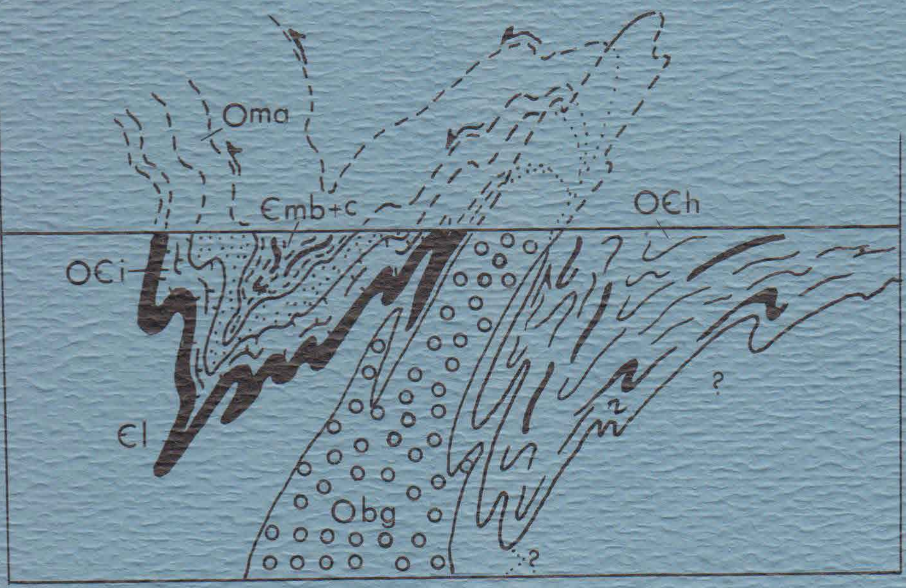
GEOLOGY OF THE BEDFORD COMPLEX AND SURROUNDING ROCKS, SOUTHEASTERN NEW YORK

BY MEHDI ALAVI



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ABSTRACT

Detailed geologic mapping of northern part of the Pound Ridge and eastern part of the Mt. Kisco quadrangles in southeastern New York, reveals that the Precambrian Fordham Gneiss is unconformably overlain by the Early Cambrian Lowerre Quartzite and the Cambrian-Ordovician Inwood Marble. The Marble and Schist members of the Middle Ordovician Manhattan A, unconformably overly the Lowerre and Inwood sequence, as well as the Fordham Gneiss. All of these are structurally overlain by an allochtonous mass which consists of Cambrian schists, gneisses, and amphibolites of Manhattan B and C.

This heterogeneous assemblage of rocks is bordered on the east and southeast by the Cambrian-Ordovician eugeosynclinal rocks of the Hartland Formation; the border being a thrust fault named the Hartland Boundary Fault. The Hartland Formation is subdivided into three members: the Schist and Amphibolite Member, the Schist and Gneiss Member, and the Schist and Granulite Member, which are all intruded by the Ordovician (?) Siscowit Granitic Gneiss.

A composite intrusive complex, the Bedford Complex, cuts across all of the stratigraphic units. The Bedford Complex comprises the Middle Ordovician Bedford Augen Gneiss, which consists of an assemblage of porphyritic and non-porphyritic, dioritic and granodioritic gneisses that are intruded by several relatively small, younger mafic and ultramafic plutons.

Four stages of folding and faulting, related to the Taconic, Acadian, and Alleghenian orogenies as well as probable Triassic-Jurassic faulting

have affected the rocks in this area. The earliest stage of deformation involved thrusting of Manhattan B and C (Cambrian) onto the Cambrian-Ordovician miogeosynclinal rocks as well as the development of the Hartland Boundary Fault. Continued deformation and metamorphism then resulted in large isoclinal folds, with highly attenuated limbs and a well-pronounced axial plane foliation. The Bedford Augen Gneiss was intruded prior to or during this stage of folding, whereas the intrusion of the small mafic and ultramafic plutons occurred later. The second stage of folding was accompanied by a second phase of regional metamorphism and superimposed large isoclinal folds on the earliest folds. The third stage resulted in generation of tight folds with well-developed axial plane slip cleavage which deformed all the pre-existing structures. The fourth stage produced a set of open folds which display no related axial plane feature.

Finally, two normal faults, possibly Triassic and/or Jurassic were developed.

INTRODUCTION

Location

The study area, approximately 35 square miles, is located in the Manhattan Prong of southeastern New York (Fig. 1). It is in the eastern portion of the Mt. Kisco and northern portion of the Pound Ridge $7\frac{1}{2}$ minute quadrangles.

Topography and Drainage

The maximum local relief in the study area is 800 feet in the Ward-Pound Ridge Reservation (Plate 1). The hills in the area are typically underlain by various gneisses, the areas of low rolling hills by schists, and the valleys by marbles. Most of the west- and northwest-facing slopes are covered with till, whereas east- and southeast-facing slopes have abundant bedrock exposures.

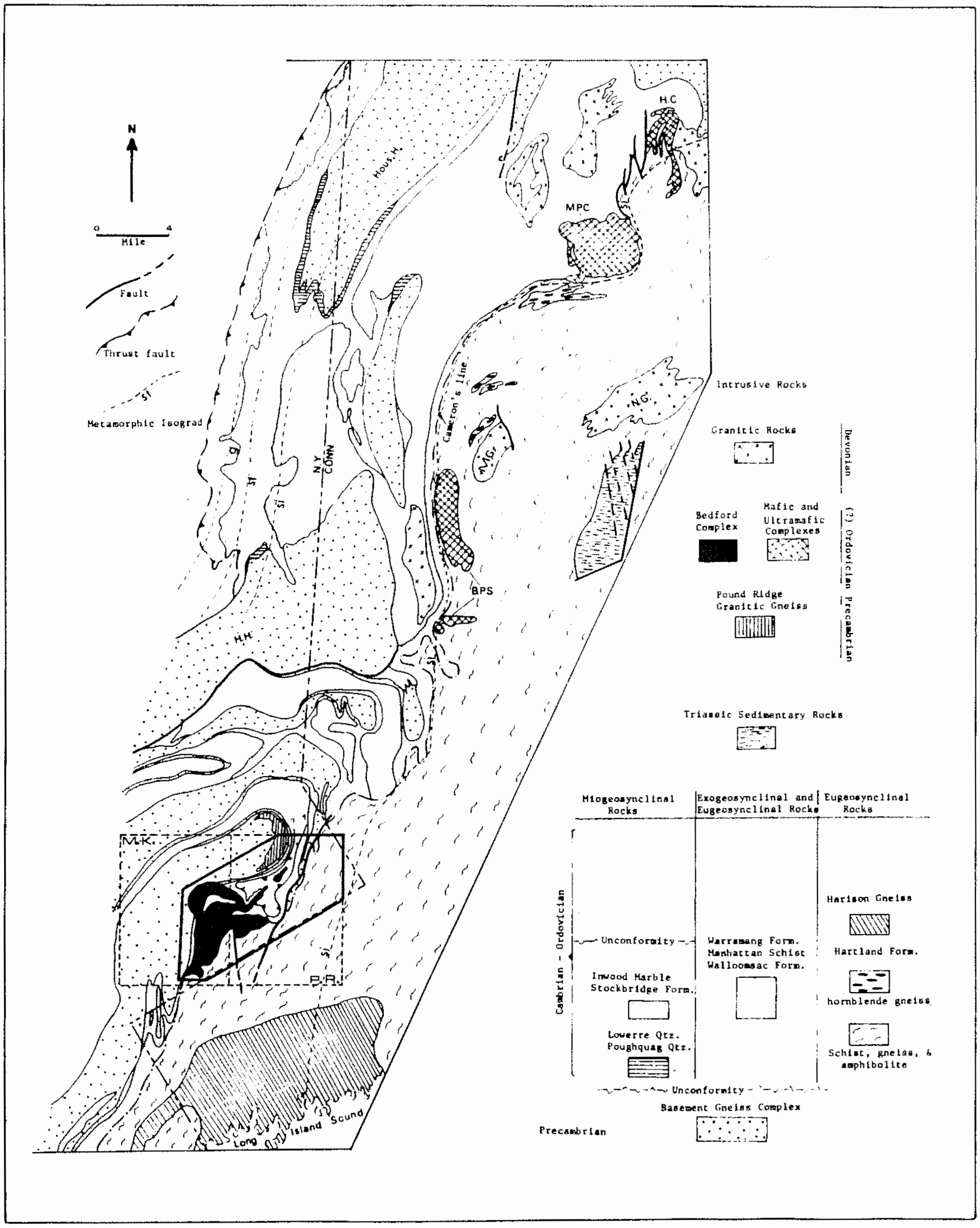
The area is drained by three major rivers, the Stone Hill River, Mill River, and Mianus River, and several small streams. The Stone Hill River is in the northern portion of the area south and east of the Ward-Pound Ridge Reservation and drains into the New Croton Reservoir northwest of the study area. The Mill River is in eastern portion of the area and drains southward into the Laurel Reservoir, about 500 feet southeast of the area. The Mianus River flows in southwestern portion of the area and drains southward into the Long Island Sound.

Regional Geology

The area is located along the east and southeastern edge of a generally NE-SW trending belt of the Fordham Gneiss (Fig. 1). The

Figure 1 - Generalized geologic map of southeastern New York and southwestern Connecticut. The Mt. Kisco and Pound Ridge $7\frac{1}{2}$' quadrangles (dashed) and the study area which lies within the two quadrangles (solid line) are indicated. M.K.: Mt. Kisco quadrangle; P.R.: Pound Ridge quadrangle; N.G.: Nonewaug Granite; M.G.: Mine Hill Granite; B.P.S.: Brookfield Plutonic Series; Hous. H.: Housatonic Highlands; H.H.: Hudson Highlands.

Sources: Balk, 1936; Cameron, 1951; Scotford, 1956; Clarke, 1958; Rogers and others, 1959; Gates and Christensen, 1965; Hall, 1968a, 1968b; Prucha and others, 1968; Thompson and Norton, 1968; and this study.


N
0 4
Mile
Fault
Thrust fault
Metamorphic Isograd
H.C
MPC
N.G.
BPS
H.H.
M-K.
P.R.
N.Y.
CONN.
Cameron's line
Long Island Sound
Intrusive Rocks
Granitic Rocks
Devonian
Bedford Complex
Mafic and Ultramafic Complexes
(?) Ordovician
Pound Ridge Granitic Gneiss
Precambrian
Triassic Sedimentary Rocks
Miogeosynclinal Rocks
Exogeosynclinal and Eugeosynclinal Rocks
Eugeosynclinal Rocks
Cambrian - Ordovician
Harison Gneiss
Unconformity
Warramang Form.
Manhattan Schist
Walloomsac Form.
Hartland Form.
Inwood Marble
Stockbridge Form.
hornblende gneiss
Lowerre Qtz.
Poughquag Qtz.
Schist, gneiss, & amphibolite
Unconformity
Basement Gneiss Complex
Precambrian

Fordham Gneiss is part of the Precambrian basement complex which forms several strike belts extending in a NE-SW direction in southeastern New York and western Connecticut. The basement complex consists primarily of high grade metamorphic rocks including various gneisses of sedimentary and volcanic origin associated with granite-granodioritic intrusives.

The Precambrian basement complex is unconformably overlain by a sequence of dominantly sedimentary Early Paleozoic rocks that include a miogeosynclinal sequence composed of basal clastics and carbonates. The miogeosynclinal sequence is overlain by a group of rocks the lower part of which consists of schists and carbonates and is thought to have formed in an exogeosyncline basin. The upper part of this group consists of schists and amphibolite with eugeosynclinal characteristics which has been considered as an allochthonous mass transported to the present position as a result of thrust faulting.

East of this heterogenous assemblage of Precambrian and overlying Early Paleozoic rocks, lies a eugeosynclinal sequence consisting predominantly of schists, gneisses, granulites, and amphibolites of sedimentary and volcanic origin. This assemblage, refered to as the Hartland Formation (Rodgers and others, 1959), is probably Early Paleozoic and stratigraphically equivalent to the rocks of the miogeosynclinal sequence (Hall, 1975). It is associated with several younger intrusive bodies of granitic, dioritic, gabbroic, and ultramafic compositions.

The grade of the Paleozoic regional metamorphism increases from northwest to southeast in southeastern New York and westernmost Connecticut and thence decreases eastward in western Connecticut (Thompson and Norton, 1968).

Statement of the Problem and Purpose of the Study

The transition from the Precambrian gneisses and the overlying Early Paleozoic rocks to the Hartland Formation is abrupt (Fig. 1). The contact between these two terranes is informally called "Cameron's Line" by geologists working in western Connecticut (Rodgers and others, 1959; Stanley, 1968; Hatch and Stanley, 1973) and is considered to be a major tectonic discontinuity. Much of the details of the structure and location of this tectonic boundary are not yet known and the origin and significance of "Cameron's Line" introduces a problem of regional importance. The occurrence of several mafic intrusive bodies along "Cameron's Line" (Fig. 1) further complicates the problem.

An assemblage of dioritic gneisses, and amphibolites, together with mafic and ultramafic bodies, is present in the vicinity of the Bedford village, southeastern New York (Plate, 1). These rocks constitute an intrusive complex which is refered to as the Bedford Augen Gneiss (Luguer and Ries, 1896), and is similar to the mafic intrusive complexes that occur in the vicinity of "Cameron's Line" in western Connecticut (Fig. 1). The geology of the Bedford complex and the surrounding rocks has been poorly understood, and the relationship of "Cameron's Line" to these rocks is not certain.

The purposes of this study are to illustrate by detailed geologic mapping and geometrical analyses of the structural features: 1) the stratigraphic and structural relationships of the rocks which surround the Bedford Complex, 2) the stratigraphic and structural relationships between the Bedford Complex and the surrounding rocks, and 3) the geologic relationships between the Hartland Formation and the rocks west of it.

Previous Work

The area was first mentioned by Percival (1842) while doing reconnaissance study of the geology of Connecticut. Merrill (1890, 1896) studied the metamorphic rocks of the Manhattan Prong and subdivided them into five formations: Fordham Gneiss, Yonkers Gneiss, Lowerre Quartzite, Inwood Limestone, and Manhattan Schist. Luquer and Ries (1896) and Fettke (1914) described the Bedford Augen Gneiss. Barbour (1930) studied the granitic pegmatites and the feldspar megacrysts present in the Bedford Augen Gneiss. Bell (1936) did a petrographic investigation on the Pound Ridge granitic gneiss and Fluhr (1950) discussed the general aspects of the structure and stratigraphy of the southeastern New York and showed the trend of the rock units on his generalized geologic map. Scotford (1956) prepared a geologic map of the area and discussed the metamorphic and structural relationships of the rock units.

More recently, Hall (1966; 1968a; 1968b) has prepared detailed geologic maps of the White Plains and Glenville areas (southwest of the present study area) and has established the stratigraphy of the region. Lessing (1967) has mapped the Pound Ridge granitic gneiss in detail and has investigated its petrological aspects. Hipple (1971) has studied the structural state and composition of the feldspar megacrysts in the Bedford Augen Gneiss.

Method of Study

This study is based on detailed geologic mapping and laboratory studies that were carried out during the period 1971 - 1975. A geologic map on a scale 1:24,000 has been prepared which presents in detail various stratigraphic units and their structural relationships (Plate 1). For the preparation of the geologic map standard field techniques were used to locate outcrops (Plate 2). Contacts were mapped by actual tracing rather than by traverses across the contacts. One hundred fifty specimens from contrasting rock types were collected for detailed petrographic study (Plate 2). In order to analyze the deformational history of the area, more than 2,000 structural elements (both planar and linear) were measured, of which only a few have been plotted on the geologic map.

Acknowledgements

I wish to thank Professor Leo M. Hall for suggesting this project and his stimulating discussions, criticisms, and corrections in the field and office. Professor Peter Robinson spent a day in the field and with Professors Gregory Webb and Sidney Siggia critically read the manuscript. Professor Howard Jaffe helped in the identification of some minerals.

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STRATIGRAPHY

General Statement

Bedrock in the study area consists of six major subdivisions, each of which comprises several lithologic units. They are:

1) A precambrian basement complex consisting of the Fordham Gneiss which includes several types of gneisses, calc-silicates, and amphibolites.

2) Cambrian-Ordovician miogeosynclinal sequence that consists of basal clastics (Lowerre Quartzite) overlain by carbonates (Inwood Marble).

3) Middle Ordovician Schists and carbonates (Manhattan A) resting unconformably on the older rocks.

4) A eugeosynclinal assemblage of schists, amphibolites, and gneisses (Manhattan B and C), of probably Cambrian age, that now overlies the Middle Ordovician Manhattan A as a result of thrust faulting.

5) A eugeosynclinal assemblage, the Hartland Formation, probably Lower Paleozoic, which includes various schists, gneisses, and amphibolites that are intruded by granites and granitic pegmatites.

6) A composite intrusive complex, the Bedford Complex, comprising dioritic and granodiodioritic gneisses which are intruded by mafic and ultramafic bodies.

These six bedrock groupings consist of twenty-three lithologic units which have areal distributions in the study area as shown on the geologic map (Plate 1).

All the bedrock in the study area has been subjected to regional metamorphism and multiple deformation. Petrographic studies indicate that contact metamorphism also has affected the rocks near the border of the mafic intrusive bodies.

Precambrian Basement Complex

Undivided Unit. The study area is bordered on the west and northwest by a unit of Precambrian basement complex which includes the Fordham Gneiss (Merrill, 1890) and the Pound Ridge Granitic Gneiss (Bell, 1936; Scotford, 1956). The Fordham Gneiss in the adjoining portion of the Mt. Kisco quadrangle consists of an assemblage of highly siliceous, well-bedded quartzofeldspathic gneisses, brown weathering calc-silicates, gray garnet-biotite gneisses, and greenish-black amphibolites (Hall, unpublished map). Radiometric data obtained from the Fordham Gneiss in the White Plains quadrangle by Grauert and Hall (1973) indicate that these rocks have been affected by the Grenvillian event about 1.1 billion years ago.

The Pound Ridge Granitic Gneiss is a pink or buff, biotite-microcline-plagioclase gneiss which may be of igneous or sedimentary origin (Lessing, 1967). Recently obtained radiometric data indicate that the Pound Ridge Granite Gneiss formed 596 $\pm$ 19 million years ago, probably during the Avalonian event (Mose and Hayes, 1975).

Quartzofeldspathic Gneiss Member. This member is typified by light-gray to gray, well-foliated, quartzofeldspathic gneiss which is typically characterized by tan and/or light-brown weathered surfaces. The gneiss is generally very-fine to fine-grained and displays a distinctive mineral lineation. Estimated modes of the specimens from this unit are listed in Table 1.

TABLE 1

Estimated modes of specimens from the members of the Fordham Gneiss

Minerals	Specimens[1]						
	Quartzofeldspathic Gneiss Member			Calc-silicate Member	Sillimanite Quartzose Gneiss Member	Biotite Gneiss Member	Microcline Gneiss Member
	P-5-6	P-2-1	P-2-16	P-5-7	P-2-9	P-2-2	P-2-8
Quartz	51	50	32	1	25	37	31
Plagioclase	27	25	8	16	2	40	5
(An%)[2]	(10)	(6)	(9)	(41)	(?)	(29)	(17)
Microcline	2	3	40	35	48[3]	1	55[3]
Biotite	20	21	20	-	10	22	6
Muscovite	tr.	1	tr.	-	2	-	3
Sillimanite	-	-	-	-	13	-	-
Calcite[4]	-	-	-	30	-	-	-
Actinolite	-	-	-	3	-	-	-
Diopside[5]	-	-	-	13	-	-	-
Epidote	-	-	-	2	-	-	-
Allanite	-	-	-	tr.	-	-	-
Hornblende[6]	-	-	-	-	-	tr.	-
Tourmaline	-	-	-	tr.	-	-	-
Sphene	tr.	-	-	tr.	-	tr.	tr.
Apatite	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Zircon	tr.	tr.	tr.	-	tr.	tr.	tr.
Opaque	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Chlorite[7]	-	-	-	-	-	tr.	tr.
Sericite[7]	tr.	tr.	tr.	-	tr.	-	-
TOTAL	100	100	100	100	100	100	100

Continued from Table 1

1 - For locations of the specimens see Plate 2.

2 - Plagioclase composition is determined by the standard immersion oil methods wherever possible; undetermined where indicated by (?).

3 - Includes microcline-perthite with replacement texture (Deer and others, 1966).

4 - With interlocking polygonal texture.

5 - Colorless to very pale green; replacing light green actinolite.

6 - Blue-green, scattered throughout the specimen.

7 - Secondary minerals produced by hydrothermal alteration of primary minerals.

Descriptions of the rock specimens.

P-5-6 : Light-gray, tan weathering, very-fine-grained, poorly-layered gneiss containing quartz, black biotite, and white plagioclase.

P-2-1 : Similar to P-5-6.

P-2-16 : Light-gray, fine-grained, biotite-quartz-microcline gneiss with a pronounced mineral lineation on the foliation plane.

P-5-7 : Greenish-gray, brown weathering, layered, diopside-rich, calc-silicate gneiss.

P-2-9 : Brown-weathering, well-foliated, quartzose gneiss with large (1 inch long) white sillimanite nodules aligned parallel to the foliation.

P-2-2 : Dark-gray, medium-grained, layered, siliceous biotite-quartz-plagioclase gneiss.

P-2-8 : Pink, fine-grained, poorly-layered, well-foliated, quartz-biotite-microcline gneiss.

The quartzofeldspathic gneiss is well-bedded near the contact with the Calc-silicate Member. This contact is well exposed in an outcrop of approximately one mile south of Trinity Lake, (Plate 1) where beds of quartzite or quartzitic gneiss, up to 3 inches thick, are present.

The Quartzofeldspathic Gneiss Member with interbedded light greenish-gray calc-silicate rocks passes into the Calc-silicate Member. A minimum thickness of 500 feet is estimated from the distribution of this unit within the study area.

Calc-silicate Member. This member of the Fordham Gneiss is light-gray to light-green, medium-grained, calc-silicate rock which is locally interbedded with light-gray, calcite marble. Green diopside crystals, scattered throughout the rock are characteristic. Locally, bedding is conspicuous and it ranges from 1 or 2 inches up to 2 feet thick. The estimated mode of a specimen representative of this rock unit is shown in Table 1.

The estimated thickness of the Calc-silicate Member is about 700 feet as determined east of Lake Kitchawan (Plate 1).

Sillimanite Quartzose Gneiss Member. North of Trinity Lake, the Calc-silicate Member is structurally overlain by a heterogeneous assemblage of gray, well-bedded, brown-weathering sillimanite-rich quartzose gneiss interbedded with light gray quartzite and tan quartzofeldspathic gneiss. The unit is characterized by the occurrence of numerous white sillimanite nodules, up to 1 inch long, which are aligned parallel to the foliation. Bedding is pronounced throughout and is from 1 inch up to 2 feet thick. Beds, rich in euhedral, red garnet porphyroblasts up to 1/2 inch in diameter, are common. Estimated modes of a typical specimen from this unit are given in Table 1.

The sillimanite quartzose gneiss is about 30 feet thick. It extends northeastward about 2,000 feet along its contact with the overlying Biotite Gneiss Member, and then pinches out leaving the Biotite Gneiss Member in contact with Calc-silicate Member (Plate 1).

Biotite Gneiss Member. The Biotite Gneiss Member is exposed north of Trinity Lake and east of Lake Kitchawan where it underlies a narrow zone that extends along strike in an N10E direction (Plate 1). North of Trinity Lake this unit structurally overlies the Sillimanite Quartzose Gneiss Member and underlies the Microcline Gneiss Member of the Fordham Gneiss.

The unit consists of gray to dark-gray, fine- to medium-grained, well-layered, well-foliated, biotite-quartz-plagioclase gneiss. It is highly siliceous near the base but grades upward to more argillaceous near the top. Greenish-black amphibolite lenses ranging from 10 inches thick and 2 feet long up to more than 20 feet thick and 100 feet long, are locally present but constitute less than five percent of the rock unit. Numerous white to pink granitic pegmatite dikes are also present.

Compositional layering in the Biotite Gneiss is defined by well-developed lithic varieties, 1/4 to 1/2 inch thick, that result from variation in mineral content and texture of adjacent layers. Bedding is very well developed in the lower part of the unit especially near the contact with the underlying Calc-silicate Member.

The estimated apparent thickness of the Biotite Gneiss Member is about 600 feet as determined east of Lake Kitchawan. North of Trinity Lake the estimated thickness is not more than 100 feet.

Microcline Gneiss Member. This member is exposed north of Trinity Lake (Plate 1). The areal distribution of this unit is restricted to approximately 500 square feet in the map area.

The Microcline Gneiss Member is characterized by a large amount of microcline which produces the distinctive pink color. It is medium-grained, well foliated, and fairly homogeneous. Estimated modes of a typical specimen of this unit is given in Table 1.

This member is above the Biotite Gneiss Member and the contact between them extends northwest for about 200 feet. A minimum thickness of about 100 feet is estimated from the distribution of this rock unit in the mapped area.

Origin and Stratigraphic Relationships. The origin of the Microcline Gneiss Member is uncertain. The granitic composition, suggests it may originally have been an arkose, a volcanic rhyolite, or intrusive granite.

In contrast to the Microcline Gneiss Member, the other members of the Fordham Gneiss display distinct bedding, interbedded transitional contacts, and gradations from siliceous to micaceous rocks. These features strongly indicate a sedimentary and/or volcanic origin for these rocks. Consequently the Quartzofeldspathic Gneiss Member is interpreted as a metamorphosed feldspar-rich sandstone, the Calc-silicate Member as a carbonate-rich deposit, the Sillimanite Gneiss Member as an arkosic sandstone interbedded with pelitic rocks, the Biotite Gneiss Member as a quartz-rich sandstone which grades to argillaceous clastics. The amphibolite lenses in the

Biotite Gneiss Member are believed to represent metamorphosed mafic volcanics.

