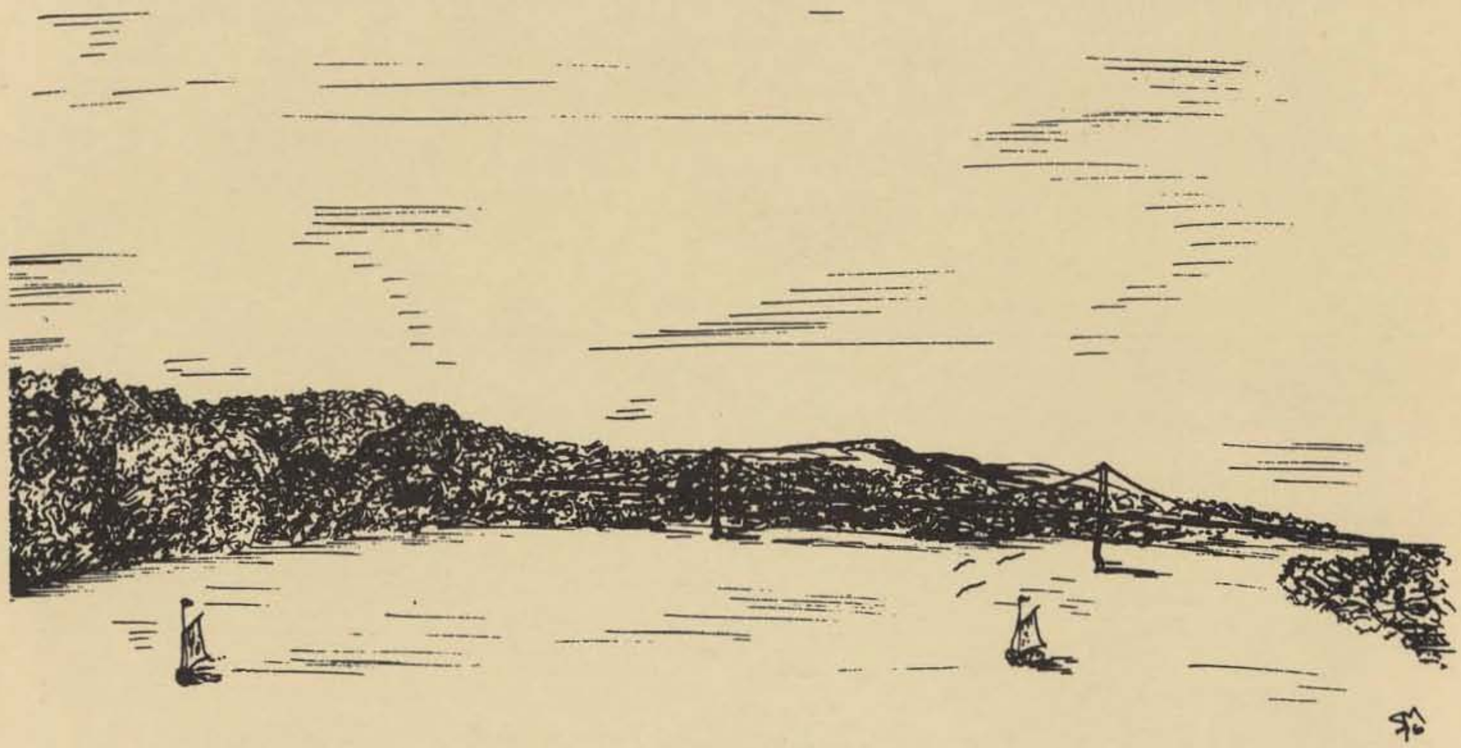
FIELD GUIDE BOOK

New York State Geological Association



48th Annual Meeting

VASSAR COLLEGE

POUGHKEEPSIE, NEW YORK

OCTOBER 15 - 16, 1976

The organizer of the field trips described in this volume, and of the meeting at which they were given, is

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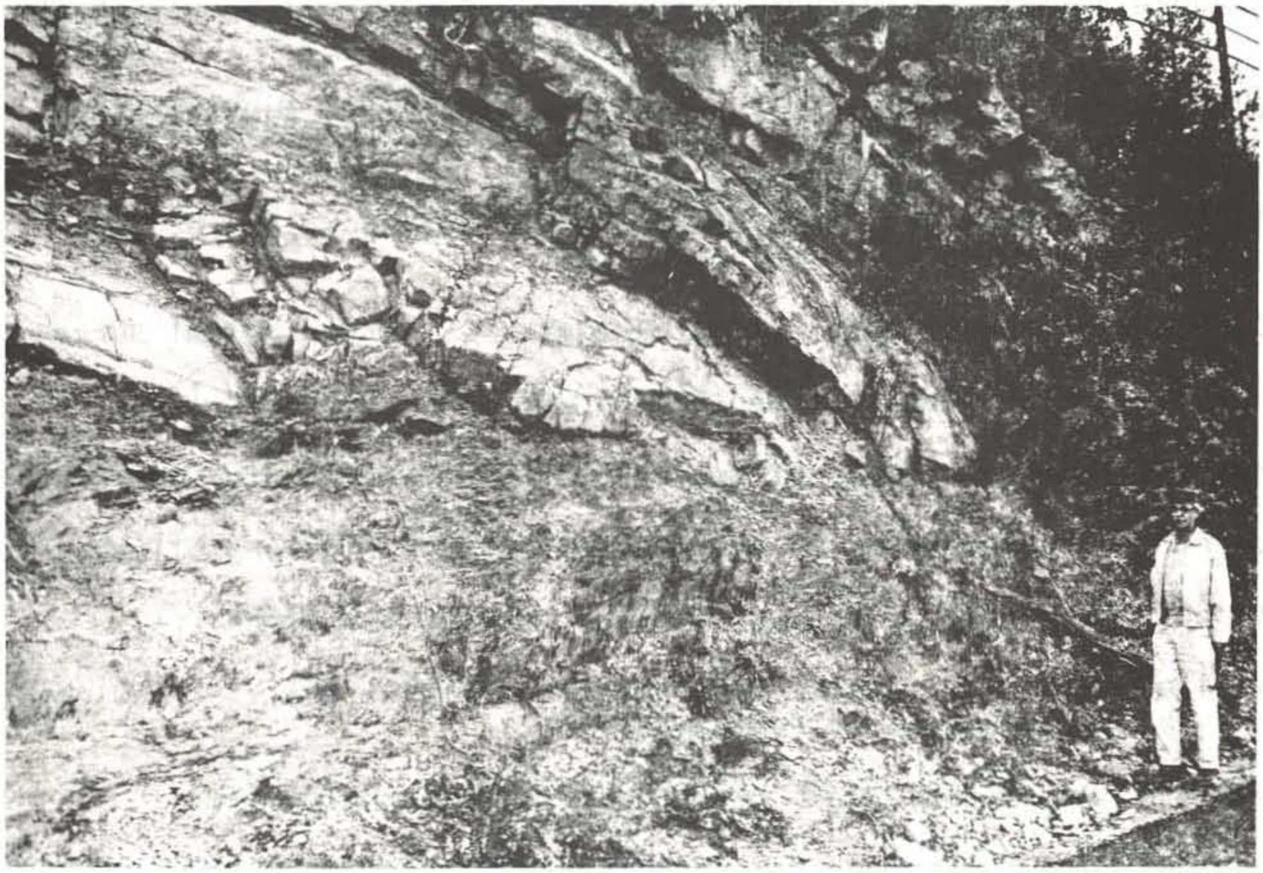
Copies of this guidebook may be purchased fr the Executive Secretary of the New York State Geo gical Association: Dr. Daniel F. Merriam, Chairma Department of Geology, Syracuse University, Syrac New York 13210.



Frontispiece - A. Scott Warthin Jr., Professor Emeritus of Geology, Vassar College, dean of Hudson Valley Geologists and expert on Dutchess County geology, examining block of Wappinger dolostone in deformed Snake Hill Shale, visible between Stops 3 and 4 on Trip B-6, south side of Spackenkill Road near Cedar Valley Road. Photograph by Donald W. Fisher, 1975.

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PREFACE

The area surrounding Vassar College provides a wealth of material for the geoscientist. It is classic ground in the study of geology - the Taconics, Hudson Highlands, Shawangunks, Catskills and the Hudson Valley each provide wonderful and exciting outdoor classrooms. Because most major rock types lie within one or more of these areas, it was possible to schedule a number of excursions into igneous, sedimentary and metamorphic terrains which exhibit simple to intensely deformed structures as well as geologically-oriented trips related to recent environmental concerns in part brought on by the presence of these structures. Each of the leaders invited to participate is either involved in current field research or has had a great deal of recent field experience within the area of his trip so that much new significant data heretofore unpublished are made available in this guidebook. The field program is sufficiently diverse in locale and content to provide something of interest for everyone.

To celebrate the Bicentennial of our country, we depart from tradition by offering a limited enrollment extra-cost trip on the Hudson River from New York City to Poughkeepsie on the first day of the meeting to view the geology along its east and west banks and to learn something of the colonial and revolutionary history that was made along its course and, on the final day, a walking trip through historic Fishkill, New York. A separate guidebook has been prepared for the participants of the river trip, but a limited number will be available for sale. In addition, the Lamont-Doherty Geological Observatory at Palisades, New York, will host an open house on the first day of the meeting to provide an opportunity for members of the New York State Geological Association to tour the facilities and meet with a number of the scientists conducting research there.

Lack of secretarial assistance and increased costs made it impossible for articles to be retyped on the same machine. By prior mutual consent, each author agreed to use one of several similar type styles and to review their manuscripts before submission. No editorial changes were made.

The Editor wishes to express his thanks, on behalf of the NYSGA, to Vassar College for serving as host to its 48th Annual meeting, to each of the authors who graciously accepted full responsibility for organizing and leading his trip, to A. Scott Warthin Jr., who ably took over the reins for me during the summer of 1976 while I was on the other side of the world and to those colleagues and majors in my department that gave so generously of their time.

Welcome to Vassar College and the historic Mid-Hudson Valley. We hope you thoroughly enjoy your brief study of this region.

John H. Johnsen
Editor

CONTENTS*

* The 48th Annual Meeting of the New York State Geological Association also includes two field excursions, Trips A-1 and A-2, not included in this guidebook. Trip A-1, GEOLOGY AND BICENTENNIAL HISTORY OF THE LOWER AND MIDDLE HUDSON VALLEY, an all-day boat trip up the Hudson River from New York City to Poughkeepsie organized and led by John H. Johnsen, was issued in a separate limited-edition guidebook. Trip A-2 was a guided tour of the Lamont-Doherty Geological Observatory at Palisades, New York.

TRIP B-1

STRUCTURE, PETROLOGY AND GEOCHRONOLOGY OF THE PRECAMBRIAN ROCKS IN THE CENTRAL HUDSON HIGHLANDS

Henry L. Helenek[1] and Douglas Mose[2]

INTRODUCTION

Recent studies in the New York portion of the Reading Prong indicate that the Hudson Highlands may consist of two terranes of Precambrian rock (Harwood and Zietz, 1974; Hall et al., 1975). A western terrane consists of charnockitic gneisses and paragneiss intruded by syntectonic granitoid plutons. An eastern terrane consists of quartzofeldspathic gneisses having lithic and structural similarities with the Fordham gneiss immediately to the south in Westchester County (Hall et al.,1975). Fundamental differences in lithology, structure, geochronology and magnetic signature have been summarized by Harwood and Zietz (1974) and Hall et al. (1975). Although the position and nature of the contact separating the two terranes remains problematical, an approximate boundary may be placed in the vicinity of the Ramapo-Canopus fault system in the Hudson Highlands. Detailed study is needed to establish the relationship between the two suites of rock. The purpose of this field trip is to examine the structure, petrology and geochronology of Precambrian rocks at select sites in both terranes. The Lake Carmel area in the eastern Highlands (stops 1 and 2) and the West Point area in the western Highlands (stops 3, 4, 5, 6, 7, 8) have been chosen for this purpose (Fig. 1).

ACKNOWLEDGEMENTS

We wish to express our appreciation to the personnel of the Mill Pond Garden Center, the Tri-County Land Management Corporation, the Harriman State Park and the United States Military Academy at West Point for the cooperation they extended us in planning this field trip and to Mr. and Mrs. August Michel for allowing us to examine rock exposures on their property.

LAKE CARMEL AREA

The following bedrock map units are found in the Lake Carmel area (Fig. 4):

p€bg. Gray, migmatitic biotite-hornblende-quartz-feldspar gneiss with sparse thin layers of amphibolite (estimated minimum thickness, 1000 feet).

p€am. Heterogeneous group of rocks consisting of three members: (1) garnetiferous amphiboloite, (2) biotite-quartz-plagioclase gneiss with sparse amphibolite, and (3) predominantly biotite-quartz-plagioclase gneiss, biotite-hornblende-quartz-plagioclase gneiss, hornblende gneiss and amphibolite with subordinate leucocratic granitic gneiss and sparse pyroxenite (estimated thickness, 600 feet).

p€ga. Weakly foliated leucocratic granitic gneiss with subordinate biotite-hornblende-quartz-plagioclase gneiss and hornblende gneiss containing

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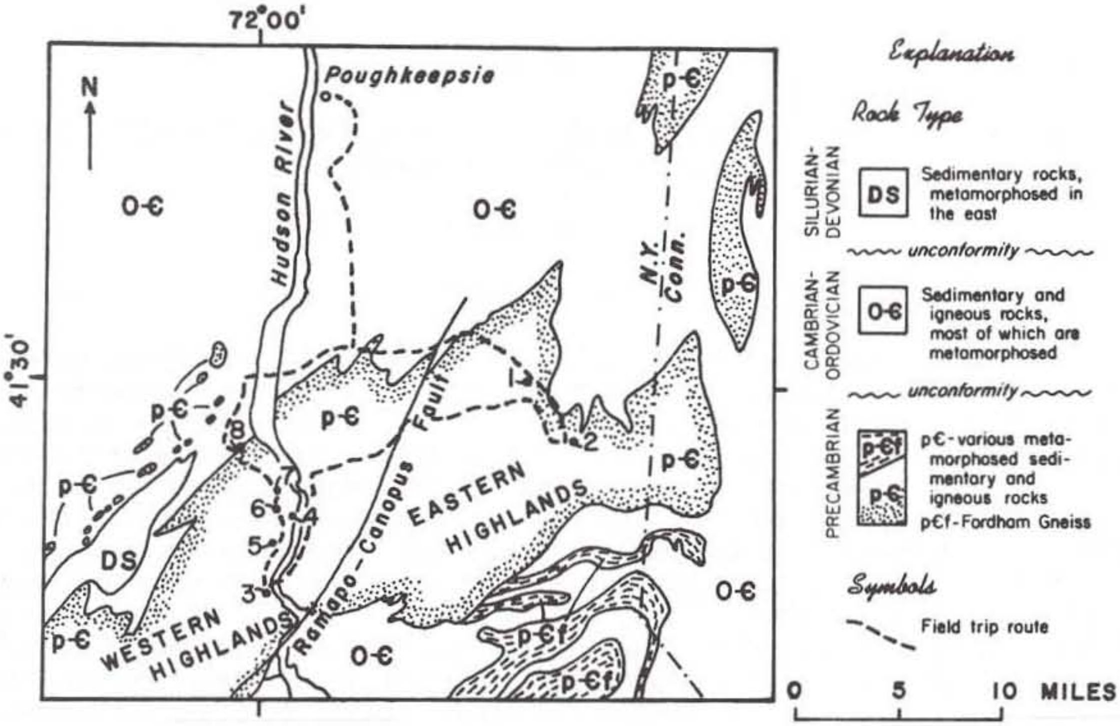

Figure 1. Index map and route for field trip B-1.

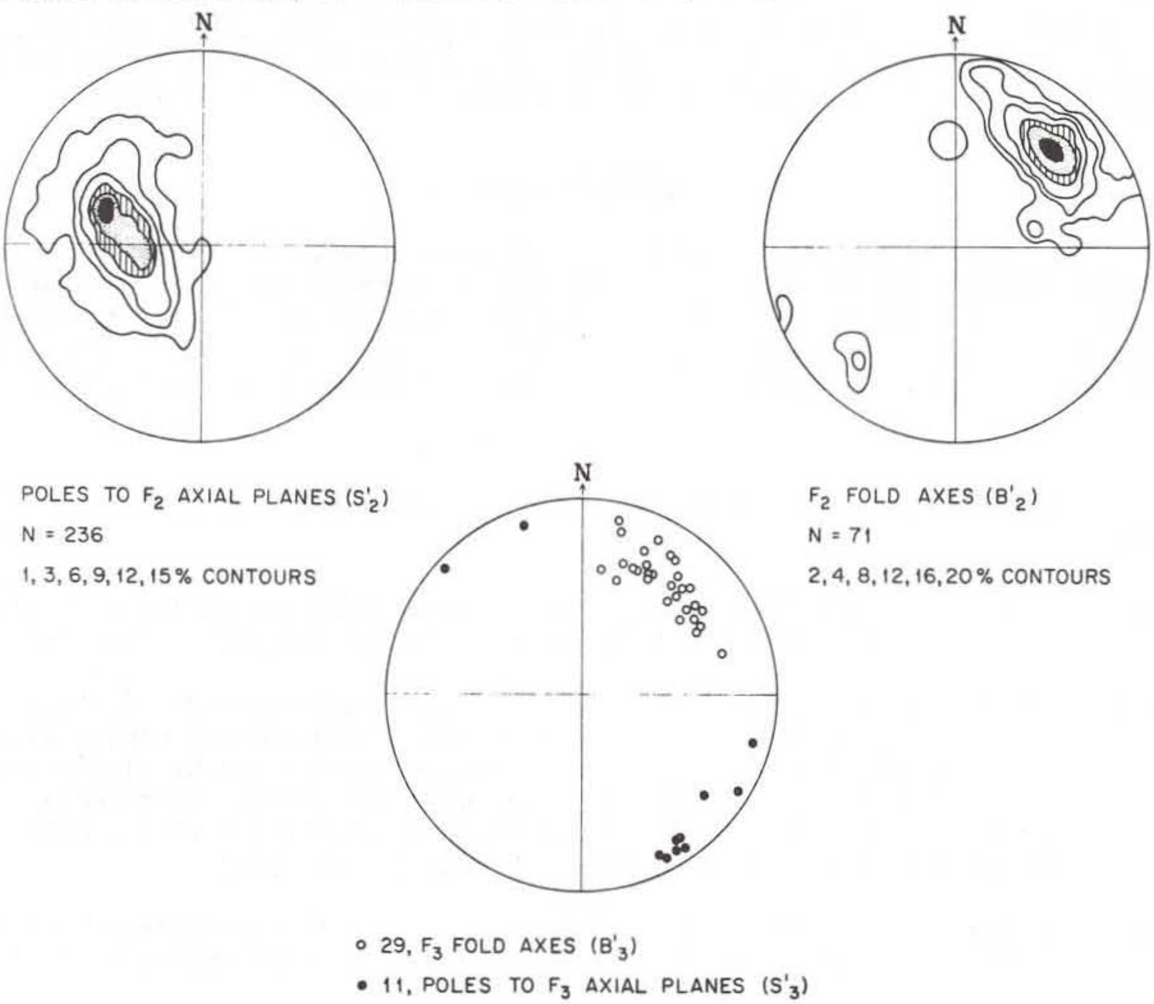

Figure 2. Equal-area diagrams of structural data for the Lake Carmel area.

amphibolite, quartz-feldspar gneiss, pyroxene-hornblende-quartz-plagioclase gneiss, pyroxenite and calc-silicate (estimated thickness, 1800 feet).

p$\mathcal{C}$lg. Layered biotite-hornblende-quartz-plagioclase gneiss with subordinate amphibolite and biotite-quartz-feldspar gneiss (estimated thickness, 1800 feet).

p$\mathcal{C}$q. Biotitic amphibolite and feldspathic quartzite (estimated minimum thickness, 800 feet).

Mineral assemblages indicate upper amphibolite facies conditions of metamorphism (Hall et al., 1975).

A preliminary summary of deformational and metamorphic events is as follows:

F0. Tightly appressed rootless intrafolial folds; orientation variable; formation of penetrative axial plane foliation (S_0) parallel to compositional layering; existence of these folds requires more thorough study to be proven; age, uncertain.

F1. Tightly appressed isoclinal folds; orientation variable; no axial plane foliation developed; age, uncertain.

F2. Reclined, recumbent and inclined similar folds; orientation of axial surfaces (S_2^1) and fold axes (B_2^1) are shown in figure 2; folding accompanied by intrusion of granite and injection of granitic seams parallel to axial surfaces of F_2-folds; transposition of S_0 into axial planar foliation (S_2^1) along thrust faults; recrystallization of high-grade mineral assemblages to upper amphibolite facies assemblages (Hall et al., 1975); age of folding and recrystallization, Taconic(?).

