. A typical exposure can be seen in the rock cut along Route 9A immediately south of the New York Thruway Bridge at Ardsley (Plate 1).

**Member C (€ic)**

The most prominent rock type of this unit is thickly-bedded blue-gray or gray dolomitic marble that is locally fetid. Also observed are gray, calcite-bearing dolomitic marbles as well as tan-weathering schist and quartzite in minor amounts. Member C bears a resemblance to Member A in some ways, although it encompasses more bluish-gray dolomitic marble and the two units are separated by Member B. A good exposure of Member C can be found along the northbound exit from the New York Thruway at Ardsley.

**Member D (€id)**

This member of the Inwood Marble (€id, Plate 1) consists of gray and tan dolomitic marbles with interbedded calcite marbles and phlogopitic calc-schists.

### *Walloomsac Formation*

Pelitic rocks predominately characterize exposures of the Walloomsac Formation (Ow, Plate 1), although calc-silicate rocks, tan-weathering phlogopitic marbles, and white calcite marbles are also present, particularly at the base of the formation. A marble member, here named the Phlogopitic Marble Member of the Walloomsac Formation, occurs locally and is mapped separately at the base of the Walloomsac (Owm, Plate 1). The contact between the Phlogopitic Marble Member and the rest of the Walloomsac is apparently sharp in some places and gradational in others. Where the contact is gradational, it is typified both by interbedding of marbles and schists and by the presence of compositionally gradational rock types such as calc-silicate rocks, mica-rich marbles, and calcite-bearing mica schists.

#### NAME

Rocks that occur between the Manhattan Schist and the Inwood Marble, or, where the Inwood is missing, between the Manhattan Schist and rocks beneath the Inwood, are here considered part of the Walloomsac Formation. It is named after the city of Thornwood, which is along the northern boundary of the White Plains quadrangle (Plate 1), where rocks of the formation are fairly well exposed.

[Editor's Note] *Dr. Leo Hall called the Walloomsac Formation the "Thornwood Formation" after exposures in the city of Thornwood. However, numerous later workers have established the name "Walloomsac Formation" for this unit. Therefore, to reduce confusion in terminology, the unit is herein called the Walloomsac Formation.*

These rocks have previously been called Manhattan A (Hall, 1968a, 1968b), but a separate name is now given to rocks of this unit because their distribution is fairly widespread, and furthermore because they are interpreted to be younger in age than rocks previously called Manhattan B and Manhattan C (Hall, 1968b).

#### DISTRIBUTION

The following sites are among the better exposures of typical rocks in the Walloomsac Formation: (1) the rock cut behind the Rose Hill Shopwell Shopping Center east of Columbus Avenue in Thornwood; (2) the various tan-weathering calcite marbles exposed in the vicinity of Kensico Road in Thornwood; (3) the northern and northwestern edges of the ridge that ends south of the junction of the Taconic and Saw Mill River Parkways and Route 9A in Hawthorne; (4) multiple exposures of the Phlogopitic Marble Member along the southeastern side of the Saw Mill River Valley in Hawthorne; (5) numerous exposures of the Phlogopitic Marble Member in East White Plains; (6) in the rock cut in the parking area for the apartments on the west side of Hillside Avenue (Rte. 100), near the entrance directly west of North Road; and (7) in White Plains, along the northwestern side of the New York Post Road approximately 320 m north of Post Road School, more or less along the 250-foot contour line. In this latter site there are exposures of both the Phlogopitic Marble Member and the Schist Member (not mapped separately), with the contact between exposed in a rock cut made for a car dealer's parking lot.

#### LITHOLOGY

**Walloomsac Formation, undifferentiated (Ow)**

The typical rocks that compose the Walloomsac Formation, undifferentiated are well-foliated dark gray- to black-weathering schists and bluish-gray sillimanite- and/or kyanite-garnet-muscovite-biotite schists that weather brown, rusty, or gray. Rusty-weathering surfaces typify many outcroppings. In weathered exposures the schists are characteristically reduced to crumbly or friable masses due to exploitation of the pronounced schistosity by weathering processes. As a result, they are well described as fissile schists. Schistosity surfaces are commonly gray or black because of biotite and, where present, graphite. Surfaces across the schistosity are gray to light gray because of quartz and feldspar. Sulfides (pyrrhotite?) and reddish biotite are characteristic minerals in many of the schists.

Bedding in the schists of the Walloomsac Formation is not readily identified but, where observed, it is fairly thin and most commonly defined by gray siliceous granulite beds 3 cm to 30 cm thick. The granulite beds locally contain sillimanite and garnet as well as the more common biotite and muscovite, and some are siliceous enough to be termed quartzites. They are separated by schist beds ranging from 20 cm to >4 m in thickness; because of

**Table 12.** Estimated modes of the Phlogopitic Marble Member of the Walloomsac Formation.

| Specimen* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Calcite | 80 | 51 | 48 | 92 | 5 |
| Quartz | X | 1 | X | X | 41 |
| Plagioclase | | 3 | 6 | | 7 |
| Microcline | 5 | 22 | 28 | | 39 |
| Phlogopite | | 7 | 7 | 4 | X |
| Clinozoisite | X | X | X | | |
| Epidote | | | | | X |
| Tremolite | 8 | 1 | 3 | X | |
| Diopside | 7 | 11 | 8 | | |
| Scapolite | X | 4 | | | |
| Chlorite | | | | 3 | 8 |
| Serpentine | X | | | | |
| Sphene | X | X | X | | X |
| Apatite | X | X | X | X | X |
| Zircon | X | X | X | | X |
| Graphite | | | | 1 | |
| Pyrite | | X | X | | X |
| Black opaque | | X | | | |
| Approximate An% of plagioclase determined by symmetrical extinction | - | $An_{36}$ | $An_{38}$ | - | $An_{33}$ |

*Specimen descriptions are missing for this table.

this apparent locally thick-bedded nature, many outcrops are not large enough to display bedding.

Commonly observed within this unit are 1 cm to 20 cm thick lenses of fine- to medium-grained, white, and glassy granular quartz that contain small amounts of muscovite, garnet, feldspar, and locally sillimanite. Lenses and thin dikes of white pegmatite and aplite are also fairly common. Garnets present in the schist are typically pale lavender or purplish-red and can measure up to 2 cm in width, although their widths are most commonly between 3 to 6 mm. Biotite found in the schists and the granulites in this formation is usually pleochroic from Z = reddish-brown to X = pale yellowish-tan, and graphite has been identified in some specimens. The fissile schists and granulites in the Walloomsac are generally not magnetic, although isolated magnetite does appear. This stands in contrast to the Manhattan Schist, in which many rocks are magnetic.

Another rock type present, if less common, in the Walloomsac Formation is dark gray, rusty-weathering garnet-muscovite-biotite schist. The rock contains elongate ovoids and lenses of yellowish-white sillimanite-rich aggregates that are typically parallel to the mineral lineation. Other subordinate rock types in this unit include black, graphitic sillimanite-garnet-muscovite-biotite schist that is rusty-weathering and greenish-gray to bluish-gray calc-silicate rocks that consist of garnet, diopside, calcite, feldspar, and quartz. The latter weather light gray so that green diopside stands out against the pale background. Representative mineral modes of rocks from the Walloomsac Formation are provided in Table 11.

[Editor's Note] *Mineral names on all available copies of Table 11 are truncated and some cannot be reliably distinguished. A partial reconstruction of Table 10 is included in Appendix 2. Specimen descriptions remain available in Appendix 1.*

Calc-silicate rocks occur most commonly near the base of the pelitic portion of the Walloomsac Formation, where 3 to 30 cm-thick calc-silicate beds are interbedded with fissile schist. Brown-weathering, greenish-gray, and micaceous calc-silicate beds up to 45 cm in thickness are also observed. White calcite marble, tan-weathering phlogopitic marbles, and calcite-bearing mica schists are additionally interbedded with the fissile schist. This is particularly the case in the vicinity of the contact with the Phlogopitic Marble Member.

The thickness of the Walloomsac Formation is variable in the White Plains quadrangle. The unit is probably absent locally along the northwestern side of Central Avenue, and it is estimated to attain a maximum thickness of 600 m elsewhere. Thicknesses on the order of 275 m or less are most common for the Walloomsac Formation in this quadrangle.

**Phlogopitic Marble Member (Owm)**

The lower, phlogopitic marble unit of the Walloomsac Formation is characterized by tan- and gray-weathering calcitic marbles that typically contain phlogopite. Where fresh, the rocks are bluish-gray and white respectively. The tan-weathering marbles contain a yellow sulfide mineral that is presumably pyrite. The well-bedded nature of these rocks is also characteristic, with bedding defined by variations in the abundance of phlogopite and the color of the weathered surfaces. Bedding thickness ranges between 2 cm and 1 m. White and relatively pure calcite marbles, calcite-bearing mica schists, and some garnet-muscovite-biotite schists are also found locally. In addition, this member includes occasional but uncommon calcite-dolomite marbles. Representative modes of the Phlogopitic Marble Member are listed in Table 12.

This marble unit was formerly referred to as Member E of the Inwood Marble (Hall, 1968b). Further work indicates that it is better to place these rocks in the Walloomsac Formation because they directly overlie various older rock units but are everywhere overlain by the pelitic part of the Walloomsac. Thus they are unconformable upon the older rock units. The Phlogopitic Marble Member is either absent or not exposed in many localities and was apparently only laid down on a local scale in the early depositional history of the Walloomsac Formation. Where present its typical thickness is estimated to be between 16 and 45 m. Its possible maximum thickness is approximately 200 m in the vicinity of East White Plains.

## Allochthonous cover rocks

The Manhattan Schist and the Hartland Formation constitute the allochthonous cover rocks in the White Plains quadrangle. These rock units include various schists, schistose gneisses, granulites, and amphibolites that are interpreted to represent clastic sedimentary rocks and volcanics that were deposited in the Cambrian and Lower to Middle Ordovician Periods, although some are possibly Late Precambrian in age. The Manhattan Schist is interpreted to be in thrust fault contact with the autochthonous cover rocks along the Elmsford thrust, while the Hartland is in thrust fault contact with the Manhattan Schist along Cameron's Line (Hall, 1968a, 1968b, 1980).

### *Manhattan Schist*

In the White Plains quadrangle, the Manhattan Schist is largely characterized by various schists, feldspathic schistose gneisses, and granulites (Cm, Plate 1). Although amphibolites are also present within the unit, their distribution is considerably less extensive. However, a relatively thin amphibolite unit has been mapped separately and is here named the Central Park Avenue Amphibolite Member of the Manhattan Schist (Cmcp, Plate 1). Although zones of Manhattan Schist within the quadrangle can be characterized by distinct rock types, it has not been possible to separate any additional members due to lack of continuity of exposure. Some of the lithic types are related to initial sedimentary differences, whereas others manifest differences in metamorphic grade. With further detailed work, member distinctions might be made.

#### Name

Merrill (1890) applied the name "Manhattan schists" to the highly schistose rocks that overlie the Inwood Marble and stated that "…these uppermost beds are well exposed on Manhattan Island of which they constitute the principal rock formation…" (Merrill, 1890, p. 390). Most of the rocks described by Merrill are believed to be equivalent to the Manhattan Schist as mapped in the White Plains quadrangle, but some of them correspond to rocks mapped as the Walloomsac Formation in the area. The Central Park Avenue Amphibolite Unit of the Manhattan Schist (*origin of this name is unknown*—Rev.) and the Manhattan Schist itself were previously designated Manhattan B and Manhattan C respectively (Hall, 1968a, 1968b). The present nomenclature is adopted to reduce confusion with earlier terminology.

#### Distribution

Three different parts of the White Plains quadrangle are underlain by the Manhattan Schist. The largest zone, although irregular due to several large-scale folds, extends in general from the south-central edge to the northeastern edge of the quadrangle (Plate 1) and is here referred to as the major zone of the Manhattan Schist. The second zone extends from the southern edge of the quadrangle in the vicinity of Fox Meadow, in Scarsdale (Plate 1), northeastward into the city of White Plains and is here referred to as the central zone of the Manhattan Schist. The third zone, here termed the southeastern zone of the Manhattan Schist, reaches from the southern edge of the quadrangle in Scarsdale northeastward into White Plains and to the eastern edge of the map (Plate 1).

#### Lithology

Micaceous rocks, generally well-foliated and schistose to gneissic in character, compose the bulk of the Manhattan Schist in the White Plains quadrangle. Amphibolites and granulites are significantly less prominent. The majority of the rocks are quartzofeldspathic (Tables 13a, b) and they are typically exposed in massive outcrops. Magnetite is a common and abundant accessory mineral in most, although not all, of the schists and schistose gneisses of this unit. For this reason, Manhattan terranes stand out as magnetically high relative to others on aeromagnetic maps of the area (Philbin and Kirby, 1964). It should be mentioned that magnetite is not as widespread in the central zone of the Manhattan Schist as it is elsewhere.

Gray, coarse-grained kyanite-garnet-staurolite-muscovite-biotite schist is characteristic of the Manhattan Schist in the kyanite zone of metamorphism. These rocks are most commonly brown-weathering and tend to have burgundy to maroon staining on weathered surfaces. Numerous exposures of such schists can be observed in the major zone of the Manhattan Schist in the

**Table 13a.** Estimated modes of the Manhattan Schist.

| Specimen* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 16† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | 38 | 72 | 31 | 32 | 32 | 52 | 64 | 36 | 34 | 35 | 46 | 46 | 35 | 51 | 38 |
| Orthoclase | 6 | | 3 | 2 | 32[1] | 4 | 3[1] | | | | | 7 | | | |
| Plagioclase | 24 | 22 | 25 | 42 | 12 | 20 | X | 30 | 43 | 4 | 21 | 24 | 23 | 12 | 43 |
| Muscovite | 12 | X | 17 | 1 | 2 | 1 | 2 | 10 | 1 | 24 | 10 | 7 | 17 | 7 | 3 |
| Biotite | 18 | 6 | 23 | 23 | 22 | 19 | 22 | 22 | 20 | 14 | 14 | 15 | 20 | 20 | 16 |
| Garnet | 2 | X | X | X | | X | 1 | 1 | 2 | 3 | 3 | 1 | 1 | 3 | X |
| Staurolite | | | | | | | | | X | 13 | | | X | X | |
| Kyanite | | | | | | | | X | X | 6 | 4 | | 4 | 6 | |
| Sillimanite | X | | X | X | X | 4 | 8 | X[2] | | X[2] | X[2] | X | X | X[2] | X |
| Chlorite | | | X | | | | | | | | | | | | |
| Apatite | X | X | X | X | X | X | X | X | X | | X | X | X | X | X |
| Zircon | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Tourmaline | | | X | X | | X | | X | | | | | X | X | |
| Hematite | X | | | | | | | | | | | | | | |
| Magnetite | | X | 1 | X | | | | 1 | X | 1 | 2 | | X | | X |
| Opaque | | | | | X | X | X | | | X | X | X | | 1 | |
| An% of plagioclase; α index given where determined, otherwise by symmetrical extinction | $An_{10}$ | $An_{12}$ | $An_{18}$ | $An_{50}$ α = 1.554 | $An_{27}$ | $An_{38}$ | | $An_{17}$ | $An_{40}$ | | $An_{35}$ | $An_{32}$ | $An_{20}$ | $An_{20}$ | $An_{26}$ |

*Specimen descriptions can be found in Appendix 1.

[1]Microcline that displays well-developed grid twinning.

[2]Sillimanite occurs as inclusions in muscovite, quartz, plagioclase, and garnet.

†*Column 15 is truncated and entirely unintelligible on all available copies and is therefore not included.* —Ed.

**Table 13b.** Estimated modes of the Manhattan Schist.

| Specimen* | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | 46 | 33 | 37 | 46 | 59 | 48 | 43 | 25 | 40 | 32 | 66 | 29 | 32 | 33 | 41 |
| Orthoclase | | X | 2 | | 1 | | 7 | | | X | 3 | | | 6 | |
| Plagioclase | 40 | 30[1] | 8 | 17 | 29 | 18 | 20 | 45 | 20 | 45 | 14 | 15[1] | 41 | 45 | 13 |
| Muscovite | X | 7 | 26 | 10 | X | 1 | 10 | 15 | 11 | 1 | X | 20 | 3 | X | 36 |
| Biotite | 14 | 26 | 9 | 21 | 11 | 12 | 19 | 9 | 17 | 22 | 16 | 30 | 22 | 16 | 9 |
| Garnet | X | 2 | 3 | X | | 1 | X | 4 | 4 | X | X | 3 | X | X | X |
| Staurolite | | | 16 | | | | | X | X | | | | | | X |
| Kyanite | | | 1 | X | | | | 1 | 7 | | | | | | |
| Sillimanite | X[2] | X | X[3] | 6 | | 18 | X | x | 1 | | 1 | 2 | 1 | X | |
| Chlorite | | | | | | | | | | | X | | | | |
| Apatite | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Zircon | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Tourmaline | | | X | | | | | X | | | | | | | |
| Hematite | X | | | | X | | | | | | | | | | |
| Magnetite | | | X | | X | 2 | 1 | 1 | X | | | 1 | 1 | X | |
| Opaque | | X | | X | X | | | | | X | X | | | | |
| An% of plagioclase; α index given where determined, otherwise by symmetrical extinction | $An_{12}$ | $An_{24}$ | $An_{28}$ | $An_{20}$ | $An_{15}$ | $An_{20}$ | $An_{20}$ | $An_{20}$ | $An_{20}$ | $An_{27}$ | $An_{21}$ | $An_{15}$ | $An_{25}$ | $An_{33}$ α = 1.544 | $An_{15}$ |

*Specimen descriptions can be found in Appendix 1.
[1]Plagioclase is locally antiperthitic.
[2]Sillimanite is highly altered to kaolin.
[3]Sillimanite occurs as inclusions in muscovite, quartz, plagioclase, or garnet.

vicinity of Ardsley. To the northeast, exposed in a cove along the western side of the Kensico Reservoir, is a distinctive silver-gray staurolite-garnet-biotite-muscovite-rich schist (Tables 13a, b; Plate 1). This silvery rock type is very distinct, but it has not been identified elsewhere and thus is not mapped separately. Biotite in the brown-weathering kyanite- and staurolite-bearing schists is typically greenish-brown to olive in color. Magnetite is a common phase in these rocks. Kyanite lathes are frequently 1.5 to 3.0 mm long, although locally their length is closer to 1 cm and in some places they appear to be bent or broken fragments of initially larger crystals. Staurolite grains are typically 1.0 to 1.5 cm across and irregular in shape, but euhedral crystals can be identified locally. Numerous fine inclusions of quartz are present in most of the staurolite grains and are often in a spiral or rotational array. Sillimanite is also observed in many of the kyanite-staurolite-garnet rocks (Tables 13a, b), but in most places it occurs as inclusions in coarse grains of muscovite. In some rocks, however, the sillimanite is scattered through the rock and in contact with kyanite. Where these two minerals occur together they appear to be fresh and stable.

