Bedrock Geology of Parts of Putnam and Westchester Counties, New York, and Fairfield County, Connecticut

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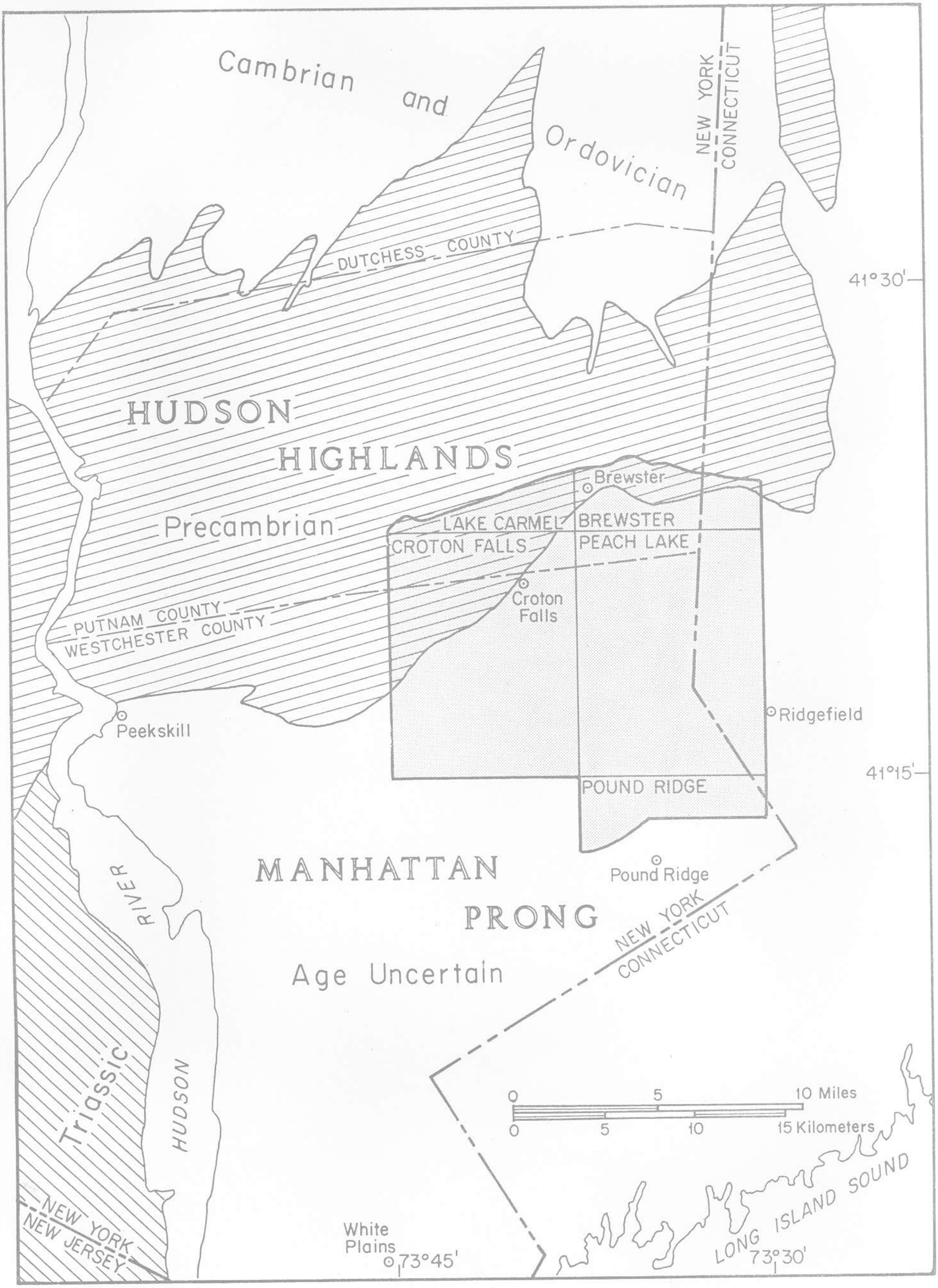
MAP AND CHART SERIES NUMBER 11

NEW YORK STATE MUSEUM AND SCIENCE SERVICE

The University of the State of New York/The State Education Department/Albany, 1968



Area of mapping (shaded) in relationship to Manhattan Prong and Hudson Highlands.

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Bedrock Geology of Parts of Putnam and Westchester Counties, New York, and Fairfield County, Connecticut

by John James Prucha[1], David M. Scotford[2], and Robert M. Sneider[3]

ABSTRACT

The map area in Westchester and Putnam Counties, New York, and adjacent Fairfield County, Connecticut, comprises two distinct structural and petrologic provinces: the Hudson Highlands and the Manhattan Prong. High-grade metamorphic rocks and subordinate amounts of igneous intrusives characterize both provinces, which are separated by a major high-angle reverse fault.

The rocks of the Hudson Highlands comprise a Precambrian complex of gneisses, migmatite, marble, granite and granodiorite. With few exceptions all formations are foliated, and in the metasedimentary rocks compositional layering within formations is conspicuous. All of the metamorphic rocks have been deformed into a complex series of northeast-plunging isoclinal folds. Discontinuity of individual lithologic layers suggests that original integrity of layering was destroyed by transposition of stratiform units during folding.

Major stratigraphic units of the Manhattan Prong are the Fordham Gneiss, Inwood Marble and Manhattan Formation of the New York City group. In close association with the New York City group are the Croton Falls and Peach Lake mafic complexes, a microcline granite, and the Pound Ridge and Siscowit granitic complexes. Within the map area no major unconformities have been recognized between any of the formations of the New York City group, which is interpreted as a conformable sequence of alternating lithologic types. In the absence of index fossils the age of the New York City group has not yet been determined. Isotopic age dates for the metamorphism are consonant with a Cambrian-Ordovician age for the original sediments but do not preclude a Precambrian age.

The formations of the New York City group behaved as an integral structural unit during deformation. Differences in behavior among the rock units during deformation are related to different inherent mechanical properties, such as ductility, rather than to different deformation histories. The dominant structure in the Manhattan Prong is a complex series of isoclinal cross-folds which, for the most part, plunge steeply northwest.

Between 1810 and 1900 the area was noted for its iron mining, which centered about Brewster, New York. Total production was about 150,000 tons of magnetite ore ranging in tenor from about 24 to 31 percent recoverable iron. The magnetite deposits are present principally in pyroxene-quartz-plagioclase gneiss and granitic gneiss, and they occur as tabular, lath-shaped concordant bodies which plunge parallel to the lineation in the enclosing gneisses. The ore is interpreted to be of hydrothermal origin from igneous sources.

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Introduction

LOCATION AND REGIONAL SETTING

The area described in this report lies principally in Westchester and Putnam Counties in southeastern New York State but includes a part of adjacent Fairfield County, Connecticut on the east (fig. 1). The area of approximately 170 square miles comprises the Croton Falls and Peach Lake $7\frac{1}{2}$-minute quadrangles and parts of the Lake Carmel, Brewster, and Pound Ridge $7\frac{1}{2}$-minute quadrangles of the U.S. Geological Survey topographic map series.

Ready access to the map area is provided by U.S. Highway 6, which extends east-west across the northern part, and by New York State Highway 22, which extends north-south. Within both the New York and Connecticut parts of the map area a close network of hard-surfaced State highways and county roads serves the surburban residential communities and provides approaches to all outcrop areas.

The map area comprises parts of two distinct structural and petrologic provinces: (1) the Hudson Highlands, which are a northeast extension of the Reading Prong and the New Jersey Highlands, and (2) the Manhattan Prong of the New England Upland (fig. 1). Both provinces are characterized by high-grade metamorphic rocks and subordinate amounts of igneous intrusives. The Precambrian rocks of the Hudson Highlands are separated from the younger (inferred) rocks of the Manhattan Prong by a major fault which has been traced across the map area.

Maximum total relief is about 600 feet. In general, the highest hills and ridges are underlain by gneisses and granite, intermediate elevations by schist, and the through-going valleys by marble. Pleistocene glaciation has affected the entire area, and the topographic features have been modified by both deposition and abrasion. The summits of the higher hills and ridges have been smoothed by the scouring action of the ice, and contours commonly have been rounded by the deposition of glacial sediments on the flanks. Northerly trending drumloidal hills modify the topography of major ridges, which are controlled by bedrock. Usually the cover of glacial sediments is thin at higher elevations, but generally it is thick in the valleys and largely obscures the bedrock. Most of the hills are wooded, but no heavy timber is present.

The principal stream in the area is the Croton River. It is the master stream of the Croton watershed, which is closely controlled by the New York City Board of Water Supply, Gas and Electricity. The Board maintains and regulates a number of large reservoirs in the area.

PREVIOUS WORK

Many earlier geologists have studied and published reports on selected aspects of the map area, but no detailed geologic map has been available. Principal emphasis has been upon stratigraphic correlation problems and economic geology. Among the earliest work was that of Mather (1834), who described the general geologic features of the First Geological District, and of Percival (1842), who in his reconnaissance study of the geology of Connecticut accurately described the general trends of the major rock units in the eastern part of the area. Dana (1879, 1880, 1881) described many of the rock units of the map area and contiguous region. Merrill (1890, 1898) concerned himself largely with the correlation problem of the metamorphic rocks of the Manhattan Prong and contributed much useful information on the rock units. Early reports by Putnam (1885), Smock (1889), and Colony (1921) contributed much description and history of the iron mines in the area but only briefly discussed the areal geology. The first detailed mapping was by Koeberlin (1909), who mapped about 18 square miles including the Brewster Magnetite District. Balk (1936) concerned himself mainly with the metamorphic rocks of Dutchess County, but his generalized map included most of the area of this report, and he discussed some of the important structural and stratigraphic problems. Fettke's (1914) paper on the Manhattan Formation and associated igneous rocks provided valuable detailed lithologic information on a major stratigraphic unit in the Manhattan Prong. Much of the area was mapped in considerable detail by T. W. Fluhr, for many years geologist with the New York City Board of Water Supply, Gas and Electricity, but his detailed maps were not published and are not generally available. Scotford's (1956) study of the metamorphism and structure in the Pound Ridge area contributed many valuable petrographic data and offered an interpretation of the complex structure.

Radioactive age determination of the metamorphic and igneous rocks of the Hudson Highlands and Manhattan Prong by Kulp (1955), Wasserberg and Hayden (1956), Eckelmann and Kulp (1957), and Long and Kulp (1958, 1962) are recent contributions important in establishing the metamorphic history of the area.

The adjoining Danbury and Bethel quadrangles in Connecticut have been mapped by Clarke (1958, and in preparation).

SCOPE OF THE WORK

The geologic map is a synthesis of independent work by the co-authors in contiguous areas (see map inset). Mapping was done on a scale of 1:31,680, except Scotford's, which was done originally on a scale of 1:24,000. The mafic complex extending northeast through the village of Croton Falls was remapped by Sneider on a scale of 1 inch=400 feet (Sneider, 1962, plate 2). For the most part, the area was mapped outcrop by outcrop, but a few gaps in original mapping were filled in subsequently by detailed reconnaissance. The combined map was compiled by the senior author, who exercised a minimum of editorial control. The responsibility for the correctness of the several contiguous map parts rests with the respective individuals who did the mapping in the field.

Correlative petrographic studies of the map units are incomplete but are planned as continuing work on the area. The only detailed petrographic studies completed are by Scotford (1956, pp. 1160-1169) in the southern part of the map area and by Sneider (1962, pp. 16-70) in the Croton Falls mafic complex. Map units, therefore, are defined principally by field observations. Scotford (1956, pp. 1194-1197) has presented an interpretation of the structural history of the area. A detailed tectonic analysis by the senior author is not yet complete.

