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The Timing and Nature of the Paleozoic Deformation in the Northern part of the Manhattan Prong, Southeast New York

by

Patrick W.G.Brock and Pamela C. Brock

INTRODUCTION

The Paleozoic rocks of the northern part of the Manhattan Prong in the Croton Falls and Peach Lake map areas have been repeatedly deformed and metamorphosed. The main objectives of this field trip are 1) to demonstrate the age relationships between the deformational events, 2) to show examples of those characteristics that help distinguish each deformation and its associated metamorphism and so permit the tracing and recognition of these events in other parts of the area, 3) to point out the constraints that we have so far on the ages of the deformational events. In addition we will point out those places where we feel it necessary to reinterpret the stratigraphic relationships determined by earlier workers.

Regional Setting

The Manhattan Prong of southeastern New York and western Connecticut is underlain by polydeformed metasedimentary and metaigneous rocks of Proterozoic Y (Grenvillian) through Lower Paleozoic age. It is bounded on the north and west by the Grenvillian rocks of the Hudson Highlands, to the southwest by the Mesozoic rocks of the Newark Basin, and to the east by the Cambro-Ordovician rocks of the Hartland Terrane (see Figure 1). Early mapping carried out by Merrill (1896), Fettke (1914) and Fluhr (1950), among others, defined general structural trends as well as the three dominant units: Fordham Gneiss, Inwood Marble, and Manhattan Schist.

STRATIGRAPHY

The oldest rocks in the Manhattan Prong are the metasedimentary and metaigneous rocks of the Fordham Gneiss. Rb-Sr whole rock data indicate that at least part of the Fordham Gneiss is about 1,350 m.y. old* (Mose, 1982). Zircon studies have also suggested Proterozoic ages for parts of the Fordham (Grauert and Hall, 1973). These rocks underwent Grenvillian metamorphism, which peaked at about 1,100 m.y. (Mose, 1982) and reached at least lower granulite facies in the Fordham (Brock and Brock, 1983).

In the central Manhattan Prong, Grenvillian units of the Fordham are truncated by the Yonkers Granite Gneiss (Hall, 1980), which has yielded Rb-Sr whole-rock ages of 563±30 m.y. (Long, 1969) and 530±43 m.y. (Mose, 1981). The Yonkers Gneiss has been mapped as part of the Fordham, and is always found below the recognized Paleozoic stratigraphic units. The absence of inherited ages in its zircons suggests that it originated as an igneous body (Grauert and Hall, 1973). A similar unit, the Pound Ridge Granite Gneiss, is found in the Fordham of the northern Manhattan Prong; it has been dated at 583±19 m.y. by Mose and Hayes (1975), who suggested that both

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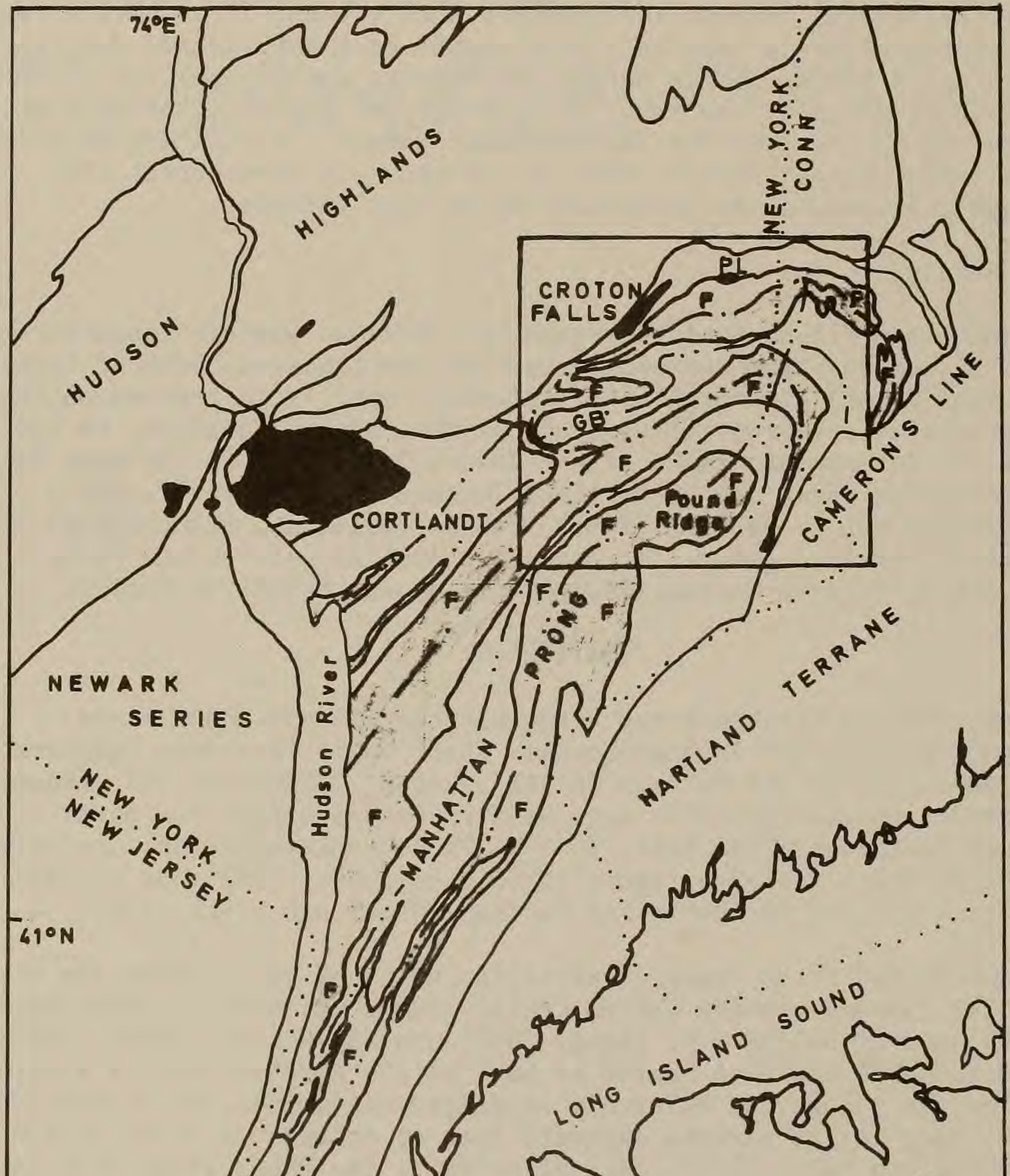
* All Rb-Sr and K-Ar ages have been recalculated using the recommended decay constants of Steiger and Jager, 1977.

FIGURE 1: Location Map showing the Manhattan Prong in relation to surrounding rocks.

Mafic complexes are shown in black. Fordham Gneiss is marked with F's.

PL = Peach Lake mafic complex. GB = Goldens Bridge.

Box encloses the area shown in more detail in figure 2.



it and the Yonkers Gneiss are best interpreted as metarhyolite bodies (an assessment we agree with). Mose, Eckelmann, and Hall (1979) subsequently favored a plutonic origin for the Yonkers on the basis of zircon morphology studies.

The stratigraphic position of the irregularly present Lowerre Quartzite, between the Fordham Gneiss and Inwood Marble, was established by Norton (1959). It has been correlated with basal sandstones of late Precambrian to early Cambrian age such as the Dalton and Poughquag Quartzites. The Inwood Marble is thought to represent carbonate bank deposition, and is correlated with the Cambro-Ordovician Stockbridge Group. The regional Mid-Ordovician unconformity that truncates the carbonate bank rocks was traced into the area by Hall (1966). Marble is found near the base of the Manhattan Schist, which overlies the unconformity; pelmatazoa from this marble, thought to be Mid-Ordovician in age, have been described by Ratcliffe (1968b) and Ratcliffe and Knowles (1969). The basal unit of the Manhattan Schist, consisting primarily of calcitic marble and sulphitic schist, has been correlated with the Mid-Ordovician Walloomsac Formation of Dutchess County and western Connecticut. Thus, the general geologic relationships found on the Lower Paleozoic platform of eastern North America are all evident in the Manhattan Prong: Grenvillian basement; late Precambrian igneous rocks; basal sandstone; carbonate bank sequence; unconformity; Mid-Ordovician calcitic carbonates; and overlying pelite (Figure 2).

Hall (1968b), making an analogy with the Taconic area to the north, proposed that the structurally higher Manhattan units ("B" and "C") were allochthonous, emplaced as early thrust slices or gravity slides. By this reasoning, Manhattan B and C should be Cambrian or older in age, and may be comparable to the Nassau Formation, the Everett Schist, and/or the Hoosac Formation. Some additional support for this point of view is derived from the Rb-Sr ages of 554± 49 m.y. yielded by upper Manhattan metasediments (Mose and Merguerian, 1985). Hall's interpretation has been adopted on the new Connecticut state map (Rodgers, 1982), where the lower Manhattan (unit "A") is shown as the Walloomsac Formation, and only the upper units ("B" and "C") are still called Manhattan Schist. In this study, the single designation Manhattan Schist has been retained because Walloomsac-type rocks have been confirmed at only a few scattered locations and we are not yet convinced of their continuity in this area. The bulk of the Manhattan Schist present here belongs to the upper (?allochthonous) unit.

Although Hall (1968b) subdivided rocks of the Fordham Gneiss into traceable map units in the Glenville and White Plains areas, we have not yet attempted to trace stratigraphy in the Precambrian except for those rocks that lie immediately below the late Precambrian "unconformity". Here, some intriguing relationships have been recognized:

1.As previously discussed, large bodies of igneous rock of very late Precambrian age are found a short distance below the "unconformity". We feel these rocks are probably metarhyolites and we have found extensive amphibolites in a similar stratigraphic position in several places.

2. A sequence of feldspathic wackes is found below Lowerre Quartzite and Inwood Marble in a number of places. These rocks show no evidence of Precambrian deformation, and, indeed, appear conformable with the overlying Paleozoic strata. In several places amphibolite (basalt flows?) is interlayered with the metasedimentary rocks.

FIGURE 2. Geologic Map of the Croton Falls and Peach Lake sheets, and adjacent areas modified from Prucha et al.,1968, Fisher et al.,1970, Alavi, 1977, and Rodgers, 1982

Explanation of Symbols

● = Stop location

x = Age determination location

DEFORMATIONAL EVENTS

7 = Zone of D_7 thrusting

6 = Zone of D_6 ductile shearing

-- v -- v -- v -- F_5 Axial Trace

— ... — ... F_3 Axial Trace

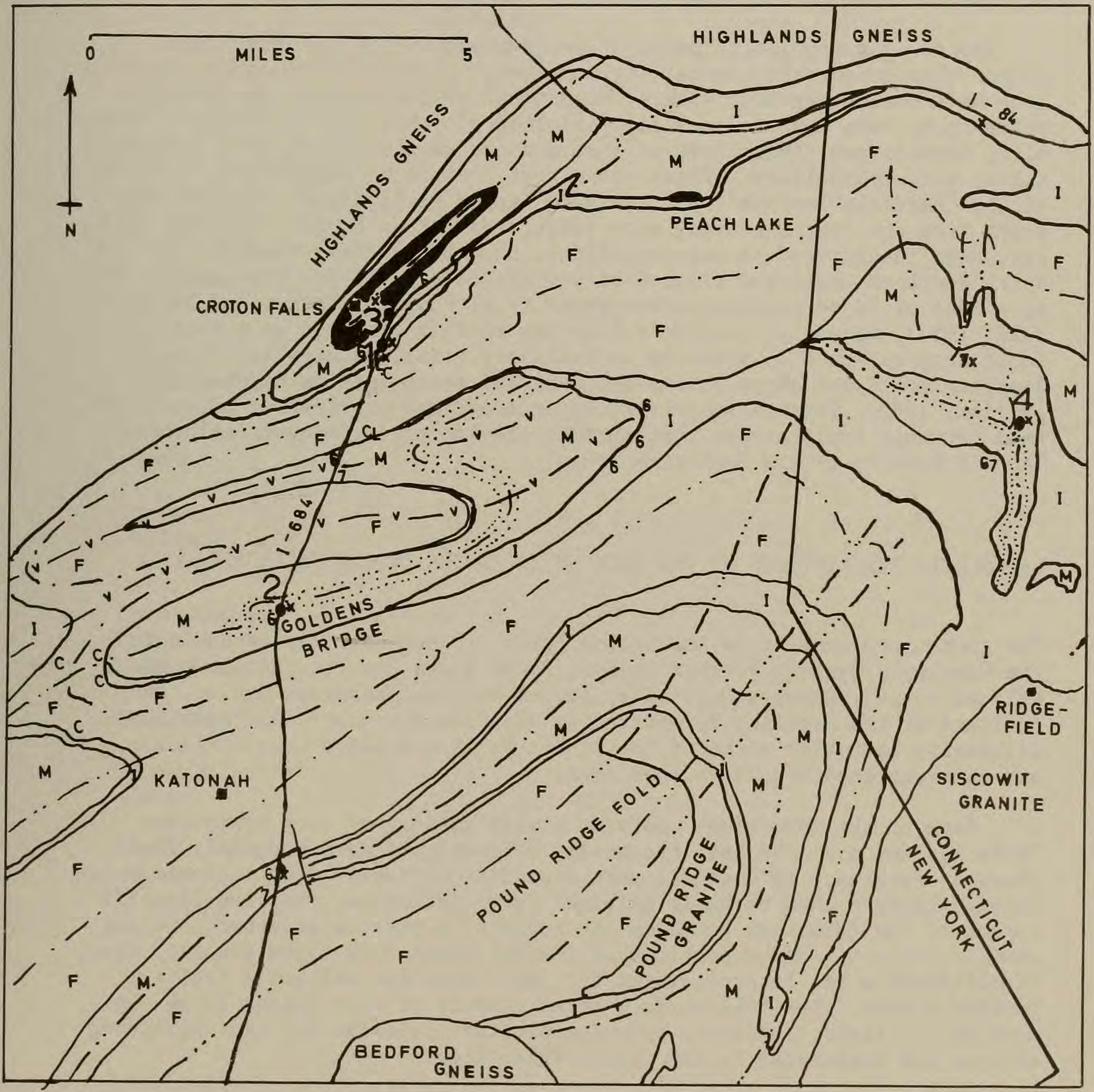
— .. — .. — F_2 Axial Trace

— . — . — F_1 Axial Trace

Note: These axial traces are derived partly from mapping, and partly from construction of cross-section of the Manhattan Prong. They are required by the cross-sections, but their geographic locations are in places only approximate.