Rocks containing sillimanite nodules are conspicuous in the Manhattan Schist in the White Plains quadrangle. These nodules are present in various rock types, and while they are most common in the schistose gneisses that are gradational toward gneiss, they also occur in schists and granulitic rocks. Although some nodules are slightly rusty-weathering, most are brown- or gray-weathering and many attract a magnet strongly. The nodules are resistant to erosion and characteristically stand out in relief on weathered surfaces. This produces a knobby appearance and outcrop surfaces that provide many hand-holds and foot-holds; the rock is therefore sometimes described as a “boot-grabber.”

Mineralogically these sillimanite-bearing rocks consist primarily of garnet, biotite, orthoclase, plagioclase, and quartz with small amount of muscovite, although muscovite is estimated to compose 10% of one of the rocks studied in thin section (Table 13b, Specimen 20) and 7% of two others (Tables 13a, b; Specimens 12 and 18). Mineral modes for the sillimanite nodules have been estimated for three of the rocks studied in thin section (Table 14). Quartz is clearly the most abundant mineral in the nodules, but sillimanite makes them distinctive and is the reason for the name. One rock type that commonly hosts sillimanite nodules has an especially unique appearance: It is a light gray, gray-weathering, sillimanite-garnet-biotite-quart feldspar granulite with muscovite scales oriented parallel to a faint foliation. This granulite has a salt-and-pepper look due to black biotite on a light gray quartz-feldspar background. Examples of modes for this rock type can be found in Table 13b (Specimens 18 and 22).

The Manhattan Schist encompasses numerous additional lithologies within the White Plains quadrangle, the following being among the more common:

*Light gray-weathering, gray sillimanite-garnet-muscovite-biotite schistose gneiss* that is slightly magnetic and has thin lenticular or boudinaged white quartz-feldspar segregations. It is well-foliated due to the parallel orientation of platy minerals, as well as to the concentration of micas in thin layers interlaminated with light-colored felsic layers. These layers, defined by mineral segregations, die out along strike, and consequently the well-foliated rock does not have a prominently layered appearance.

*Brown-weathering, gray sillimanite-garnet-muscovite-biotite schist* that has black tourmaline grains up to 2.5 cm long and attracts the magnet. Muscovite segregations up to 4 cm long are present in this rock and may be due to retrograde metamorphism.

*Gray, slabby, and magnetic sillimanite-garnet-muscovite-biotite schistose gneiss* with coarse muscovite flakes typically about 6 mm across, but up to 1.2 cm across, on its foliation surfaces. This distinctive rock type has a “slabby” nature that is apparently due to mica-rich laminae that weather relatively faster than the interlayered quartz-feldspar-rich schistose gneiss. It is not certain whether this character represents bedding or is tectonic in origin, but within these rocks are beds of garnet-muscovite-biotite-quartz-feldspar gneiss up to 20 cm thick that are parallel or subparallel to the “slabby” surfaces.

*Blue-gray, medium- to coarse-grained, feldspathic sillimanite-garnet-biotite schistose gneiss* that is typically rich in magnetite and hosts quartz-feldspar segregations that are locally pegmatitic. It is well-foliated, and while bedding is locally defined by siliceous garnet-biotite gneiss beds up to 0.6 m thick, most outcrops do not display identifiable bedding. Coarse muscovite clots are common and may reflect retrograde metamorphic changes. Yellowish-white quartz-rich layers that contain scattered feldspar grains up to 5 cm across are associated with this rock.

*Gray to dark gray, well-foliated sillimanite-garnet-muscovite-biotite schist* that hosts light gray to yellowish-white lenticular sillimanite-rich aggregates. These aggregates form aligned elongate ellipsoidal features on the foliation plane and are as much as 30 cm in length. White granitic and pegmatitic lenses and layers are common in most of these schists, presumably a result of local partial melting. Some of these pegmatitic bodies contain tourmaline, one of them with crystals up to 8 cm long. Some lenses crosscut foliation while others lie in the foliation itself.

**Table 14.** Estimated modes of sillimanite nodules in the Manhattan Schist.

| Specimen* | 1 | 2 | 3 |
|---|---|---|---|
| Quartz | 62 | 65 | 63 |
| Sillimanite | 12 | 26 | 37 |
| Muscovite | 23 | 7 | X |
| Biotite | 3 | X | |
| Magnetite | | 2 | X |

*Specimen descriptions can be found in Appendix 1.

## Local areas in the Manhattan Schist

The rocks that are mapped as the Manhattan Schist differ somewhat from place to place in the White Plains quadrangle. This section will describe some of the lithologies found at various localities in order to highlight this variation.

Coarse, garnetiferous schistose gneisses and schists occur frequently in the Manhattan Schist along the hills north and south of the Rosary Hill Home in Thornwood and Hawthorne. Brownish-weathering, gray, and garnet-rich biotite-quartz-feldspar schistose gneiss is particularly common here. The garnets are dark red in color, up to 2.5 cm in diameter, and stand out in relief on weathered outcrop surfaces. Many are rimmed by white aggregates of quartz and feldspar that are more extensive at opposite ends of the grain, forming pressure shadows. The garnets contain inclusions of quartz, plagioclase, biotite, opaques, staurolite, and sillimanite. In some places, the inclusion trains indicate that the garnets are rolled. Foliation in these garnetiferous rocks is brought out by the preferred orientation of biotite and by light gray migmatitic lenses and layers of quartz and feldspar up to 7.5 cm in thickness.

The hills between West Lake Drive and Columbus Avenue, southwest of Thornwood, are underlain by an interesting assemblage of fairly well-bedded rocks in the Manhattan Schist. Excellent examples are exposed in the rock cuts in the parking lot behind the buildings immediately north of Stevens Avenue and east of Columbus Avenue. In this assortment is a gray sillimanite-garnet-biotite schist with some muscovite and sillimanite nodules, a lithology with varying abundances of quartz and feldspar so that it is a schistose granulite in places. The contrast of light gray quartz and feldspar with black biotite yields a black-and-white speckled appearance, although the general background colors of the fresh rock are light gray, bluish gray, or dark gray to black. Weathered surfaces of this rock type are typically gray to brown. The schist is commonly magnetic, strongly so in many places, due to the presence of magnetite. This mineral apparently also accounts for the brownish-weathering nature of many of the rock exposures. Foliation subparallel to bedding occurs in relation to both dimensional grain orientation and compositional layering. The latter includes black biotite-rich layers, with abundant sillimanite mats, which range in thickness from less than 1 mm to 1 cm. These are interspersed with 2 mm to 4 cm thick layers of quartz and feldspar with sparsely scattered biotite that tends to be dimensionally oriented parallel to the layer boundaries. Red garnets measuring from 1 mm to 1 cm in the long dimension are commonly distorted into ellipsoidal shapes, with short dimensions perpendicular to the layering foliation.

The schist and schistose granulites are interbedded with gray sandy granulites that consist largely of quartz and feldspar. These granulites host fine red garnets 1 to 3 mm in diameter, as well as some black biotite grains. The biotite is dimensionally oriented, though not rigorously so, and thus the rock has a faint foliation that is enhanced locally by concentrations of this dark mineral in discontinuous layers. Sillimanite nodules are present in many of the gray granulite beds and are ellipsoidal in shape, with short dimensions perpendicular to the foliation. They are crenelated along with the foliation in which they lie and, in such places, tend to be elongate parallel to the hinge lines of the crenulations. Magnetite is locally present in the granulite beds but is not abundant, as it is in the schist and schistose granulitic beds. These gray granulite beds range from 5 cm to 1.2 m in thickness, but beds of thicknesses between 7 and 20 cm are most typical. White to gray quartzite beds, 5 cm to 0.3 m in thickness, are also locally observed, but at 1% or less of the outcrop they are not abundant. In comparison, the abundance of the schistose beds is approximately equal to, or somewhat more than, that of the granulites.

Near the Sprain Brook Parkway at Stevens Avenue, a distinctive rock type is a gray, feldspathic sillimanite-muscovite-garnet-biotite schist with very coarse garnets 1.2 to 2.5 cm across. The garnets have numerous inclusions of biotite and feldspar that are aligned parallel to one another but oblique to the surrounding foliation, and thus there has been some relative rotation. Other minerals are deformed around the garnets, and the garnets themselves are slightly flattened in the foliation and display pressure shadows at the ends of their longer dimensions. Gray biotite-quartz-feldspar granulite beds up to 30 cm in thickness are interbedded with the schists. Many of the fracture surfaces in this area exhibit rusty stains.

Near Sunningdale Country Club, the prevalent rock type within the Manhattan Schist is a gray, feldspathic garnet-muscovite-biotite schistose gneiss with sillimanite nodules that stand out in relief on weathered surfaces. In places, rocks of this kind display coarse muscovite clots that may represent retrograded sillimanite nodules or possibly kyanite. Locally the rock is very magnetic, a quality exhibited particularly strongly by the sillimanite nodules. Foliation in this schistose gneiss arises from both mineral grain orientation and compositional layering. Layers are 2 to 3 mm in thickness and are typified by light gray feldspar-rich bands, which are scattered with biotite grains that yield a black-and-white speckled appearance, and layers that contain garnet and muscovite.

While bedding is difficult to discern in many of the exposures near the Sunningdale Country Club, beds or lenses are locally identifiable due to a greater abundance of sillimanite nodules, or because some sections are more micaceous or schistose than the surrounding rock. There are discontinuous layers with abundant sillimanite nodules, which stand out markedly on weathered surfaces and are therefore striking to observe. Where biotite-quartz-feldspar granulites or white to gray quartzites are present, bedding can be readily seen. Isolated biotite amphibolite and pyroxene-bearing biotite amphibolite beds have also been noted but these lithologies are localized and not abundant.

## Central Park Avenue Amphibolite Member (Cmcp)

The Central Park Avenue Amphibolite member of the Manhattan Schist has previously been referenced as Member B.

**Table 15.** Estimated modes of rocks in the Hartland Formation.

| Rock type | Schists | | | | Feldspathic granulite | | Amphibolite |
|---|---|---|---|---|---|---|---|
| **Specimen*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| Quartz | 60 | 39 | 53 | 44 | 17 | 42 | 10 |
| Plagioclase | 14 | 20 | 19 | 7 | 48 | 38 | 40 |
| Muscovite | 12 | 22 | 18 | 40 | 5 | X | |
| Biotite | 14 | 17 | 10 | 8 | 30 | 20 | 1 |
| Garnet | X | 2 | X | 1 | | X | |
| Sillimanite | | X | | | | | |
| Hornblende | | | | | | | 49 |
| Apatite | X | X | X | X | X | X | X |
| Zircon | X | X | X | X | X | X | X |
| Pyrite | | X | | | | | |
| Magnetite | X | | X | X | X | | X |
| Opaque | | X | | | | X | |
| An% of plagioclase determined by symmetrical extinction | $An_{28}$ | $An_{35}$ | $An_{26}$ | $An_{20}$ | $An_{20}$ | $An_{22}$ | $An_{45}$ |

*Specimen descriptions can be found in Appendix 1.

It is named for typical exposures in the southern part of the White Plains quadrangle (Plate 1) along the northwestern side of the valley followed by Central Park Avenue. This unit extends northeastward along the northwest side of Central Park Avenue to the wooded hills immediately north of the Cross Westchester Expressway (I-287), and from there southwestward to the vicinity of Woodlands High School where it tapers out (Plate 1). It lies near or at the structural base of the Manhattan Schist.

Dark green to greenish-black amphibolite characterizes the Central Park Avenue Amphibolite Member, although garnet-muscovite-biotite schist also occurs minorly within the unit. Typical exposures of this member consist of well-foliated, greenish-gray and greenish-black biotite amphibolite and well-foliated epidote-biotite amphibolite. The former is gray- to greenish gray-weathering. Diopside is a common phase in all of the amphibolites, and garnet is present locally. Foliation occurs in relation to the preferred orientation of inequant grains and also to pronounced compositional layering. Layers are typically 1 mm to 2 cm in thickness and consist of bands that are light gray and feldspar-rich juxtaposed against bands that are dark and hornblende- or biotite-hornblende-rich. In addition, beds or layers of garnet-biotite-hornblende gneiss and gray feldspathic schist similar to those elsewhere in the Manhattan Schist occur interbedded with the amphibolites. The schist beds are more common near the contacts of Cmcp. The unit as a whole is layered or bedded, a characteristic most evident where its various constituents occur together, and where there are color differences between rock types that are directly related to differences in modal abundance of minerals.

Also within this member are local white pegmatitic lenses that are rich in feldspar and contain subordinate biotite, but that have little or no quartz. These lenses are up to 2 m across. Layers that are hornblende-rich enough to be in essence hornblendite locally occur parallel to the foliation at thicknesses of approximately 2.5 cm. They are presumed to be the product of metamorphic reactions.

The amphibolites of the Central Park Avenue Amphibolite Member of the Manhattan Schist are interpreted to be metamorphosed volcanics or calcareous sediments.

### *Hartland Formation*

The rocks of the Hartland Formation (Och, Plate 1) are separated from the Manhattan Schist by Cameron's Line, a structure which is interpreted to be a major regional thrust fault. It is along this thrust fault that rocks inferred to have been deposited upon oceanic crust, i.e. the Hartland Formation and associated rocks, are interpreted to have been transported onto North American continental crust (Hall, 1980; Hall and Robinson, 1982; Robinson and Hall, 1980).

While some of the schists in the Hartland Formation are very similar to those in the Manhattan Schist, the contact between the two units is fairly clear-cut in most places. In contrast to the Manhattan Schist, the Hartland Formation in the White Plains quadrangle is generally well-bedded and characterized by interlayered schists, granulites, and amphibolites. Amphibolite beds are abundant in the Hartland compared to the Manhattan. Many of the schistose rocks in the Hartland have a spangled appearance that arises from coarse muscovite and biotite on the foliation surfaces.

## NAME

Hartland (Hoosac) Schist was first used as a rock unit name in the literature by H.E. Gregory (Rice and Gregory, 1906) for rocks that extend into Connecticut from Hoosac Mountain and adjacent regions in Massachusetts. The name is taken from the town of Hartland, Connecticut (Rodgers et al., 1959). This formation occurs throughout western Connecticut, where it has been mapped and studied extensively (Clarke, 1958; Hall, 1976; Gates and Martin, 1976; Stanley and Hatch, 1976).

## DISTRIBUTION

The Hartland Formation extends diagonally across the southeastern corner of the White Plains quadrangle (Plate 1). Exposures are not very abundant in this region, and many of them either entirely or predominantly comprise pegmatites and pegmatitic granitic gneisses. In spite of this, there is enough exposed country rock to allow characterization of the Hartland in this quadrangle.

## LITHOLOGY

Metamorphosed sedimentary and volcanic rocks of the Hartland Formation most commonly display bedding that is up to about 2.4 m in thickness. Thicker beds may be present, for in many outcrops only one of the bedding contacts is exposed. Observable bedding is often a few centimeters to several tens of centimeters thick and is a characteristic feature of the Hartland. Most exposures of the Hartland comprise various schists, schistose gneisses, gneisses, granulites, and amphibolites (Table 15). For the most part these lithologies are brown-weathering but gray- and rusty-weathering rocks are also observed, and rusty stains that typically do not penetrate the rock may be present on fracture and foliation surfaces. Muscovite and biotite are present in most of the schistose rocks, but some host only one mica. Biotite is the dominant mica in most lithologies but on occasion muscovite dominates. Many of the schists have a characteristic spangled look when viewed on foliation surfaces. This feature, distinctive for rocks in the Hartland, arises from coarse-grained mica. Beyond quartz and feldspar, garnet and sillimanite are found in a number of the micaceous rocks (Table 15), with the latter occurring in aggregates or nodules in places. Numerous quartz-feldspar, granitic, and pegmatitic lenses parallel the foliation in many localities.

Granulite beds with thicknesses ranging from approximately 10 cm to 2 m are fairly common in the Hartland Formation and are frequently interbedded with schists to produce outcrops with a well-layered appearance. Such striking co-occurrences of schist and granulite suggest the presence of graded bedding in places. The granulites are typically brown-weathering, and most are gray to dark gray on fresh surfaces. Some are quite feldspathic and others very quartzose. While the latter achieve the composition of micaceous quartzite or even quartzite, other beds are significantly micaceous and can be classified as sandy feldspathic schists. Garnet is present in many of the granulites, and some of the quartz-feldspar rocks are foliated well enough to be called gneiss. Green to greenish-black amphibolite beds of thicknesses commonly 0.5 m or less, but up to 1.5 m, are found in numerous localities within the Hartland. Most of these amphibolites contain biotite, and some are garnetiferous. In the White Plains quadrangle, amphibolite is distinctly more abundant in the Hartland Formation than in the Manhattan Schist.