ACKNOWLEDGMENTS

Fieldwork and correlative laboratory studies by Prucha were supported by the Geological Survey-New York State Museum and Science Service. Most of his mapping was done during the summers of 1953-55 while he was employed as a Senior Geologist on the Survey; financial support for field checking during the summer of 1963 was also provided by the Survey. He was assisted in the various phases of the fieldwork by Messrs. J. A. Graham, R. M. Sneider, and R. M. Cassie.

Scotford received financial support for his fieldwork during 1952-53 from the Society of Sigma Xi, which provided a grant-in-aid from the Sigma Xi-Resa Research Fund. Additional financial support for laboratory work was obtained from Miami University, Oxford, Ohio, and from the Miami University Research Fund.

Sneider's detailed field study of the Croton Falls mafic complex was supported during the summer of 1954 by the Geological Survey-New York State Museum and Science Service. Funds for 125 thin sections were provided by the Wisconsin Alumni Research Foundation. Mapping by Sneider in the Connecticut part of the map area during the summers 1955-56 was supported by the State Geological and Natural History Survey of Connecticut.

John Rodgers and Yngvar W. Isachsen critically reviewed the manuscript. Many of the revisions suggested by them have been incorporated into this report.

Bedrock Geology

GENERAL RELATIONSHIPS

The Hudson Highlands are part of a continuous range of Precambrian metamorphic and igneous rocks extending 140 miles northeastward from Reading, Pennsylvania to southern Dutchess County, New York, and western Fairfield County, Connecticut. At the northern end of the Highlands, the Precambrian rocks plunge northward beneath younger sedimentary and metasedimentary rocks. Seven miles to the north, they reappear in the Housatonic Highlands. Near Reading, Pennsylvania, on the southwestern end of the range, the Precambrian rocks are down-faulted and covered by Triassic rocks of the Gettysburg Basin. South of the basin they emerge again and persist southwestward as a continuous range as far as northern Georgia. The Blue Ridge and Great Smoky mountains are parts of this range.

Within the map area, the Precambrian rocks of the Hudson Highlands comprise a complex of various gneisses, migmatite, calc-silicate bearing marble, granite and granodiorite. The complicated distribution pattern of the various rock types, coupled with an irregular outcrop pattern, has thus far made impossible the resolution of a detailed stratigraphy in the Precambrian rocks. Accordingly, map units in the Highlands part of the map are somewhat generalized and represent much lumping of different rock types into composite formations.

The Precambrian rocks of the Hudson Highlands are separated from the metamorphic rocks of the Manhattan Prong by a major fault. Southeast and south of the fault the younger New York City group of metamorphic rocks comprises the Fordham Gneiss, the Inwood Marble, and the Manhattan Formation. Occurring within the New York City group are the gabbro, diorite and ultramafics of the Croton Falls and Peach Lake mafic complexes, a microcline granite which is younger than the New York City group formations, the Pound Ridge granitic complex, and the Siscowit granitic complex. Dioritic gneisses are associated with the mafic complexes, and amphibolites are abundant in the Fordham gneiss and the Manhattan formation.

DESCRIPTIONS OF FORMATIONS[1]

Hudson Highlands

The sequence in which the Precambrian mapping units are discussed is somewhat arbitrary inasmuch as age relationships are not precisely known. In general, the metasedimentary units are discussed in the order of their distribution from west to east across the geologic map.

Granitic gneiss

The granitic gneiss typically is moderately foliated, white and grayish white to pink on fresh surfaces, and generally light-gray to pinkish gray on weathered surfaces. For the most part it is medium-grained; but locally it has prominently developed pegmatitic phases, and shearing has produced aplitic textures in a few places. The pegmatites occur both concordant and discordant to the foliation and are nonfoliated. In many places earlier concordant pegmatites have been cut by slightly later ones. Locally a strong mineral lineation exists in the granitic gneiss and consists principally of oriented rods of quartz, and of hornblende and biotite together. Thin sections show the usual texture to be granoblastic, but in some specimens a good mortar structure is developed. The gneiss includes abundant layers of amphibolite ranging in thickness from a few inches to several feet. Commonly these are deformed into isoclinal folds displaying great attenuation on the limbs and thickening in the hinge areas.

Typically the granitic gneiss is composed essentially of plagioclase (An_9-An_{13}), either microcline or microcline microperthite, abundant quartz, green hornblende, commonly a little brown biotite, and very small amounts of accessory magnetite, apatite, zircon and sphene. The ratio

[1] Following the convention of the Geological Survey—New York State Museum and Science Service, the mineral which is generally most abundant in a rock designated by hyphenated mineral names is listed last.

of plagioclase to microcline or microcline microperthite varies somewhat from place to place but commonly approaches 1:1. Horneblende and biotite tend to be aligned with planar orientation and are commonly concentrated in thin tabular zones instead of being evenly distributed throughout the rock. Hence, individual specimens may differ considerably in the amount and ratios of hornblende and biotite, and commonly zones within a given outcrop area are wholly devoid of both mafic minerals. Similar shifts in the relative amounts of the other minerals are common but not so extreme. Approximate modes of representative samples of the granitic gneiss are listed in table 1.

Table 1

Approximate modes (volume percent) of Granitic Gneiss in Hudson Highlands

	SPECIMEN				
	1	2	3	4	5
Microcline	28.0	25.8	—	—	—
Microcline microperthite	—	—	39.9	21.0	24.2
Plagioclase	32.7	32.1	20.9	39.7	58.9
Quartz	33.9	32.4	35.2	34.3	13.3
Hornblende	4.0	—	3.7	3.0	3.0
Biotite	1.5	7.0	—	1.1	1.1
Magnetite	Tr	1.8	0.1	1.0	1.1
Apatite	Tr	0.5	—	Tr	0.1
Zircon	—	Tr	Tr	—	—
Sphene	—	Tr	—	—	Tr
Muscovite	—	Tr	—	Tr	—
	100.1	99.6	99.8	100.1	100.6

(From Prucha, 1956b, p. 22)

Locations of Specimens:

1. Peninsula shore, 250 feet northwest of Croton Falls Reservoir dam, Croton Falls quadrangle.
2. Near base of hill 600 feet west of where Putnam-Westchester Counties line crosses West Branch of Croton River, ½ mile northwest of Croton Falls, Croton Falls quadrangle.
3. Head of steep ravine south of intersection of Deans Corner Road and Daisy Lane, Croton Falls quadrangle.
4. Small hill west of bridge across Diverting Channel, Croton Falls quadrangle.
5. 1300 feet east of intersection of Deans Corner road and Daisy Lane, Croton Falls quadrangle.

Although in general configuration the granitic gneiss conforms to the regional grain of the other Precambrian gneisses of the Highlands, it is locally transgressive along its margins. Immediately south of the Croton Falls Reservoir dam, for example, the granitic gneiss cuts completely across the pyritic gneiss. Within the granitic gneiss some amphibolite layers have been broken across, rotated and invaded by mobile granitic phases of the gneiss. Contacts between such amphibolite layers and the granitic phases characteristically are sharp.

Whether or not the granitic gneiss was derived from a granite magma is a moot question. It is clear from its partly discordant relationship to both enclosed and adjacent rock units, however, that it was at least partly mobile and that its final crystallization post-dated the maximum orogenic deformation which determined the principal structural grain of the adjacent country rock. It is obvious that the undeformed pegmatites associated with the granitic gneiss have not been severely stressed since final consolidation, but it may be that some of them were formed by local remobilization and coarse recrystallization of the slightly older gneiss.

Pyroxene-quartz-plagioclase gneiss

This formation is a gray, medium grained pyroxene-quartz-plagioclase gneiss which lies immediately northwest of the Highlands border fault from Somers to Brewster, New York. The outcrop belt ranges in width from about 900 feet to 2700 feet. On the southwest end, near Somers, it is cut out by the Highlands border fault, but on the northeast it extends beyond the limits of the map. It is the principal mineralized formation in the Brewster Magnetite District (Prucha, 1956b).

Constituent minerals range widely in relative abundance from place to place, but almost everywhere sodic plagioclase, quartz and pyroxene are present as essential components. The formation as a whole has moderately good gneissic layering, but generally the compositional banding is much less conspicuous than in other Precambrian gneiss units within the map area. Locally, however, prominent mineralogic layering is developed. Commonly, shifts in the ratios of constituent minerals from layer to layer involve principally light-colored plagioclase and quartz. In such cases the compositional layering is not conspicuous in outcrops. Very commonly quartz is predominant over all other constituents so that the gneiss is quartzitic locally. Concordant amphibolite and thin granite pegmatite sheets are abundantly intercalated with the pyroxene-quartz-plagioclase gneiss. Small lenses of graphitic and moderately silicated marble intercalated with the gneiss close to the Highlands border fault have been mapped as Precambrian marble, but the possibility that they are Inwood marble slices caught up in the gneiss along the fault zone cannot be completely ruled out.

Approximate modes (volume percent) of typical pyroxene-quartz-plagioclase gneiss are given in table 2. In thin sections the gneiss is seen to have a very well-developed mortar texture modified somewhat by subsequent partial recrystallization. Sutured quartz grains are common in the crushed zones.

Table 2

Approximate modes (volume percent) of Pyroxene-quartz-plagioclase Gneiss in Hudson Highlands

	SPECIMEN					
	1	2	3	4	5	6
Plagioclase	29.9	45.4	19.1	55.9	31.3	58.8
Quartz	56.0	13.2	52.0	25.0	58.4	4.6
Clinopyroxene	6.7	26.0	19.3	13.0	9.1	33.2
Magnetite	1.8	14.7	2.3	4.8	—	Tr
Microcline	4.9	—	6.0	—	1.5	—
Biotite	—	—	—	—	Tr	3.0
Hornblende	—	—	—	—	Tr	Tr
Sphene	.3	1.1	.8	1.2	Tr	Tr
Apatite	Tr	Tr	.3	.2	Tr	Tr
Zircon	Tr	Tr	Tr	Tr	—	Tr
	99.6	100.4	99.8	100.1	100.3	99.6

(From Prucha, 1956b, p. 17)

Locations of Specimens:

1. 600 feet southwest of McCollum Pond, Croton Falls quadrangle.
2. 250 feet northwest of midpoint of northwest shore of Diverting Reservoir, Lake Carmel quadrangle.
3. Hillside outcrop 1½ miles southwest of Croton Falls station, Croton Falls quadrangle.
4. 800 feet northeast of bridge over Diverting Channel, Croton Falls quadrangle.
5. Summit of hill 700 feet southeast of McCollum Pond, Croton Falls quadrangle.
6. Precipitous outcrops just below summit of steep hill northwest of Diverting Reservoir, Lake Carmel quadrangle.

The origin of this formation is not clearly discernible. The persistence of the unit along strike and its consistent stratigraphic position suggests a sedimentary origin for the gneiss. The compositional layering, especially the highly quartzose facies, and the interbanding of amphibolites of probable metasedimentary or meta-volcanic nature are consonant with this view. However, the present composition of the gneiss was doubtless determined in some measure by introduction and/or removal of material during one or more cycles of regional metamorphism; and, although it is believed that the pyroxene-quartz-plagioclase gneiss is essentially a metasediment, the present compositional layering probably does not reflect simple isochemical recrystallation of an original sedimentary sequence.

