BEDROCK GEOLOGY AND FRACTURE SYSTEMS

This map shows the distribution of bedrock units and major fracture systems in the Croton-Ossining area. The geologic contacts between bedrock units were modified from maps by Wissig (1979) and Fisher and others (1970); fracture traces were taken from maps by the Westchester County Department of Planning (1982).

Major Bedrock Units

Bedrock in the Croton-Ossining area consists of igneous and metamorphic Proterozoic and lower Paleozoic rocks. The major bedrock units, in ascending order, consist of the Fordham Gneiss, the Inwood Marble, and the Manhattan Schist, all of which are metamorphic. Igneous intrusives of the Cortlandt Complex of Late Ordovician age (Fisher and others, 1970) appear at the extreme northwestern part of the mapped area. The oldest rocks in the Croton-Ossining area are believed to be the Fordham Gneiss of Middle Proterozoic age. The Inwood Marble, of Cambrian and Ordovician age, conformably overlies the Fordham Gneiss, while the Manhattan Schist, of Cambrian and Ordovician age, similarly overlies the Inwood Marble (Fisher and others, 1970). All of these units have been extensively folded throughout their deformational history, thus, their surface outcrops appear as alternating bands of Fordham Gneiss, Inwood Marble, and Manhattan Schist that trend generally southeast-northwest along the fold axis.

Fordham Gneiss

The Fordham Gneiss is the lowermost and oldest formation in the study area and underlies about 30 percent of Westchester County (van der Leeden, 1962, p. 23). It generally can be described as a coarse-textured, banded, black-and-white biotite gneiss that is rich in quartz and biotite and contains hornblende and feldspar. Interlayering of marble, mica schist, and granite are common, which can make identification difficult. The Fordham Gneiss has been divided into five units on the basis of mineralogical differences and stratigraphic position (Hall, 1968); but only three of these units have been recognized and mapped in the Croton-Ossining area, however (Wissig, 1979). Of the Fordham units in the mapped area, Fordham unit C is the youngest and most widely exposed; small exposures of units B and A are found in the extreme southeast corner of the mapped area. The Fordham Gneiss is highly resistant to weathering and therefore tends to form ridges wherever it is exposed.

Inwood Marble

The Inwood Marble, a metamorphosed limestone, conformably overlies the Fordham Gneiss in the Croton-Ossining area. Its composition is variable and ranges from white and gray calcitic to dolomitic marble (Wissig, 1979, p. 6). In some areas, a minor unit, the Lowerre Quartzite, is interposed between the Inwood Marble and the Fordham Gneiss. Hall (1968, p. 120) has divided the Inwood in southeastern New York into five members on the basis of stratigraphic position and mineralogy, but these have not been mapped separably in the Croton-Ossining area (Wissig, 1979, p. 6).

The Inwood Marble is found in narrow belts across Westchester County parallel to and sandwiched between larger belts of Fordham Gneiss and Manhattan Schist. Because the Inwood has poor resistance to erosion, it has been incised and eroded in many areas where it is exposed at the surface, and is thus found to underlie many valleys in the Croton-Ossining area as well as across the rest of Westchester County. The New Croton Reservoir is underlain by the Inwood, and the Croton River valley below New Croton Dam is crossed by three separate belts of the Inwood.