ROCK UNITS

	Granites (Too small to show on this scale)	Devonian and Mississippian
	Croton Falls and Peach Lake Mafic Complexes	? Mid-Ordovician
....	Schematic representation of Hartland Formation along the F_2 axial trace that we think is responsible for its presence	?Cambro-Ordovician
M =	Manhattan Schist (Not subdivided)	b+c: ? Cambrian a: early Mid-Ordovician
I =	Inwood Marble	Cambro-Ordovician
L =	Lowerre Quartzite	Early Cambrian
C =	Slabby-weathering unit underlying Lowerre Quartzite	? Late Precambrian or early Cambrian
F =	Fordham Gneiss Highlands Gneiss	Grenvillian



0
MILES
5
N
HIGHLANDS GNEISS
HIGHLANDS GNEISS
I-84
PEACH LAKE
CROTON FALLS
3
I-684
2
GOLDENS BRIDGE
4
KATONAH
RIDGEFIELD
SISCOWIT GRANITE
POUND RIDGE FOLD
POUND RIDGE GRANITE
CONNECTICUT
NEW YORK
BEDFORD GNEISS
M
F
I
C
v

We believe the simplest interpretation for these rocks to be that they were deposited in a late Precambrian rift basin, perhaps before the opening of Iapetus. The association of feldspathic clastic sediments with a suite of volcanic rocks suggests a rifted margin, and has parallels in some Taconic allochthons (e.g., in the Nassau and Hoosac Formations) and elsewhere in the Taconics (e.g., in Newfoundland; Strong and Williams, 1972). Ratcliffe has found probable Catoctin age mafic dikes in the Hudson Highlands (Ratcliffe, 1983), and has recently determined that the geochemistry of the mafic volcanic rocks in the Nassau Formation suggests a continental rift environment (Ratcliffe, 1985).

Another stratigraphic "package" we have identified has structural rather than paleoenvironmental implications. Rocks of distinctive appearance have been recognized within "Manhattan" belts in three localities; these rocks form a suite including interbedded schist and granulite (resembling turbidites), thick beds of fine-grained quartzo-feldspathic metasediments, and amphibolites. These rocks bear a striking resemblance to parts of the "Hartland Terrane", and are here mapped as Hartland; they are distinct from the poorly bedded, more pelitic Manhattan Schist. Hartland rocks have been interpreted as eugeosynclinal, and the boundary between them and North American shelf and slope facies (Cameron's Line) has been interpreted as a zone of major tectonic convergence (e.g. Rodgers, Gates, and Rosenfeld, 1959). Recently, Cameron's Line has been interpreted as a ductile fault deep within a west-facing accretionary prism, along which North American shelf and slope facies and Hartland rocks were juxtaposed (Merguerian, 1983). Thus these previously unrecognized occurrences of Hartland have tectonic implications that must be considered in reconstructing the Taconic history of the Manhattan Prong.

LITHOLOGIC DESCRIPTIONS OF THE ROCK UNITS IN THE CROTON FALLS AREA

The rock units present in the Croton Falls / Peach Lake map areas include the Highlands Gneiss, Fordham Gneiss, Pound Ridge Granitic Gneiss (and related rocks), Lowerre Quartzite, Inwood Marble, Manhattan Schist, and outliers of the Hartland Formation. In addition there are intermediate to ultramafic intrusive rocks of the Croton Falls and Peach Lake Complexes, and numerous granites of various ages.

Each of the formations contains a wide variety of rock types (see Table 1), and all have been repeatedly deformed and metamorphosed. Their present appearance is commonly more dependent on their local tectonic/metamorphic history than on their original characteristics. Positive identification of the formation to which the rocks of a particular outcrop belong usually rests on the proportions of the different rock types present. Thus, identification can be problematic for small outcrops and small fault-bounded blocks. What follows is a brief summary of what appear to be the most useful field, textural, and mineralogical criteria for distinguishing between the formations in the Croton Falls area.

TABLE 1
Estimated Proportions of Various Rock Types in the Manhattan Prong

XXX = dominant   xx = major   x = minor

Rock Type	Highlands Gneiss	Fordham Gneiss	Pound Ridge Granitic Gneisses & Related Rx	Lowerre Quartzite	Inwood Marble	Manhattan Schist		Hartland Formation
						Lower unit	Upper unit	
Pelites	xx	x		x	x	XXX	XXX	xx
Wackes	x	x	x	x	x	xx	xx	xx
Quartz-free Calc-Sil	x	x			XXX	x		xx
Qtz-bearing Calc-Sil	x	x			xx	xx		xx
"Limey Sandstones"	x	x				xx		xx
Arkosic Rocks	xx	xx	xx	XXX	x	xx	xx	xx
Quartzo-Feldspathic Rocks	XXX	XXX	xx	x		x	x	xx
Intermediate Rocks and Amphibolites	xx	XXX	xx				x	xx
Mafic Rocks	xx	x	x				x	x
Ultramafic Rocks	x	x						
Granitic Rocks	x	x	x		x	x	x	x

Proterozoic Y Units (Grenvillian)

The Highlands Gneiss includes meta-igneous and meta-sedimentary rocks of various compositions that were metamorphosed under granulite facies conditions. Although they were somewhat remetamorphosed and deformed during the later Paleozoic orogenic events, they were not as modified as were the rocks of the Manhattan Prong. Many of the rocks in the Highlands are massive, relatively homogeneous, and relatively poorly foliated. Some still look recognizably igneous (for instance, some of the pyroxene-bearing granites). However, the Highlands Gneiss also includes layered quartzo-feldspathic gneisses, amphibolites, occasional small calc-silicate layers, and belts of sulfide-bearing pelitic schist.

The Fordham Gneiss is generally more distinctly layered and foliated than the Highlands Gneiss. These differences are attributed to the fact that the Fordham Gneiss has been repeatedly redeformed and remetamorphosed during the Paleozoic. Relict pods or blocks of homogeneous rocks that still retain their granulite facies assemblages are present throughout the Fordham, but they are relatively small, and cannot be traced for more than a few tens of feet. The layering in the Fordham Gneiss is commonly irregular, and in many places appears to be related to migmatization associated with the Paleozoic metamorphism: Coarse-grained quartzo-feldspathic leucosomes are separated from the neighboring hornblende-bearing gneiss by biotite-rich selvages. Where significant biotite is present, the rocks can be distinctly schistose. Layered quartzo-feldspathic gneisses predominate, but the Fordham Gneiss also includes amphibolites, pelitic and calc-silicate assemblages, and relict blocks of mafic to ultramafic rocks.

? Late Precambrian to Early Cambrian Units

The Pound Ridge Granitic Gneiss is relatively homogeneous and strongly foliated. Around its edges the rocks are migmatized (Scotford, 1956). Associated with the granitic gneiss are numerous layers of relatively fine-grained, distinctly foliated amphibolite. Other rocks that appear to lie stratigraphically below the Paleozoic metasedimentary rocks and above the Grenvillian basement include migmatized amphibolites, various quartzo-feldspathic rock types, and a few calc-silicate and slightly pelitic rocks. They differ from the underlying Fordham gneiss in their slabby fracture pattern: layers are more continuous, boundaries are straighter and, after exposure, the rocks tend to weather and break along the planar lithologic boundaries. Where the quartzo-feldspathic members have been migmatized or granitized the resultant rock is relatively homogeneous granitic gneiss (in contrast to the lit-par-lit layering that characteristically develops in the Fordham Gneiss). Migmatization of the amphibolites commonly produces a brecciated rock.

A detailed study of these rocks is being undertaken, and a more complete description of their characteristics will become available when the study has been completed. At the moment our preferred interpretation is that they and the associated Pound Ridge Granitic Gneiss represent a metasedimentary/ metavolcanic suite that underlies the Inwood Marble and unconformably overlies the Grenvillian Fordham Gneiss. Earlier workers have placed the unconformity immediately below the sporadically distributed outcrops of Lowerre Quartzite or Dalton Formation: we feel that it should be placed below the Pound Ridge Gneiss and its related rocks.

At stop #1 Lowerre Quartzite overlies the slabby-weathering unit described above. It is thin to massively bedded, and characteristically retains its fine, even grain size through all the ensuing metamorphism. It is commonly arkosic, and the feldspar is almost entirely potassic. (In contrast, feldspathic quartzites in the lower Manhattan Schist contain little if any K-feldspar. Note: this generalization is based on examination of several dozen etched and stained chips of Lowerre and Manhattan quartzites from many localities supplemented by a few thin sections.)

Cambro-Ordovician Units

The Inwood Marble consists largely of foliated, impure dolomitic marbles, with locally well-developed layering. The layers contain different proportions of the calc-silicate minerals olivine, diopside, tremolite, phlogopite, scapolite, and/or epidote.The marbles are irregularly distributed, and the thickness of the unit varies significantly. Greater than normal thickness is present on many fold noses, and the unit is completely missing along some fold limbs.

The Manhattan Schist is a composite unit: the lower part (the Walloomsac Formation) consists of interbedded sulfide-bearing pelites, fine-grained quartz-rich rocks with calc-silicate affinities, and occasional impure marble layers. The upper (probably allochthonous) unit, is more extensive, more homogeneous, less layered, and generally richer in quartz and feldspar than the lower. In many places, metamorphic segregation has produced distinct, if irregular layering in which quartzo-feldspathic leucosomes and extremely aluminous melanosomes (or "restites") have taken the place of the more homogeneous quartzo-feldspathic pelites. Scattered fine-grained amphibolites are present at or near the base of this unit.

The Hartland Formation as we see it in the Croton Falls area, consists of generally distinctly layered fine-grained quartzo-feldspathic granofelsic rocks interlayered with pelitic schists and occasional fine-grained foliated and/or lineated amphibolites. In places the interlayered granofelses and schists appear to reflect original graded bedding. Elsewhere extensive granofelses are present in which only minor intercalated pelites are present.

Intrusive Rocks of Paleozoic Age

The rocks of the Croton Falls and Peach Lake Complexes range in composition from dunite, pyroxenite, and pegmatitic hornblendite through gabbro and diorite, to perthite syenite. Intrusion of the ultramafic rocks produced emery (corundum-magnetite±garnet) assemblages in the adjacent Manhattan Schist, and in xenoliths of the schist that were incorporated into the magma.

Granites of several different ages intrude the rocks of the Manhattan Prong. The youngest ones are the easiest ones to recognize: they contain primary muscovite and/ or tourmaline, and in several places contain distinctly zoned plagioclase (An_{32} to An_{20}). They range from fine grained to pegmatitic, are generally rich in K-feldspar, and commonly produce muscovite-rich selvages in the adjacent host rocks. In many places tourmaline is present along the contacts or extending out from the contacts parallel to the older schistosity. In a number of places kyanite and staurolite concentrations or pods up to 4 inches long have formed in the host rocks and along fractures in the host rocks adjacent to the granite intrusions. Although they have been deformed in places by the latest two deformational events, they do not generally look as deformed and recrystallized as the older granites. Young granites from three localities have been dated by the Rb-Sr isochron method. They give ages of 335±13 m.y.at the Trattoria outcrop (Stop #1), 343±9 m.y.at the Goldens Bridge outcrop (Stop # 2), and 358±9 m.y.at an outcrop near Katonah (see Figure 2), (Brock *et al.*, 1985).

One set of older granites that intrudes the Croton Falls mafic rocks has been dated by the Rb-Sr isochron method at 387± 37 m.y. (Brock and Mose, 1979). These granites contain no tourmaline and no primary muscovite, contain more plagioclase, and are generally more zoned, more layered, and more foliated than the younger granites. Where the older granites intrude the emeries in the xenoliths in the Croton Falls Complex, they produce biotite-garnet selvages in contrast to the muscovite selvages produced by the younger granites in the same area.

Additional older granites are present in other parts of the area, but their age relationships are not as certain, and they have not yet been dated. Like the Croton Falls granites, they contain neither tourmaline nor primary muscovite.

Rock Compositions based on Mineral Proportions

In order to compare mineralogical characteristics of the different formations, the rocks were subdivided into compositional categories, and the mineralogy of rocks of similar composition from each formation were compared. (See Table 2.)