Microcline granite gneiss

The microcline granite gneiss occurring in and to the east of East Branch Reservoir is a pink, medium to coarse grained, strongly foliated rock composed essentially of microcline and quartz and minor amounts of sodic plagioclase. Biotite and a little hornblende are commonly present in quantities ranging widely from layer to layer and are strongly oriented to provide a prominent foliation. Typically the biotite-rich layers are less than one inch thick; where abundant they give the gneiss a conspicuous thin-banded appearance. Locally within the gneiss, pink, very coarse and irregularly shaped microcline-quartz pegmatites are developed. The pegmatites are generally concordant to the lithologic layering of the gneiss, but in a few places apophyses and dikes cut across the gneiss layers. Within the microcline granite gneiss are numerous layers of biotitic and pyroxenic amphibolite. These are generally less than two feet thick but are very persistent along strike and wholly concordant with the foliation of the gneiss. Locally the amphibolite layers have broken apart and separated parallel to their strike. In some places the boudins of amphibolite have necked appreciably before fracturing; more commonly they simply failed on straight fractures normal to the layer boundaries. Almost invariably the space between separated boudins is occupied by coarse, pink pegmatite. In a few places along the reservoir shore south of Joe's Hill, amphibolite layers in the gneiss have been brecciated chaotically and cemented by pegmatite. The microcline granite gneiss is an integral part of a major metasedimentary sequence, but the exact nature of its antecedents is not known.

Pyritic gneiss

The pyritic gneiss is a medium to fine grained rock characterized by a rusty, gossan-type weathering that makes the formation very conspicuous in outcrops. Locally the weathering has been extreme and the gneiss is very crumbly. Oxidation of disseminated sulfides attains maximum development locally in strongly sheared zones. Occasional thin sheets of granite occur within the gneiss, and east of Round Top hill, northwest of Somers, New York, a lense of highly silicated marble is partly intercalated with it. The map width of the pyritic gneiss ranges from about 2300 feet, northwest of Somers, to 300 feet or less where it passes under Croton Falls Reservoir at the eastern limit of the formation. Exceptionally good outcrops of the unit may be seen at the south end of Croton Falls Reservoir dam and at the road intersection just south of the causeway separating the eastern and western parts of the reservoir.

Mineralogic composition of the pyritic gneiss ranges considerably from place to place, but it is almost everywhere characterized by disseminated pyrite and flake graphite. In a few places the graphite comprises 10 to 15 percent of the rock by volume. Locally a little pyrrhotite occurs with pyrite. Plagioclase is the dominant constituent of the gneiss in most places and in amount ranges from about 20 to 70 percent by volume. Precise determination of the plagioclase composition is commonly impossible because of partial alteration to sericite and clay minerals, but it appears generally to be around albite-oligoclase (An_{10}). Quartz is invariably present in amounts ranging from 10 to 30 percent. Green diopside is a very common constituent and is especially abundant close to the southeast contact of the formation, where it ranges in amount up to 30 percent. Biotite commonly runs as high as 15 percent. In a few thin sections studied, microcline was an important constituent and nearly equalled the amount of plagioclase, which it appears to have replaced to some degree. In addition to the sulfides and graphite, common and characteristic minor constituents of the pyritic gneiss are tremolite, sphene, zircon and apatite. Locally, acicular tremolite comprises 15 to 20 percent of the rock.

The pyritic gneiss is tentatively considered to be a metasedimentary unit derived from a poorly sorted sediment containing abundant carbonaceous and sulfurous muds, which upon metamorphism yielded the graphite and sulfides. An alternative hypothesis is that the pyritic gneiss represents a mineralized zone into which hydrothermal sulfides were introduced. Local shearing within the formation might have controlled the distribution of pyrite, although there is no evidence of a major shear zone. Magnetite, with which pyrite and pyrrhotite are associated locally in the ore zones of the Brewster Magnetite District (Prucha, 1956b), is absent in the pyritic gneiss.

Hornblende-biotite-quartz-plagioclase gneiss with intercalated marble

This formation occurs in two separate areas within the map limits. A broad belt extends across the northwest part of the map and persists for some distance beyond the northern edge of the mapped area. It is separated from the smaller belt along the northeastern limit of the mapped area by the granitic gneiss and pyritic gneiss formations. It is not known whether the two belts are stratigraphically distinct units having the same lithologic characteristics, or a single stratigraphic unit involved in a major fold structure truncated by the fault bordering the Hudson Highlands on the south and extending to the north beyond the limits of the map.

The gneiss is generally gray, well-foliated, and characterized by strongly developed but discontinuous layering of felsic and mafic bands. In many places the gneiss has been injected by thin sheets of hornblende-biotite granite, and commonly it is difficult to distinguish between igneous and metamorphic components. Layers of dark amphibolite ranging in thickness from a few inches to 100 feet are common and may persist for hundreds of feet along strike. Locally, thin layers of silicated graphitic marble and calc-silicate rock are intercalated with the gneiss. East of Watermelon Hill, in the northwest quadrant of the map area, a single layer of pyritic gneiss is intercalated with the formation. The pronounced compositional layering of the hornblende-biotite-quartz-plagioclase gneiss ranges from inch-scale banding to large-scale alternations between individual layers tens of feet thick.

The mineralogic composition of the gneiss ranges widely from place to place and changes abruptly from layer to layer. Sodic oligoclase (An_{11-14}) is generally the dominant constituent of the more felsic layers and ranges in amount up to 70 percent by volume. Quartz, too, is abundant and ranges widely in amounts up to 40 percent or more locally. Biotite is generally somewhat more abundant than hornblende; the two minerals together commonly compose 20 to 25 percent of the rock. In the darker layers biotite and hornblende may exceed the combined feldspar-quartz content.

Accessory mineral constituents are abundant and include clinopyroxenes, apatite, sphene, magnetite, garnet and zircon. The relative amounts and assemblages of the accessory minerals range widely from place to place. Microcline and microcline perthite commonly are abundant in the gneiss close to intrusive granite sheets.

The origin of the hornblende-biotite-quartz-plagioclase gneiss is doubtless complex, but the gneiss is tentatively interpreted as a dominantly metasedimentary unit highly metamorphosed and injected by granitic magma and solutions. The characteristic compositional banding of the gneiss may in part reflect original bedding, but such inherent layering certainly has been accentuated by processes of metamorphic differentiation. As with similar complex gneisses elsewhere that have undergone repeated cycles of deformation and recrystallization, it is not always possible to separate completely the metasedimentary from the meta-igneous components.

Marble member

Within the hornblende-biotite-quartz-plagioclase gneiss are a few concordant lenses of white to gray marble containing disseminated silicate minerals, including diopside, phlogopite, and tremolite. These marble lenses are mostly calcitic and usually contain a small amount of graphite in disseminated flakes. Similar lenses of marble within the pyroxene-quartz-plagioclase gneiss are shown on the map by the same symbol. Without doubt the marble layers are metasedimentary in origin.

Mahopac gneiss

The Mahopac gneiss crops out abundantly in the vicinity of Mahopac in the northwest corner of the map area. Important outcrop areas include Senior Hill and Lake Mahopac Ridge. The gneiss ranges in color from white to light gray and pink, and in granularity from fine to coarse grained. It is everywhere strongly foliated and locally is banded by dark layers containing abundant hornblende and biotite. Essential constituent minerals are plagioclase, subordinate microcline and quartz. Dark green pyroxene is abundantly disseminated in certain layers. Many of the larger pyroxene grains (0.5 - 2.0cm) contain a rim of brown hornblende. Abundant accessory sphene and lesser amounts of zircon and magnetite occur throughout the gneiss. Included within the formation are a few small conformable sheets of pegmatite. The Mahopac gneiss is tentatively inferred to be of metasedimentary origin, but definitive criteria have not been recognized.

Pyroxenic amphibolite member

Within the Mahopac gneiss nine concordant interlayers of dark green to black, strongly foliated pyroxenic amphibolite were mapped separately. The amphibolite layers contain abundant disseminated magnetite locally. Chlorite is abundant in a few outcrops. In places the pyroxenic amphibolite is intimately interlayered with inch-scale layers of granite to form a conspicuous mixed rock. The origin of the pyroxenic amphibolite is enigmatic.

Granodiorite

The granodiorite is a gray to pink, medium to medium-coarse grained rock composed essentially of plagioclase, potash feldspar, quartz, biotite and minor hornblende. Small red garnets are abundant locally. Texture ranges from granitoid to slightly foliated. Where the biotite content is high, foliation is more pronounced. The granodiorite contains abundant layers of amphibolite, biotitic gneiss and microcline granite and pegmatite. Irregularly shaped segregations of pink pegmatite are abundant locally. In general the granodiorite is concordant with the included amphibolite and gneiss layers, but on the east side of the peninsula jutting into the south end of Bog Brook Reservoir the granodiorite in one place cuts across the foliation of an amphibolite layer and contains angular inclusions of it. The maximum extent and distribution pattern of the granodiorite are not known because of inadequate outcrop control and incomplete mapping to the north. Whether the granodiorite is of magmatic or anatectic origin is problematical. The local discordance with and angular inclusions of amphibolite indicate with certainty only a differential mobility between the two rock types prior to final crystallization.

Granite

Numerous sheets of white to pink, medium to coarse grained granite occur within the hornblende-biotite-quartz-plagioclase gneiss and are especially abundant west of Croton Falls Reservoir. Individual granite sheets range in thickness from less than ten feet to more than 800 feet. All are concordant with the layering of the surrounding gneiss except very locally at the margins where minor, irregular crosscutting of the gneiss layers is common.

The granite is composed predominantly of microcline (commonly perthitic) and quartz but usually contains in addition minor (< 15% sodic plagioclase. A little biotite and hornblende is present locally; less common are minor amounts of garnet. The granite typically has a granitoid texture, but a moderate to strong foliation may be present in biotitic and hornblendic zones. Pegmatite is abundant locally and commonly contains a little muscovite. Pegmatite zones are irregularly distributed within the granite sheets and lack any characteristic corporate shape.

The ultimate origin of the granite is conjectural, but it is clear that it attained final crystallization well after the culmination of the regional metamorphism.

Migmatite

Within and to the east of East Branch Reservoir, on the west end of Joe's Hill in the northeast part of the map area, is a conspicuously banded migmatite consisting of alternating layers of coarse grained, pink microcline granite and hornblende-biotite-quartz-plagioclase gneiss with dark biotitic amphibolite layers locally. Many of the microcline granite layers are coarsely pegmatitic. The various layers of the migmatite range in thickness from a few inches to ten feet. Commonly the gneiss layers are highly contorted locally, especially where associated with pegmatitic phases of the granite. On the northern side of the larger area of migmatite, xenoliths of coarse-grained amphibolite occur within pegmatitic interlayers and are randomly oriented with respect to the foliation of the inclusions. Eastward the migmatite grades into the hornblende-biotite-quartz-plagioclase gneiss by a diminution of the granitic component. An identity between the granitic layers of the migmatite and the adjacent microcline granite gneiss formation is inferred. The distinction between the migmatite and the microcline granite gneiss formations is principally based upon the relative amounts of felsic and mafic layers. An additional distinction, however, is that in general the granitic components of the migmatite lack the conspicuous foliation of the microcline granite gneiss.

Manhattan Prong

Relative ages of rocks in the Manhattan Prong are discussed in sequence from oldest to youngest, as known or inferred.

Fordham Gneiss

The Fordham Gneiss typically is a coarsely banded hornblende-biotite-quartz-plagioclase gneiss. Minor constituents include potash feldspar, perthite, garnet, magnetite, pyroxene, sillimanite, and locally chlorite. The alternately light-gray and dark-gray to black layers are generally 2 to 4 inches thick and seldom exceed 2 feet in thickness. Textures typically are granoblastic but range to schistose in some layers. The banding reflects marked changes in the ratios of the constituent minerals from layer to layer and is the most conspicuous feature of the gneiss in outcrops. Individual layers are very persistent along strike and commonly can be traced for hundreds of feet. Typically the Fordham Gneiss makes massive, rounded outcrops which are dark gray on weathered surfaces and which are strongly expressed topographically as isolated hills and long ridges parallel to strike.