## STRUCTURAL GEOLOGY

[Editor's note] *Clusters of fracture data are referenced throughout this section. They do not appear on the digital Plates 1 or 2 approved by reviewers and published with this text. However, as they are integral to the following discussion of structural geology in the quadrangle, they are published on Plate 3 as a scanned original copy of the fracture map. Note that Plate 3 was also reviewed by W. Kelly and N. Ratcliffe. Faults, lineaments, and fracture zones appear on both Plates 1 and 3. For these features, digital Plate 1 is preferentially referenced.*

*In addition, data tables associated with the equal area diagrams described below are missing and only the combined plots of all measurements have survived (Figures 4 and 5). Please see Plate 3 for insight into fracture and joint orientations.*

Geologic structures in the White Plains quadrangle are the result of at least three phases of deformation which occurred (1) in the middle Proterozoic Eon, (2) during the Taconic orogeny of the Ordovician Period, and (3) during the Acadian orogeny of the Devonian Period. Each period of orogenesis may have involved multiple episodes.

Moderate-to-high-grade dynamothermal metamorphism accompanied these deformation events. The peak metamorphic mineral assemblages in rocks at sillimanite and orthoclase grade are believed to have been produced by the Taconic orogeny at approximately 460 to 470 Ma. The extent of the Acadian metamorphic overprint is still uncertain. It cannot be ruled out on the present data that high-to-moderate-grade Acadian deformation and remetamorphism affected the rocks within the White Plains quadrangle, especially those in the southeastern part of the map.

### Folds

Hall (1979) recognized five key phases of deformation in the Paleozoic rocks of the Manhattan Prong. In the White Plains area three major classes of folds, all accompanied by plastic deformation, are easily recognizable, as is thrust faulting.

Evidence for pre-Lowerre deformation is provided by the unconformable relationship between the Lowerre Quartzite and the Fordham Gneiss. The Lowerre Quartzite truncates a large and complex fold system in the Tarrytown Reservoir belt of the Fordham Gneiss, and symmetrical repetition of Fordham units about this belt requires a large pre-Lowerre fold. Plunges on the hinge of later Paleozoic refolds of this fold suggest that the axial surface of the Proterozoic fold dipped moderately to the north or northeast prior to Paleozoic deformation. A second symmetrical repetition of Fordham Gneiss units occurs in the East Irvington Unit south of Buttermilk Hill. The two identifiable Proterozoic folds here trend west-northwest at nearly right angles to the northeast trend of the intensely developed folds in the cover rocks.

The relationship of the Yonkers Gneiss to the pre-Lowerre deformation event expressed by isoclinal folds is uncertain. The Yonkers Gneiss and the Fordham Gneiss are beveled by the pre-Lowerre unconformity, and this suggests that some post-Yonkers, pre-Lowerre deformation did affect the Yonkers and the Fordham both. Whether this deformational event was the same as the isoclinal folding demonstrated by the Fordham, or whether it reflects another pre-Lowerre event, cannot be accurately judged from the data at hand.

The geologic map and cross section (Plate 1) display a complex series of post-Lowerre folds and thrust faults that have affected the cover rocks and the Fordham basement. The most obvious folds on the map are relatively late folds with axial surfaces dipping steeply northwest. Four major folds of this generation are responsible for the repetition of the Fordham and cover rocks in belts that trend southwest-northeast across the map. A regional plunge to the northeast is characteristic of these folds and is expressed as predominance of northeast-trending mineral lineations. Folds of this generation deformed pre-existing folds that were presumably recumbent. Two such early folds have axial traces that pass (1) through the central belt of Manhattan Schist and (2) through the Fordham Gneiss belts that contain Yonkers Gneiss in the southeast corner of the map. The early central fold in the Manhattan is presumably synclinal, closing downwards and to the west, whereas the early fold in the Fordham Gneiss is believed to be anticlinal and closed to the east. The cross section does not portray the closure of either fold, both of which are exposed outside of the quadrangle. The two belts of Yonkers and Fordham Gneiss close to the northeast in the Glenville quadrangle (Hall, 1968a).

Minor cross folds with upright axial surfaces trend northeast and northwest across the map as a series of small interference folds. The age of the very late cross folds is uncertain, but they may well be Acadian or Alleghenian in origin (Hall, 1979). Post-Acadian deformation in the Manhattan Prong is not well established, but it may exist, as suggested by Brock and Brock (1985). Late brittle structures, clearly without metamorphic fabrics, are closely related to discrete brittle faults with small effects. These faults and their attendant structures are discussed in the brittle deformation section of this report.

### Thrust faults

For a discussion of the Cameron's Line thrust fault, see the preceding section on the Hartland Formation as well as the later section on brittle deformation. A lesser if still major thrust fault between the Manhattan Schist and other units is referred to as the Elmsford thrust (Plate 1). The presence of this thrust fault is largely interpretive based upon regional correlation of rock in the Manhattan Prong with thrust-faulted rocks that form the cover of the Berkshire and Housatonic massifs to the north. These are namely the Hoosac Formation (Zen et al., 1985) and the Canaan Mountain Formation (Harwood, 1975). In parts of the Manhattan Prong, the Manhattan Schist rests on units aside from the Walloomsac Formation, and, locally, units within the Manhattan

Schist are truncated by its lower contact with other units. These relationships invite the hypothesis (Hall, 1979) that the Manhattan (then referred to as Manhattan C) is allochthonous. No straightforward exposures of thrust fabric related to this fault are known in the White Plains quadrangle. Emplacement of the Manhattan Schist previously occurred as an early ductile thrust of Taconian age (Hall, 1980 and Figure 3).

In the same early event, rocks of the Hartland Formation were thrust over the Manhattan Schist and other rocks of the Manhattan Prong. The trace of this major fault passes through the southeastern corner of the quadrangle, where it now dips somewhat steeply northwest as an overturned thrust fault (Plate 1). No fabrics or mineral lineations dating from the early thrust event are recognized in the area, perhaps owing to the complexity of later metamorphism and deformation.

Several minor thrust faults, presumably associated with the fold set and strongly overturned to the southeast, are mapped near East White Plains. These faults are responsible for repetition of the Fordham Gneiss and the Lowerre Quartzite and also for a thrust fault within the Inwood Marble. None of these thrust faults extend northward through the closure of the Fordham Gneiss in the adjacent Glenville quadrangle, suggesting that they probably have only minor displacement.

## Northwest-trending faults and fracture zones

Northwest-trending faults and fracture zones are the most significant map-scale brittle deformation features in the White Plains quadrangle (Plates 1, 3). They are believed to be of important regional significance and, of the various structural elements in the quadrangle, have the highest potential to be related to recent seismicity. These and other kinds of brittle deformation will be discussed separately in a later section.

## Metamorphism

Based on regional mapping outside of the White Plains area, the bulk of the White Plains quadrangle is in the sillimanite-muscovite-potassium feldspar zone of Taconian metamorphism. However, kyanite and even staurolite are widely present, probably as relict minerals, although retrogressive textures accompany some of the lower-grade phases. In the southeastern part of the map, the Manhattan Schist closest to the Hartland Formation is in the sillimanite-muscovite zone. This high-grade metamorphism appears to have occurred during the episode that produced the prominent schistosity in the Manhattan Schist and is probably related to the northeastward-overturned folding event. It is probably Taconian in origin.

The Fordham Gneiss contains local hypersthene and wollastonite, which attests to hornblende granulite or higher-grade metamorphism during the Proterozoic Eon. It is not known whether the Yonkers Gneiss experienced this granulite facies metamorphism.

## Tectonic synthesis of the ductile phases of deformation

A diagrammatic sketch (Figure 3A) illustrates the distribution of the various rock units in southeastern New York during Middle Ordovician time, prior to major deformation. The names of individual formations are indicated on the figure. The Lowerre Quartzite, Inwood Marble, and Walloomsac Formation represent autochthonous cover (white, unpatterned areas on cross sections 3C, 3D, and 3E) and Manhattan Schist represents a facies which later became allochthonous. The Hartland Formation represents eastern region Cambrian-Ordovician cover that is interpreted to have been deposited on oceanic crust. Early in Taconian compression and crustal shortening, Manhattan Schist cover and the Hartland Formation were transported westward along faults (Figure 3B).

Cameron's Line is the thrust fault along which eastern cover was transported, together with possible bits and pieces of oceanic crust that may be represented by the Bedford Gneiss Complex, Croton Falls complex, and Peach Lake complex located north of the White Plains quadrangle (Hall, 1980). This initial thrust surface had a long and complex history of subsequent movement during Taconian and probably Acadian deformation, and also became the site of some later (Mesozoic and younger (?)) high-angle faults. Isoclinal nappe-like folds developed later in Taconian deformation, involving the basement, autochthonous cover, and allochthonous cover (Figure 3C). These folds were refolded by a later set of isoclinal folds that are probably also Taconian (Figure 3D). There is local evidence for some faulting on the overturned limbs of the early phase isoclinal anticlines, and work is in progress to determine the nature and extent of such faulting. The White Plains anticline, a later regional anticline (antiform) that is asymmetrical to the east, subsequently refolded the previous set of folds (Figure 3E). This probably occurred during Acadian deformation, and again basement, autochthonous cover, and allochthonous cover were involved in the folding and associated metamorphism.

## Brittle deformation

A reconnaissance study was made of faults and fractures in the White Plains quadrangle during June 1981 with the detailed 1:24,000 scale bedrock geologic map as a base (Plate 1). The bedrock geologic map was completed beforehand with financial support from the New York State Geological Survey. No previously-unidentified major faults were found in the present study, but new data was obtained particularly in relation to post- metamorphic fracture zones and steeply-dipping faults, here called high-angle faults. These findings are presented both on Plate 3 and lower hemisphere equal area net plots (Figures 4, 5). A series of brief comments on specific fault- and fracture-related features follows this general discussion. It should be kept in mind that the orientation data shown on the equal area plots does <u>not</u> represent extensive or statistically representative data but simply

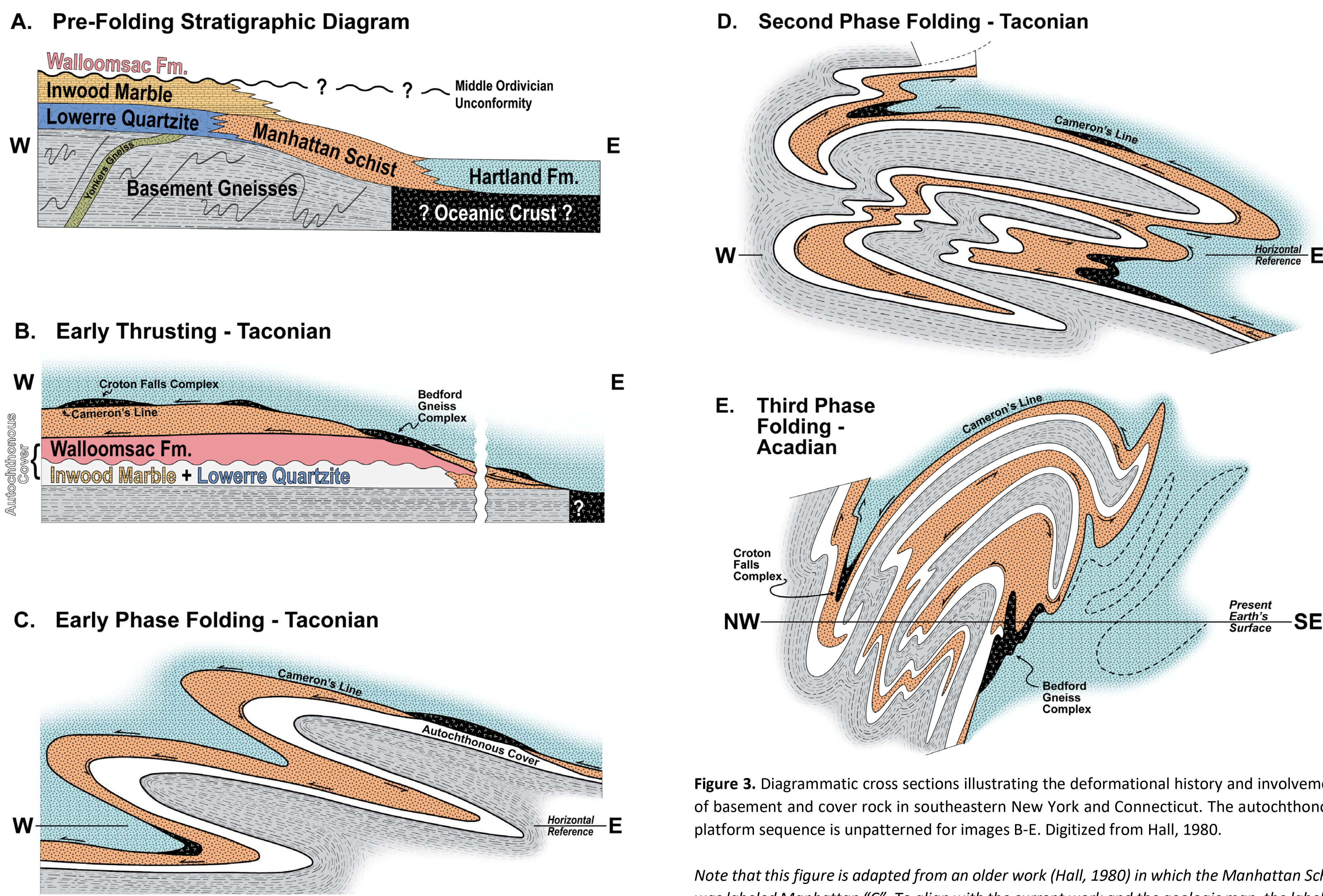


**Figure 3.** Diagrammatic cross sections illustrating the deformational history and involvement of basement and cover rock in southeastern New York and Connecticut. The autochthonous platform sequence is unpatterned for images B-E. Digitized from Hall, 1980.

*Note that this figure is adapted from an older work (Hall, 1980) in which the Manhattan Schist was labeled Manhattan "C". To align with the current work and the geologic map, the label on this version is Manhattan Schist. —Ed.*

measurements of structural features selected subjectively on the basis of apparent prominence in the rock exposures visited.

### *Thrust faults*

Two main regional thrust faults are known to be present in the quadrangle, both of which developed in association with Taconian deformation. One of these, the Elmsford thrust, separates the Cambrian Manhattan Schist from the Middle Ordovician Walloomsac Formation; and the other, the Cameron's Line thrust fault, separates the schists, amphibolites, and gneisses of the Hartland Terrane from the Manhattan Schist to the west (Plate 1 and Hall, 1980). The recognition of these thrust faults is based on regional stratigraphic relations (Rodgers et al., 1959; Hall, 1968b, 1980) but their presence is supported by minor thrusts and local mylonitic foliation present in individual outcrops near the large-scale structures. In addition to the two regional thrust faults, there is evidence for thrusting on at least the local scale involving the Middle Proterozoic Fordham Gneiss and the Cambrian Lowerre Quartzite in the vicinity of Silver Lake at the eastern edge of the quadrangle (Plate 1). This deformation is evidenced by local stratigraphic repetition of rock units on the northwestern side and northern end of Silver Lake in the Glenville quadrangle and mylonitic foliation in the gneisses. This structure could be an extensive fault involving basement and cover rocks in the inverted limb of a large nappe cored by Fordham Gneiss (Hall, 1968b, 1980), but further work is needed to evaluate the possibility.

### *High-angle faults and fracture zones*

All of the post-metamorphic faults and all of the fracture zones that are recognized in the quadrangle, except for the Gory Brook zone, have general trends of N20°W to N40°W (Plate 1). This is also a common trend for outcrop-scale fractures and slickensided surfaces. High-angle faults are easier to recognize if they lie athwart the regional trend of the stratigraphy, foliation, and map-scale folds. It is thus relatively easy to see where stratigraphic contacts are offset by northwest-trending faults in this quadrangle, and this orientation effect was understood before field reconnaissance of fracturing was begun.

An effort was made to identify post-metamorphic high-angle faults with northeasterly trends by studying rock exposures for evidence of faulting or unusual fracturing along northeast-trending topographic lineaments, and also by locating and tracing sets of slickensided fractures and fracture zones from outcrop to outcrop along the regional strike. This attempt was unsuccessful, and there is presently no concrete evidence for northeasterly-trending, high-angle post-metamorphic faults in the White Plains quadrangle. There is, however, some evidence for northeast-trending faults in the Fordham Gneiss and Yonkers Gneiss northeastward along strike in the Glenville quadrangle, and these faults may extend into the White Plains quadrangle.

Northeast-trending brittle faults and slickensided fracture surfaces were observed in numerous outcroppings, and their orientations are shown on Plate 3 and on the equal-area plots (Figures 4, 5). These are mostly outcrop-scale fractures, but some extend beyond the limits of the outcrop and may belie somewhat larger-scale northeast-trending faults not yet identified.

The only features mapped as post-metamorphic high-angle faults are those where offsets of stratigraphic contacts are mappable. Fracture zones are shown on the map (Plate 1) where the rocks are more highly fractured, slickensided surfaces are present, or mylonitic foliation is common. The fracture zones are represented by lines on the map that are meant to include rocks in a region several hundred meters wide. On this basis, three high-angle faults and four fracture zones have been identified in the White Plains quadrangle (Plate 1). In addition, the topographic lineaments have been mapped (Plate 1).

The Hawthorne fault and the State Line fault both show clear offset of stratigraphic contacts in the White Plains quadrangle region. The White Plains City Boundary fault is queried on the map because the apparent offset of contacts may also be explained by folding (Plate 1). There is some topographic expression of the map traces of the faults in that stream valleys of various sizes tend to be etched out along them. All three of these faults have an apparent right-lateral sense of movement indicated by the offset of contacts, but the amount of dip-slip movement contributing to the offset map patterns is unknown. Assuming that slickensided fracture surfaces in outcrops near the high-angle faults are directly related to movements that produced the faults, an oblique-slip sense of movement is indicated by the rakes of the slickensides.