The compositional categories used in Tables 1 and 2 are intended to approximately follow distinctive primary compositions, but since the extensive metamorphism can have modified those compositions either by segregation, anatexis, or metasomatism, the mineralogical categories are not perfectly analogous to their original counterparts. In general, anatexis will have reduced the proportion of quartz and/or feldspar in the rocks, and the resulting "restite" will be relatively rich in garnet, sillimanite, biotite and other Fe-Mg- ±Al minerals that are not readily taken up by the granitic melt. The ultimate "restites" are the emery assemblages in the xenoliths in the Croton Falls Complex, and the garnet-sillimanite-biotite-magnetite rocks with virtually no quartz and feldspar that are found in the regionally metamorphosed pelites elsewhere in the area.

Opaque minerals are not separated on the Table 2. In most cases magnetite (or titano-magnetite) predominates, but in a number of cases reflected light shows several black opaque phases to be present together with some complex intergrowths. In the emery deposits a number of Fe-Ti oxide phases are present. These include members of the ilmenite-hematite and magnetite-ulvospinel solid solution series'. Primary pyrite is present in the sulfidic schists, and secondary pyrite is common on and alongside late fractures in many rocks.

The estimates of percentages of minerals present are based on thin sections (and some hand specimens) selected to be "representative" and to show the ranges of composition present. The percentages have been rounded because in many of these rocks percentages vary both along and across strike, and even a precise determination of mineral percentages in a particular thin section can serve as no more than a gross approximation of those in adjacent rocks.

The rules used to classify the compositional categories in thin sections are outlined below.

I Rocks Containing Alumino- Silicate Minerals

>5% Alumino-silicates = Pelite

0.1-5% Alumino-silicates = "Wacke" [Note: some of the "wackes" contain less than 30% quartz, which would be unusual in normal wackes. It is likely that some quartz was lost by anatexis, but that the low, but significant alumino-silicate content still indicates a wacke origin].

II Rocks Containing Carbonate and/or Calc-Silicate Minerals

>15% Carbonate or calc-silicate minerals:-

a. Quartz-free Marble or Calcsilicate Rock
b. Quartz-bearing Marble or Calcsilicate Rock

[The normal calc-silicate minerals in these rocks are diopside, tremolite, scapolite, phlogopite, epidote, and greater than normal amounts of sphene: chondrodite and vesuvianite are present in Fordham marbles in one locality].

0.1-15% carbonate and/or calc-silicate minerals (and usually relatively quartz-rich) = "Limey Sandstone"

III Rocks Containing Neither Alumino-Silicate nor Calc-Silicate Minerals

>30% Quartz and no alumino-silicate or calc-silicate minerals = Arkosic Rock [As in the "wackes", the relatively low silica content is attributed to segregation or anatexis].

15-30% Quartz = Quartzo-Feldspathic Rocks

a. with >5% K-Feldspar
b. with <5% K-Feldspar

5-15% Quartz = "Quartz-bearing Amphibolites and other Intermediate Rocks"
0.1-5% Quartz, and relatively sodic plagioclase ($<An_{40}$)= Amphibolites and other Intermediate Rocks

<5 % Quartz, and relatively calcic plagioclase ($>An_{40}$)= Mafic Rocks

<5% Quartz and <5% Feldspar = Ultramafic Rocks

TABLE 2
MINERAL CONTENTS OF EQUIVALENT ROCK TYPES IN THE DIFFERENT FORMATIONS IN THE CROTON FALLS AREA
(See explanatory notes at the bottom of the third page of the table)

ARKOSIC ROCKS

Formation	Quartz	K-Felds	Perth	Plag	Oliv	O-Px	C-Px	O-Amp	Cum	Hbld	Biot	Muscovite Early	?	Late	Chlor	Gar	Epi	AL	Op
Fordham n=9	30-60	0-60 0	0	15-60	0	0-15 0	0-15 0	0	0-30 0	0-15	1-30 15-30	0	0	0	0-15 0	0-15	0-15		.1-5
Highlands n=2	30-60	0-1	0	15-60	0	0	0	0	0	0-5	5-15	0	0	0	0	0-1	0-1	0-1	1-30
Hartland n=4	30-60	0-1 .1-1	0-1 0	5-60 30-60	0	0	0	0	0	0	15-30		0-15 0	0-15	0	0-5	0-15 0		.1-5 .1-1
Manhattan n=12	30-90 30-60	0	0	.1-60 15-30	0	0	0	0	0	0-15 0	5-30		0-60 0	0-30 0-5	0	0-15 5-15	0-5 0		0-15 1-5
Lowerre n=1	40	35		1							15		2	1		6			1

QUARTZO-FELDSPATHIC ROCKS WITH MORE THAN 5% K-FELDSPAR

Formation	Quartz	K-Felds	Perth	Plag	Oliv	O-Px	C-Px	O-Amp	Cum	Hbld	Biot	Muscovite Early	?	Late	Chlor	Gar	Epi	AL	Op
Fordham n=6	15-30	5-30 5-15	.1-5	5-60 30-60	0	0-15 0	0-15	0	0	.1-30 5-15	0-15 5-15		0	0-1 0			0-15 0	0-1 0	.1-5 1-5
Highlands n=7	15-30	15-60	0-5 0	5-60 15-30	0	0	0	0	0	0-15 0	.1-30 5-15		0-5 0	0-1 0			0-5 1-5	0-1 .1-1	0-5
Hartland n=1	20	35		15	0	0	0	0	0	0	15		0	0		15			.5
Manhattan n=3	15-30	5-90	0-60	1-30 15-30	0	0	0	0	0	0	0-30		0-1 .1-1	0-15	0-15 0	0-5 0			0-5 1-5

QUARTZO-FELDSPATHIC ROCKS WITH LESS THAN 5% K-FELDSPAR

Formation	Quartz	K-Felds	Perth	Plag	Oliv	O-Px	C-Px	O-Amp	Cum	Hbld	Biot	Muscovite Early	?	Late	Chlor	Gar	Epi	AL	Op
Fordham n=16	15-30	0-1 0	0-5 0	15-60	0	0-60 0-15	0-60 0-15	0	0	0-30 5-15	0-60 15-30		0	0		0-15	0-1 0		0-30 1-5
Highlands n=6	15-30	0-5 0	0	15-60 30-60	0	0	0	0	0	0-30 1-30	5-60 15-30		0	0		0-5 0	0-15		.1-5
Hartland n=3	15-30			30-70 30-60	0	0	0	0	0	0	15-30		0	0-15		0-1 0	0-5 0	0-1 .1-1	.1-5 1-5
Manhattan n=3	15-30	0	0-1 0	1-60	0	0	0	0	0	0	5-30		0	0-30 0		1-15 5-15	0	0-1 0	1-15

AMPHIBOLITES AND RELATED ROCKS WITH LESS THAN 5% QUARTZ

Formation	Quartz	K-Felds	Perth	Plag	Oliv	O-Px	C-Px	O-Amp	Cum	Hbld	Biot	Muscovite Early	?	Late	Chlor	Gar	Epi	AL	Op
Fordham n=7	0-5 1-5	0-1 0	0-5 0	5-60 30-60	0	0-15 0	0-30 0	0	0-30 0	5-90 30-90	1-30		0	0	0-5 0	0	0-1		0-5 1-5
Highlands n=6	0-5	0-5 0	0	30-90	0	0	0-30 15-30	0	0	1-60 5-30	.1-30 5-30		0	0	0	0	0-5 0		.1-5 1-5
Hartland n=2	1-5			15-60	0	0	0	0	0	30-90	1-5		0	0	0	0			1-15
Manhattan n=4	.1-5 1-5			15-30	0	0	0	0	0	0-90 60-90	.1-90		0	0	0-5	0	0-15 0		0-5 1-5

AMPHIBOLITES AND RELATED ROCKS WITH 5-15% QUARTZ

Formation	Quartz	K-Felds	Perth	Plag	Oliv	O-Px	C-Px	O-Amp	Cum	Hbld	Biot	Muscovite Early ?	Late	Chlor	Gar	Epi	AL	Op
Fordham n=16	5-15	0-30 0-1	0-15 0-5	5-60 30-60	0	0-60 5-15	0-30 5-15	0	0-15 0	0-30 1-5	1-60 15-30	0	0	0-5 0	0-15 0	0-15 0		0-5 1-5
Highlands n=4	5-15	0-30	0-30 0	5-60 30-60	0	0	0-30	0	0	0-30	.1-30	0	0		0-1 0	0-5 0	0-1 0	0-5 1-5
Hartland n=2	5-30	0	0	5-30	0	0	0	0	0	30-60	.1-1	0	0	0	0	1-15	0	.1-15
Manhattan n=5	5-15	0	0	5-30 5-15	0	0	0-15 0	0	0-15 0	0-60 0	0-30 15-30	0-15 0	0-15 0		1-15 5-15	0-1 0		1-15 1-5

MAFIC ROCKS

Formation	Quartz	K-Felds	Perth	Plag	Oliv	O-Px	C-Px	O-Amp	Cum	Hbld	Biot	Muscovite Early ?	Late	Chlor	Gar	Epi	AL	Op
Fordham n=1	0	0	0	2	0	0	0	0	0	90	5	0	0	1				2
Highlands n=8	0-5 1-5	0-5 0	0	5-60 30-60	0	0	0-60	0	0	5-90 30-60	0-30 0	0	0		0-15 0	0-1 0	0-1 0	.1-15 1-5
Hartland n=1	2	0	0	40	0	0	.5	0	0	60	0	0	0	0	.5			.5
Manhattan n=2	1-5	0	0	15-30	0	0	0	0	0	60-90	1-15	0	0	0	0			1-15

QUARTZ-FREE CARBONATE AND CALCSILICATE ROCKS

Formation	Quartz	K-Felds	Perth	Plag	Oliv	C-Px	Hbld	Biot	Musc	Chlor	Gar	Epi	AL	Scap	Carb	Sph	Op	Serp
Fordham n=1					18	15	5	2		4					45		.5	10
Hartland n=		x		x		x	x				x	x		x	x	x	x	
Irwood n=6	0	0-1 0	0	0-1 0	.1-30 .1-5	0-30 1-5	0-1 0	5-30 15-30		0-15 0		0-1 0			30-90		0-1 .1-1	1-30 5-15
Manhattan n=1	0	0	0	0	10	.5	0	10		.5					80		.5	

QUARTZ-BEARING CARBONATE AND CALC-SILICATE ROCKS

Formation	Quartz	K-Felds	Perth	Plag	Oliv	C-Px	Hbld	Biot	Musc	Chlor	Gar	Epi	AL	Scap	Carb	Sph	Op	Serp
Fordham n=2	10-40	5-25		0-10	0	10-40	2-10	0-5						0-30	.5-10	0-5	0-1	
Highlands n=2	15-30	0-30	0-5	5-30	0	15-60	1-5	0-15				0-30				1-5	.1-5	
Irwood n=4	1-15	5-90 5-15	0	0-15 5-15	0	5-30 15-30	1-15 5-15	0-15 0				0-15		0-5 0	.1-60 15-30	0-15 1-5	.1-5	
Manhattan n=10	1-30 5-30	0-30 0+10	0	5-60 5-30	0	5-60 5-30	1-30 5-15	0-30 5-15	0-1 0	0-15 0		0-15 5-15		0-30 0-15	0-15 0	.1-15 1-5	.1-15 1-5	

"LIMEY SANDSTONES"; relatively Quartz-rich rocks containing calc-silicate minerals

Formation	Quartz	K-Felds	Perth	Plag	Oliv	C-Px	Hbld	Biot	Musc	Chlor	Gar	Epi	AL	Scap	Carb	Sph	Op
Fordham n=1	25	15		15		15	3	3				15				8	.5
Highlands n=1	35	30		.5		15	15					4				3	2
Hartland n=1	30	20		20				20				7				2	.5
Manhattan n=6	5-60 15-30	0-15 0	0-1 0	15-30		0-15 5-15	.1-30 1-5	5-30 15-30			0-15 1-15	0-5 0				0-5 0	0-15 1-5

PELITES

Formation	Quartz	K-Felds	Perth	Plag	O-Amp	Biot	Muscovite			Chlor	Gar	Cord	Staur	Kyan	Sillimanite			Op
							Early	?	Late						Fib	Acic	Pris	
Fordham	5-60	0-60	0-15	1-30		5-30			0-30	0-15	5-30			0-5	1-30	.1-30	0-5	.1-5
n=7	15-30	5-15	5-15			15-30			0	0	5-15			0	5-15		1-5	1-5
Highlands	30			30		0			20					20		.5		.5
n=1																		
Hartland	.1-60		0-5	.1-30		15-60	0-30	0-30			.1-30		0-15	0	0-15	.1-5	0-5	.1-15
n=4			0			15-30	0	5-15			.1-1		0		5-15	.1-1	0	1-5
Manhattan	0-60	0-15	0-90	0-60		0-60	0-1	0-30	0-30	0-15	0-60	0-60	0-15	0-90	0-60	.1-30	0-60	0-15
n=47				.1-15		1-30	0	0	1-15		5-60	0	0	0		1-15	.1-30	1-5