The Fordham Gneiss formation includes abundant intercalated layers of amphibolite, marble, calc-silicate rock, quartzite, granitic gneiss, pegmatite, and microcline granite. Locally the gneiss is migmatitic. Several units of Inwood-type marble and a single unit of highly silicated marble were mapped separately within the Fordham Gneiss. Attempts to subdivide the Fordham Gneiss of the map area into other persistent and mappable sub-units were not successful.

Intercalated amphibolite layers are present nearly everywhere in the Fordham Gneiss and range in thickness from a few inches to 15 feet. They are invariably conformable with the compositional layering and foliation of the gneiss and in all respects appear to be indistinguishable from the intercalated amphibolites of the Manhattan Formation and those in the gneisses of the Hudson Highlands. Individual amphibolite layers may be continuous for hundreds of feet but invariably lens out or form disconnected boudins along strike.

Most intercalated marble units in the Fordham Gneiss are less than 2 feet thick and were not mapped separately. Exceptions have already been noted. Many of the intercalated marble layers are indistinguishable lithologically from the Inwood Marble, but in general such interlayers are more highly silicated than the Inwood. Commonly the marble interlayers contain knots and boudins of calc-silicate rock and quartzo-feldspathic gneiss. All gradations are present from slightly silicated marble to calc-silicate rock containing only traces of remaining carbonate.

Quartzite layers within the Fordham Gneiss are widely distributed but comprise much less than one percent of the whole formation and typically are less than one foot thick. The quartzite units are medium to medium coarse grained, are highly vitreous and possess a granular texture. They are locally feldspathic but are lithologically distinct from the quartzo-feldspathic rock comprising the typical felsic layers of the gneiss and are not to be confused with the lenses of white bull quartz, which are present locally throughout the map area.

The Fordham Gneiss is interpreted to be dominantly of metasedimentary origin; this interpretation is supported principally by the mineralogical and chemical evidence discussed in detail elsewhere by Scotford (1956, p. 1181-1183). Although he recognized that no specific sedimentary antecedent for the Fordham Gneiss can be definitely established now, he concluded that the original sedimentary rock was probably mostly graywacke.

Calc-silicate bearing marble member

A marble unit interbedded with the Fordham Gneiss was mapped separately by Sneider in the southeast part of the Peach Lake quadrangle about a mile west of Ridgefield, Connecticut. The marble member contains abundant disseminated diopside, tremolite, and phlogopite. Locally abundant calc-silicate rock (mostly diopside) is intercalated with the marble. This unit, which does not crop out abundantly, includes some amphibolite and quartzo-feldspathic gneiss layers. The carbonate and calc-silicate rocks contain many sheets of pegmatite and microcline granite too small to map separately. They are especially abundant in the northern part of the unit. Lithologically, the carbonate rocks of this map differ from the Inwood Marble principally in the abundance of intercalated calc-silicate rock and in the abundance of disseminated calc-silicate minerals.

Inwood Marble

The Inwood Marble is a white to gray, medium to coarse grained rock ranging in composition from calcite to nearly pure dolomite. Locally it is rusty brown on weathered surfaces where disseminated pyrite is relatively abundant. The marble does not crop out abundantly and commonly is expressed topographically by valleys and swamps. Topography alone is not a sound basis for mapping the marble belts, but in the absence of outcrops abundant cleavage grains of carbonate in the soil commonly provide a reliable means of extrapolation between outcrops. The common perennial, herbaceous horsetail plant (genus *Equisetum*) in its distribution in the area shows a marked preference for the marble belts and is useful in locating small low-lying outcrops that might otherwise go unnoticed.

Nearly everywhere the marble contains small to moderate amounts of silicate minerals. Common silicate minerals present are diopside, tremolite, phlogopite, muscovite, forsterite and serpentine. Quartz, microcline, pyrite and graphite are irregularly distributed and locally may be abundant. Locally, thin ($<$ 2 inches) discontinuous layers and knots of quartz are present.

Typically the marble has a well-defined layering reflecting differences in granularity. Where silicate minerals and other impurities are abundant, distinct mineralogic layering and color banding are discernible. Texture of the marble is generally granoblastic, but locally the formation is sheared and strongly foliated parallel to the lithologic layering. The marble is clearly metasedimentary and is inferred to have been derived from a slightly siliceous limestone.

In map view the marble belts range widely in width as a result of marked tectonic thinning and thickening Locally the marble is inferred to have been completely squeezed out between the Fordham Gneiss and the Manhattan Formation at the present level of erosion. Small-scale isoclinal folds occur in the marble and are especially conspicuous in the more highly silicated zones. Interlayers of Manhattan-type schist are common in the marble, and locally thin sheets of granitic rock and pegmatite are intercalated. The Inwood Marble is indistinguishable lithologically from marble layers within the Fordham and Manhattan Formations. Such interlayers were mapped as Inwood where the scale of the mapping permitted it.

Manhattan Formation

The Manhattan Formation is dominantly a garnetiferous quartz-biotite-plagioclase gneiss characterized by abundant sillimanite and locally much muscovite. Potash feldspar (orthoclase $>>$ microcline) is present locally in amounts up to 20 percent by volume, but generally it is much less abundant and may be wholly lacking. Accessory minerals commonly include magnetite, pyrite, apatite, graphite, and zircon. The gneiss is everywhere strongly foliated and commonly is schistose. Generally, thin ($<$ 1 inch) layers alternating light and dark gray accentuate the foliation. Inch-scale crenulations of the foliation are abundant. The dominant lithologic type crops out abundantly and typically weathers rusty brown. Many outcrops are slabby. Locally, thin (6 inches to 15 feet) lenses of dark amphibolite are abundantly intercalated concordantly with the typical gneissic or schistose phases. Interbedded layers of silicated marble are common. A few interbedded units of amphibolite and of marble are large enough to have been mapped separately. Granitic layers 5 to 20 feet thick, and small pods of granite and pegmatite are common in the Manhattan Formation. Scotford (1956, p. 1181-1184) concluded that the Manhattan Formation is derived from a sedimentary antecedent which was dominantly an alternating sequence of siltstone and shale.

Amphibolite member

The amphibolite occurring in the Manhattan Formation is a dark, medium to coarse grained foliated rock composed essentially of hornblende and plagioclase (An_{26-42}). Almost invariably it contains abundant biotite and some quartz. Relative amounts of the principal constituents range widely from place to place, but hornblende and plagioclase combined usually comprise 80 percent or more of the rock by volume. Minor clinopyroxene and garnet are commonly present, as are the accessory minerals magnetite, zircon, and apatite.

Microcline-hornblende-biotite-quartz-plagioclase gneiss member

In the northern part of the map area a light gray to nearly black, well-foliated, microcline-hornblende-biotite quartz-plagioclase gneiss, here considered to be a major unit within the Manhattan Formation, was mapped separately. This unit includes numerous concordant amphibolite layers and occasional thin interlayers of garnetiferous and sillimanitic gneiss. Locally, the gneiss is interlayered with granitic material to give in outcrop a strongly banded appearance with individual layers only a few inches thick. From south of Peach Lake east and northeast, and extending into Connecticut for about 1800 feet, the southern limit of the gneiss unit is in contact with the Inwood Marble. Assuming that the gneiss is dominantly metasedimentary, this contact relationship suggests either a local unconformity within the original sedimentary sequence or a sharply defined facies change. It may be that the microcline-hornblende-biotite-quartz-plagioclase gneiss is of meta-volcanic origin.

Pound Ridge gneiss complex

The Pound Ridge granitic complex is dominantly a pink, medium grained leptite (the Pound Ridge granite of Bell, 1936; Scotford, 1956) with abundant layers and lenses of granite pegmatite, quartz-biotite-plagioclase gneiss, and amphibolite. All rock types comprising the complex have a moderate to strong foliation which is concordant with that in the Fordham Gneiss which surrounds the complex. Strongly developed lineations in the leptite and interlayered rock types define the axes of countless crenulations and small isoclinal folds plunging about 45°NW. These structures range from a few inches across to several hundred feet. Conspicuous folds are marked by amphibolite and quartz-biotite-plagioclase gneiss layers; numerous isoclinal crenulations in the leptite are marked by thin (< 1 inch) leaves of quartz. The leptite approximately consists of quartz (30-45%), microperthite (30-68%), microcline (0-45%), plagioclase (< 30%), and highly variable amounts of biotite and muscovite. Minor amounts of garnet, zircon, sillimanite, and magnetite are commonly present. The origin of the leptite in the complex has been considered in detail by Lessing (1967). He points out that available data are consonant with each of three possible modes of origin: (1) intrusion of a granitic magma, (2) granitization of a kaolinitic arkose, or (3) *in situ* anatexis of a kaolinitic arkose.

Siscowit granitic gneiss complex

The Siscowit granitic complex occurs in the southeastern part of the mapped area. Reconnaissance mapping only has been done on a part of the complex. The limits of the complex beyond the borders of the map are unknown at present.

The Siscowit complex is dominantly a medium to fine grained pink granitic gneiss with a weak to strong foliation throughout. Mineralogic layering is accented principally by wide ranges in amounts of muscovite and biotite from layer to layer. Limited petrographic work (Scotford, 1956, p. 1177) indicates that typical samples of the gneiss consist of microcline (> 50%), quartz (20-40%), biotite (< 15%), and minor amounts of muscovite, oligoclase, myrmekite, zircon, apatite, garnet, and magnetite.

Gabbro and diorite

This formation comprises the major part of the Croton Falls mafic complex which crops out in an elongate area trending northeast through the village of Croton Falls, New York. The complex lies concordantly within the Manhattan Formation and along most of its northwest boundary is within ¼ mile of the major fault which separates the Precambrian rocks of the Hudson Highlands from the New York City group. A smaller area of gabbro-diorite rocks occurs in the vicinity of Peach Lake. In all respects this occurrence is similar to the Croton Falls mafic complex, but it is not so well exposed; hence, the description here is based principally upon detailed study of the larger area.

The major part of the complex comprises gray to black rocks ranging in composition from diorite to gabbro. Except for a few road cuts, outcrops are generally flat-lying and are very dark on weathered surfaces. The randomly distributed gabbros occur in irregularly shaped masses ranging in maximum dimension at the surface from a few inches up to several tens of feet; gabbro bodies are always surrounded by and grade into dioritic rocks. This gradation makes it difficult to distinguish between the two types megascopically. Petrographically they are distinguished on the basis of plagioclase composition and principal mafic minerals:

	Dioritic Rocks	*Gabbro*
Plagioclase range	$An_{38\text{-}47}$	$An_{52\text{-}58}$
Principal mafics	Hornblende	Augite and hornblende

The dioritic rocks, which range in color from light gray to black, are extremely variable in fabric and composition. Two broad groups are recognized, layered and nonlayered. Most dioritic rocks of the complex are layered The layering is the result of contrasting mineral compositions and textures. Most layers are lenticular and range in length from a few feet to several tens of feet, and in width from a few inches to three feet. A few layers are at least 150 to 200 feet long in plan. Contacts between individual layers range from sharp to ill-defined. Nonlayered dioritic rocks are intimately associated with the layered type but are abundant only near the boundaries with the Manhattan Formation. They are strongly foliated, and in thin section the biotite, hornblende, and plagioclase are seen to have a strong preferred orientation marked by parallelism between elongate grains. Dikes a few inches thick of fine-grained diorite cut both the dioritic rocks and the gabbro.