The oblique-slip sense tends toward strike-slip in that the rakes of the slickensides are typically less than 45° and a great many are less than 25°. It follows that an oblique-slip to strike-slip sense of movement is also indicated by the typically-steep plunges of the rotation axes shown on the equal-area plots (Figures 4, 5). A rotation axis theoretically approximates the orientation of the intermediate stress axis and is defined by the orientation of a line on the slickensided surface that is perpendicular to the slickensides. The sense of relative movement on slickensided surfaces as shown on the map and equal-area plots (Figures 4, 5) was determined by one or more of the following criteria: 1) the smooth and rough sense felt along the direction of the slickensides; 2) the sense indicated by fibrous minerals ("slip fibers") on the surface; 3) the drag sense of foliation or bedding; and 4) observed apparent offset of veins, dikes, or beds in conjunction with slickenside orientation. Determinations of relative movement sense by touch were evaluated as excellent, good, fair, or poor, and only those rated excellent or good are plotted on the equal-area diagrams.

In many but not all instances, the sense of movement determined using the above criteria on small-scale fracture surfaces is opposite to that indicated by the offset contacts on the map. The reason for this apparent lack of consistency between outcrop-scale observations and map-scale offset is uncertain, but it may be that many of the observations of relative movement sense

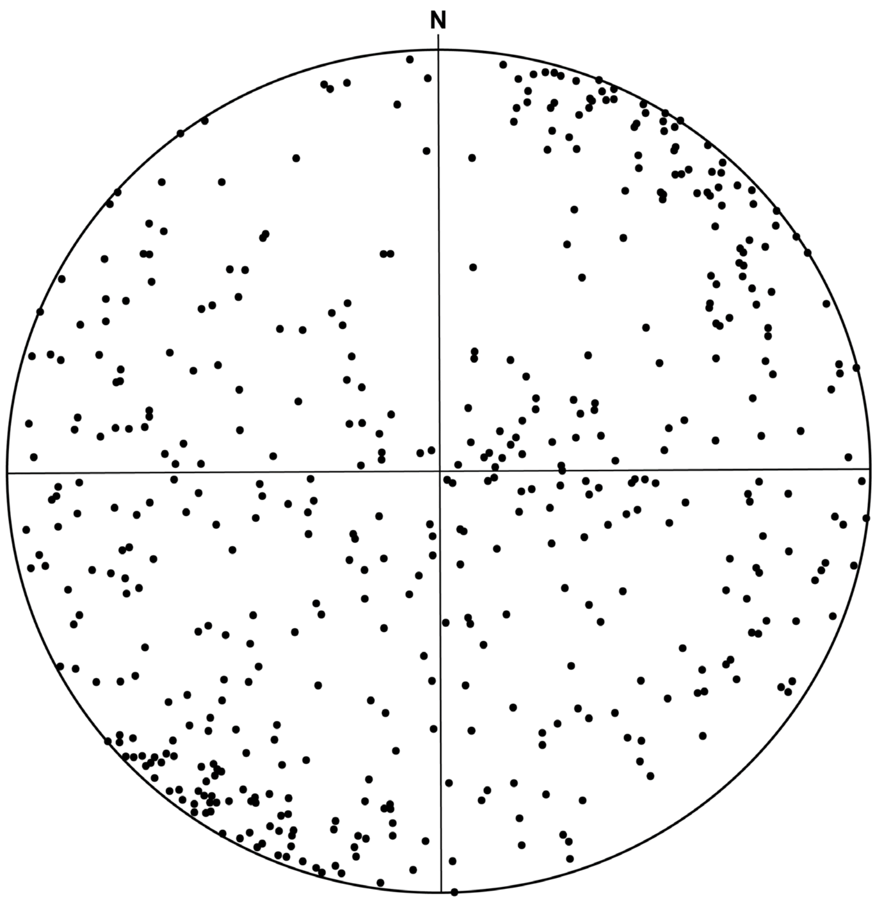


**Figure 4.** Poles to joints measured in the White Plains quadrangle.

*The very leftmost edge of the available scan was truncated and it is possible that there were data points in that area —Ed.*

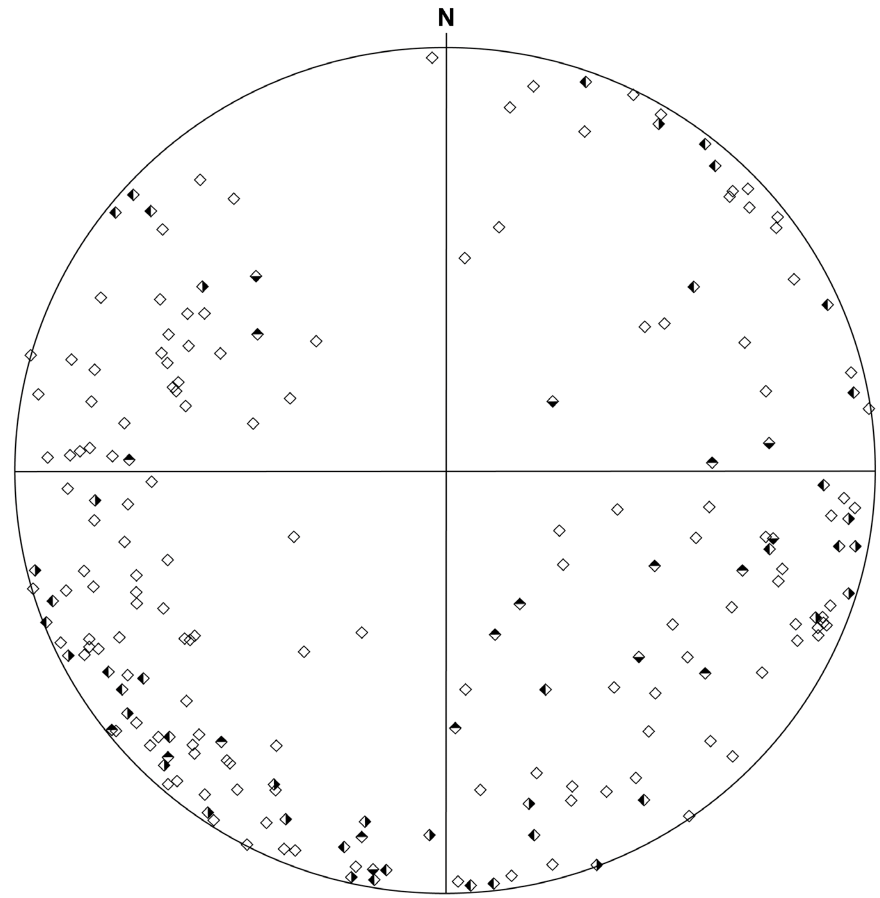


**Figure 5.** Poles to slickensided surfaces and faults measured in the White Plains quadrangle.

*The very leftmost edge of the available scan was truncated and it is possible that there were data points in that area —Ed.*

based on touch yield incorrect results, that many of the small-scale features are not related to the map-scale faults, or that slickensides record rejuvenated movement on the faults under a different stress system.

The northwest trend of three of the four fracture zones shown on the map (the Archville, Reservoir, and Dobbs Ferry fracture zones) implies a relationship with the high-angle faults. In spite of outcrop-scale evidence for faulting in the form of relatively high concentrations of fractures and slickensided surfaces, there is no well-defined mappable offset of stratigraphic contacts along the traces of the fracture zones. Thus, although there may be some displacement, it is either very small or parallel (or subparallel) to the traces of the stratigraphic contacts on the fracture zone(s). After these fracture zones were mapped, the locations of three earthquake epicenters in the White Plains quadrangle were supplied by Ellyn Schlesinger-Miller of the Lamont Doherty Geophysical Observatory. One of the epicenters (May 7, 1980, magnitude 2.6 and depth of 0.2 km) plots on the trace of the Dobbs Ferry fracture zone. Taken at face value, this seismic activity indicates that the Dobbs Ferry fracture zone is currently active.

[Editor's note] *The earthquake epicenters are not plotted on any available draft of the map and do not appear on the digital version or Plate 3. Latitudes and longitudes could not be found. In-text references to an associated plate ("the map") have been removed.*

A line projected southeastward on the map directly along the trend of the Archville fracture zone aligns very well with the White Plains City Boundary fault, and there are several elongate topographic features along its length. This may or may not be significant. There is no well-defined offset of stratigraphic contacts along this projected line. Nor is it possible to map the fracture zone along it with the limited outcrop information available, although more field work might provide the additional data needed. The alignment of topographic features along the projected line is discontinuous and may only be an artifact because the regional northwesterly-trending set of fractures controls the orientation of many valleys throughout the quadrangle. Thus the topographic array does not necessarily demonstrate a through-going fracture zone. The Reservoir fracture zone (named for White Plains Reservoir No. 1) has a pronounced topographic expression, and although it branches off from the Hawthorne fault, no mappable offset of stratigraphic contacts occurs along it.

The Gory Brook fracture zone trends northeastward parallel to the regional strike and has a marked topographic expression. Shearing is interpreted to have occurred along the zone during folding and metamorphism, as bedrock along much of its extent is marked by metamorphic mylonitic textures. There may also be a degree of post-metamorphic movement along the Gory Brook zone. Slickensided surfaces and fractures are locally abundant, although they are not found consistently across its length. There is intense fracturing and evidence for faulting along the northeasterly extension of the Gory Brook fracture zone in the Ossining quadrangle, called by Ratcliff the Willwood fault (Hall, 1981).

### *Topographic lineaments*

There are numerous topographic lineaments in the White Plains quadrangle, some of which may be controlled by fractures. Several were studied for evidence of faulting and/or unusual concentrations of fractures. Some of the data obtained are presented on the map and the equal-area plots (Figures 4, 5). There is no evidence in bedrock exposures for fault control of any of the topographic lineaments studied, and the only such feature that is named and plotted on the map is the Bloomingdale Pond lineament in the southeastern part of the quadrangle.

### *Seismicity and its possible relation to geologic features*

In addition to the epicenter located in the Dobbs Ferry fracture zone, the locations of two other epicenters were supplied by Ellyn Schlesinger-Miller of the Lamont Doherty Geophysical Observatory and are plotted in the northeast ninth of the quadrangle. The epicenter of the August 20, 1976 earthquake (magnitude 2.5 and depth of 6.22 km) is near the northeastern edge of the quadrangle, and the epicenter of the September 4, 1980 earthquake (magnitude 3.2 and depth of 12.61 km) is south of Thornwood and west of Columbus Avenue. The errors in horizontal location amount to less than 1 km. The errors in depth are somewhat greater but are also less than 1 km (personal communication, Ellyn Schlesinger-Miller, 1981). Error bars of 1 km are indicated on the map.

[Editor's note] *The earthquake epicenters are not plotted on any available draft of the map and do not appear on the digital version or Plate 3. Latitudes and longitudes could not be found. In-text references to an associated plate ("the map") have been removed.*

Neither of these epicenters is very near to the map trace of a known fault or fracture zone, which is not surprising considering their focal depths. Due to the horizontal and vertical errors involved in locating the foci and the uncertainty in the amount of dip of the State Line fault, it is not presently possible to positively relate either of these earthquakes to a known fault. However, taking the vertical and horizontal locations of the foci at face value and assuming constant southwestward dip values for the fault as outlined below, there is a good suggestion that both earthquakes represent movement on the State Line fault. The August 1976 epicenter plots about 0.67 km from the projected trace of the State Line fault on the map, and if the fault is assumed to be planar and to dip 84° southwestward, the focus lies on its projection at a depth of 6.22 km. The epicenter of the September 1980 earthquake plots about 2.23 km southwest of the State Line fault, 0.5 km northwest of the valley occupied by Columbus Avenue, and 0.72 km southeast of the Saw Mill River

Valley. Both of these valleys are marked topographic lineaments related to marble bedrock beneath them, and there is no evidence in the few bedrock exposures present that either is fracture-controlled. If one assumes that the State Line fault dips about 80° southwestward, the focus lies on its projection at a depth of 12.61 km beneath the epicenter.

There are some post-metamorphic high-angle faults in a building excavation in bedrock approximately 100 feet downhill from the 1980 epicenter, west of Westlake High School and east of Columbus Avenue. Many of these faults dip more steeply than 85°, and their exposure occurs within the range of horizontal error for the epicenter location. It is possible that they are related to, or perhaps are even part of the surface expression of, a fault associated with the September 1980 earthquake. However, there is no hard evidence that any of the above structural features or topographic lineaments are directly related to either earthquake; the seismicity could be linked to faults exposed at the surface outside of the quadrangle.

Despite this paucity of hard evidence, it is interesting to note that if the State Line fault dips 82° southwestward, the foci of the August 1976 and September 1980 earthquakes lie about 200 meters and 450 meters, respectively, from its projection at depth (Figure 6). If the dip decreases slightly with increasing depth, both foci will be closer to the projection of the fault and can easily be made to plot on the fault. Thus in attempting to relate the current seismicity data to the geologic data, it is concluded that there is a reasonable likelihood that there is some current seismicity associated with the Dobbs Ferry fracture zone and a reasonable possibility that current seismicity is associated with the State Line fault. If either one or both of these geologic features are in truth related to current seismicity, it is noteworthy that both are steep and trend northwest across the regional northeasterly strike of the stratigraphy.

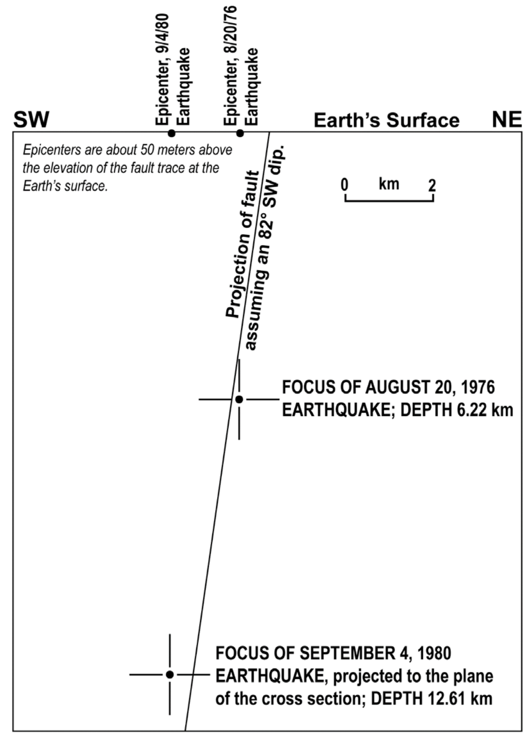


**Figure 6.** A vertical cross section perpendicular to the State Line fault with the positions of the August 1976 and September 1980 earthquake foci projected to it.

### *Manhattan Schist thrust*

Structural data collected in the vicinity of the Manhattan Schist thrust fault in the rock cuts along the abandoned railroad west of Mamaroneck Avenue in White Plains are presented on the map and equal-area plots (Plate 3, Figures 4, 5). Numerous faults and shear zones subparallel to bedding and foliation as well as some northwest-trending slickensided surfaces are exposed in these rock cuts. The ductile faults developed during metamorphism, as indicated by metamorphic minerals in the mylonites and the pegmatitic rocks locally associated with them. A particularly good example of this is an extremely sillimanite-rich layer, about 2.5 cm thick, which developed in a shear zone seen subparallel to bedding in a rock cut located on the west side of a railroad bed a few meters north of the Bryant Avenue Bridge. There is also evidence for post-metamorphic fault movement in the form of slickensided fractures and brecciated or highly fractured rocks—both of which are related, in some places, to renewed movement on older shear zones.

There is uncertainty concerning how much of the faulting displayed in these rock cuts is related to the Manhattan Schist thrust and how much may be due to shearing beneath the Fordham Gneiss on the overturned southeast limb of the White Plains anticline (Hall 1979). There are also faults, shear zones, and rocks with mylonitic textures in rock cuts in the vicinity of the Manhattan Schist thrust along the Cross Westchester Expressway at Elmsford and along the southbound entrance to the Sprain Brook Parkway (Plate 3). Most of the slickensided surfaces and small-scale faults here trend northwest and tend to be strike-slip in nature, as seen from the steeply plunging rotation axes on the equal-area diagram (Figure 5). Thus most of the faults in this locality are post-metamorphic and unrelated to the Manhattan Schist thrust, although northeast-trending mylonitic foliation shown on the equal-area diagram may be related to the thrusting.

### *Cameron's Line thrust*

There are relatively few bedrock exposures in the vicinity of the Cameron's Line thrust in the White Plains quadrangle. Data that are available are shown on the map.

### *Hawthorne fault*

This high-angle fault trends N20°W to N30°W across the quadrangle, extending from the north-central edge, near

Hawthorne, southeastward to the eastern edge, south of East White Plains. The location of the fault is questionable between the intersection of the Taconic State and Saw Mill River Parkways and the ravine at Virginia Avenue, south of the center of Valhalla. There is good evidence for a fault in the valley northwest of the intersection of the Parkways, here called "Graham Valley," and for a fault in the ravine at Virginia Avenue. The map trace of the Hawthorne fault as drawn on Plate 1 is based on the interpretation that these two localities are along the same fault and that it runs along the main valley south of Hawthorne.

There are two alternate possibilities that also seem reasonable. The fault trace could project along a straight line, approximately N22°W, from Virginia Avenue to "Graham Valley." This has the advantage of bringing the fault trace somewhat closer to the faulted rocks exposed along the Sprain Brook Parkway and also along some suggestive topographic features. It is also possible that there are two separate en echelon faults and that the Hawthorne fault extends southeastward along the main valley, dying out in the Reservoir fracture zone, while a second fault extends northwest and southeast from the ravine at Virginia Avenue. There is no compelling evidence in the present rock exposures to choose among these possibilities.

The extension of the Hawthorne fault southeastward from Virginia Avenue to the east edge of the map is based on the offset of the apparent projections of contacts where there is very little outcrop control, and also on topography. Fracture data are plotted on the map in the vicinity of the fault, and equal-area diagrams of data collected from the "Graham Valley" region, the roadcuts along the Sprain Brook Parkway, and the sharp valley at Virginia Avenue are also presented (Figures 4, 5).

All of these diagrams show the presence of steeply dipping northwest-trending fractures and faults, and the rotation axes on slickensided surfaces plunge steeply, indicating strike-slip movement. There is no strong consistency of relative movement on the northwest-trending slickensided surfaces; evidence exists for both left-lateral and right-lateral movement on different surfaces. The amount of dip-slip component that contributes to the apparent right-lateral sense indicated by the offset of contacts is unknown.