MANHATTAN PELITES

Assemblage	Quartz	K-Felds	Perth	Plag	O-Amp	Biot	Muscovite			Chlor	Gar	Cord	Staur	Kyan	Sillimanite			Op
							Early	?	Late						Fib	Acic	Pris	
Cord-bearing	1-90	0-5	0-30	0-30	0-5	1-30		0	0-15	0-5	5-60	.1-60	0	0-1	0-60	1-15	0-60	.1-15
n=6	15-30	.1-1		5-15	0	5-15			1-5	0	15-30			0	5-15			1-5
Perthite-	1-60	.1-15	.1-90	.1-15	0	1-60		0	0-15	0-15	0-60		0	0-1	0-60	.1-15	0-30	0-5
bearing n=42	5-30	.1-1	5-60			15-30			1-5	0	5-60			0	.1-1	1-5	1-30	1-5
K-feldspar-	1-60	.1-15	0	1-60	0	1-60		0-30	0-15	0-15	1-30		0	0	0-15	.1-15	0-30	.1-5
sill n=15	15-60			5-30		5-30		0	5-15	0	15-30				.1-1	5-15		1-5
Kyanite-	.1-90	0-5	0-30	.1-60	0	1-30		0-1	0-30	0-1	.1-60		0	.1-90	0-15	.1-15	0-30	.1-15
bearing n=17	5-30	0	0	5-30		5-30			.1-1	0	5-15			1-15	5-15		0-5	1-5
Staurolite +	0-60	0	0	0-60	0	.1-60		0-1	0-30	0-30	0-60		.1-30	.1-90	0-15	.1-30	0-15	0-15
kyanite n=14	1+30			5-15		5-30		0	.1-1	0	15-30		5-15	5-30	.1-1	1-5	0	1-5
Staurolite	1-30	0	0	1-30	0	1-30		0-60	0-60	0-1	5-30		1-30	0	0-5	1-15	0-5	.1-5
n=6	15-30			15-30		15-30				0					0	.1-1	0	.1-1
Sill-Musc.No	1-90	0	0	1-60	0	1-60		.1-30	0-15	0	.1-15		0	0	0-15	.1-5	0-15	.1-15
ky,st,crd.n=8				15-30		15-30		5-15	0		5-15				0	.1-1	0	1-5
Sill-lateMusc	15-60	0	0	.1-30	0	5-60		0	.1-30	0-30	5-60		0	0	0-60	.1-60	0-30	.1-15
n=11	15-30			5-30		5-30				0					1-5	1-5	1-5	1-5
Sill. No Musc	1-60	0	0	0-5	0	.1-60		0	0	0	15-60		0	0	0-30	.1-60	0-60	0-5
n=4	15-30																	1-5

The upper numbers in each box show the maximum range of percentages of the minerals observed.
The lower numbers show the normal range.

Explanation of abbreviations

K-Felds = Kfeldspar; Perth = Perthite; Plag = Plagioclase; Oliv = Olivine; O-Px = Hypersthene;
C-Px = Clinopyroxene; O-Amp = Gedrite; Cum = Cummingyonite/Grunerite;
Hbld = Hornblende (including end-members Tremolite and Hastingsite); Biot = Biotite;
Muscovite: Early ? Late: : ? = uncertain age relationships, or both early and late Muscovite present;
Chlor = Chlorite; Gar = Garnet; Epi = Epidote; Al = Allanite; Scap = Scapolite; Carb = Carbonates;
Sph = Sphene; Op = Opaques; Sillimanite: Fib = Fibrous; Acic = Acicular; Pris = Prismatic
Cord = Cordierite; Staur = Staurolite; Kyan = Kyanite;

The most striking, and potentially the most useful mineralogical differences, include:-

1. The arkosic and quartzo-feldspathic rocks of the Highlands and Fordham Gneisses routinely contain hornblende and commonly clino- and orthopyroxenes. In contrast the rocks of equivalent composition in the Manhattan and Hartland Formations contain no amphiboles or pyroxenes but only biotite (±garnet). In addition these rocks in the Highlands and Fordham commonly contain more K-feldspar than their equivalents in the younger formations.

2. Amphibolites in the Highlands and Fordham Gneisses tend to be medium grained and unfoliated or only poorly foliated, and generally contain at least some surviving pyroxene. In contrast, amphibolites in the younger formations tend to be finer grained, show distinct planar and/or linear parallelism of the amphiboles, and contain no pyroxene. One exception to this generalization is an amphibolite with calc-silicate affinities in the Hartland Formation (outside the Croton Falls area) that contains diopside and epidote and is only poorly foliated.

3. The Lowerre Quartzite characteristically contains a significant amount of K-feldspar and little or no plagioclase, whereas the sandy units in the overlying Manhattan contain significant plagioclase and little or no K-feldspar.

SEQUENCE OF DEFORMATIONAL EVENTS

The sequence of events that we have worked out in the Croton Falls area is summarized in Table 3. Much of our work has been focussed on the Manhattan Schist in order to avoid the added confusion of the pre-Taconian structures.

F_1 folds are rarely preserved on outcrop scale. Where they are found they are recognized by the fact that no discernible older foliation is deformed by the folding. In these instances the axial plane foliation (S_1) is seen to correspond to the dominant schistosity or foliation in the outcrop, and we therefore assume that in most (but not all) places the dominant foliation that we see being deformed by younger events is the S_1 foliation. Because the earliest events have been overprinted by all the younger deformation and recrystallization, we cannot tell what grade of metamorphism was associated with the D_1 deformation. However, since coarse-grained quartzo-feldspathic segregations are deformed by D_2 deformation, it is clear that the grade of metamorphism was high enough for these segregations to form.

D_2 deformation also is only rarely demonstratable in outcrop. One of the clearest examples will be pointed out at stop 1. Here the D_2 is strongly cataclastic, and older coarse-grained quartzo-feldspathic segregations have been sheared into flasers. Elsewhere, isoclinal folds are present that fold the S_1 schistosity and are themselves refolded by the ubiquitous F_3 folding. The grade of metamorphism associated with this folding reached at least sillimanite grade since F_3 folds bend and break pre-existing sillimanite. In the eastern part of the Peach Lake map sheet

TABLE 3. PROVISIONAL GEOLOGIC HISTORY OF THE CROTON FALLS AREA, SOUTHEAST NEW YORK

GEOLOGIC AGE	FOLD EVENT	FORMATIONS, ROCK TYPES, ETC	META EVENT	FACIES/DISTINCTIVE ASSEMBLAGES	RADIOMETRIC AGE (in M.Y.)	COMMENTS
Mesozoic		Faulting, and some folding.				In adjacent areas
	D7	Late thrust faulting.		Muscovite	294±13 309±8	K-Ar on Biotite & Muscovite Seiderman & Brock(unpub.data
Carbonif-erous		"Latest metamorphic event."			318±6 329±13	White Plains area, Grauert and Hall, 1974 . K-Ar on Biotite. Clark and Kulp, 1968
	D6	Ductile shearing and related folding. Deforms Goldens Bridge & Katonah Gntes.	M5	Musc-Staur-Kyan-Gar(±Sill)		NNE/Mod NW. NW-side-down movement
		Goldens Bridge & Katonah Granites. Tourmalinized fractures.		Tourmaline-Musc-(+Kyanite) Chlorite-Musc-Gar(Staur)	335-358	Brock et al., 1984 + Margarite in metamorphosed emeries of the Croton Falls mafic complex. Brock & Brock 1981.
(Acadian)	F5	Close to tight folding. ?Doming. Deforms Croton Falls Granites.	M4	Musc-Kyan-Staur in west rising to Kf-Sill in E & N		Brock and Mose, 1979. + recent field work.
Devonian		Croton Falls Granite.		No Muscovite in pelitic selvages	387±34	Brock and Mose, 1979.
(Taconian2)	F4	Close reclined folds. Quartz-K-Feldspar, and Qtz-Gar-Sill segregations. Deforms F3 segregations.			442	Brock et al., 1985 (F4 segregations)
	F3	Ubiquitous tight to isoclinal folds. Axial-planar Quartz-K-Feldspar segregations. Deforms F2 flasers.	M3	K-Feldspar-Sillimanite		
Mid- to late Ordovician		Croton Falls Complex. Ultramafics + Diorite. Cortlandt Complex. Ultramafics, Norite + " .		Emery Emery	 423 430±34	Brock and Brock, 1981. Ratcliffe et al., 1982. Nd-Sm Domenick and Basu, 1981
Mid-Ordovician (Taconian1)	F2	Isoclinal folds, Cataclastic flasers, Presumed recumbent, associated with major thrusts.	M2	Sillimanite rising to Kf-Gar-Cord in E		
	F1	Isoclinal folds. Quartzo-feldspathic segregations, Porphyroblastic Garnet. Presumed recumbent, associated with thrusting/sliding.	(M1)			
Cambro-Ordovician		Manhattan Schist. Upper unit predominantly pelites and wackes, but with some amphibolites near base. Upper unit was probably tectonically emplaced early in the Taconic Orogeny			554±59	Hall, 1968. Mose & Merguerian, 1985
		Basal unit includes carbonates, limey sandstones and graphitic, sulphitic schists.				lower Middle Ordovician fossils in basal beds Ratcliffe and Knowles, 1968
		Unconformity.- - - u - - - u - - - u - - - u - - - u - - - u - - - u - -				
		Inwood Marble. Dolomitic marbles near base, becoming more calcitic near top.				
		Lowerre Quartzite. Quartzite and arkosic wackes.				
Proterozoic Z		Yonkers & Pound Ridge Granite Gneisses. and related metasdimentary and metavolcanic rocks			583±19 563±30 538±43	Mose and Hayes, 1976. Long, 1969. Mose, 1981.
		Unconformity - - - u - - - u - - - u - - - u - - - u - - - u - - - u - -				
Precambrian (Grenvillian)		Highlands & Fordham Gneisses. Two episodes of granitic intrusion.				
	F(-1) F(-2)	At least two episodes of folding and metamorphism.	M(-1) M(-2)	Hornblende Granulite? Pyroxene Granulite Hypersthene-K-Feldspar	914±31 1169±44	Helenek and Mose, 1976. Helenek and Mose, 1976. Brock and Brock, 1983.
Proterozoic Y		Deposition of sediments and volcanics.			1358	Mose, 1982

Radiometric ages are Rb-Sr isochron ages unless otherwise specified the grade was higher: the flasers include cordierite-garnet-perthite-sillimanite assemblages. Although rocks of this grade have been reported in Grenvillian metamorphism in the Highlands and Fordham Gneisses, and in Acadian metamorphism in south-central Massachusetts (Tracy and Robinson, 1980, and Robinson et al.,1982), this is the first such occurrence that we know of in Taconian metamorphism in the northern Appalachians.

On the map scale, a number of major F_1 and F_2 fold closures and associated thrusts are required in order to explain the map distribution patterns of the stratigraphic units. When we have attempted to reconstruct the geometry of the early folding of the Prong using the structural and stratigraphic constraints that we have collected both here and in other parts of the Prong, as well as those that are available in the literature, a number of solutions have always proved possible. Figures 1 and 2 show the approximate locations of the major F_1 and F_2 closures required in the reconstruction that comes closest to fitting all the facts as we know them. Because the dominant folding in the Croton Falls/Peach Lake region is moderately-plunging upright F_3 folding, a cross section through this part of the Prong looks like a slightly fore-shortened map-view of the area; for this reason, no cross section is presented here. More work is still needed to trace and delimit these early structures in detail. The apparent amplitude of these folds implies that both the F_1 and F_2 were recumbent.

D_2 flasers and associated sillimanite prisms are folded and broken by upright, tight to isoclinal F_3 folds. The latter folds are characteristically visible on outcrop scale throughout most of the western half of the map area, and are associated over almost the entire area with K-Feldspar-sillimanite grade metamorphism. Generally, the S_3 axial plane cleavage is only weakly developed. At stop 1, the F_3 folds are associated with quartz-K-feldspar segregations that are aligned approximately parallel to the axial planes of the folds. In the eastern part of the area fewer recognizable F_3 folds are present on outcrop scale, because fewer parasitic folds developed on the nose of the major F_3 fold that passes through the Pound Ridge area.

The Croton Falls mafic rocks were intruded after the D_2 deformation but before the F_3 folding: small F_3 folds can be seen folding original igneous layering in previously undeformed (unfoliated) mafic rocks. The dominant foliation in the mafic rocks is parallel to the axial planar foliation in these folds. In addition, emery assemblages that were formed in Manhattan Schist alongside and incorporated within the mafic rocks were locally remetamorphosed during the F_3 deformation prior to the emplacement of the Croton Falls granites.

The F_3 folds at Stop 1 are refolded by close, reclined F_4 folds. These folds commonly have rounded noses on the broad scale, and small-scale chevron folds in pelitic layers as they pass round the noses of the larger folds. A distinct axial plane cleavage is developed in some places, and sillimanite has grown along this cleavage as it passes through the S_3 quartz-K-feldspar segregations. The F_4 folding is relatively restricted in its distribution, and probably has less tectonic significance than any of the other deformational events. However, it is extremely useful since its associated quartz-feldspar-garnet-sillimanite segregations that cross-cut F_3 hinge surfaces, are amenable to Rb-Sr age determination analysis (See discussion of age constraints below).

S_3 foliation in the Croton Falls mafic rocks has controlled the emplacement of the Croton Falls granites that give an Rb-Sr isochron age of 387± 34 m.y. (Brock and Mose, 1979).