Petrographically the dioritic rocks are composed mainly of varying proportions of andesine ($An_{38\text{-}47}$), hornblende, biotite and opaque ore minerals. Small to trace amounts of sphene, sericite and apatite are present in most samples. A few contain very small to trace amounts of one or more of the following: zoisite, clinozoisite, carbonate, chlorite, quartz. Although the relative proportions of plagioclase, hornblende and biotite vary from sample to sample, the total amount of these three constituents is approximately uniform (92-95 %) in any sample.

The fabric of the dioritic rocks ranges from very fine to coarse grained and from moderately to strongly foliated. Relict subdiabasic and poikilitic textures are found locally in small areas in a few samples. In the layered rocks, textural differences from layer to layer result mostly from variations in grain size and degree of orientation of biotite, hornblende, and plagioclase. Compositional differences between layers are small. In many layers there is some tendency for slight concentration of felsic or mafic minerals, but actual differences in the ratios of felsic to mafic minerals from layer to layer are small ($< 10\%$). Usually the finer grained rocks are slightly richer in biotite.

The dioritic rocks are interpreted as derivatives from subdiabasic gabbro by a combination of recrystallization, mineral reconstitution, and introduction of constituents. The layering is believed to be secondary in origin and formed concomitantly with the conversion of subdiabasic gabbro in an environment of moderate deformation.

The gabbro is composed essentially of labradorite ($An_{52\text{-}58}$), augite, hornblende, biotite and opaque ore minerals. Tremolite is abundant locally, small amounts of clinozoisite, sericite and apatite are present in most specimens. Some contain minor amounts of quartz, sphene, carbonate and chlorite. Mineral proportions vary from sample to sample, and within a few inches in the same sample. In general the gabbro runs 43-49 percent plagioclase by volume. Hornblende may proxy almost completely for augite in some samples. The amount of plagioclase decreases as the amount of hornblende increases, and ranges from 32 to 38 percent in samples in which hornblende exceeds 50 percent.

The fabric of the gabbro ranges from medium to coarse grained and from subdiabasic to slightly foliated. In foliated gabbro locally, plagioclase laths, prismatic hornblende crystals, and elongate hornblende aggregates are weakly aligned. The gabbro is interpreted as a primary igneous rock.

Ultramafic rocks

These rocks, which range from olivine pyroxenite to hornblendite, occur as irregularly shaped masses distributed over most of the Croton Falls mafic complex. Five large masses ranging from 600 to 1800 feet in maximum map dimension contain about 90 percent of the exposed ultramafic rocks in the complex. The other masses, with maximum dimensions in plan generally less than three feet, are fairly evenly distributed over the outcrop areas of the complex.

The ultramafic rocks appear to lie wholly within the gabbro-diorite assemblage; they are not known to be in contact with the Manhattan Formation anywhere, but outcrops are not sufficient to preclude that possibility. The contacts of the ultramafic rocks with the gabbro-diorite rocks are everywhere sharp and generally conformable. Discordant relationships are found only locally where small ultramafic apophyses a few inches to a few feet in width and a few feet to several tens of feet in length extend into gabbro-diorite. Within the apophyses the hornblende crystals are always strongly aligned parallel to the walls. Apophyses commonly contain abundant small inclusions of gabbro-diorite rocks generally less than a foot in maximum dimension.

Hornblende pyroxenite is the predominant ultramafic rock; hornblendite is fairly rare. The pyroxenite, where uncontaminated by the younger microcline granite, consists essentially of various proportions of augite ($En_{50\text{-}53}$), olivine ($Fo_{72\text{-}78}$), and hornblende. Accessory minerals are abundant and include biotite, opaque minerals, calcite, tremolite, plagioclase (An_{68}), talc, serpentine, pleonaste, sphene, clinozoisite, and apatite. The hornblendite consists of the same minerals as the pyroxenite except olivine. Hornblende ranges in amount from 90 to 93 percent by volume. Pyroxene is generally present only in trace amounts.

Texture of the ultramafic rocks ranges from medium to very coarse grained. Changes in granularity are gradational and may vary greatly in a random way in very small distances. The pyroxenites with relatively small amounts of hornblende have a hypidiomorphic granular texture. Increases in the amount of hornblende are accompanied by a change to poikilitic textures. In some hornblendites and hornblende-rich pyroxenites, hornblende crystals are subhedral to euhedral and have strong parallel alignment.

The pyroxenite is interpreted as an igneous rock differentiated early from a primary gabbroic magma and subsequently emplaced at higher levels in the complex. The hornblendite is believed to have been formed by uralitization of pyroxenite.

Microcline granite

Within the Fordham Gneiss, Inwood Marble, and Manhattan Formation of the New York City group, as well as in the gabbro-diorite of the Croton Falls and Peach Lake mafic complexes, are a large number of steeply dipping sills and dikes of microcline granite ranging in thickness from less than five feet to about 600 feet, and in length up to 1200 feet. Commonly the granite sheets have positive topographic expression. By far the greater number are concordant with the foliation and compositional layering of the formation in which they occur, but may cut across foliation and compositional layering of the country rock at large angles. Some of the larger bodies are composite and include thin ($< 10'$) screens of gneiss or schist oriented parallel to the granite boundaries. The discordant bodies commonly have apophyses extending concordantly out into the enclosing formation. Larger sills and dikes are essentially tabular; smaller ones are lenticular.

The granite is typically white to pink. A conspicuous and characteristic feature of many of the thicker sheets is a crude to well-developed textural layering parallel to the borders. This is produced by differences in granularity from layer to layer. The granite locally is coarsely pegmatitic with individual feldspars up to 10 inches long. In most places coarser textures are typical of a medial layer; whereas, finer textures typify the outer layers. Except for this generalization, however, alterations in relative granularity from layer to layer are not usually systematic. Within the limits of granularity, textures generally range from granitoid to gneissic, but the former is more typical. In many places individual sheets are strongly sheared along the contacts with the country rock, and gneissosity is produced by layers of relatively abundant biotite near the contacts. Commonly a strong down-dip mineral lineation of quartz and biotite is present at the upper and lower contacts of the granite sheets. This lineation is independent of that in the country rocks and appears to be related to the emplacement of the granite sheets.

The microcline granite consists of varying proportions of microcline and microcline perthite, orthoclase, plagioclase (oligoclase-andesine), and quartz. Muscovite and biotite are important varietal minerals. Accessories include apatite, sphene, zircon, tourmaline, magnetite, pyrite, clinozoisite, zoisite and garnet.

Range in composition of the microcline granite is illustrated by modal analyses (Table 3) made by Sneider (1962, p. 69) on typical sheets within the gabbro-diorite of the Croton Falls mafic complex.

The microcline granite clearly is intrusive, for many of the sheets obviously cut across the foliation and lithologic layering of the country rock. Although the intrusives are post-orogenic, the emplacement and crystallization were accompanied by slight movement as indicated by the textural features. Analogous textural layering in the Nonewaug granite of Connecticut is explained by Gates and Scheerer (1963, pp. 1045-46, 1065) as the result of repeated movement when the granite was a crystal mush.

Included with the microcline granite on the map is a layer of granitic rock within the Inwood Marble extending through Lake Kitchawan in the southeastern part of the map. It is distinctly different from the microcline granite sills and dikes described here, but it is not symbolized separately on the map. This foliated biotite-quartz-microcline rock containing minor oligoclase and muscovite is interpreted by Scotford (1956, p. 1175-1176) as a product of metasomatic replacement of an originally argillaceous bed within the marble.

Table 3.—Approximate modes (volume percent) of microcline granite sheets in the Croton Falls mafic complex

	S-5-54	S-184-54	S-187-54	S-175-54
Microcline*	54.4	40.3	79.3	14.0
Orthoclase	2.9	27.6	1.1	15.1
Plagioclase	2.9	2.5	2.4	38.6
Quartz	28.8	21.2	13.2	28.5
Muscovite	8.4	0.4	0.4	3.8
Biotite	....	8.1	2.2	....
Chlorite	1.4	....	....	....
Sericite	....	Tr.	0.7	....
Apatite	....	Tr.	0.6	....
Ore minerals	0.7	....	Tr.	....
Garnet	0.5	....	....	....
Total	100.0	100.1	99.9	100.0

* Includes microperthite

(From Sneider, 1962, p. 69)

Locations of Specimens:

S-5-54. Village of Croton Falls, 1100 feet southeast of junction of highways 22 and 202, Croton Falls quadrangle.

S-184-54. 200 feet south of Westchester County line and 7800 feet west of east boundary of Croton Falls quadrangle.

S-187-54. 100 feet north of Westchester County line, 4800 feet west of east boundary of Croton Falls quadrangle.

S-175-54. 2000 feet northeast of railroad station in Croton Falls village, Croton Falls quadrangle.

Age and Stratigraphic Relationships

HUDSON HIGHLANDS

The Precambrian age of the Hudson Highlands complex is well established. The high-grade metamorphic rocks are known to be Precambrian because near Poughquag, New York (outside the map area), they are overlain unconformably by the unmetamorphosed Poughquag quartzite, which is dated definitely by fossils as Lower Cambrian (Gordon, 1911, p. 46).

Isotopic age determinations of gneisses and granites in the Hudson Highlands (Tilton, et al, 1960; Hart, 1961; Carr and Kulp, 1957; Long and Kulp, 1962; Hart and Dodd, 1962) clearly corroborate the Precambrian age of the complex. Long and Kulp (1962) summarize available isotope dates from the Hudson Highlands and point out that major metamorphic events in the Highlands took place at about 1150 and 840 m.y. A 360 m.y. date in Highlands gneiss close to the border between the Highlands and the Manhattan Prong is interpreted by them to be the result of a reheating of Precambrian gneisses during the major metamorphic event in the adjacent Manhattan Prong. The locality of this date, 1.6 miles west of Somers, New York lies within a transitional zone of modified ages, which in a general way increase westward across the Highlands.

MANHATTAN PRONG

The age of the New York City group of the Manhattan Prong is not definitely established. Mather (1843, p. 464) considered the group to be the metamorphic equivalent of the Paleozoic sequence north of the Hudson Highlands. Merrill (1890, p. 391) also considered the group to be Paleozoic, but in 1898 he relegated the Fordham Gneiss to the Precambrian and assigned the Inwood Marble and the Manhattan Formation to the Ordovician. Berkey (1907, p. 377) considered the entire group to be Precambrian and later suggested it was equivalent to the Grenville series—a correlation based chiefly upon similarities in rock types. Knopf and Jonas (1929, p. 71) correlated the Fordham Gneiss with the Baltimore Gneiss, which they considered to be Archean; the Inwood Marble and Manhattan Formation they correlated with the supposedly Precambrian Glenarm series of Pennsylvania and Maryland.

General acceptance of a Precambrian age for the entire New York City group persisted until the publication of Balk's Dutchess County studies (1936). He believed that the Fordham Gneiss is the equivalent of the Precambrian gneisses of the Hudson Highlands, and that within the area of our map a complex system of faults, arcuate in map view, separated the Fordham Gneiss and younger (inferred) New York City group formations in narrow parallel belts south of the Highlands. The formations overlying the Fordham Gneiss he correlated with the Cambrian-Ordovician sequence north of the Highlands (basal Poughquag quartzite, Wappinger limestone, Hudson River pelite).

Balk traced the increasing rank of metamorphism of the Poughquag-Wappinger-Hudson River pelite strata eastward and attached great importance to a presumed identity of stratigraphic order between that sequence and a higher-rank Lowerre quartzite-Inwood Marble-Manhattan Formation sequence southeast of the Hudson Highlands. He concluded that the two sequences were essentially the same, that they were both Cambrian-Ordovician, and that the Fordham Gneiss is Precambrian and equivalent to the Highlands gneisses rather than an integral member of the original sedimentary sequence of the New York City group.