### *State Line fault and White Plains City Boundary fault*

The evidence for these two high-angle faults is described above in the general discussion, and structural data associated with them are plotted on the map and equal-area diagrams (Plate 3, Figures 4, 5).

### *Archville fracture zone*

The Archville fracture zone, in the northwestern corner of the quadrangle, is defined on the basis of highly fractured and faulted rocks in (1) the road cuts on Route 117 where it intersects the New York to Albany Post Road, (2) in road cuts south of the large building west of the Post Road, and (3) along the railroad tracks at the shore of the Hudson River. Localities (1) and (2) display particularly good examples of faulting and fracturing. The presence of granitic and pegmatitic rocks, as well as mylonitic textures associated with some of the northeast-trending faults, indicates ductile faulting during metamorphism, whereas twisted, brecciated, and deeply-weathered rock zones indicate post-metamorphic fracturing and faulting. In places the post-metamorphic features are developed along the older fault zones and elsewhere in new zones.

There appear to be two general sets of steeply-dipping faults in this fracture zone, although they are not grouped together in well-defined clusters on the equal-area plots (Figures 4, 5). One set trends southeasterly, subparallel to the regional foliation, and the other trends northwesterly. Rotation axes have various orientations, indicating that some faults have dominantly dip-slip movement while others are dominantly strike-slip in nature.

One speculation is that the northeast-trending faults associated with mylonitic zones are related to thrusting in the vicinity of the Fordham Gneiss and the cover-rock contact, which trends northeast and is exposed just north of the White Plains quadrangle at the Hudson River. If indeed a regional thrust fault occurs in association with this contact, it may be the same thrust as that indicated by the mylonitic rocks and repetition of stratigraphy in the vicinity of Silver Lake at the eastern edge of the White Plains quadrangle. If this speculation has any validity, the connection between the two would be beneath the surface and around several folds.

Joints in the Archville zone are generally arrayed in orientations subparallel to the faults, but there is an apparently important additional set that dips gently (Figure 4). Notably, a peculiar fragmental material is present in the vicinity of the Archville zone in the rock cut south of the large building west of Post Road (Plate 1, see *Fragmental rocks*).

### *Dobbs Ferry fracture zone*

The Dobbs Ferry fracture zone extends N42°W from the vicinity of the Saw Mill River Parkway at the southern edge of the quadrangle, past Springhurst School and toward Mercy College. The epicenter of the May 1980 earthquake plots on its map trace south of Ashford Avenue and represents a shallow-focus earthquake that is apparently related to movement in the Dobbs Ferry zone. One might interpret the offset contacts of units of the Fordham Gneiss as being due to apparent right-lateral displacement along a fault, but other contacts do not show such a relationship and this apparent offset is here interpreted to represent a fold.

Evidence for the Dobbs Ferry fracture zone is indicated by the data clusters plotted along its extent on the map and orientation data on the equal-area diagram (Plate 3 and Figures 4, 5). The zone is also marked by valleys that are seemingly controlled by fracturing. Rock exposure is unfortunately limited here, but the concentration and prominence of slickensided surfaces increases toward the fracture zone, and scattered about its general northwest trend is a set of steeply dipping fractures with a range of strikes (Plate 3). Some of the fractures in this set are slickensided, and many are lined with the minerals quartz, epidote, chlorite, or calcite. Note that a number of these fractures trend nearly east-west and dip steeply northward (Figures 4, 5).

Another steeply-dipping set of fractures trends northeasterly subparallel to the foliation and includes numerous slickensided surfaces and joint zones. Mylonitic foliation is parallel to this set of fractures and appears to be a dominant feature on the equal-area diagrams (Figures 4, 5), but this is misleading because the mylonitic rocks were chosen selectively during field work. It is typical for rocks with this older mylonitic texture to be the sites of younger, more brittle deformational behavior in that they commonly display numerous fractures that may or may not be slickensided.

Both the northwest- and northeast-trending fracture sets, including many slickensided surfaces, are very prominently developed where the Dobbs Ferry zone intersects the Saw Mill River Valley. There is no strong evidence that the Saw Mill River Valley is controlled by fracturing or faulting, and thus the apparent enhancement of fracturing in its vicinity along the Dobbs Ferry fracture zone is presumed to be due to the intersection of the fracture zone with the anisotropy caused by the contact between the Fordham Gneiss and the Inwood Marble (see *Saw Mill River Valley*).

An array of gently dipping fractures is also prominent in the vicinity of the Dobbs Ferry zone, and its relationship to this fracture zone is uncertain inasmuch as gently-dipping sets of fractures are common elsewhere (Figure 4). The fractures in this set dip generally northeastward in the Dobbs Ferry zone, and there are numerous joint zones in this orientation as well (only two are plotted on the equal-area diagram of Figure 4). Some of these joints are marked by deeply-weathered rock, a feature perhaps related to the exploitation of broken rock. There are also smooth joint surfaces in this orientation, at least one of which displays slickensides.

### *Reservoir fracture zone*

This fracture zone extends southeastward from the presumed trace of the Hawthorne fault and follows fairly straight valleys to the edge of the quadrangle. Two equal-area diagrams show orientation data for the Reservoir zone (Figures 4, 5). One diagram contains data from the basement gneisses along the fracture zone in the vicinity of White Plains Reservoir No. 1, and the other plots data from the cover rocks along the zone in the vicinity of Valhalla. In the gneisses a steeply-dipping set of fractures strikes northwesterly, and another set dips moderately (±50°) eastward and strikes nearly north-south. Both of these sets are at an angle to the foliation, which trends northeast and dips northwest. No evidence was found for faulting in the gneisses along the Reservoir zone, and even slickensided fractures are uncommon. A steeply-dipping and northwest-trending set of fractures is present in the cover rocks northwest of the basement gneisses (Plate 3), and a number of slickensided surfaces have been observed within it. The development of the slickensided surfaces may be related to the proximity of the Hawthorne fault.

### *Gory Brook fracture zone*

The Gory Brook fracture zone crosses the northwestern corner of the quadrangle, from Tarrytown northeastward along the valley of the Pocantico River and Gory Brook (Plate 1). This straight and narrow valley appears to be controlled by the presence of well-foliated, rusty-weathering sillimanite (±) garnet-biotite schist (or schistose gneiss) that locally has muscovite and/or chlorite on the foliation surfaces. The latter two minerals presumably occur in relation to retrograde metamorphism. The schistose foliation is axial planar to early isoclinal folds and is mylonitic in many places. The presence of metamorphic minerals, granitic and pegmatitic layers, and quartz layers and veins that lie along the foliation indicate that mylonitic textures developed during metamorphism. Garnets are deformed and flattened in the plane of the foliation, indicating that they were further deformed following their formation.

All of these features that are parallel to the foliation are folded along with the foliation, and this set of folds has an axial planar crenulation cleavage locally developed in the schistose rocks, as well as a faint axial planar foliation defined by the preferred orientation of biotite in the granitic rocks. Therefore, at least the initial development of the mylonitic textures and possible associated larger-scale shearing occurred during an early phase of deformation that was related to metamorphism and the production of isoclinal folds. The distorted garnets and the presence of muscovite and chlorite on the foliation surfaces indicate that mylonitic foliation continued to develop after the peak of prograde metamorphism, perhaps in its waning stage or perhaps associated with a subsequent event.

A later phase of deformation resulted in another set of folds with an axial planar crenulation cleavage and apparently associated shearing. There are local shear zones or faults on the foliation in this area, some of which have very high concentrations of biotite along them and some of which are marked by fractured rocks. This shearing and faulting is particularly noticeable along the contacts of granitic gneiss and pegmatitic gneiss with the schistose rocks. It is difficult to be certain whether the granitic rocks localize the faulting because they produce an anisotropy in the rock, or whether they are intruded along shear zones. However, the first of these interpretations seems to fit best in this case.

There is little evidence for late brittle fracturing along the Gory Brook fracture zone in the White Plains quadrangle because highly fractured rocks with slickensided surfaces do not persist along it. Where such brittle features are present, they seem to be related to northwest-trending structures represented on the equal-area diagram (Figure 5), in contrast to the common northeast-trending mylonitic foliation. For example, the rocks in the highway cuts on Route 117 near the bridge over Gory Brook display brittle features, as well as shear zones with mylonitic rocks, that are parallel to the Gory Brook fracture zone. It is suggested that the brittle features at this locality are related to a northwest-trending zone that extends along the topographic lineament (or fracture zone?) marked in part by the valley on the south side of Route 117 that contains a small tributary to the Pocantico River (Plate 1). Thus, the Gory Brook fracture zone has a marked topographic expression that seems to be due to rock type and foliation, much of which is mylonitic. While there may be some post-metamorphic renewed slippage along it, such movement is not prominently displayed in the White Plains quadrangle, although it is evidenced in the Ossining Quadrangle to the north.

## Topographic lineaments: Possible fault-related features

### *Hudson River shore north of Kingsland Point*

The Hudson River Valley is a major regional topographic lineament, and it marks the eastern edge of the Newark Basin at the latitude of White Plains. In the White Plains quadrangle, the gneisses along the shore of the Hudson River are the rocks that most closely approach this Mesozoic basin and its associated faults. Therefore the railroad cuts and other rock exposures near the Hudson River north of Kingsland Point were studied for evidence of Mesozoic and younger brittle faulting. The orientation data obtained are plotted on an equal-area diagram (Figures 4, 5).

The plot shows (1) the common steeply-dipping, northwest-trending set of fractures; (2) a gently-dipping (mainly westward) set of fractures; and (3) a set fractures, including numerous faults and shear zones, that is subparallel to the northeast-trending foliation. Some of these shear zones are deeply weathered, and in many places they are marked by concentrations of biotite, amphibole, or chlorite that occur alone or in combination. Such concentrations seem to represent the residue of minerals that remained after differential solution during shearing. Slippage has occurred along some foliation surfaces (such as in the pink granitic gneisses east of the Philipse Manor railroad station) that are markedly smooth and display mineral lineation as well as a slickensided appearance. These shear zones developed at an early stage in the deformational history, as they are folded in a number of places, but minor renewed movement may have occurred along them. It should be added that much of the rock exposed in this region shows little or no evidence of faulting.

### *Sheldon Brook Valley*

The Sheldon Brook Valley is an east-west trending valley located to the east of the Tappan Zee Bridge. It is a marked topographic depression developed largely atop biotite-hornblende-quartz-feldspar gneiss and pinkish granitic gneisses of the East Irvington Unit of the Fordham Gneiss (Plate 1). These gneisses are not marked by mylonitic textures or intense fracturing, and nor is there any evidence for faulting in the map pattern. The valley is apparently controlled to a large extent by the orientation of the foliation and gneiss layers, which wrap around the hinge of a fold there. Fracture data from the region of the Sheldon Brook Valley are displayed on the map and an equal-area diagram (Plate 3, Figure 5).

An interesting rock exposure that displays faults and related features in the Sheldon Brook Valley is found at the eastern end of a building construction site south of Route 119, in a rock cut about 225 m west of the bridge where the Cross Westchester Expressway overpasses Route 119 (Plate 1). A fault dipping gently southwestward that slightly offsets a fold in the foliation by an amount less than 0.5 m is a prominent feature in the exposure. The dip of the fault is varied because of irregularities and warps within it, but the estimated average is 20° to the southwest.

A small fissure, up to about 10 cm in width, is developed along this fault, and it is occupied by a finely laminated unconsolidated clay that contains scattered small rock fragments. The clay laminations are folded into asymmetrical and southwesterly overturned folds. If these folds developed as a result of slippage on the fault, they indicate dip-slip movement with a normal fault sense. Such slippage could, of course, be related to recent sliding on this wet clay layer. Dip-slip movement is also indicated by the elongation direction of irregularities in the fault surface. The nature of the origin of the unconsolidated material is problematical.

A topographic lineament is plotted on the map along the valley occupied by the New York Thruway south of the Sheldon Brook Valley (Plate 1). The gneisses exposed in the rock cuts along this valley do show a number of northeast-trending faults and shear zones subparallel to the foliation and along pegmatitic gneiss contacts.

### *Saw Mill River Valley*

The Saw Mill River Valley is a prominent linear topographic feature (Plate 1). It is underlain by dolomitic marbles of Members A, B, and C of the Inwood Marble, which probably control its development. The contact between the Inwood Marble and the Fordham Gneiss—located along the western side of the valley—dips steeply judging by the attitudes of bedding and foliation, which dip from vertical to about 70° southeastward. This steeply-dipping contact occurs between rocks that have a high contrast in mechanical properties and thus is a boundary along which some motion might occur, but evidence for major movement is lacking. Slickensided surfaces and small-scale faults are present in local outcrops along the valley (Plate 3); orientation data are shown on two equal-area diagrams, one for the region north of

Elmsford and the other for that south of Elmsford.

Mylonitic foliation and slickensided surfaces have orientations that encompass the trend of the Saw Mill River Valley and thus show some evidence for minor movement in the rocks. One notable “fault” is present in the Inwood Marble east of the south end of Woodlands Lake (Hall, 1968b). There is almost no offset of bedding along it, but the attitude of bedding differs slightly on opposite sides of the fault and numerous fractures occur in association. If there is a major fault along the Saw Mill River Valley in the White Plains quadrangle, it must be along a surface or a very narrow zone. There is no evidence of any major disruption of the rocks even in outcrops toward the center of the valley, such as those east of the Saw Mill River Parkway at Ardsley. The fractures and slickensided surfaces that are pronounced in the valley east of Chauncey are interpreted to be related to the intersection of the Dobbs Ferry fracture zone with the anisotropy caused by the contact between the Fordham Gneiss and Inwood Marble.

### *Bloomingdale Pond topographic lineament*

The Bloomingdale Pond topographic lineament is a north-south-trending topographic feature in the southeastern part of the White Plains quadrangle. It lies along the north-south valley that contains Bloomingdale Pond and extends off the southern edge of the map about 700 m east of Mamaroneck Road (Rte. 125). North of Bloomingdale Pond it is defined by some smaller valleys and the valley of the White Plains Reservoirs. The railroad cut west of Mamaroneck Avenue is in the region of this lineament, but the fracturing and faulting there are believed to be related mainly to the Manhattan Schist thrust (see *Manhattan Schist thrust)*, and the orientations of these features are included only on the equal-area diagram associated with the thrust (Figure 5). Otherwise, outcrops are relatively scarce along the lineament, and data are thin (Plate 3). There is no particular evidence in the White Plains quadrangle to indicate that this lineament is fault-controlled (Figures 4, 5), although there is an intense set of fractures that strikes N16°E near the dam at the foot of White Plains Reservoir No. 1 and a fault is mapped along its extension in the Mamaroneck quadrangle to the southeast (Pelligrini, 1977).

### *North White Plains*

Numerous northeast-trending faults, shear zones, and zones of mylonitic foliation are present in outcrops in North White Plains in the vicinity of Route 22 and the prominent valley that extends southwestward from it (Plate 3). These structural features are shown in cluster plots on the map and on an equal-area diagram (Figure 5). It is not presently possible to tie these outcrop-scale structural elements to any map-scale fault, although they may be somehow related to the Reservoir fracture zone or a northeast-trending fault that is parallel to the contacts between rock units.

### *Columbus Avenue Valley*

This northeast-trending linear valley located south of Thornwood is apparently controlled by the marble beneath it.

### *Joint-controlled valley at Ardsley*

The sharp and narrow valley cut in Manhattan Schist in Ardsley, about 800 m south of Ardsley High School (Plate 1), is controlled by prominent large joints. No slickensides were identified on any of the fracture surfaces, however.

## Fragmental rocks

A peculiar fragmental material that is consolidated at some places and unconsolidated at others occurs along small-scale faults at three localities in the White Plains quadrangle. Two of the localities were pointed out above, one along the Archville fracture zone and the other near the east end of the Sheldon Brook Valley. The third is in the rock cut that faces the southbound Saw Mill River Parkway exit at Eastview. The material in all of these places is sand-size and clay-size with larger rounded pebble-size rock clasts, and it has a consistency ranging from wet clay, to friable, to well-indurated material. The relative abundance of the different grain sizes is varied, and in one place, at the Sheldon Brook Valley locality, there is a folded laminated clay. The material may be Mesozoic or younger debris filling that sifted in along fissures that were connected to the surface, or it may be cataclastically-derived or have some other origin. The origin of this material is uncertain, but it is thus far know to occur only along small-scale faults.

## Granitic and pegmatitic rocks

Many of the observed shear zones and mylonitic textures occur along the margins of and/or within granitic gneiss layers and pegmatitic layers that are subparallel to the foliation and compositional layering in the surrounding rocks. Where these rocks display mylonitic textures, the shearing clearly postdates their emplacement. It is difficult to decide whether these rocks are the sites of shearing because they constitute an anisotropy or whether they are generally preferentially emplaced along shear zones.

## Slickensided surfaces and faults

Most of the slickenside orientations indicate the marked tendency toward strike-slip movement that is both left-lateral and right-lateral. This can be seen from the rotation axes, which are predominantly steeply-plunging, on the equal-area diagrams and the movement senses indicated by the poles to slickensided surfaces and faults (Plate 3; Figures 4, 5). Also, there is a general tendency for these slickensided surfaces to trend northwest and to dip steeply. One might conclude from this tendency that the larger-scale faults are of strike-slip nature and also that there is an important set of northwest-trending faults in the region.

## Gently dipping fractures

A set of gently dipping fractures is present throughout the White Plains quadrangle (Figure 5). These fractures begin to become prominent in rocks west of the Saw Mill River Valley and become increasingly prominent from there to the Hudson River. Thus they seem to be associated with proximity to the Newark Basin, and therefore are probably not simply sheeting. They may be related to the flexing of the rocks in the vicinity of a hinge zone, where the crust was warped downward toward the west as the Newark Basin developed during the Mesozoic.