The F_5 fold event is complex. The Croton Falls granites are cut by S_5 cleavage, and in a few places are visibly folded by F_5 folds. Outside the Croton Falls complex the S_5 is sporadically developed in distinct zones through much of the area. In the western part of the area the S_5 is readily recognizable because it is associated with kyanite-staurolite grade metamorphism, and thus produces visible down-grading in the K-feldspar-sillimanite schists. To the north and east, however, the grade of metamorphism associated with it increases to K-feldspar-sillimanite grade, and positive identification of F_5 folds becomes more difficult. However, enough places have been found where a full sequence of events can be worked out, and it can be shown that folding of this age is present, and that it takes several different forms. In the north D_5 ductile shearing deforms $F_{2,\ 3,\ \text{and}\ ?4}$ folds, and in the east, D_5 appears to entail doming that is responsible for the inflection in the F_3 axial trace as it passes through the Pound Ridge area, and some large-scale drag folding on the limbs of the "dome" (see Figure 2).

The S_5 cleavage and all older structures are cut by tourmaline, two-mica granites and associated tourmalinized fracture surfaces, and these granites are themselves deformed by two episodes of ductile shearing, one syntectonic with the intrusion of the dikes, and the other later. The dikes are in most cases small (less than 4 feet thick) but a few irregularly-shaped bodies up to 45 feet across are also present. The tourmalinized surfaces, and the majority of the more regular dikes, strike northeast and dip moderately to the northwest, and their emplacement was largely controlled by a fracture system with this orientation. The older shear zones (D_6) have a similar orientation and the associated slip has a down-dip component, suggesting an extensional regime. The coarse-grained muscovite-kyanite-staurolite rocks that are associated with these dikes and shear zones indicate that water-rich fluids circulated along the shear zones through an otherwise dried out K-feldspar-sillimanite terrane.

The later thrusting (D_7) has similar attitudes, and in many places reuses pre-existing planes of weakness. Where they affect rocks already rehydrated during D_6 deformation, new skeletal staurolite is seen growing in the shear zone. In other cases, however, where dry rocks are deformed, textural changes (to mylonite) are striking, but the associated mineral assemblages are relatively little changed from the original, and it is not clear what pressure and temperature conditions prevailed during the deformation.

The age relationships between the deformational/metamorphic events are preserved because the later events are not evenly developed throughout the area: D_6 and D_7 in particular are developed only in restricted zones separated by large areas that show little or no evidence of young deformation. D_5 is more widespread, but even here, the normal pattern is of older K-feldspar-sillimanite assemblages surviving between the muscovite-bearing S_5 cleavage surfaces and shear zones. Other striking examples of survival of older metamorphic assemblages and their associated textures include the granulite assemblages in the Fordham Gneiss that have survived through all the Paleozoic deformation and metamorphism, and the scattered patches of emery in the Croton Falls complex that have survived with only minor modification through all the post F_2 events.

Age constraints on the timing of the deformational events are provided by a number of Rb-Sr whole rock isochron age determinations (see Figure 3). A determination on the F_4 quartz-feldspar-garnet-sillimanite segregation that crosscuts F_3 hinge surfaces gives an age of at least 442 m.y. (or 462 m.y. if one sample with very low Sr content is discarded as unreliable). This date restricts the four early deformational events to the Taconic Orogeny (Brock et al., 1985)

The D_5 is bracketed by the 387±34 m.y. Croton Falls granites (Brock and Mose, 1979) and the 335 to 358 m.y. two-mica granites (Brock et al., 1985). Even though the error bars on the Croton Falls granite age are large, the D_5 is restricted to Devonian age.

The the two-mica granites appear to have been intruded during the D_6 deformation: the D_6 fracture surfaces control the emplacement of the two-mica granites and D_6 fabrics are locally developed within in them. The D_6 deformation therefore extends into the Mississippian. The D_7 is clearly younger: it deforms the granites, breaks and bends the associated tourmaline and makes flasers of the kyanite pods. K-Ar age determinations on biotite carried out by Kulp and Long from a zone that we map as a D_6 gives an age of 329±13 m.y., and preliminary analyses by Seidermann and Brock on biotite from two D_7 shear zones give ages of 309±8 and 294±13 m.y.(2 sigma) We hope to get more K-Ar ages from biotites from the shear zones in the near future.

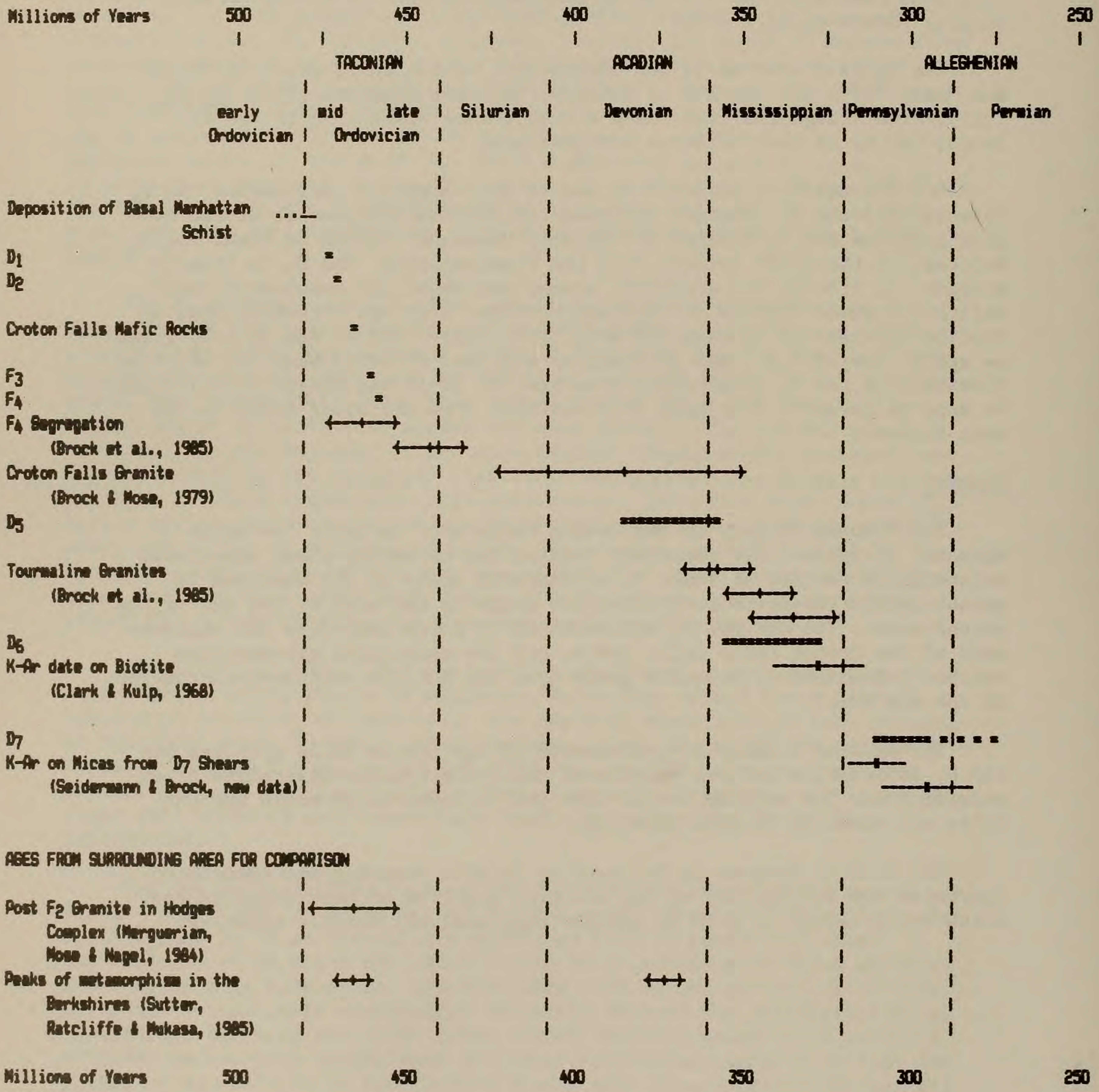
Summary

The Taconic Orogeny in the Croton Falls area includes two early episodes of large-scale recumbent folding and thrusting whose associated metamorphism reached at least to sillimanite grade in the west and to garnet-cordierite-perthite-sillimanite grade in the east by the end of the second event. The upright F_3 and reclined F_4 folds post-date the emplacement of the Croton Falls mafic rocks, and the associated metamorphism reached K-feldspar-sillimanite grade over all but the southwestern quarter of the map area.

The Acadian Orogeny is represented by the Croton Falls granites and the D_5 deformation and its associated muscovite-kyanite-staurolite grade metamorphism. The deformation of this age includes large-scale upright folds and zones of ductile shearing.

The Acadian Orogeny is followed by ductile shearing and associated intrusion and deformation of the two-mica granites of Mississippian age, which are followed in turn by younger compressional ductile shearing.

FIGURE 3. AGE CONSTRAINTS ON THE DEFORMATIONAL EVENTS IN THE CROTON FALLS AREA



ROADLOG

Miles from start	Miles from previous point	Remarks
0	0	Kline Geological Laboratory, New Haven
2.3	2.3	Through New Haven following road signs onto route 34
10.0	7.7	Pass through Shelton
22.9	12.9	Turn West on I-684 (towards Danbury & New York)
39.7	16.8	Connecticut-New York Border
41.6	1.9	Outcrop on right of Manhattan Schist with D_5 ductile shear
42.2	0.6	Exit 20. Turn south onto I-684 (towards White Plains & New York)
45.2	3.0	Croton Falls Complex makes up the ridge to the right
	0	Inwood Marble crops out in roadcut on right
46.9	1.7	Turn off on Exit 8. (Hardscrabble Road & Croton Falls)
47.1	0.2	Turn left from exit ramp onto Hardscrabble Road
47.3	0.2	Turn left onto Route 22 south
48.0	0.7	Underpass; route 22 passes under I-684
48.1	0.1	STOP 1. Park beside road just to the east of the underpass.

Stop 1: Climb up on the east side of the I-684 overpass on the north side of route 22. Walk north parallel to I-684 behind the crash-barrier to the first place you can readily climb up on top of the outcrop. Most features we want to see can be adequately seen from the top, and the troopers (and we) are worried about the distracting effects on the drivers in the heavy traffic on the highway of crowds of people at ground level.

Stop 1 encompasses over half a mile of road cuts (see Figure 4) that contain most of the stratigraphic units of the area, and many of the structural relationships we wish to show you. We will be here for several hours.

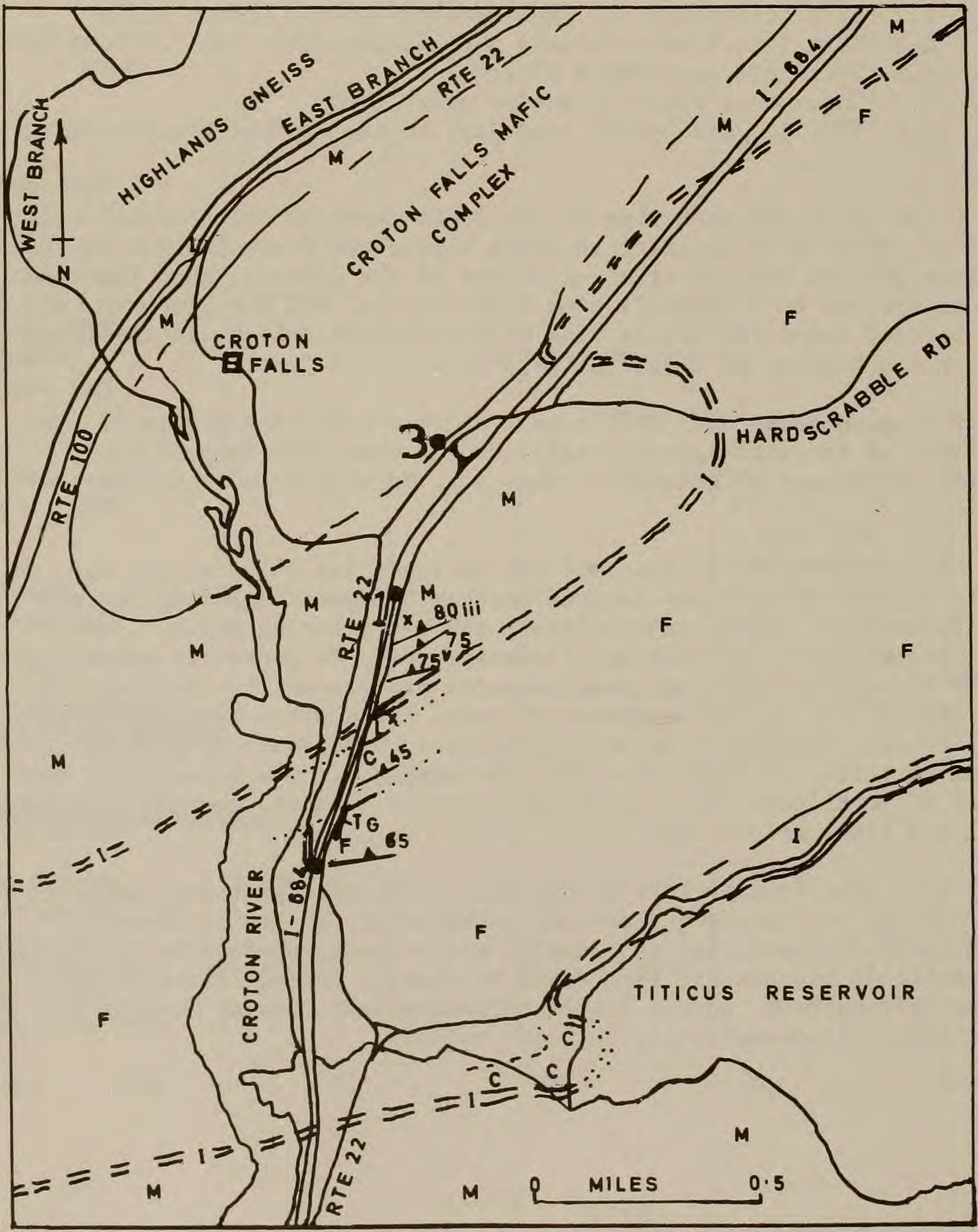
At the southern end of the road cut is a granite of uncertain age. To the north of this granite are layered Fordham Gneisses including various quartzo-feldspathic types, amphibolites, rusty-weathering pelites, calc-silicate assemblages, and pods of ultramafic rock. No granulite assemblages have been recognized here, but good examples are present in this belt of Fordham half a mile to the southwest of here. The quartzo-feldspathic rocks commonly contain hornblende as well as biotite. K-feldspar is present in many, and perthitic feldspar in a few. The amphibolites are generally made up mostly of hornblende and plagioclase, with or without some clinopyroxene relicts, and with various amounts of biotite,

Pelitic rocks in this belt of Fordham to the northeast and southwest of the road cut are coarse-grained and garnet-rich. To the northeast perthite (or K-feldspar) and sillimanite are present, whereas to the southwest, kyanite is present and K-feldspar is absent. Calc-silicate assemblages in this outcrop contain little carbonate, and consist largely of clinopyroxene, clino-amphibole, and some epidote.