Cambrian-Ordovician Miogeosynclinal Rocks

Lowerre Quartzite. The Lowerre Quartzite (Merrill, 1896) of Early Cambrian age (Hall, 1968a) is exposed in the vicinity of Trinity Lake (Plate 1). It consists primarily of light gray, medium-grained, well-bedded feldspathic quartzite interbedded with pure, vitreous quartzites. Gray, micaceous granulites that contain sillimanite nodules up to 1/2 inch long are also present. The Lowerre Quartzite is very well bedded, with bedding 1/2 to 2 inches thick in most outcrops, but up to 2 feet thick in some places.

Table 2 shows that the major minerals in the specimens from the Lowerre Quartzite are quartz and microcline, and plagioclase (An_{35}-An_{37}) is subordinate.

Specimen P-2-14 (Table 2) represents an unusual rock in the Lowerre Quartzite which was collected from a bed 5 feet below the contact with the Marble Member of Manhattan A, southwest of Trinity Lake. It contains medium-grained microcline and light tan to red biotite as the major constituent minerals. Quartz, in contrast with the typical rocks of this unit, constitutes only 15 percent of the rock.

Geologic mapping in the White Plains area demonstrates the unconformable relationship between the Lowerre Quartzite and the underlying Precambrian gneisses (Hall, 1966). Within the study area (Plate 1) the Lowerre Quartzite rests on three different members of the Fordham Gneiss, the Calc-silicate Member, along the peninsula on the west side of

TABLE 2

Estimated modes of specimens collected from the Lowerre Quartzite

Minerals	Specimens[1]		
	P-2-4	P-2-15	P-2-14
Quartz	53	58	15
Microcline	40	34	65
Plagioclase[2]	5	5	-
(An%)	(37)	(35)	-
Muscovite	tr.	1	3
Biotite	-	2	17
Garnet	-	tr.	-
Zircon	tr.	tr.	tr.
Apatite	tr.	tr.	tr.
Opaque[3]	2	tr.	tr.
Chlorite[4]	-	tr.	-
TOTAL	100	100	100

1) For location of specimens see Plate 2

2) Plagioclase compositions determined by oil immersion techniques.

3) Includes both magnetite and pyrite.

4) Alteration product of biotite.

Description of rock specimens

P-2-4 : Light-gray, buff weathering, medium grained, foliated, feldspathic quartzite.

P-2-15 : Light-gray, dense, medium-grained, foliated, feldspathic quartzite.

P-2-14 : Gray, medium-grained granulite with white quartz-feldspar veins from a layer about 5 feet below the contact with the Marble Member of the Manhattan A.

Trinity Lake, the Microcline Gneiss Member, and the Biotite Gneiss Member. North of Trinity Lake the base of the Lowerre truncates the contact between the Microcline Gneiss and Biotite Gneiss Members of the Fordham (Plate 1). These relationships are due to the unconformity between the Lowerre Quartzite and the Fordham Gneiss. This unconformity is equivalent to the basal Cambrian angular unconformity elsewhere in eastern New York (Balk, 1936; Knopf, 1967) and western New England (Emerson, 1917; Brace, 1953; Ratcliffe, 1969; Alavi, 1971).

The Lowerre Quartzite is up to 200 feet thick as determined north of Trinity Lake.

Inwood Marble. The Inwood Marble is Early Cambrian to Middle Ordovician (Hall, 1968a) and was named by Merrill (1896). It occurs along the Stone Hill River valley, north of Trinity Lake, and along Mill River Road (Plate 1). The formation which is predominantly composed of calcite and dolomite is subdivided into four members in the White Plains area (Hall, 1975). In the study area, members A and B have been recognized.

Member A - This unit crops out north of Trinity Lake, where it overlies the Lowerre Quartzite and along the Stone Hill River valley where it overlies the Fordham Gneiss. It is a white to light-gray, medium- to coarse-grained, generally thick-bedded (1 - 2 feet) but locally thin-bedded (less than 1/2 inch), dolomite marble which has a distinctive gray weathering surface. On the fresh surface, some layers, about 1/2 inch thick, are dark gray, which is a result of replacement of forsterite crystals by serpentine.

Rock specimens collected from this unit are chiefly composed of interlocking dolomite grains (Table 3). Pholgopite, serpentinized forsterite, diopside, tremolite, and opaques (mostly iron sulfides) are among the accessory minerals.

The estimated thickness of Member A is about 100 feet as determined north of Trinity Lake and about 300 feet as determined along the Stone Hill River valley.

Member B - of the Inwood Marble is exposed along the Mill River Road near the northern boundary of the Pound Ridge quadrangle. It consists of very light-gray, light-brown to tan weathering, well foliated, dolomitic marble interbedded with calcite marble. Well-developed bedding, commonly about 1-3 inches thick, and the existence of calcite marble beds, distinguish this rock unit from the Member A. A specimen from a dolomitic marble is virtually pure dolomite (P-3-1; Table 3).

Middle Ordovician Exogeosynclinal Rocks - Manhattan A

General Statement. Merrill (1896) proposed the name Manhattan Schist for an assemblage of schists, schistose gneisses and amphibolites which overlies the clastic and carbonate rocks of the miogeosynclinal sequence. Hall (1968a), in the White Plains area, subdivided this assemblage into three members designated by the letters A through C and established the unconformity at the base of the structurally lowest member. The lowest member, Manhattan A, is a dark-gray, sillimanite-garnet-biotite schist with calcitic marble beds and a locally mappable tan-weathering calcite marble unit at the base. Manhattan A is correlative of the Middle Ordovician exogeosynclinal shales of the Walloomsac Formation and Balmville Limestone mapped further north in eastern New York and western Massachusetts (Hall, 1968a).

TABLE 3

Estimated modes of specimens collected from the Inwood Marble.

Minerals	Specimens[1]		
	Member A		Member B
	P-1-1	P-2-3	P-3-1
Calcite	5	1	-
Dolomite	80	98	99
Tremolite[2]	-	1	-
Diopside[3]	2	-	-
Forsterite[4]	3	-	-
Serpentine	8	-	-
Phlogopite[5]	2	tr.	1
Opaque[6]	tr.	tr.	tr.
TOTAL	100	100	100

1) For location of specimens see Plate 2.
2) it occurs as very-fine-grained aggregates.
3) Colorless; 2V≈55; it contains patches of phlogopite and dolomite as inclusions.
4) Optically positive; 2V=85°; highly serpentinized.
5) Randomly oriented and mostly curved and kinked; colorless to very pale brown; 2V = 2-3° .
6) Mostly iron sulfides.

Description of rock specimens

P-1-1 : White to very light-gray, medium- to coarse-grained, dolomite marble with dark-gray layers rich in serpentine

P-2-3 : Very light-gray, coarse-grained, massive dolomite spotted with white tremolite.

P-3-1 : Very light-gray, medium-grained, fairly homogeneous dolomite.

Members B and C of the Manhattan Schist have eugeosynclinal characteristics and Hall (1968a) suggests that the Manhattan B and C may be older rocks which have been transported and emplaced on the Manhattan A as a result of thrust faulting.

In the study area, the three members of the Manhattan Schist, in the same structural sequence mapped by Hall (1968a) in the White Plains area, have been recognized. In this part of the report Manhattan A will be described, and Manhattan B and C will be categorized as the allochthonous rocks.

Marble Member. The Marble Member which occupies the lower part of the Manhattan A is exposed in the vicinity of Trinity Lake and southeast of Bedford village (Plate 1). It consists of white, light-gray, greenish gray, medium-grained, calcite marble which characteristically weathers tan-brown and "dirty" brown. Brown phlogopite flakes are abundant in some layers. Modes of four specimens, presented in Table 4, show the mineralogic variations in this unit.

The Marble Member locally contains lenses and layers of schist ranging from less than 1/2 inch up to 5 feet thick (P-2-11, Table 4). Lithic similarities between the schist layers and the rocks that belong to the Schist Member of the Manhattan A, suggest that these two units are facies of each other. This stratigraphic relationship is the same as the relationship found between the Middle Ordovician Walloomsac Formation and the Balmville Limestone in Dutchess County, New York (Fisher, 1962) and elsewhere in Manhattan A (Hall, 1968a).

The pattern of distribution of the rock units in the vicinity of Trinity Lake (Plate 1) clearly reveals the unconformity at the base of

Manhattan A. North of Trinity Lake, the Marble Member rests on the Inwood Marble; further south, where the Inwood is absent, it is in contact with the Lowerre Quartzite. Northeast of Trinity Lake, the Marble Member overlies the Calc-silicate Member of the Fordham Gneiss.

The thickness of the Marble Member is up to 250 feet as determined west of Trinity Lake.

Schist Member. This unit consists dominantly of gray to purple-gray, fine- to coarse-grained, sillimanite-bearing, garnet-biotite-schist with some quartzose layers that occur locally and make the unit more siliceous. Typically the rocks in this unit have a brown-weathering color; in some outcrops rusty-weathering layers are present. Bedding is only locally recognizable, particularly where more quartzose layers occur in the schist. Euhedral red garnet porphroblasts are common and sillimanite fibers are distinquished on the foliation planes. Lenses of greenish-black amphibolite, less than 3 feet thick, are present at two localities. One is in a road cut about 2 miles southeast of Bedford on U.S. Route 104, and the other in an outcrop about one mile west of Pound Ridge. The unit also contains thin calc-cilicate layers, less than 1/2 inch thick. Estimated modes, and other notes on specimens from this unit are presented in Table 5.

Along the contact between the Schist Member and the Bedford Complex, the schist is feldspar rich and contains K-feldspar megacrysts up to 1/2 inch long. Specimen P-6-29 (Table 5), collected from an outcrop northeast of Twin Lakes, represents this rock type and except for the large (1/2 inch) orthoclase crystals rimmed by very fine grains of quartz, plagioclase, and orthoclase, it is the same as the other schists.

TABLE 4

Estimated modes of specimens collected from the Marble Member of the Manhattan A

Minerals	P-2-5[2]	P-2-13[3]	P-6-20[2]	P-2-11[3]
Quartz	2	-	1	35
Plagioclase	6	5	2	17
(An%)	(63)	(44)	(34)	(36)[4]
Microcline	15	12	-	7
Biotite	-	-	-	23
Muscovite	-	-	-	-
Phlogopite	-	4[5]	-	-
Garnet	-	-	-	5
Sillimanite	-	-	-	3
Calcite	62	61[6]	90	-
Actinolite	-	-	tr.	-
Diopside	11	8	-	-
Scapolite	-	7	-	-
Epidote	4	3	-	-
Sphene	tr.	tr.	tr.	-
Tourmaline	-	-	-	tr.
Apatite	tr.	tr.	-	-
Opaque[7]	tr.	tr.	1	tr.
Chert[8]	-	-	6	-
TOTAL	100	100	100	100

Continued from Table 4

1) For the locations of specimens see Plate 2

2) Texture: granular, defined by interlocking calcite polygons.

3) Texture: foliated.

4) Plagioclase composition is determined by dispersion method as revised by Morse (1971); the other plagioclase compositions are determined by standard immersion methods.

5) Oriented parallel to foliation; pleochroic from light tan to tan-brown.

6) Grains are mostly curved and kinked, indicating severe deformation.

7) Mostly pyrite.

8) A secondary mineral replacing calcite grains.

Description of the rock specimens

P-2-5 : Very light-gray, medium-grained, borwn on weathered surface, calcite marble.

P-2-13 : Greenish-gray, well-foliated, phlogopitic, calcite marble with green diopside. The specimen was collected from a layer near the base of the unit.

P-6-20 : Light-gray, coarse-grained, borwn-weathering, calcite marble which is spotted by fine, euhedral grains of pyrite.

P-2-11 : Dark-gray, brown weathering plagioclase-biotite-quartz schist with large (1/4 inch) garnet porphyroblasts. Collected from a schist lens about 5 feet thick and 30 feet long in the Marble Member.

TABLE 5

Estimated modes of specimens from the Schist Member of the Manhattan A.

Minerals	Specimens[1]							
	P-1-4	P-6-5[2]	P-6-12	P-6-23	P-6-24[2]	P-6-15	P-6-2	P-6-1
Quartz	29	31	40	47	42	32	29	48
Plagioclase	26	22	18	31	29	18	22	34
(An%)	(32)	(39)[6]	(39)	(35)[5]	(32)	(30)	(25)	(37)
Microcline	-	-	-	tr.	-	-	-	-
Orthoclase	-	-	-	tr.	-	-	-	-
Biotite[8]	30	30	25	18	21	36	38	12
Muscovite	-	-	tr.	1	1	2	tr.	tr.
Garnet[9]	6	6	8	3	4	4	2	4
Sillimanite	9	9	6	tr.	3	5	7	2
Kyanite	tr.	-	-	-	-	-	tr.	-
Actinolite[10]	-	-	-	-	-	-	-	-
Diopside[11]	-	-	-	-	-	-	-	-
Clinozoiizite	-	-	-	-	-	-	-	-
Allanite	-	-	-	-	-	-	-	-
Sphene	-	-	-	-	-	-	-	-
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Apatite	-	tr.	-	tr.	-	tr.	-	-
Tourmaline	-	-	-	-	-	-	-	-
Opaque[12]	tr.	2	3	tr.	tr.	2	2	tr.
Chlorite	-	-	-	tr.	-	-	-	-
TOTAL	100	100	100	100	100	99	100	100

Continued from Table 5

Minerals	Specimens						
	M-4-5	M-4-4[3]	P-6-41	P-6-22	P-2-29	P-6-39	P-6-36
	36	65	32	44	35	44	45
Plagioclase	31	17	22	23	25	22	38
(An%)	(26)	(18)[5]	(17)	(35)	(25)	(36)	(37)
Microcline	1	-	10	-	-	6	-
Orthoclase	-	-	-	-	8[7]	-	-
Biotite[8]	17	10	25	22	20	23	12
Muscovite	6	1	tr.	tr.	2	1	3
Garnet[9]	4	5	5	2	6	4	2
Sillimanite	5	2	6	5	4	-	tr.
Kyanite	5	-	-	-	-	-	-
Actinolite[10]	-	-	-	-	-	-	-
Diopside[11]	-	-	-	-	-	-	-
Clinozoizite	-	-	-	-	-	-	-
Allanite	-	-	-	-	-	-	-
Sphene	-	-	-	-	-	-	-
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Apatite	-	-	-	tr.	tr.	-	tr.
Tourmaline	-	-	-	-	-	tr.	-
Opaque[12]	tr.	tr.	tr.	4	tr.	tr.	tr.
Chlorite	tr.	-	tr.	-	tr.	-	tr.
TOTAL	100	100	100	100	100	100	100

Continued from Table 5

Minerals	Specimens						
	P-6-33	P-5-12	P-5-5	P-6-10[2]	P-6-19	M-4-1	M-4-2
Quartz	37	35	42	45	42	42	36
Plagioclase	20	16	36	30	15	28	35
(An%)	(29)	(26)	(48)	(27)	(45)	(35)	(25)
Microcline	-	20	-	-	17	tr.	-
Orthoclase	-	-	-	-	-	-	-
Biotite[8]	35	20	21	15	20	17	22
Muscovite	5	7	tr.	-	1	tr.	4
Garnet[9]	2	2	1	3	tr.	7	2
Sillimanite	1	-	-	4	-	5	-
Kyanite	-	-	-	-	-	-	-
Actinolite[10]	-	-	-	-	-	-	-
Diopside[11]	-	-	-	-	-	-	-
Clinozoizite	-	-	-	-	-	-	-
Allanite	-	-	-	-	-	-	-
Sphene	-	-	-	-	-	-	-
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Apatite	-	tr.	tr.	tr.	tr.	tr.	tr.
Tourmaline	-	-	-	-	tr.	-	-
Opaque[12]	tr.	tr.	tr.	3	5	1	1
Chlorite	-	-	-	-	tr.	tr.	-
TOTAL	100	100	100	100	100	100	100

Continued from Table 5

Minerals	Specimens			
	P-6-21	M-9-24	P-2-17	P-6-40[4]
Quartz	40	36	38	32
Plagioclase	32	19	30	15
(An%)	(27)[5]	(38)	(55)	(81)[5]
Microcline	-	4	3	-
Orthoclase	-	-	-	-
Biotite[8]	14	23	25	25
Muscovite	tr.	5	2	-
Garnet[9]	8	5	1	-
Sillimanite	4	8	1	-
Kyanite	-	-	-	-
Actinolite[10]	-	-	-	21
Diopside[11]	-	-	-	tr.
Clinozoizite	-	-	-	tr.
Allanite	-	-	-	tr.
Sphene	-	-	-	tr.
Zircon	tr.	tr.	tr.	tr.
Apatite	tr.	-	tr.	-
Tourmaline	-	-	tr.	-
Opaque[12]	2	tr.	tr.	7
Chlorite	-	tr.	-	-
TOTAL	100	100	100	100

Continued from Table 5

1) For locations of the specimens see Plate 2.

2) Large (up to 2 mm) quartz grains with strong undulose extinction, and plagioclase grains with curved abite twins are rimmed by ultra-fine-grained quartz, plagioclase, and sillimanite aggregates.

3) From a quartzitic bed.

4) Biotite is concentrated in schistose bed, while actinolite is in the calc-silicate bed.

5) Plagioclase composition is determined by dispersion method as revised by Morse (1971). The others are determined by standard immersion methods.

6) It includes one grain of antiperthite with replacement texture (Deer and others, 1966).

7) As lenticular megacrysts rimmed by fine grained quartz, plagioclase, and orthoclase.

8) Pleochroic from light-tan to red.

9) It is in fresh euhedral crystals in some rocks, and as strongly deformed lenticular (1/2 inch long) porphyroblasts parallel to foliation in others.

10) Large, poikilitic, light green; 2V=80° ; Z C=17° .

11) Colorless, with inclusions of quartz and actinolite.

12) Mostly pyrite.

Descriptions of the rock specimens:

P-1-4 : Gray to brown-weathering, coarse-grained, garnet-biotite schist with layers of quartz and feldspar.

P-6-5 : Gray to brown-weathering, biotite schist that has white layers composed of quartz and feldspar. This rock is highly folded.

P-6-12 : Purple-gray, brown-weathering, medium-grained, sillimanite-rich, garnet-biotite schist, strongly folded.

P-6-23 : Gray, well-layered, biotite schist with feldspar megacrysts (1/4 inch).

P-6-24 : Gray, medium grained, garnet-biotite schist with scattered quartz and feldspar grains about 1-2 millimeters in diameter.

P-6-15 : Well-layered (1/4 inch), fissile, biotite schist. Biotite in the dark layers, quartz and feldspar in white layers.

P-6-2 : Gray, brown-weathering, coarse-grained, feldspar rich, sillimanite-biotite schist.

P-6-1 : Gray, medium-grained, well-layered, feldspar-rich garnet biotite schist.

M-4-5 : Gray, medium-grained, biotite feldspathic schist with garnet porphyroblasts.

M-4-4 : Light-gray, fine-grained, very thinly (0.5 mm) layered, garnet-biotite quartzose schist.

P-6-41 : Gray, very-fine-grained, very-thinly-layered, garnet-biotite schist.

P-6-22 : Gray, very-fine-grained, very-thinly-layered, sillimanite-biotite schist which displays isoclinal folds.

P-6-29 : Gray, biotite schist with garnet porphyroblasts (up to 1/4 inch) and white feldspar megacrysts (1/2 inch).

P-6-39 : Gray, medium-grained, garnet-biotite schist with white layers composed of quartz and feldspar. Sillimanite fibers on the foliation are conspicuous.

P-6-36 : Gray, brown-weathering, sillimanite-biotite schist.

P-6-33 : Gray, brown-weathering, fissile, well-layered sillimanite-garnet-biotite schist.

P-5-12 : Gray, brown-weathering, coarse-grained, garnet-rich, feldspathic, muscovite-biotite schist.

P-5-15 : Gray, brown-weathering, very-fine-grained biotite schists.

P-6-10 : Purple-gray, coarse-grained, brown-weathering, feldspar-rich, sillimanite-garnet-biotite schist is highly folded.

P-6-19 : Gray, fine-grained, brown-weathering, biotite-quartz-feldspar schist.

M-4-1 : Gray, fissile, sillimanite-garnet-biotite schist, with large white feldspar megacrysts.

M-4-2 : Dark-gray, very-fine-grained, thinly-layered, (1 mm thick) biotite schist.

P-6-21 : Gray, sillimanite-garnet-biotite schist.

M-9-24 : Gray, thinly-layered, medium-grained, sillimanite-garnet-biotite schist.

P-2-17 : Gray, fine-grained, garnet-biotite schist.

P-6-40 : Gray, brown-weathering, well-bedded, well-foliated, fine-grained schist interbedded with very-fine-grained, dark-gray, calc-silicates less than 1/2 inch thick. The rock displays an isoclinal fold in bedding with foliation parallel to its axial plane.

The apparent thickness of the Schist Member is estimated at about 700 feet from its map distribution in the study area.

Contact Relation with the Underlying Rocks. North of Trinity Lake, the Marble Member rests on the Inwood Marble; further south it is in contact with the Lowerre Quartzite. Northeast of Trinity Lake, the Marble Member overlies the Calc-silicate Member of the Fordham Gneiss. In the absence of the Marble Member the overlying Schist Member of the Manhattan A, rests on the older rocks of the miogeosynclinal sequence and the Precambrian basement gneisses.

These contact relationships between the members of the Manhattan A and the underlying rocks in the study area clearly reveal the unconformity at the base of the Manhattan A. This unconformity is the same regionally wide-spread Middle Ordovician unconformity which is well documented in the Northern Appalachian Orogen (Cady, 1945; Fisher, 1962; Zen, 1967; Hall, 1968a).

Allochthonous Rocks

Manhattan B. Hall (1968b) described the Manhattan B as discontinuous, greenish-gray amphibolite which is within and at the base of the Manhattan C. In the study area Manhattan B is exposed in the vicinity of Trinity Lake. It consists of black or greenish-black, medium-grained, well-foliated hornblende amphibolite. Estimated modes of one typical specimen (P -2-12) from this unit are given in Table 6.

From place to place, Manhattan B is in contact with the Schist or the Marble members of the Manhattan A (Plate 1). This discordance is interpreted as a thrust fault. The estimated thickness of this unit is about 30 feet as determined along the Trinity Pass (Plate 1).

TABLE 6

Estimated modes of specimens from
the Manhattan B and C.

Minerals	Specimens[1]							
	Manhattan C							
	P-2-6	P-2-19	P-5-9	P-5-10	P-5-8	P-5-4	P-5-2	P-1-3
Quartz	30	27	40	39	40	33	48	12
Plagioclase[4]	38	37	28	29	20	38	30	62
(An%)	(36)	(27)	(30)	(30)	(35)	(27)	(32)	(35)
Microcline	tr.	-	tr.	11	17	-	8	-
Biotite[5]	22	20	26	17	20	15	10	19
Muscovite	1	6	1	4	2	12	2	tr.
Garnet	3	2	3	-	1	-	-	4
Sillimanite	6	7	2	tr.	-	-	tr.	-
Kyanite	tr.	tr.	-	-	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-
Actinolite[8]	-	-	-	-	-	-	-	-
Diopside	-	-	-	-	-	-	-	-
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	-	tr.
Apatite	tr.	-	tr.	tr.	tr.	-	-	-
Tourmaline	tr.	tr.	-	-	-	-	-	-
Sphene	-	-	-	-	-	-	-	-
Magnetite	tr.	1	tr.	tr.	-	2	2	3
Chlorite[10]	-	-	-	tr.	-	tr.	-	-
Sericite[10]	tr.	-	-	tr.	-	tr.	tr.	tr.
TOTAL	100	100	100	100	100	100	100	100

Continued from table 6

Minerals	Specimens[1]									
	Manhattan C									Manhattan B
	P-6-3	P-6-13	P-6-14	P-6-30	P-6-17	P-6-4	P-6-32	M-9-23	P-5-31[2]	P-5-3[3]	P-2-12
Quartz	53	28	50	45	38	39	35	39	20	21	9
Plagioclase	18	34	32	26	28	40	27	24	45	28	40
(An%)	(29)	(36)	(37)	(31)	(27)	(30)	(36)	(28)	(68)	(70)	(33)
Microcline	-	7	-	1	8	-	-	-	-	-	-
Biotite	20	19	14	17	22	15	28	17	-	6	10
Muscovite	5	3	2	10	1	4	tr.	15	-	-	-
Garnet	4	1	2	1	2	1	9	1	-	1	-
Sillimanite	-	4	-	tr.		tr.	1	-	-	-	-
Kyanite	-	-	-	-	-	-	tr.	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-	-	35[6]	36[7]
Actinolite[8]	-	-	-	-	-	-	-	-	9	-	-
Diopside	-	-	-	-	-	-	-	-	25	-	-
Zircon	tr.	tr.	-	tr.	tr.	-	tr.	tr.	tr.	tr.	tr.
Apatite	tr.	-	tr.	tr.	-	-	tr.	tr.	tr.	tr.	tr.
Tourmaline	-	-	-	-	-	tr.	-	-	-	-	-
Sphene	tr.	-	-	-	-	-	-	-	1	-	-
Magnetite	tr.	4	tr.	tr.	1	1	-	4	tr.	9[9]	tr.
Chlorite[10]	-	-	-	-	-	-	-	-	-	-	5
Sericite[10]	-	-	tr.	-	-	-	tr.	-	tr.	tr.	-
TOTAL	100	100	100	100	100	100	100	100	100	100	100

Continued from table 6

1) For locations of the specimens see Plate 2.