Manhattan Schist

The Manhattan Schist, the youngest and uppermost unit of the area, conformably overlies the Inwood Marble and consists of a general assemblage of schists, shistose gneisses, and amphibolites. Hall (1968) has recognized three members of the Manhattan Schist in southeastern New York, two of which are in the Croton-Ossining area (Wissig, 1979, p. 10). Manhattan unit A, the lowermost unit, generally consists of fissile garnet-sillimanite-feldspar-muscovite-quartz-biotite schist (symbol "Oma" on pl. 4) but may grade into a pyroxene-hornblende-biotite-quartz-feldspar schist or schistose gneiss ("Omab" on pl. 4) (Wissig, 1979, p. 10). Locally, the basal part of the formation contains interlayered calcitic marble and schistose gneiss. Manhattan unit C ("Omc" on pl. 4), which is stratigraphically the uppermost bedrock unit in the Croton-Ossining area, is a fine- to medium-grained feldspar-quartz-biotite-muscovite-schistose gneiss with well-defined planes of foliation (Wissig, 1979, p. 11). The rock is resistant to weathering, and tightly folded ridges of the schist can be traced from Westchester County into New York City (van der Leeden, 1962, p. 27). It also is increasingly metamorphosed southward from Croton-on-Hudson (E. T. Simmons, U.S. Geological Survey, written commun., 1955).

Aquifer Properties

The bedrock aquifers in the Croton-Ossining area, and most of Westchester County, are extensively used because high-yielding, stratified-drift aquifers are limited. Most stratified-drift aquifers in this area occupy small, narrow stream valleys and typically have a relatively small saturated thickness. Their limited areal extent and saturated thickness constrains their ability to support the large ground-water demands of this densely populated area. Thus, most homeowners who do not have access to public water supplies rely on private bedrock wells.

More than 90 percent of the public and domestic wells in Westchester County obtain their supplies from bedrock aquifers (van der Leeden, 1962, p. 54), and data on 851 wells in Westchester County (Asselstine and Grossman, 1955; van der Leeden, 1962) indicate that 85 percent of these wells tap ranked (in order of relative ground water yield) either the Inwood Marble, the Manhattan Schist, or the Fordham Gneiss.

Manhattan Schist

The Manhattan Schist is the most important bedrock aquifer in the Croton-Ossining area and all of Westchester County because of its large areal extent and moderate permeability. The Manhattan Schist has been estimated to underlie 30 to 40 percent of Westchester County (E. T. Simmons, U.S. Geological Survey, written commun., 1955; van der Leeden, 1962). Yields of wells that tap this formation range from 0 to 280 gal/min (gallons per minute) with a median yield of 12 gal/min (van der Leeden, 1962). The average specific capacity of 56 wells that tap undifferentiated schists in Westchester County was 0.67 gal/min per foot of drawdown (van der Leeden, 1962, p. 56), which is second only to the limestone and marble units in the county. The moderately high permeability (for bedrock) of the Manhattan Schist is due to the presence of well-defined joints and fissures, which resulted from compression and extension caused by folding. Two joint sets are indicated; one strikes northeastward, roughly parallel to the fold axis, and the second strikes at an angle of about 45° to the first and trends northwest-southeast (van der Leeden, 1962, p. 59-60). The well-defined foliation of schist also may be partly responsible for this high yield because small cracks and fissures tend to open along planes of foliation, especially in weathered schistose rock.

Fordham Gneiss

The Fordham Gneiss is probably the second most important bedrock aquifer in the Croton-Ossining area because of its large extent. Yield data from 851 bedrock wells in Westchester County (Asselstine and Grossman, 1955) indicate that 32 percent of the bedrock wells tap undifferentiated gneiss and that individual well yields ranged from 0 to 365 gal/min with a median of 10 gal/min (van der Leeden, 1962, p. 55). The average specific capacity of 30 wells that tap gneiss was 0.57 gal/min per foot of drawdown, which is the third highest of any bedrock aquifer in the county (van der Leeden, 1962, p. 56). The Fordham Gneiss exhibits much the same pattern of jointing as the Manhattan Schist (van der Leeden, 1962, p. 59-60) and also has a similar, but less defined, trend in foliation (Wissig, 1979, p. 35).