FIGURE 4. Geologic map of the area surrounding Stops 1 and 3, modified from the maps of Prucha et al.,1968, and Sneider, 1969.

Explanation of Symbols o = Stop location x = Age determination location
TG = Two-mica granite ± Tourmaline
M = Manhattan Schist
== == == I == = Inwood Marble (Shown schematically: it is rarely more than a few tens of feet thick)
L = Lowerre Quartzite
C = Slabby-weathering unit underlying Lowerre Quartzite
F = Fordham Gneiss

Attitudes shown are of the dominant foliation (generally parallel to S_1), except where they are accompanied by small Roman numerals indicating the deformational event represented.



Layering is steep. and the most conspicuous upright folds are presumably of Taconian age. (No direct evidence of their age has been found here.)

The northern end of this segment of the road cut is a large two-mica granite.

To the north of the granite, after 30 feet without exposure, is the start of the (?) late Precambrian slabby-weathering unit. It consists of interlayered quartzo-feldspathic gneisses, schistose gneisses, migmatized gneisses, and fine-grained, lineated amphibolites. In some of the fine-grained migmatitic layers the dominant mafic mineral is a blue-green hastingsitic amphibole. In a few places the quartzo-feldspathic rocks are finer-grained than normal, and resemble arkosic quartzites.

The contact between these rocks and the overlying Lowerre Quartzite is sharp; being marked by a change from migmatitic gneissose rock to a fine-grained, rusty-weathering arkosic quartzite. To the north the quartzite becomes more impure, and more schistose.

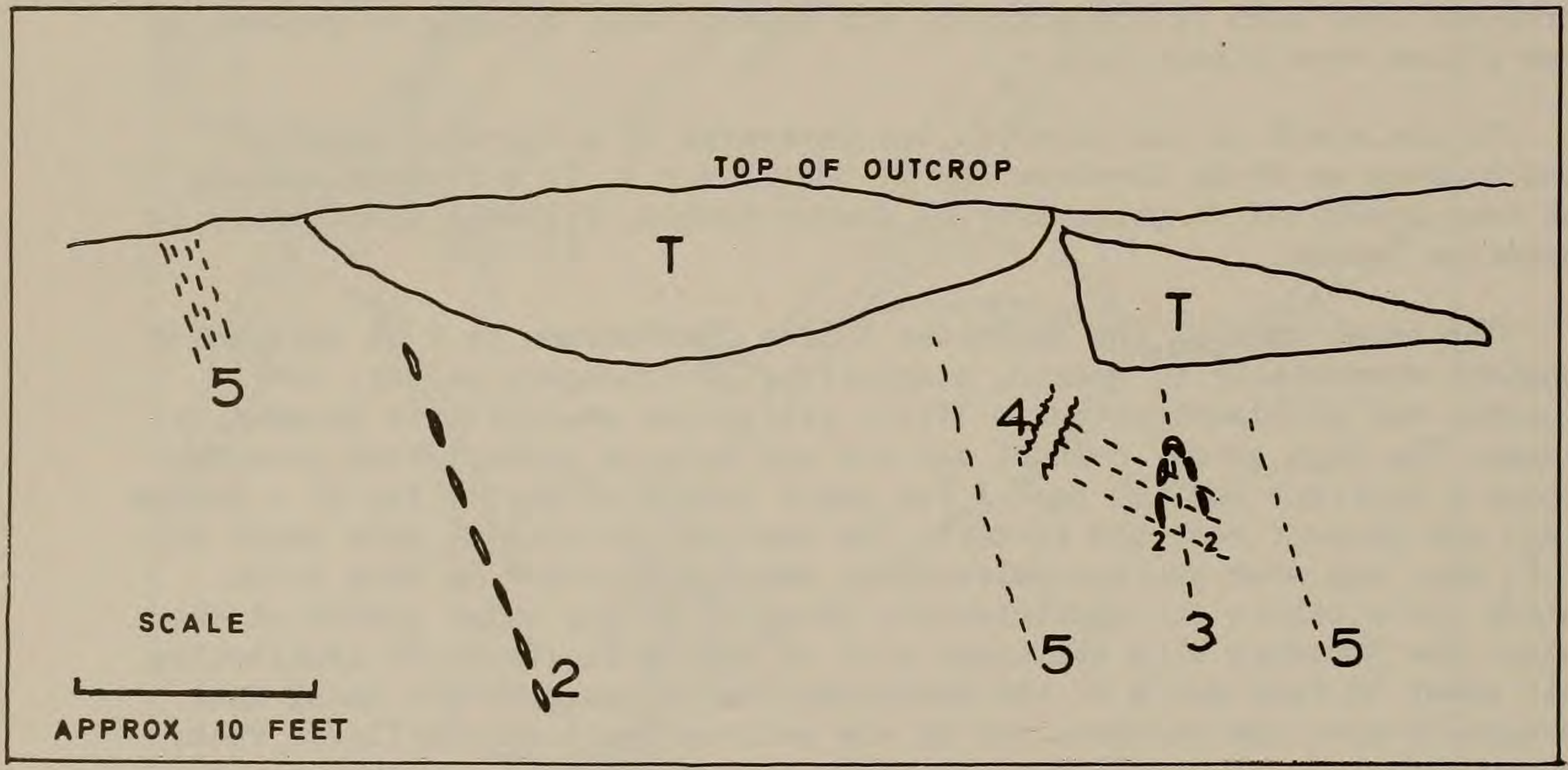
Hinge surfaces and the layering and bedding on the long limbs in the slabby-weathering unit and the Lowerre Quartzite dip moderately to the northwest over much of the outcrop, but considerable folding is present in some places (see Figure 6a).

To the north of the Lowerre, but separated by a two-mica granite (which gives an Rb-Sr isochron age of 335±13 m.y.), is a 10-foot outcrop (at road-level) of diopside-bearing Inwood Marble, followed immediately by Manhattan Schist.

The basal unit of the Manhattan Schist (Walloomsac Fm.) at this point consists essentially of quartz, plagioclase, K-feldspar, garnet, red biotite, and sillimanite, but a little retrograde muscovite is present in places. The high garnet content and the red biotite between them give the schist a distinct reddish hue. A few small layers of marble (up to 4 inches wide) are present near the contact. The dominant folding at this point is of F_3 age, and some quartzo-feldspathic segregations can be seen to be folded while others are approximately parallel to the axial planes of the folds. The boundary with the upper unit is placed at the first amphibolite unit about 50 feet north of the Manhattan-Inwood contact. The basal unit re-appears near the northern end of the outcrop where calc-silicate rocks are present.

Approximately 100 feet north of the contact, and about two thirds of the way up the face of the road cut, is a small area where S_1, D_2, F_3, F_4, S_5, and the post-D_5 tourmalinized surfaces are all seen together (see Figure 5). A large tourmalinized surface makes up the top of the road cut, and below it, near its northern end, a zone of D_2 flasers runs down the face of the cut. The zone is 1 to 2 feet wide, and is bounded along part of its south side by a younger quartz-K-feldspar segregation. The flasers consist mostly of schist, but some are quartzo-feldspathic and some consist largely of porphyroblastic plagioclase. A few consist of an intergrowth of coarse-grained quartz and plagioclase that is taken to be an earlier (S_1) segregation. Twenty feet to the south of this D_2 flasered zone is another

FIGURE 5. Schematic, oblique view of the face of the roadcut at stop 1 showing the geographic relationships between the D_2 flasered zone, the folded D_2 flasers, and the Tourmalinized joints.



Explanation of Symbols

2 = D_2 flasered zone
3 = F_3 fold deforming D_2 flasers. S_3 quartz-K-feldspar segregations aligned approximately parallel to the F_3 hinge surface.
4 = F_4 chevron folds. S_4 cleavage cuts across the F_3 hinge surface.
5 = S_5 muscovite cleavage.
6 = fracture surface with tourmaline rosettes up to 18 inches in diameter.

similar one that is isoclinally folded by an F_3 fold. The flasers are clearly visible where they bend around the F_3 hinge surface. K-feldspar-rich segregations cut through the fold in approximately the F_3 axial-planar orientation. S_4 cleavage is faintly visible here cutting across the F_3 hinge surface, and is more clearly visible a few feet to the north where F_4 crinkle folds have formed in the more biotite-rich layers. D_2 sillimanite is bent and broken by F_3 folding; F_3 sillimanite co-exists with K-feldspar; and S_4 sillimanite cuts across K-feldspar of the D_3 segregations. No primary muscovite is present in these rocks, but young muscovite is present a) on zones of S_5 granulation, b) on and adjacent to the tourmalinized surfaces, and c) in some randomly distributed spots where later circulating fluids were able to penetrate.

The S_5 cleavage is oriented approximately parallel to the S_3 (and S_1) foliations and as a result is difficult to detect in many places. One clear zone is present at the top of the roadcut about 15 feet north of the northern end of the big tourmalinized surface, and another (containing staurolite) is present 50 feet further to the north. Less conspicuous zones are present near the folded D_2 flasers. Here, individual S_5 surfaces containing granulated quartz and feldspar and fine-grained muscovite, cut through coarser (ungranulated) schists that contain K-feldspar and sillimanite and no muscovite.

The D_6-related tourmalinized surfaces cut across all the older structures. They are extensive, traceable fractures that maintain their orientation over much of the Croton Falls map sheet. On the large exposed surface at the top of the roadcut (Figure 5) tourmaline has grown into rosettes up to 18 inches in diameter that appear to be completely undeformed. Some tourmalinized surfaces have abundant muscovite on them; others (for example low on the roadcut about 70 feet north of the D_2 flasered zone) have up to an inch of feldspar with minor quartz emplaced along them; and in one case (in the Croton Falls complex) tourmaline and kyanite have crystallized together on one of the surfaces. Two hundred feet to the northwest of here (Figure 5), in the roadcut on Route 22, two-mica granites are intruded along these surfaces.

From this point northwards, the Manhattan Schist is relatively unremarkable until, near the northern end of the roadcut, considerable segregation and granitization has taken place. Here the less-modified host rocks consist largely of quartz-K-feldspar-plagioclase-sillimanite-biotite-garnet schists with minor interlayered calc-silicate rocks and amphibolites. A large, irregularly-shaped segregation cuts across the layering and across the F_3 hinge surfaces. The segregation varies considerably in composition from one place to another. In some places it consists of quartz, K-feldspar, and plagioclase, with minor garnet, biotite, sillimanite and graphite; whereas in others the feldspar content is negligible, and the rock consists almost entirely of quartz, garnet, and sillimanite. Where this rock is cut by S_5 cleavage, kyanite is seen overgrowing two ages of older sillimanite (see illustration in Brock and Mose, 1979). A suite of seven specimens from this segregation gave an Rb-Sr isochron age of 442 m.y.,(or 462 my. if one sample with extremely low Sr content is discarded as unreliable) (Brock, Brueckner and Brock, 1984).

		Continue south on Route 22
48.4	0.3	Junction with Route 116. Continue south on Route 22
51.0	2.6	Turn left on Route 138.
51.1	0.1	Turn right into supermarket parking lot. Park near the southern end of the parking lot. Stop 2.

STOP 2

The outcrop at this stop extends from the southern end of the parking lot, north to the northeastern end of the shopping center. The outcrop consists of fine-grained gronofelsic quartzo-feldspathic rocks interlayered with thin schists and scattered thicker layers of fine-grained, lineated amphibolites. All these rocks have been repeatedly refolded and then cross-cut by two-mica granites. This suite of rocks is distinctly different to the normal Manhattan Schist, and we interpret it to be part of the Hartland Formation emplaced along the hinge zone of a major F_2 fold.