2) Representative of a calc-silicate layer.

3) A typical specimen from the amphibolite.

4) Plagioclase occurs as both very-fine grains and relatively large grains (up to 2 mm in diameter). In P-6-30, one large grain of plagioclase about 1/2 inch long has patches of microcline (antiperthite). Plagioclase compositions were determined by oil immersion methods.

5) Biotite is commonly pleochroic from light-tan to greenish-brown. In a few specimens (P-5-10, P-5-8, P-6-32, and P-2-12) it is tan to red.

6) Pleochroic from yellowish-green to blue-green.

7) Relatively large, poikilitic, and oriented parallel to foliation; pleochroic from tan to olive green.

8) Pleochroic from colorless to light-green.

9) It occurs as both fine and very large (up to 2 mm), subhedral grains.

10) Secondary mineral.

Description of the rock specimens:

P-2-6 : Gray, slabby, brown-weathering, fine-grained, garnet-biotite schist.

P-2-19 : Gray, fissile, sillimanite-bearing, feldspathic-biotite schist.

P-5-9 : Gray, brown-weathering, fissile, biotite schist.

P-5-10 : Light-gray, coarse-grained, highly feldspathic, biotite schistose gneiss.

P-5-8 : Gray, medium-grained, thinly-layered (1 mm thick), biotite gneiss with white plagioclase megacrysts

Continued from table 6

about 1/4 inch across.

P-5-4	:	Gray, very-coarse-grained, quartzofeldspathic, muscovite-biotite schist with garnet porphyroblasts.
P-5-2	:	Light-gray, coarse-grained, highly-feldspathic, biotite schistose gneiss.
P-1-3	:	Gray, medium-grained, highly feldspathic, garnetiferous, biotite schist.
P-6-3	:	Dark-gray, medium-grained, well-layered (2 mm thick), garnet-muscovite-biotite gneiss.
P-6-13	:	Light-gray, very-coarse-grained, highly feldspathic, biotite schistose gneiss.
P-6-14	:	Gray, medium-grained, feldspathic, garnet-biotite schistose gneiss.
P-6-30	:	Light-gray, medium-grained, feldspathic, muscovite-rich biotite schist.
P-6-17	:	Gray, coarse-grained, feldspathic, layered, garnet biotite gneiss.
P-6-4	:	Light-gray, very-coarse-grained, highly-feldspathic biotite schistose gneiss.
P-6-32	:	Gray, coarse-grained, layered, feldspathic, garnet-biotite gneiss with white plagioclase megacrysts up to 1/2 inch in diameter.
M-9-23	:	Gray, well-layered (1/4 inch thick), coarse-grained, muscovite (sparkling), feldspathic, garnet-muscovite-biotite gneiss.
P-5-31	:	Gray to greenish-gray, well-layered, very-fine-grained, calc-silicate.
P-5-3	:	Dark-gray, very-fine-grained, well-foliated, amphibolite.
P-2-12	:	Black, medium-grained, well-foliated amphibolite.

Manhattan C. Manhattan C is most widely exposed west of Lake Kitchawan, in the vicinity of Pound Ridge, and near Blue Heron Lake (Plate 1). It consists of a heterogeneous assemblage of schists and schistose gneisses interlayered with granulites and amphibolites. Owing to structural complexity and the interlayered character of this assemblage, attempts to subdivide Manhattan C, led to defining one amphibolite layer (Plate 1).

The most prominent rock type in the Manhattan C is light-gray or gray, fine- to coarse-grained, highly feldspathic, garnet-muscovite-biotite schist which locally has large (up to 1/2 inch long) plagioclase porphyroblasts. Locally, the rock has a distinctive compositional layering defined by alternating white quartzo-feldspathic layers with gray or dark-gray, more micaceous layers. The thickness of the layers ranges from 1/8 to 1/2 inch. In some exposures, the rock is strongly sheared, and consequently it is fissile.

The granulite layers in this unit are blue-gray, fine-grained and largely composed of quartz and feldspar. Commonly they are 2-3 inches thick, but locally they are up to 1 foot thick. The amphibolite layers are dark-gray or black, ranging in thickness from less than an inch up to 30 feet. Garnet is present in these amphibolites. In some exposures contrasting rock types of this assemblage are interbedded, the beds being about 1 to 4 inches thick.

At one locality, about 1500 feet southeast of Blue Heron Lake and the same distance northeast of the Mallard Lake (Plate 1) a layer of calc-silicate about 1 inch thick is present. The rock is very-fine-grained, greenish-gray; it is internally layered with the layering consisting of alternate concentrations of actinolite and diopside. The layering is parallel to the pronounced foliation of the rock.

Estimated modes and other notes on specimens from the Manhattan C are given in Table 6.

The Manhattan C overlies the Schist Member of Manhattan A; the contact being interpreted as a thrust fault. The top of this unit is not exposed in the study area and therefore no estimate of the true stratigraphic thickness could be made. A minimum thickness of 1,000 feet is estimated from the distribution of this unit within the study area.

Origin and Age of the Manhattan B and C. The amphibolites of the Manhattan B and C are believed to be metamorphosed mafic lavas and pyroclastics which were introduced discontinuously into the basin of deposition. The granulite in the Manhattan C may be felsic volcanics. The schists and schistose gneisses in the Manhattan C are largely of sedimentary origin and were deposited as group of argillaceous sandstones and shales.

Lithic characteristics of the rocks in the Manhattan B and C strongly suggest that they have formed in a marine, eugeosynclinal environment. Hall (1968a) has noted the lithic similarities between the rocks in the Manhattan C and eugeosynclinal rocks of the Waramaug Formation in northwestern Connecticut. Hall (1968b) has also correlated the Manhattan C with the Hoosac Formation which forms the basal unit in the eugeosynclinal sequence of western Massachusetts and southeastern Vermont. Available descriptions indicate that the rocks in the Hoosac Formation are at least partly similar to the rocks of the Manhattan C in the study area. The large and small plagioclase porphyroblasts which characterize the Hoosac Formation (Emerson, 1917; Hatch and other, 1968; Norton, 1969) are present locally in the Manhattan C. On the basis of these similarities the Manhattan B and C are correlated with the basal portion of the Early Cambrian to Middle Ordovician eugeosynclinal rocks exposed further north on the east limb of the Green Mountain - Berkshire anticlinorium in Vermont and Massachusetts.

Eugeosynclinal Rocks - Hartland Formation

General Statement. An assemblage of schists, gneisses, and amphibolites in western Connecticut and southeastern New York is refered to as the Hartland Formation (Rodgers and others, 1959). This assemblage has been considered as a Cambrian-Ordovician eugeosynclinal sequence (Hall, 1975). In the Glenville area, Hall (1968b) has recognized and mapped four units in the Hartland Formation. Three of these members are recognized in the study area. Owing to structural complexity and lack of primary sedimentary structures indicative of the stratigraphic tops, the relative ages of different members in the Hartland Formation are uncertain. On the basis of structural considerations, however, the relative ages are thought to be, from oldest to youngest: the Schist and Amphibolite Member, the Schist and Gneiss Member, and the Schist and Granulite Member. Accordingly, due to the westward dip, the Hartland Formation is inverted in the study area.

Schist and Amphibolite Member. The Schist and Amphibolite Member of the Hartland Formation is exposed in southeastern part of the study area, notably north and northwest of Banksville (Plate 1). The prominent rock type in this unit is gray, brown- and rusty-weathering, fine- to medium-grained, fissile, muscovite-rich, biotite schist interlayered with dark-gray or greenish-black amphibolites ranging in thickness from 1 to 20 feet. Locally the schist is layered and appears as schistose gneiss. The layering is defined by the alternating white layers composed of quartz and feldspar, and layers rich in muscovite and biotite. Garnet porphyroblasts as large as 1/4 inch, are common and sillimanite is locally present.

The schists of this unit locally resemble schists of the Manhattan A. Petrographic studies, however, indicate that these schists contain much more muscovite than those of Manhattan A (Table 7).

The Schist and Amphibolite Member locally has layers of white or light-gray felsic gneisses which are essentially composed of quartz, microline, and plagioclase with subordinate amounts of biotite and muscovite (Table 7). Locally, they contain white microcline and plagioclase megacrysts, up to 1.5 inches long with distinctive carlsbad twins. At a few localities feldspar megacrysts constitute about 30 to 35 percent of the volume of the rock. Although these megacrysts are generally parallel to foliation, in some places they display random orientation. The thickness of the felsic layers ranges from 1/2 foot up to 20 feet.

Locally, near the contact with the Bedford Complex, the Schist and Amphibolite Member of the Hartland Formation is structurally overlain by gray, fine-grained, thinly laminated, well-bedded, biotite gneiss (M-9-3) and granulite interbedded with thin layers of light greenish-gray calc-silicate and tan or pink coticule (quartz-garnet granulites). The calc-silicate layers are about 1/2 inch thick and are composed chiefly of quartz, plagioclase, garnet and diopside (P-6-44; Table 7). The coticule layers range in thickness from 1/4 to 1/2 inch. The tan pink color of

TABLE 7

Estimated modes of the specimens from the Schist and Amphibolite Member of the Hartland Formation

Minerals	Specimens[1]							
	P-6-43	P-6-55	P-6-53	P-6-57	M-4-26	M-9-6	M-9-7	M-9-21
Quartz	34	35	44	25	48	37	33	45
Plagioclase	14	12	20	5	30	14	31	26
(An%)	(21)	(25)	(24)	(?)	(21)	(25)	(27)	(29)
Microcline	1	10	-	13	-	6	-	-
Biotite	23	20	16	22	14	22	25	23
Muscovite	20	22	13	25	7	18	10	4
Garnet	3	1	1	10	1	3	1	-
Sillimanite	5	-	6	-	tr.	-	tr.	-
Kyanite	-	-	-	-	-	--	-	-
Cordierite	-	-	-	-	-	-	-	-
Diopside	-	-	-	-	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-
Tourmaline	-	-	-	-	-	-	-	-
Sphene	-	-	-	-	-	-	-	-
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Apatite	tr.	-	tr.	-	tr.	tr.	tr.	tr.
Opaque	tr.	tr.	tr.	tr.	tr.	tr.	tr.	2
Chlorite[13]	-	tr.	-	tr.	-	-	-	-
Sericite[13]	-	tr.	tr.	-	-	tr.	-	-
TOTAL	100	100	100	100	100	100	100	100

Continued from Table 7

Minerals	Specimens[1]							
					Felsic	Gneiss	Amphibolite	calc-silicate
	M-9-13	M-9-3	M-9-17[2]	M-9-18[3]	M-9-22[3]	M-9-5	M-9-20	P-6-44[4]
Quartz	40	29	35	45	35	33	10	32
Plagioclase	17	16	16[5]	2	20	16	45	20[5]
(An%)	(30)	(32)	(39)	(?)	(29)	(31)	(41)	(62)
Microcline	5	24	–	–	33[6]	37[6]	–	–
Biotite	21	21	26[7]	19	8	11	–	–
Muscovite	10[8]	–	–	–	4	3	–	–
Garnet	2	10[10]	8[9]	21[10]	tr.	–	–	8
Sillimanite	4	–	2	12[11]	–	–	–	–
Kyanite	1	–	–	tr.	–	–	–	–
Cordierite	–	–	9[12]	–	–	–	–	–
Diopside	–	–	–	–	–	–	–	39
Hornblende	–	–	–	–	–	–	43	–
Tourmaline	–	–	tr.	tr.	–	–	–	–
Sphene	–	–	–	–	–	–	1	1
Zircon	tr.	–	–	tr.	tr.	tr.	–	–
Apatite	tr.	–	–	–	tr.	tr.	–	–
Opaque	tr.	tr.	4	–	tr.	tr.	1	tr.
Chlorite[13]	–	–	–	–	–	–	–	–
Sericite[13]	tr.	tr.	–	–	–	–	–	–
TOTAL	100	100	100	100	100	100	100	100

Continued from Table 7

1) For locations of the specimens see Plate 2.

2) This rock is extremely fine grained and displays a hornfels texture.

3) This rock is layered; the layering consists of alternate concentrations of garnet and quartz grains (coticule layer) and biotite, garnet, and quartz.

4) Foliation is prominent in this rock and consists of alternate concentrations of ultra-fine-grained garnet and diopside, and medium grained diopside, plagioclase and quartz.

5) Plagioclase composition determined by dispersion method as revised by Morse (1971); the other plagioclase compositions were determined by the oil immersion methods.

6) Many grains have patches of plagioclase (perthite).

7) Relatively large, poikiblastic grains that show no preferred orientation.

8) Large (up to 5 mm) fresh grains that transect foliation.

9) Occurs as ultra-fine-grained aggregates that display distinctive overgrowths.

10) Ultrafine-grained aggregates that are mostly concentrated along coticule layers.

11) Occurs as facicular bundles and radiating acicular aggregates.

12) Most are large poikiblastic grains with poly-synthetic twins.

13) A secondary mineral.

Description of the rock specimens

P-6-43 : Gray, slabby, medium-grained, garnet-muscovite-biotite schist.

P-6-55 : Gray, brown-weathering, medium-grained, garnet-muscovite-biotite schist.

P-6-53 : Gray, fine-grained, layered, granulitic, quartzose schist with a layer rich in biotite

P-6-57 : Gray, medium-grained, quartzo-feldspathic, layered muscovite-biotite schist.

M-4-26 : Gray, medium-grained, thinly-layered, garnet-muscovite-biotite schist.

M-9-6 : Gray, brown-weathering, slabby, medium-grained, garnet-muscovite-biotite schist.

M-9-7 : Gray, coarse-grained, highly feldspathic, garnet-muscovite-biotite schist with white feldspar megacrysts up to 1/2 inch long.

M-9-21 : Gray, rusty-weathering, fissile, fine-grained, sillimanite-garnet-muscovite-biotite schist.

M-9-13 : Gray, slabby, medium-grained, well-foliated, sillimanite-garnet-muscovite-biotite schist.

M-9-3 : Gray, slabby, very-fine-grained, granulitic biotite gneiss with a thin (3 mm), discontinuous layer of coticule.

P-9-17 : Gray, extremely fine-grained, brown-weathering, granulite. Specimen is from an exposure about 10 feet away from the contact with the diorite-gabbro intrusive body (Plate 2).

P-9-18 : Gray, well-foliated, fine-grained garnet-biotite-quartz gneiss interlayered with light-gray, slightly pink, very-fine-grained, garnet-quartz granulites (coticule). Specimen is from an exposure about 20 feet away from the contact with the diorite-gabbro intrusive body (Plate 2).

M-9-22 : Light-gray, medium-grained, muscovite-biotite-quartz feldspar gneiss with coarser grains of microcline.

M-9-5 : Light-gray, fine-grained, muscovite-biotite feldspar gneiss with medium size microcline grains.

M-9-20 : Dark-gray, fine-grained, amphibolite with profound mineral lineation.

P-6-44 : A thin (less than 1 inch) layer of well foliated calc-silicate. The foliation is defined by the concentration of garnet and diopside along one layer (white or light-gray), and diopside and feldspar along other layers (greenish-gray).

these layers is due to very-fine-grained aggregates of poikilitic garnet crystals with numerous quartz inclusions (M-9-18; M-9-3; Table 7).

Northwest of Banksville, the Schist and Amphibolite Member is intruded by a diorite-gabbroic pluton which is part of the Bedford Complex. Specimens from the rocks of the Schist and Amphibolite Member near the contact with this intrusive body (M-9-17, and M-9-18; Table 7) contain large poikiloblastic cordierite, and biotite crystals. The rocks are very-fine-grained and display a hornfels texture. Mineralogical and textural evidence indicate that this portion of the Schist and Amphibolite Member has been subjected to contact metamorphism.

The Schist and Amphibolite Member is a correlative of the Carrington Pond Member of the Hartland Formation as mapped and described by Hall (1968b) in the Glenville area.

The rocks in the Schist and Amphibolite Member must be largely of sedimentary origin. The schists present in this unit are believed to be predominantly metamorphosed shales. The existence of calc-silicate layers, originally carbonate beds, and quartz-garnet granulites which may have been originally sedimentary chert layers, strongly indicate a deep marine environment of deposition.

The amphibolites of this member are metamorphosed mafic volcanics. The felsic gneisses, which are lithically similar to the rocks in the Siscowit Granitic Gneiss may have originally been sills extended from the Siscowit intrusive body into the Hartland Formation, or they may well be metamorphosed felsic volcanics.

Schist and Gneiss Member. This member is exposed east of the recently constructed reservoir east of Trinity Lake, and along the Mill River Road in the northeastern portion of the mapped area (Plate 1). It forms a narrow strip which is intruded by the Siscowit Granitic Gneiss on the eastern side and is in fault contact with the Precambrian gneiss complex on the western side.

The Schist and Gneiss Member consists of gray, brown-weathering, coarse-grained, fissile, garnetiferous, muscovite-bitite schist interlayered with gray, fine-to medium-grained, biotite-quartz-feldspar gneiss. The unit contains layers of white or light-gray felsic gneisses which are composed chiefly of muscovite, biotite, quartz, and feldspar.

At one locality in northeastern portion of the study area where Miller Road intersects Kitchawan Road, a 5 foot thick layer of very-fine-grained, micaceous, feldspathic quartzite is present in this rock unit.

The dominant rock type in this assemblage is schist. It is characterized by coarse muscovite flakes sparkling on the foliation plane. Locally, the schist is feldspar-rich and has orthoclase megacrysts up to 1/2 inch long. Estimated modes of two specimens from the schists are listed in Table 8.

The schists and gneisses in this member may have been originally sandstones and shales. The felsic gneisses originally may well be sills extended from the Siscowit pluton into the Schist and Gneiss Member, or they may be metamorphosed volcanics of rhyolitic composition.

Schist and Granulite Member. The Schist and Granulite Member of the Hartland Formation is exposed in the vicinity of the Siscowit Reservoir in eastern part of the area. (Plate 1). It consists of a heterogenous assemblage of dark-gray, brown-weathering, coarse-grained, garnet-muscovite-biotite granular schist interlayered with light- and dark-gray,

TABLE 8

Estimated modes of specimens from the Schist and Gneiss Member of the Hartland Formation.

Minerals	Specimens[1]	
	P-2-10	P-3-2
Quartz	34	38
Plagioclase[2]	41	27
(An%)	(30)	(33)
Orthoclase	-	9
Biotite[3]	14	18
Muscovite	11	7
Garnet	-	1
Sillimanite	-	tr.
Zircon	tr.	tr.
Apatite	tr.	tr.
Opaque	tr.	tr.
TOTAL	100	100

1) For the location of the specimens see Plate 2.

2) Plagioclase compositions are determined by oil immersion methods.

3) Pleochroic from tan to red.

Description of the rock specimens:

P-2-10 : Gray, coarse-grained, muscovite-biotite quartz-plagioclase schist.

P-3-2 : Gray, coarse-grained, fissile, muscovite-biotite schist with orthoclase megacrysts up to 1/2 inch long.

TABLE 9

Estimated modes of specimens from the Schist and Granulite Member of the Hartland Formation.

Minerals	Specimens[1]	
	P-4-2	P-4-1
Quartz	32	43
Plagioclase[2]	23	12
(An%)	(20)	(25)
Microcline	3	3
Biotite	30[3]	26[4]
Muscovite	10	7
Sillimanite	-	4
Garnet	tr.	5
Zircon	tr.	tr.
Apatite	tr.	tr.
Opaque	2	tr.
Sericite[5]	tr.	tr.
Chlorite[5]	-	tr.
TOTAL	100	100

1) For the location of the specimens see Plate 2.

2) Plagioclase compositions are determined by oil immersion methods.

3) Pleochroic from tan to greenish-brown.

4) Pleochroic from tan to red.

5) A secondary alteration product.

Description of the rock specimens:

P-4-2 : Gray, coarse-grained, muscovite-biotite schist. Muscovite flakes are sparkling on the foliation plane.

P-4-1 : Gray, brown-weathering, coarse-grained, garnet muscovite-biotite schist.

fine- to coarse-grained biotite-feldspar-quartz granulite. Layers of dark-gray or black amphibolites, ranging in thickness from 1/2 inch up to 20 feet are present in this unit. Bedding is locally well preserved in the granulites. Coarse crystals of muscovite, sparkling on the foliation, characterize the schists in this unit. Garnet porphyroblasts are common and sillimanite is locally present. The granular texture of the schists in this unit, distinguish them from those in the Schist and Gneiss Member. Estimated modes of specimens from this rock unit are given in Table 9.

The Schist and Granulite Member is correlated with the Schist and Granulite Member of the Hartland Formation as mapped by Hall (1968b) in the Glenville area. It may be correlated with the Moretown Formation (Hall, 1968b) in western Massachusetts as described by Hatch and others (1968).

The schists and granulites of this member of the Hartland Formation are believed to be largely of sedimentary origin. They represent metamorphosed sandstone, siltstone, and shales. The amphibolites present in this unit are considered metamorphosed mafic volcanics.

Summary

The stratigraphic relationships of the rocks in the study area are essentially the same as those suggested by Hall (1968a,1968b,1971, and 1975) for southeastern New York and western Connecticut (Table 10), and are similar to those which have been suggested for western Massachusetts (Hatch and others, 1968) and eastern New York (Fisher, 1962). In this area the Precambrian Fordham Gneiss forms a basement complex which is unconformably overlain by the Cambrian to Middle Ordovician miogeosynclinal

Age	Dutchess County N.Y. (Fisher, 1962)	White Plains area (Hall, 1968a)	This Report: Autochthonous Rocks	This Report: Allochthonous Rocks	Glenville area (Hall, 1968b)	Western Massachusetts (Hutch and others, 1968)
Middle Ordovician	Walloomsac Formation	Manhattan A: Schist	Manhattan A: Schist Member	(hatched)	Harrison Gneiss	Hawley Formation
Middle Ordovician	Balmville Limestone	Manhattan A: Interbedded Schist & Marble	Manhattan A: Marble Member	Hartland Formation: Schist & Granulite Member	Hartland Formation: Schist and Granulite	Moretown Formation
Lower Ordovician	Stockbridge Group: Copake Limestone	Inwood Marble: (hatched)	Inwood Marble: (hatched)	Hartland Formation: Schist & Granulite Member	Hartland Formation: Light-Gray Gneiss	Rowe Schist
Lower Ordovician	Stockbridge Group: Rochdale Limestone	Inwood Marble: (hatched)	Inwood Marble: (hatched)	Hartland Formation: Schist & Granulite Member	Hartland Formation: Light-Gray Gneiss	Rowe Schist
Lower Ordovician	Stockbridge Group: Halcyon Lake Ls.	Inwood Marble: Member D	Inwood Marble: (hatched)	Hartland Formation: Schist & Granulite Member	Hartland Formation: Light-Gray Gneiss	Rowe Schist
Cambrian	Stockbridge Group: Briarcliff Dolomite	Inwood Marble: Member C	Inwood Marble: (hatched)	Hartland Formation: Schist & Amphibolite Member	Hartland Formation: Schist, Gneiss	Rowe Schist
Cambrian	Stockbridge Group: Pine Plains Formation	Inwood Marble: Member B	Inwood Marble: Member B	Hartland Formation: Schist & Amphibolite Member	Hartland Formation: Amphibolite	Rowe Schist
Cambrian	Stockbridge Group: Stissing Dolomite	Inwood Marble: Member A	Inwood Marble: Member A	Hartland Formation: Schist & Amphibolite Member	Hartland Formation: Amphibolite	Rowe Schist
Cambrian	Poughquag Quartzite	Lowerre Quartzite	Lowerre Quartzite	Manhattan C / Manhattan B	Manhattan C / Manhattan B	Hoosac Formation
Precambrian	Gneiss Complex	Fordham Gneiss and Yonkers Gneiss	Fordham Gneiss & Pound Ridge Granitic Gneiss			Gneiss Complex

Table 10 - Regional Correlation of the Stratigraphic Units

sequence consisting of the basal clastics of the Lowerre Quartzite overlain by the dolomitic marbles of the Inwood marble. The Middle Ordovician marbles and schists of the Manhattan A unconformably overly the older rocks. The eugeosynclinal rocks of the Manhattan B and C, which are probably Early Cambrian, have been thrust over the Middle Ordovician Manhattan A. Manhattan B and C are considered as the lower portion of the eugeosynclinal sequence, the upper, and partially equivalent part of which is know as the Hartland Formation.

INTRUSIVE ROCKS

Siscowit Granite Gneiss

The three members of the Hartland Formation are intruded by homogeneous, two-mica granitic gneiss, which underlies the eastern and southeastern portions of the mapped area (Plate 1). The rocks are referred to as Thomaston Granite by Agar (1934) and are named as the Siscowit Granite for their exposures in the vicinity of the Siscowit Reservoir in the eastern part of the Pound Ridge quadrangle (Scotford, 1956).

The rocks are typically light-gray, tan-weathering, fine- to coarse-grained, locally garnetiferous, muscovite-biotite-quartz-feldspar gneisses which tend to be rounded on the outcrop surface. They possess a well-developed foliation defined by the preferred orientation of biotite and muscovite flakes. Layering, characterized by variations in granularity, is locally recognized. Estimated modes of specimens from this rock unit are given in Table 11.

Numerous small and large inclusions of the country rocks which measure from a few inches up to more than 50 feet in length, are present near the border of the Siscowit Granitic Gneiss. The Geologic map (Plate 1) shows a separately mapped inclusion in the southeastern part of the Mt. Kisco quadrangle. Small inclusions, about 4 inches long are present in an outcrop about 200 feet west of the junction between Upper Shad Road and U.S. Route 104.