## Combined fracture data

All of the orientation data shown on the equal-area plots and on the map (Plate 3) are combined for joints (Figure 4) and for slickensided surfaces and faults (Figure 5). The prominence of steeply dipping northwest-trending fractures stands out on both of these diagrams. It is interesting to note that whereas most of the mapped high-angle faults and fracture zones (Plate 3) trend N20°W to N40°W, there is no marked concentration of fractures in this orientation revealed in either of the combined plots (Figures 4, 5). Instead there is a high concentration of joints (Figure 4) and a lesser abundance of faults and slickensided surfaces (Figure 5) that trend N40°W to N80°W. The reason for this relationship is uncertain, but it may be that fractures in these two orientations are contemporaneous and fewer but larger throughgoing surfaces or zones concentrated rupture in the N20°W to N40°W directions.

The scatter plot of poles to joints (Figure 4) also displays a concentration of gently dipping joints that most commonly dip westerly. It is this set of fractures that is perhaps directly related to flexing in the vicinity of a hinge zone on the eastern flank of the Newark Basin.

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## REFERENCES CITED


Aleinikoff, J. N., 1985, *Isotopic and morphological evidence for the age of the Fordham Gneiss*: American Journal of Science, 285:459-479.

Balk, R., 1936, *Structural and petrologic studies in Dutchess County, New York, II*: Geological Society of American Bulletin, 47:775-850.

Berkey, C.P., 1907, *Structural and stratigraphic features of the basal gneisses of the Highlands*: New York State Museum Bulletin 107, 361-378.

Berkey and Rice, 1919, *Geology of the West Point quadrangle, New York*: New York State Museum Bulletin, no. 225-226.

Brock, P.W.G., and Brock, Pamela C., 1985, *The timing and nature of the Paleozoic deformation in the northern part of the Manhattan Prong*, in Tracy, R.J. (Editor), Guidebook to fieldtrips in Connecticut and adjacent areas in New York and Rhode Island. 77th Annual Meeting of the New England Intercollegiate Geologic Conference, pp. 241-275.

Clarke, J.W., 1958, *The bedrock geology of the Danbury quadrangle*: Connecticut Geologic and Natural History Survey Quadrangle Report, 7:47 p.

Dana, J.D., 1881, *Geological relations of the limestone belts of Westchester County, New York*: American Journal of Science, 20.

Dietsch, C., Ratcliff, N.M., Sutter, J.F., 2006, *$^{40}Ar/^{39}Ar$ metamorphic ages from the Manhattan Prong and Rowe-Hawley zone of New York and Connecticut*: Geological Society of America Abstracts with Programs, 38:2:20.

Fenneman, N.M., 1938, *Physiography of Eastern United States*: McGraw-Hill Book Company, Inc., New York and London, 714 p.

Fisher, D., Isachsen, Y.W., and Rickard, L.V., 1972, *Geologic Map of New York, 1970*: New York State Museum and Science Service Map and Chart Series, 15, scale 1:250,000.

Fluhr, T.W., 1950, *The Delaware aqueduct: some geological data (compiled from unpublished maps at 1:62,500 of parts of Carmel, Stanford, and Tarrytown quadrangles)*: N.Y. Academy of Science 2:12:6:182-186.

Gates, R.M., and Martin, C.M., 1967, *The bedrock geology of the Waterbury quadrangle*: State Geological and Natural History Survey of Connecticut, Quadrangle Report 22, 36 p.

Grauert, B., and Hall, L.M., 1973, *Age and origin of zircons from metamorphic rocks in the Manhattan Prong, White Plains area, southeastern New York*: Carnegie Institute Annual Report for 1972, p. 293-297.

Hall, L.M., 1966, *Some stratigraphic relationships within the New York City group in Westchester County, New York*: Abstract, Geological Society of America Special Paper 87:69.

Hall, L.M., 1968a, *Times of origin and deformation of bedrock in the Manhattan Prong*, in Zen, E-an; White, W.S.; Hadley, J.B.; Thompson, J.B., Jr. (Editors), Studies of Appalachian geology: northern and maritime (Billings volume), 117-127.

Hall, L.M., 1968b, *Bedrock geology in the vicinity of White Plains, New York*, in Finks, R.M. (Editor), Guidebook to Field Excursions, 40th Annual Meeting of the New York State Geological Association, Queens College, 7-31.

Hall, L.M., 1979, *Preliminary correlation of rocks in southwestern Connecticut*, in Page, L.R. (Editor), Geological Society of America Memoir 148: Contributions to the stratigraphy of New England, 337-349.

Hall, L.M., 1980, *Basement-cover relations in western Connecticut and southeastern New York*, in Wones, D.R. (Editor), Proceedings of the Caledonides in the U.S.A.: 1979 I.G.C.P. Project 27 Meeting, Virginia Polytechnic Institute and State University, Blacksburg, V.A., 299-306.

Hall, L.M., 1981, *Brittle faults in the White Plains Quadrangle*, New York State Geological Survey Open File No. 1g1439.

Hall, L.M., and Robinson, P., 1982, *Stratigraphic-tectonic subdivisions of southern New England*, in St. Julien, P., Beland, J. (Editors), Major structural zones and faults of the northern Appalachians: Geological Association of Canada Special Paper 24:15-41.

Harwood, D.S., 1979, *Bedrock geology of the Norfolk quadrangle, Connecticut*: U.S. Geological Survey Geological Quadrangle Maps of the United States, GQ-1518, 1:24,000.

Lobeck, A.K., 1950, *Physiographic diagram of North America* (text accompanying 1948 map): Columbia University Geographical Press, New York, 16 p.

Long, L.E., 1969, *Whole-rock Rb-Sr age of the Yonkers gneiss, Manhattan Prong*: Geological Society of America Bulletin, 80: 2087-2090.

Merrill, F.J.H., 1890, *On the metamorphic strata of southeastern New York*: American Journal of Science, 3rd series, 39:382-392.

Merrill, F.J., 1896, *The geology of the crystalline rocks of southeastern New York*: New York State Museum Annual Report, 50: Appendix A, 21-31.

Merrill, F.J., Darton, N.H., Hollick, A., Salisbury, R.D., Dodge, D.E., Willis, Bailey, and Pressey, H.A., 1902, *Description of the New York City District*: Folios of the Geologic Atlas, New York City Folio, 83, 19 p.

Mose, D.G., 1982, *1,300-million-year-old rocks in the Appalachians*: Geological Society of America Bulletin, 93:391-399.

Mose, D.G., Eckelmann, E.D., and Hall, L.M., 1979, *Age determination and zircon morphology studies of the Yonkers and Pound Ridge granite gneisses in the Manhattan Prong of southeastern New York*: Geological Society of America Abstracts with Programs, 11:45-46.

Mose, D.G., and Hall, L.M., 1979, *Rb-Sr whole-rock age determination of Member C of the Manhattan Schist and its bearing on allochthony in the Manhattan Prong, southeastern New York*: Geological Society of America Abstracts with Programs, 11:46.

Mose, D.G., and Hayes, J., 1975, *Avalonian igneous activity in the Manhattan Prong, southeastern New York*: Geological Society of America Bulletin, 86:929-932.

Naylor, R.S., Boone, G.M., Bondette, E.L., Ashenden, D.D., and Robinson, P., 1973, *Pre-Ordovician rocks in the Bronson Hill and Boundary Mountain anticlinoria, New England, U.S.*: Abstract, American Geophysical Union Transactions, 54:495.

Norton, M., 1959, *Stratigraphic position of the Lowerre Quartzite*: Annual Report of the New York Academy of Sciences, 80, no. 4.

Norton, M.F., and Geise, R.F., 1957, *Lowerre Quartzite problem*: Geological Society of America Bulletin, 68:1577-1580.

Pellegrini, T.L., 1977, *Geologic Map of the Mamaroneck quadrangle, New York*: New York State Museum and Science Service Map and Chart Series, 29, 1:24,000.

Philbin, P.W., and Kirby, J.R., 1964, *Aeromagnetic map of parts of the Yonkers and Mt. Vernon quadrangles, Bergen County, New Jersey and Bronx, Rockland, and Westchester Counties, New York*: U.S. Geological Survey Geophysical Investigations Map GP-495.

Prucha, J.J., 1956, *Stratigraphic relationships of the metamorphic rocks in southeastern New York*: American Journal of Science, 254: 672-684.

Prucha, J.J., 1959, *Field relationships bearing on the age of the New York City Group of the Manhattan Prong*: New York Academy of Science, Annals, 80:1159-1169.

Prucha, J.J., Scotford, D.M., and Sneider, R.M., 1968, *Bedrock geology of parts of Putnam and Westchester Counties, New York, and Fairfield County, Connecticut*: New York State Museum and Science Service Map and Chart series, 11, 26 p.

Ratcliffe, N.M., 1968a, *Contact relations of the Cortlandt Complex at Stony Point, New York and their regional implications*: Geological Society of America Bulletin, 79:777-786.

Ratcliffe, N.M., 1968b, *Stratigraphic and structural relations along the western border of the Cortlandt intrusives*, in R. Finks (Editor), Guide to Field Trips: New York State Geological Association, 40th meeting, 157-220.

Ratcliffe, N.M., and Knowles, R.R., 1968, *Fossil evidence from the "Manhattan Schist-Inwood Marble" sequence at Verplanck, New York*: Abstract, Geological Society of America, Program for Northeastern Section Meeting, Washington D.C., 48.

Ratcliffe, N.M., and Aleinikoff, J.N., 2009, *Pre-Ottawan (1.09 Ga) infrastructure and tectonics of the Hudson Highlands, New York*: in Vollmer, F.W. (Editor), Field Trip Guidebook, New York Geological Association, 81st Annual Meeting, Trip 9, 9.1-9.36.

Rice, W.N., and Gregory, H.E., 1906, *Manual of the geology of Connecticut*: State Geological and Natural History Survey Bulletin 6, 96-100.

Robinson, P.R., and Hall, L.M., 1980, *Tectonic synthesis of southern New England*: in Wones, D.R. (Editor), Proceedings of the Caledonides in the U.S.A.: 1979 I.G.C.P. Project 27 Meeting, Virginia Polytechnic Institute and State University, Blacksburg, V.A., 73-82.

Rodgers., J., 1970, *The tectonics of the Appalachians*: Interscience Publishers, Inc., New York, 271 p.

Rodgers, J., Gates, R.M., Cameron, E.M., and Ross, R.J., Jr., 1956, *Preliminary geologic map of Connecticut*: Connecticut Geological and Natural History Survey, scale 1:253,440.

Scotford, D.M., 1956, *Metamorphic and axial plane folding in the Pound Ridge area, New York*: Geological Society of America Bulletin, 67:1155-1198.

Stanley, R.S., and Hatch, N.L., Jr., 1976, *Discussion: Early Paleozoic stratigraphy of western Massachusetts and Connecticut and southeastern New York*: Geological Society of America Memoir 148, 351-356.

Stevens, R.P., 1867, *Report upon the past and present history of the geology of New York Island,* Annual N.Y. Lyceum Natural History, 8:108-120.

Tollo, R.P., Aleinikoff, J.N., Bartholomew, M.J., and Rankin, D.W., 2004, *Neoproterozoic A-type granitoids of the central and southern Appalachians: interpolate magmatism associated with episodic rifting of the Rodinian supercontinent*: Precambrian Research, 128:3-38.

Wissig, G., 1979, *Bedrock geology of the Ossining quadrangle, New York*: New York State Museum and Science Service Map and Chart Series, 30, 1:24,000.

Zen, E-an, editor, and Goldsmith, Richard, Ratcliffe, N.M., Robinson, Peter, and Stanley, R.S., compilers, 1983, *Bedrock geologic map of Massachusetts*: Reston, V.A., U.S. Geological Survey, 3 sheets, scale 1:250,000.

## APPENDIX 1: SPECIMEN DESCIRPTIONS FOR TABLES 1 - 15

### Specimen descriptions for Table 1.

**1.** WP-33k, dark greenish biotite amphibolite; located in the long rock cut on the west side of the parking lot 130 m (425 feet) west of the south end of Bloomingdale Pond.

**2.** WP-33n, dark green biotite-hornblende-diopside schistose gneiss (calc-silicate rock); located in the same rock cut as WP-33k above.

**3.** WP-330, dark greenish-gray diopside-quartz-feldspar calc-silicate rock; located in the same rock cut as WP-33k above.

**4.** WP-3641', gray biotite-quartz-feldspar gneiss; located on the northwest side of Silver Lake along the 280-foot contour line 275 m (900 feet) N31E of the road intersection at an elevation of 174 feet near the southwest end of Silver Lake.

**5.** WP-443b, greenish-gray biotite-hornblende-quartz-feldspar gneiss; located along the west side of the railroad tracks, west of the Bronx River, 240 m (740 feet) southwest of the bridge where Fenimore Road crosses the Bronx River.

**6.** WP-524a, very well foliated garnet-biotite-hornblende gneiss; located along the northwest side of Chatterton Parkway in White Plains and 395 m (1,300 feet) southwest of the intersection of Battle Avenue and Chatterton Parkway.

**7.** WP-683a, gray garnet-hornblende-biotite-quartz-plagioclase gneiss; located along the 240-foot contour line on the northwest side of the Bronx River valley 120 m (395 feet) north of the south edge of the quadrangle measured parallel to the contour lines.

**8.** WP-158a, dark gray garnet-pyroxene amphibolite; located in White Plains on the east side of the Bronx River valley along the east side of Ferris Avenue immediately south of its intersection with Park Avenue.

**9.** WP-503b, well foliated biotite amphibolite; located along the 280-foot contour line, where the slop is steep, on the northwest side of the Bronx River valley 120 m (400 feet) N20W of the Bronx River Parkway Bridge over the Bronx River west of Rochambeau school.

**10.** WP-523a, dark gray biotite amphibolite; located in White Plains east of Battle Hill Junior High School, between Battle Avenue and Chatterton Parkway 110 m (370 feet) southwest of their intersection.

**11.** WP-636a, gray biotite amphibolite; located on the Scarsdale Country Club golf course, southwest of Hartsdale Lake, 670 m (2,200 feet) S48W of the circle drive in front of the country club buildings.

**12.** WP-684, dark gray biotite amphibolite; located along the 240-foot contour line on the steep slope on the northwest side of the Bronx River valley 180 m (590 feet) northeast of the south edge of the quadrangle measured parallel to the contour lines.

**13.** WP-490a, gray biotite-quartz-feldspar gneiss; located along the top of the steep slope on the northwest side of the Bronx River valley 190 m (625 feet) southwest of the bridge where the Bronx River Parkway crosses the Bronx River east of Hartsdale Junior High School.

**14.** WP-503a, very well foliated, light pinkish-gray biotite-quartz-feldspar gneiss; located along the 280-foot contour line, where the slope is steep, on the northwest side of the Bronx River valley 120 m (400 feet) N20W of the Bronx River Parkway Bridge over the Bronx River west of Rochambeau School.

**15.** WP-442a, light gray, yellowish-tan-weathering muscovite-biotite granitic gneiss with a mylonitic foliation; located along the west side of the road that is west of the railroad tracks along the northwest side of the Bronx River, 190 m (625 feet) northeast of the south edge of the quadrangle measured along the road.

## Specimen descriptions for Tables 2a and 2b.

**1.** WP-3101, gray biotite-quartz-feldspar gneiss; located 120 m (395 feet) S29E of B.M. 387, which is along Route 22, southwest of Clarkson School.

**2.** WP-672a, gray-weathering, gray garnet-biotite-quartz-plagioclase gneiss; located in North White Plains near the south end of the rock cut behind the buildings on the east side of Virginia Road 190 m (625 feet) north of the intersection of Virginia Road and Route 22.

**3.** WP-3236', gray biotite-quartz-feldspar gneisses; located along the west side of the ridge 500 m (1,640 feet) S44E of B.M. 387, which is along the east side of Route 22, southwest of Clarkson School.

**4.** WP-5643, gray garnet-biotite-quartz-feldspar gneiss; from the rock cut on the north side of the road at the east end of Kensico Dam.

**5.** WP-3234, gray garnet-biotite-quartz-feldspar gneiss; located in the vicinity of thee 450-foot contour line along the county park boundary at a point 200 m (655 feet) N60W of the road intersection at 155 m (511 feet) near the east edge of the quadrangle.

**6.** WP-3233, gray sillimanite-garnet-biotite-quartz-feldspar gneiss with sillimanite-rich zones or layers that stand out in relief on the weathered outcrop surfaces; located along the 340-foot contour line, 200 m (655 feet) N70W of the road intersection at 155 m (511 feet) near the east edge of the quadrangle.

**7.** WP673c, rusty-weathering, gray garnet-sillimanite-biotite-quartz-feldspar schistose gneiss; located in North White Plains near the south end of the rock cut behind the buildings on the east side of Virginia Road 190 m (625 feet) north of the intersection of Virginia Road and Route 22.

**8.** WP-5741', rusty-weathering hornblende-biotite-quartz-feldspar granulite; located along the west side of Route 22, 320 m (1,050 feet) S33W of B.M. 387, which is along the east side of Route 22 southwest of Clarkson School.

**9.** WP-33560b, gray hornblende-biotite-quartz-feldspar gneiss interlayered with dark gray biotite amphibolite (WP-33560a); located 275 m (900 feet) N22W of the road intersection at 155 m (511 feet) near the east edge of the quadrangle.

**10.** WP-3560a, dark gray biotite amphibolite interlayered with hornblende-biotite-quartz-feldspar gneiss (WP-3560b); located in the same place as WP3560b above.

**11.** WP-3058, light gray garnet-biotite-quartz-feldspar gneiss with magnetite; located along thee 400-foot contour line at the south end of the ridge that is 410 m (1,350 feet) N43E of B.M. 370, which is east of Kensico Dam.

**12.** WP-3060, gray garnet-biotite-quartz-feldspar gneiss; located on the small spur at an elevation of 115 m (380 feet) and 475 m (1,560 feet) N59E of B.M. 370, which is east of Kensico Dam.

**13.** WP-3062, gray garnet-biotite-quartz-feldspar gneiss; located 530 m (1,740 feet) N41E of B.M. 370, which is east of Kensico Dam.