F3. Open, upright folds; poles to axial planes of F_2-folds lie on a girdle defining an axis oriented N55^{o}E at 28^o which coincides with F_3-fold axes (Fig. 2); retrograding of upper amphibolite mineral assemblages (?); intrusion of pegmatite (?); development of quartz-filled extension fractures (?); age, Paleozoic.

F4. Open, upright folds; warping of F_0-F_3 fabric elements about a horizontal axis trending about N20^{o}W; folding results in reversal in plunge of F_2- and F_3-folds and is responsible for the dome-and-basin interference pattern; age, Paleozoic (?).

The significance of a prominent mineral lineation throughout the area is not clearly understood.

We are tentatively assigning a Taconic age to the F_2-deformation and recrystallization for the following reasons:

(1) textural studies of mineral assemblages indicate that recrystallization of Precambrian gneisses to amphibolite facies conditions accompanied the F_2-folding (Hall et al., 1975).

(2) $^{40}Ar/^{39}Ar$ studies indicate that a single Paleozoic recrystallization of these gneisses occurred about 480 m.y. ago during a Taconic event (Dallmeyer and Sutter, 1976).

Radiometric studies are being carried out in areas adjacent to the Lake Carmel area. Rb/Sr whole rock work on samples of a major biotite-muscovite-quartz-plagioclase gneiss to the north and west of Lake Carmel has shown that this rock has an age of 1296 ± 77 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7032 ± 0.0003 (all errors given at the 95% confidence level). Another sample set from a similar rock immediately north of Peekskill yielded an age of 1256 ± 16 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7021 ± 0.0005. A granite gneiss southeast of Croton Falls Reservoir (Prucha et al., 1968) has yielded an age of 1308 ± 41 m.y. and an initial ratio of 0.7029 ± 0.0005 (Mose, unpub. data). No U/Pb age determinations have been made on rocks of the eastern Hudson Highlands.

K/Ar and Rb/Sr age determinations on single mineral separates (usually biotite) from rocks in this area range from about 300 m.y. to 800 m.y. (Long and Kulp, 1962; Clark and Kulp, 1968). The younger mineral ages (300-450 m.y.) were obtained over most of the eastern Hudson Highlands where the Paleozoic metamorphic overprint reached garnet grade or higher. The older mineral ages (700-800 m.y.) are from the western edge of the eastern Hudson Highlands (along the eastern side of the Ramapo-Canopus fault zone), where the Paleozoic metamorphic overprint reached biotite grade or lower.

THE WEST POINT AREA

The following bedrock map units are found in the West Point area (Fig. 3):

Metasedimentary and metavolcanic rock

p€qp. Various charnockitic quartz-plagioclase gneisses with subordinate amphibolite, quartz-plagioclase leucogneiss, calc-silicate and minor additional metasediments.

p€pg. Migmatitic paragneiss with subordinate amphibolite and rusty weathering pyroxenic gneisses (p€pga), quartz-plagioclase gneisses (p€pgg) and minor calcareous, ferruginous and quartzitic metasediments.

Early tectonic and syntectonic intrusive rocks

p€sk. Hornblende granitic and quartz monzonitic gneisses with subordinate hornblende granite (all derived from lower crustal or mantle sources); intrudes p€qp and p€pg.

Syntectonic and late tectonic intrusive mobilizates

p€ch. Coarse-grained, garnet and biotite-bearing leucocratic granite (Canada Hill granite); derived by anatexis of paragneiss (p€pg); intrudes p€pg and p€sk.

p€pd. Coarse-grained diorite (Pochuck diorite); derived by partial anatexis of intermediate rocks as charnockitic quartz-plagioclase gneisses; intrudes p€qp; forms local pockets too small to be indicated on map.

Late to post-tectonic intrusive rocks

p€al. Coarse-grained magnetite alaskite; intrudes p€qp, p€pg and p€sk.

Mineral assemblages indicate lower granulite facies conditions of metamorphism (Dallmeyer and Dodd, 1971; Hall et al., 1975).

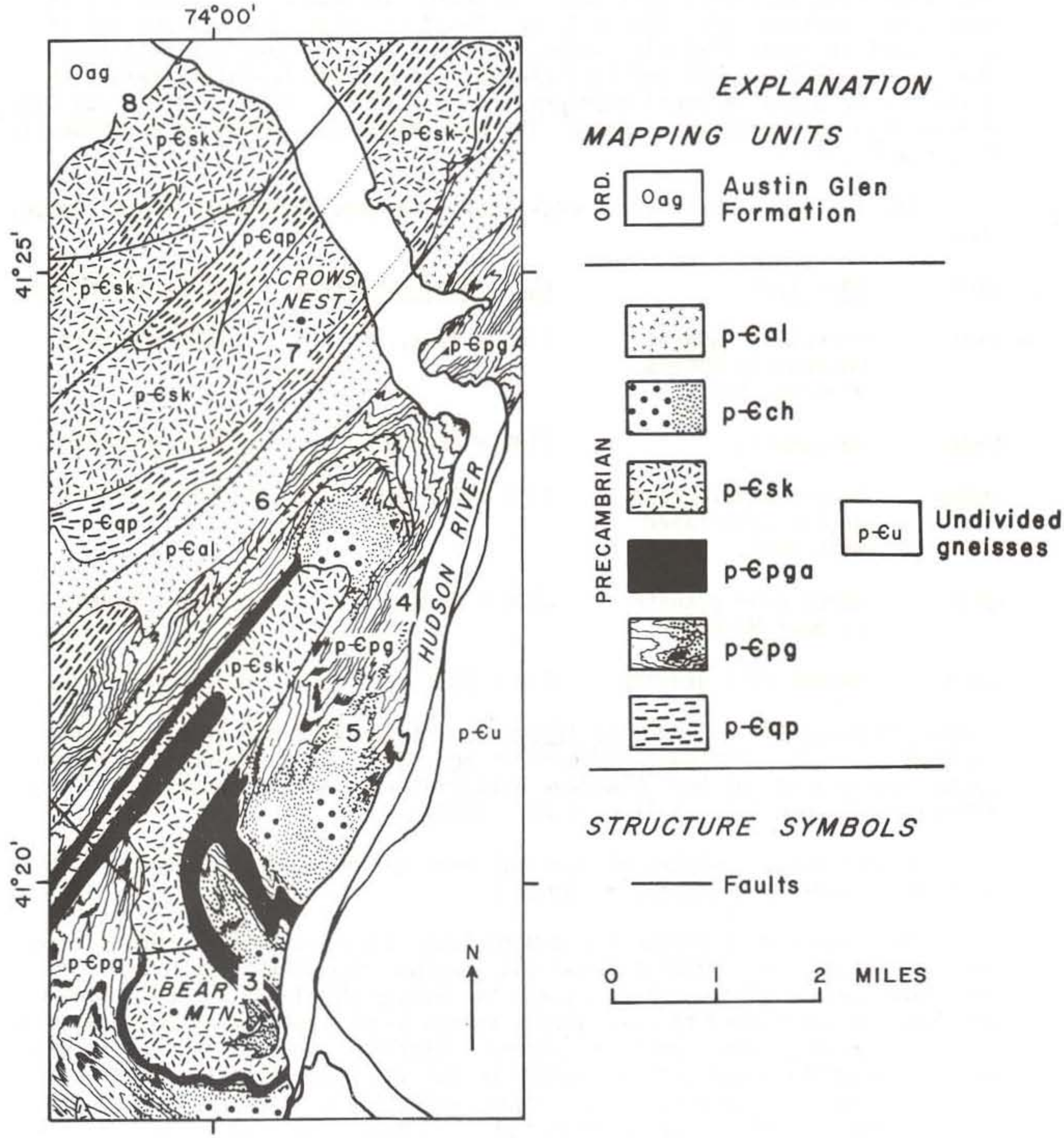

Figure 3. Generalized geologic map of the West Point area. Numbers indicate field trip stops.

At least three periods of folding have deformed rocks in the West Point area. The earliest fold generation (F_1) resulted in regional isoclinal folds. The prominent regional foliation is axial planar to F_1-folds. The second generation of folds (F_2) developed as plane, cylindrical, isoclinal folds with southeast dipping axial planes and fold axes that plunge approximately N35°E at 10° parallel to the regional mineral lineation (L_2). The Crows Nest antiform, West Point antiform, Hessian Lake synform and Ft. Montgomery antiform are regionally developed F_2-folds. A localized set of open, upright folds (F_3) with nearly vertical axial planes and fold axes that plunge N45°E at 35° refolded elements of F_1- and F_2-folds. Refolding during F_3 resulted in local reorientation of minor F_2-folds and mineral lineation (L_2) to a southwest plunge. The Bear Mountain synform is a regionally developed F_3-fold.

The following Rb/Sr whole rock ages have been determined (Mose, unpub. data):

Unit	Rock Type	Age ± 95% C.L. error	Initial $^{87}Sr/^{86}Sr$
p€sk	Hornblende quartz monzonitic gneiss at Crows Nest	1169 ± 44 m.y.	0.7055 ± 0.0019
p€pg	Paragneiss	1139 ± 26 m.y.	0.7067 ± 0.0010
p€pgg	Quartz-plagioclase gneiss associated with p€pg	1115 ± 208 m.y.	0.7033 ± 0.0017
p€sk	Hornblende granite at Bear Mountain	1086 ± 34 m.y.	0.7020 ± 0.0021
p€ch	Canada Hill granite	914 ± 31 m.y.	0.7193 ± 0.0013

Zircons from Canada Hill gneiss (p€pgg, quartz-plagioclase gneiss,?) have yielded a nearly concordant $^{207}Pb/^{206}Pb$ age of 1170 m.y.; zircons from the hornblende granite at Bear Mountain have yielded a nearly concordant $^{207}Pb/^{206}Pb$ age of 1060 m.y. (Tilton et al., 1960).

A preliminary summary of deformational and metamorphic events for the West Point area is presented in Table 1.

The scheme of petrogenetic and tectonic events presented here differs in several important respects from that proposed by Berkey and Rice (1919) and Lowe (1950). Both workers viewed the Hudson Highlands as consisting of a series of metasediments selectively intruded and reworked by an early dioritic phase of plutonic activity (Pochuck diorite, p€pd) to form rocks characteristic of the p€qp unit. A second pervasive, highly active phase of plutonism (Canada Hill granite, p€ch) again selectively granitized original metasediments to form migmatitic paragneiss (p€pg). The final phase of plutonism resulted in the syntectonic emplacement of hornblende granite (Storm King granite, p€sk) with its more fluid phase, the alaskite (p€al).

We consider the following observations critical in supporting our proposed sequence of events:

(1) p€pd is restricted to rocks of basic and intermediate composition (p€qp) and p€ch to migmatitic paragneiss (p€pg). Rather than a model

Deformational Event	Fold System	Type of Folds	Important Tectonic Features	Metamorphic Event	Important Crystalloblastic and Other Features	Igneous Intrusions	Age of Events
		Post-Grenville uplift of the Hudson Highlands					
					Retrogression of high grade mineral assemblages with cooling Deuteric mineralization in the Canada Hill granite	Intrusion and crystallization of alaskite	
D_3	F_3	Local, open, upright, isoclinal folds; vertical axial planes; fold axis almost coaxial with F_2-fold axis; refolding causes local reversal in plunge of F_2-folds	Local fracture cleavage subparallel to axial surface of F_3-folds	$M_{p\epsilon}$		Final emplacement and crystallization of Canada Hill granite in axial regions of F_3-folds	Crystallization of Canada Hill granite, 914 m.y. Formation of uraninite in hornblende pegmatite (Phillips mine), 920 m.y.
D_2	F_2	Regionally developed isoclinal folds plunging about N35°E at 10°; refolding of F_1-folds	Development of penetrative mineral lineation (L_2): prominent regionally developed mineral lineation. Local development of axial plane foliation (S_2); prominent F_1 foliation is preserved			Large-scale mobility of Canada Hill granite; emplacement in axial regions of F_2-folds	
				Thermal maximum, 1100-1150 m.y. T = 700°-750°C; P = 3-6 kb.	Continued recrystallization and rotation of prismatic and platy minerals parallel to F_2-fold axes	Final crystallization of melt in the core of the Bear Mtn. pluton Initiation of anatexis of paragneiss and incipient mobilization of partial melt Canada Hill granite; partial anatexis in the quartz-plagioclase gneisses	Final crystallization of the Bear Mtn. pluton, 1086 m.y.
D_1	F_1	Tightly appressed, isoclinal folds oriented NW-SE with axial surfaces moderately to steeply inclined with variable orientation	Development of penetrative axial plane foliation (S_1) subparallel to primary compositional layering; prominent regionally developed foliation in Precambrian rocks		Recrystallization of minerals to granulite facies	Recrystallization of the Crows Nest pluton and crystallized portions of the Bear Mtn. pluton; core of the Bear Mtn. pluton remains melt Intrusion and partial crystallization of the Bear Mtn. pluton	Recrystallization of quartz-plagioclase gneiss (1115 m.y.) and paragneiss (1139 m.y.)
				$M_{p\epsilon}$		Intrusion and crystallization of the Crows Nest pluton	Crystallization of the Crows Nest pluton, 1169 m.y.
Sequence of sedimentary and volcanic rock; deposition prior to 1170 m.y.							

Table 1. Preliminary summary of Grenville petrogenetic, tectonic and metamorphic events in the West Point area of the Hudson Highlands, New York.

of selective intrusion, we believe that anatexis of gneisses of differing initial bulk compositions followed by a period of limited movement for the mobilizate best explain the distribution and composition of these rocks. An anatectic origin for Canada Hill granite from paragneiss is supported by isotopic studies (Mose and Helenek, 1976).

(2) hornblende quartz monzonitic gneiss from the Crows Nest pluton yields an Rb/Sr whole rock age of 1169 ± 44 m.y. while hornblende granite from the Bear Mountain pluton yields an age of 1086 ± 34 m.y. Both plutons are deformed to varying degrees, the older pluton being structurally more complex than the younger pluton. This indicates a rather long period of early tectonic and syntectonic intrusion for these granitoid rocks. Initial $^{87}Sr/^{86}Sr$ ratios indicate a lower crustal or mantle source for these rocks.

(3) Canada Hill granite cross-cuts structures in and contains inclusions of p€pg and p€sk. A Rb/Sr whole rock age of 914 ± 31 m.y. and a high initial $^{87}Sr/^{86}Sr$ ratio support the contention that Canada Hill granite is a syntectonic to late tectonic, palingenetic intrusive rock post-dating intrusion of Storm King granite plutons.

(4) alaskite cross-cuts structures in and contains inclusions of p€qp, p€pg and p€sk. It differs petrographically from the hornblende granitic rocks. Its relationship to the Canada Hill granite is uncertain.

APPENDIX I. INTERPRETATION OF RADIOMETRIC DATA FOR THE HUDSON HIGHLANDS

WESTERN HIGHLANDS TERRANE

The interpretation of Rb/Sr and U/Pb ages from regionally metamorphosed terranes has been a subject much discussed among Appalachian geologists. The ages reported here for the metasedimentary (paragneiss, p€pg) and metavolcanic (quartz-plagioclase gneisses, p€qp) units in the western terrane are most reasonably interpreted to be the time of regional metamorphism. Strontium isotopic homoginization presumably occurs during metamorphism of these rocks because of their relatively porous, water-rich and fine-grained nature. On the other hand, the ages reported for the plutonic rocks (hornblende granitic rocks, p€sk, and Canada Hill granite, p€ch) are most reasonably interpreted to be the time of rock crystallization. The hornblende granites (containing zircon populations characteristic of plutonic rocks, Eckelmann and Helenek, 1975) are interpreted by us to be part of a series of syntectonic sills and phacolithic plutons. Their low $^{87}Sr/^{86}Sr$ initial ratios suggest that they were formed in the lower crust or upper mantle and were emplaced with little or no contamination by crustal strontium. Taken together with the ages from the metasediments and metavolcanics, the data reveal that the western Hudson Highlands were metamorphosed about 1100 m.y. to 1150 m.y. ago during what is commonly known as the Grenville dynamothermal event.

The Canada Hill granite is a late tectonic body which formed about 914 m.y. ago. Field relations, rock chemistry and initial strontium isotopic compositions of the granite and its enclosing paragneiss show that this granite formed by partial melting of the paragneiss. The 914 m.y. age places a lower limit on the interval on Grenville metamorphic activity.

K/Ar biotite age determinations from Grenville rocks in the western Hudson Highlands average 829 ± 34 m.y. (1 , 12 ages; data from Tilton et al., 1960, and Long and Kulp, 1962). One interpretation of the K/Ar data is that the rocks experienced a metamorphic event at this time. In the absence of any dated plutonic rocks produced at this time, this interpretation seems doubtful. Another interpretation is that the biotite in these rocks was kept at a temperature greater than its argon retention temperature until about 830 m.y. ago. Dallmeyer et al. (1975) have used biotite (retention temperature estimated to be 300^{o} to 350^{o} C) and hornblende (average age about 900 m.y.; retention temperature estimated to be 500^{o}-550^{o} C) to determine a Late Precambrian uplift rate for this area of about 10^{-5} meters per year.

EASTERN HIGHLANDS TERRANE

Although not conclusive, evidence suggests that the granite gneiss and biotite-muscovite-quartz-plagioclase gneiss dated by the Rb/Sr technique may be metamorphosed plutonic rock. We interpret these data to indicate that the eastern Hudson Highlands were formed during a major dynamothermal metamorphism about 1250-1300 m.y. ago. These are among the oldest rocks in the Appalachian system. A similar age has beem determined for layered gneisses in the Blue Ridge of North Carolina (Fullagar and Odom, 1973; Rankin et al., 1969).

Recent work in the Manhattan Prong by Grauert and Hall (1973) has shown that syntectonic zircon formed in the Fordham gneiss 980 m.y. ago. Since similar gneisses are found in the eastern Hudson Highlands, it is likely that the Highlands were again metamorphosed at this time.

Rb/Sr whole rock work on granitic gneisses in the Manhattan Prong (Yonkers gneiss, Long, 1969; Pound Ridge gneiss, Mose and Hayes, 1975) has shown that the Fordham gneiss was partially melted and formed the granitic gneisses about 600 m.y. ago. Hall (pers. comm.) has observed other similar rocks associated with Grenville terranes in New England. It is not unreasonable to think that this 600 m.y. event (Avalonian orogeny, ?) was felt in the eastern Hudson Highlands.

The K/Ar and Rb/Sr single mineral ages from the eastern Hudson Highlands and from the adjacent Manhattan Prong have been interpreted in different ways. Long and Kulp (1962) and Clark and Kulp (1968) interpreted the data to indicate that the area experienced a metamorphic event at about 460-480 m.y. ago (the oldest K/Ar ages from the Fordham gneiss in the Manhattan Prong) and another metamorphic event at about 360 m.y. ago (the average K/Ar age from micas in the zone of Paleozoic sillimanite grade metamorphic overprint in the Highlands and in the Manhattan Prong).

We prefer to interpret the data using the model proposed by Butler (1972) for K/Ar biotite ages on the Blue Ridge rocks. In this model, the metamorphic isograds and K/Ar age pattern are inferred to be the result of a single metamorphic event. K/Ar mica ages from crystalline rocks which existed before the Paleozoic metamorphism (e.g. Grenville gneisses) are not regarded as useful chronometers for the Paleozoic event. These micas may or may not have lost all their pre-Paleozoic metamorphism radiogenic argon, or they may have continued to lose argon after the Paleozoic metamorphic event if they were not rapidly uplifted after the metamorphic event. K/Ar ages from high grade metasedimentary rocks first metamorphosed during the Paleozoic are also not regarded as useful. These rocks, which have yielded biotite K/Ar ages of 300-350 m.y., are thought to have remained continually at high temperatures in excess of the biotite argon retention temperature until 300-350 m.y. ago. The only useful K/Ar data (for determining the time of metamorphism) are biotite K/Ar ages from rocks which were first progressively metamorphosed (and formed biotite) during the Paleozoic, and which were uplifted soon after metamorphism. The best area (for biotite formation followed by earliest uplift and cooling) would be in the zone of biotite grade regional metamorphism.

In the Blue Ridge, K/Ar data from the zone of biotite grade metamorphism reveals that the Paleozoic event occurred at least 435 m.y. ago. In the Manhattan Prong, the only useful K/Ar data come from the Manhattan schist, a mid-Ordovician metasediment. There are no K/Ar data from biotite grade schist, but K/Ar data from garnet grade schist (Long and Kulp, 1962) shows that the Paleozoic metamorphism occurred at least 410 m.y. ago.