TABLE 11

Estimated modes of specimens from the Siscowit Granitic Gneiss

Minerals	P-3-3	P-5-11[2]	P-6-52	P-7-1	P-6-56
Quartz	49	47	35	38	40
Plagioclase	19	35	24	12	18
(An%)	(27)	(35)	(32)[3]	(25)	(21)
Microcline	24	6	29	30	27
Biotite[5]	3	10	8	8	5
Muscovite	5	2	4	12	10
Garnet	tr.	-	-	tr.	tr.
Zircon	tr.	tr.	tr.	tr.	tr.
Apatite	tr.	tr.	tr.	tr.	tr.
Opaque	-	tr.	-	tr.	tr.
Chlorite[6]	-	-	tr.	-	tr.
TOTAL	100	100	100	100	100

1) For the locations of the specimens see Plate 2.

2) Plagioclase and microcline crystals contain numerous quartz intergrowths.

3) Plagioclase composition was determined by dispersion method as revised by Morse (1971); in other specimens, the standard oil immersion method was used.

4) It has patches of plagioclase and, hence, shows perthitic texture. It also displays myrmekite texture with quartz.

5) Pleochroic from tan to brownish-red.

6) A secondary alteration mineral.

Descriptions of the rock specimens

P-3-3 : Light-gray, medium-grained muscovite-biotite granitic gneiss with muscovite flakes sparkling on the foliation plane.

P-5-11 : Light-gray, brown-weathering, fine- to medium-grained, muscovite-biotite granitic gneiss.

P-6-52 : Light-gray, tan-weathering, fine-grained muscovite-biotite granitic gneiss.

P-6-56 : Light-gray, medium-grained, muscovite-biotite granitic gneiss.

Several granitic layers as well as granitic dikes in the Hartland Formation may be sills and dikes that extend from the Siscowit pluton into the Hartland Formation.

The intrusive nature of the Siscowit Granite indicates that it is younger than the Hartland Formation. Also, the fact that the Siscowit Granitic Gneiss is folded and foliated, indicates that it has been affected by at least one dynamothermal event which might have been either the Taconic or Acadian (or both) orogenies. On the basis of structural considerations, the intrusion of the Siscowit Granitic Gneiss is interpreted as a probable Ordovician event.

Bedford Complex

General Statement. The term Bedford Complex is applied to an assemblage of dioritic, quartz-dioritic, and granodioritic gneisses and associated mafic and ultramafic rocks that are exposed in the vicinity of Bedford and Pound Ridge (Plate 1). The Bedford Complex which underlies about 8 square miles of the area, trends generally northeasterly, parallel to the regional strike, and dips northwesterly. The rocks in the Bedford Complex have long been known to geologists working in southeastern New York and have been referred to as the Bedford Augen Gneiss (Luquer and Ries, 1896;

Fettke, 1914; Barbour, 1930; Scotford, 1956). Fettke (1914) considered the Bedford Complex as part of the sedimentary and volcanic assemblage of the Fordham Gneiss. Barbour (1930) interpreted the Bedford Complex to be a metasomatic product which was originally part of the Manhattan Schist. Scotford (1956) states that the Beford Complex is partly intrusive diorite and partly schist, but shows the contact on his geologic map (Scotford, 1956; Plate 1) as a gradational contact.

In this study the rocks in the Bedford Complex have been subdivided into several units and because of the variety of rock types with the Complex, emphasis is placed on the lithic characteristics of the rocks. The classical term, Bedford Augen Gneiss, is applied only to the dioritic, quartz dioritic, and granodioritic gneisses which form the bulk of the Complex.

Bedford Augen Gneiss. The Bedford Augen Gneiss consists of an assemblage of interlayered light-gray, gray and dark-gray gneisses which display considerable variations in texture and mineralogy. The dominant rock type in this assemblage is a gray to dark-gray, fine- to medium-grained, well-foliated, dioritic or quartz-dioritic gneiss which is composed essentially of plagioclase, biotite, and hornblende with local pyroxene (Table 12). Quartz, where present, is a minor constituent. Where viewed in natural exposures the rocks appears as if sprinkled with coarse salt and pepper. In many places the rock is characterized by amphibole megacrysts up to 1/4 inch long which produce a porphyritic texture. The presence of large (up to 1/2 inch), brown, euhedral crystals of sphene is another characteristic of this rock.

TABLE 12

Estimated modes of Specimens
from the Bedford Augen Gneiss.

Minerals	Specimens[1]								
	M-4-13	M-4-18	M-4-19	M-4-20	M-4-8	M-4-7[+]	M-4-6[+]	M-4-12	M-4-10
Quartz	3	-	-	-	tr.	-	tr.	tr.	1
Plagioclase[2]	63	51	48	69	49	55	59	54	45
(An%)[3]	(41)	(39)	(35)	(44)	(57)	(45)	(45)	(39)	(50)
Microcline	2	-	-	-	-	-	-	-	tr.
Augite[4]	-	8	-	4	9	-	-	13	8
Hornblende[5]	15	28	34	10	24	28	23	22	36
Biotite[6]	16	13	17	15	16	14	15	11	2
Muscovite	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-
Epidote	-	-	-	-	-	-	-		-
Allanite	tr.	-	-	-	tr.	tr.	tr.	-	tr.
Sphene[7]	1	tr.	1	tr.	1	1	1	tr.	1
Rutile	-	-	-	-	-	-	-	-	tr.
Apatite	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Zircon	-	-	-	-	tr.	-	tr.	tr.	-
Opaque[8]	tr.	tr.	tr.	2	1	2	2	tr.	5
Calcite[9]	-	-	-	-	-	-	-	-	-
Chlorite[9]	-	-	-	-	-	tr.	-	-	2
Sericite[9]	-	-	tr.	tr.	tr.	tr.	tr.	tr.	tr.
TOTAL	100	100	100	100	100	100	100	100	100

Continued from table 12

Minerals	Specimens[1]								
	M-4-11+	M-9-8+	M-9-10	P-6-6	P-6-11	P-6-51*	P-6-48+	P-6-45	M-4-9*
Quartz	-	-	3	2	tr.	tr.	-	-	5
Plagioclase[2]	54	52	56	52	49	70	45	40	44
(An%)	(42)	(41)	(45)	(40)	(38)	(35)	(35)	(30)	(45)
Microcline[3]	-	-	tr.	-	-	2	2	20	22
Augite[4]	15	-	-	15	-	-	1	-	-
Hornblende[5]	20	30	16	13	28	8	35	30	13
Biotite[6]	9	13	21	18	18	18	15	10	15
Muscovite	tr.	tr.	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-
Epidote	tr.	-	-	-	-	-	-	-	-
Allanite	-	tr.	-	tr.	tr.	-	-	-	tr.
Sphene[7]	tr.	3	4	tr.	1	2	2	tr.	tr.
Rutile	tr.	-	-	-	-	-	tr.	-	-
Apatite	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Zircon	tr.	tr.	tr.	-	tr.	tr.	-	-	tr.
Opaque[8]	2	2	tr.	tr.	4	tr.	tr.	tr.	1
Calcite[9]	-	tr.	-	-	-	tr.	-	-	-
Chlorite[9]	tr.	tr.	-	-	tr.	-	-	-	-
Sericite[9]	tr.	-	-	-	-	tr.	tr.	tr.	-
TOTAL	100	100	100	100	100	100	100	100	100

Continued from table 12

Minerals	Specimens[1]									
	P-6-7	P-6-37	P-6-16	P-1-2	P-2-7*	P-6-9	M-4-3	P-6-18	P-6-27	P-6-28
Quartz	4	4	6	5	6	6	9	12	9	14
Plagioclase[2]	53	66	70	57	74	42	59	60	45	42
(An%)	(41)	(28)	(45)	(41)	(45)	(55)	(39)	(42)	(41)	(55)
Microcline[3]	-	-	-	-	tr.	-	tr.	-	-	tr.
Augite[4]	2	-	-	6	-	-	-	-	-	-
Hornblende[5]	17	5	-	14	-	31	18	12	25	18
Biotite[6]	21	21	23	18	20	16	12	16	18	22
Muscovite	-	-	-	-	-	-	-	-	tr.	-
Garnet	-	-	tr.	-	-	-	-	-	-	tr.
Epidote	-	-	-	-	-	-	-	-	-	-
Allanite	-	tr.	tr.	-	tr.	tr.	-	tr.	tr.	-
Sphene[7]	-	tr.	-	-	-	-	-	-	-	-
Apatite	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	-	tr.	tr.	tr.
Opaque[8]	3	1	1	tr.	tr.	5	tr.	tr.	2	3
Calcite[9]	-	-	-	-	-	-	-	-	-	-
Chlorite[9]	tr.	-	-	tr.	tr.	-	tr.	-	-	-
Sericite[9]	tr.	-	-	-	tr.	tr.	-	tr.	tr.	tr.
TOTAL	100	100	100	100	100	100	100	100	100	100

Continued from table 12

Minerals	Specimens[1]							
	P-2-18	P-6-42	P-6-34	M-4-25	P-6-47*	M-9-19*	P-5-1*	M-9-4*
Quartz	21	45	10	25	30	26	31	29
Plagioclase[2]	49	36	45	48	40	39	24	14
(An%)	(45)	(27)	(46)	(25)	(25)	(24)	(28)	(32)
Microcline[3]	-	-	9	10	10	21	29	43
Augite[4]	5	-	-	-	-	-	-	-
Hornblende[5]	3	-	12	tr.	-	-	-	-
Biotite[6]	21	18	21	17	20	14	12	14
Muscovite	-	tr.	-	tr.	-	tr.	3	tr.
Garnet	-	-	-	-	-	-	-	-
Epidote	-	tr.	-	-	tr.	-	tr.	-
Allanite	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Sphene[7]	1	tr.	3	-	tr.	-	-	-
Rutile	-	-	-	-	-	-	-	-
Apatite	tr.	tr.	tr.	tr.	tr.	tr.	-	tr.
Zircon	tr.	tr.	tr.	tr.	tr.	-	tr.	tr.
Opaque[8]	tr.	1	tr.	tr.	tr.	tr.	1	tr.
Calcite[9]	-	-	-	-	-	-	-	-
Chlorite	-	-	-	-	-	-	-	-
Sericite[9]	-	tr.	-	tr.	tr.	tr.	-	tr.
TOTAL	100	100	100	100	100	100	100	100

Continued from table 12

* Specimen contains microcline and/or plagioclase megacryst.

(An%) Plagioclase composition determined by dispersion method.

\+ Texture is hypidiomorphic-granular. Others are foliated; in some, grain contacts are granulated.

1) For locations of the specimens see Plate 2.

2) As both fine, interlocking crystals with albite twins which fill spaces between the mafic minerals and large euhedral grains commonly with albite and carlsbad twins. Normal, reverse, and oscilatory zoning are common. Replacement antiperthitic texture is also present.

3) As very large, euhedral or subhedral crystals, commonly with carlsbad twinning and myrmekitic on the periphery. Inclusions of biotite and quartz are common. Also, occurs as fine, anhedral grains in the matrix of the porphyritic rocks.

4) Colorless to very pale-green commonly with simple twins (100); as subhedral to euhedral crystals largely replaced by amphibole. Uralitization of augite has resulted in formation of colorless amphibole in the core and green hornblende on the periphery.

5) Commonly as clusters of fine to medium grains; also as large, single poikilitic crystals with inclusions of plagioclase. In some specimens, it is pleochroic from light-green to blue-green; in others from light-tan to olive-green. The olive-green crystals have relatively large 2V, i.e., 60°-85°. In the blue-green hornblende 2V is about 20°-40°. In some specimens both blue-green and olive-green hornblende are present.

6) Occurs both as very-fine and very-large crystals. In some specimens it is pleochroic from light-tan to brownish-green; in others it is from light-tan to deep-red. The red biotite flakes commonly enclose large ilmenite crystals rimmed by sphene. In foliated rocks it shows preferred orientation; in others it occurs as large poikilitic, anhedral flakes.

Continued from table 12

7) As both large, euhedral crystals and anhedral grains rimming ilmenite.

8) Mostly, large, anhedral grains of ilmenite.

9) A secondary, alteration product.

Description of the rock specimens:

M-4-13 : Light-gray, very-fine-grained porphyritic diorite gneiss with a layer rich in pink feldspar. Large, brown, euhedral sphene (1/2 inch long) is present.

M-4-18 : Black, medium-grained, massive diorite with a white apatite dike about 1 inch thick.

M-4-19 : Dark-gray, very-fine-grained, amphibolite with amphibole megacrysts.

M-4-20 : Black, fine-grained, massive diorite with an apatite dike about 1/3 inch thick which is not incorporated in the modal analysis.

M-4-8 : Black and white, coarse-grained, foliated, biotite diorite.

M-4-7 : Black and white, medium-grained, massive diorite.

M-4-6 : Black and white, massive, medium-grained diorite.

M-4-12 : Dark-gray, fine-grained, dioritic gneiss.

M-4-10 : Black and white, massive, dense, medium-grained dioritic gneiss.

M-4-11 : Dark-gray, fine-grained, dense, massive dioritic gneiss.

M-9-8 : Black and white, coarse-grained, massive, biotite diorite.

M-9-10 : Dark-gray, medium-grained dioritic gneiss with K-feldspar megacrysts up to 1/2 inch long.

P-6-6 : Black and white, coarse-grained, foliated, dioritic gneiss with plagioclase, megacrysts about 1/6 inch long,

P-6-11 : Black, medium-grained, dioritic gneiss with large biotite

Continued from table 12

		flakes.
P-6-51	:	Dark-gray, fine-grained, dioritic gneiss with K-feldspar megacrysts up to 2 inches and plagioclase megacrysts up to 1/4 inch in length.
P-6-48	:	Black and white, medium-grained, dioritic gneiss.
P-6-45	:	Light-gray, fine-grained porphyritic diorite with black amphibole megacrysts about 1/3 inch in length scattered throughout the rock.
M-4-9	:	Black and white, medium-grained, layered dioritic gneiss with amphibole megacrysts up to 1/4 inch long and K-feldspar megacrysts up to 1/2 inch long.
P-6-7	:	Dark-gray, fine- and coarse-grained, layered, dioritic gneiss with layers rich in feldspar.
P-6-37	:	Dark-gray, medium-grained, dioritic gneiss.
P-6-16	:	Medium-grained, garnet biotite porphyritic gneiss with plagioclase megacrysts.
P-1-2	:	Dark-gray, medium-grained, poorly-foliated, dioritic gneiss.
P-2-7	:	Black, biotite dioritic gneiss with plagioclase megacrysts up to 1/2 inch long.
P-6-9	:	Black, coarse-grained, foliated, biotite-rich dioritic gneiss spotted with white plagioclase crystals.
M-4-3	:	Black and white, fine-grained biotite-amphibole dioritic gneiss with layers rich in feldspar.
P-6-18	:	Black and white, medium-grained, layered dioritic gneiss with some layers rich in feldspar.
P-6-27	:	Dark-gray, medium-grained, well-layered, dioritic gneiss.
P-6-28	:	Dark-gray, medium-grained, porphyritic, diorite gneiss with white plagioclase megacrysts.
P-2-18	:	Black and white, coarse-grained, foliated, dioritic gneiss with numerous plagioclase megacrysts about 1/4 inch long.

Continued from table 12

P-6-42	:	Gray, fine- to medium-grained, biotite dioritic gneiss with plagioclase megacrysts up to 1/4 inch long.
P-6-34	:	Black and white, medium-grained, dioritic gneiss with garnet porphyroblasts about 1/4 inch in diameter.
M-4-25	:	Medium-grained, biotite-quartz-feldspar gneiss with K-feldspar megacrysts.
P-6-47	:	Gray, quartz diorite with white microcline megacrysts (up to 2 inches long) that show no preferred orientation.
M-9-19	:	Gray, fine-grained, biotite granodioritic gneiss with randomly oriented K-feldspar megacrysts.
P-5-1	:	Light-gray, medium-grained, biotite quartz feldspar gneiss spotted with white plagioclase grains.
M-9-4	:	Light-gray, biotite gneiss with white feldspar megacrysts up to 1.5 inches long. Foliation wraps around the megacrysts.

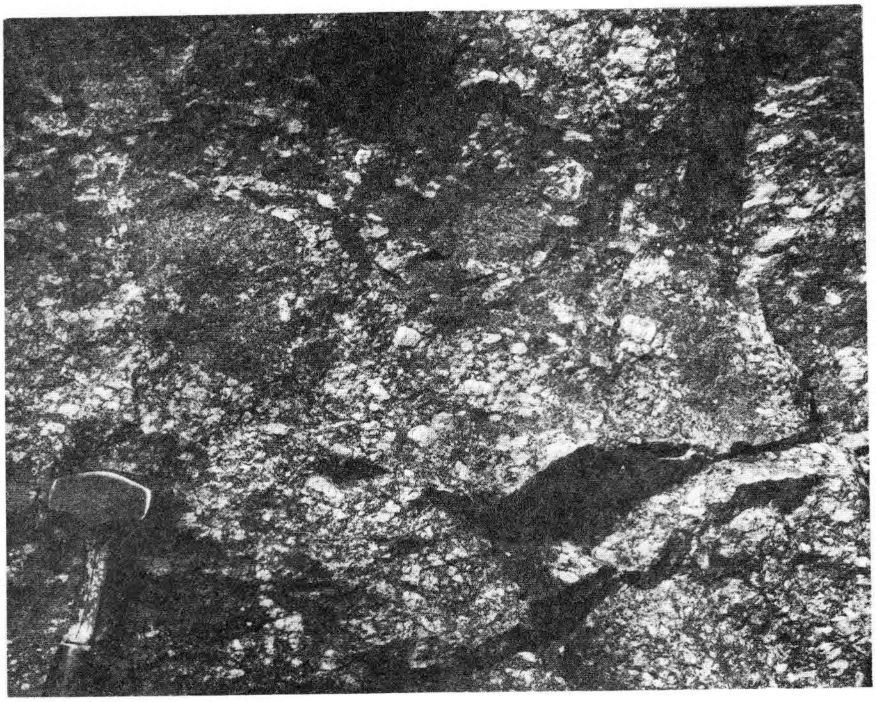
Locally, the dioritic gneisses in this assemblage are black and white mottled, coarse-grained, well-foliated, pyroxene-amphibole-plagioclase gneiss which contain large (5 mm), black biotite flakes. This type of rock is similar to the Harrison Gneiss mapped by Hall (1968b) in the Glenville area.

Another rock type in the Bedford Augen Gneiss is a light-gray to gray, medium- to coarse-grained, granodioritic gneiss which is essentially composed of quartz, biotite and feldspar (Table 12). Hornblende may or may not be present. The rock is well-foliated due to alternate concentrations of quartz and feldspar grains and the biotite and amphibole crystals. Garnet porphyroblasts are locally abundant in the less mafic parts of these rocks.

The rocks in the Bedford Augen Gneiss are highly sheared, and zones of intensely crushed dioritic gneisses with a cataclastic texture wrapping around the more massive blocks of the same rocks are commonly present.

The presence of white or pink, euhedral megacrysts commonly with carlsbad twins, non-uniformly distributed in the above gneisses produces a porphyritic texture that characterizes parts of the Bedford Augen Gneiss (Fig. 2-A). The feldspar megacrysts are of two types: 1) white plagioclase crystals ranging from 1/8 to 1/2 inch long and 2) pink or white microcline megacrysts generally coarser than the plagioclase megacrysts, ranging from 1/4 inch to 2 inches long. Locally, microcline megacrysts constitute about 50 to 60 percent of the rock. In most outcrops the feldspar megacrysts are parallel to the foliation (Fig. 2-B), but there are many places where feldspar megacrysts have no prefered orientation.

A



B

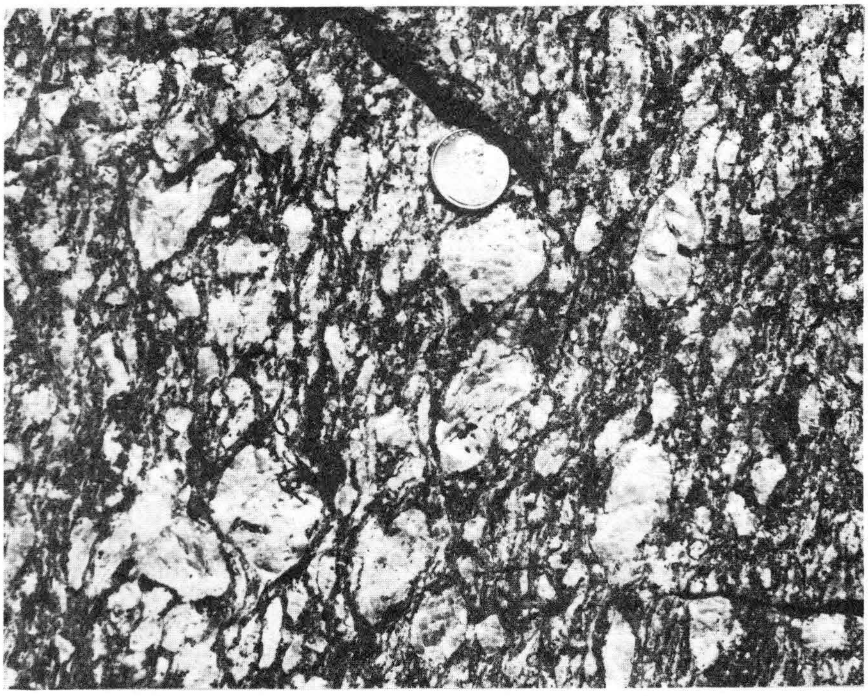


Figure 2-A - Non-uniformly distributed feldspar megacrysts in the Bedford Augen Gneiss. Notice a portion of the rock is free of megacrysts. Locality: a road cut on a recently constructed Dead End Road about 2,000 feet northeast of the Middle Patent School.

B - Plagioclase and microcline megacrysts aligned parallel to the foliation in the Bedford Augen Gneiss. Locality: a large road cut on U.S. Route 104 about 2 miles southeast of Bedford village.

The distribution of the rocks with porphyritic texture is irregular and their relationship with other rocks in the Bedford Augen Gneiss is not the same everywhere. In some outcrops the porphyritic rock appears as regular interlayers with the dioritic and granodioritic gneisses. In other places the porphyritic rock shows a distinctive dike-like pattern. In these outcrops, it seems that porphyritic bodies have been developed in and along the pre-existing fractures in the dioritic and granodioritic gneisses. Moreover, in some outcrops highly angular inclusions of the dioritic gneisses are present in a groundmass of porphyritic rocks.

Pegmatites and Aplites in the Bedford Augen Gneiss - The Bedford Augen Gneiss is intruded by granitic pegmatites and aplitic dikes which vary greatly in size and extent. Their thicknesses ranges from less than 1 inch to several feet. They are white or pink, coarse-grained, and composed chiefly of quartz, plagioclase, microcline, muscovite and biotite. A set of granitic pegmatites occur parallel to the foliation; another set shows random orientation and truncates the foliation planes sharply. Southeast of Bedford, three large irregular bodies of very-coarse-grained granitic pegmatites, extending for more than 100 feet and crosscutting the foliation of the Bedford Augen Gneiss, have been quarried for feldspar. A radiometric age determination on uraninite from a granitic pegmatite at Bedford, yielded an age 380 million years (Muench, 1931).

Inclusions in the Bedford Augen Gneiss - Numerous inclusions of country rocks are present within and along the edge of the Bedford Augen Gneiss. They are mostly schists and granulites and range in length from 3 inches to several feet. They are oriented parallel to the foliation.

At two localities, large (greater than 10 feet long) inclusions of schist, identified as fragments of the Schist and Amphibolite Member of the Hartland Formation, have been recognized. These two localities are: 1) about 1.5 miles southwest of Bedford village where the U.S. Route 172 joins the U.S. Route 22; and 2) less than 100 feet north of the St. Mary's Church in the eastern part of the Mt. Kisco quadrangle. The inclusions at these localities are well-layered sillimanite-garnet-biotite schist which enclose fragments of calc-silicate and light brown granulites. Modal analysis of specimens from the schist inclusion at the St. Mary's Church locality (M-4-22; Table 13) shows that the rock is rich in garnet.

A schist inclusion about 10 feet long, is present at a locality about 500 feet north of Twin Lakes in western part of the Pound Ridge quadrangle. A typical specimen from this inclusion (P-6-25; Table 13) is a fine-grained, brown-weathering, slabby, siliceous biotite schist which appears similar to the more siliceous layers of the Schist Member of the Manhattan A, and hence, is considered as a fragment of the Schist Member.

At a locality less than a mile west of Pound Ridge where the contact between the Manhattan A and Manhattan C is truncated by the Bedford Augen Gneiss, several schist inclusions, identified as fragments of the Schist Member of the Manhattan A, are present in the Bedford Augen Gneiss. They range from less than a foot up to 5 feet in length, and have rusty- and brown-weathering outcrop surfaces. Thin (less than 1 inch) layers of calc-silicate have been recognized in these inclusions.

Small inclusions (about 3-4 inches long) of granulite and calc-silicate have been found in the rocks of the Bedford Augen Gneiss at several localities. A specimen of the Bedford Augen Gneiss (P-6-8; Table 13) collected from an outcrop on the Indian Hill east of Bedford village contains a

TABLE 13

Estimated modes of specimens from the inclusions in the Bedford Augen Gneiss

Minerals	M-4-22[2]	P-6-25[3]	P-6-8[4]
Quartz	25	40	25
Plagioclase	42	28	28
(An%)[5]	(65)	(35)	(40)
Microcline	-	12	-
Biotite[6]	22	20	-
Muscovite	-	tr.	-
Garnet[7]	10	-	-
Sillimanite	1	-	-
Diopside[8]	-	-	34
Epidote	-	-	1
Allanite	-	-	tr.
Apatite	tr.	-	-
Zircon	tr.	tr.	-
Opaque	tr.	tr.	7[9]
Secicite[10]	tr.	-	5
TOTAL	100	100	100

1) For the location of specimens see Plate 2.