Most of the schists and granofelsic rocks are devoid of alumino-silicate minerals, and many have only limited amounts of garnet and muscovite. The absence of even relict alumino-silicate minerals leaves us uncertain about the maximum grade of metamorphism reached. Near the northern end of the main exposure, a small layer of quartz-plagioclase-muscovite-biotite-garnet-staurolite schist is present, but since this rock occurs in a zone that appears to have been significantly deformed and hydrated during D_6 deformation, it only indicates the grade associated with the D_6 rather than the maximum grade attained.

The granites range from relatively fine-grained unfoliated dikes with sharp boundaries, slightly chilled edges, and zoned plagioclase grains, to coarser-grained to pegmatitic rocks with or without swirling flow foliation and with or without a later tectonic mineral alignment imposed. These granites give an Rb-Sr isochron age of 345±9 m.y. (Brock *et al*.. 1985).

At the southern end of the rock-cut beside the parking lot, shallow-dipping two-mica pegmatitic granites cut across the host schists. The granites have been slightly deformed, and a rough fracture cleavage is locally developed. Near the center of the cut beside the parking lot, the granite is finer-grained and is locally distinctly foliated. Several small apophyses of this granite and others in this outcrop can be seen to be folded, and in these cases it can be seen that the mineral parallelism in the granite cuts across the contacts and is parallel to the axial planes of the folds. Pre-D_6 structures in this outcrop are anomalously oriented and appear to show varying degrees of rotation due to D_6 deformation. Although shear-related fabrics are only sporadically developed, rotation of up to 60° appears to be present in the host rocks. Where a set of folds of the same age could be identified and the variation in attitudes due to heterogeneous D_6 shearing recorded, a moderate northwest-plunging D_6 slip line has been derived (see Figure 6b). The sense of rotation indicates normal movement. The slip line is parallel to the aligned tourmaline commonly found in D_6 zones throughout the area. The granites in this outcrop are little deformed, but similar (Mississippian) granites elsewhere sometimes show well-developed c-s fabrics reflecting normal shear sense.

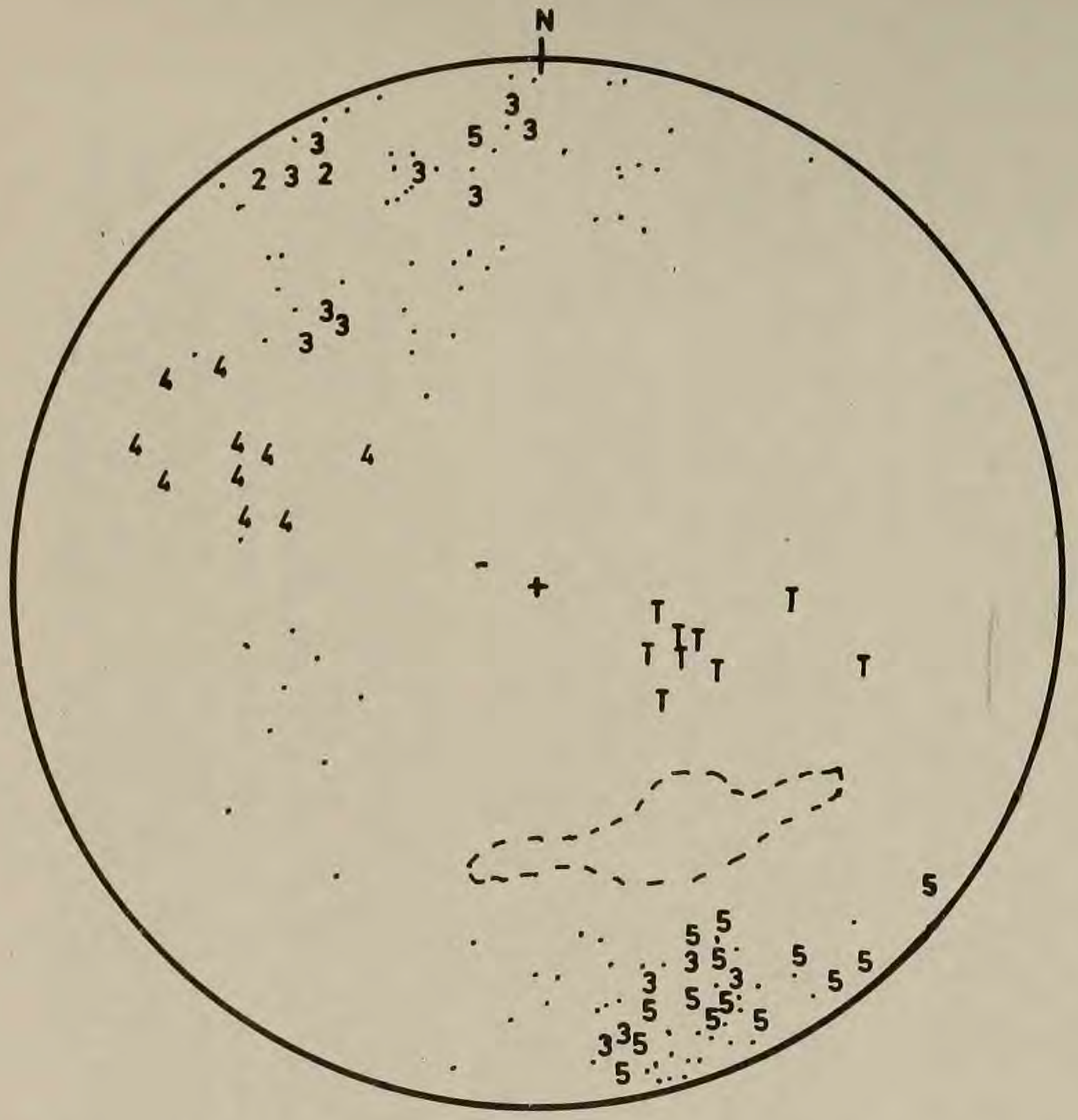


FIGURE 6a. (left) Equal area net showing orientations of S-surfaces in the post-Fordham units at Stop # 1.

Explanation of symbols

i. S-surfaces in the Manhattan Schist

• = Pole to S_1. 2 = Pole to S_2.
3 = Pole to S_3. 4 = Pole to S_4.
5 = Pole to S_5. T = Tourmalinized Fracture Surface.

ii. Area outlined with dashes encloses poles to S_1 and S_3 surfaces in the Lowerre Quartzite and in the underlying slabby-weathering unit.

iii. The S-surfaces in the Fordham Gneiss overlap with the dominant cluster of the Manhattan S_3 and S_5 cleavages and cannot be plotted without unduly cluttering the diagram.

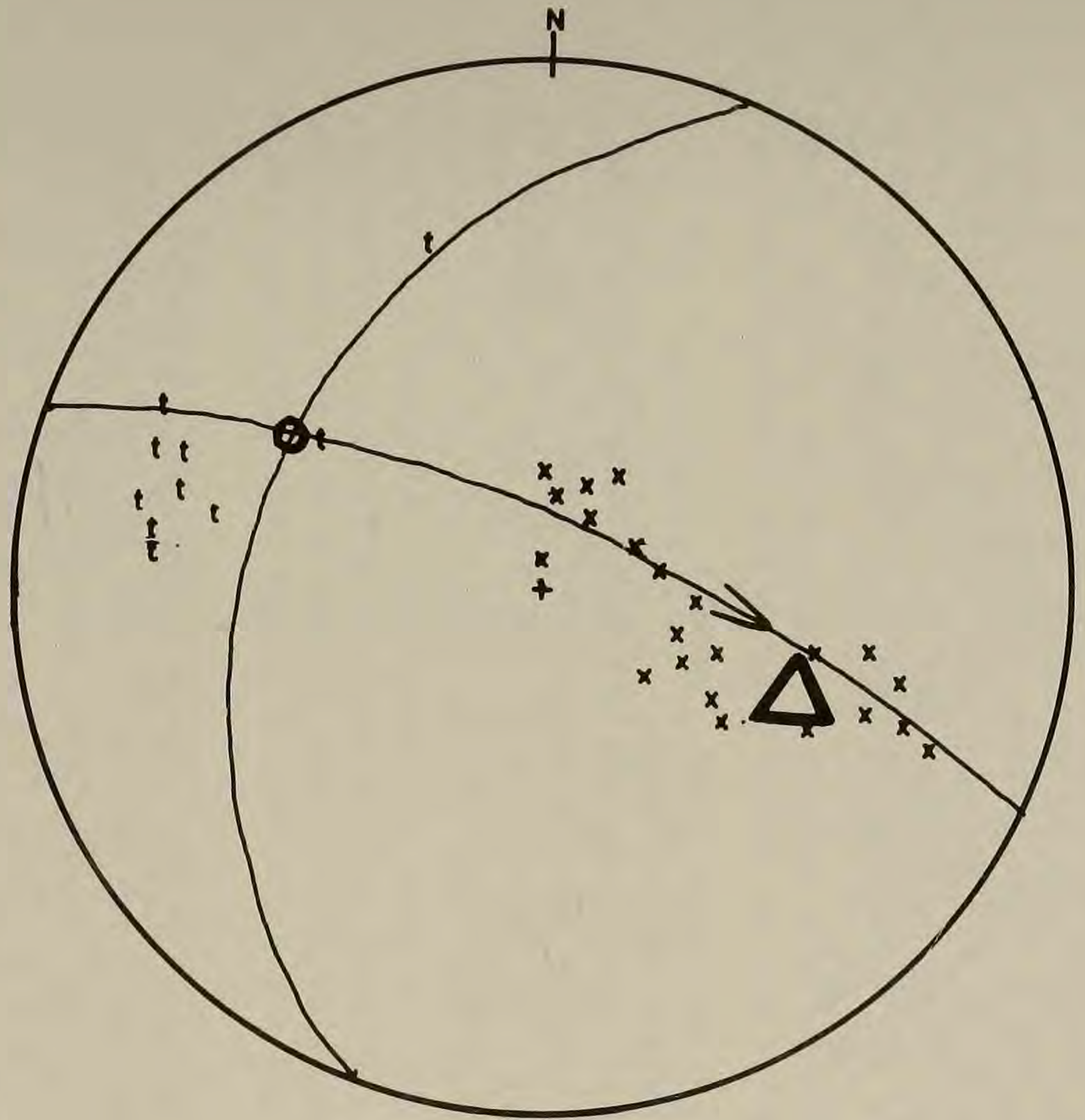


FIGURE 6b. (right) Equal area net showing the rotation of F_3 hinge lines by D_6 in the Goldens Bridge outcrop (Stop 2)

Explanation of Symbols

x = Hinge line to F_3 fold

Triangle = S_6 shear zone boundary derived from average of slip cleavages

O = D_6 slip line

t = Tourmaline lineations in this and other outcrops

Tourmaline is present within some of the granites, concentrated along the contacts of others, and as rosettes on some appropriately oriented fracture surfaces.

The identification of the fold events present in this outcrop is still uncertain for a number of reasons: the lack of evidence of difference of grades of metamorphism associated with the obvious sequence of fold events; the rotation of all axial surfaces to strike southeast making it difficult to connect with structures in surrounding areas; and the lack of older segregations or granitic markers all leave us without a strong basis for correlating from this outcrop to others.

		Return to Route 22 and turn right (north)
54.9	3.8	Bear right onto Hardscrabble Road
55.1	0.2	Outcrop on the left (opposite the entrance ramp to I-684) is stop 3. Drive on across the overpass over I-684 to find a safe parking space (for instance on the side road opposite the Getty Service station). Stop 3.

STOP 3

Stop 3 is located on the contact of the Croton Falls mafic complex (see figure 4). The rocks exposed here include modified dunite, pyroxenite, gabbro and diorite of the complex, and down-graded emery-related rocks derived from blocks of Manhattan Schist that were incorporated into the mafic complex at or near its margin. Also present is a belt of foliated, leucocratic plagioclase-biotite-amphibole rock that cuts through and incorporates blocks of the mafic rocks, and stringers of more-normal quartzo-feldspathic vein material. The rocks in this contact zone have been subjected to considerable deformation and recrystallization during F_3, D_5, D_6, and possibly D_7 times. The neighboring outcrops along the road in both directions are Manhattan Schist.

In the altered mafic rocks, the olivine has been partly replaced by phlogopite (and more rarely to anthophyllite), and the pyroxene by amphibole, although the augite in some of the more gabbroic rocks is still fresh and unaltered. The diorites are texturally the most modified rocks, having taken on a strong S_3 foliation as they have throughout the complex. They consist of andesine and biotite with only minor amounts of original hornblende surviving, though a late-stage dark blue-green amphibole can be present around grain boundaries of biotite in places.