Dallmeyer (1975) has suggested that the Cortlandt complex, situated between the Rosetown complex and the Peekskill pluton, is coeval with part of the Rosetown complex. The Rosetown complex exhibits no metamorphic textures and is known to be a series of Cambro-Ordovician intrusions (Mose et al., 1975; Dallmeyer, 1975). Since the Cortlandt was emplaced after the Paleozoic metamorphic event (it intruded rocks in the zone of garnet through sillimanite grade), the metamorphic event which produced the Paleozoic metamorphic isograds occurred after the deposition of the youngest sedimentary rock (Manhattan schist- Unit A; about 460 m.y. old) and before the intrusion of the Cortlandt complex, which Dallmeyer interprets to be about 440 m.y. old.

It now appears that the metamorphic activity which affected the Manhattan Prong and the eastern Hudson Highlands was a single mid-Ordovician event (440-460 m.y. ago), commonly called the Taconic orogeny. It is, however, not clear to what extent the Devonian age Acadian orogeny (which is recorded in the rocks of New England and in the Piedmont of the central and southern Appalachians) was felt in the Manhattan Prong and eastern Hudson Highlands. The Peekskill pluton (Mose et al., 1976), the Bedford, New York, pegmatite and the Branchville, Connecticut, pegmatite (Clark and Kulp, 1968) all formed in Devonian time, indicating that the Manhattan Prong and probably the eastern Hudson Highlands were at high enough temperatures to generate igneous intrusions. Chase and Brock (1976) have shown that the Paleozoic sillimanite isograd in the Croton Falls area (north-central Manhattan Prong) appears folded, indicating that structural deformation occurred after the Taconic orogeny. Granitoid to gneissic granitic rocks in the Croton Falls complex have yielded a Rb/Sr whole rock age of 407 $\pm$ 25 m.y. (95% C.L.), indicating that they were formed in post-Taconic time (i.e., after 440-460 m.y.), but were subsequently recrystallized (Mose, unpub. data).

Post-Taconic deformation and igneous activity has clearly occurred in the Manhattan Prong and probably also in the eastern Hudson Highlands. However, it is not yet possible to decide if this activity represents a distinct Acadian orogenic event, preceded by a post-Taconic cooling, or if the activity merely represents adjustments which occurred during a long mid-Paleozoic interval of slow post-Taconic uplift and cooling. Most workers today favor the second interpretation, relating the uplift to the folding of Silurian-Devonian rocks west of the Hudson Highlands and not to the metamorphism of Silurian-Devonian rocks east of Cameron's line in New England.

15.4	0.8	Carey Rd. overpass. Exposures of lower members of the Wappinger Group on both sides of I-84.
16.9	1.5	Gently folded syncline in the Wappinger Group on the left (north) side of I-84. The Hudson Highlands are seen to the right (south).
17.8	0.9	Exposures of lower members of the Wappinger Group.
19.2	1.4	The prominent valley to the right (south) is an extension of the Ramapo fault through the Hudson Highlands.
19.4	0.2	Intersection of I-84 and the Taconic State Parkway. Continue east along I-84.
20.1	0.7	Large exposures of Precambrian gneiss. Biotite granitic gneiss predominates with subordinate amphibolite and hornblende biotite granite gneiss. Rocks have varying degrees of cataclastic deformation. Minerals are partially altered. Toward the eastern end of the exposure is infolded Poughquag quartzite.
20.7	0.6	Large exposures of Precambrian gneiss. Predominant rocks are biotite-quartz-plagioclase gneiss and quartz-plagioclase leucogneiss with subordinate amphibolite, biotite-hornblende-quartz-plagioclase gneiss and pyroxenite. All minerals are partially altered and replacement textures common.
21.3	0.6	Large exposures of Precambrian gneiss. Entering the Poughquag $7\frac{1}{2}'$ quadrangle.
21.7	0.4	Rest area on I-84.
22.2	0.5	Toward the left (northwest) is a spectacular view of the Hudson Valley.
22.3	0.1	Large exposure of Precambrian gneiss. Precambrian rocks from this point to stop 1 consist of biotite-quartz-plagioclase gneiss, biotite-hornblende-quartz-plagioclase gneiss, amphibolite and biotite-muscovite-quartz-plagioclase gneiss.
24.4	2.1	Large roadcut of Precambrian amphibolite.
25.1	0.7	Large exposure of light gray, biotite-muscovite-quartz-plagioclase gneiss. Sampling locality for Rb/Sr whole rock dating (1296 $\pm$ 77 m.y.).
25.2	0.1	Turn off I-84 at Exit 17 (Ludingtonville Rd.).
25.6	0.4	Turn right at stop sign onto Ludingtonville Rd.
25.7	0.1	Intersection of Ludingtonville Rd. and Route 52. Turn right (north) onto Route 52.
25.9	0.2	Turn right into the parking area at the Mill Pond Garden Center.

STOP 1. Mill Pond Garden Center. (No hammers, please!)

Exposure of light gray, biotite-muscovite-quartz-plagioclase gneiss. This foliated gneiss is one of the most important lithologies in the eastern Hudson Highlands. The exposure seen here is on strike with the large roadcut of light gray gneiss on I-84. In the I-84 outcrop, the biotite-muscovite-quartz-plagioclase gneiss contains bands consisting of biotite-actinolite-plagioclase gneiss. Foliation trends about N40°E and is almost vertical. The light gray, biotite-muscovite gneiss is among the oldest rocks found in the Hudson Highlands and yielded a Rb/Sr whole rock age of 1296 $\pm$ 77 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7032 $\pm$ 0.0005.

Exit parking lot and turn left onto Route 52. Return to I-84 East.

26.2	0.3	Turn right onto entrance ramp of I-84 East and proceed on I-84.
26.8	0.6	Entering the Lake Carmel 7½' quadrangle. Exposures of Precambrian rock.
28.1	1.3	Exposures of metamorphosed Middle Ordovician clastic rocks (Walloomsac formation).
28.9	0.8	Turn off I-84 at Exit 18 (N.Y. Route 311, Lake Carmel-Patterson).
29.2	0.3	Turn right at stop sign onto Route 311.
29.6	0.4	Entering the Village of Lake Carmel.
29.9	0.3	Intersection of Route 311 and Terry Hill Rd. (street marker on the right). Turn left onto Terry Hill Rd.
30.8	0.9	Intersection of Terry Hill Rd. and Fair St. Continue straight and proceed south on Fair St.
31.6	0.8	Intersection of Fair St. and Bullet Hole Rd. Turn left onto Bullet Hole Rd.
32.0	0.4	Pass beneath I-84 overpass.
32.3	0.3	Turn left into Forest Haven Apartments.

STOP 2. Forest Haven Apartments.

A short traverse will be made through the upper pꞒga unit and the lower pꞒlg unit (Fig. 4). No hammers, please!

Station A. pꞒlg unit. Exposures of layered, medium-grained, mesocratic biotite-hornblende-quartz-plagioclase gneiss. Prominent F_2-folds have axial planes trending about N40°E, 60°S. Fold axes plunge about S70°E at 60° but marked variability from this direction is noted. Abundant crenulation folds are related to F_2-folds.

Station B. pꞒga unit. Leucocratic granitic gneiss forms large domical exposures. Amphibolite with calc-silicate nodules defines a large F_2-fold.

Station C. pꞒlg unit. Exposures of layered biotite-hornblende-quartz-plagioclase gneiss. Prominent F_2-folds have axial planes oriented N-S, 55°E; folds plunge N58°E at 34°. The change in orientation of F_2-axial planes from station A is a result of F_3-folding.

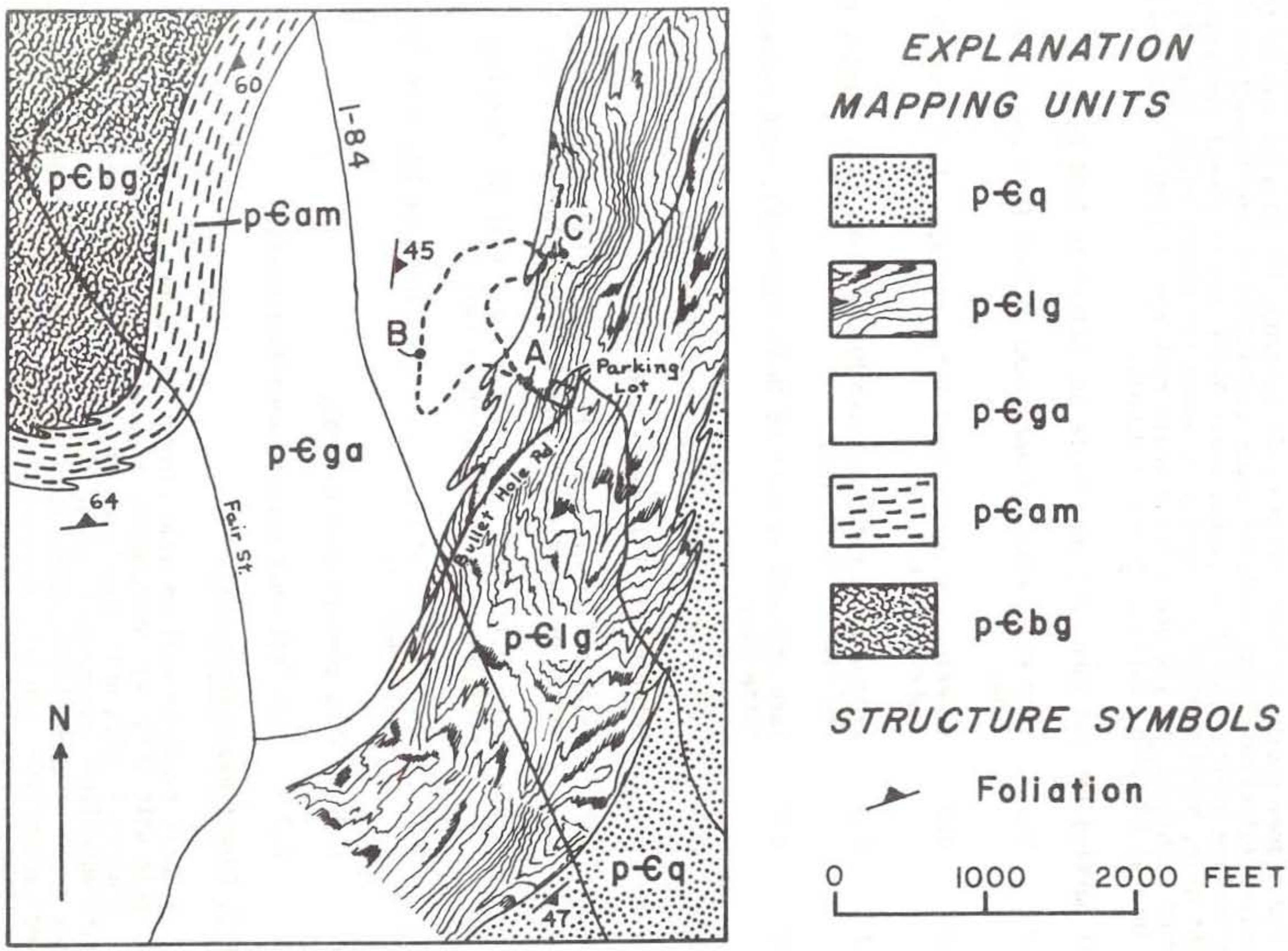

Figure 4. Geologic map of the region in the vicinity of stop 2.

Turn right and proceed west along Bullet Hole Rd.

32.6	0.3	Pass beneath I-84 overpass and continue on Bullet Hole Rd.
33.0	0.4	Intersection of Bullet Hole Rd. and Fair St. Turn left and proceed along Fair St.
33.6	0.6	To the right is George Fischer Middle School.
34.1	0.5	Intersection of Fair St. and Tilly Foster Rd. Turn left (south) onto Tilly Foster Rd.
35.5	1.4	Intersection of Tilly Foster Rd. and Route 6. Turn left (east)and proceed on Route 6. About one mile to the south, samples of a granite gneiss yielded a Rb/Sr whole rock age of 1308 $\pm$ 41 m.y.
35.8	0.3	Intersection of Route 6 and Route 312. Turn left at traffic signal and proceed along Route 312. To the right (south) is the Tilly Foster Mine.
36.9	1.1	Intersection of Route 312 and I-84. Geology of the large roadcut to the right described by Fenster and Brock, 1975.
37.1	0.2	Turn left onto entrance ramp of I-84 West and proceed on I-84.
38.5	1.4	Large exposures of the p€q unit and the p€lg unit.
39.2	0.7	Large exposure of the p€ga unit. This roadcut is described in detail in Hall et al. (1975).
39.8	0.6	Exposures of the contact between the p€ga unit and the p€am unit.
40.1	0.3	To the left in the eastbound lane of I-84 are exposures of the p€bg unit.
40.5	0.4	Turn off Exit 18 (N.Y. Route 311, Lake Carmel-Patterson).
40.7	0.2	Turn left at stop sign onto Route 311. Proceed beneath I-84 overpass and continue west on Route 311 South.
41.2	0.5	Entering Lake Carmel.
41.8	0.6	Intersection of Route 311 and Route 52. Turn right and proceed north on Route 52.
43.6	1.8	Kent Primary School to the left.
43.8	0.2	Turn left onto North Kent Rd. immediately beyond the Kent Primary School.
44.7	0.9	Intersection of North Kent Rd. and Whangtown Rd. Bear right and continue on North Kent Rd.
44.8	0.1	Exposure on the left is a sampling locality for Rb/Sr

		whole rock dating (1296 $\pm$ 77 m.y.) of the biotite-muscovite-quartz-plagioclase gneiss.
45.1	0.3	Intersection of North Kent Rd. and Church Hill. Proceed along North Kent Rd.
45.4	0.3	Exposure on the left is a sampling locality for Rb/Sr whole rock dating (1296 $\pm$ 77 m.y.) of the biotite-muscovite-quartz-plagioclase gneiss.
45.7	0.3	Intersection of North Kent Rd. and Ressique Rd. Continue along North Kent Rd.
46.8	1.1	Three-way intersection between North Kent Rd., Farmers Mills Rd. and Gypsy Trail Rd. (North Kent Rd. becomes Farmers Mills Rd.). Continue along Farmers Mills Rd.
47.5	0.7	Intersection of Farmers Mills Rd. and Milltown Rd. Proceed along Farmers Mills Rd.
47.9	0.4	Intersection of Farmers Mills Rd. and Ninham Rd. Continue along Farmers Mills Rd.
48.6	0.7	Entering the Oscawana Lake 7½' quadrangle.
49.8	1.2	Intersection between Farmers Mills Rd. and Route 301. Bear right and proceed west on Route 301.
52.0	2.2	Entering Clarence Fahnstock State Park.
52.3	0.3	Exposures of paragneiss on the right side of Route 301.
52.9	0.6	Intersection of Route 301 with the Taconic State Parkway. Continue straight on Route 301.
53.1	0.2	Entering the Ramapo-Canopus fault zone. Note sheared rock on both sides of road.
53.9	0.8	Canopus Lake. The Ramapo-Canopus fault roughly trends along the axis of the lake.
55.0	1.1	Exposure on the right is a sampling locality for Rb/Sr whole rock dating (914 $\pm$ 31 m.y.) of the Canada Hill granite.
56.8	1.8	Entering the West Point 7½' quadrangle. Exposure to the right of the road is sampling locality for Rb/Sr whole rock dating (914 $\pm$ 31 m.y.) of the Canada Hill granite.
59.1	2.3	Intersection of Route 301 and Route 9. Jog right and left and continue on Route 301.
60.6	1.5	Intersection of Route 301 and Fishkill Rd. (from the right). Continue straight on Route 301.
61.0	0.4	Turn left onto Peekskill Rd. and proceed south. This allows us to bypass the town of Cold Spring.

61.5	0.5	Intersection between Peekskill Rd. and Route 9D. Turn left and proceed south on Route 9D.
64.0	2.5	Entering the Village of Garrison.
64.9	0.9	Intersection of Route 9D and Route 403. Continue south on Route 9D.
65.0	0.1	Entering the Peekskill 7½' quadrangle.
65.7	0.7	Site of the Robinson House on the left. Benedict Arnold secretly offered the British the surrender of West Point and settled the particulars in a midnight meeting with Major John Andre in the Robinson House on Sept. 21, 1780. Andre was captured two days later and hanged at Tappan, Oct. 2, 1780. Arnold made his escape to the British sloop, Vulture.
66.0	0.3	Prominent landform to the left is Sugarloaf Mountain.
68.1	2.1	Eastern anchor for the chain across the Hudson River which failed to prevent British ships from sailing up the Hudson River during the War of Independence.
69.5	1.4	Turn right onto the Bear Mountain Bridge at the intersection of Route 9D and Route 6W/202W. The large mountain straight ahead and to the left is Bear Mountain. The prominent knob straight ahead and to the right is the Torne. Proceed across the bridge to the traffic circle.
70.0	0.5	Bear right into the traffic circle. Proceed 3/4 the way around the traffic circle and turn right onto Route 9W to the Bear Mountain Inn.
70.3	0.3	Entering Rockland County. Proceed on Route 9W South.
70.6	0.3	Turn right onto service road and proceed to Bear Mountain Inn parking area.

STOP 3. Bear Mountain.

Stop 3 is a short walk north of Bear Mountain Inn to the roadway north of Hessian Lake (Fig. 3). The exposures that will be studied at this locality are in Harriman State Park and regulations prohibit destruction of the environment in any way. NO HAMMERING, PLEASE!

Several lithologies typical of the western Highlands terrane are seen in these exposures. These include the paragneiss (p€pg) with its associated amphibolite and rusty pyroxenic gneiss (p€pga) and foliated hornblende granite (p€sk). Canada Hill granite (p€ch) cross-cuts structures in all three lithologies. These units form the lower limb of a reclined isoclinal F_2-antiform (Ft. Montgomery antiform).

p€pg, p€ga and p€sk are folded into isoclinal digitations and compositional layering is completely transposed into an F_1 axial planar foliation. F_2-folds are locally similar in style and are usually more open than F_1-isoclinal folds. Several minor F_2-folds occur in the hornblende granite at this locality. A hornblende lineation best seen in the amphibolite (p€pga) trends about N37°E at 37° and is parallel to fold axes of F_2-folds. The broad curvature to the units in the Bear Mountain area seen on the map (Fig.3), is due to F_3-folding. Fold axes of F_3-folds plunge N50°E at 36° in this area.

The deformation seen in the hornblende granite at this locality is absent in the main mass (core) of hornblende granite at Bear Mountain. However, a strong hornblende lineation in the core granite parallels the hornblende lineation in the amphibolite (p€pga) of the paragneiss unit (p€pg). Since marginal gneissic facies of the hornblende granite locally possess secondary foliation related both to D_1 and D_2, the Bear Mountain pluton has been involved in all phases of deformation. The Rb/Sr whole rock age of 1086 m.y. and the U/Pb age of 1060 m.y. obtained from the lineated core facies of the pluton probably indicate the time of crystallization of residual melt in the Bear Mountain pluton. This would suggest that final crystallization of the hornblende granite was coeval with the termination of F_2-folding in the West Point area.

The coarse-grained, leucocratic Canada Hill granite cross-cuts linear and planar structures in the granite-gneiss sequence and contains inclusions of p€sk and p€pga (the latter not seen in these exposures). In other localities where the hornblende granite and Canada Hill granite are in close proximity, the relationship between the two granites is at best equivocal. Field relationships seen at these exposures clearly demonstrate the cross-cutting nature of the Canada Hill granite. This, combined with a Rb/Sr whole rock age of 914 m.y., supports the assignment of a post-Storm King age to the Canada Hill granite. The crystallization of Canada Hill granite represents the termination of Grenville activity in the Hudson Highlands.

Leave the Bear Mountain Inn parking lot and turn left onto the service road. Proceed approximately two hundred yards and turn left onto Routes 9W and 202.

71.1	0.5	Enter the traffic circle and proceed halfway around. Bear right onto Route 9W north toward West Point-Newburgh.
71.4	0.3	Bridge over Popolopen Brook (also known as Hell Hole).
71.6	0.2	To the right of the road is the site of Fort Montgomery, prominent in the American Revolution.
72.0	0.4	Entering the town of Ft. Montgomery.
73.1	1.1	Exposures of Canada Hill granite in the core of the Crystal Lake pluton.
73.8	0.7	To the left side of Route 9W is a large exposure of Canada Hill granite.
75.3	1.5	Large exposure on the left side of Route 9W is hornblende granitic gneiss. This is an extension of the Bear Mountain pluton and forms the core of the West Point antiform.
75.6	0.3	Bear right off Route 9W and proceed to stop sign. Turn right onto Route 218 South.
75.8	0.2	On the left side of the road are exposures of paragneiss in contact with hornblende granitic gneiss in the core of

the West Point antiform.