2) Foliation is obliterated by growth of the newly formed biotite and garnet crystals

3) Well-foliated texture.

4) Granular texture.

5) Plagioclase composition determined by standard oil immersion method.

6) Pleochroic from light-tan to red.

7) As fresh, euhedral grains up to 1 mm. in diameter; some have inclusions of biotite and quartz.

8) Colorless to light-green, as ultra-fine grains mostly concentrated near the edge of the inclusion.

Continued from Table 13

9) Relatively large grains of iron sulfide, probably pyrite.

10) An alteration product of mostly plagioclase crystals near the edge of the inclusion.

Description of the rock specimens

M-4-22 : Dark-gray, fine-grained, foliated, garnet-biotite-quartz feldspar schist.

P-6-25 : Gray, brown-weathering, slabby, fine-grained quartzitic, biotite-feldspar schist. Rock is well-foliated and displays mineral lineation.

P-6-8 : Greenish-gray, ultra-fine-grained calc-silicate enclosed by the black and white mottled, coarse-grained, dioritic rock of the Bedford Augen Gneiss composed of biotite, hornblende, pyroxene, and plagioclase. The calc-silicate inclusion is internally layered, near the edge it is greenish-gray and rich in pyroxene, while in the core it is light-gray and rich in quartz and plagioclase.

calc-silicate inclusion composed of extremely fine-grained quartz, plagioclase and diopside. The inclusion is in sharp contact with the dioritic rock of the Bedford Augen Gneiss. The contact is characterized by a distinctive zone of highly sericitized plagioclase crystals.

Contact Relations - The Bedford Augen Gneiss is in contact with different rock types of the Schist and Amphibolite Member of the Hartland Formation along its southeastern boundary. In most places, the rock exposures of the schist and Amphibolite Member along this contact display schists or schistose gneisses which are typical of this stratigraphic unit. There are, however, two localities at which the rocks in contact with the Bedford Augen Gneiss are interbedded fine-grained biotite gneisses, calc-silicates, and coticule layers. These two localities are: 1) on the east-facing high cliff about 1500 feet west of the East Middle Patent School, and 2) on the southern slope of the hill located about 4,000 feet NNW of Banksville. The first locality is the best place to study the contact relations between the Bedford Augen Gneiss and the Schist and Amphibolite Member. Here, the rocks of the Schist and Amphibolite Member are thinly laminated and strongly sheared. Most of the calc-silicate and coticule beds appear as deformed discontinuous layers or boudins. These rocks are structurally overlain by the Bedford Augen Gneiss. The thinly laminated, gray, biotite gneisses of the Schist and Amphibolite Member appear to be interlayered with the porphyritic granit-granodioritic rocks of the Bedford Augen Gneiss at this locality. Close inspection of the granite-granodioritic layers, however, reveals that these rocks contain several angular inclusions of the gray, laminated gneisses. In addition, brecciated blocks consisting of angular fragments of light-gray, granulite in a laminated, gray, biotite gneiss matrix are included in the granite-granodioritic Bedford Augen Gneiss. The origin of the brecciated blocks is uncertain but may be related to pre- or syn-intrusive shearing.

Geologic map (Plate 1) shows that the Bedford Augen Gneiss is in contact with the Precambrian Fordham Gneiss, the miogeosynclinal sequence, Manhattan A, and the overlying Manhattan C along its northwestern boundary. The contact is poorly exposed, but a feature related to this contact is the porphyroblastic texture, due to occurence of the alkali feldspar megacrysts, of the schists of the Manhattan A wherever this unit is exposed near the Bedford Augen Gneiss.

The actual contact is exposed at only one locality; i.e., about a mile west of Pound Ridge, 100-150 feet north of the point at which the contact between Manhattan A and Manhattan C is truncated by the NNE trending Bedford Augen Gneiss. At this locality, the gray, feldspathic schistose gneisses of Manhattan C are in contact with black and white mottled dioritic gneisses of the Bedford Augen Gneiss. A two-foot-thick layer of very fine-grained dioritic gneisses, probably sugestive of a chilled zone, is found at the contact. The rocks on both sides of the contact are crushed and sheared.

Origin of the Bedford Augen Gneiss - The Bedford Augen Gneiss is regarded as an assemblage of metamorphosed intrusive igneous rocks. The following lines of evidence, indicate the intrusive nature of this rock unit:

1) Many specimens collected from this unit, especially those with pyroxene crystals, display a relict igneous texture. In these rocks a hypidiomorphic-granular texture is defined by equidimensional crystals of subhedral plagioclase and subhedral to euhedral augite.

2) Numerous small and large inclusions of shists, granulite and calc-silicate rock, some identified as fragments of the Schist and Amphibolite Member of the Hartland Formation and Schist Member of the Manhattan A, are present within and along the edge of the Bedford Augen Gneiss.

3) Along its southeastern border, the Bedford Augen Gneiss is in contact with various rocks of the Schist and Amphibolite Member and contact phenomena suggest lit-parlit injection of the Bedford Augen Gneiss into the country rocks.

4) Along the northwestern border of the Bedford Augen Gneiss, schists of Manhattan A are highly feldspathic and carry alkali-feldspar megacrysts.

On the basis of the observed lithic, structural, and stratigraphic features, the Bedford Augen Gneiss is considered as an igneous body, largely of dioritic and granodioritic composition, which intruded the Fordham Gneiss, the miogeosynclinal sequence, the exogeosynclinal Manhattan A and allochthonous rocks of the Manhattan C, as well as the Hartland Formation.

The interpretation that the contact between the Bedford Augen Gneiss and the Fordham Gneiss and the Lowerre-Inwood-Manhattan is an intrusive contact, is essentially based on the lithic similarity between some of the inclusions in the Bedford and the Schists of the Manhattan A. If these inclusions turn out to not be fragments of the Manhattan A, the contact may well be a thrust fault. Furthermore, the fact that the Bedford Augen Gneiss is present along the Hartland Boundary Fault suggests that the magma exploited this zone of weakness during intrusion.

Time of Intrusion - As previously was mentioned, a radiometric age determination on uraninite from a pegmatite dike at Bedford which has intruded the Bedford Augen Gneiss, yielded an age of 380 million years (Muench, 1931) and suggested a pre-Upper Devonian for the Bedford Augen Gneiss.

The time of intrusion, however, may be established more precisely on the basis of stratigraphic and structural features observed in the study area and contact relations between the Bedford Augen Gneiss and the surrounding rocks. The allochthonous Manhattan C, which was thrust onto Manhattan A during the Middle Ordovician, is intruded by the Bedford Augen Gneiss. Moreover, the rocks in the Bedford Augen Gneiss have been affected by polyphase structural deformation and regional metamorphism which is thought to be Middle Ordovician. These considerations suggest that intrusion of the Bedford Augen Gneiss occurred in late Middle Ordovician during the Taconic Orogeny.

Gabbro and Diorite. Three separate intrusive bodies have been mapped in the southeastern portion of the Mt. Kisco quadrangle. They range in composition from olivine gabbro to diorite and appear as black, or black and white mottled, medium- to very-coarse-grained, dense and massive rocks. Foliation is locally conspicuous and is outlined by alternation of dark (amphibole, biotite, pyroxene) and light (mostly plagioclase) layers. Locally, gabbro contains feldspar megacrysts and, hence, displays a porphyritic texture similar to that of the Bedford Augen Gneiss (Fig. 3-C). The rocks are essentially composed of plagioclase, hornblende, biotite, and augite, with hypersthene and olivine in more mafic portions. Large crystals of garnet, up to one inch in diameter, abundantly scattered throughout the rock, have been observed locally in this unit. Estimated modes of specimens of these rocks are given in Table 14.

The cross cutting relationships between these plutons and the Bedford Augen Gneiss as well as the Hartland Formation are exposed in a number of outcrops, and can best be studied at two localities: 1) on the east-facing high cliff about 1,500 feet west of the East Middle Patent School, and 2) on southern slope of the small hill about 4,000 feet north-northwest of Banksville. At both localities gabbroic rocks cut across the contact between the Bedford Augen Gneiss and the Schist and Amphibolite Member of the Hartland Formation, and deform the foliation in these rocks. An intrusive breccia consisting of several angular inclusions of the country rock in a matrix of diorite and gabbro is present at these localities (Fig. 3a and 3b).

A specimen of the plutonic rock (M-9-16) 4 feet away from the contact with the schists of the Hartland Formation at the second locality mentioned above, is composed largely of fine, polygonal quartz grains, large poikilitic plagioclase (An_{68}) and actinolite, and poly-synthetically twinned cummingtonite. Moreover, in specimen M-9-12, pargasite accompanied by green biotite, characteristically rims olivine and pyroxene and in M-9-1 cummingtonite rims the hypersthene crystals (Fig. 4a and 4b). The texture and mineralogy of these rocks clearly indicate that a metamorphic event affected them.

An inclusion of quartzite about 8 feet long is present in the gabbro exposed on the east-facing high cliff about 4,500 feet northwest of Banksville. The inclusion is pink, well-bedded, vitreous quartzite which is lithically very similar to the basal quartzites of the miogeosynclinal sequence. A specimen from this inclusion (M-9-9) is virtually a pure

TABLE 14

Estimated modes of specimens from metamorphosed mafic and ultramafic igneous bodies which have intruded the Bedford Augen Gneiss.

Minerals	Specimens[1] Gabbro and Diorite						
	M-4-23	M-9-2*	M-9-1	M-9-15+	M-9-16	M-9-11	M-9-12
Quartz	1	tr.	-	tr.	24	tr.	-
Plagioclase[2]	40	59	35	52	40	28	19
(An%)	(45)	(58)	(63)	(61)	(68)	(58)	(68)
Forsterite	-	-	tr.	-	-	-	20
Hypersthene	-	-	-	-	-	8	8
Augite	-	4	18	10	-	20	30
Hornblende[3]	31	31	27	19	-	32	9
Pargasite[4]	-	-	-	-	-	-	1
Actinolite[5]	-	-	-	-	11	-	-
Cummingtonite[6]	-	-	8	-	8	-	-
Red Biotite	19	6	10	14	10	10	12
Green Biotite[7]	-	-	-	-	-	-	tr.
Allanite	-	-	-	tr.	-	-	-
Sphene	5	tr.	-	-	-	-	-
Apatite	tr.	tr.	-	tr.	-	tr.	-
Zircon	-	tr.	-	-	tr.	-	-
Rutile	-	tr.	tr.	-	tr.	-	-
Spinel	-	-	-	-	-	-	-
Opaque[8]	4	tr.	2	5	6	2	1
Chlorite[9]	-	-	-	-	1	-	-
Surpentine[9]	-	-	tr.	-	-	-	tr.
Calcite[9]	-	-	-	-	-	-	-
Sericite[9]	tr.	tr.	tr.	-	tr.	-	-
TOTAL	100	100	100	100	100	100	100

Continued from table 14

Minerals	Specimens[1]								
	Norite and Gabbro				Orthopyroxene Hornblendite			Biotite-Augite Hornblendite	
	M-4-14	M-4-15	M-4-16	M-4-17	P-6-46	M-9-14	M-4-21	P-6-49	P-6-50
Quartz	-	-	-	-	-	-	-	-	-
Plagioclase	48	51	57	51	13	15	9	10	9
(An%)	(69)	(70)	(55)	(65)	(73)	(71)	(66)	(33)	(35)
Forsterite	-	5	-	-	tr.	-	-	-	-
Hypersthene	1	16	-	7	tr.	14	2	-	-
Augite	22	-	9	1	tr.	1	1	25	24
Hornblende	15	15	12	32	75	59	80	37	54
Pargasite	-	3	-	-	-	8	-	-	-
Actinolite	-	-	-	-	-	-	-	-	-
Cummingtonite	-	-	-	-	-	-	-	-	-
Red Biotite	10	4	16	7	8	1	2	-	-
Green Biotite	-	tr.	-	-	-	-	-	26	10
Allanite	-	-	-	-	-	-	-	-	-
Sphene	-	-	tr.	-	-	-	-	1	1
Apatite	tr.	tr.	tr.	tr.	tr.	tr.	tr.	1	2
Zircon	-	-	-	-	-	-	tr.	-	-
Rutile	-	tr.	-	tr.	tr.	-	-	-	-
Spinel	-	tr.	-	-	-	-	-	-	-
Opaque	4	4	6	2	4	2	6	tr.	tr.
Chlorite	-	-	-	-	-	-	-	-	-
Surpentine	-	2	-	-	tr.	-	-	-	-
Calcite	-	-	-	-	-	-	tr.	-	-
Sericite	-	-	-	tr.	-	-	-	-	-
TOTAL	100	100	100	100	100	100	100	100	100

Continued from Table 14

* A dike composed of quartz and feldspars (not included in the estimated modes) is present in this specimen.

+ A tiny calcite vein (1/16 inch thick) cross-cuts this rock specimen. It is not incorporated in the modal analysis.

@ Plagioclase composition determined by the dispersion method. Others determined by standard oil immersion method.

1) For location of the specimens see Plate 2.

2) Plagioclase laths form a cluster enclosed by the mafic minerals. They are large, and cloudy subhedral to euhedral with well-developed albite and carlsbad twins. Normal zoning is abundant. In M-9-16, plagioclase is highly poikilitic with numerous inclusions of quartz. In P-6-49 and P-6-50, it occurs as fine, anhedral, and untwinned crystals.

3) In M-4-23, M-9-2, M-9-1, M-9-15, M-4-14, and M-4-16 hornblende is green and replaces augite, in M-9-11, M-9-12, M-4-15, M-4-17, P-6-46, M-9-14, and M-4-21, it is light-brown and occurs either as large poikilitic crystals or ultra-fine-grained aggregates which have replaced pyroxene. In P-6-49 and P-6-50 it is as very large, green, poikilitic crystals with numerous inclusions of augite, plagioclase, and apatite.

4) Pargasite is present with intergrowths of plagioclase and/or spinel, showing symplectic texture and rimming forsterite and pyroxene crystals. It grades to brown hornblende.

5) Occurs as large poikilitic grains with inclusions of plagioclase. Pleochroic from colorless to pale-green.

6) Optically positive, $2V \approx 75°$, colorless, polysynthetically twinned. In M-9-1, it rims hypersthene.

7) Associated with pargasite

8) Mostly magnetite and illmenite. Magnetite shows a dendritic texture and occurs along the fractures in serpentinized forsterite. Illmenite is either as large anhedral grains or as tiny needles aligned parallel to the cleavage of brown hornblende. Pyrite, chalcopyrite, and pyrrhotite-pentlandite are also present. Identification of these opaque minerals was by reflected light microscopic studies on polished samples.

9) A secondary alteration product.

Continued from Table 14

Description of the rock specimens

M-4-23	: Black and white, coarse-grained gabbro with large (5 mm) black biotite flakes, it displays a fracture cleavage.
M-9-2	: Black and white, massive, coarse-grained biotite gabbro.
M-9-1	: Black, medium-grained, massive gabbro with black biotite flakes up to 5 mm across.
M-9-15	: Dark-gray, fine-grained, dense, massive gabbro with two cross-cutting quartz-feldspar dikes about 1/8 inch.
M-9-16	: Gray, massive, dense, medium-grained gabbro.
M-9-11	: Very-dark-gray, massive, dense, coarse-grained, olivine gabbro with black biotite flakes.
M-9-12	: Very-dark-gray, massive, dense, coarse-grained, olivine gabbro with black biotite flakes.
M-4-14	: Black and white, dense, massive, medium-grained gabbro.
M-4-15	: Very-dark-gray, coarse-grained, massive norite with large biotite flakes.
M-4-16	: Black and white, massive, very-coarse-grained gabbro with large biotite flakes.
M-4-17	: Very-dark-gray, very-coarse-grained, massive biotite-bearing norite.
P-6-46	: Brownish-black, massive, dense, medium-grained, hornblendite.
M-9-14	: Black, massive, coarse-grained hornblendite with large biotite flakes.
M-4-21	: Black, dense, massive, coarse-grained hornblendite.
P-6-49	: Greenish-black, very-coarse-grained, massive, dense, hornblendite.
P-6-50	: Greenish-black, medium-grained, massive, biotite-augite bearing hornblendite.

quartzite (99.5 percent quartz) but also contains a few muscovite, biotite and plagioclase grains.

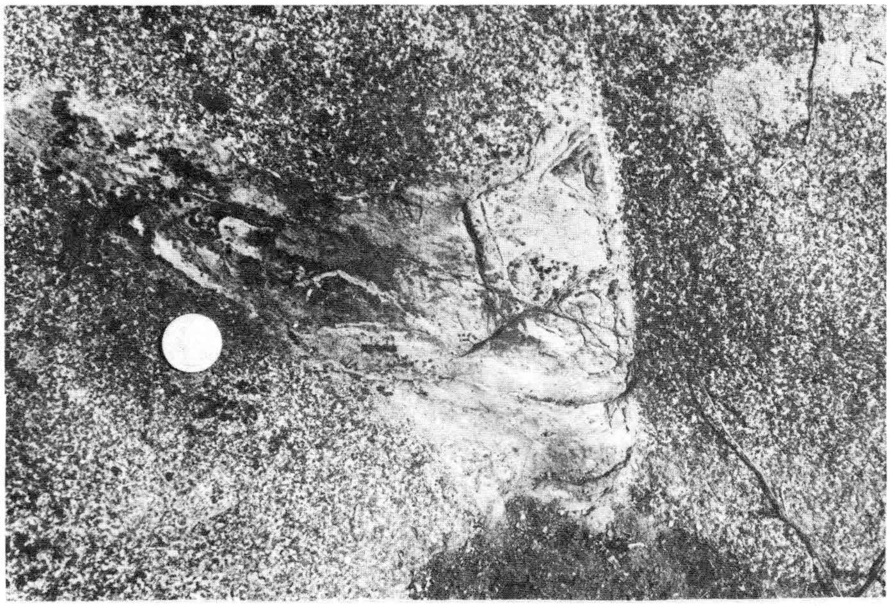
Norite and Gabbro. Two bodies of noritic and gabbroic rocks have been mapped separately within the Bedford Complex. They consist primarily of dark-gray or black, coarse-grained, massive or very-poorly-foliated gabbros, norites and olivine norites which contain large (5 mm) black biotite flakes. These rocks are composed chiefly of plagioclase, hypersthene, augite, hornblende, biotite with subordinate forsterite in olivine norites. Pargasite, rimming hypersthene, similar to that in the gabbro-diorite plutons, is also present. Estimated modes of specimens from these rocks are listed in Table 14.

The intrusive contact between one of these two plutons with the Bedford Augen Gneiss is well exposed on the southern slope of the rounded hill which is about 4,000 feet east-northeast of the Middle Patent Church (Plate 1).

Orthopyroxene Hornblendite. Three discrete, small (less than 30-40 feet across) bodies of orthopyroxene hornblendite are present within the Bedford Complex. They appear on the outcrop surface as medium- to coarse-grained, black or brownish-black massive hornblendites. They are essentially composed of subhedral to euhedral interlocked crystals of plagioclase surrounded by the clusters of very-fine-grained hornblende aggregates which retain the replaced pyroxene morphology. Estimated modes of the specimens from these rocks are given in Table 14.

Biotite-Augite Hornblendite. This unit is a dark-green or greenish-black, coarse- to very-coarse-grained hornblendite that is exposed east of the Mianus River in the western part of the Pound Ridge quadrangle (Plate 1). The rock is composed largely of hornblende, augite, and

A



B

C

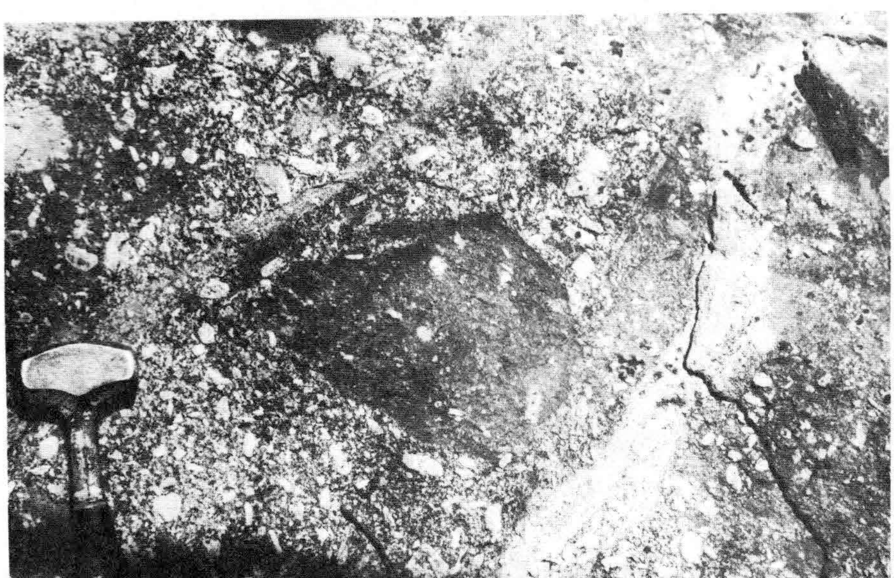
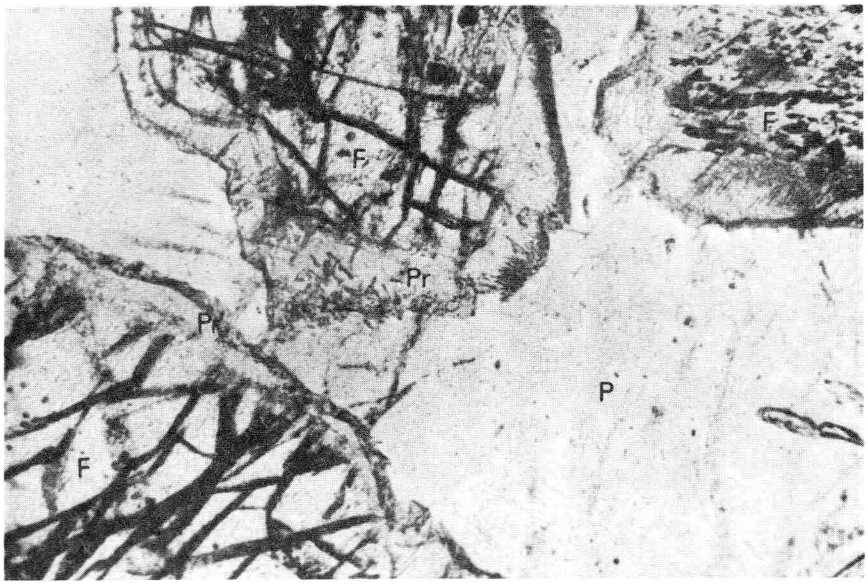


Figure 3 - Inclusions in the gabbro about 1,500 feet west of the East Middle Patent School. A - inclusion of schist in the gabbro. B - inclusion of the Bedford Augen Gneiss in the gabbro. C - inclusion of the Bedford Augen Gneiss in the porphyritic gabbro.

A



B

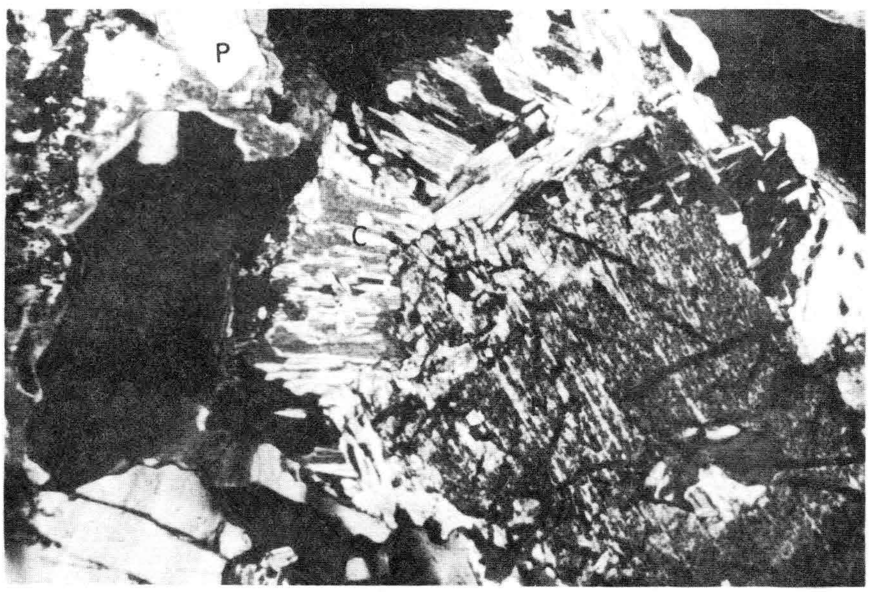


Figure 4 - A - Pargasite rimming forsterite crystals in olivine gabbro. F - forsterite; Pr. - pargasite; P. - plagioclase. Specimen M-9-12; plain light. X 100. B - cummingtonite rimming hypersthene. C - cummingtonite; H - hypersthene; P. - plagioclase; B. biotite - Specimen M-9-1. Crossed nocols. X 100.

green biotite with minor amounts of plagioclase (Table 14). In contrast to the well-foliated country rock, this rock is massive. It has intruded the dioritic rocks of the Bedford Augen Gneiss and the intrusive contact is well-exposed in a road cut on the U.S. Route 104 about 3 miles southeast of Bedford. (Plate 1). Here the poorly foliated hornblendite intersects well-developed foliation of the rocks in the Bedford Augen Gneiss.

STRUCTURAL GEOLOGY

General Statement

An analysis of the distribution and mutual relations of the rock units and their minor structural features indicate that the present outcrop pattern (Plate 1) was produced by a sequence of events which took place in the Precambrian, Paleozoic, and probably Triassic and Jurassic. These tectonic events are listed chronologically from oldest to youngest as follows:

1) Precambrian folding and metamorphism.