More recent work by Hall (1966) and by Isachsen (1964) has led to a recommendation by those workers of a possible Precambrian age for the Fordham Gneiss.

An understanding of the relationship of the Fordham Gneiss to the other formations of the New York City group and to the Precambrian gneisses of the Hudson Highlands is a prerequisite to solving the regional stratigraphic and structural problems.

The Fordham Gneiss is generally considered to be the basal formation of the New York City group, although tops and bottoms of the formations have never been determined. No unconformity between the Fordham and Highlands gneisses is known, for the Highlands boundary with the New York City group is everywhere known or inferred to be faulted. The Fordham Gneiss may be traced almost continuously from New York City northeast and east to the vicinity of Danbury, Connecticut—a distance of 60 miles—and exhibits throughout its extent a remarkably persistent stratigraphic position relative to the overlying Inwood Marble and Manhattan Formation.

Within the map area no major unconformities have been recognized between any of the formations of the New York City group, although this possibility should not be ruled out. Indeed, some workers have suggested that the apparent conformity between the Fordham Gneiss and Inwood Marble is structural. However, it seems unlikely that pseudoconformity produced by intense deformation would be so complete and persistent over such a great distance, or that the Fordham Gneiss would maintain so constant a stratigraphic position. On the basis of detailed mapping in the vicinity of Tarrytown and White Plains, New York, Hall (1966) concluded that the Inwood Marble and a sporadic quartzite beneath lie with angular unconformity upon the Fordham Gneiss, but comparable relationships are lacking in the present map area.

Perhaps the strongest argument in favor of a conformable sequence of New York City group formations in the map area is the alternation in lithologic types, especially at formation boundaries (Prucha, 1956a, pp. 675-676). The Fordham Gneiss, Inwood Marble, and Manhattan Formation are certainly valid formations and can be traced as recognizable units in persistent stratigraphic sequence by both reconnaissance and detailed mapping methods. Yet anyone who has tried to examine a number of individual outcrops within the formation belts has probably been confused at one time or another to find Manhattan-type rocks in Fordham Gneiss belts, and Fordham-type rocks in Manhattan Formation belts, and Inwood-type rocks mixed in with both Fordham and Manhattan rocks.

Fluhr's (1941) cross sections of the Delaware Aqueduct, which pass through Purdys and cuts south across the Croton Falls quadrangle, show in great detail the interlayering of lithologic types within the formations of the New York City group. He noted especially the marble layers within the Fordham Gneiss and used these in support of his interpretation of a sedimentary origin for the gneiss and a conformable relationship between the Fordham Gneiss and the Inwood Marble (Fluhr, 1950, p. 185).

Our mapping has shown that such interlayering of lithologic types is characteristic of the New York City group. Especially common are rocks of Inwood-type and Manhattan-type lithologies interlayered with the Fordham Gneiss in the Fordham Gneiss belts, and Inwood-type rocks interlayered with Manhattan-type rocks in the Manhattan Formation belts. This interlayering of lithologic types occurs on a wide range of scales, including interlayers no more than a few inches thick. Generally this type of interlayering is most abundant close to the contacts between the formational belts. Locally the alternation of rock types in the contact zones is so well developed that in large measure the actual contacts drawn on a map must be arbitrary.

In a few cases the occurrence of thick layers of Inwood-type marble and Manhattan-type formation within the Fordham Gneiss belts possibly is the result of tight infolds of the higher formations into the Fordham Gneiss. In most cases, however, the lack of mirror repetition of rock types on opposite sides of the axial plane of any presumed infold militates against the interpretation of apparent interlayering being the result of severe folding.

The intimate small-scale interlayering of distinct lithologic types is perhaps the most convincing evidence that within the map area the Fordham Gneiss is an integral part of the metasedimentary New York City group. One of the most interesting sections is that exposed along the Titicus River immediately below the Titicus Reservoir dam at Purdys, New York (Prucha, 1956a, p. 676). Here a continuous section 283 feet thick is exposed in New York City group rocks that are dipping about 90°. The sequence exposed is shown in simplified form in table 4.

Table 4

Sequence of Lithologic Types in Titicus Dam Section

Lithologic type	*Thickness in feet*
Manhattan	2.5
Inwood	1.5
Manhattan	69.5
Inwood	19.5
Fordham	54.0
Inwood	3.0
Fordham	54.0
Inwood	6.0
Fordham	1.0
Inwood	0.2
Fordham	21.0
Inwood	0.1
Fordham	2.0
Inwood	0.2
Fordham	49.0

This interlayering is interpreted as a reflection of original alternation of types of sediments laid down. As might be expected, the various combinations of sedimentary types differ from one locality to another and are most pronounced close to the contacts between the principal formation belts.

The name *Lowerre quartzite* was introduced by Merrill (1898, p. 26) and was applied to a supposed thin-bedded quartzite overlying the Fordham Gneiss in a former exposure near the old Lowerre railroad station in Yonkers, New York. Merrill considered the quartzite to be the same as the basal quartzite of the Cambrian-Ordovician sequence north of the Hudson Highlands, and in his New York City folio (1902, p. 4) he called the quartzite "Poughquag" because he believed it to be equivalent to the Poughquag quartzite of Dutchess County, which carries Lower Cambrian fossils and rests with sharp unconformity upon the Precambrian gneisses of the Hudson Highlands. Balk (1936, p. 689) also correlated the supposed Lowerre quartzite with the Poughquag quartzite north of the Highlands. His correlation was based in large part upon the presumed similarity in stratigraphic sequence of the formations in the two groups involved. The general excellence of Balk's paper did much to establish the Lowerre quartzite in the literature.

Within the present map area, no quartzite has been observed lying between the Fordham Gneiss and the Inwood Marble. Earlier the senior author (Prucha, 1956a, pp. 677-683; 1959, pp. 1165-1167) concluded that available evidence fails to establish unequivocably that a separate, distinct, and recognizable quartzite exists as a stratigraphic entity between the Fordham Gneiss and the Inwood Marble in the Manhattan Prong, and that the Lowerre quartzite does not constitute a valid formation in the New York City group.

Norton and Giese (1957) and Norton (1959) reviewed the question of the Lowerre quartzite and concluded that, in fact, a quartzite does exist between the Fordham and the Inwood at a number of places, although its sporadic distribution is recognized. Norton and Giese (1957, p. 1579) suggests that the absence, or apparent absence, of a quartzite almost everywhere between the Fordham Gneiss and Inwood Marble could be the ". . . result of nondeposition, of concealment by glacial or alluvial deposits, of removal by erosion or faulting, or of granitization and cannot be taken as disproving correlation . . ." between the New York City group and the Cambrian-Ordovician rocks north of the Hudson Highlands. In more recent work in the White Plains-Tarrytown area, approximately 15 miles southwest of our map area, Hall (1965) recognizes a sporadically distributed quartzite (generally feldspathic and/or micaceous) which lies conformably beneath the Inwood Marble and which he calls Lowerre quartzite.

In our map area the presumed similarity of stratigraphic sequence between the New York City group and the Cambrian-Ordovician rocks north of the Hudson Highlands on two counts fails to be a valid basis of correlation: (1) the Lowerre quartzite is not established as an acceptable equivalent of the Poughquag quartzite; (2) the Fordham Gneiss is demonstrably an integral part of the New York City group both stratigraphically and structurally, but has no recognizable counterpart in the Cambrian-Ordovician rocks north of the Highlands.

It should be emphasized that the Fordham Gneiss is not the equivalent of the undoubted Precambrian Gneisses of the Hudson Highlands. This is demonstrated by the structural and stratigraphic characteristics of the Fordham, but it is also seen in the lithologic dissimilarity between the gneisses. It is not always possible, in the case of isolated outcrops, to distinguish between the Fordham Gneiss and the Highlands gneisses; but wherever adequate outcrops permit careful observation of the general characteristics of the gneisses, it is possible to distinguish the separate identities (Fluhr, 1945, 1950; Scotford, 1956, p. 1160; Prucha, 1956a, p. 675; 1959, pp. 166-177).

With regard to the stratigraphic correlation problem, Long and Kulp (1962, pp. 972-973) call attention to an alternative concept:

"Even if the Fordham Gneiss is assumed not to be the equivalent of Highland Gneiss, Balk's hypothesis that the Cambrian-Ordovician Dutchess County rocks and the Manhattan Prong rocks are the same should not be ruled out according to W. H. Bucher (personal communication). He points out that on the outcrop map of Dutchess County (Balk, 1936, pl. 1) the Highlands are overlapped by the Poughquag Quartzite, which in turn is overlapped by the carbonate facies. Finally, the shale facies in some places extends over the entire underlying series to rest unconformably upon the Highlands and suggests that a sea transgressed over the old Precambrian basement. At the Highlands border the Poughquag Quartzite is as much as 600 feet thick and contains pebbly bands. At Stissing Mountain, an upfaulted Precambrian block approximately 25 miles north of the Highlands where the quartzite is also exposed, it is thinner, fine-grained, and dolomitic. Still farther north, the lowermost Cambrian Nassau-Schodack graywacke succession is exposed. Bucher (1957, p. 662, 670-671) considers the Poughquag-Stissing facies to be the condensed shore phase of the Lower Cambrian which is replaced farther from the margins of the Precambrian 'highs' by the Lower Cambrian Nassau-Schodack facies. The Fordham Gneiss is therefore interpreted by Bucher as the equivalent of the Nassau-Schodack succession. As the Highlands block was partly above sea level during Poughquag time, the quartzite may be expected to be conglomeratic near land, grading into finer sediment containing less sand offshore. South of the Highlands barrier the sandy phase (Lowerre) might have developed only locally if at all within the upper portion of the Fordham, depending on near-shore conditions."

In the absence of recognizable index fossils, the age of the New York City group cannot be determined directly.

Among metamorphic rocks, correlations based upon lithologic similarity are always extremely tenuous, and the present case is no exception. Thus, for example, it is not sound to consider the New York City group to be the equivalent of the Precambrian Grenville series (Berkey, 1907, p. 377) simply because of admitted similarities in lithologic type.

Isotopic age dating of the New York City group and related intrusives indicates the ages of recrystallization of the metamorphic rocks and the consolidation of magmatic intrusives. They do not, however, provide dates for the original sedimentation, which, of course, preceded any metamorphic recrystallization. Long and Kulp (1962, pp. 979-989) summarized available isotope dates of rocks from the Manhattan Prong, including our map area. Thirteen K-Ar ages from micas from both igneous and metamorphic rocks agree within experimental error at about 360 m.y. This appears to be the strongest and most widespread thermal event recorded among New York City Group and related rocks. Several isotope ages from Fordham Gneiss and Manhattan Formation schist are higher than 360 m.y. and indicate either an earlier metamorphism ranging up to 480 m.y. or a partially re-set Precambrian age for at least part of the Manhattan Prong. None of the dates obtained so far in New York City Group rocks rules out a Cambrian-Ordovician age for the original sedimentation of the Fordham Gneiss, Inwood Marble, and Manhattan Formation. On the basis of isotope ages, however, a Precambrian age for the original sediments is not precluded if one supposes that later (360 m.y.) reheating altered the isotope ratios of Precambrian metamorphic rocks. In the absence of definitive age data, the present writers favor a probable Cambrian-Ordovician age for the deposition of the entire New York City group, but we recognize that the problem is not yet solved.

Structure

GENERAL RELATIONSHIPS

The rocks of the map area belong to two major structural provinces of regional extent the Hudson Highlands on the north and northwest and the Manhattan Prong to the south and southeast (fig. 1). Separating these two provinces is a major reverse fault which extends across the map area and beyond. Both provinces have had complex histories of repeated intense deformation and metamorphism which are not yet completely investigated. A thorough understanding of the regional structure and structural history must await completion of detailed mapping over a much larger area, and the resolution of important problems of stratigraphy and of the kinematics of deformation.