**14.** WP-3187, gray garnet-biotite-feldspar gneiss; located 320 m (1,050 feet) S82E of B.M. 370, which is east of Kensico Dam, in an exposure near the west edge of the pond.

**15.** WP-3363, dark gray garnet-biotite-pyroxene-hornblende gneiss; located along the narrow ridge that lies directly southwest of the valley occupied by Cranberry Lakes, 200 m (655 feet) N20W of hill top 532, which is along the White Plains-North Castle boundary.

**16.** WP3065, dark gray biotite-hornblende-quartz-feldspar gneiss; located on the east side of the 135 m (450 foot) knob 550 m (1,800 feet) S5E of B.M. 387, which is along the east side of Route 22 southwest of Clarkson School.

**17.** WP-3194, gray biotite-hornblende-quartz-feldspar gneiss; located along the 500-foot contour line on the north side of the small valley near the east edge of the quadrangle 410 m (1,350 feet) N53E of the water tower southeast of Clarkson School.

**18.** WP-3563', light gray to gray biotite-quartz-feldspar gneiss; located at the east edge of the quadrangle 400 m (1,300 feet) N13E of the road intersection at 155 m (511 feet) near the east edge of the quadrangle.

## Specimen descriptions for Table 3.

**1.** WP-1183, gray to blue-gray garnet-biotite-quartz-feldspar gneiss; located southeast of Taxter Road and east of the New Croton Aqueduct, 100 m (330 feet) S60W of the radio tower that is west of the New York Thruway.

**2.** WP-1419, light gray garnet-biotite-muscovite-quartz-feldspar gneiss; located in a stream south of the Tappan Zee Bridge 9 m to 12 m (30 feet to 40 feet) above the level of the Hudson River and 624 m (2,050 feet) N17E of B.M. 8, which is along the railroad tracks south of the Tappan Zee Bridge.

**3.** WP-2349, light gray garnet-biotite-quartz-feldspar granulitic gneiss; located north of Hackley School, 3360 m (1,180 feet) N38E of hill top 502.

**4.** WP-5584, gray garnet-biotite-quartz-plagioclase gneiss; located on the east side of the New York Thruway, south of Interchange 8, 120 m (395 feet) south of the east end of the Taxter Road bridge over the New York Thruway.

**5.** WP-1668, gray, sillimanite-rich garnet-sillimanite-quartz gneiss; located near the top of the steep slope, 225 m (750 feet) S15W of the radio tower that is west of the New York Thruway, south of Taxter Road and east of the New Croton Aqueduct.

**6.** WP-2280, dark gray garnet-sillimanite-biotite-quartz-feldspar gneiss with pink-stained sillimanite-rich aggregates; located in Tarrytown, 920 m (3,020 feet) N88E of B.M. 11, which is near the east end of the Tappan Zee Bridge.

**7.** WP-5081, rusty-weathering, gray garnet-biotite-quartz-feldspar gneiss; located in the rock cut on the southwest side of the New York Thruway a few meters (feet) west of the south end of the Route 9 bridge at Interchange 9, east of the Tappan Zee Bridge.

**8.** WP-2224, dark gray pyroxene-biotite-hornblende-quartz-feldspar gneiss; located a short distance west of the Saw Mill River Parkway and 700 m (2,300 feet) S46W of B.M. 220, which is located southeast of the Parkway east of Tarrytown Reservoir.

**9.** WP-2459, dark gray amphibolite with a pale, a bladed amphibole; located under the power line west of Route 9A in the north-central part of the quadrangle, 700 m (2,300 feet) S24E of B.M. 271 at Graham.

**10.** WP-476a, gray to pale greenish-gray biotite-pyroxene-quartz-feldspar gneiss; located north of Pocantico Hills, 350 m(1,150 feet) N225W of the road intersection 468, between a side road and Bedford Road.

**11.** WP-2281, gray garnet-biotite-hornblende-quartz-feldspar gneiss; located in Tarrytown on the hill top at an unmarked elevation of 420± feet, west of the intersection of Benedict Avenue and Martling Avenue, which is southwest of Hackley School.

**12.** WP-2813, gray pyroxene-epidote-garnet-hornblende-quartz-feldspar gneiss; located 100 m (330 feet) N50W of the outlet of Swan Lake, which is nearly 2 km (1.2 miles) north of Pocantico Hills.

**13.** WP-5015, gray pyroxene-hornblende-quartz-plagioclase gneiss; located 330 m (1,080 feet) N20E of the water tower on the north side of Tarrytown Reservoir.

**14.** WP-5028, gray garnet-hornblende-quartz-plagioclase gneiss; located 380 m (1,250 feet) N44W of the water tower on the north side of Tarrytown Reservoir.

**15.** WP-5032, dark gray garnet-biotite-hornblende-quartz-feldspar gneiss; located north of Kykuit Hall 1.12 km (3,675 feet) N8E of the water tower on the north side of Tarrytown Reservoir.

## Specimen descriptions for Table 4.

**1.** WP-2231, gray to pinkish biotite-quartz-feldspar augen gneiss; located along the 450-foot contour line, 790 m (2,600 feet) S47W of the south end of the dam at the east end of Tarrytown Reservoir.

**2.** WP-2239, pink biotite-quartz-feldspar augen gneiss; located on the island in Tarrytown Reservoir that is S30E of the intersection of Old White Plains Road and Neperan Road on the north side of the reservoir.

**3.** WP-2323, pink biotite-quartz-feldspar augen gneiss; located 1.225 km (4,100 feet) S48W of the south end of the dam at the east end of Tarrytown Reservoir.

**4.** WP-2233, pinkish-gray garnet-biotite-quartz-feldspar augen gneiss; located 1.32 km (4,330 feet) S46W of the south end of the dam at the east end of Tarrytown Reservoir.

**5.** WP-2179, pinkish-gray biotite-quartz-feldspar augen gneiss; located 550 m (1,800 feet) S49W of the south end of the dam at the east end of Tarrytown Reservoir.

**6.** WP-5034, pinkish-gray biotite-quartz-feldspar augen gneiss; located north off Kykuit Hill 1.175 km (3,850 feet) N6E of the water tower on the north side of Tarrytown Reservoir.

## Specimen descriptions for Table 5.

**1.** WP-454a, rusty-weathering sillimanite-garnet-biotite schistose gneiss; located north of Pocantico Hills, 435 m (1,430 feet) N10E of intersection 468 between Bedford Road and a side road to the northwest.

**2.** WP-2620, rusty-weathering sillimanite-garnet schistose gneiss; located in Tarrytown, 100 m (330 feet) S65E of B.M. 155, which is east of Irving Junior High School.

**3.** WP-2827, rusty-weathering sillimanite-garnet-biotite gneiss with graphite; located 390 m (1,280 feet) S66W of the outlet of Swan Lake.

**4.** WP-4170, rusty-weathering, reddish-brown garnet-biotite-quartz-feldspar gneiss; located near the north edge of the quadrangle at the top of the 112 m (370 foot) high hill southwest of Beech Hill Pond and north of Route 117.

**5.** WP-4466, rusty-weathering, graphite-bearing sillimanite-garnet-muscovite-biotite-quartz-feldspar gneiss; located east of Gory Brook, 200 m (650 feet) south of intersection 214 on Sleepy Hollow Road, in the northwest part of the quadrangle.

**6.** WP-5080A, rusty-weathering, gray sillimanite-biotite-quartz-feldspar gneiss; located in the rock cut on the south side of the New York Thruway in the island between the Interchange 9 entrance and exit ramp.

**7.** WP-5270, brown-to-rusty-weathering garnet-biotite-quartz-feldspar schistose gneiss; located at the south end of the Pocantico Hills, 200 m (655 feet) S37W of the water tower that is located near the north end of the small reservoir near the south end of the Pocantico Hills.

**8.** WP-2769, dark gray sillimanite-muscovite-biotite-quartz-feldspar gneiss with coarse clots that appear to be retrograded sillimanite nodules; located east of the south end of Swan Lake 390 m (1,280 feet) S60E of hill top 431, which is west of the south end of Swan Lake.

**9.** WP-4991, brownish-weathering, strongly magnetic, gray garnet-biotite-quartz-feldspar gneiss; located east of Kykuit Hill, 900 m (2,950 feet) S42W of road intersection 385 in Pocantico Hills.

**10.** WP-5080, light gray, siliceous biotite-quartz-feldspar gneiss; located in the rock cut on the south side of the New York Thruway in the island between the Interchange 9 entrance and exit ramps.

**11**. WP-4991a, gray garnet-sillimanite-biotite quartzite; located east of Kykuit Hill, 900 m (2,950 feet) S42W of road intersection 385 in Pocantico Hills.

**12.** WP-1203, gray sillimanite-garnet-biotite schist with a mylonitic foliation; located north of Beaver Hill and 1 km (3,280 feet) S19W of B.M. 220, which is at Eastview.

**13.** WP-5061, greenish-gray garnet-chlorite-muscovite schist (retrograded rock) with a mylonitic foliation; located in Gory Brook at North Tarrytown, 475 m (1,560 feet) S82W of the top of Cedar Hill.

**14.** WP-5062, gray garnet-muscovite-quartz-schist with a mylonitic texture; located in Gory Brook at North Tarrytown, 490 m (1,610 feet) S89W of the top of Cedar Hill.

## Specimen descriptions for Table 6.

**1.** WP-1160, gray hornblende-epidote-quartz-feldspar gneiss; located at an elevation of 425 feet along the southern extension of the north-trending ridge approximately 580 m (1,900 feet) east of the northeast corner of the Harriman Road Reservoir and 300 m (985 feet) west of the Saw Mill River Parkway.

**2.** WP-1435, epidote-hornblende-biotite-quartz-feldspar gneiss; located at the north end of the 290-foot-high knob 2215 m (700 feet) S50W of the 267' pond that is  east of Route 9 at Ardsley on Hudson.

**3.** WP-2398, gray garnet-biotite-hornblende gneiss; located 110 m (360 feet) Ss63E of the castle north of Sheldon Brook in Tarrytown.

**4.** WP-3819, gray garnet-biotite-hornblende gneiss; located 625 m (2,050 feet) Ss60E of B.M. 271 at the bridge over the Taconic Parkway at Graham.

**5.** WP-4406, gray biotite-hornblende-quartz-plagioclase gneiss; located a few meters west of the water tank that is east of Gory Brook in Briarcliff Manor.

**6.** WP-4560, gray biotite-hornblende-quartz-plagioclase gneiss; located 825 m (2,700 feet) N10W of B.M. 161, which is south of Rockefeller Brook in Sleepy Hollow.

**7.** WP-4878, gray biotite-hornblende-quartz-plagioclase gneiss; located 100 m (330 feet) S46E of road intersection 299 along Sleepy Hollow Road southeast of Sleepy Hollow Country Club.

**8.** WP-4883, gray epidote-biotite-hornblende-quartz-feldspar gneiss; located 100 m (330 feet) N57E of road intersection 299 along Sleepy Hollow Road southeast of Sleepy Hollow Country Club.

**9.** WP-5083, gray epidote-biotite-hornblende-quartz-plagioclase gneiss; located on the south side of the New York Thruway, 230 m (775 feet) east of the east-bound entrance ramp to the Thruway at Interchange 9.

**10.** WP-5085, gray epidote-hornblende-biotite-quartz-plagioclase gneiss; located on the south side of the New York Thruway 110 m (360 feet) east of  the eastbound entrance ramp to the Thruway at Interchange 9.

**11.** WP-1839, gray pyroxene-biotite-hornblende-quartz-feldspar gneiss; north of Barney Brook in Irvington, 660 m (2,165 feet) due east of B.M. 99, which is along the Old Croton Aqueduct.

**12.** WP-1888, dark gray biotite-hornblende-quartz-feldspar gneiss; located on the west side of the north-south street on the north side of the New York Thruway overpass east of Interchange 9.

**13.** WP-2099, gray biotite-hornblende-pyroxene-quartz-feldspar gneiss; located in East Irvington 40 m (130 feet) east of the intersection of Eller Lane and Taxter Road.

**14.** WP-1163, dark gray amphibolite; located 230 m (755 feet) S17W of the water tank south of Peter Bont Road and northeast of the Harriman Road Reservoir.

**15.** WP-59a, gray biotite-quartz-feldspar gneiss; located 75 m (250 feet) S4E of the crest of Buttermilk Hill in the north-central part of the quadrangle.

**16.** WP-1218, pink, granitic biotite-quartz-feldspar gneiss; located in Dobbs Ferry on the north side of Myrtle Avenue, 300 m (985 feet) N38W of the fire station on Ashford Avenue.

**17.** WP-5083b, pink biotite granitic gneiss; located on the south side of the New York Thruway, 230 m (755 feet) east of the eastbound entrance ramp to the Thruway at Interchange 9.

## Specimen descriptions for Table 7.

**1.** WP-1194, gray-weathering, medium to dark gray garnet-biotite-quartz-feldspar gneiss; located northeast of Harriman Road Reservoir 290 m (950 feet) S59W of the water tank on hill top 470, which is south of Peter Bont Road.

**2.** WP-1241, gray garnet-biotite-quartz-feldspar gneiss; located northeast of Harriman Road Reservoir 230 m (755 feet) S43W of the water tank on hilltop 470, which is south of Peter Bont Road.

**3.** WP-1263, gray, biotite-quartz-plagioclase gneiss; located near the eastern edge of the Harriman Road Reservoir.

**4.** WP-1263a, gray garnet-biotite-quartz-plagioclase gneiss; located near the eastern edge of the Harriman Road Reservoir.

**5.** WP-1558a, very coarse garnets with inclusions of sillimanite and biotite surrounded by a matrix of gray garnet-biotite-quartz-feldspar gneiss (1588b); located at the Ardsley Country Club, 125 m (410 feet) N71W of the point where the Ardsley-Dobbs Ferry line crosses the hill top (380 feet) where the large building on the country club is located.

**6.** WP-1558b, gray garnet-biotite-quartz-feldspar gneiss that surrounds very coarse poikilitic garnets (WP-1588a); located at the Ardsley Country Club, 125 m (410 feet) N71W of the point where the Ardsley-Dobbs Ferry line crosses the hill top (380 feet) where the large building on the country club is located.

**7.** WP-1122a, gray garnet-pyroxene-hornblende gneiss; located along the east side of Cyrus Field Road 260 m (850 feet) southeast of the southeast corner of the Harriman Road Reservoir.

**8.** WP-1141, dark gray to greenish-black plagioclase-pyroxene amphibolite; located on the northwest side of the narrow valley at a point 480 m (1,575 feet) N30E of the point where the Ardsley-Dobbs Ferry line crosses Washington Avenue.

**9.** WP-1013, dark greenish-black, chlorite-bearing amphibolite; located on the knob at the west side of the Saw Mill River Parkway 630 m (2,065 feet) N22E of the point where the Parkway crosses the south edge of the quadrangle.

**10.** WP-123b, amphibolite containing augite that is rimmed by hornblende; located in Dobbs Ferry 640 m (2,100 feet) N12E of the fire station on Ashford Avenue.

**11.** WP-1317, dark gray, garnetiferous amphibolite; located on the north slope of the hill south of the Harriman Road Reservoir about 150 m (490 feet) south of the south edge of the reservoir.

## Specimen descriptions for Table 8.

**1.** WP-1031, gray, graphitic muscovite-biotite-quartz-feldspar schistose gneiss; located 110 m (360 feet) S87W of the bridge where Ashford Avenue crosses the Saw Mill River Parkway.

**2.** WP-1043, rusty-weathering, graphitic biotite-amphibole schist; located 350 m (1,150 feet) S35E of the fire station on Ashford Avenue in Dobbs Ferry.

**3.** WP-1392, tan-weathering, garnet-bearing quartz-feldspar gneiss; located 500 m (1,160 feet) N42W of the point where the Ardsley-Dobbs Ferry line crosses the Saw Mill River Parkway.

**4.** WP-4930, pinkish biotite-quartz-feldspar gneiss located 510 m (1,675 feet) N7E of B.M. 10 along the Conrail railroad tracks at the shore of the Hudson River north of Sleepy Hollow Manor.

**5.** WP-1114, gray garnet-hornblende-quartz-plagioclase gneiss; located along the east-sloping hillside 850 m (2,790 feet) N4E of the point where the Ardsley-Dobbs Ferry line crosses the Saw Mill River Parkway.

**6.** WP-4894, gray garnet-biotite-hornblende gneiss; located 470 m (1,540 feet) S48E of the intersection of Sleepy Hollow Road and the New York-Albany Post Road near Archville.

**7.** WP-4941, gray garnet-biotite-hornblende gneiss; located 560 m (1,840 feet) N19E of B.M. 10 along the Conrail railroad tracks at the shore of the Hudson River north of Sleepy Hollow Manor.

**8.** WP-5075, gray garnet-biotite-hornblende gneiss; located 300 m (985 feet) N80E of B.M. 10 along the Conrail railroad tracks at the shore of the Hudson River north of Sleepy Hollow Manor.

**9.** WP-982, gray to pinkish-gray biotite-hornblende-quartz-feldspar gneiss; located 200 m (655 feet) N67W of the point where the Saw Mill River Parkway crosses the south boundary of the quadrangle.

**10.** WP-4888, gray biotite-hornblende gneiss; located 750 m (2,460 feet) S20W of the intersection of Sleepy Hollow Road and the New York-Albany Post Road near Archville.

**11.** WP-4946, gray biotite-hornblende gneiss; located along the east side of the Conrail railroad tracks 1.75 km (1.1 miles) south of the north edge of the quadrangle.

**12.** WP-1059, black, hornblende-rich amphibolite; located 400 m (1,310 feet) S77W of the water tower at Childrens Village in Dobbs Ferry.

**13.** WP-4902, black, hornblende-rich gneiss; located 650 m (2,130 feet) S38E of the intersection of Sleepy Hollow Road and the New York-Albany Post Road near Ashville.

## Specimen descriptions for Table 9.

**1.** WP-27, pink biotite-quartz-feldspar gneiss; from the outcrop on Soundview Avenue southwest of St. Bernard's School in White Plains.