2) Middle Ordovician thrust-faulting which resulted in transportation of the eugeosynclinal rocks of Manhattan B and C, and their emplacement on the Middle Ordovician Manhattan A.

3) Development of the Hartland Boundary Fault which resulted in displacement of the eugeosynclinal Hartland Formation with respect to the Precambrian basement and the overlying autochthonous and allochthonous Early Paleozoic rocks.

4) A - The first stage of Paleozoic folding which was accompanied by regional metamorphism resulting in formation of isoclinal folds with a generally ENE-WSW trend.

B - A second stage of folding that was accompanied by a second phase of regional metamorphism resulted in the formation of a second generation of isoclinal folds and deformation of the pre-existing structural features.

C - A third stage of folding generated a new class of west or northwest plunging tight folds which deformed all the pre-existing structural features.

D - A fourth stage of folding that resulted in the formation of open to very open north-south trending folds.

5) Brittle-faulting, possibly Triassic and/or Jurassic, produced the Mianus River and the Mill River faults.

Minor Structural Features

First Folds. The earliest folds, recognized in the study area, are those in bedding with a well-developed foliation parallel to the axial plane. The first folds are characteristically isoclinal with extremely long limbs and narrow hinge regions. The axial plane foliation is due to the parallel alignment of the platy minerals and also to their concentration in layers which has yielded a prominent compositional layering. This observation indicates that this foliation, hereafter referred to as the first foliation, is a pervasive axial plane feature generated during the first stage of folding and accompanying regional metamorphism. The attitudes and the general trend of this prominent planar structure in the entire area are shown in Plate 3-A and C.

Mineral lineation is pronounced in most rocks of the study area. Two thin sections, one perpendicular to the axial plane and the other parallel to the axial plane of first folds show that the constituent minerals are aligned parallel to the fold axis. The orientation of this mineral lineation, referred to as the first mineral lineation, measured throughout the area is represented in Plate 3-B.

Second Folds. In some exposures in the study area, a set of second generation folds is superimposed upon the pre-existing axial plane foliation and bedding. The second folds are mostly of similar type, class 2 (Ramsay, 1967; p. 367), tight to isoclinal (Fleuty, 1964) with long and highly attenuated limbs. They may be generally classified as slip folds (Billings, 1972; p. 120) or passive slip and passive flow folds (Donath and Parker, 1964). They are dominantly overturned to east or southeast with axial planes dipping to northwest. The generation of the second folds has been accompanied by considerable amounts of continuous flow (Donath and Parker, 1964) parallel to the axial planes and locally has resulted in reorientation of the pre-existing mineral lineation. The orientation of the axes of the second folds is a function of the orientation of the pre-existing planar structures and the degree of rotation by the later deformational events.

In the schists of Manhattan A and the sillimanite-rich layers of the Lowerre Quartzite, the axial plane feature related to the second folds is a foliation. This second foliation is due to parallel alignment of the sillimanite crystals. In the Gabbro and Diorite plutons of the Bedford Complex, this foliation is only locally-developed. Recognition of this planar feature is extremely difficult in the marbles and amphibolites, and consequently the second folds can be distinguished from the third-generation folds only where the super-position of the third folds, or their associated axial plane cleavage, upon the second folds is actually observable.

A poorly developed mineral lineation, the second mineral lineation, defined by the alignment of the mica (especially muscovite) parallel to the second fold axes has been recognized in a few outcrops of the study area.

Third Folds. In many exposures in the study area, both the first and the second foliations are crenulated and folded by a third set of folds. The third folds, which are the most abundant, are open to tight, class 1C (Ramsay, 1967) and overturned to east or southeast. In the schists, they locally display a chevron style characterized by short limbs and narrow, angular hinges. Asymmetric folds of the third generation with both clockwise and counter-clockwise rotation senses are present in individual outcrops but the data in each locality are too few to determine a separation angle and orientation of slip line after the method of Hansen (1971). A well-developed slip cleavage, parallel to the axial plane of the third folds, is developed throughout the study area (Plate 3-A). In many exposures, this axial plane slip cleavage is parallel or subparallel to the first foliation; in such cases only the first foliation symbol is used on Plate 3-A. Fabric analysis of the third folds present in the specimens from different rock units (e.g., P-4-1; P-6-12; and P-6-5), show no evidence of mineral growth parallel to the cleavage. The intersection of the axial plane slip cleavage with the first foliation is the only lineation produced during the third stage of folding (Plate 3-B).

Fourth Folds. The orientation of the axial plane cleavage associated with the third stage folds is varied throughout the area (Fig. 5). The folds of the fourth generation are open with wavelengths ranging from 3 inches up to several feet. They commonly plunge N; and the angle of plunge is a function of the orientation of the pre-existing planar features.

Major Folds

Procedure and Terminology. The major folds, outlined by the map pattern of the rock units (Plate 1), are named after the nearby geographic localities. Plate 3-D shows the axial traces of the major folds. In order to elucidate geometrical aspects of the major folds the study area is divided into 52 subareas (Fig. 6). The structural data obtained from field study have been analyzed for each of the subareas. The polès to the first foliation planes have been plotted and contoured (Plate 4). The prominent linear features have been plotted on the same stereonet but left uncontoured (Plate 4).

The term fold system is used for a set of complementary anticlines and synclines, formed during the same stage of deformation and therefore having the same structural characteristics. A number of folds and fold systems which have been formed during different stages of folding, hence producing a complicated interference pattern, constitute a fold complex.

Trinity Lake Fold Complex. The distribution of the stratigraphic units and geometry of the minor structural features in the vicinity of Trinity Lake, reveal a highly complicated fold complex, the Trinity Lake fold complex, which is truncated by a late normal fault (Plate 1). This fold complex is composed of two large, isoclinal folds of the first

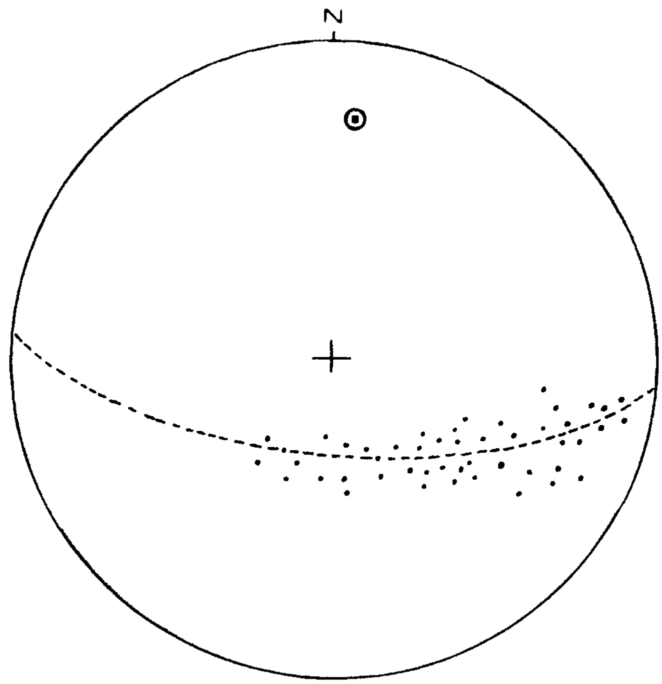


Figure 5 - Poles to axial plane slip cleavage throughout the area. Statistical fold axis about which the cleavage is rotated (the fourth fold axis), is indicated.

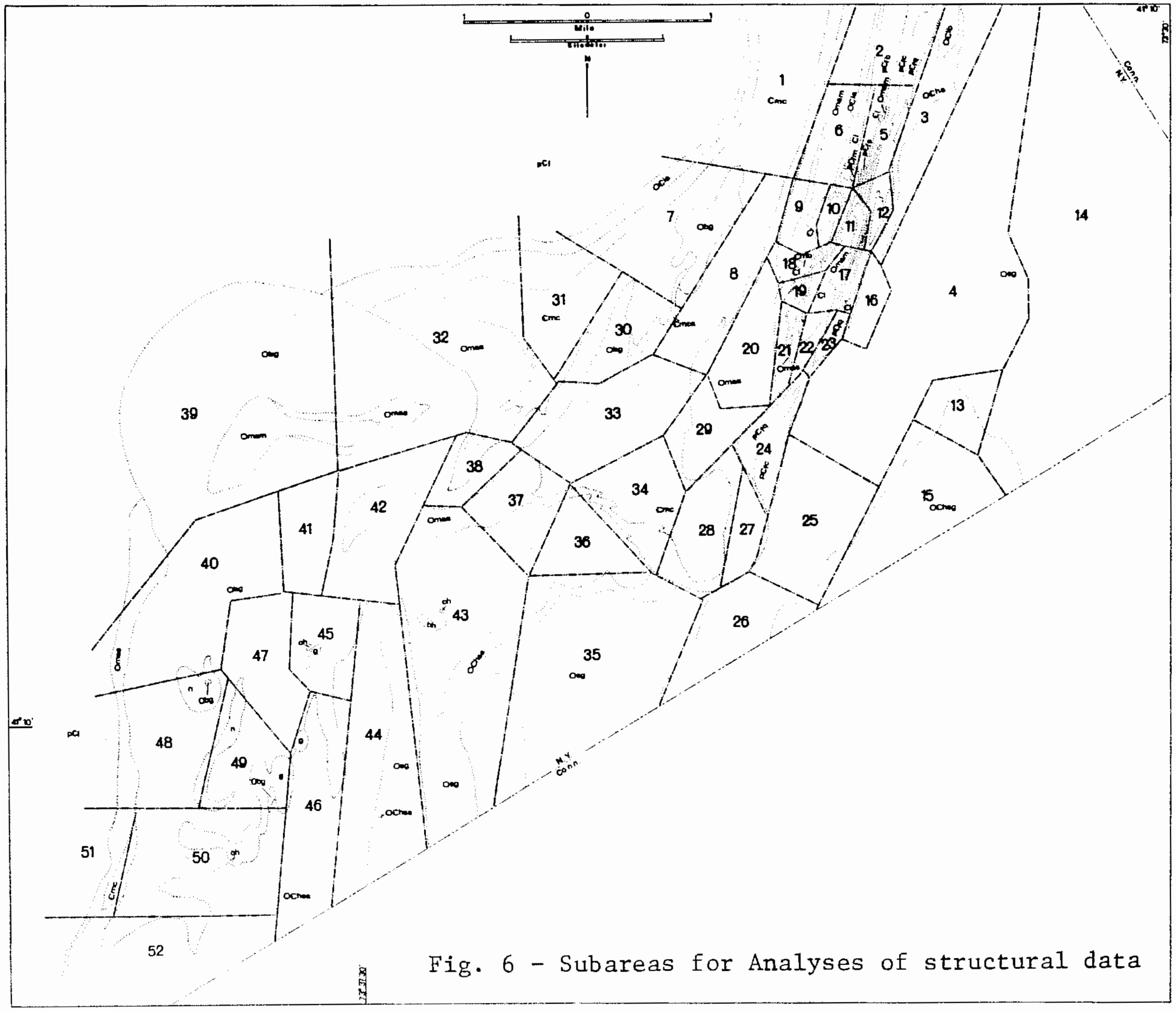


Fig. 6 - Subareas for Analyses of structural data

generation which form the Trinity Lake fold system (the Trinity Lake syncline and anticline), a generally NNE-SSW trending second fold (the Trinity Lake antiform), and a set of west plunging third folds which form the Lake Kitchawan fold system (Plate 3-D). In order to better visualize the geometry of this fold complex a simplified, perspective digram showing a single stratigraphic unit, the Marble Member of the Manhattan A, has been constructed (Fig. 7).

Trinity Lake Fold System - The hinge of the Trinity Lake syncline is located to the east and southwest of Trinity Lake where Manhattan B is terminated (Plate 1; Plate 3-D). The first foliation, trending NE-SW in the amphibolites intersects the contact in the hinge region (Plate 3A and C). The strong, pervasive first mineral lineation, believed to be parallel to the syncline axis plunges NW in the eastern hinge region (Plate 3-B; subarea 17, Plate 4) and SW in the western hinge region (Plate 3-B; subarea 21, Plate 4).

The repetition of the stratigraphic units to the west and northwest of Trinity Lake (Plate 1) dictates an anticline, the Trinity Lake anti-cline (Plate 3-D), with the Lowerre Quartzite and the Fordham Gneiss in its core.

The hinge of this major structure is not exposed in the present study area due to refolding by a later fold (see below). The geometry of the entire fold complex, as shown in Fig. 7, however, indicates that the hinge should be deep under the present erosional level somewhere to the north, probably in the Peach Lake quadrangle.

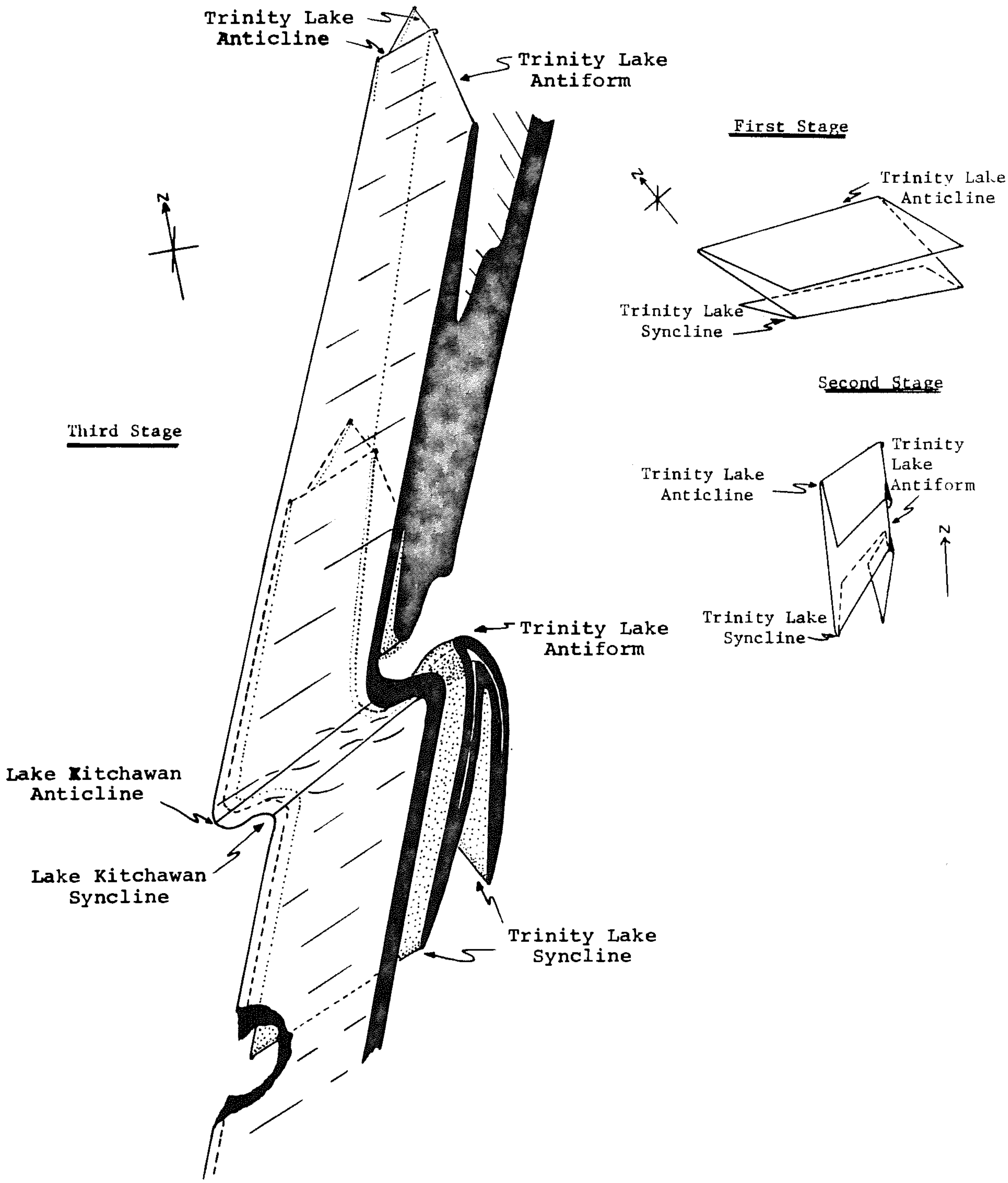


Figure 7 - Simplified perspective diagram showing the surface of a single stratigraphic unit, the Marble Member of Manhattan A, in the Trinity Lake fold complex.

Trinity Lake Antiform - The Trinity Lake fold system is refolded by the Trinity Lake antiform (Plate 1; cross section B-B', Plate 5). The superposition of the Trinity Lake antiform on the two pre-existing first folds has resulted in rotation of the axial plane first foliation into parallelism with the NW dipping and NNE trending second foliation. The reorientation of the first mineral lineation due to superposition of the Trinity Lake antiform is best illustrated in subarea 6 (Plate 4) where the hinge of the antiform is outlined by the Lowerre Quartzite. In this subarea, the first mineral lineations fall into two groups: one group, corresponding to the outcrops east of the axial plane of the antiform, plunges NW; and the other, corresponding to the outcrops west of the axial plane of the antiform, plunges SW (Plate 3-B; Plate 4). Also, in subareas 11 and 17 which are on the eastern limb of the antiform, the first mineral lineation has been rotated about the N-S trending axis of the antiform and thus plunges NW, whereas in subareas 10, 19, and 21, on the western limb of the antiform, it is plunging SW (Plate 4).

The minor folds of the second generation, related to the Trinity Lake antiform, in subareas 6,9,11,19,21, and 22 are plunging gently NNW, whereas in subareas 10 and 18, due to later deformation, are plunging SW.

Lake Kitchawan Fold System - The axial trace of the Trinity Lake antiform, shown on Plate 3-D, indicates that the structure is refolded by a set of later folds which form the Lake Kitchawan fold system. The Lake Kitchawan fold system consists of the Lake Kitchawan anticline and syncline (cross section B-B', Plate 5), as well as the unnamed major anticline and syncline which lie to the east and deform the Trinity Lake antiform. The orientation of the Lake Kitchawan anticline and syncline axes, is determined by plotting the poles to the first foliation measured in the hinge regions of the two folds (subareas 9 and 10, Plate 4). The two statistically determined fold axes in subareas 9 and 10 plunge westerly parallel or subparallel to the axes of the minor third folds measured in the subareas 9,17,18,19,21, and 22 (Plate 4).

The effect of the fourth stage of folding on the Trinity Lake fold complex, is restricted to rotation of the entire complex as indicated by the broad deflection in trend of the first foliation and slip cleavage on Plate 3-A and C.

Pound Ridge Fold Complex. The Pound Ridge fold complex consists of intricately refolded folds, which extend several miles in a NE-SW direction in the vicinities of Bedford and Pound Ridge villages (Plate 1). In the northeastern portion of the study area it appears as a tight N-S trending syncline which extends into the Peach Lake quadrangle (Plate 1; Cross Section A-A', Plate 5). This fold complex consists of the Twin Lakes syncline, the Pine Brook syncline, the Pound Ridge anticline, the Bedford anticline and the Pitch Swamp syncline, as well as a set of open folds of the fourth generation (Plate 3-D).

The Twin Lakes and the Pine Brook synclines are two isoclinal folds which were generated during the first stage of folding. The interpretation is essentially based on the fact that the first foliation passes undeflected through the hinges of these major structures (Plate 3-A and C). The orientation of the first mineral lineation measured in the hinge regions of the Pine Brook (subarea 38) and the Twin Lakes (subareas 37 and 42) suggest that the axes of the major folds are plunging generally WNW and NNW respectively (Plate 3-B; Plate 4). Cross section D-D' (Plate 5) illustrates these two early structures.

The Pound Ridge anticline which is superimposed on the Pine Brook and Twin Lakes synclines, is an isoclinal fold with an axial plane which strikes northeast and dips northwest (Plate 3-D). This isoclinal fold, shown in cross section D-D' (Plate 5), is interpreted as second generation because the first foliation is deflected in its hinge region and the slip cleavage (axial plane of the third folds) cuts across the axial plane of this structure at a moderate angle (Plate 3-A). Numerous minor folds of the third generation are superimposed on the limbs of this major fold, but scale limitation does not permit illustration of them on the geologic map.

The Bedford anticline and the Pitch Swamp syncline, as well as the unnamed major syncline to the east of the Pound Ridge anticline (Plate 3-D), form a fold system of the third generation which is superimposed upon earlier folds such as the Pine Brook syncline. The well-developed axial plane slip cleavage which intersects the pre-existing planar features at a high angle east of Bedford, and at a moderate angle west of Pound Ridge, strikes generally ENE-WNW (Plate 3-A). Further northeast, west of Lake Kitchawan (Plate 1), the slip cleavage is subparallel to the first foliation and strikes NNE (Plate 3-A).

The stereographic projections of the minor structural elements measured on the limbs and in the hinge region of the Bedford anticline (subarea 32; Plate 4) reveal that the second folds plunge gently N or NE, whereas over most of the area the third folds plunge NW.

The effect of the fourth stage of folding on the earlier folds in the Pound Ridge fold complex is that of a set of open folds which deflect the planar features. Generally the axial traces of these folds trend N-S (Plate 3-D) and their axes plunge N.

On a gross scale, the complicated structural pattern displayed on the geologic map by the Pound Ridge fold complex, seems to be similar to the structural pattern displayed by the Trinity Lake fold complex. The Pine Brook and the Twin Lakes synclines, which have formed during the first stage of folding, appear to be similar to the Trinity Lake syncline. The Pound Ridge anticline, which is superimposed upon the Pine Brook and the Twin Lakes synclines, can be considered a fold structurally similar to the Trinity Lake antiform. The superposition of the Bedford-Pitch Swamp fold system on the preexisting major folds is similar to that of the Lake Kitchawan fold system.

Other Major Folds. Major folds similar to those described above have been recognized in other parts of the study area. West of Banksville, the first foliation is parallel to the axial plane of a major fold called the Banksville syncline (Plate 3-D), which is defined by the contact between the Bedford Augen Gneiss and the Schist and Amphibolite Member of the Hartland Formation. This fold is interpreted as first generation and the orientation of the mineral lineation indicates that its axis is plunging WNW (subarea 52; Plate 4).

The axial plane of the Banksville syncline is deflected and wraps around the hinge of a later fold (cross section F-F'; Plate 5) which may be of either second or third generation. The slip cleavage which strikes NE and dips NW (Plate 3-A) is generally parallel to the axial plane of this later fold, suggesting that it may have formed during the third stage of folding. On this basis, it has been considered as a third generation fold.

A major first fold, the Mill River Fold, defined by the contact between Member B of the Inwood Marble and the Schist and Gneiss Member of the Hartland Formation, "Cameron's Line", is recognized in the northeasternmost part of the study area. The first foliation, passing through the hinge of the fold with no deflection strikes in a NNE-SSW direction and dips about 60° northwest (Plate 3-A and C). The orientation of the first mineral lineation in the hinge region of this fold suggests that the fold plunges to the northwest (Plate 3-B; subarea 3, Plate 4).

In the southeastern part of the study area, a north-plunging, open fold is defined by the contact between the Siscowit Granitic Gneiss and the Schist and Granulite Member of the Hartland Formation, which is considered as a fold formed during the fourth stage of folding (Plate 3-D).

Major Faults

Apart from major folds, several major faults are present in the area (Plate 1) and they will be described chronologically from oldest to youngest.

Thrust Fault. On the basis of lithologic characteristics and regional geologic relations, the Manhattan B and C, which structurally overlie the Middle Ordovician Manhattan A, are correlated with Cambrian eugeosynclinal rocks of the Waramaug and Hoosac Formations of northwestern Connecticut and western Massachusetts (Hall, 1968a; 1975). If these stratigraphic correlations are valid, then, as Hall (1968a) suggested, the contact between Manhattan B and C and the underlying Manhattan A should be a thrust fault. Detailed geologic mapping in the study area provides more evidence to support this interpretation. In the vicinity of Trinity Lake, the amphibolite of the Manhattan B is in contact with both the Marble and the Schist members of the Manhattan A. The contact which is locally exposed, is sharp and characterized by strong lithic contrast.

On the basis of stratigraphic arguments presented by Hall (1968a) and contact relationships observed in the study area, the contact between Manhattan B and C and the underlying rocks of the Manhattan A is interpreted as a major thrust fault. This faulting resulted in transport of Manhattan B and C from their original site of deposition onto the clastic and carbonate sediments of the Manhattan A. Transportation of such large rock masses is also found further north in eastern New York and western New England (Zen, 1967). Geologic mapping indicates that the thrust fault must have occurred after deposition of the Middle Ordovician Manhattan A, but before the earliest isoclinal folds (Plate 1). This points to a Middle Ordovician age for the time of thrust faulting.

<u>Hartland Boundary Fault</u>. On a regional scale, the northwestern and western boundary of the Hartland Formation, "Cameron's Line" (Rodgers, 1970), has been considered as a major discontinuity of uncertain nature. Geologic mapping in the study area has provided enough information to permit the interpretation that the discontinuity is a fault, hereafter called the Hartland Boundary Fault. The fault strikes generally NE and dips northwest.