Inwood Marble

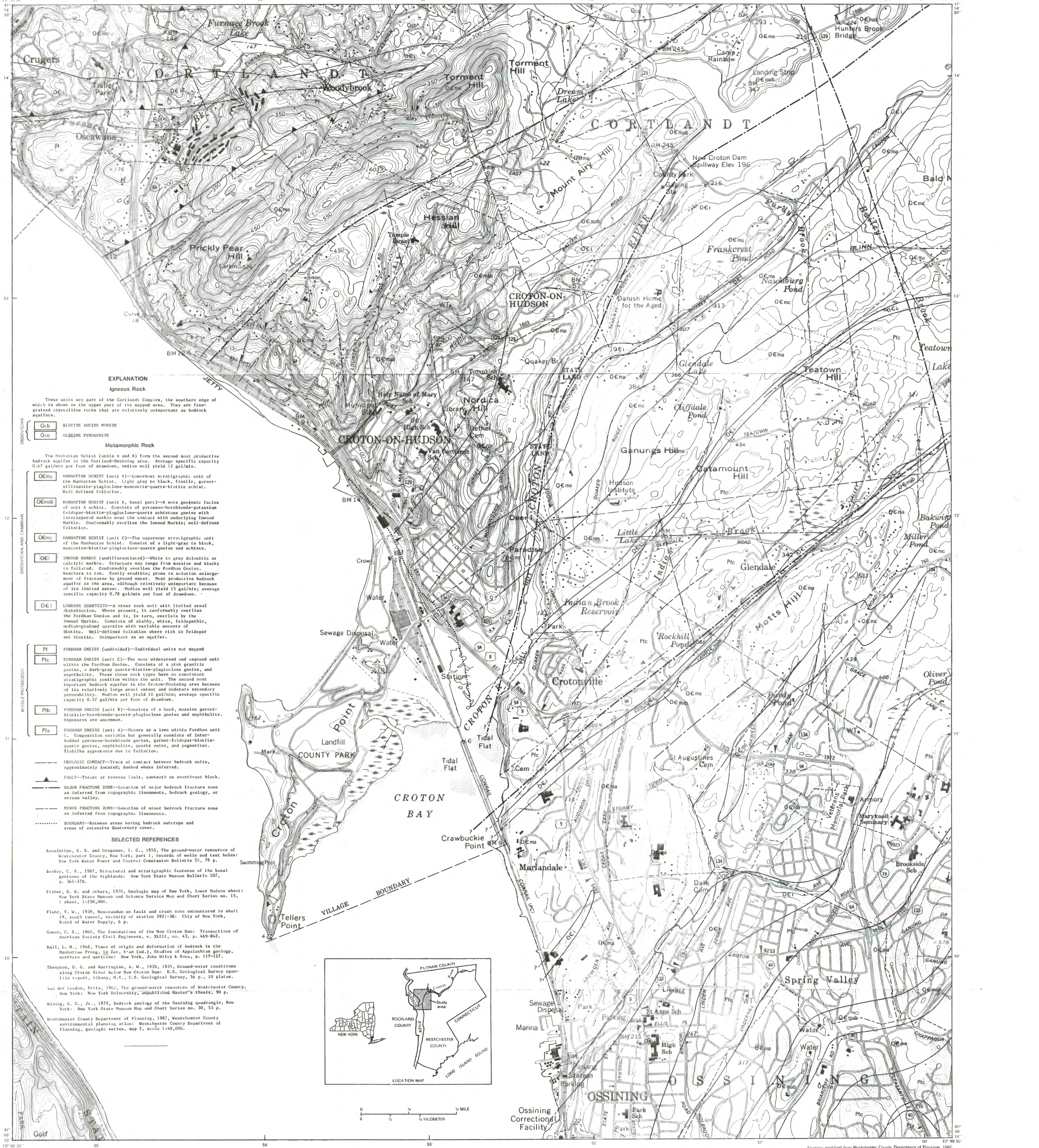
The Inwood Marble is the most productive of the three major bedrock aquifers in the Croton-Ossining area, although it is much less extensive than either the Manhattan Schist or Fordham Gneiss. Data from 97 wells that tap the Inwood Marble and other limestone units in Westchester County show that yields of individual wells range from 1 to 450 gal/min and have a median yield of 15 gal/min. Yield and drawdown data show that the average specific capacity of 25 wells that tap undifferentiated limestone was 0.78 gal/min per foot of drawdown. This is the highest average specific capacity for any bedrock aquifer in the county (van der Leeden, 1962, p. 56) and is due, in part, to the structural weakness of the rock. The Inwood Marble is relatively soft and erodible and has been incised to form many stream valleys. As with limestone, this dolomitic marble is subject to solution enlargement of cracks and fissures by ground water so that, in some areas, the secondary permeability of the rock is quite large. Gowen (1900, p. 480-481), in describing the construction of the New Croton Dam, described the upper 10 to 30 ft of the Inwood Marble, which completely underlies the dam site, as being considerably weathered "soft white rock." During excavation for the dam site (section B-B', pl. 3), even the more competent underlying marble was found to contain large solution channels, some with cross sections as large as 7 by 9 feet, and filled with sand and gravel (Gowen, 1900, p. 500-501).