76.2	0.4	Entering the Village of Highland Falls. Proceed on Route 218 (Mountain Rd.).
76.6	0.4	To the left is Highland Falls Junior High School. Continue down Mountain Rd.
76.8	0.2	Turn right at stop sign onto Main Street and immediately left onto Mill Street along small triangular park. Proceed to stop sign and turn left onto two lane concrete highway (Route 970). Route 970 parallels Main St. and allows us to bypass the town of Highland Falls.
77.3	0.5	Turn right at Station Hill and park in cleared area.

STOP 4. Northern margin of the Crystal Lake pluton.

The next two stops will illustrate field relationships between the paragneiss unit (p€pg) and the Canada Hill granite (p€ch) by taking a cross-sectional traverse through the Crystal Lake pluton (Fig. 3). Canada Hill granite is found in several zoned plutons restricted to the paragneiss unit, the largest of which is the Crystal Lake pluton. Stop 4 is located at the northern margin of the pluton; stop 5 is located in the core of the pluton. In traversing the Crystal Lake pluton from margin to core, we will proceed from non-migmatitic paragneiss, through a marginal zone of migmatite (metatexite of Mehnert, 1968) into a core of diatexite (a rock characterized by "complete or nearly complete melting, when molten and unmolten portions can no longer be distinguished", Mehnert, 1968, p. 253). The following lithologies make up the Crystal Lake pluton and its enclosing rocks:

Non-migmatitic paragneiss is an equigranular rock with a metamorphic fabric containing quartz, plagioclase feldspar, microcline, biotite and garnet. Quartz, microcline and plagioclase feldspar are present in about equal amounts.

Migmatite consists of leucosome and melanosome. Leucosome is a coarse-grained, inequigranular rock containing quartz, microcline, plagioclase feldspar and biotite with or without garnet. In mineralogy, leucosome is similar to diatexite. Melanosome is finer and more even grained than leucosome and consists of varying proportions of quartz, plagioclase feldspar, biotite, garnet and occasionally sillimanite. Alkali-feldspar is minor or absent.

Diatexite is a coarse-grained, inequigranular rock consisting of quartz, slightly perthitic microcline, plagioclase feldspar (calcic oligoclase) and varying amounts of garnet and biotite. Sphene and zircon are ubiquitous accessory minerals; sillimanite, graphite and tourmaline are rare. Two facies of diatexite occur in the Crystal Lake pluton: homophanous diatexite (a homogeneous granite) and schlieric diatexite (homogeneous granite with schlieren of restite). Alteration related to crystallization of diatexite resulted in the formation of secondary muscovite and epidote and the alteration of biotite.

The Q:Ab/Pl:Or and mineralogical ratios for these rocks are plotted in figure 5. The normative Q:Ab:Or ratio of diatexite lies in the field of igneous plutonic rocks containing 80% or more normative quartz-albite-orthoclase (Fig. 5A). These data support a magmatic origin for the

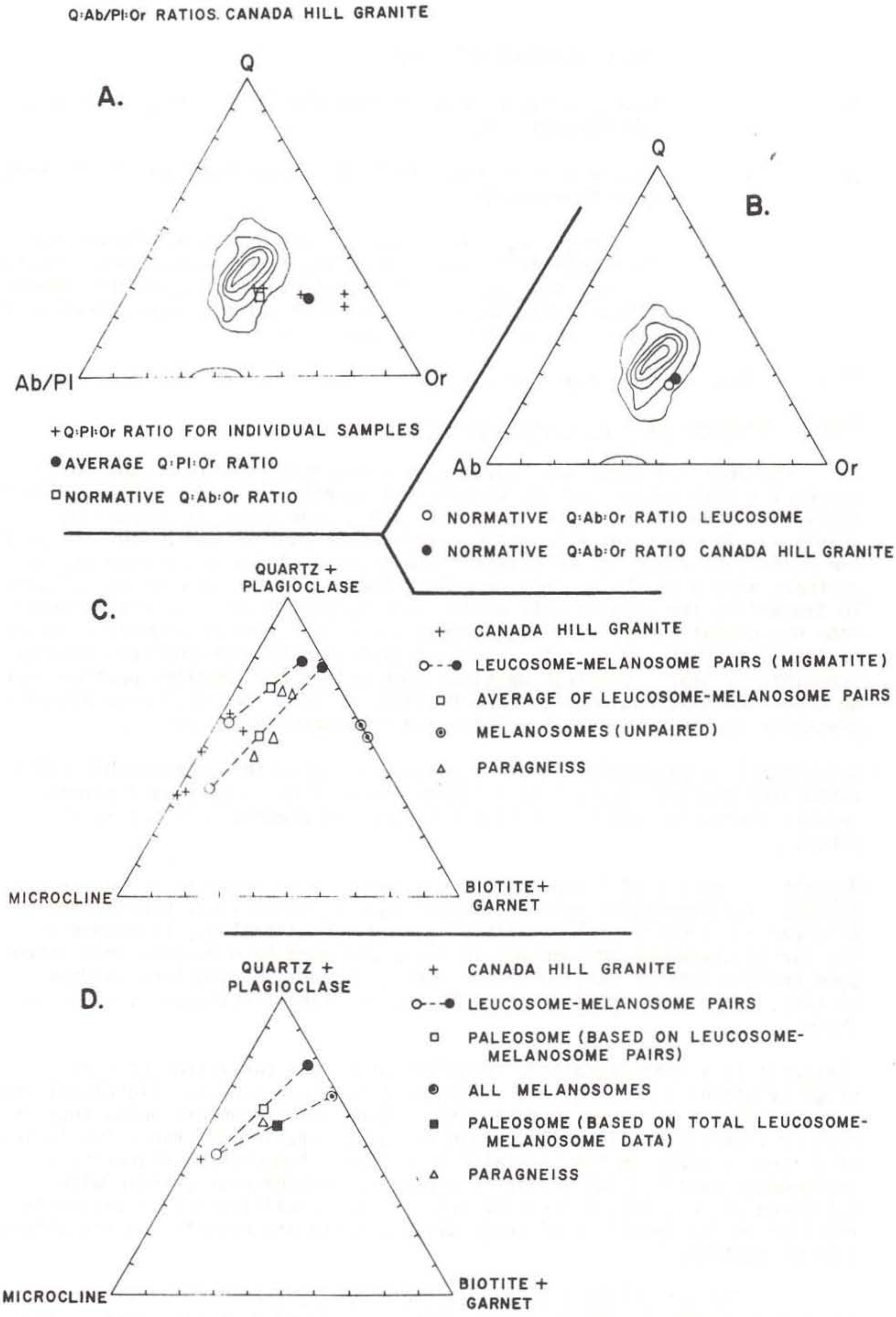

Figure 5. Q:Ab/Pl:Or and mineralogical data for Canada Hill granite, migmatite and non-migmatitic paragneiss.

diatexite facies of the Canada Hill granite. The normative Q:Ab:Or ratio of leucosome in migmatite likewise lies in the field of magmatic rock (Fig. 5B). Mineralogical data for Canada Hill granite (diatexite), migmatite and non-migmatitic paragneiss are plotted in figures 5C and 5D. The composition of Canada Hill granite and leucosome is virtually identical. The homogenized composition of leucosome-melanosome pairs approximates the mineralogical composition of non-migmatitic paragneiss. These data indicate that non-migmatitic paragneiss represents paleosome from which migmatite and Canada Hill granite formed by anatexis.

Isotopic studies also support an anatectic origin for the Canada Hill granite. Paragneiss yielded a Rb/Sr whole rock age of 1139 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7067. The Canada Hill granite (diatexite) yielded an age of 914 m.y. and an initial ratio of 0.7193. The data also show that the average $^{87}Rb/^{86}Sr$ ratio of the paragneiss is 3.8. If the paragneiss remained a closed chemical system between 1139 m.y. and 914 m.y. ago, **its average $^{87}Sr/^{86}Sr$ ratio would have changed from 0.7067 to about 0.718.** A calculated ratio of about 0.718 is essentially the same (given the error) as 0.7193, the initial $^{87}Sr/^{86}Sr$ ratio of the 914 m.y. old Canada Hill granite. This indicates that the paragneiss anatectically yielded a granitic melt in an isotopically non-fractionating manner which crystallized at about 914 m.y. ago to form Canada Hill granite.

Station A. Leave the parking area and proceed to Route 970/Main St. Turn right onto Route 970/Main St. and walk to large outcrop of the non-migmatitic paragneiss on the east side of the road.

Proceed down Route 970/Main St. in the direction of the parking area. Continue south past Station Hill several hundred feet to Michel's Gift Shop. Bear left off Route 970/Main St. and proceed down gravel road passing through the nursery (this gravel road is known as Wood Lane). Proceed to the end of Wood Lane past three private houses to the large exposure overlooking the Hudson River.

Station B. Large exposure of migmatite and Canada Hill granite. No hammers, please!

Return to the parking area at Station Hill. Turn left onto Route 970.

77.8	0.5	Intersection of Route 970 and Main St./Route 218. Bear left and proceed south on Route 218.
78.9	1.1	Proceed over the overpass of Route 218 and Route 9W and park in the large area immediately beyond the overpass.

STOP 5. Canada Hill granite (diatexite)

Large roadcut exposing the schlieric facies of Canada Hill diatexite.

Turn around and drive back over the overpass (Route 218 over Route 9W).

79.1	0.2	Take a sharp right at stop sign and turn onto the entrance ramp of Route 9W. Bear right onto Route 9W. Proceed north on Route 9W.
80.5	1.4	Hornblende granitic gneiss in the core of the West Point antiform is seen to the left.

80.8	0.3	Entering the West Point 7½' quadrangle.
80.9	0.1	Large roadcut to the left is paragneiss (p€pg).
81.3	0.4	To the right is an exposure of a thin sheet of honrblende quartz monzonitic gneiss (p€sk).
81.7	0.4	Pull off to the right into small parking area south of the West Point Golf Course.

STOP 6. Magnetite alaskite.

Magnetite alaskite (p€al) is a late to post-tectonic plutonic rock occupying a narrow fault-controlled valley between the Crows Nest antiform and West Point synform (Fig. 3). Alaskite is a medium- to coarse-grained, massive rock consisting of quartz (21%), white plagioclase feldspar (41%), pink microcline (35%) and magnetite (3%). Secondary minerals include muscovite, sericite and opaque oxides. Inclusions of country rock and xenocrysts derived from the country rock are common in the marginal facies of the alaskite. Recrystallized biotite inherited from the adjacent paragneiss is seen in this exposure of alaskite. A fracture cleavage is commonly developed in alaskite.

The relationship of alaskite to other Highlands lithologies remains uncertain. While it intrudes p€qp, p€pg and p€sk, its relationship to Canada Hill granite is not at all clear. The fracture cleavage in the alaskite may be related either to D_3 or to some post-D_3 deformational event. The lack of any penetrative structures related to D_1 and D_2, however, indicates the alaskite was intruded late in the deformational history.

Carefully pull back onto Route 9W.

82.0	0.3	Route 9W overpass over Route 218. Continue straight on Route 9W.
82.3	0.3	To the left are large exposures of charnockitic quartz-plagioclase gneisses (p€qp). Coarser grained, massive rock is the alaskite which intrudes the quartz-plagioclase gneisses.
83.4	1.1	Pull off the road into the parking area at the overlook.

STOP 7. Crows Nest Lookout.

View of the Hudson River, Constitution Island and the United States Military Academy at West Point. The ridge southwest (to the right) of the Military Academy is held up by a thin sheet of hornblende quartz monzonitic gneiss. The hornblende granitic gneisses are the most resistant of the Highlands lithologies to weathering and are the major ridge formers in the Hudson Highlands. The quartz monzonitic gneiss at West Point forms a prominent ridge which outlines the structure of the West Point antiform. The fold axis of this antiform plunges N36°E at 22°; the axial plane is oriented N30°E, 74°S. The valley at the base of the Crows Nest is underlain by magnetite alaskite.

The Crows Nest lookout is situated along the southeasterm limb of the Crows Nest antiform. Exposures of hornblende quartz monzonitic gneiss surround the lookout. The foliation in the gneiss is an F_2 axial planar foliation oriented N45°E, 70°N. This foliation is continuous with a secondary foliation described by Murray (1965) in the crest of the Crows Nest antiform at Bull Hill. The hornblende quartz monzonitic gneiss forms the core of the Crows Nest structure and yielded an Rb/Sr whole rock age of 1169 m.y. The Crows Nest antiform plunges N43°E at 18°; the axial plane is oriented N60°E, 45°N. A prominent mineral lineation trends N40°E at 22°.

On the far side of Route 9W across from the lookout, a basic dike (orientation, N75°W, 62°S), about 90 feet thick, cuts the trend of the Crows Nest fold. Undeformed basic dikes are plentiful in the Highlands and parallel the dominant joint directions in the Highland gneisses. The majority of dikes are lamprophyric or diabasic; dioritic and andesitic as well as dikes consisting of syenite and quartz porphyry are less common. The age of these dikes is uncertain.

Carefully leave the parking area and proceed north on Route 9W.

83.6	0.2	Exposures of hornblende quartz monzonitic gneiss in the core of the Crows Nest antiform.
84.6	1.0	Entering the Cornwall 7½' quadrangle. To the left is a shear zone separating the Crows Nest block from the Storm King block.
84.9	0.3	Large hill of bedrock to the right is the crest of Storm King Mountain (Butter Hill, elevation 1380 feet) underlain by hornblende granitic gneiss.
85.5	0.6	Turn right onto Mountain Rd. and proceed up hill past Storm King School to the left.
86.0	0.5	Intersection of Mountain Rd. and Maple Rd. (from the left). Continue along Mountain Rd.
86.9	0.9	Three-way intersection between Mountain Rd. and the Boulevard (roadway not marked). Turn left and proceed along the Boulevard.
87.2	0.3	Park along the road at Edward Payson Roe Memorial Park.

STOP 8. Northern border fault of the Hudson Highlands.

Hornblende granite thrust adjacent to Ordovician clastic rocks. The trace of the fault on the map trends about N35°E. Berkey (1910), however, reported an orientation of N70°E, 45°S for the fault plane based on subsurface data obtained from the Catskill aqueduct project. The question arises as to whether the northern border fault is a high angle thrust fault or a low angle overthrust. A short distance southeast of this locality, Lowe (1958) reported overthrusting of Storm King granite over intensely crumpled Ordovician slaty shales. Further to the southeast (1400 feet southeast of this stop), Berkey (1910) noted that sheared hornblende granite was penetrated to a depth of 412 feet in a series of drill holes in Pagenstechers Gorge (ravine along Mountain Rd.). A tunnel bored across the Hudson River in 1912 from Storm King Mountain to Breakneck Ridge at a depth of 1100 feet and two inclined drill holes across the Hudson in the same area intersecting at a depth of about 1500 feet, both penetrated hornblende granite beneath the Hudson River (Kemp, 1912). These data would appear to suggest that the northern border fault of the Hudson Highlands is a high angle thrust fault with local overthrusting.

87.3	0.1	To the left is the Museum of the Hudson Highlands.
87.5	0.2	Exposures of hornblende granite gneiss are seen on both sides of the road.
88.0	0.5	Intersection of the Boulevard and Maple Rd. (from the left). Continue along the Boulevard.
88.2	0.2	Intersection of the Boulevard and Hasbrouck Rd. Bear left along the Boulevard.
88.6	0.4	Turn right onto the service road for Route 9W.
88.7	0.1	Turn right onto Route 9W and proceed northwest along Route 9W.
91.8	3.1	Bridge over Moodna Creek.
93.3	1.5	Hills off to the right are the Hudson Highlands.
93.7	0.4	Entering New Windsor. Continue along Route 9W.
94.4	0.7	Entering Newburgh. Continue along Route 9W.
94.8	0.4	To the right is a road leading to Washington's headquarters in Newburgh (1782-83). Continue north acorss Main St. on Route 9W.
94.9	0.1	Entering the Newburgh 7½' quadrangle.
96.1	1.2	Intersection of Route 9W and Route 52. Bear left onto Route 52.
96.2	0.1	Turn right onto I-84 East.
96.7	0.5	Cross the Beacon-Newburgh Bridge. To the right (south) is a spectacular view of the northern passage of the Hudson Highlands. On the right is Storm King Mountain. On the left is Beacon Hill-Breakneck Ridge. The small island in the Hudson River is Pollepel Island. Entering the Wappingers Falls 7½' quadrangle.
98.4	1.7	Toll booths. Proceed through the toll booths east on I-84.
101.3	2.9	Hornblende granite in the Glenham gneiss belt.
101.6	0.3	Exposure of the upper members of the Wappinger Group with conglomeratic Middle Ordovician Balmville limestone.
103.2	1.6	Turn off I-84 at Exit 13 (Route 9 to Poughkeepsie).
103.4	0.2	Turn left (north) at stop sign onto Route 9 and proceed north on Route 9 to the Village of Wappingers Falls
108.5	5.1	Entering the Village of Wappingers Falls.

109.6	1.1	Bridge over Wappingers Lake.
110.2	0.6	Intersection of Route 9 and Vassar Rd. Turn right onto Vassar Rd.
113.9	3.7	Five-way intersection at traffic signal in Red Oaks Mill (Route 376, Spackenkill Rd., Vassar Rd.). Proceed straight through the intersection (north) onto Route 376.
116.2	2.3	Intersection of Route 376 and Raymond Ave. (road sign reads "to 44 and 55"). Bear right onto Raymond Ave.
116.3	0.1	Turn right into south parking lot on the Vassar College Campus.

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TRIP B-2

STRUCTURAL GEOLOGY OF THE TACONIC UNCONFORMITY

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INTRODUCTION

The Hudson Valley is one of the classical areas of North American geology. One of its most prominent geological features is the Taconic unconformity separating the Ordovician and Cambrian sediments from the overlying Silurian and Devonian strata. The Taconic unconformity records the earlier of two (or possibly three) Paleozoic orogenies in the Hudson Valley. The Taconic unconformity has been known since the first half of the nineteenth century and its significance for stratigraphy and the geologic history of eastern North America has been discussed by many authors (Davis,1883a, Schuchert and Longwell, 1932, Rodgers, 1971). It is a favorite subject of textbooks of historical geology which often illustrate and discuss the relationships displayed at the unconformity (for example Dunbar and Waage, 1969, Figs. 9-8 and 9-9, Kay and Colbert, 1965, p. 174, 214).

By contrast, the structural significance of the Taconic unconformity has received little attention. The entire subject of deformation of unconformities has been neglected in comparison to its structural importance. The numerous existing studies of multiple deformation deal mainly with superimposed folding deep in the basement complex and very few of them take into account what happens at or near unconformities. Textbooks of structural geology often do not even mention the subject. The field trip area offers excellent opportunities to study the effects of folding of an unconformity and the underlying as well as the overlying rocks. The plan of the field trip is to start by inspecting the formations involved in places where the structure is simple and then to proceed to outcrops at which folding of the unconformity has complicated the structures.

The present field trip is an outgrowth of class field trips I have conducted for my structural geology class. It is based on study of easily accessible outcrops that are particularly instructive by virtue of the major and minor structures they exhibit. Study of these outcrops has been carried only to the point of developing a conceptual scheme to explain the structures visible. Thus identification of formations is in some cases still tentative and I have made no attempt to record attitudes on an areal basis. Thus much work remains to be done and the field trip area should be a highly rewarding subject for one or more studies of structural details. It is difficult to find two unconformities in which the geometry of the older structures and the mechanical properties of the rocks are exactly alike at the time of the second deformation and the general principles of multiple deformation apply here to a unique array of structural details

UNDERLYING ROCKS

The Taconic unconformity cuts across a number of Ordovician and Cambrian formations. In the field trip area, however, we encounter mainly or only one of the underlying stratigraphic units: the Austin Glen Graywacke

Member of the Normanskill Shale (Berry, 1962). The Austin Glen Member consists of interbedded graywacke and dark shale. The thickness and the spacing of the Graywacke beds vary greatly through the section and intervals dominated by thick, closely spaced graywacke beds follow predominantly shaly intervals containing few and thin layers of graywacke. The mechanical properties of the strata vary accordingly and give rise to variations in structural detail.

We can infer that at the onset of the Taconic orogeny sediments of the Austin Glen Graywacke Member must still have been in a hydroplastic condition. The hinges of many folds in the Austin Glen Graywacke show signs of plastic deformation and the shale layers show signs of much thickening by flexural flow folding (Fig. 1). Development of slaty cleavage went hand in hand with lithification wherever the Taconic orogeny produced strong deformation. In the next orogeny (most probably the Acadian orogeny but conceivable the Alleghanian orogeny) the older strata had to react to the orogenic force in different ways as they had already acquired considerable strength.