HUDSON HIGHLANDS

With few exceptions the Precambrian rocks of the Hudson Highlands are all moderately to strongly foliated. In the larger sense, a crude foliation is produced by the interlayering of beds and laminae of different mineralogical composition. Doubtless this reflects both compositional differences in original sediments and subsequent accentuation of original layering by processes of metamorphic differentiation. On a smaller scale, the foliation consists of parallelism of platy and elongate mineral grains within compositional layers. Principally biotite and hornblende produce such planar structures, but tabular feldspars and flattened, leaf-like quartz are also important. Such parallelism of platy minerals was produced under conditions of regional stress during deformation and recrystallization. Almost without exception the planar orientation of mineral grains is parallel to that of the compositional layering. Southwest of Brewster, the foliation trends generally northeast, but in the vicinity of Brewster it swings to the east and persists with an approximately east-west trend to the eastern limit of the map in Connecticut. Nonvertical foliation generally dips to the northwest or north, but local changes in the direction of dip are common. Similarly, the trend of the foliation may deviate widely from the regional trend in reflecting local structural complexities, such as minor folds.

Lineations of two kinds occur within the foliation planes. One is formed by the parallelism of elongate grains of biotite, hornblende, quartz and feldspar; the other is formed by the parallelism of the axes of crenulations and small-scale folds in the foliation planes. The second type of lineation is often conspicuous as a fluting or ribbing on the foliation surfaces. Practically without exception the two types of lineation are parallel to each other and commonly may be observed together in the same outcrop. Throughout the map area the lineations within the formations of the Hudson Highlands generally plunge northeasterly.

All the metamorphic rocks of the Hudson Highlands within the map area have been subjected to intense orogenic forces which have produced a complex series of northeast-plunging isoclinal folds. In the absence of persistent horizon markers it was not possible to work out larger fold structures at the scale of mapping used; however, abundant small-scale isoclinal folds discernible in individual outcrops indicate that this type is to be expected in large-scale structures. The common *en echelon* arrangement of discontinuous, lenticular bodies of any given lithologic type within the gneiss formations suggests that the initial integrity of layering may have been destroyed by transposition of stratiform units during folding.

MANHATTAN PRONG

The formations of the New York City group have behaved structurally as an integral unit. The Fordham Gneiss, Inwood Marble and Manhattan Formation have been deformed simultaneously and in general belong to the same metamorphic facies. No discernible angular discordance exists between these formations within the map area, and the penetrative fabric of the deformed sequence is consistent among all formations of the group. Slight differences in behavior among the several rock units during deformation are clearly related directly to different inherent mechanical properties, such as ductility, rather than to different deformation histories. For example, the Inwood Marble was highly ductile during deformation and flowed readily during the folding of the rocks. This accounts in large part for the wide range in thickness of the marble belts which, in places, have been completely squeezed out from between the Fordham Gneiss and the Manhattan Formation at the present level of erosion.

Foliation is prominent in all formations of the Manhattan Prong with the exception of the ultra-mafic rocks and some of the microcline granite dikes and sills. Foliation in all formations is steep and predominantly parallel to compositional layering. It is best developed in the micaceous and hornblendic units of the Manhattan Formation and the Fordham Gneiss, and in the Pound Ridge and Siscowit granitic complexes. Muscovite, biotite, hornblende, tabular feldspars and flattened quartz leaves produce most of the mineralogical foliation within layered lithologic units.

As in the metamorphic rocks of the Hudson Highlands, both mineral lineations and axial lineations are abundant; similarly, both kinds are almost invariably parallel to one another whether they occur separately or together. The orientation of lineations throughout the map area within the Manhattan Prong is remarkably consistent. With few local exceptions, such as in the Fordham Gneiss southeast of Titicus Mountain, the predominant orientation of lineations is northwesterly, plunging 45°-50° on the average. Exceptional domains include the area from the west end of Cross River Reservoir westward through Whitehall Corners, and a mile-wide zone extending northeastward from Amawalk Reservoir to the vicinity of Croton Falls. In these areas lineations show a statistical concentration of easterly and northeasterly plunges, respectively.

Between the Hudson Highlands on the northwest and north and the Siscowit granitic gneiss on the southeast, the dominant structure is a complex series of isoclinal cross-folds which produce the great arcuate belts of New York City group formations conspicuously evident on the map. For the most part these large cross-folds plunge steeply northwest, and the formation belts and foliation swing around a "core" of Fordham Gneiss and Pound Ridge granitic complex in the vicinity of the Ward Pound Ridge Reservation east of Cross River Reservoir. Scotford (1956, pp. 1190-1197) applied the term "axial plane folding" to these structures. They represent cross-folding, about steeply plunging axes, of isoclinal folds with steeply dipping axial planes. It is not known whether the steeply plunging cross-folds are the result of a separate episode of deformation, or whether they were formed more or less simultaneously with the original isoclinal folds. The consistent penetrative fabric of the cross-folded sequence is consonant with the latter viewpoint.

East of Titicus Reservoir, the belt of Inwood Marble lying between belts of Fordham Gneiss is the keel of a double plunging synclinorium. The synclinorium opens up to the west, south of Titicus Reservoir, and to the east, east of the Connecticut State line. The cross-folded synclinorium forms part of the major axial-plane fold which wraps around the Ward Pound Ridge Reservation area.

It should be emphasized that within the map area the Fordham Gneiss appears to be wholly conformable with the rest of the New York City group and maintains a consistent stratigraphic and structural position within the group. Within the Fordham Gneiss the foliation and lineations are everywhere consistent with those in the overlying Inwood and Manhattan Formations. Minor folds, including true drag folds, are abundant in both the Fordham Gneiss and the Manhattan Formation. Their relatively greater abundance in the Fordham is believed to reflect the more pronounced inherent layered anisotropy of the formation. Small-scale folds occur also in the Inwood Marble, but they are not common. In part this is because of the relative paucity of outcrops, but it is inferred that the high ductility of the marble during deformation led to extreme attenuation and shearing out of fold limbs with consequent obliteration of minor folds.

FAULTS

Only two faults of major significance are recognized in the map area. These are the fault which separates the Hudson Highlands from the Manhattan Prong and that which bounds the northwest side of the Siscowit granitic complex. In a number of places, both in the Highlands and in the Prong, minor faults with separations of only a few feet were noted, but they are too small to show on the scale of the map and have little or no importance to the over-all deformation pattern. Numerous reverse faults of small displacement were mapped by Fluhr (1941) in the Delaware Aqueduct tunnel, but none of these is evident at the surface. It is probable that the typical discontinuity of specific stratiform units within the gneisses of the Hudson Highlands in part reflects ductile faulting along localized zones of shear displacement without loss of cohesion, but neither stratigraphic nor outcrop control is sufficient to define such features if indeed they do exist.

The fault bounding the Hudson Highlands can be followed more or less continuously across the map area. It has been traced from the northeast corner of the map, east of Mill Plain, Connecticut, westward into New York State to Brewster, thence southwestward along the Croton River to Croton Falls, and beyond to Lincolndale and the Amawalk Reservoir. A pronounced sulcus or topographic break marks its trace most of the way.

Direct evidence is not everywhere discernible along the fault trace, but it is marked locally by severe crushing and mylonitization of the rocks on both sides in a zone ranging up to several hundred feet in width. For most of its extent within the area the fault is in contact with the Inwood Marble, which locally is conspicuously dragfolded next to the fault. In a few places, slices of marble are caught up in the fault zone and are intercalated with the adjacent Precambrian gneisses. The fault is exceptionally well-exposed along the west side of Croton River north of Croton Falls. Here at the surface, as elsewhere along its extent, is a steep reverse fault dipping 70° or more under the Precambrian block of the Hudson Highlands.

Indirect evidence for the Hudson Highlands boundary fault provides strong corroboration of the direct evidence. Included are the abrupt changes in bedrock and structural style across the break; the truncation of stratigraphic units on both sides of the break, and of folds in the New York City group, especially in the Lincolndale-Somers area; and relevant regional geologic relationships along the break outside the present map area (Isachsen, 1964).

The fault delimiting the northwest side of the Siscowit granitic complex was first recognized by Scotford (1956, pp. 1193-1194) and subsequently extended in mapping by Sneider northeast through Ridgefield, Connecticut, to the eastern limit of the map. Direct evidence for the fault is meager except in the vicinity of Lake Kitchawan, where it truncates the easternmost belt of Inwood Marble, and east and southeast of Trinity Lake (about one mile south of the present map limit) where the fault truncates successive belts of Inwood Marble, Fordham Gneiss, Inwood Marble, and Manhattan Formation (Scotford, 1956, pp. 1193-1194, pl. 1). Based upon a shear zone marked by slickensides and prominent mullion structure in the Siscowit granitic complex east of Trinity Lake, Scotford (1956, pp. 1193-1194, pl. 1) concluded that the fault dips to the northwest (ca. 45°), but the sense of shear is not known.

Brewster Magnetite District

The Brewster Magnetite District (Prucha, 1956b) lies within the map area. Principal magnetite deposits, none of which is active today, are the Croton Magnetic Iron Mine, the Brewster mine and the Clover Hill mine. These occur west of the Croton River in a belt within the Precambrian gneisses of the Hudson Highlands between Brewster and Somers, New York. Total production for the district during the period of active mining from around 1810 to 1900 was approximately 150,000 tons of magnetic ore. Of this amount, more than 100,000 tons came from the Croton Magnetic Iron mine. Maximum tenor of unsorted ore ran about 31 percent recoverable iron. Substantial tonnages of ore produced ranged from 24.5 percent to 28.7 percent recoverable iron.

The magnetite deposits occur in pyroxene-quartz-plagioclase gneiss and in granitic gneiss. Magnetite, the only iron ore mineral of the district, is disseminated in a dominantly silicate gangue. Higher grade ore zones may include narrow bands and lenses of massive magnetite as minor components of the mineralized zones. Ilmenite commonly is intergrown with the magnetite, but available analyses of ore from the district indicate the TiO_2 content to be less than one percent. Locally the magnetite is associated with pyrite (FeS_2) and pyrrhotite ($Fe_{x-1}S_x$).

The magnetite deposits occur as tabular, lath-shaped bodies which plunge parallel to the lineation of the enclosing gneisses. Margins of the ore bodies of disseminated magnetite usually are gradational with the country rock, but in some cases they are sharply defined. The ore has been interpreted to be of hydrothermal origin from igneous sources (Prucha, 1956b, pp. 33-36).

Prospects for reactivation of mining in the district are poor. Tenor of possible ore reserves is low and proved reserves are small. Previous drilling of the Croton Magnetic Iron mine ore body has shown a reserve of about 10 million short tons averaging 28.48 percent recoverable iron, but the necessity for underground mining and the difficulties in carrying out mining and milling operations on the reservoir watersheds and in a rapidly developing area of suburban residences further detract from the economic prospects for renewed mining.

Conclusions

Within the map area the Hudson Highlands comprise a sequence of metasedimentary and igneous rocks which are undoubtedly Precambrian. These form a province which is structurally and petrologically distinct from the Manhattan Prong to the south and southeast. The New York City group and related rocks of uncertain age in the Manhattan Prong are separated from the Hudson Highlands by a major high-angle reverse fault which dips steeply beneath the Precambrian rocks of the Highlands. The fault within the map area is marked by abrupt changes in bedrock and structural style across the break, by truncation of stratigraphic units on both sides, and by truncation of folds in the New York City group of the Manhattan Prong. Locally the fault is delineated by crushing and mylonitization of the rocks on both sides in a zone ranging up to several hundred feet in width.