Thompson and Harrington (1935, p. 14-17) showed that shallow ground water and surface water in the Croton River valley below New Croton Dam is considerably harder than water impounded by the reservoir. In their study, they found hardness concentrations of 42 to 45 mg/L (milligrams per liter) (as $CaCO_3$) in reservoir water but found concentrations ranging from 70 to 123 mg/L (as $Ca\ CO_3$) in river water and shallow ground water from observation wells and supply wells downstream from the dam. These data support the theory that impounded water, under high head, is leaking through joints, cracks, and solution channels in the Inwood Marble beneath the dam, which increases the calcium and magnesium concentration of the water through dissolution of the marble.

Fracture System

This map shows the locations of possible bedrock fracture systems as inferred from the location of lineaments, valleys, and other surface expressions (Westchester County Department of Planning, 1982, pl. 2). The lineaments were delineated by stereoscopic evaluation of 1:20,000-scale aerial photos and correlated with bedrock geologic maps and engineering data. Most of the lineaments are surface expressions of fracture traces in the underlying bedrock. Many of the larger fractures underlie stream valleys, such as the Croton River valley, and are closely associated with the Inwood Marble, which is easily fractured and eroded. The fracture traces generally show two directions of strike, one northeastward, parallel to the regional fold axis, and another north-northwestward at a 60- to 70-degree angle to the first set.

The fracture traces are hydrologically significant in that they represent areas of increased secondary permeability in the bedrock that results from fracturing. Wells drilled near established fracture zones can be expected to have greater yields than wells drilled into the same formation at some distance from these zones. The only exceptions are fracture zones that represent faults along which significant movement, and thus rock disintegration, has occurred over geologic time. These crushed and decayed zones of faults typically contain an impermeable mixture of pulverized rock flour (gouge) and coarser fragments (fault breccia) (van der Leeden, 1962, p. 59). Wells drilled directly into a fault zone tend to produce little or no water because of the presence of clayey rock flour, whereas wells drilled to either side of the fault would be likely to intercept "cleaner" jointed and broken rock and would thus be likely to have larger yields. Many such fault zones were encountered during the construction of both the Catskill and Delaware aqueducts several miles to the east. Fluhr (1939, p. 5) noted that ground water generally percolated slowly along the contact planes of a fault but tended to flow much more rapidly through the crushed and jointed rock to either side of it. For example, during construction of the Kensico-Hillview water tunnel as part of the Delaware Aqueduct, a fault zone in the Manhattan Schist was encountered in which the rock was so "badly crushed and decayed that it resembled a mixture of clay, sand, and gravel." This material was impermeable and thus no leakage occurred through it, although, a nearby joint in the schist permitted a leakage of 750 gal/min of ground water (Fluhr, 1939, p. 2).