Many authors (Davis, 1883b, Dale, 1899, Ruedemann, 1942, Craddock, 1957, Berry, 1962) have noted the intense faulting and shearing in the Austin Glen Graywacke and related stratigraphic units. A few have correctly attributed the various minor structures they observed to a second period of deformation in rocks that already were folded (Dale, 1899, Ruedemann, 1942). None, however, have gone into any detail on the subject.

OVERLYING ROCKS

The Taconic unconformity is overlain by limestones and dolomites of the Rondout Formation which in turn are followed by further limestone units of the Helderberg Group. These strata must have been fairly well lithified by the time of the second (Acadian (?)) orogeny.

TACONIC FOLDS

The folding of the Austin Glen Graywacke took place during the Taconic orogeny. Later deformation in the Acadian (?) orogeny has affected these folds very little, if at all, as the rocks underlying the unconformity responded to the tectonic stress by fracturing.

Typically these older folds are small-scale features, often measuring of the order of tens of feet (Fig. 1). They are often quite tight and chevron folds are common.

ACADIAN (?) FOLDS

The folds of the second orogeny, tentatively identified as the Acadian orogeny, are much broader. Typically their diameter exceeds that of the Taconic folds we see in the Austin Glen Graywacke by an order of magnitude or more. Broad, open folds are typical but locally one can encounter sharply bent and steep limbs and even overturning.

The Acadian folds are typical flexural slip folds as can be seen from the geometry of the folds and the slickensides on bedding planes in many places in the Hudson Valley. This suggests low ductility of the rocks during the deformation (Donath and Parker, 1964). I have not seen any signs of flow folds in the Silurian and Devonian limestones of the area.

Fig. 1 Contrasting styles of deformation in the Austin Glen Graywacke: Chevron fold at top and right consists mainly of graywacke and has been moved as a single unit. It is in fault contact with predominantly shaly unit at bottom and left. Bedding has been entirely disrupted by closely spaced shear fractures in the shaly unit. Note that all planar structures in shaly unit are truncated by fault that follows bedding at bottom of lowest graywacke layer. Stop 7

The rocks above the unconformity differ sufficiently from those below to give rise to disharmonic folds. It is conceivable that the difference in style between the Taconic and Acadian folds could be only an expression of disharmonic folding. To the southwest of Kingston disharmonic folding may have accentuated the unconformity or even locally produced the appearance of an angular unconformity where there is none. In the Kingston area and along the Hudson River this can be ruled out because the minor structures show that the folds in the Austin Glen Graywacke already existed before the Acadian orogeny took place.

DEFORMATION OF THE UNCONFORMITY AND ITS EFFECTS ON THE UNDERLYING STRATA

Our first clue to an understanding of the structures seen on this field trip are the folds in the Silurian and Devonian limestones above the unconformity. The geometry of these folds records the gross amount of deformation that has actually affected the rocks above and below the unconformity. The folds of the plane of unconformity are filled out by the underlying rocks. The folds in the younger rocks could form only if and when the older rocks underwent the same amount of shortening. Overlying strata can be deformed independently from the underlying basement only in the case of decollement. This possibility can be ruled out because of the character of the contact and the properties of the Silurian limestones directly at the unconformity.

The second clue lies in the conditions of deformation during the Acadian (?) orogeny. The Acadian (?) folds attest to deformation at a relatively shallow depth at which the rocks must have been essentially brittle above the unconformity and to some depth below it. This is shown by the flexural slip folding of the formations above the unconformity, as this mechanism involves a minimum of plastic deformation during folding. The Austin Glen Graywacke underneath the unconformity could not undergo further flexural slip folding. The bedding in the Austin Glen Graywacke was already too highly inclined to the tectonic force to permit the process of folding to operate within the layers. Furthermore, the Taconic folds had reached the limit of tightness to which folding could proceed and their dimensions did not fit the new folds that were forming in the overlying strata.

Bedding planes along which slip could occur were truncated by the unconformity. If flexural slip folding took place, slip along the bedding planes would offset the plane of unconformity. The same result would be produced by slippage along fracture planes: faulting. Where the angle between the unconformity and the bedding in the underlying strata is small to moderate, flexural slip folding still could take place. Where the bedding planes that actually permit slip are widely spaced, slip along these bedding planes produces a fault that follows bedding below the unconformity but is propagated across the bedding above the unconformity as was demonstrated by H. Cloos in 1917. The Taconic unconformity differs from the one studied by Cloos along the margins of the Harz Mountains in Germany by much tighter folds underneath the unconformity, consequently folding is at most a minor mechanism in the deformation of the underlying rocks. Limited analogies also exist between the folding of the Taconic unconformity and folding of the unconformity between basement complex and sedimentary cover in the Rocky Mountains during the Laramide orogeny (LeMasurier, 1970, Hudson, 1955).

The folds of the Silurian and Devonian limestones act as a measure of the amount of deformation the rocks underneath the unconformity actually

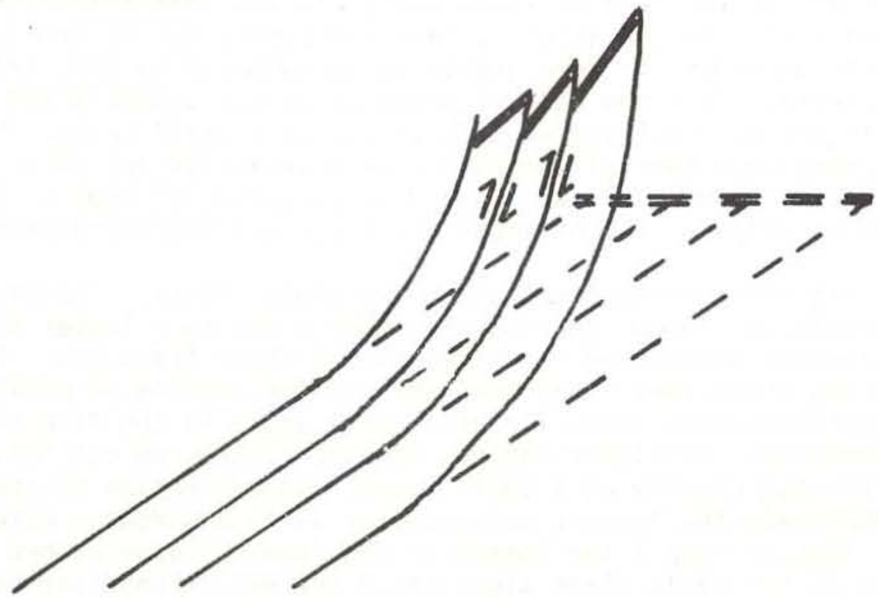

Fig. 2. Offsets of unconformity produced by folding of underlying strata. (schematic diagram modified after Cloos, 1917)

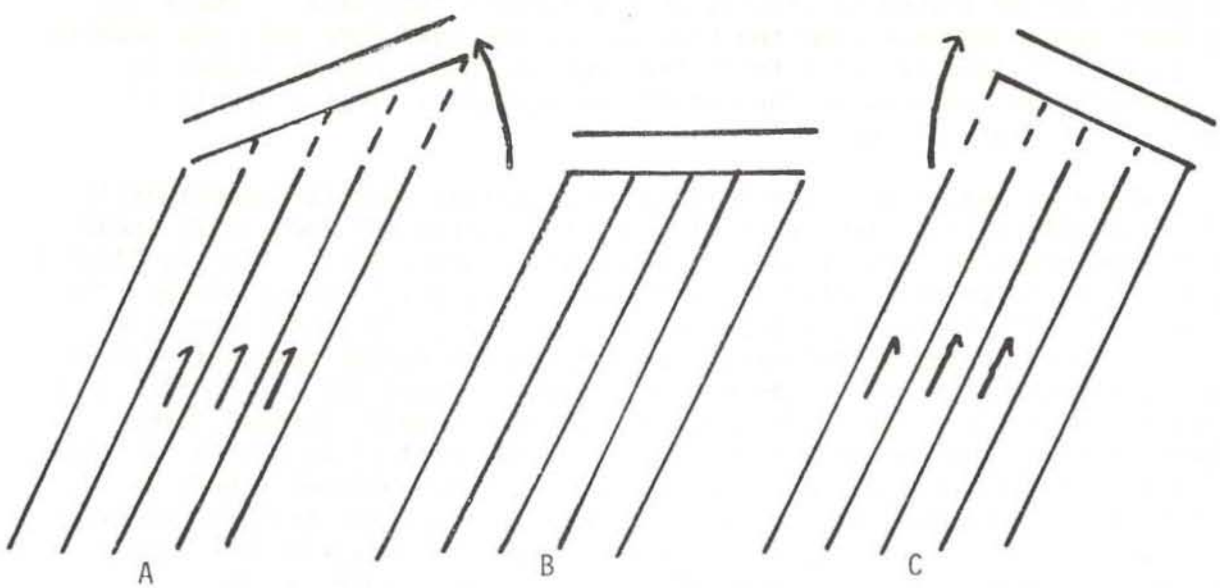

Fig. 3. Changes in angle of unconformity from original angle (B) decreasing (A) or increasing (C) as overlying strata are folded while underlying units are displaced parallel to themselves.

have undergone. The folds indicate extension in a direction that lies in the axial surface of the fold at right angles to the fold axis. In a direction perpendicular to the axial surface shortening has occurred. The rocks below the unconformity were unable to accommodate to this deformation by further folding. Thus the bulk of deformation was accomplished by slip along shear fractures: faulting on a small and very small scale. Much of the movement must have been of the nature of translation but small amounts of rotation are evident. This was caused by curvature of some of the shear fractures and by intersection of shear fractures and bedding planes (Fig. 4).

Two factors affected movement along the shear planes. The direction of planar structures, in our case mainly bedding but to a lesser extent also slaty cleavage determined the direction of shear fractures. Donath (1962, 1965) has shown that shear fractures follow bedding or previous cleavage directions where these lie at a small angle to the direction of maximum compression. At higher angles the shear fractures cut obliquely across bedding, but usually at a small angle. The direction of shear fractures underneath the Taconic unconformity is in accordance with these principles. Thus at stop 7 the bottom of the lowest graywacke bed in the syncline acts as the fault plane along which the entire snycline has been faulted against a predominantly shaly sequence. (Fig. 1). On the other hand in almost every outcrop we find graywacke layers cut off by shear fractures oblique to the bedding.

The thickness and spacing of graywacke beds controls the spacing of the shear fractures. Where graywacke beds are thick and closely spaced, shear fractures tend to be widely spaced and form few but conspicuous faults. At stop 7 a sequence of several small folds forms a single block a few tens of feet across which has moved as one unit. Faults bounding such large rigid blocks must have had considerable effects on the limestones overlying the unconformity. They could accommodate themselves to large offsets at the bottom of the unconformity only by faulting (Stop 4) or by sharp flexures (Stop 6). Many faults in the Silurian and Devonian limestones probably can be traced to offsets of the Taconic "basement". Where the younger strata deviate from the kind of regular curvature that one expects to develop in flexural slip folds the probable cause can be sought in irregularities produced in the underlying unconformity as a result of shifting of rigid blocks.

Where graywacke beds are thin and the section consist predominantly of shale deformation also takes place by fracturing but individual shear fractures are more closely spaced, often only inches apart (Fig. 6, Stops 7 and 8). As movement is distributed between innumerable shear planes, the megascopic effect closely approaches that of flow. In such places the rocks underneath the unconformity can accommodate themselves perfectly to the curvature of folds in the overlying beds by what amounts to flow in a statistical sense. The folds thus can assume a regular rounded form. Where intense shearing of the rock went to the point of an overall effect of flow deformation individual slivers of shale and graywacke were torn out of their stratigraphic context and the rock mass was transformed into a tectonic breccia (Fig. 6) which in appearance closely resembles some tectonic melanges such as those illustrated by Hsu (1968, pl 1).

As a result of folding the limestones of the Silurian and Devonian were rotated through angles of as much as 90^{o} and occasionally even more. Below the unconformity deformation consisted mainly of slip along fractures and bedding planes. In this process some individual blocks and slivers of rock were rotated, but rarely through angles of much over 30^{o}. The aggregate effect of this deformation more closely approaches translation than rotation so that the overall average orientation of the older

Fig. 4 Graywacke block partly bounded by shear fractures (left of hammer). Intensely sheared shale acts as filler. Stop 5

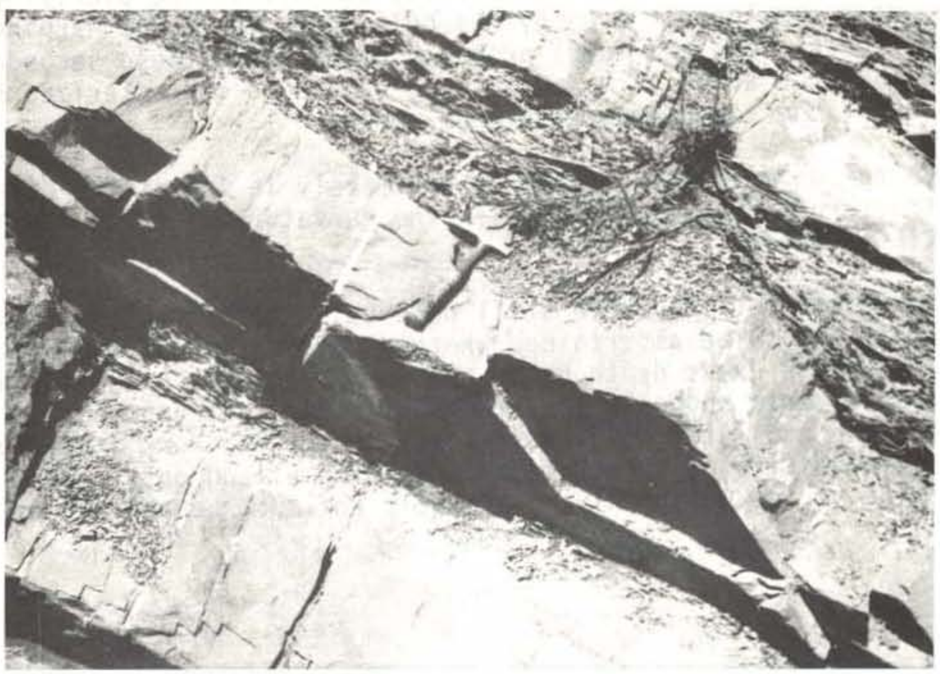

Fig. 5 Tension gashes in graywacke bed. (Close-up of part of structure seen in Fig. 1.

structures did not change. As a consequence the angle between the plane of unconformity and the underlying strata had to change. The angle could increase or decrease, depending on the dip of the bedding below the unconformity and the sense of rotation of the overlying strata. (Fig. 3). In most cases the angle at the unconformity would decrease. If the angle of unconformity changes, the unconformity itself tends to be torn open except in cases of extreme fracturing of the underlying rocks. At Stop 5 quartz veins can be found marking the unconformity.

While the overall deformation during the Acadian (?) orogeny was compressional in nature, the geometry of the folds above the unconformity requires extension in direction of the axial plane of the folds as a secondary effect, particularly in the cores of anticlines. Graywacke layers oriented in directions close to that of the axial surface of the folds therefore show tensional fractures which tend to be occupied by quartz veins. Boudinage can be observed in a few graywacke layers (Stop 5). Tension gashes also are present locally in shaly units (Stop 8). There they cut across the slaty cleavage.

REGIONAL IMPLICATIONS

Such features as boudinage, tension gashes in folded beds of graywacke or cutting across slaty cleavage, disruption of bedding by closely spaced shear fractures etc. are all signs of a second orogeny acting upon rocks that already have undergone considerable folding in a previous orogeny. Presence of these features shows promise as a criterion for delimiting areas in which the Taconic orogeny has produced major deformation, even where erosion has removed the unconformity and all of the overlying strata. Areas in which the Taconic orogeny has only produced gentle warping of the strata in typical foreland folds probably do not show these secondary structures but the areas of major folding should be characterized by some combination of the structures mentioned above.

Above the unconformity faults approximately in the strike direction of the structure and irregularities in the curvature of folds may have similar significance.

The criteria outlined here still need to be tested in the field. In particular it has to be ascertained whether deformation of the same intensity persists to a great depth below the unconformity. A cursory application of the criteria suggests that Taconic folding extended not as far west as Acadian and later folding at least in the New York State region. Structures suggestive of strong Taconic folding extend only a very short distance west of the Hudson River, probably not much beyond two miles.

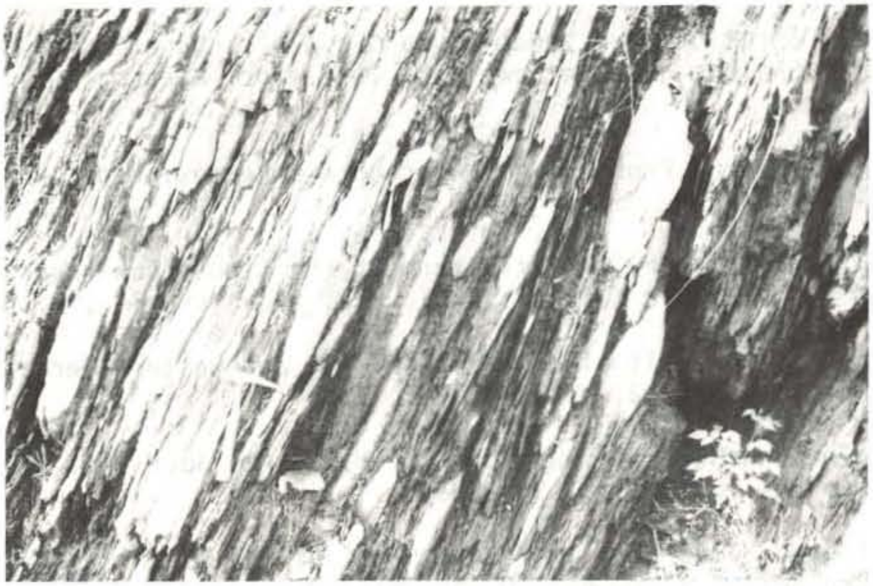

Fig. 6 Tectonic breccia consisting of sheared slivers of graywacke floating in a shale matrix. Stop 8

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ROAD LOG FIELD TRIP B-2

From the Vassar College student parking lot at Raymond Avenue and Route 376 the field trip will turn unto Route 376 (Hooker Avenue) heading west and follow it for approximately 2 miles to a five-point intersection. Bear left onto Montgomery Street at the five-point intersection and follow it for approximately 1/2mile, then turn right on Jefferson Street following it for approximately 1/2 mile to the approach to Mid-Hudson Bridge, turn left onto Mid-Hudson Bridge. The formal road log starts at the west end of the Mid-Hudson Bridge.

Cumulative Mileage	
0.0	West end of Mid-Hudson Bridge. Start of a long road-cut in Austin Glen Graywacke.
1.0	Turn right on Route 9W heading north.
3.5	Turn left on Route 299.
3.6	Note large erratic boulder in road-cut on left side.
5.9	STOP 1 (not included in Sunday trip). Beds of sandstone and shale in the Austin Glen Graywacke exhibit here very regular structures indicating that only one orogeny produced major deformation in this locality. Good slaty cleavage developed in shaly layers.
6.9	Slate in road cut.
8.6	Entrance to New York Thruway at left.
9.4	Entering Village of New Paltz.
9.5	Junction Route 32, proceed straight ahead.
9.9	Turn right on Route 32 heading north.
10.1	Another right turn following Route 32.
10.8	For next two miles there are several small road cuts in shale (possibly Snake Hill).
14.7	Turn right on Route 213.
15.0	Underpass under New York Thruway.
15.2	Outcrops of Austin Glen Graywacke show only gentle deformation.
15.6	Bear left following Route 213.
16.1	Enter Rifton.

20.6 STOP 2. Two roadcuts in the Austin Glen Graywacke show some of the variations in lithology in the unit. Again the structure is very simple, suggesting that the Taconic orogeny had little effect at this locality.

21.2 Bridge across Rondout Creek.

22.2 Gravel pits on left side of road.

22.7 Turn left on Wilbur Avenue following Route 213.

23.9 Turn right at traffic light following Route 213.

24.0 After one block turn left on Clinton Following Route 213.

24.1 Turn right, junction Route 32.

24.4 Turn right on Route 28 heading east (Broadway).

25.1 Turn left on Route 9W.

26.4 Junction Route 32, continue straight.

26.5 Roadcut in Onondaga Limestone.

26.9 For next mile outcrops of Onondaga in roadcuts and in back buildings.

28.5 Turn right on Route 199.

28.9 Road cut in Espous and Schoharie Formations.

29.2 STOP 3. Anticline in Lower Devonian Becraft, Alsen and Port Ewen formations exposed in roadcut on both sides. The regular curvature for the formations is characteristic of flexural slip folding where there are not complications caused by the underlying rocks.