**2.** WP-420, fine-grained, thinly laminated pink biotite gneiss; east of the West New York Post Road and south of Post Road School.

**3.** WP-491, thinly laminated pink hornblende-biotite gneiss, behind Highview School on the southeast side of Central Park Avenue (Route 100).

**4.** WP-565, thinly laminated, pinkish garnet-biotite-hornblende gneiss; in Hartsdale west of the Bronx River and north of the Scarsdale Country Club.

**5.** W-637, pink biotite-hornblende gneiss; from the southern portion of the Scarsdale Country Club.

**6.** WP-661, light gray, fine-grained biotite-quartz-feldspar gneiss; from the west edge of the Scarsdale Country Club, north of the access road from Central Park Avenue.

**7.** WP-781, bluish-gray to purplish-gray garnet-biotite-hornblende gneiss; from the southwest side of the Cross Westchester Expressway near Good Counsel College.

**8.** WP-818, pinkish garnet-biotite-hornblende gneiss; in the Quarry Heights region east edge of White Plains Reservoir No. 1.

**9.** WP-3380, pinkish biotite-hornblende gneiss; in the Quarry Heights region near the east edge of White Plains Reservoir No. 1.

**10.** WP-3385, pink to bluish-gray hornblende gneiss; in the Quarry Heights region northeast of White Plains Reservoir No. 1.

**11.** WP-3517, pink biotite gneiss; in the Quarry Heights region from the quarry southeast of the southernmost of the two Cranberry Lakes.

**12.** WP-3524, pinkish-gray garnet-biotite-hornblende gneiss; in the Quarry Heights region at the east edge of the quadrangle east of B.M. 445.

**13.** WP-3532, bluish-gray garnet-biotite-hornblende gneiss; in the Quarry Heights region east of White Plains Reservoir 2.

## Specimen descriptions for Table 10.

1. WP-1290, buff-weathering, feldspathic quartzite; from an outcrop in the stream that forms the outlet to the pond on the grounds at Sunnyside, Washington Irving's former home in Irvington, New York.

2. WP-1292b, light-brown-weathering, well foliated biotite-quartz-feldspar granulite; at the contact with Inwood A in the stream at Sunnyside.

3. WP-2205, gray biotite-quartz-feldspar granulite; from the north side of Beaver Hill between the Saw Mill River and the Saw Mill River Parkway north of the center of Elmsford.

4. WP-2207, buff-weathering, feldspathic quartzite; from the same hillside as No. 3 (WP-2205).

5. WP-2209, tan-weathering, micaceous quartzite; from the railroad cut near the bottom of the hill where No. 3 (WP-2205) is located.

6. WP-2414, buff-weathering, feldspathic quartzite; from an outcrop east of the Saw Mill River Parkway on Beaver Hill, northwest of Elmsford.

7. WP-3028, buff-weathering, coarse-grained quartzite; from the rock cut behind the A & P warehouse on the west side of the Saw Mill River in Elmsford.

8. WP-3032, tan-weathering, micaceous quartz-feldspar granulite; from the northeast side of Beaver Hill.

9. WP-3032a, buff-weathering, feldspathic quartzite; from the same outcrop as No. 8 (WP-3032).

10. WP-3034, pale-tan-weathering biotite-quartz-feldspar granulite; from the northeast side of Beaver Hill.

11. WP-5611, buff-weathering feldspathic quartzite; from an outcrop on the east side of the Sprain Brook Valley and south of Heatherdell Road.

## Specimen descriptions for Table 11.

**1.** WP-423, dark gray sillimanite-garnet-muscovite-biotite schist; from an outcrop in White Plains on the northwest side of Route 22, 375 m (1,225 feet) southeast of Rochambeau School.

**2.** WP-438, gray, siliceous muscovite-biotite schist; from an outcrop on the northwest side of Route 22, 210 m (700 feet) northeast of WP-423.

**3.** WP-769, dark gray sillimanite-kyanite-garnet-muscovite-biotite schist; from an outcrop in East White Plains, 500 m (1,600 feet) south of Silver Lake.

**4.** WP-2156, gray sillimanite-garnet-biotite schist; from the railroad cut along the Penn Central railroad west of the Taconic State Parkway and south of Mt. Pleasant.

**5.** WP-2304, gray sillimanite-garnet-biotite schist; from an outcrop southeast of Route 141 in Hawthorne.

**6.** WP-3808, brown-weathering garnet-sillimanite-muscovite-biotite schist; from an outcrop along the west side of the ridge south of Thornwood.

**7.** WP-3951, gray garnet-sillimanite-biotite schist; from an outcrop in Thornwood 125 m (400 feet) south of the northern boundary of the White Plains quadrangle.

**8.** WP-5575a, gray garnet-sillimanite-muscovite-biotite schist; from the rock cut on the south side of the Cross Westchester Expressway east of the eastbound entrance ramp at Elmsford.

**9.** WP-5575b, black garnet-kyanite-sillimanite-biotite schist; from the same location as No. 8, WP-5575a.

**10.** WP-5787a, gray garnet-biotite-quartz-feldspar granulite; from the rock cut behind the shopping center on the east side of Columbus Avenue and along the west edge of Reynolds Hill.

**11.** WP-5787b, dark gray to black sillimanite-garnet-muscovite-biotite schist; from the same location as No. 10, WP-5787a.

## Specimen descriptions for Tables 13a and 13b.

**1.** WP-28, brown-weathering garnet-muscovite-biotite schist; from an outcrop in White Plains on the north side of Bolton Avenue between Mamaroneck Road and Mamaroneck Avenue.

**2.** WP-50, gray, siliceous muscovite-biotite schist; from an outcrop in Scarsdale, northwest of Garden Road and approximately 500 m (1,600 feet) northeast of the intersection of Fenimore Road and Route 22.

**3.** WP-145, dark gray garnet-muscovite-biotite schist; from an outcrop in Scarsdale on the southeast side of Cushman Road approximately 300 m (950 feet) southeast of No. 2 (WP-50).

**4.** WP-406, brown-weathering, gray sillimanite-garnet-muscovite-biotite schist with sillimanite nodules; from an outcrop in Scarsdale on the east side of Greenacres Avenue approximately 400 m (1,300 feet) northwest of the Greenacres School.

**5.** WP-415, gray, feldspathic muscovite-biotite-quartz-feldspar schistose gneiss; from an outcrop east of Greenacres Avenue and in White Plains a little north of the White Plains-Scarsdale boundary.

**6.** WP-437b, brown-weathering, gray sillimanite-garnet-muscovite-biotite schist with small sillimanite pods up to 5 mm (0.25 inches) across; from an outcrop in White Plains north of the East New York Post Road (Route 22) and west of South Lexington Avenue.

**7.** WP-437c, light gray garnet-muscovite-biotite schist; from the same outcrop as No. 6 (WP-437b).

**8.** WP-629, brown-weathering, gray garnet-muscovite-biotite-schist; from an outcrop west of Central Park Avenue and approximately 300 m (950 feet) east of Juniper Hill School.

**9.** WP-729, gray garnet-muscovite-biotite schist with local white plagioclase porphyroblasts; from an outcrop on the northwest side of Central Park Avenue approximately 800 m (2,600 feet) north of the intersection with Underhill Road.

**10.** WP-953, brown-weathering kyanite-garnet-staurolite-biotite-muscovite schist; from an outcrop in Ardsley approximately 400 m (1,300 feet) southwest of Ardsley High School.

**11.** WP-1546, brown-weathering staurolite-garnet-kyanite-muscovite-biotite schist; from an outcrop in Ardsley south of Heatherdell Road.

**12.** WP-1558, brownish-weathering, gray, feldspathic garnet-biotite-muscovite schistose gneiss with sillimanite knots; from an outcrop north of Sunningdale Country Club and approximately 550 m (1,800 feet) south of Ridge Road in the south-central part of the White Plains quadrangle.

**13.** WP-2697, brown-weathering (with maroon streaks) staurolite-garnet-kyanite-muscovite-biotite schist; from an outcrop in Ardsley, south of Heatherdell Road approximately 300 m (950 feet) southeast of No. 11 (WP-1546).

**14.** WP-2753, brown-weathering, gray kyanite-garnet-muscovite-biotite schist; from an outcrop east of Saw Mill River Road (Route 9A) and approximately 800 m (2,600 feet) north of Dobbs Ferry Road (Route 100B).

**15.** WP-3050, brown-weathering, gray garnet-kyanite-staurolite-muscovite-biotite schist; from an outcrop east of the Sprain Brook Parkway and south of Underhill Road in the south-central part of the White Plains quadrangle.

**16.** WP-3686, gray garnet-muscovite-biotite gneiss with sparse sillimanite nodules; from an outcrop approximately 150 m (500 feet) west of the Kensico Reservoir and east of West Lake Drive in the northeastern part of the White Plains quadrangle.

**17.** WP-3828, bluish-gray garnet-biotite-quartz-plagioclase gneiss with sparse muscovite; from an outcrop west of the Westchester Community College and east of Knollwood Road in the central part of the White Plains quadrangle.

**18.** WP-3842, gray garnet-muscovite-biotite schistose gneiss with sillimanite nodules and scattered coarse muscovite grains 5 mm to 12 mm (0.2 inches to 0.5 inches) inn the long dimension; from an outcrop along Russell Street northwest of Central Park Avenue and approximately 250 m (800 feet) northeast of Juniper Hill School.

**19.** WP-3997, gray kyanite-staurolite-garnet-biotite-muscovite schist; from an outcrop on the rounded hilltop immediately north of the Cross Westchester Expressway and west of the Bronx River Valley.

**20.** WP-4237, brown-weathering garnet-muscovite-biotite schist with sillimanite nodules; from an outcrop west of Central Park Avenue and south of Ridge Road.

**21.** WP-4737, gray garnet-biotite-quartz-plagioclase gneiss; from an outcrop on the Knollwood Country Club golf course west of Knollwood Road approximately 800 m (2,600 feet) northeast of the club house.

**22.** WP-4859, gray, feldspathic muscovite-garnet-biotite schist with sillimanite nodules; from an outcrop south of Tarrytown-White Plains Road(Routes 100 and 119) and north of Russell Street approximately 600 m (2,000 feet) northeast of Juniper Hill School.

**23.** WP-4861, gray, feldspathic sillimanite-garnet-muscovite-biotite schistose gneiss; from the rock cut along the north side of the Cross Westchester Expressway near the westbound exit ramp at Route 100.

**24.** WP-5173, gray kyanite-staurolite-garnet-biotite-muscovite schist; from an outcrop in Ardsley on the west side of the Sprain Brook Valley and south of Ashford Avenue.

**25.** WP-5179, gray kyanite-garnet-muscovite-biotite schist with sillimanite; from an outcrop in Ardsley south of Ashford Avenue near the water tower.

**26.** WP-5194, gray garnet-muscovite-biotite-quartz-feldspar granulite; from an outcrop south and west of West Hartsdale Avenue and approximately 300 m (1,000 feet) east of Ridge Road County Park.

**27.** WP-5221, gray biotite-quartz-feldspar gneiss with sillimanite nodules; from an outcrop east of West Hartsdale Avenue and approximately 250 m (800 feet) north of Woodlands High School.

**28.** WP-5296, bluish-gray sillimanite-garnet-muscovite-biotite schist; from an outcrop west of Hillsdale Avenue (Route 100) and approximately 250 m (800 feet) southeast of St. Mary's in the Field School.

**29.** WP-5301, gray garnet-muscovite-biotite schistose gneiss with sillimanite nodules; from an outcrop approximately 300 m (950 feet) south of No. 28 (WP-5296).

**30.** WP-5303, gray muscovite-biotite-quartz-feldspar gneiss with sillimanite nodules; from an outcrop in Valhalla west of the Bronx River valley and north of Virginia Avenue.

**31.** WP-5359b, silver-gray, coarse-grained staurolite-garnet-biotite-muscovite schist; from an outcrop in the cove on the west side of the Kensico Reservoir east of Valhalla High School.

## Specimen descriptions for Table 14.

**1.** WP-3842, sillimanite nodule in gray garnet-muscovite-biotite schistose gneiss; from an outcrop along Russell Street, northwest of Central Park Avenue and approximately 250 m (800 feet) northeast of Juniper School.

**2.** WP-5221, gray biotite-quartz-feldspar gneiss; from an outcrop east of West Hartsdale Avenue and approximately 250 m (800 feet) north of Woodlands High School.

**3.** WP-5303, gray muscovite-biotite-quartz-feldspar gneiss; from an outcrop in Valhalla west of the Bronx River valley and north of Virginia Avenue.

## Specimen descriptions for Table 15.

**1.** WP-3a, gray garnet-muscovite-biotite schist; located south of Ridgeway Avenue and 0.52 km (1,706 feet) N86W of the point where Mamaroneck Avenue leaves the east edge of the quadrangle.

**2.** WP-6c, gray garnet-biotite-muscovite schist that is brown-weathering; located 600 m (1,969 feet) west of the southeast corner of the quadrangle.

**3.** WP-8b, brown-weathering, gray garnet-biotite-muscovite schist with spangled foliation surfaces; located 610 m (2,000 feet) west of the southeast corner of the quadrangle.

**4.** WP-10, brown-weathering, gray garnet-biotite-muscovite schist; located 0.73 km (2,395 feet) N64W of the southeast corner of the quadrangle.

**5.** WP-8a, dark gray muscovite-biotite-quartz-feldspar granulite; located in the Mt. Vernon quadrangle 600 m (1,969 feet) S89W of the southeast corner of the White Plains quadrangle.

**6.** WP-16a, gray muscovite-biotite-quartz-feldspar granulite; located 900 m (2,953 feet) N76W of the southeast corner of the quadrangle.

**7.** WP-24b, dark greenish-black amphibolite; located east of Highlands High School and 100 m (328 feet) N34E of the intersection of Mamaroneck Road and Hartsdale Avenue.

# APPENDIX 2: PARTIAL RECONSTRUCTIONS OF TRUNCATED TABLES

[Editor's note] *This is a legacy work and over four decades parts of the original have been lost. The leftmost column of Tables 10 and 11 was truncated on the surviving scans available. Some mineral names are therefore unintelligible. It is likely, however, that the list of minerals is arranged and grouped similarly between either table and those throughout the rest of the document.*

*Partial information can be valuable information even still, and rather than omit Tables 10 and 11 in entirety they are provided here below. A column has been added to each entitled "On scan" under which the truncated mineral name on the paper reference is provided. In this column, "-e" indicates that only the letter "e" at the end of the word is visible. In the column to the right are mineral names considered highly probable for each entry based upon the truncated word and the context of the other tables. These possibilities are by no means definitive.*

***Interpret the information below with caution.***

**Table 10.** Modal analyses of the Lowerre Quartzite.

| | Specimen | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| On scan | Number of points | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| -z | *Quartz* | 67 | 34 | 32 | 63 | 64 | 56 | 95 | 14 | 65 | 41 | 79 |
| -cline | *Microcline* | 30 | 50 | 52 | 32 | 25 | 36 | | 74 | 31 | 51 | 20 |
| -oclase | *Plagioclase* | | 1 | 5 | X | X | 6 | 3 | X | | 3 | |
| -e | | 1 | 15 | 7 | 1 | 9 | 2 | X | 11 | 2 | 3 | X |
| -ite | | 2 | X | | 4 | 2 | | 2 | 1 | 2 | | 1 |
| -te | | X | X | | | X | | X | X | X | 2 | |
| | | | | | | | | X | | | | |
| -e | | | | 1 | | | | | | | | |
| -e | | | | | | X | | | | | | |
| | | | | 2 | | | | | | | | |
| | | | | | | | | | | | | X |
| | | X | X | 1 | X | X | X | | X | X | X | X |
| | | X | X | X | X | X | X | X | X | X | X | X |
| -e | | | | X | | | | | | | | |
| -ine | | X | | | | | X | | X | | | |
| -te | | | | X | | | | | | | | |
| | *Opaque* | X | X | | X | X | X | X | X | X | X | X |
| | *An% of plagioclase determined by symmetrical extinction* | | | | | | $An_{16}$ | $An_{20}$ | | | | |

**Table 11.** Estimated modes of the Walloomsac Formation.

| On scan | Specimen | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -rtz | *Quartz* | 36 | 58 | 33 | 13 | 59 | 37 | 12 | 20 | 49 | 48 | 23 |
| -hoclase | *Orthoclase* | | X | | | | 1 | 13 | | | | 5 |
| -gioclase | *Plagioclase* | 41 | 20 | 17 | 44 | 14 | 18 | 39 | 20 | 1 | 38 | 16 |
| -covite | *Muscovite* | 2 | 1 | 8 | X | X | 1 | X | 16 | 2 | 1 | 7 |
| -tite | *Biotite* | 21 | 21 | 15 | 22 | 16 | 26 | 17 | 25 | 21 | 12 | 34 |
| -net | *Garnet* | X | X | 2 | 15 | 4 | 4 | X | 4 | 2 | X | 3 |
| -imanite | *Sillimanite* | X[1] | | 2 | 5 | 7 | 13 | 19 | 15[1] | 17 | | 12 |
| -ite | | | | 22 | | | | | | 8 | | |
| -rite, -orite? | | | | X | | | | | | | X | |
| -maline | *Tourmaline* | | X | X | X | | | | | | | X |
| -ite | | X | X | X | X | X | X | X | X | X | X | X |
| -on | *Zircon* | X | X | X | X | X | X | X | X | X | X | X |
| -le | | | | | | | | | | X | | |
| -ite | | | | | | | | | | | X | |
| -ue | *Opaque* | X | X | 1 | 1 | X | X | X | X | X | 1 | X |
| | *An% of plagioclase determined by symmetrical extinction* | $An_{12}$ | $An_{54}$ | $An_{50}$ | $An_{26}$ | $An_{38}$ | $An_{34}$ | $An_{36}$ | $An_{17}$ | $An_{32}$ | $An_{69}$ | $An_{31}$ |

[1]Sillimanite highly altered to kaolin.