EXPLANATION

Igneous Rock

These units are part of the Cortlandt Complex, the southern edge of which is shown on the upper part of the mapped area. They are fine-grained crystalline rocks that are relatively unimportant as bedrock aquifers.

ORDOVICIAN

- Ocb — BIOTITE AUGITE NORITE
- Oco — OLIVINE PYROXENITE

Metamorphic Rock

The Manhattan Schist (units A and B) form the second most productive bedrock aquifer in the Cortlandt-Ossining area. Average specific capacity 0.67 gal/min per foot of drawdown, median well yield 12 gal/min.

ORDOVICIAN AND CAMBRIAN

- O€ma — MANHATTAN SCHIST (unit A)--Lowermost stratigraphic unit of the Manhattan Schist. Light gray to black, fissile, garnet-sillimanite-plagioclase-muscovite-quartz-biotite schist. Well defined foliation.
- O€mab — MANHATTAN SCHIST (unit A, basal part)--A more gneissic facies of unit A schist. Consists of pyroxene-hornblende-potassium feldspar-biotite-plagioclase-quartz schistose gneiss with interlayered marble near the contact with underlying Inwood Marble. Conformably overlies the Inwood Marble; well-defined foliation.
- O€mc — MANHATTAN SCHIST (unit C)--The uppermost stratigraphic unit of the Manhattan Schist. Consist of a light-gray to black, muscovite-biotite-plagioclase-quartz gneiss and schists.
- O€i — INWOOD MARBLE (undifferentiated)--White to gray dolomitic or calcitic marble. Structure may range from massive and blocky to foliated. Conformably overlies the Fordham Gneiss. Weathers to tan. Easily erodible; prone to solution enlargement of fractures by ground water. Most productive bedrock aquifer in the Croton-Ossining area, although relatively unimportant because of its limited extent. Median well yield 15 gal/min; average specific capacity 0.78 gal/min per foot of drawdown.
- O€l — LOWERRE QUARTZITE--A minor rock unit with limited areal distribution. Where present, it conformably overlies the Fordham Gneiss and is, in turn, overlain by the Inwood Marble. Consists of slabby, white, feldspathic, medium-grained quartzite with variable amounts of biotite. Well-defined foliation where rich in feldspar and biotite. Unimportant as an aquifer.

MIDDLE PROTEROZOIC

- Pf — FORDHAM GNEISS (undivided)--Individual units not mapped
- Pfc — FORDHAM GNEISS (unit C)--The most widespread and exposed unit within the Fordham Gneiss. Consists of a pink granitic gneiss, a dark-gray quartz-biotite-plagioclase gneiss, and amphibolite. These three rock types have no consistent stratigraphic position within the unit. The second most important bedrock aquifer in the Croton-Ossining area because of its relatively large areal extent and moderate secondary permeability. Median well yield 10 gal/min; average specific capacity 0.57 gal/min per foot of drawdown.
- Pfb — FORDHAM GNEISS (unit B)--Consists of a hard, massive garnet-biotite-hornblende-quartz-plagioclase gneiss and amphibolite. Exposures are uncommon.
- Pfa — FORDHAM GNEISS (unit A)--Occurs as a lens within Fordham unit C. Composition variable but generally consists of interbedded pyroxene-hornblende gneiss, garnet-feldspar-biotite-quartz gneiss, amphibolite, quartz veins, and pegmatites. Slablike appearance due to foliation.

- GEOLOGIC CONTACT--Trace of contact between bedrock units, approximately located; dashed where inferred.
- FAULT--Thrust or reverse fault, sawteeth on overthrust block.
- MAJOR FRACTURE ZONE--Location of major bedrock fracture zone as inferred from topographic lineaments, bedrock geology, or stream valley.
- MINOR FRACTURE ZONE--Location of minor bedrock fracture zone as inferred from topographic lineaments.
- BOUNDARY--Between areas having bedrock outcrops and areas of extensive Quaternary cover.

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Plate 3. Bedrock Geology and Fracture Systems