29.5 Road cut in Coeymans, Kalberg and New Scotland formations

29.6 Turn right on exit to Route 32.

29.9 Turn left on Route 32 heading south.

30.2 STOP 4. The Austin Glen Graywacke forms the bottom part of the outcrop at the north end. It is unconformably overlain by the Rondout Formation but the unconformity itself is not well exposed because of weathering of the contact. A number of faults cut through the limestones above the unconformity. Their presence lets one to expect massive graywacke underneath the unconformity. Continue south.

30.7 STOP 5. One of the best outcrops of the Taconic unconformity in the Hudson Valley. In places the unconformity is torn open into a tension gash and occupied by a quartz vein. Walking a short distance south along the outcrop one can see numerous slickensided shear fractures, blocks of shale displaced along curved or irregular shear fractures and rotated as a result so that the directions of the slaty cleavage vary in the outcrop. Note the contrast between the highly complex and irregular structure in this outcrop and the very simple and regular structures at Stops 1 and 2.

31.6 STOP 6. (not included in Sunday trip) Sharp flexure in Schoharie Formation. It probably lies in the continuation of a fault separating relatively large rigid blocks below the unconformity.

32.6 Junction Route 9W. Turn right retracing route to Route 199. (On Saturday we will depart from regular field trip route at this point to go for a lunch stop in Kingston. After lunch we will pick up the road log at this point again heading north on 9W).

34.7 Turn right on Route 199.

35.9 Continue straight past exit to Route 32.

36.2 Toll booth, Kingston-Rhinecliff Bridge.

38.0 STOP 7. Long roadcut. A variety of structures can be observed on the north side of the highway. A series of folds including chevron folds and isoclinal folds in a predominantly graywacke unit has moved as a single rigid block. It is in fault contact (Fig. 1) with a predominantly shaly sequence that is intensely sheared so that the original continuity of the beds is destroyed. Tension gashes can be seen cutting some graywacke beds. Shale layers in the chevron folds are greatly thickened in the hinges by flow folding. Some graywacke layers exhibit sole markings at their bottom.

38.6 Folds in Austin Glen Graywacke.

39.2 Junction with Route 9G, turn left following Route 199.

41.1 Turn right following Route 199.

41.2 Roadcuts in Austin Glen Graywacke.

42.2 Entering Red Hook.

42.8 Intersection with Route 9. Continue straight ahead following Route 199.

45.1 Note quartz veins in outcrop at right.

45.2 STOP 8. Intensely sheared shale and graywacke. In places the strata have been turned virtually into a tectonic breccia with an appearance resembling a melange. Note slivers of graywacke floating in a shale matrix. The direction of the slaty cleavage is variable. Close study is needed to determine whether two intersecting directions of cleavage actually exist or whether different slices of shale have been rotated out of their original position.

46.5 Turn right on Route 308. Follow Route 308 to junction with Route 9 and follow Route 9 to Poughkeepsie and return to starting point.

Trips B-3 and C-3

STRATIGRAPHY AND PALEONTOLOGY OF THE BINNEWATER SANDSTONE FROM ACCORD TO WILBUR, NEW YORK

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The Binnewater Sandstone was first recognized as a stratigraphic unit by Hartnagle (Binnewater quartzite, 1905, p. 346). It has long been recognized in outcrop within a narrow, structurally complex belt extending nine miles southwest from Wilbur (just south of Kingston) to High Falls. In addition, the Binnewater Sandstone has been recognized in bore holes just west of High Falls (Berkey, 1911, p. 132), near Accord (Port Jackson) (Johnsen and Waines, 1969, p. 30) and near Wawarsing (Bird, 1941, p. 276-278). These borings are located eight tenths, six and twelve miles southwest of High Falls respectively so that the total linear extent of the Binnewater as presently recognized is about twenty-one miles.

The Binnewater Sandstone thickens progressively from Wilbur where 4.3 feet have been measured on the east bank of Roundout Creek to about thirty feet in the Rosendale area to about forty feet at High Falls to about sixty at Accord. Bird's stratigraphic columns for Wawarsing (1941, p. 276-278) indicate 125 or 170 feet depending on the scale of the column used. According to his lithologic descriptions the thickness is more likely 85 or 105 feet. In addition, the scale in his column on page 278 seems to be in error. North and east of Wilbur the Binnewater has apparently been removed by pre-Rosendale erosion.

The lithology of the Binnewater is variable. From High Falls northeast to Wilbur it is predominantly a slightly dolomitic, fine to medium-grained quartz arenite with sparse interbeds of dolomitic shale and argillaceous dolostone. Southwest from High Falls interbeds of dolomitic shale and argillaceous dolostone tend to increase at the expense of the sand content. Non-sand content increases southwest from High Falls to Accord to Wawarsing from about five to fifty to apparently seventy per cent.

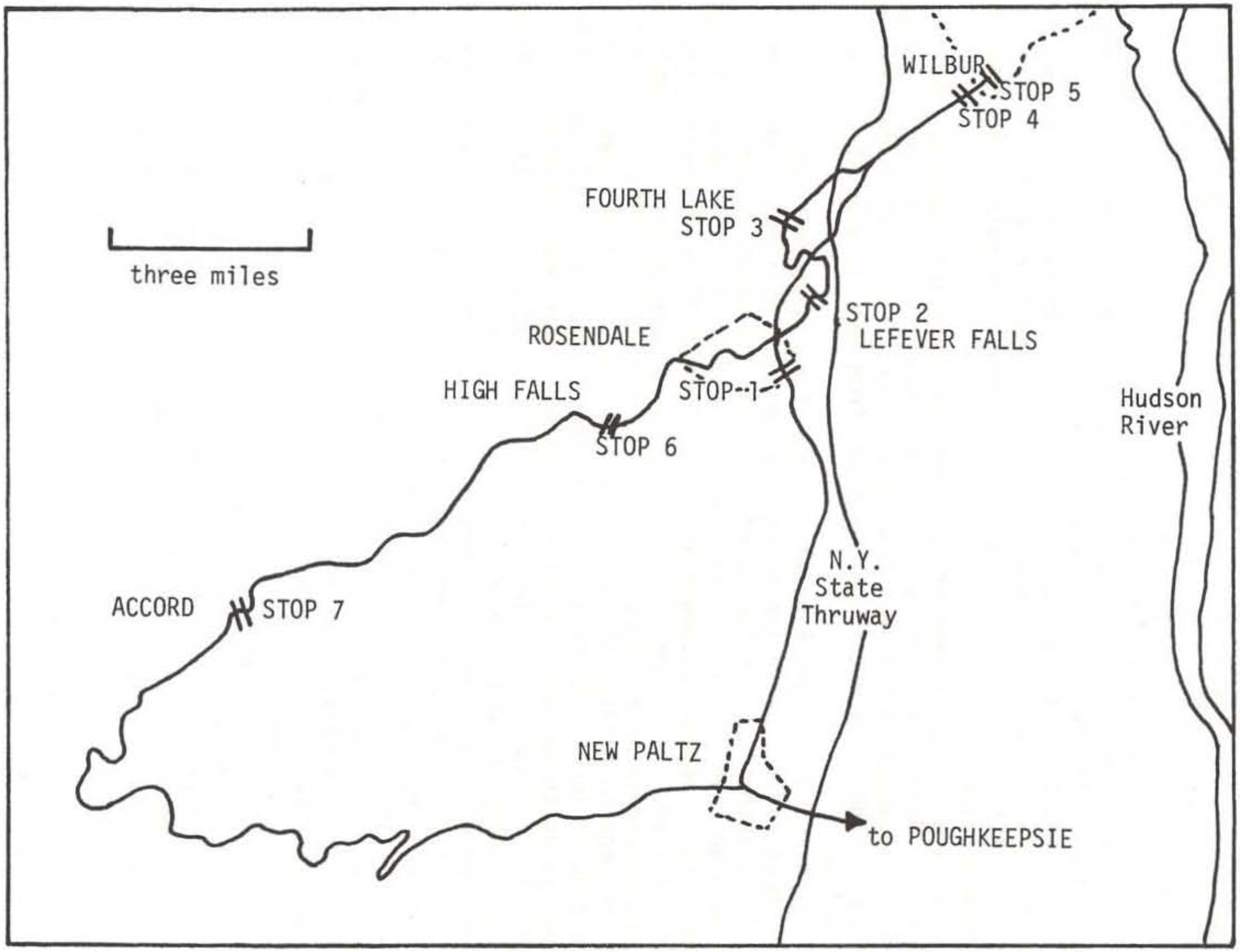
The sandstones of the Binnewater are generally dark grey to light grey to white, weathering orange to buff to grey to white. Increase in dolomite content is attended by an increasingly orange to rusty appearance when weathered. Shales and dolostones within the Binnewater may be dark grey to light grey-green. Again, increasing dolomite content is accompanied by an increasingly darker rusty color. Distinct red coloration more typical of the High Falls Shale may occur in sandstones, shales or dolostones and varies from traces at High Falls to about 15 per cent in drill core at Accord to perhaps as much as 30 per cent at Wawarsing.

From Wilbur to Accord and apparently to Wawarsing the Binnewater Sandstone is in contact with the overlying Rosendale Member of the Rondout Formation. From Wilbur to Accord the contact is disconformable although perhaps conformable at High Falls (STOP 6). Discontinuous concentrations of pyrite may mark the contact as at Wilbur (STOP 5). From Rosendale to Wilbur the contact may exhibit vermiform borings into the Binnewater which are filled with carbonate of Rosendale lithology. Relief along the contact rarely exceeds one inch.

For the most part the Binnewater Sandstone overlies the High Falls Shale but from a point about 0.6 miles south of STOP 5 northeast to the termination of Binnewater outcrops the lower contact is in angular unconformity with Ordovician shales, siltstones and greywackes. Where the Binnewater overlies the High Falls the contact seems to be conformable to gradational, or at times disconformable. In the Rosendale area, between longitudes $74^{o}3'30''$W and $74^{o}5'00''$W, a thin shale overlying an argillaceous dolostone occurs at the base of the major Binnewater sandstone unit. Occasional thin shale bebbles occur in the basal inch or so of the main sandstone. It would normally be argued that the shale (which does not have a typical High Falls aspect) represents the top of the High Falls Shale. However, thin sand lenses of Binnewater aspect may be seen occasionally in the dolostone underlying the shale. In addition, the dolostone occasionally contains shale clasts and in some localities appears to be a clastic dolostone breccia. For the purposes of this paper the base of the Binnewater is placed somewhere within the argillaceous dolostone layer or at its base.

The title of this paper is, no doubt, somewhat misleading because the fossil content of the Binnewater is very sparse and such fossils as have been found are generally very poorly preserved. Detail is largely destroyed by fragmentation and silicification and fossils are presently known from only five or six outcrops. Most fossils occur in an upper massive sand unit in the Rosendale area which lies between the latitudes of $74^{o}4'10''$W and $74^{o}5'20''$W. These include infrequent fragmentary silicified stromatoporoid coenostea and even more infrequent fragmentary solitary rugose corals. In addition, Ringler (1970, 1971) reported the presence of favositid corals and brachiopods as well as stromatoporoids at STOP 1 near Rosendale. These are also fragmentary and silicified. One or two fragments of stromatoporoid coenostea preserved in the usual manner have been observed on a bedding plane near the top of the Binnewater sequence at High Falls. An ostracod has been reported from the Binnewater at High Falls and another from the Accord Shale equivalent in core taken from a drill hole at Accord.

One of the more interesting occurrences of fossils is at Lefever Falls (STOP 2) where the upper massive sandstone unit is missing due to pre-Rosendale erosion and the Rosendale Dolostone lies directly on remnants of the thin shale which underlies the upper massive unit. In places the shale unit has been stripped away to expose the bedding surface of the underlying main sand unit. Here and there in apparent growth position on this bedding plane substrate are hemispherical, completely silicified stromatoporoid coenostea.



SKETCH MAP

figure 1

Field Trips B - 3 and C - 3

The presence of stromatoporoids in situ on a sandstone substrate suggests a somewhat more marine environment just before and during at least part of the time of shale deposition. The time interval was probably relatively short and preceeded the deposition of the upper massive sandstone unit. The presence of fragmentary fossils in the upper massive unit (including broken stromatoporoid coenostea) suggests that the material was derived from marine deposits to the north and east of the present upper massive sandstone occurrences. Consequently, the upper massive unit seems to represent a recessional deposit formed as the sea margin was withdrawing to the south and west of the Wilbur area.

The only other fossils encountered in the Binnewater are the worm-like borings at the upper contact which were mentioned earlier. It is most likely that these represent life forms of early Rosendale rather than late Binnewater time.

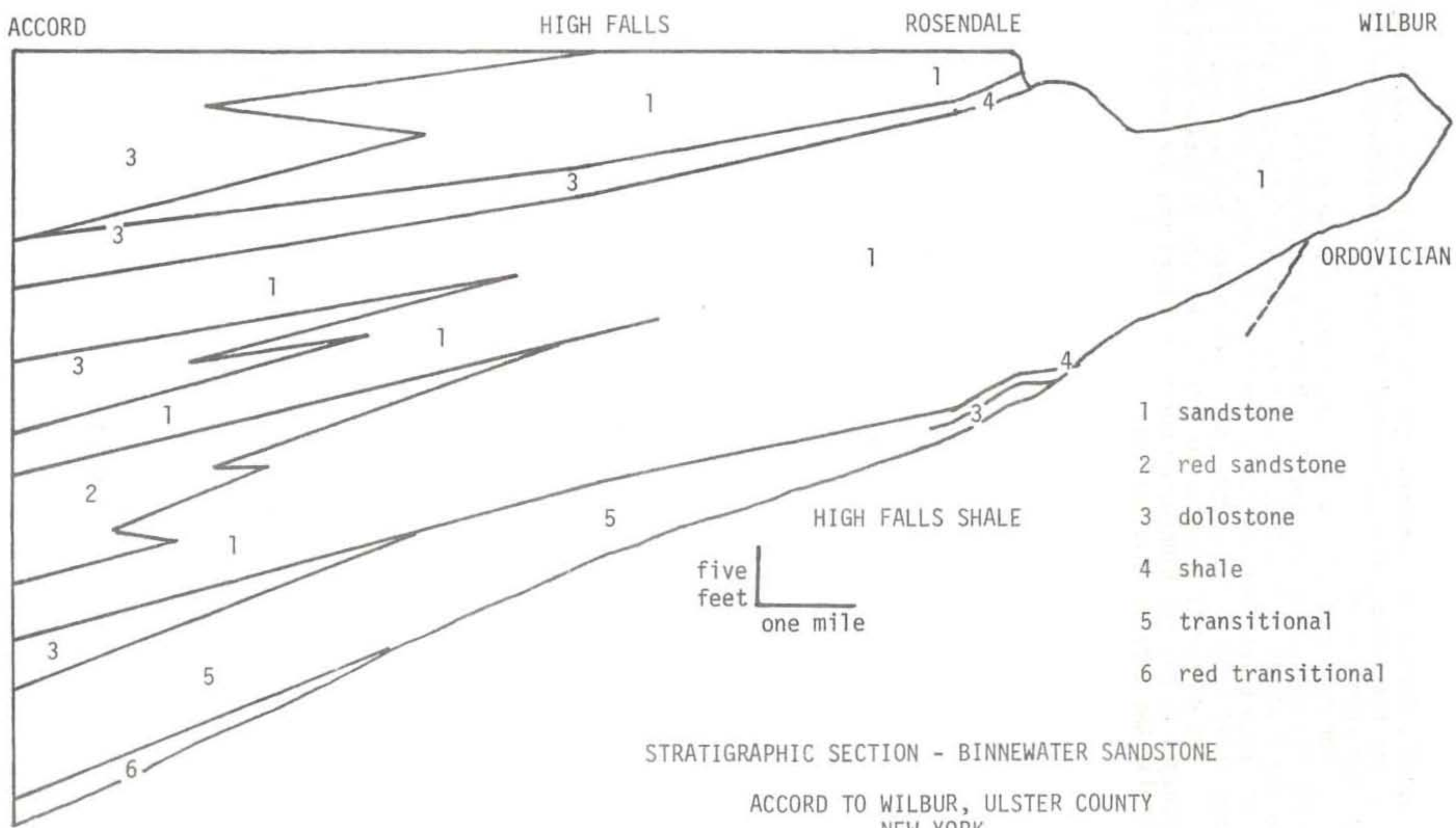
The age of the Binnewater Sandstone has been indicated as Late Silurian - Murderian (part) according to Fisher (1960). The paleontology of the Binnewater is not well enough understood to assist in determining the age so that inferences must be drawn from more datable strata above and below.

Bedding in the main Binnewater sand of the Rosendale area varies from about one to twelve inches in thickness and averages between two and three inches. Cross-laminated beds comprise about 25 per cent of the main unit at STOP 1. Average maximum angles of cross laminae range from 18 to 25 degrees although angles as high as 34 to 36 degrees have been observed. Ripple marks on bedding planes are generally asymmetrical in the Rosendale area indicating waves of translation. Mud cracks are not uncommon on bedding planes in the same area. Erosion channels of more than an inch in depth are rare in the outcrop area, but some up to a foot in depth and up to about ten feet wide have been observed at High Falls and about 0.6 miles south of STOP 5 at Wilbur. Cross laminae in the Binnewater Sandstone are generally tangential and tabular. Topset laminae are generally absent. Current directions as determined by cross laminations and asymmetric ripple marks are markedly bimodal in the sections studies with one mode especially dominant suggesting a back and forth direction of current with a net shift of material in one preferred direction. A tidal flat environment is proposed for the main sand in the High Falls to Wilbur area at least. The bimodal aspect of the cross laminations, the desiccation marks and rare casts of salt hoppers, the asymmetric ripple marks, the relative uniformity of bedding thickness, the tabular nature of the cross laminations, the general absence of erosion channels,deeper than average bedding thickness all point to an environment in which base level is close to that of the level of the sediments and in which there is a persistent net shift of sediments from land to sea. The studies of Ringler (1970, 1971) and Fields (1975a, 1975b) (STOP 1) and of Christianson (1964) (STOP 3) together with studies by the author at several other localities indicate that the providence of the Binnewater lay generally to the east and that the net shift of sediment was generally to the west and possibly southwest.

It would appear that the bulk of the Binnewater represents an onlap from southwest to northeast or west to east during the greater part of Binnewater time. Following a short existence of more open marine conditions offlap accompanied by cannibalization and re-deposition of more upshore Binnewater sediments (as is evidenced by the upper massive unit in the Rosendale area) culminated in complete withdrawal of the Binnewater sea from the area.

The author would like to acknowledge the help, assistance and academic stimulation in the field, laboratory and classroom of the following students at S.U.N.Y., New Paltz: Don Christianson, Terry Ringler, Ruth Ellen Nielson, Harry Dembicki, Sue Mocco, and Ron Fields. Without their contributions, this paper would not have been possible.

The author is grateful to John H. Johnsen of Vassar College who managed to get the Binnewater cored at Accord and for permission to display the core at this meeting.



STRATIGRAPHIC SECTION - BINNEWATER SANDSTONE

ACCORD TO WILBUR, ULSTER COUNTY
NEW YORK

figure 2

ROAD LOG

(Field Trips B-3 and C-3)

Total Miles	Miles Between Points	
0.0	-	Vassar College north parking lot. Exit turning left (west) onto College View Avenue.
0.2	0.2	Continue straight across Raymond Avenue and proceed west on Fulton Avenue, then Forbus Street to Hooker Ave.
1.3	1.1	Turn right onto Hooker Avenue and proceed northwest.
1.5	0.2	Veer left at the traffic light onto Montgomery Street and proceed west.
2.0	0.5	Turn right onto Jefferson Street and proceed north.
2.2	0.2	Turn left on Church Street (US 44 - NY 55) and proceed west.
2.6	0.4	East bank of Hudson River. Pass onto Mid-Hudson Bridge.
3.1	0.5	West bank of Hudson River.
4.0	0.9	Take right lane to US 9W north toward Highland and proceed north.
6.3	2.3	Junction with NY 299. Turn left at the traffic light and proceed west towards New Paltz.
11.5	5.2	N.Y. State Thruway entrance and exit (18) on left. Continue west on NY 299 toward New Paltz.
12.8	1.3	Downtown New Paltz. Elting Memorial Library on the right. Turn right (northwest) and continue downhill to NY 32.
12.9	0.1	Turn right at stop sign and proceed north on NY 32.
17.6	4.7	Bridge over Wallkill River.
19.5	1.9	Park on right beside road cut towards bottom of long hill. Pull well off road because of fast traffic.