Unmodified emeries in the xenoliths deep within the Complex can consist entirely of corundum and magnetite, though usually some garnet is also present. In contrast, here at the margin of the Complex aluminosilicates and some plagioclase survived the contact metamorphism, though because of all the later modification, it is not always certain which minerals belong with which metamorphic event. One of the most striking rocks in this outcrop is the light-colored garnet-rich rock making up the steepest high cliff near the center of the roadcut. It contains sillimanite, staurolite, cordierite, almandine, gedrite, oligoclase, and members of the magnetite-ulvospinel and ilmenite-hematite solid solution series', together with minor amounts of late kyanite, biotite and muscovite. Of these minerals the almandine and cordierite were clearly no longer stable together during the later metamorphism, and they are now always separated from one another by screens of Sillimanite, staurolite, and/or gedrite. In sheared chloritized zones emery relicts characteristically consist of magnetite, corundum, plagioclase, and biotite in which the original minerals are now largely replaced by sericite, chlorite, and epidote. Other common rocks include pelites containing plagioclase, sillimanite, ± kyanite, corundum, biotite, garnet, magnesian hercynite, and black Fe-Ti oxides, and amphibolites that now have a grayish-green amphibole of the cummingtonite-grunerite family as the dominant mineral.

The leucocratic foliated plagioclase-biotite-hornblende rock is something of an enigma. In its light color, its foliation, layering and folding, it looks similar the host schists. However, in its mineralogy (andesine, hornblende and biotite) it very closely resembles the Croton Falls diorite except that it is much more leucocratic than any of the normal diorites. In addition, it has blocks of the Croton Falls mafic rocks (tectonically) incorporated into it. It is possible that it represents a xenolith of host schist that was incorporated into the diorite magma and that equilibrated chemically with the diorite (as opposed to the emery xenoliths that equilibrated with the ultramafic magma).

The rocks in this outcrop have been deformed and remetamorphosed a number of times, but the recrystallization has not affected all areas equally: some patches of dunite have survived almost unmodified; the gabbroic rock appears fresh and unaltered; and the cordierite-garnet rock has resisted recrystallization during most of the later, lower-grade events. In other areas, by contrast, the rocks have been severely recrystallized and/or redeformed several times. Recrystallization during each event was largely controlled by access to water. Thus a zone of remetamorphism surrounds those shear zones and S-surfaces that penetrated the highly competent rocks of the complex, and partial preservation of mineral assemblages reflecting each metamorphic event is the rule. Based on relationships worked out within the complex, the lowest grade of metamorphism occurred early in the D_6 cycle (Brock and Brock, 1981), although recent work elsewhere suggests a second metamorphic low with D_7. By this reasoning the chlorite-epidote-sericite alteration of the emery relicts could be assigned to either the D_6 or D_7.

Within the Complex, emeries modified by D_6-related metamorphism develop assemblages containing kyanite, chlorite, and staurolite, ±muscovite, ±tourmaline, and old garnets often show extensive alteration to chlorite. Later prograde metamorphism is suggested by a number of textures, including the growth of biotite screens between chlorite and staurolite, and around young euhedral garnets that contain inclusions of chlorite. Young acicular sillimanite is present in these assemblages. It is uncertain whether this prograde metamorphism pertains to a late stage of D_6 deformation or to D_7.

At this outcrop, the alteration of olivine to anthophyllite in dunite, and of pyroxene to hornblende in gabbro is attributed to D_3- or D_5-related metamorphism. The cordierite-garnet rock is texturally complex, and it is

FIGURE 7. Geologic Map of the area around stop 4, modified from Prucha et al., 1968, Fisher et al., 1970 and Rodgers, 1982

Explanation of Symbols   ✱ = Stop location   x = Age Determination Location

.. .·.. = Stream   + = Cordierite-Garnet Locality

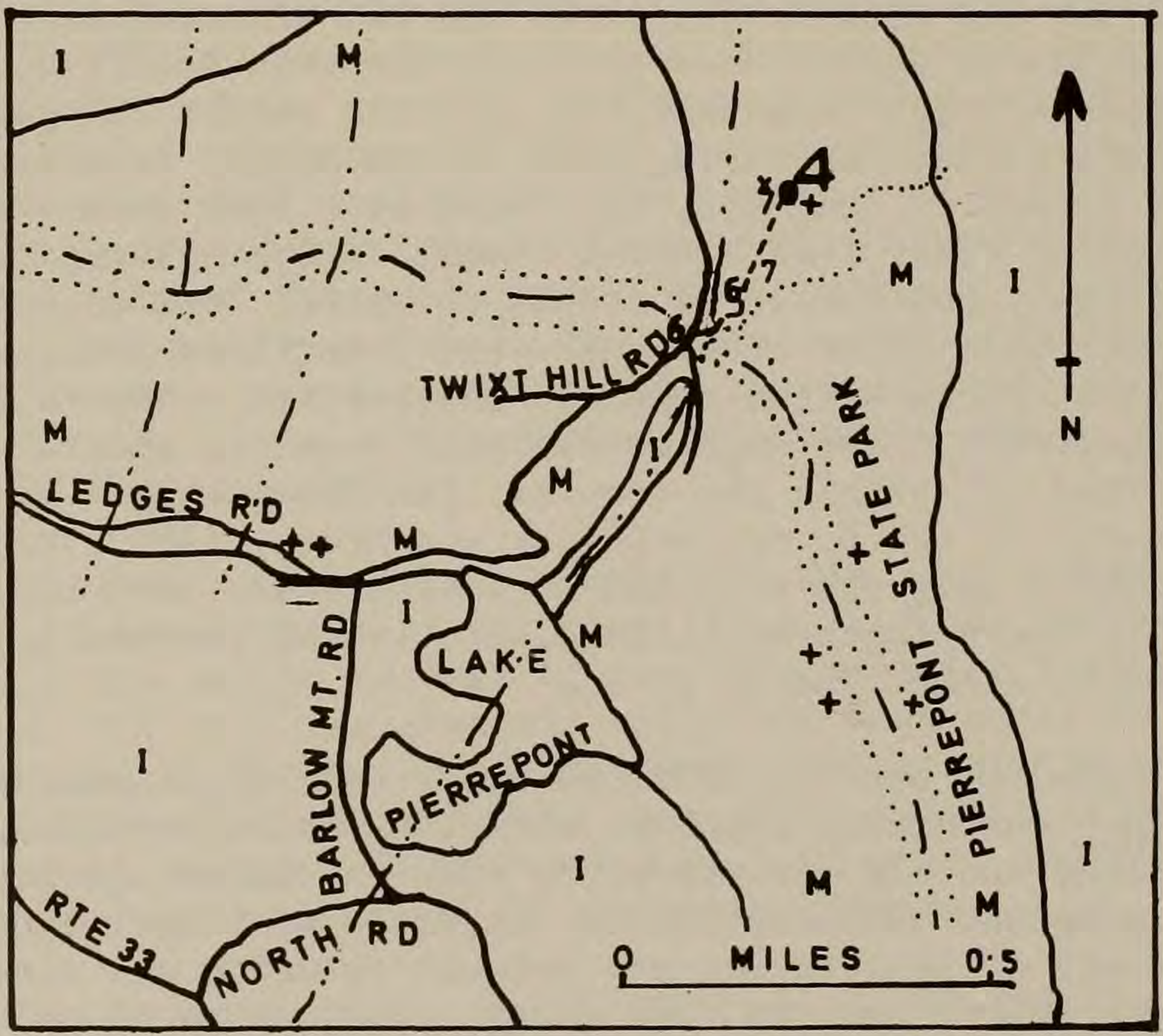
M = Manhattan Schist   I = Inwood Marble

∴∴∴ Schematic representation of Hartland Formation along the F_2 axial trace that we think is responsible for its presence

— .. — .. — F_2 Axial Trace

— ... — ... — F_3 Axial Trace

6 = Zone of D_6 ductile shearing   7 = Zone of D_7 thrusting



difficult to relate its muddle of assemblages to specific deformational events, but within the Complex emeries locally alter to gedrite + staurolite+sillimanite along S_3 cleavages.

Deformation that disturbs the foliation in the diorite is post D_3. Where such deformation shows high-grade character it is probably of D_5 age. (F_4 has not been recognized in the complex.) Deformation of D_3, D_5, D_6, and D_7 age are all thought to be present at some point along the eastern contact of the Croton Falls Complex.

Retrace route back down Hardscrabble Road and onto Route 22 south

55.4	0.2	(Mileage counted from outcrop of stop 3, not where you parked)
56.7	1.3	Turn left (east) onto Route 116
60.3	3.6	Cross Route 124
60.8	0.5	Bear left onto combined Routes 116 & 121
61.5	0.7	Balanced rock on right
61.9	0.4	Turn right onto Route 116
62.1	0.2	Turn left onto dirt road (Mopus Bridge Road)
63.6	1.5	Bear right onto Spring Valley Road
63.8	0.2	Bear right onto George Washington Highway
64.0	0.2	At stop sign turn left onto Ledges Road
64.9	0.9	At stop sign turn left onto Barlow Mountain Road
65.2	0.3	Hairpin bend on Pierrepont Drive
65.5	0.3	Turn right onto Twixt Hill Road
65.6	0.1	Turn right onto deadend road and park, without blocking the road. Stop 4.

STOP 4 is in the Pierrepont State Park. No hammering.

It is located off the trails in fairly thick bush, and is not easy to find. If you get separated from the group, walk west till you reach the road, and then follow the road south until you find the starting point (see Figure 7).

Enter the park through the chained gate across the dirt road. Bear left on the larger track and follow it down until it is about to cross a small north-flowing stream. Just before the stream turn let onto a very old track that goes off to the left. It is barely recognizable at this point. but becomes a little more obvious as one follows it. The track goes approximately north, passing between the main height of land to the west and a smaller ridge to the east. We will visit this ridge if time permits after the main stop. Follow the track for about a quarter of a mile, at which point it will once more become hard to follow. Bear right for a few tens of feet until the ground drops away between some quite large outcrops and you find yourself in a small amphitheater surrounded by outcrops.

The rocks at this stop are Manhattan pelites that were metamorphosed to perthite-cordierite-garnet-sillimanite grade during the D_2 deformation, were somewhat down-graded (to K-feldspar-sillimanite grade) during the D_3, and then locally slightly modified during the D_6 and D_7 deformational events. The main purpose of this stop is to show you what the Manhattan looks like when it has been up to such high metamorphic grade.

Most of the pelites consist of coarse-grained perthite and garnet, separated by trains of finer-grained quartz, biotite, sillimanite and magnetite that have been folded by F_3 folds. The pelites at this locality have a higher percentage of potassic feldspar in them than is normal in the Manhattan Schist. A few grains of kyanite are present in a few places, and small amounts of sericite and chlorite are visible in most thinsections. Coarser-grained secondary muscovite is also present in a few places. Cordierite is only present in restricted areas; generally in only small a small amounts (less than 15%). (Specimens from nearby localities where it constitutes nearly 50% of the rock will be available for your inspection on the bus.) Cordierite, perthite and garnet ± sillimanite co-existed stably during D_2 times, but during F_3 times the garnet-cordierite pair was unstable, and screens of biotite and sillimanite are generally present along the grain boundaries. In a few places cordierite is partly replaced by gedrite, and in others it is replaced by green biotite and/or a yellow ?amorphous material. In one locality along Washington Ledges the rock has been flasered, and the flasers of garnet-perthite-cordierite are separated by trains of almost pure sillimanite. In many of the cordierite-bearing rocks both the cordierite and the plagioclase have grown into large sieve crystals that enclose smaller grains of most other minerals. Garnet porphyroblasts routinely enclose biotite, sillimanite, quartz, plagioclase and opaques, but only rarely enclose perthite, and then only in the outermost zone.

The pelites have been intruded by perthite-bearing granites that have been deformed during F_3 deformation. The contacts of these granites are now rather diffuse in many places. Trains of sillimanite cut across the perthite porphyroblasts .

Most of the rocks in this "amphitheater" area show only limited signs of late, lower-grade metamorphism, except in a zone of D_7 shearing along the western edge of the amphitheater. In the shear zone grain-size is reduced and the rock is made up of fine-grained red biotite, quartz, and feldspars, with scattered relict sheared and/or rotated porphyroblasts of garnet and perthite, and with lesser amounts of sericite and chlorite (±a little surviving sillimanite). In places the muscovite and chlorite are concentrated in strain shadows of some of the porphyroblasts. A few small euhedral garnets grew towards the end of the deformation. The granites near the shear zone show more signs of recrystallization: some feldspars are completely sericitized and some garnets are completely chloritized.

Biotite from this D_7 zone has given a K-Ar age of 294±13 m.y., and muscovite from another zone two miles north of here gives an age of 309±8 m.y.

The outcrop on the small mound to the south of the amphitheater (that we passed as we walked in) shows more evidence of lower grade remetamorphism. Here D_6 deformation has produced muscovite-rich shear zones that cut across older structures, including F_3 and possibly F_5 hinge surfaces. The introduction of water necessary to make the muscovite is characteristic of the D_6, and where the D_7 shearing follows D_6, it too has more muscovite associated with it.

		Turn around and turn left onto Twixt Hill Road
65.7	0.1	Turn left onto Pierrepont Drive
66.6	0.9	At Stop sign, continue straight ahead (south, on Barlow Mt. Road)
67.0	0.4	Turn right at "T" junction onto North St
67.3	0.3	Turn left onto Route 33
69.4	2.1	At Stop sign turn right onto combined Routes 33 and 35
70.0	0.6	Center of Ridgefield
		END OF TRIP
		From here there are several possible routes back to New Haven. The simplest is probably to follow route 33 (Not 35) south to the Merritt Parkway (Route 15), or to the New England Throughway
	45.5	

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