In southwesternmost part of the study area Hartland Boundary Fault is defined by the contact between the Schist and Amphibolite Member of the Hartland Formation, and the Manhattan Schist. Here, the contact truncates the thrust fault which separates Manhattan A from Manhattan C and itself is truncated by the Bedford intrusive complex (Plate 1). In the central part of the study area, west of Sarles Corner, the Bedford Complex is terminated at the Hartland Boundary Fault. Here, the Hartland Boundary Fault trends NW, truncates the contact between the Siscowit Granitic Gneiss and the Schist and Amphibolite Member, and is itself truncated about 500 feet south of Sarles Corner by a later, northeast-trending, probably Triassic, fault (Plate 1). To the northeast, northwest of Scotts Corner, the Hartland Boundary Fault is defined by the eastern boundary of the Precambrian Fordham Gneiss which truncates the contact between the Siscowit Granitic Gneiss and the Schist and Gneiss Member of the Hartland Formation. In the northeastern portion of the study area the Hartland boundary fault is defined by the contact between Member B of the Inwood Marble and the Schist and Gneiss Member of the Hartland Formation (Plate 1). The Hartland Boundary Fault, here, outlines an early isoclinal fold with a NNE-SSW trending and northwestward dipping axial plane which is truncated by a later, probably Triassic, normal fault (Fig. 8).

A zone of highly sheared and cataclastic rock is present locally near the Hartland boundary fault. Southeast of the new reservoir located east of Trinity Lake the light-gray felsic gneisses present in the Schist and Gneiss Member of the Hartland Formation, and rocks of the Siscowit Granitic Gneiss display intense mylonitization and a mineral lineation which plunges to the northwest. Further north, on the western slope of the Mill River, a zone of strongly mylonitized rocks (about 100 feet thick) has been found in the quartzo-feldspathic gneisses of the Fordham Gneiss. The strike of this mylonitized zone is parallel to the foliation, indicating severe crushing and recrystallization parallel to the foliation planes.

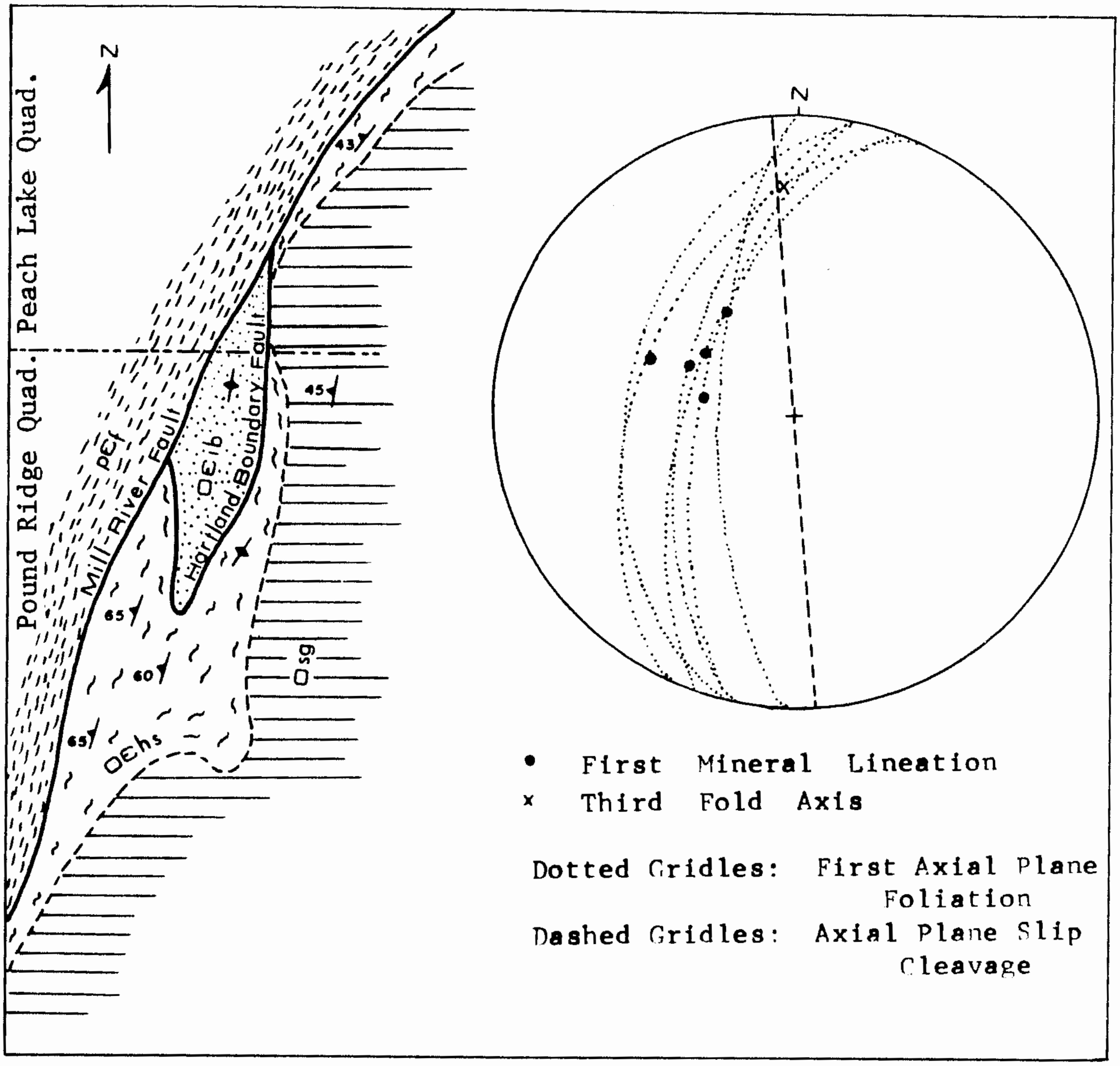


Figure 8 - Generalized geologic map of northeastern part of the Pound Ridge and adjacent portion of the Peach Lake quadrangles showing the isoclinally folded Hartland Boundary Fault, truncated by a later, probably Triassic fault (Mill River Fault). Symbols are the same as those used in Plate 1. The geometry of the minor structures measured in the hinge region of the isoclinal fold is shown stereographically.

On the basis of these stratigraphic and structural observations the contact between the members of the Hartland Formation and the Precambrian Fordham Gneiss and overlying early Paleozoic rocks, is interpreted as a fault which has become segmented as a result of intrusion of the Bedford Complex and the occurence of later faults.

Mianus River Fault and Mill River Fault. The geologic map (Plate 1) of the study area, reveals two major normal faults, the Mianus River fault and the Mill River fault, along which the stratigraphic units are displaced. Topographic expression of these faults appear as the Mianus River and the Mill River gorges from which the names of the faults are derived.

The Mianus River fault is a N-S trending fault which has displaced the Schist and Amphibolite Member of the Hartland Formation and part of the Bedford Complex. The Mill River fault trends NNE and displaces several stratigraphic units (Plate 1). In the northeasternmost part of the study area and adjacent portion of the Peach Lake quadrangle, the fault has brought Member B of the Inwood Marble and the Schist and Gneiss Member of the Hartland Formation into fault contact with different members of the Fordham Gneiss. Southeast of Trinity Lake, the fault has brought the Schist Member of the Manhattan A into contact with members of the Fordham Gneiss. South of Sarles Corner, the fault cuts across the Siscowit Granitic Gneiss and extends southwestward into Connecticut.

Although the age of these faults is uncertain, they intersect the foliation of the rocks and post-date the open folds formed by the latest Paleozoic folding; they may be Triassic and/or Jurassic.

METAMORPHISM

Regional Metamorphism of the Precambrian Rocks

The most common mineral assemblages found in different members of the Precambrian Fordham Gneiss are as following:

1) Quartz-plagioclase-biotite.

2) Quartz-microcline-perthitic microcline-plagioclase-biotite-muscovite

3) Quartz-microcline-perthitic microcline-plagioclase-biotite-garnet-sillimanite.

4) Calcite-diopside-actinolite-microcline-plagioclase-quartz.

The Microcline Gneiss Member and the Sillimanite Quartzose Gneiss Member of the Fordham Gneiss contain large perthitic microcline which suggests that the temperature of crystallization was above the critical temperature of the K-feldspar solvus. Experimental work by Tuttle and Bowen (1958), Orville (1963), and Morse (1970) show 700°C as the critical temperature at 5 Kbar pressure. Therefore, a minimum temperature of the regional metamorphism can be established as 700°C which suggests a moderate to high grade metamorphism.

Paleozoic Regional Metamorphism

General Statement. Evidently two phases of regional metamorphism have accompanied the first two stages of Paleozoic folding in the study area. The occurence of the first phase must have been prior to the intrusion of the gabbro and diorite igneous bodies because the foliation generated during the first stage of folding is truncated at the contact of the gabbro and diorite plutons (see page 76). The second phase must have occurred after intrusion of the gabbro and diorite plutons, because the mineralogy and texture of the rocks in these plutons indicate that they have been subjected to regional metamorphism (see page 76). The two phases of regional metamorphism may or may not be part of a single thermal event during which tectonic stresses were progressively producing folds of the first and the second generations; and therefore, they can be attributed either to the Taconic orogeny alone, or to both the Taconic and Acadian orogenies.

Grade of Metamorphism. The Paleozoic rocks of the study area have been subjected to sillimanite-K·feldspar grade metamorphism. These rocks represent various compositions and therefore, display a wide variety of mineral assemblages. The most common mineral assemblages found in these rocks are listed in Table 15.

Sillimanite is found as an abundant constituent mineral in rocks which have pelitic composition, and occurs together with kyanite in some. Muscovite, and the assemblages sillimanite-muscovite and sillimanite-K-feldspar-muscovite are found in many rock specimens. The appearance of sillimanite together with K-feldspar, as a result of the muscovite breakdown, allows estimation of the P-T condition of the regional metamorphism. Experimental work by Evans (1965), Kerrick (1972), and Day (1973) indicates that muscovite is stable up to temperatures ranging from 600°C to approximately 710°C with increasing pressure, and Richardson and others (1969) give the andalusite-kyanite-sillimanite triple point at 622°C and 5.5 kilobars. From this information approximately 650°C and 5.5 Kilobars

TABLE 15

The common metamorphic mineral assemblages corresponding to different rock compositions

Composition	Metamorphic Mineral Assemblage
Quartzofeldspathic	1) Quartz-microcline-plagioclase (andesine) 2) Quartz-microcline-plagioclase (andesine) biotite-muscovite ± garnet
Pelitic	1) Quartz-plagioclase (andesine)-biotite-muscovite-microcline-garnet-magnetite 2) Quartz-plagioclase (oligoclase-labradorite)-biotite-sillimanite-muscovite-K·feldspar 3) Quartz-plagioclase (oligoclase-labradorite)-biotite-sillimanite-muscovite-kyanite
Carbonate	1) Calcite-plagioclase (andesine)-microcline-diopside-actinolite-epidote-quartz-sphene 2) Calcite-plagioclase (andesine)-quartz-actinolite 3) Calcite-microcline-diopside-scapolite-phlogopite-plagioclase-epidote 4) Dolomite-phlogopite 5) Dolomite-tremolite-phlogopite-calcite 6) Dolomite-forsterite-diopside-phlogapite-calcite
Mafic and ultramafic	1) Plagioclase (andesine)-hornblende-biotite± microcline 2) Plagioclase (andesine)-hornblende-biotite-illimanite-sphene+microcline 3) Plagioclase (andesine)-hornblende-cummingtonite-biotite 4) Hornblende-plagioclase (labradorite)-biotite 5) Plagioclase (labradorite)-biotite-hornblende-pargasite 6) Plagioclase (labradorite)-quartz-actinolite-biotite-cummingtonite

can be estimated as the minimum temperature and minimum pressure of metamorphism which affected the rocks in this area. Similar estimations of the metamorphic conditions for the pelitic rocks with mineral assemblages as those found in the rocks of the present study area, have been suggested by Evans and Guidotti (1966), Lundgren (1966), and Tracy (1975).

Retrograde Metamorphism

Retrograde metamorphism identified in the study area is restricted to the complete or partial alteration of the biotite crystals to chlorite.

Contact Metamorphism

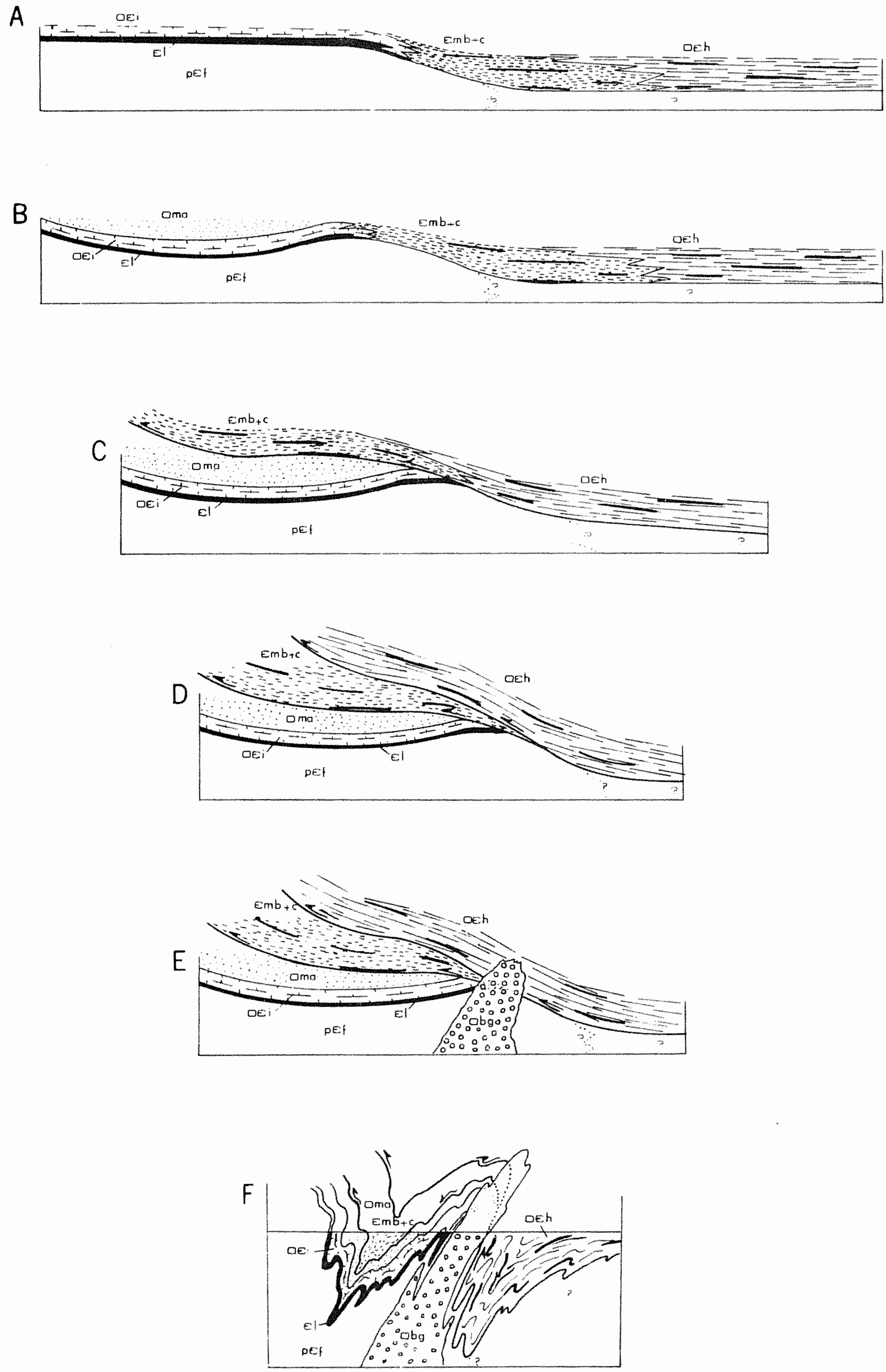
As already noted, in the southwestern part of the study area, the gabbro and diorite intrusive bodies cut across the contact between the Bedford Augen Gneiss and the Schist and Amphibolite Member of the Hartland Formation and metamorphose its wall rocks. Specimens collected from the outcrops of the Schist and Amphibolite Member near the intrusive contact about 4,000 feet NNW of Banksville, indicate that metamorphism has resulted in the destruction of the pre-existing axial plane first foliation and production of a granoblastic (quartz-plagioclase-biotite-cordierite) hornfels texture in the schists (M-9-17 and M-9-18; Table 7). Randomly oriented crystals of red-biotite and cordierite characterize the rocks which are less than 50 feet away from the contact. Overgrowths on garnet crystals and radiating acicular crystals of sillimanite have also been observed in these rocks. The rocks have retained their hornfels texture during the later (the second) phase of regional metamorphism and associated deformational movements.

GEOLOGIC HISTORY

The distribution pattern of the members in the Fordham Gneiss in the vicinity of Trinity Lake (Plate 1) and their truncation by the overlying Early Cambrian Lowerre Quartzite indicates that the Fordham Gneiss has been subjected to at least one episode of Precambrian folding and metamorphism. The structural details related to this Precambrian deformational event are extremely difficult to elucidate because of the superposition of intense Paleozoic deformation and metamorphism. Further studies on the Precambrian rocks in the adjacent areas may provide more information about this deformational event.

The stable condition that prevailed during the early Paleozoic, when clastic (Lowerre Quartzite) and carbonate (Inwood Marble) sediments were deposited (Fig. 9-A), must have changed to unstable conditions by the structural movements of the late Early Ordovician tectonic activity that resulted in development of an exogeosynclinal basin in which carbonate and clastic sediments of the Manhattan A became deposited (Fig. 9-B). Later, extremely strong deformational movements of the Middle Ordovician Taconic, the Devonian Acadian, and probably the Late Paleozoic Allegheny orogenies affected the rocks of the study area. First, part of the eugeosynclinal sequence, the Manhattan B and C, thrust westwa : onto the exogeosynclinal sediments (Fig. 9-C). Then the occurrence of the Hartland Boundary Fault brought the eugeosynclinal rocks of the Hartland Formation in fault contact with the Precambrian Fordham Gneiss and the overlying miogeosynclinal sequence (Figure 9-D). The generation

Figure 9. Schematic diagrams illustrating the geologic history of the area. Letter designations of the rock units are the same as those used in Plate 1.


A
OЄi
Єl
pЄf
Єmb+c
OЄh
B
Oma
OЄi
Єl
pЄf
Єmb+c
OЄh
C
Єmb+c
Oma
OЄi
Єl
pЄf
OЄh
D
Єmb+c
Oma
OЄi
Єl
pЄf
OЄh
E
Єmb+c
Oma
OЄi
Єl
pЄf
Obg
OЄh
F
Oma
Єmb+c
OЄi
Єl
pЄf
Obg
OЄh

of the Hartland Boundary Fault was followed by the intrusion of the Bedford Augen Gneiss (Fig. 9-E). Then, four stages of folding affected the area (Fig. 9-F). The first stage, which was accompanied by the first phase of regional metamorphism, produced large ENE-WSW trending isoclinal folds. This stage of folding was followed by intrusion of the relatively small mafic and ultramafic igneous bodies. A second stage of folding, accompanied by a second phase of metamorphism produced NNE-trending isoclinal folds which deformed the mafic and ultramafic plutons as well as other rocks in the study area. Tight to isoclinal folds formed during the fourth stage of folding reoriented the earlier folds.

The normal faults which may have formed during Triassic and/or Jurassic, characterize the closing of the deformational history of the study area.

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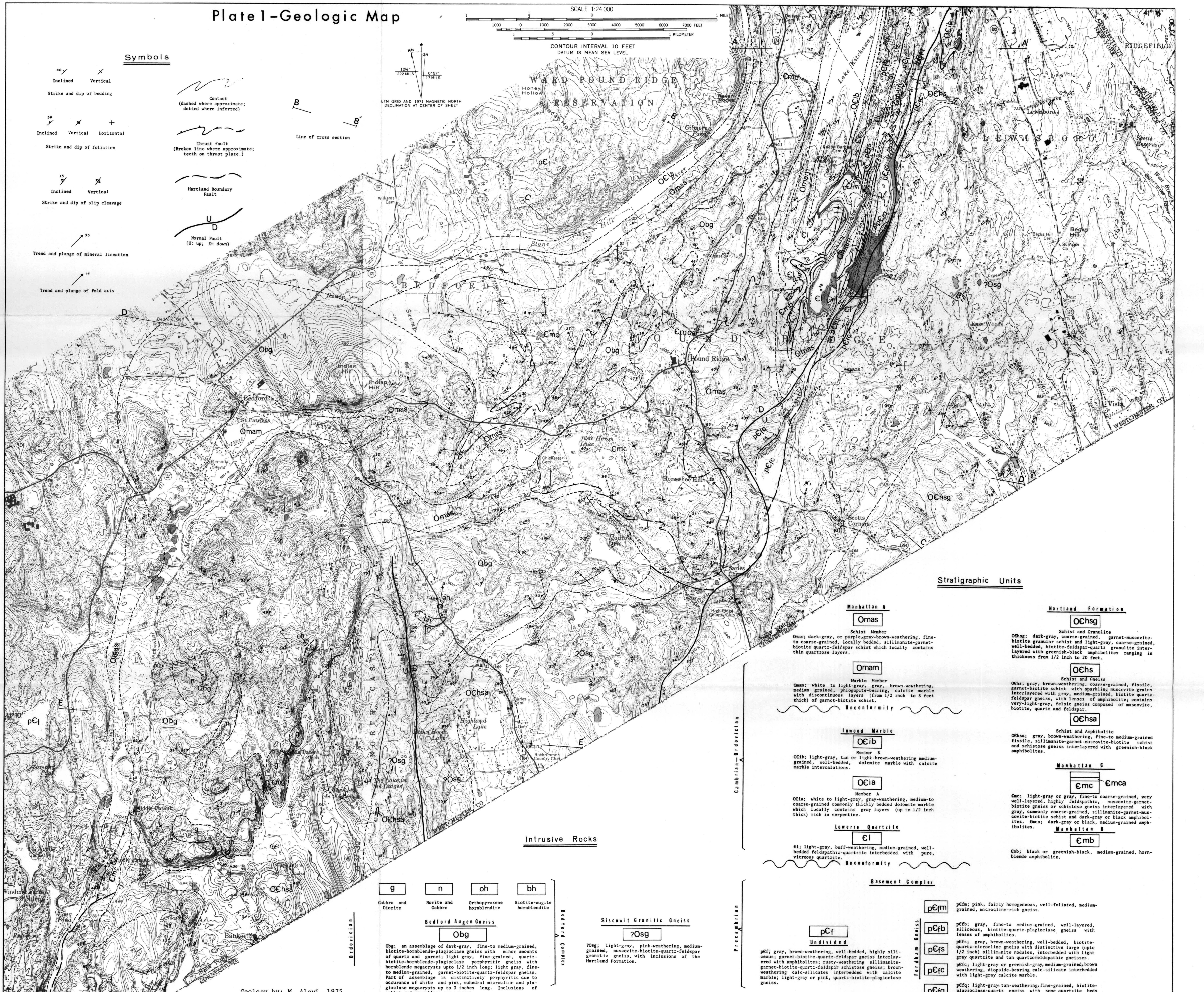
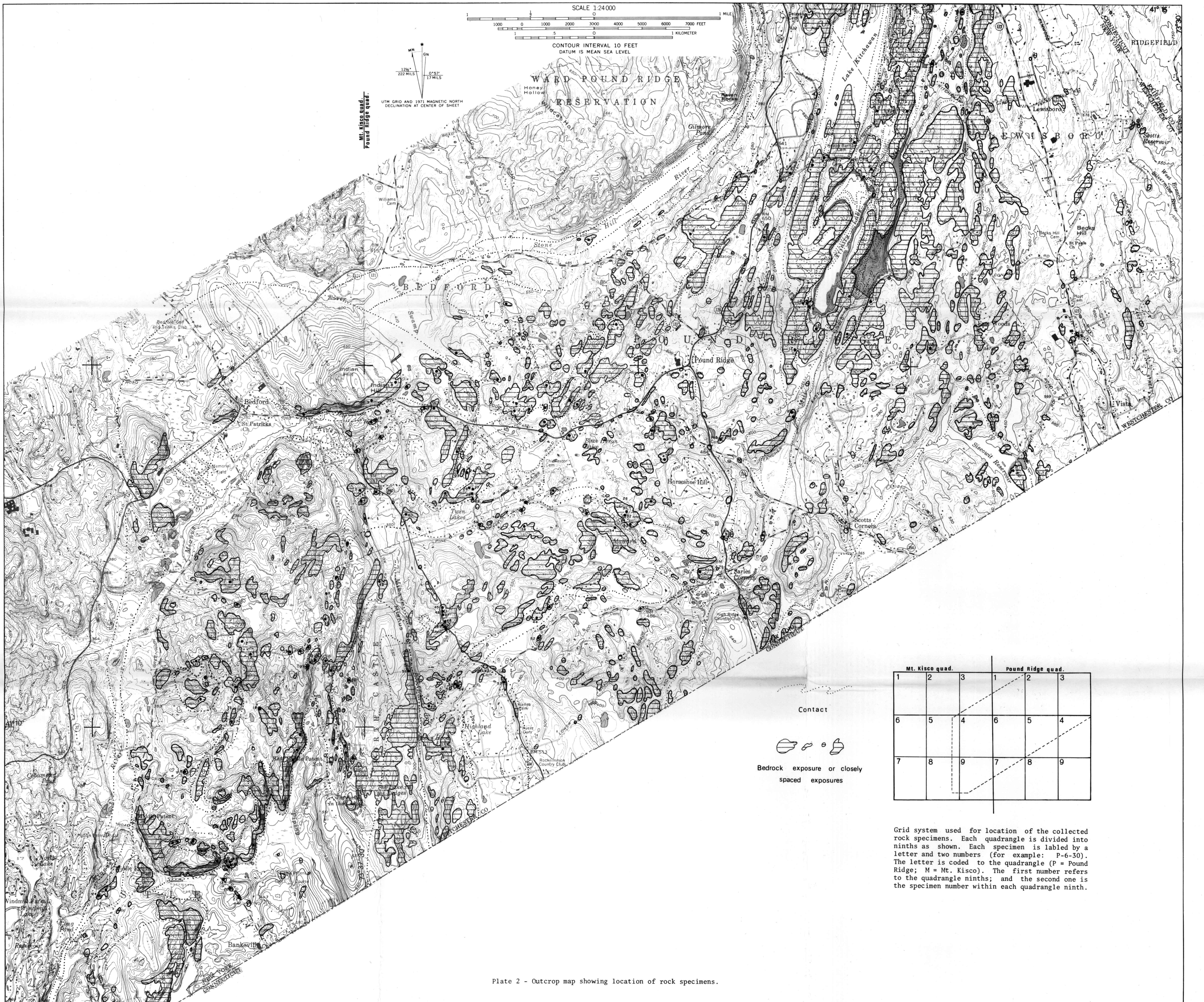
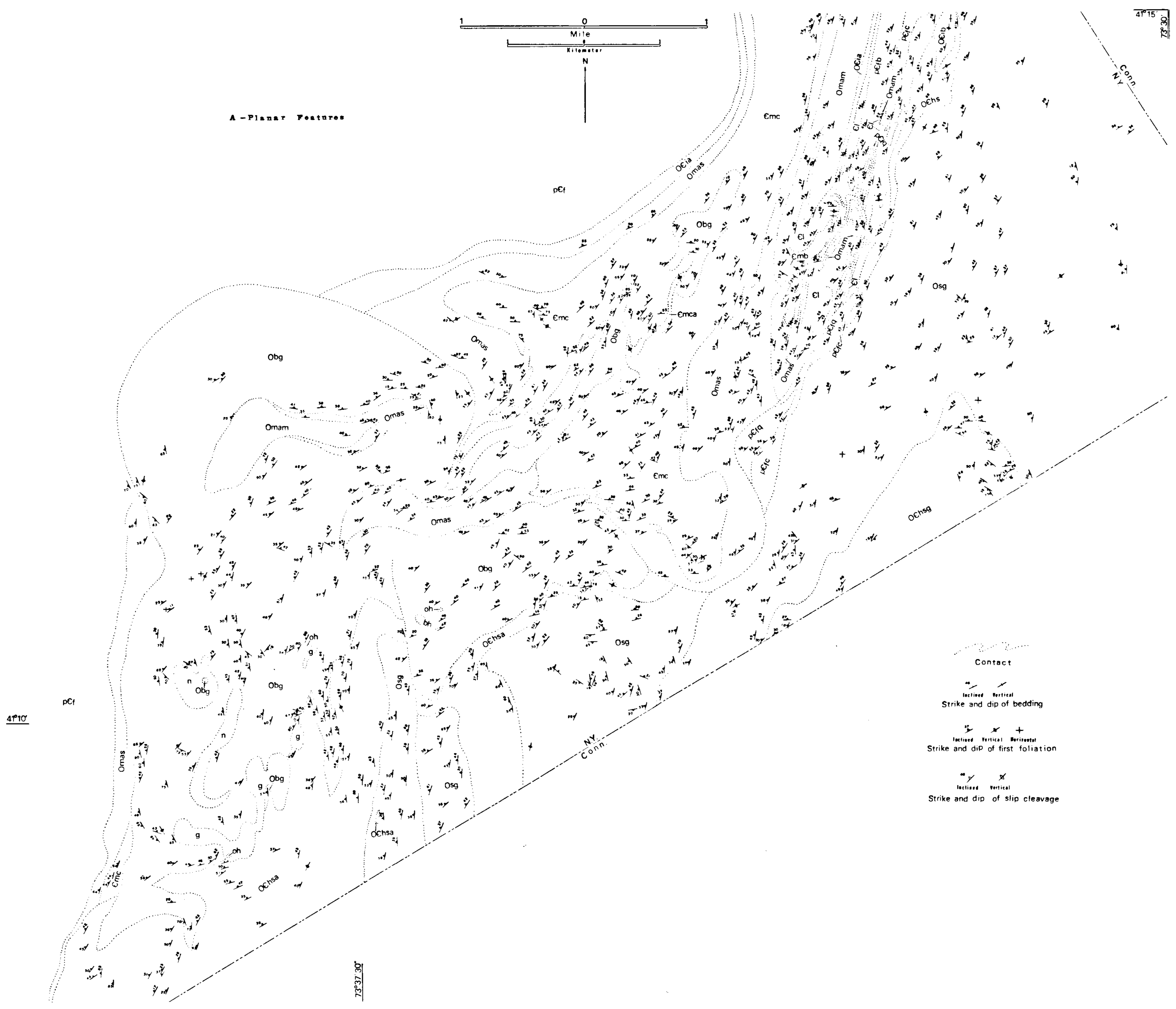