STOP 1: Complete exposure of Binnewater Sandstone can be seen at this stop; including upper contact with Rosendale Dolostone, upper massive sandstone unit, poorly developed underlying shale unit, main cross-laminated sandstone unit, lower shale unit, bottom dolostone breccia unit and possible lower contact with the High Falls Shale. Cross-laminations, ripple marks and desiccation cracks can be observed in the middle unit. Casts of salt hoppers have been found in the upper part of the middle unit and will be displayed in the Geology Department at Vassar College at the conclusion of this trip. Studies of cross-laminations by Ringler (1970, 1971) and of sand grain orientations by Fields (1975a, 1975b) indicate a preponderant net shift of sediment to the northwest (N36^{o}W) with a statistical allignment of long axes of sand grains (N80^{o}E-S80^{o}W). This may indicate that the bulk of the sand grains progressed northwestward as

"rollers" rather than as "sliders". A tidal flat environment is proposed for most of this section.

Caution - This road cut has become increasingly unstable over the years. Watch out for falling rocks and blocks!

Return to transportation and proceed north on NY 32.

21.1 - 0.6	Bridge over Rondout Creek.
21.2 - 0.1	Turn right onto Creeklocks Road and proceed northeast.
22.0 - 0.8	Lefever Falls below to the right has been somewhat modified by the U.S. Army Corps of Engineers.
22.1 - 0.1	At bottom of hill after passing through a decending left-hand curve park on loading platform on the right. This platform once served barges berthed in a turning basin of the Delaware and Hudson Canal. The canal was last used around the turn of the Century. Walk back uphill on Creeklocks Road about 300 feet or where the road turns sharp left. Turn right and proceed into the woods over a low mound. Head north on the trail beyond the mound for about 300 feet. Follow the trail which now turns sharp left and proceed uphill on the trail to the Lefever Falls Mine entrance.

STOP 2: Caution - Please do not fall into the mine as accidents will impeed the progress of this field trip and we are on a tight schedule! Do not crowd one another near the edge of the mine!

A nearly complete section of Binnewater Sandstone can be seen at this stop in the southwest wall of the mine entrance. It is not as well exposed as that in STOP 1 due to cover by mosses and lichens. The upper massive sandstone has been removed by pre-Rosendale erosion. The shale beneath is not exposed but can be seen several hundred feet to the south on the dip slope of the top surface of the main sandstone unit. The contact between the shale and the overlying Rosendale Dolostone can be observed in the vicinity only with difficulty. The lower shale unit and the bottom argillaceous dolostone unit can be observed on both the north and south walls of the mine entrance. Pass through the archway in the wall on the left (south) and proceed with care past the steeply dipping mine opening on the right. Your first slip may be your last. Continue south for several hundred feet with the dip slope of the main sandstone unit on your left. Where possible, examine the slope for signs of silicified, hemispherical stromatoporoid coenostea in growth position. Should you find one please do not collect it as our studies of this location are not completed. Continue south until the upper shale unit is reached and can be examined. The significance of this locality is discussed in the text.

Return with care to transportation on Creeklocks Road and continue northeast.

22.3 - 0.2	Turn left on Lefever Falls Road and proceed north parallel to N.Y. State Thruway.
22.9 - 0.6	Map Hill - Turn right onto Old Route 32 and proceed west.
23.1 - 0.2	NY 32 - Proceed across and continue on Old Route 32 which bears toward the south.
23.6 - 0.5	Bear to right at junction and continue on Hickory Bush Road which bears north.
24.6 - 1.0	Cross Penn Central RR tracks and park on left side of road. Return to tracks and bear right. Walk about 1200 feet to the southwest.

STOP 3: A complete section of Binnewater Sandstone can be seen with all units as at STOP 1 but the upper dolomitic shale unit is much more clearly defined. The relief on the top of the upper massive sandstone unit can be seen on the dip slope of the floor of the mine where the overlying Rosendale Dolostone has been removed. The Binnewater - High Falls contact probably lies within or at the base of the lower argillaceous dolostone unit. Studies of cross-laminations and ripple marks by Christianson (1969) indicate a marked net shift of sand toward the southwest (S75^{o}W). Some yewars ago Susan Mocco, a student in the Dept. of Geological Sciences at S.U.N.Y. New Paltz, studied this section extensively to determine if there was indication of periodicity in the lithological variation within the main sandstone unit. The variation appears to be more random than periodic. Note the silicified stromatoporoid coenosteum in the upper massive unit, and flat shale pebbles in the bottom of the main sandstone unit.

Caution - As at STOP 2, please avoid falling into the mines as it will unnecessarily delay the trip!

Return to transportation and proceed north on Hickory Bush Road - now Whiteport Road.

25.3 - 0.7 Pass under Penn Central RR tracks then N.Y. State Thruway.

25.5 - 0.2 Whiteport

26.1 - 0.6 Turn left and proceed north on Byersdorfer Street.

26.2 - 0.1 Highway 32 - Proceed left (north) with caution.

26.4 - 0.2 Turn right onto DeWitt Lake Road which bears east then north.

27.2 - 0.8 Veer left onto Mountain Road and continue north.

27.9 - 0.7 Park on right just before junction with NY 213. Walk back (south) facing traffic along Mountain Road about 300 feet then cross to uphill side opposite road cut.

STOP 4: Caution - The roadway is narrow and local drivers often speed along this stretch. At this location the main sandstone unit is all that remains of the Binnewater at this latitude and it is in distinct contact with the High Falls Shale. The lower shale unit and the bottom dolostone unit are missing, probably indicating an onlap relation with the High Falls in an apparent northeast direction. The High Falls at this location is an uncharacteristic, poorly sorted, argillaceous, quartzose, quartz pebble-bearing material which was mistaken for a basal unit of the Binnewater sandstone by Waines and Sander (1968, p. 18).

Return to transportation and proceed straight ahead (north) and onto Abeel Street with caution. NY 213 enters from the right.

28.0 - 0.1 Pass under Nytralite conveyor.

28.5 - 0.5 Entrance to City of Kingston gravel pit on the left (west). Pull off to the left with caution and park in the entrance. Walk uphill past the gate about 200 feet.

STOP 5: At this location the Binnewater Sandstone consists solely of the main sandstone unit which is completely exposed at the north end of the outcrop. The unit consists of an upper dark, somewhat silicified portion and a lower lighter colored portion. This subdivision occurs only locally. Cross-lamination is primarily confined to a very narrow zone. Dolomitic content in this section is uncharacteristically high. The Binnewater-Rosendale Dolostone contact is delineated by a discontinuous line of bleeding pyrite and can be closely observed at the north end of the outcrop. The Binnewater-Ordovician contact can best be seen near the base of the outcrop several tends of feet south of the main exposure of Binnewater. The contact is in angular unconformity with Ordovician shales, siltstones and greywackes. Quartz pebbles occur within the base of the Binnewater up to several inches above the contact. In several large blocks of Binnewater Sandstone which have fallen forward from the outcrop a cross-laminated, ripple-marked, mud-cracked bedding plane can be observed along with the Binnewater-Rosendale contact. Preliminary estimates of net sand transport from cross laminations indicate a general net shift to the south.

Return to transportation and turn right with caution onto Abeel Street. Proceed south.

29.1 - 0.6	Stay right onto Mountain Road.
29.8 - 0.7	Veer right onto DeWitt Lake Road.
30.6 - 0.8	Turn left onto NY 32 and proceed south.
33.9 - 3.3	Veer right onto NY 213 just opposite Creek Locks Road on left and pass through Village of Rosendale.
34.7 - 0.8	Pass under Penn Central R.R. trestle.
35.8 - 1.1	Bridge over Rondout Creek.
37.7 - 1.9	High Falls and Central Hudson generating facilities (not operating) on right. Park in entrance on right or on opposite side of road where possible.

STOP 6: Walk north to edge of Rondout Creek and observe falls from platform. Do not crowd! Upper contact of Binnewater Sandstone with Rosendale Dolostone occurs near base of falls and can be observed only with difficulty if at all. A complete exposure on the far side of the river is not accessible on this trip. Continue downhill (east) on paved road and observe exposure of Binnewater on right (south). This sequence lies somewhere in the middle and lower part of the Binnewater. Generally the Binnewater is not quite the same as in the Rosendale area. The sands especially in the lower part become somewhat vugular and tend to be more dolomitic.

Occasional traces of red coloration begin to appear. The lowermost five feet or so are somewhat transitional to more typical High Falls lithology. The lower part of the section is in some ways more akin to that in the Accord drill core which will be displayed at Vassar at the conclusion of this trip.

Return to transportation and proceed west on NY 213.

37.8 - 0.1 Bridge over Rondout Creek.
37.9 - 0.1 Turn left onto Lucas Avenue and proceed south.
43.2 - 5.3 Junction with US 209. Turn left and proceed south.
44.0 - 0.8 Turn left (south) with care off US 209 and cross bridge over Rondout Creek into Accord (Port Jackson).
44.1 - 0.1 Turn right onto side road just past bridge.
44.2 - 0.1 Road fork. Bear right.
44.3 - 0.1 Bear right onto main road, then immediately right onto dead end road. Proceed 0.1 miles bearing left then right into Town of Rochester Highway Department yard. Park. Walk a short distance southeast over abandoned road and descent into abandoned railroad cut. Walk to west end of cut.

STOP 7: Here the Rosendale Limestone contains a highly arenaceous unit at the base which disconformably overlies a laminated, soft-weathering, argillaceous dolomit with the fissility of shale. This has been referred to as the Accord Shale by Fisher (1959). Drill cuttings of the top six feet of this unit obtained in a nearby quarry were examined for insoluble residues through six inch intervals by Ruth Ellen Nielson, a student at S.U.N.Y. New Paltz several years ago. All residues proved less than half the samples by weight; generally between thirty and forty-five per cent. Harry Dembicki, another student, determined a general fifty-fifty ratio in the Ca/Mg ratios in the dissolved portions of the samples suggesting dolostone. According to drill core taken in a nearby boring, this argillaceous dolostone unit is about 14 feet thick. The disconformable contact with the overlying Rosendale Limestone can also be seen in the same core. There is a possibility that ostracods may be found in this outcrop. One was encountered in the drill core in about this interval. Possible relation of this dolostone to the Binnewater

Sandstone at High Falls is indicated in figure 2.

Walk back to transportation and return to main road.

44.7 - 0.4	Turn right (southwest) onto Granit Road.
44.8 - 0.1	On left is quarry mainly excavated in Rosendale Limestone. Road skirts northwest side of quarry. Drill core mentioned at STOP 7 was taken on far side of quarry.
47.0 - 2.2	Entrance to the Granit.
47.4 - 0.4	Junction. Bear left.
47.7 - 0.3	Cross Bridge then bear right.
48.6 - 0.9	Turn sharp left onto US 44 - NY 55 and proceed southeast.
57.2 - 8.6	Junction NY 299. Turn left and proceed east towards New Paltz.
63.0 - 5.8	Bridge over Wallkill River.
63.4 - 0.4	Junction with NY 32 North on left. This brings us back to Mile 12.8 on the outward bound portion of this trip. Return to Vassar College in reverse order of the road leg.
76.2 - 12.8	Turn right into north parking lot of Vassar College. The drill core of the Binnewater Sandstone obtained at Accord will be displayed in the Geology Department.

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STRATIGRAPHY AND STRUCTURE OF SILURIAN AND DEVONIAN ROCKS IN THE VICINITY OF KINGSTON, N.Y.

Kenneth Pedersen, Michael Sichko, Jr., Manfred P. Wolff

I. INTRODUCTION

On this trip the lower contact of the Rondout formation will be observed at two locations (Fig. 1). In the southernmost exposure at Tillson Hill the Rondout lower contact is sharp to gradational with the Binnewater sandstone. The significance of this contact is that it is in paraconformity or conformable with the earlier Silurian rocks.

At stops two and three to the north of Kingston (Fig. 1) the lower contact of the Rondout formation lies in angular unconformity to the Ordovician Normanskill formation. At these two northern stops the Shawangunk conglomerate, High Falls shale and Binnewater sandstone are all missing. There are three possible hypotheses which may explain this:

a. The northern area was being eroded while the southern area was submerged for deposition (a Silurian shoreline).

b. The northern area was undergoing deposition and later erosion. Thus, eroding the unconsolidated earlier Silurian sediments (a regressive sea).

c. In the later Devonian time, the entire area was thrust faulted and the angular unconformity is a thrust fault plane.

The authors favor explanation "a" since the missing formations are all thinning in a northeasterly direction although there is some evidence in support of each hypothesis

In the later Silurian the upper part of the Rondout formation was gradationally deposited with the Thacher limestone of Early Devonian. The Silurian-Devonian time division has therefore been placed within the upper Rondout formation (Rickard, 75). The Early Devonian was characterized by rather low energy environments in which a general carbonate and calcareous mud sequence was deposited.

The lower Devonian carbonates are exclusively marine, although the energy levels vary indicating fluctuations in sea level throughout the area. The lowermost Thacher limestone is variable from low to high energy levels perhaps tidal to subtidal while the Thacher is biostromal near the top.

From the overlying Ravena limestone through the Kalkberg limestone and New Scotland formation the energy levels fell off and the sea level was rising until the depth exceeded 200 feet at local wave base level. This sequence was followed by a recession of the sea during the deposition of the Becraft limestones. The environments deepened again during the deposition of Alsen limestone and the Port Ewen formation.

Fluctuations occurred perhaps during the deposition of the Glenerie formation and stabilized in a deep water environment during Esopus and Schoharie times (Waines, 67).

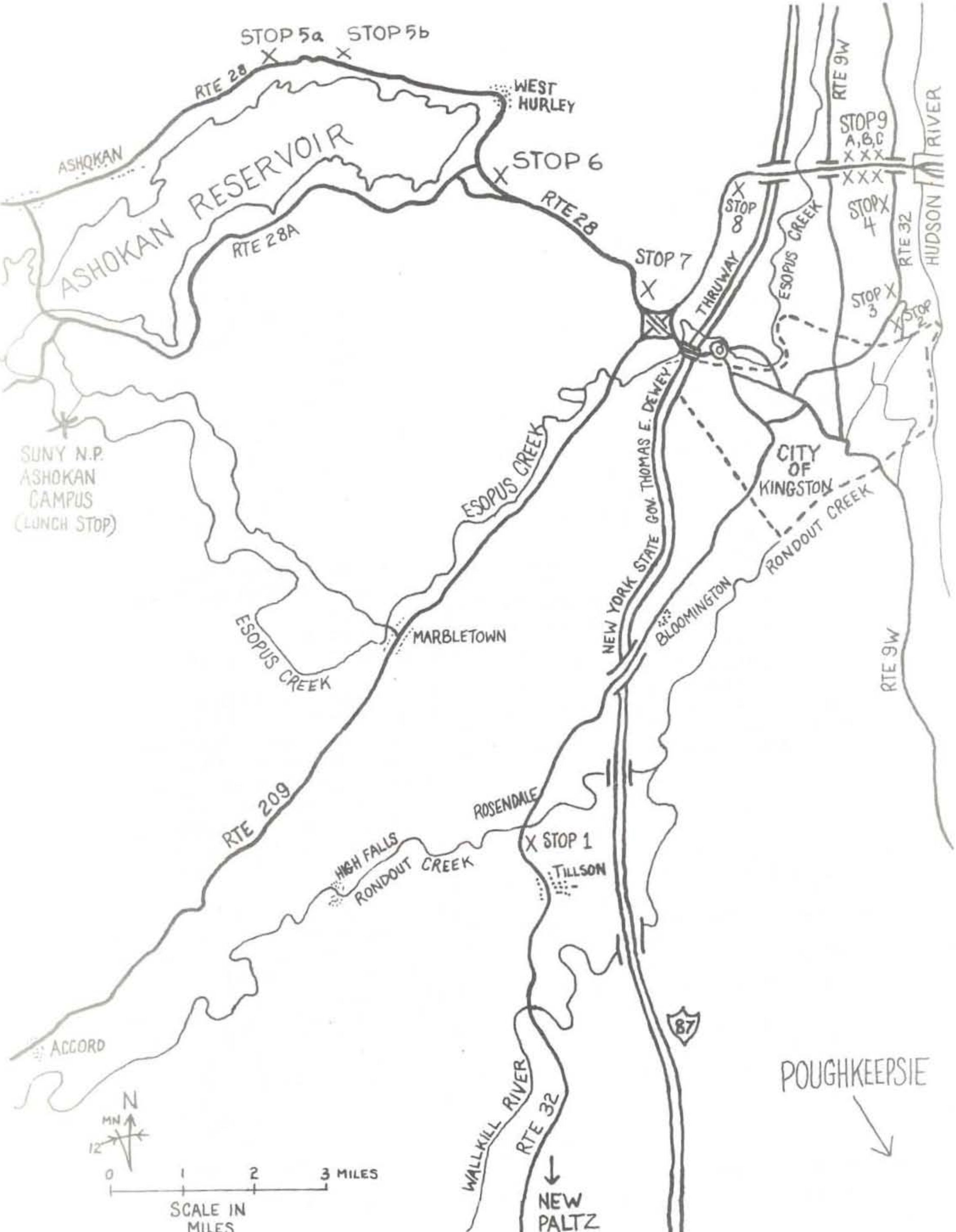

FIGURE 1. ROAD MAP.

The Middle Devonian Period is initiated with the deposition of the cherty Onondaga Limestone which has been subdivided into various units (Oliver, 1956, 1962). Only the Edgecliff and Moorehouse members occur in this region. This culminates the lower Paleozoic periods of carbonate deposition; the remainder of the Paleozoic is now characterized by the various clastics derived from the uplifted New England provinces deformed during the Acadian orogeny.

The first major pulse of sediments (Hamilton Group) form a vertical and lateral progradation of marine, coastal, and alluvial deltaic environments that continue to fill the various embayments near the edge of the basin and spread westward across the state - the initial development of the classic Catskill delta or deltaic complex (Barrell, 1913, Chadwick, 1933, Wolff, 1965, Friedman and Johnson, 1966).

This trip will examine some of these sediment phases or "facies" as represented by the Marcellus Formation (Table 1). Each of these units can be traced northward by physical correlation because of the similarity between regional structure (the Hoogeberg escarpment) and depositional strike, and then westward by thickening rates (Rickard, 1964) and paleontological control (Cooper, 1933). The vertical section of rock units and inferred depositional environments seen here are quite similar to those seen southward toward Pennsylvania (Mazzullo, 1973) and northward toward Albany (Wolff, 1969).

The Onondaga Limestone is conformably overlain by the fissile, black, Bakoven Shale which transitionally grades into the Stony Hollow Siltstone. Both of these units are slightly calcareous. They are overlain by a thick sequence of interbedded dark gray shales, siltstones, and massive fine-grained sandstones (Mt. Marion Fm.), and these transitionally grade into the cross-bedded, relatively unfossiliferous, sandstones of the Ashokan Formation. This unit, of variable thickness, is also transitionally overlain by the sandstones and shales of the Plattekill Formation. The presence of red shales and mudstones in place of only olive-green knobby mudstones adjacent to and in conjunction with the cross-bedded sandstones, is used as the facies boundary between these units.

The entire vertical section represents the single initial deltaic progradational sequence followed by a series of at least four other major deltaic sequences (Wolff, 1965, 1969) within the Devonian "Catskill deltaic complex." Road stops (5A-8) will begin at the top of the section (Table 1) in the Plattekill Formation and end at the Bakoven Shale. Previous trips examining the stratigraphy of this area include: Dunn and Rickard (1961), and Wolff (1969).