Although the age of the New York City group of the Manhattan Prong is uncertain, the Fordham Gneiss-Inwood Marble-Manhattan Formation is considered to be essentially a conformable sequence of alternating lithologic types. No discernible angular discordance exists between these formations within the map area, and the fabric of the deformed sequence is consistent among all formations of the group. The Fordham Gneiss, Inwood Marble and Manhattan Formation appear to have behaved structurally as an integral unit simultaneously deformed, and in general they belong to the same metamorphic facies.

In contrast to what has been reported in other areas within the Prong (Hall, 1966; Norton, 1959), no quartzite unit, either continuous or discontinuous, was found between the Fordham Gneiss and the Inwood Marble within the map area. In the absence of definitive age data, a Cambrian-Ordovician age for the entire New York City Group is favored, but the problem is not yet solved.

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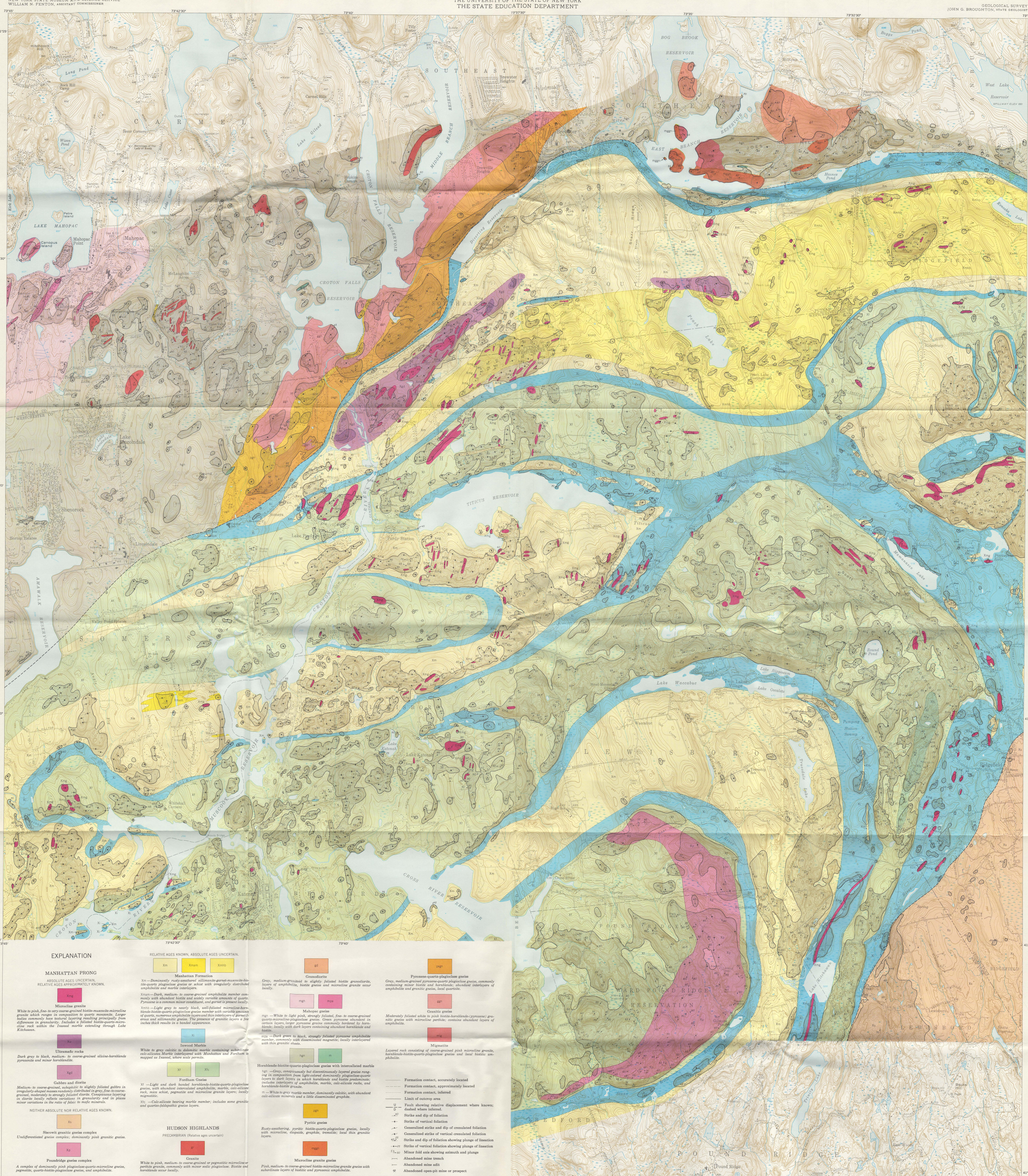

EXPLANATION

MANHATTAN PRONG

ABSOLUTE AGES UNCERTAIN, RELATIVE AGES APPROXIMATELY KNOWN.

Xmg — **Microcline granite**

White to pink, fine- to very coarse-grained biotite-muscovite-microcline granite which ranges in composition to quartz monzonite. Larger bodies commonly have textural layering resulting principally from differences in granularity. Includes a foliated biotite-quartz-microcline rock within the Inwood marble extending through Lake Kitchawan.

Xu — **Ultramafic rocks**

Dark gray to black, medium- to coarse-grained olivine-hornblende pyroxenite and minor hornblendite.

Xgd — **Gabbro and diorite**

Medium- to coarse-grained, subophitic to slightly foliated gabbro in irregularly-shaped masses randomly distributed in gray, fine- to coarse-grained, moderately to strongly foliated diorite. Conspicuous layering in diorite locally reflects variations in granularity and in places minor variations in the ratio of felsic to mafic minerals.

NEITHER ABSOLUTE NOR RELATIVE AGES KNOWN.

Xs — **Siscowit granitic gneiss complex**

Undifferentiated gneiss complex; dominantly pink granitic gneiss.

Xp — **Poundridge gneiss complex**

A complex of dominantly pink plagioclase-quartz-microcline gneiss, pegmatite, quartz-biotite-plagioclase gneiss, and amphibolite.

RELATIVE AGES KNOWN, ABSOLUTE AGES UNCERTAIN.

Xm, Xmam, Xmhb — **Manhattan Formation**

Xm —*Dominantly rusty-weathered sillimanite-garnet-muscovite-biotite-quartz plagioclase gneiss or schist with irregularly distributed amphibolite and marble interlayers.*

Xmam —*Dark, medium- to coarse-grained amphibolite member commonly with abundant biotite and widely variable amounts of quartz. Pyroxene is a common minor constituent, and garnet is present locally.*

Xmhb —*Light gray to nearly black, well-foliated microcline-hornblende-biotite-quartz-plagioclase gneiss with variable amounts of quartz, numerous amphibolite layers and thin interlayers of garnetiferous and sillimanitic gneiss. The presence of granitic layers a few inches thick results in a banded appearance.*

Xi — **Inwood Marble**

White to gray calcitic to dolomitic marble containing subordinate calc-silicates. Marble interlayered with Manhattan and Fordham is mapped as Inwood, where scale permits.

Xf, Xfc — **Fordham Gneiss**

Xf —*Light and dark banded hornblende-biotite-quartz-plagioclase gneiss, with abundant intercalated amphibolite, marble, calc-silicate rock, mica schist, pegmatite and microcline granite layers; locally migmatitic.*

Xfc —*Calc-silicate bearing marble member; includes some granitic and quartzo-feldspathic gneiss layers.*

HUDSON HIGHLANDS

PRECAMBRIAN (Relative ages uncertain)

gr — **Granite**

White to pink, medium- to coarse-grained or pegmatitic microcline or perthite granite, commonly with minor sodic plagioclase. Biotite and hornblende occur locally.

gd — **Granodiorite**

Gray, medium-granitoid to slightly foliated biotite granodiorite, layers of amphibolite, biotite gneiss and microcline granite occur locally.

mgn, mpa — **Mahopac gneiss**

mgn —*White to light pink, strongly foliated, fine- to coarse-grained quartz-microcline-plagioclase gneiss. Green pyroxene abundant in certain layers, larger pyroxene grains commonly bordered by hornblende; locally with dark layers containing abundant hornblende and biotite.*

mpa —*Dark green to black, strongly foliated pyroxene amphibolite member, commonly with disseminated magnetite; locally interlayered with thin granitic sheets.*

hgn, m — **Hornblende-biotite-quartz-plagioclase gneiss with intercallated marble**

hgn —*Gray, conspicuously but discontinuously layered gneiss ranging in composition from light-colored dominantly plagioclase-quartz layers to dark layers in which hornblende and biotite predominate; includes interlayers of amphibolite, marble, calc-silicate rocks, and hornblende-biotite granite.*

m —*White to gray marble member, dominantly calcitic, with abundant calc-silicate minerals and a little disseminated graphite.*

pgn — **Pyritic gneiss**

Rusty-weathering, pyritic biotite-quartz-plagioclase gneiss, locally with microcline, diopside, graphite, tremolite; local thin granitic layers.

mggn — **Microcline granite gneiss**

Pink, medium- to coarse-grained biotite-microcline granite gneiss with subordinate layers of biotitic and pyroxenic amphibolite.

pxgn — **Pyroxene-quartz-plagioclase gneiss**

Gray, medium-grained pyroxene-quartz plagioclase gneiss, commonly containing minor biotite and hornblende; abundant interlayers of amphibolite and granitic gneiss, local quartzite.

ggn — **Granitic gneiss**

Moderately foliated white to pink biotite-hornblende-(pyroxene) granitic gneiss with microcline perthite; contains abundant layers of amphibolite.

mig — **Migmatite**

Layered rock consisting of coarse-grained pink microcline granite, hornblende-biotite-quartz-plagioclase gneiss and local biotitic amphibolite.

Formation contact, accurately located
Formation contact, approximately located
Formation contact, inferred
Limit of outcrop area
U/D Fault showing relative displacement where known; dashed where inferred.
40 Strike and dip of foliation
Strike of vertical foliation
Generalized strike and dip of crenulated foliation
Generalized strike of vertical crenulated foliation
40 25 Strike and dip of foliation showing plunge of lineation
25 Strike of vertical foliation showing plunge of lineation
FA 50 Minor fold axis showing azimuth and plunge
Abandoned mine trench
Abandoned mine adit
Abandoned open-pit mine or prospect

BEDROCK GEOLOGY OF PARTS OF PUTNAM AND WESTCHESTER COUNTIES NEW YORK, AND FAIRFIELD COUNTY, CONNECTICUT

By: John James Prucha, David M. Scotford and Robert M. Sneider

SCALE 1:24 000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

Mapped, edited, and published by the Geological Survey
control by USGS, USC&GS, USCE, and Connecticut Geodetic Survey
Planimetry by photogrammetric methods from aerial photographs taken 1941. Topography by planetable surveys 1942-1943. Revised 1958, 1960, and from aerial photographs by photogrammetric methods. Aerial photographs taken 1949. Field check 1951. Revised 1960. Culture and drainage in part compiled from aerial photographs taken 1941.
Polyconic projection. 1927 North American datum

12½°
MAGNETIC NORTH
TRUE NORTH
APPROXIMATE MEAN DECLINATION, 1960

New York State Museum and Science Service
Geological Survey, Map and Chart Series: No. 11
(1968)

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D. M. Scotford
R. M. Sneider

Lake Carmel | Brewster | N.Y. | CONN. | Croton Falls | Peach Lake | Mount Kisco | Pound Ridge

MAPPING CREDIT
Geologic mapping 1952—1956

NEW YORK
QUADRANGLE LOCATION