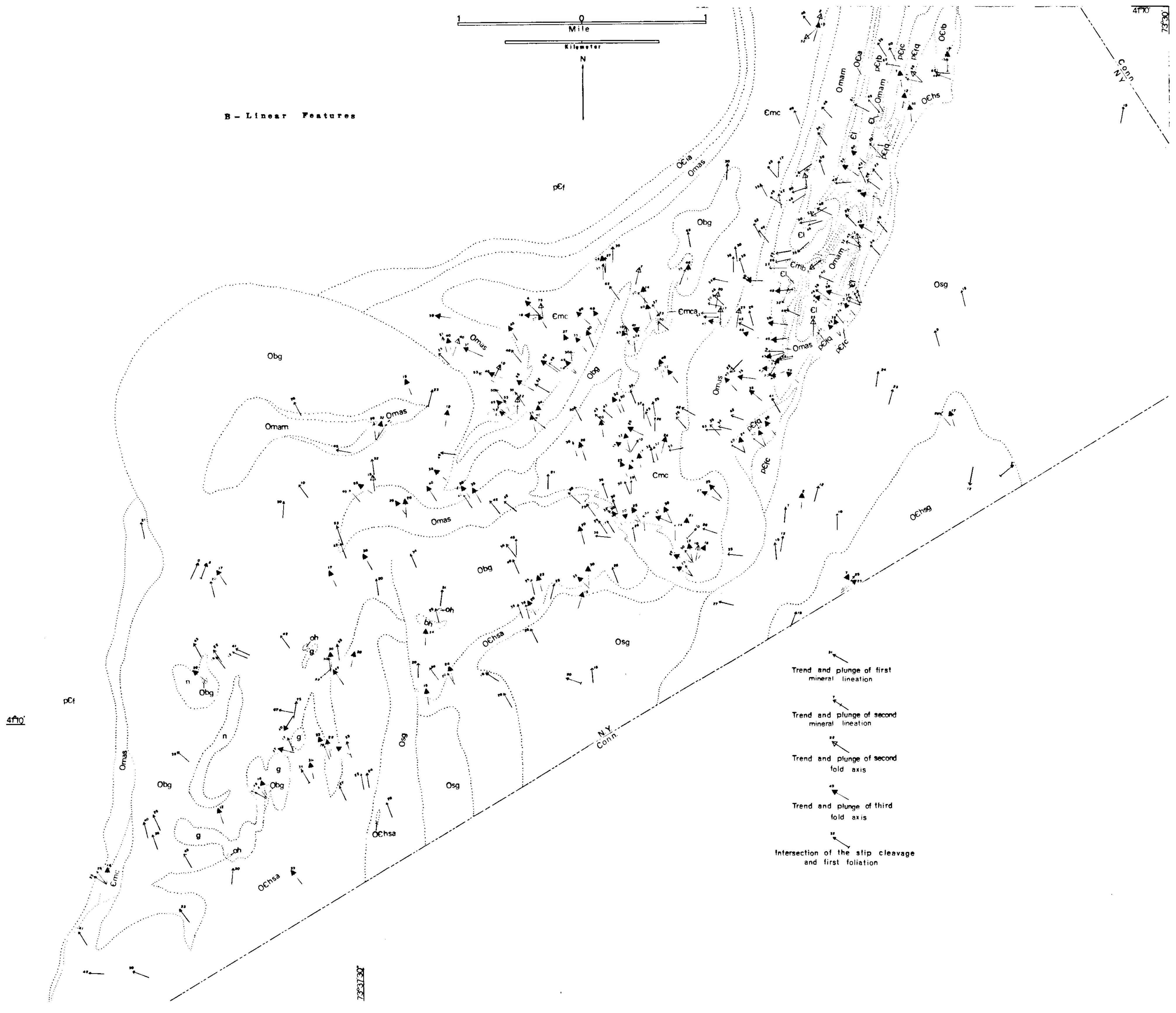
Plate 1-Geologic Map
SCALE 1:24 000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
MN
GN
12½°
222 MILS
0°57′
17 MILS
UTM GRID AND 1971 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
Symbols
Inclined
Vertical
Strike and dip of bedding
Inclined
Vertical
Horizontal
Strike and dip of foliation
Inclined
Vertical
Strike and dip of slip cleavage
Trend and plunge of mineral lineation
Trend and plunge of fold axis
Contact (dashed where approximate; dotted where inferred)
Thrust fault (Broken line where approximate; teeth on thrust plate.)
Hartland Boundary Fault
U
D
Normal Fault (U: up; D: down)
B
B′
Line of cross section
WARD POUND RIDGE RESERVATION
BEDFORD
POUND RIDGE
LEWISBORO
NORTH CASTLE
Stratigraphic Units
Cambrian–Ordovician
Manhattan A
Omas
Schist Member
Omas; dark-gray, or purple,gray-brown-weathering, fine- to coarse-grained, locally bedded, sillimanite-garnet-biotite quartz-feldspar schist which locally contains thin quartzose layers.
Omam
Marble Member
Omam; white to light-gray, gray, brown-weathering, medium grained, phlogopite-bearing, calcite marble with discontinuous layers (from 1/2 inch to 5 feet thick) of garnet-biotite schist.
Unconformity
Inwood Marble
OЄib
Member B
OЄib; light-gray, tan or light-brown-weathering medium-grained, well-bedded, dolomite marble with calcite marble intercalations.
OЄia
Member A
OЄia; white to light-gray, gray-weathering, medium-to coarse-grained commonly thickly bedded dolomite marble which locally contains gray layers (up to 1/2 inch thick) rich in serpentine.
Lowerre Quartzite
Єl
Єl; light-gray, buff-weathering, medium-grained, well-bedded feldspathic-quartzite interbedded with pure, vitreous quartzite.
Unconformity
Hartland Formation
OЄhsg
Schist and Granulite
OЄhsg; dark-gray, coarse-grained, garnet-muscovite-biotite granular schist and light-gray, coarse-grained, well-bedded, biotite-feldspar-quartz granulite interlayered with greenish-black amphibolites ranging in thickness from 1/2 inch to 20 feet.
OЄhs
Schist and Gneiss
OЄhs; gray, brown-weathering, coarse-grained, fissile, garnet-biotite schist with sparkling muscovite grains interlayered with gray, medium-grained, biotite quartz-feldspar gneiss, with lenses of amphibolite; contains very-light-gray, felsic gneiss composed of muscovite, biotite, quartz and feldspar.
OЄhsa
Schist and Amphibolite
OЄhsa; gray, brown-weathering, fine-to medium-grained fissile, sillimanite-garnet-muscovite-biotite schist and schistose gneiss interlayered with greenish-black amphibolites.
Manhattan C
Єmc
Єmca
Єmc; light-gray or gray, fine-to coarse-grained, very well-layered, highly feldspathic, muscovite-garnet-biotite gneiss or schistose gneiss interlayered with gray, commonly coarse-grained, sillimanite-garnet-muscovite-biotite schist and dark-gray or black amphibolites. Єmca; dark-gray or black, medium-grained amphibolites.
Manhattan B
Єmb
Єmb; black or greenish-black, medium-grained, hornblende amphibolite.
Precambrian
Basement Complex
pЄf
Undivided
pЄf; gray, brown-weathering, well-bedded, highly siliceous; garnet-biotite-quartz-feldspar gneiss interlayered with amphibolites; rusty-weathering sillimanite-garnet-biotite-quartz-feldspar schistose gneiss; brown-weathering calc-silicates interbedded with calcite marble; light-gray or pink, quartz-biotite-plagioclase gneiss.
Fordham Gneiss
pЄfm
pЄfm; pink, fairly homogeneous, well-foliated, medium-grained, microcline-rich gneiss.
pЄfb
pЄfb; gray, fine-to medium-grained, well-layered, siliceous, biotite-quartz-plagioclase gneiss with lenses of amphibolites.
pЄfs
pЄfs; gray, brown-weathering, well-bedded, biotite-quartz-microcline gneiss with distinctive large (upto 1/2 inch) sillimanite nodules, interbedded with light gray quartzite and tan quartzofeldspathic gneisses.
pЄfc
pЄfc; light-gray or greenish-gray, medium-grained, brown weathering, diopside-bearing calc-silicate interbedded with light-gray calcite marble.
pЄfq
pЄfq; light-gray, tan-weathering, fine-grained, biotite-plagioclase-quartz gneiss with some quartzite beds near the contact with pЄfc.
Intrusive Rocks
Ordovician
g
Gabbro and Diorite
n
Norite and Gabbro
oh
Orthopyroxene hornblendite
bh
Biotite-augite hornblendite
Bedford Complex
Bedford Augen Gneiss
Obg
Obg; an assemblage of dark-gray, fine-to medium-grained, biotite-hornblende-plagioclase gneiss with minor amounts of quartz and garnet; light gray, fine-grained, quartz-biotite-hornblende-plagioclase porphyritic gneiss with hornblende megacrysts upto 1/2 inch long; light gray, fine-to medium-grained, garnet-biotite-quartz-feldspar gneiss. Part of assemblage is distinctively porphyritic due to occurance of white and pink, euhedral microcline and plagioclase megacrysts up to 3 inches long. Inclusions of schist and granulites are present.
Precambrian
Siscowit Granitic Gneiss
?Osg
?Osg; light-gray, pink-weathering, medium-grained, muscovite-biotite-quartz-feldspar granitic gneiss, with inclusions of the Hartland Formation.
Geology by: M. Alavi, 1975

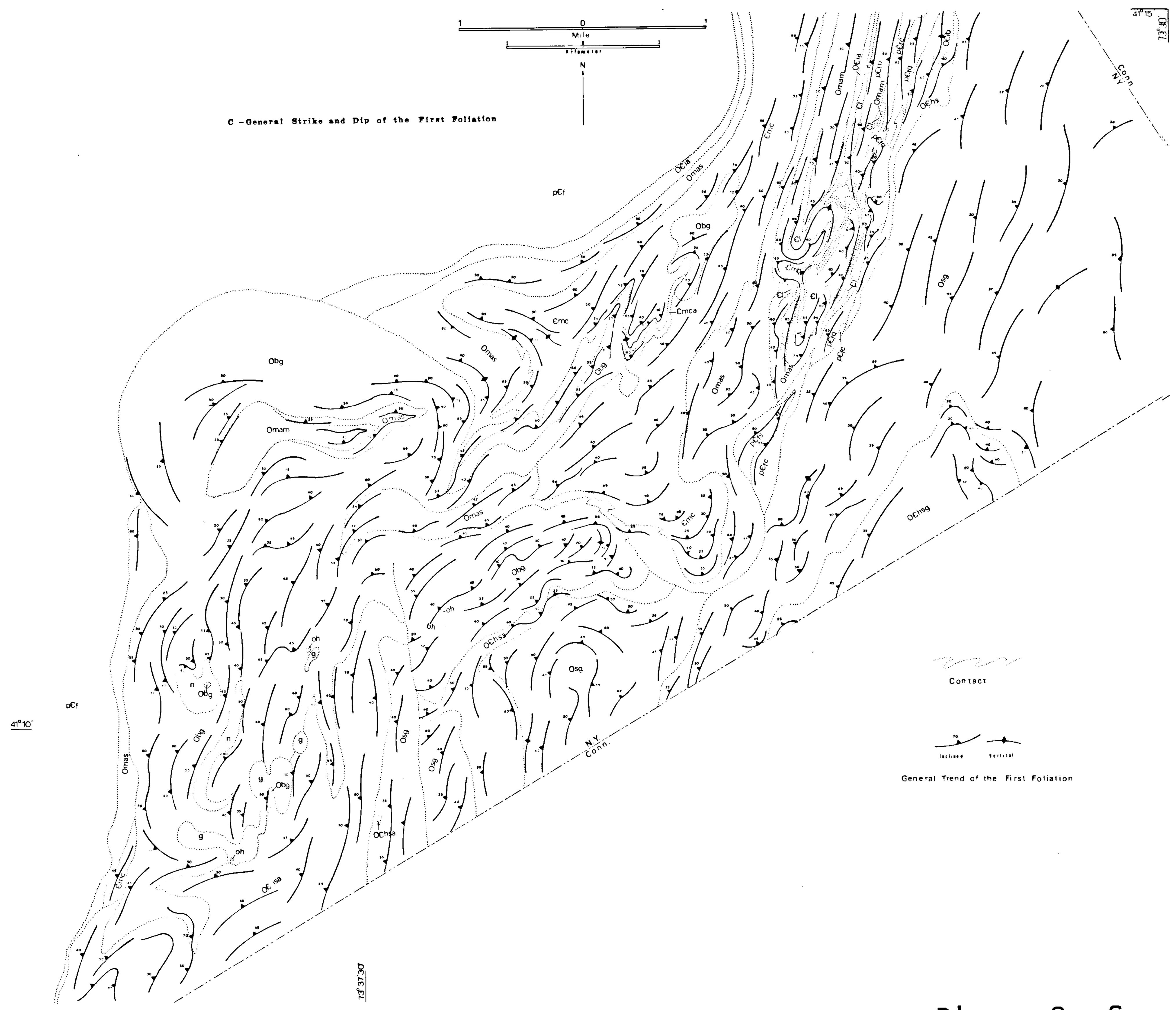


Grid system used for location of the collected rock specimens. Each quadrangle is divided into ninths as shown. Each specimen is labled by a letter and two numbers (for example: P-6-30). The letter is coded to the quadrangle (P = Pound Ridge; M = Mt. Kisco). The first number refers to the quadrangle ninths; and the second one is the specimen number within each quadrangle ninth.

Plate 2 - Outcrop map showing location of rock specimens.







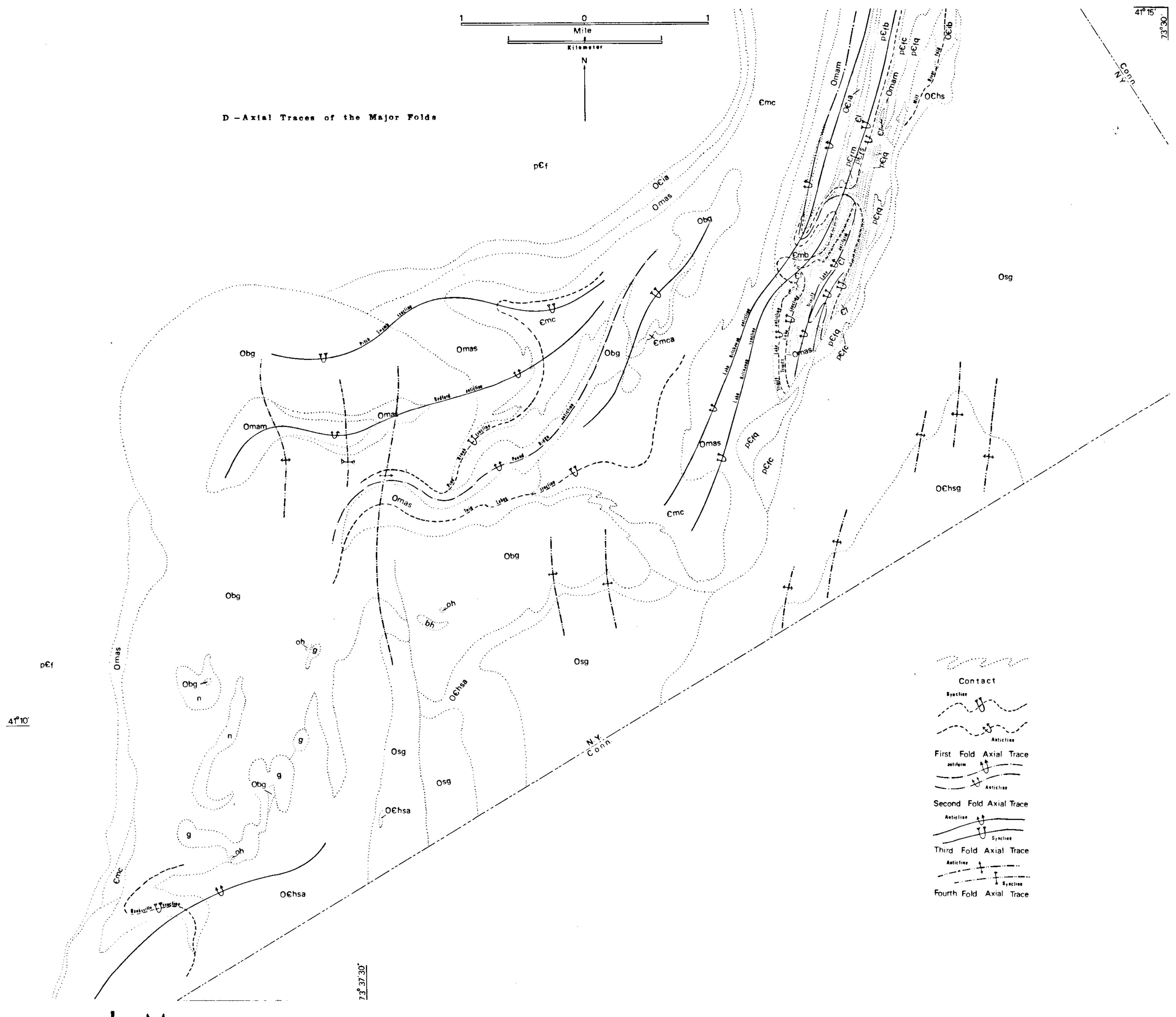


Plate 3—Structural Maps

Plate 4 – Orientation Diagrams

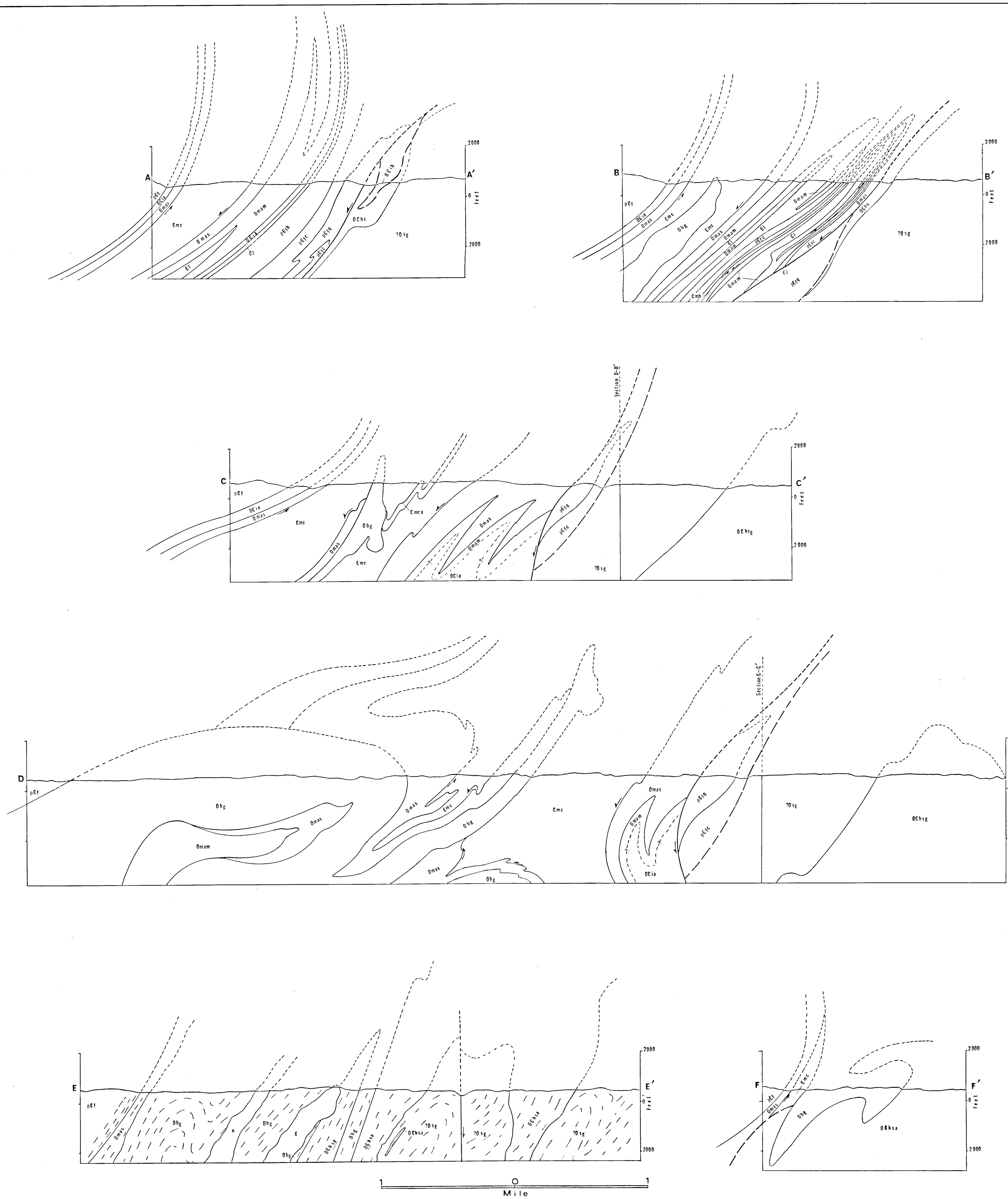


Plate 5– Structure Sections