II, STRUCTURES

The New York sector of the Appalachians is unusual because it includes much of a major recess in the Appalachian mountain chain. The recess is that part of an orogenic belt where the axial traces of the folds are concave toward the outer part of the belt and is notable for the angular intersection of structural trends. The angularity may have been produced by the overlapping and crossing of orogenic trends

TABLE 1

GENERALIZED GEOLOGIC SECTION FOR THE TRIP

FORMATIONS	THICKNESS IN FEET	GENERAL LITHOLOGY
DEVONIAN PERIOD		
Middle Devonian		
Plattekill Fm.	800	Reddish-purple mudstones and siltstones, dark-gray shales and impure sandstone
Ashokan Fm.	300	Bluish-gray sandstone (flagstone), olive-gray shale
Mt. Marion Fm.	800	Gray sandstone and shale
Bakoven Fm.	200	Black shale
Onondaga Fm.	170-180	Gray limestone with dark-gray chert, gray coralline limestone with light-gray chert
Lower Devonian		
Schoharie Fm.	74-222	Medium-gray argillaceous limestone and calcareous mudstone, calcareous mudstone and siltstone with some gray argillaceous limestone; occ. chert
Esopus Fm.	150-200	Dark-gray shale and siltstone
Glenerie Fm.	20-55	Dark-gray siliceous limestone with chert
Port Ewen Fm.	10-100+	Gray argillaceous limestone with interbedded shale
Alsen Fm.	20-25	Dark-gray limestone with some chert
Becraft Fm.	35-50	Gray to pinkish-gray crinoidal limestone
New Scotland Fm.	95-150	Dark-gray calcareous mudstone and argillaceous limestone
Kalkberg Fm.	75	Gray argillaceous limestone and limestone with some dark-gray calcareous shale, dark-gray to gray limestone, gray shale partings, chert at base
Coeymans Fm.		
Ravena Member	20-28	Medium-gray to gray limestone
Manlius Fm.		
Thacher Member	48-50	Dark-gray to medium-gray limestone, occ. laminated; magnesium at base

FORMATIONS	THICKNESS IN FEET	GENERAL LITHOLOGY
SILURIAN PERIOD		
Upper Silurian		
*Rondout Fm.	30-55	
Whiteport Member	4-16	Gray argillaceous magnesian limestone
Glasco Member	10-13	Gray coralline limestone
Rosendale Member	6-27	Gray argillaceous magnesian limestone
Wilbur Member	4-12	Medium-to light-gray limestone
Binnewater Fm.	0-35	Blue-gray to greenish-gray cross-bedded, occ. ripple-marked quartz sandstone
High Falls Fm.	0-85	Red and green shale
Middle Silurian		
Shawangunk Fm.	0-6004	Milky white to gray quartzite and quartz pebble conglomerate
ORDOVICIAN PERIOD		
Middle Ordovician		
Normanskill Fm. (Martinsburg Fm)	2000	Graywackes, black and gray shale and siltstones

*The Silurian-Devonian time division has recently been placed within the upper Rondout Formation (Rickard, 75).

Adapted from J. H. Johnsen 4/67

produced at several different times in the Paleozoic. Probably the first geologist to emphasize the angularity was Arthur Holmes, who used it as an argument for Continental Drift, for he saw the westward convergence of Caledonian and Hercynian trends in the British Isles finally completed by the crossing in the New York recess, where, as noted above, the polarity of the orogenic migration during the Paleozoic reverses (Rodgers, 1967). In the Kingston area the angular intersection of structual trends can be observed.

The Silurian and Devonian formations lie unconformably on Ordovician graywackes, siltstones and shales which have undergone deformation. The Taconic orogeny is represented by the Normanskill-Rondout angular unconformity. The structures produced by tectonic processes in the Silurian and Devonian strata consist of symmetrical and asymmetrical folds and thrust faults which dominate the area, however, a normal fault was observed at the southeastern end of Stop 9 b.

A principal stress determination of the folds at stop 9 a, b, c and the thrust fault at stop 4 clearly indicates that the compressional regimes in this area did change in direction over time. The symmetrical anticline and syncline have their axial planes trending north-south, whereas the thrust planes dip 20° - 30° to the south. The thrust fault at stop 4 has developed a drag wedge which consists of several feet of crumpled, tilted and deformed beds produced when faulting occurred. Secondary calcite veins have filled feather joints which are the tension fractures genetically related to the thrust faulting. These feather (tension) joints are not confined to one side of the fault due to the equivalency of the tensile strength of the rocks on either side.

At stop 3 the Normanskill sandstones, siltstones and shales have reacted differently to the tectonic forces which have effected these rocks. The high angle thrust faults in these beds are evidence of the compressional stresses which acted on these rocks. During the faulting the sandstone and siltstones were the most compenent beds and failed by brittle fracture, the shales (which became phyllitic) behaved incompetently and adjusted themselves by flowage. The resulting structure exhibits rectangular blocks of sandstone and siltstone which have been forcibly plugged into the shales (phyllite) which in turn have flowed into any shape dictated by the moving blocks. This thrust plugging phenomena can be observed in the Normanskill in other outcrops in this area.

At stop 5B in the massive red-green mudstone of the Plattekill formation deep convolutions consisting of rounded synclines with intervening cuspate anticlines can be observed in the lower section of the outcrop (Fig. 6). This structure may have developed during deposition of the bed over initial synclinal troughs or by sliding or slumping after deposition had taken place.

An interesting soft-rock structure can be observed at stop 8 in the sandstones and shales of the Marcellus formation (Fig. 9). The soft rock structures are termed "pull-apart." The pull-aparts formed at the soft-rock stage where hydroplasticity is involved. There was limited hydro-plastic flow after deposition of the full sequence of beds. The sandstone layer which was embedded in the shale reacted differently to the overload compressional stresses at work. This normal stress disrupted the sandstone by lateral extension to produce a 'necking,' with final complete separation of this bed into segments. The more plastically behaving shale flowed around the sandstone segments. Finally, the flowage of the shale layers caused transposition of the sandstone segments so that now they overlap.

III. REGIONAL STRATIGRAPHY AND PALEOENVIRONMENTS OF MARCELLUS FORMATION (MIDDLE DEVONIAN)

A. Previous Work - Correlations

The initial clastic sequences above the Lower and Middle Devonian limestones in this area were described as the Hamilton Group in the first reports of the N.Y. State Geological Survey by Mather (1840) and Vanuxem (1842). The Marcellus Formation was not included as a subdivision until the work of Darton (1894) and this was further subdivided through the efforts of Grabau (1919), Cooper (1933), and Goldring (1935, 1943). Most of the members could not be adequately extended east of Schoharie Valley because of the lack of guide fossils and facies changes, though some suggestions were included (Cooper (in Goldring) 1935, 1943).

An attempt to extend these correlations between central and eastern New York and define the contact between the Marcellus and Skaneateles Formations was based on the last appearance of *Paraspirifer acuminatus* and the first appearance of *"Spirifer" sculptilis* (Wolff, 1967), but these are no longer recognized as guide fossils (Rickard, personal communication, 1969). However, based on the suggested fossil correlations of Cooper (op. cit.) and the application of sedimentologic criteria developed for the recognition of constructional and destructional deltaic phases (Scruton, 1950, Allen, 1965, McCave, 1968) the extension of the members of the Marcellus Formation in east-central N.Y. into the Mt. Marion-Ashokan Formations in this region are still believed to be valid (Wolff, 1969).

B. Regional Lithofacies and Depositional Environments

A recent description and correlation of the Devonian facies for the entire Catskill delta complex was proposed by Fisher and Rickard (1975) - a modification and extension of a previous model (Rickard, 1964). The suggested relation to the lithofacies and environments of the Marcellus Formation is indicated in Figure 2.

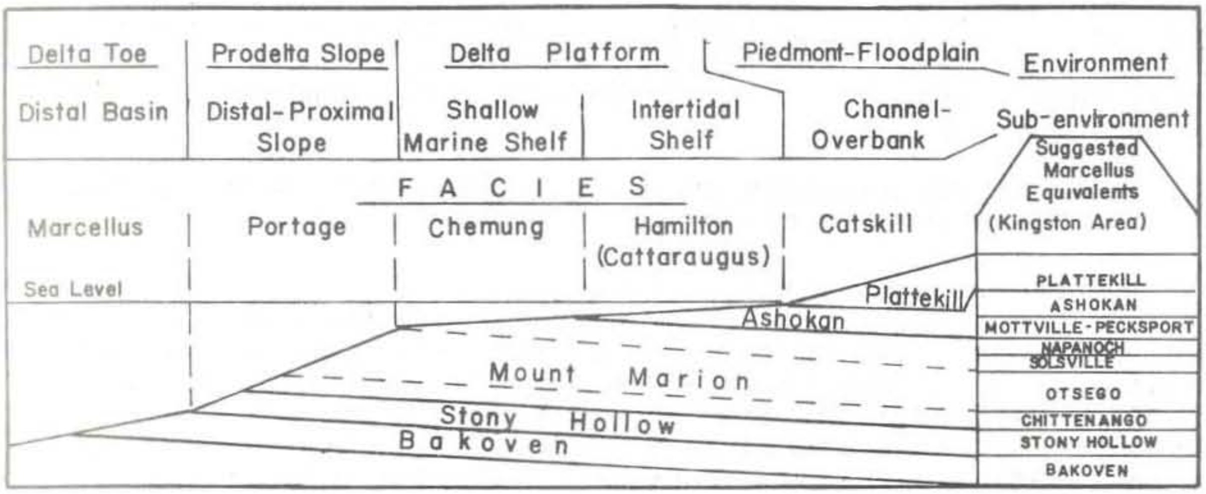

Figure 2. Deltaic environments, facies, and regional-and-local correlations for Middle Devonian Marcellus Formation in the Kingston area.

The following units and their facies and inferred depositional environments can be recognized (top to bottom).

1. Plattskill Formation - Catskill Facies: defined by Fletcher (1963) it consists of medium-coarse grained, large and small scale planar and trough cross-bedded subgraywacke sandstones over an erosional base arranged in upward-fining rhythmic sequences. The upper part of the sequence contains layers of siltstone, mudstone or shale, usually maroon-red or green, and lenses of pebbly conglomerates, mud clasts, and plant fragments. The knobby red mudstones may contain zones or horizons of calcareous nodules, plant root traces, or mud cracks. These have been interpreted by many (Burtner, 1963, Allen, 1968, McCave, 1968) as active and abandoned stream channel and floodplain deposits - the alluvial braided or meandering rivers draining the Devonian piedmont.

2A. Ashokan Formation - Chemung - Hamilton Facies: defined by Grabau (1919) and analyzed by Mencher (1938), it consists of interbedded medium-grained sandstones, (bluestones or "flagstone") massive siltstones, dark gray shales, and olive mudstones. Many of the cross bedded sandstones are laminated; the siltstones cross-laminated (wavy or lenticular bedding). Vertical and lateral contacts are sharp (erosional unconformities and pinchouts) or gradational. Current or wave ripples, load casts, zones of pebbles, mud clasts or plant fragments, iridescent organic films, and burrow mottles or vertical bioturbated structures (Taonurus velum) also occur.

A few brachiopods and pelecypods have been noted (Cooper (in Goldring) 1943, Cooper, 1957).

The thick sets of cross-bedded sandstones are interpreted as marginal alluvial channels and river mouth bars of deltaic distributaries, the thinner, more shallow-dipping and more variably-oriented cross-beds with frequent laminations represent minor distributaries and tidal channels (Wolff, 1969). The associated burrow-mottled gray siltstones and olive mudstones, and the abundance of plant detritus may indicate the presence of adjacent levees and interdistributary swamps. The predominance of the gray-green colors reflects the solution of ferric iron minerals by groundwater. The presence of a high water table and the few brackish-marine fossils support a nearshore coastal position.

A series of lenticular bar-like sandstones interbedded with dark shales and siltstones and low angle cross-bedded sandstones in upward coarsening sequences also can be noted. These may be laterally continuous but are frequently partially eroded by tidal or alluvial channels. They are characteristic of transgressive sequences associated with tidal flats, lagoons, barrier bars and beaches (Reineck, 1972) and have been so interpreted for the Devonian in this region (McCave, 1968, 1973, Johnson and Friedman, 1969, Wolff, 1969).

While now classified as the "Chemung-Hamilton" facies by Rickard (1975) the features and inferred depositional environments are more like his "Cattaraugus" facies except for the absence of redbeds and a brachiopod-crinoid fauna. They are intertidal rather than subtidal features - more like the original "Smethport" phase as originally defined by Rickard (1964). Perhaps a designation as "Hamilton" (restricted) would be more appropriate.

2B. Upper Mt. Marion Formation - Chemung-Hamilton Facies: originally defined by Grabau (1919) this unit now includes all the non-calcareous marine strata between the Stony Hollow and Ashokan Formations (Rickard, 1975). The upper part contains fine-medium grained, thick and thin bedded sandstones with interbedded siltstones and dark gray shales. There are some horizons of coquinites, low-angle, planar cross-bedding, ball and pillow structures, quartz or siltstone pebble conglomerates and megaripples.

This is the classic "Chemung" facies that is characteristic of the subtidal shelf and marine delta platform (Woodrow and Nugent, 1963, Sutton, Bowen, and McAlester, 1970, Fisher and Rickard, 1975), and initially appears within the Marcellus Formation. Based on the lateral persistence of some of these horizons, suggested faunal associations (Cooper (in Goldring), 1935, 1943, Chadwick, 1944), and the lateral relations of prograding deltaic sequences, these sections have been tentatively correlated with those in central New York (Wolff, 1967, 1969) based on suggestions of previous investigators. This would place the Ashokan sandstones into the Skaneateles Formation and subdivides the upper Mt. Marion Formation into the Solsville and Pecksport members of the Marcellus Formation (Fig. 2).

3. Middle and Lower Mt. Marion Formation - Portage Facies: as described in some detail by Chadwick (1944) it consists of thin-bedded gray sandstones, siltstones and dark arenaceous or fissile shales. Though shales dominate, interbedded siltstones are common and these become thicker, coarser, and more prevalent as one rises through the section. Current ripples, cross laminations and bioturbated layers also occur; flute and groove casts usually associated with these "turbidite" sequences, are relatively rare.

This facies forms the thickest part of the Marcellus (Mt. Marion) Formation and contains characteristics similar to the prodelta slope of most recent deltaic environments (Scruton, 1960, Allen, 1965, Kanes, 1970) though the influence of tectonics and subsidence must also be considered (Sutton, 1963, Sutton, Bowen, and McAlester, 1970). Based on the lateral variations associated with proximal and distal prodelta slope environments, the initial development of upward coarsening sequences (Rickard and Zenger, 1964), thickening rates (Rickard, 1964), and the suggested correlation of several fossil horizons (Cooper (in Goldring), 1935, 1943) the lower Mt. Marion has also been tentatively subdivided into equivalent strata (i.e. Otsego and Chittenango members) from east-central New York (Wolff, 1969). The distal position of the prodelta slope would also include the Stony Hollow member (Fig. 2).

4. Bakoven Shale - Portage - Marcellus Facies: originally defined by Chadwick (1933) this is a soft, black, calcareous shale with some large black calcareous or pyritiferous concretions. The lack of bioturbation, the high organic water content, and sparce pelagic fauna (Chadwick, 1944) all suggest a strongly reducing anerobic environment in the distal basin. A local disconformity (solution pits on the surface of the Onondaga Limestone filled with black shale) has been reported in the Kingston area (Chadwick, 1927, Cooper, 1930, Wolff, 1963). This indicates a marginal, nearshore (rather than distal basin) deposited environment for this unit.

ROAD LOG FIELD TRIP B-4

Leaders: Kenneth Pedersen, Michael Sichko, Jr., Manfred P. Wolff

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
0.0	0.0	Vassar College parking. Exit parking lot, left turn for 0.075 miles to Raymond Avenue.
0.15	0.075	Right turn to Hooker Avenue.
2.10	1.95	Left turn to Montgomery Street.
2.60	0.50	Right turn to Lincoln Avenue.
2.80	0.20	Left turn to Mid-Hudson Bridge.
4.00	1.20	On the right ripple marks in the Martinsburg formation.
4.75	0.75	Right turn to 9W north.
7.25	2.50	Left turn to route 299.
13.70	6.45	Right turn onto route 32 (North Front Street).
13.85	0.15	Right turn onto route 32.
20.50	6.65	STOP 1: Silurian System - Tillson Hill, N.Y.: This stop shows an exposure of the formations of Silurian age which are exposed in the Hudson Valley. The Shawangunk conglomerate, the High Falls shale and the Binnewater sandstone are all found below the Rondout formation. The contact between the Binnewater sandstone and the Rondout formation is conformable at this locality. Farther North, however, the Rondout is found in angular unconformity to the underlying Normanskill formation of Ordovician Age. Proceed north on route 32 toward Kingston, N.Y.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
27.60	7.10	Right turn at the stop sign onto Greenkill Avenue.
27.80	0.20	Left turn onto Clinton Avenue.
27.85	0.05	Right turn onto Cedar Street.
28.20	0.35	At traffic light proceed straight across Broadway to Cornell Street.
28.70	0.50	At the stop sign left turn onto Foxhall Avenue.
29.00	0.30	Right turn onto Flatbush Avenue (route 32).
31.45	2.45	Right turn onto East-Kingston turn-off (a hairpin turn).
31.80	0.35	STOP 2: Subterranean exposure of the Ordovician-Silurian angular unconformity. The steeply tilted Normanskill formation is exposed in angular unconformity with the Rondout formation. At this location the only remnants of the Rosendale and Whiteport members are the columns which support the roof in the mines (Fig. 3). Make a U-turn and proceed back to route 32. Right turn onto route 32.

Figure 3. Subterranean exposure of the Rondout Formation.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
32.35	0.55	STOP 3: Subaerial exposure of the angular unconformity: Again the Normanskill-Rondout angular unconformity. At this locality, major structural deformation due to the Taconic Orogeny are easily observed. Proceed north on route 32.

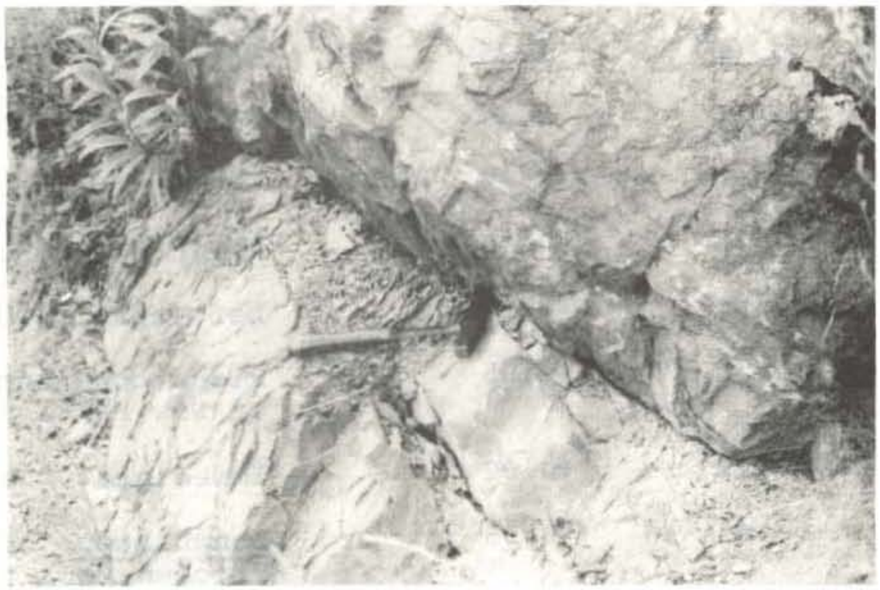

Figure 4. Subaerial exposure of the angular unconformity.

32.75	0.40	STOP 4: Thrust faulting within the Thacher member of the Manlius limestone: The Thacher limestone shows major structural deformation from the Acadian Orogeny in the form of thrust faulting. The carbonaceous interbedded shales have been metamorphosed into phyllites and phyllites shists. Proceed north on route 32.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
33.30	0.55	Right turn on entrance ramp to route 199 west.
34.40	1.10	Route 199 ends, proceed straight onto route 209 south.
37.95	3.55	Right turn onto route 28 west.
49.65	11.70	Left turn onto Ashokan Reservoir road.
51.40	1.75	Make a left turn.
51.50	0.10	Bear right (downhill).
51.90	0.40	Intersection of route 28A.
51.95	0.05	Aeration plant on the right.
52.05	0.10	Left turn onto Beaverkill Road.
53.10	1.05	Right turn onto State University of New Paltz Ashokan campus.
53.12	0.02	Immediately bear right.
53.45	0.33	Lunch Stop: Enjoy the scenery. Proceed back to Route 28.
53.75	0.30	Bear left.
53.80	0.05	Left turn onto Beaverkill Road.
54.80	1.00	Right turn onto 28A
55.00	0.20	Bear left.
55.45	0.45	Right turn onto Reservoir road.
57.20	1.75	Intersection of Reservoir road with Route 28 at Winchell's corner. Turn right onto route 28.
57.50	4.30	STOP 5A: Plattekill Formation (Catskill Facies) stream channel environment: Exposure consists of 14 feet (4.3 m.) of flat bedded and planar cross-bedded sandstones. These occur in a series of overlapping and truncated wedges

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		averaging 1-3 feet (0.3-1 m.) in thickness (Figure 5). The individual dark subgraywackes are 1/2 to 2 inches (1-3 cm.) thick and form accretionary slopes of 2-5°. While the regional direction of flow is S80°W, the individual sets of crossbeds trend northeast-southwest. Rather than a major upward-fining alluvial channel, this section is interpreted as an area of shallow distributary or braided stream channels laterally filled through point bar accretion and vertically filled by channel agradation. Continue east on route 28.

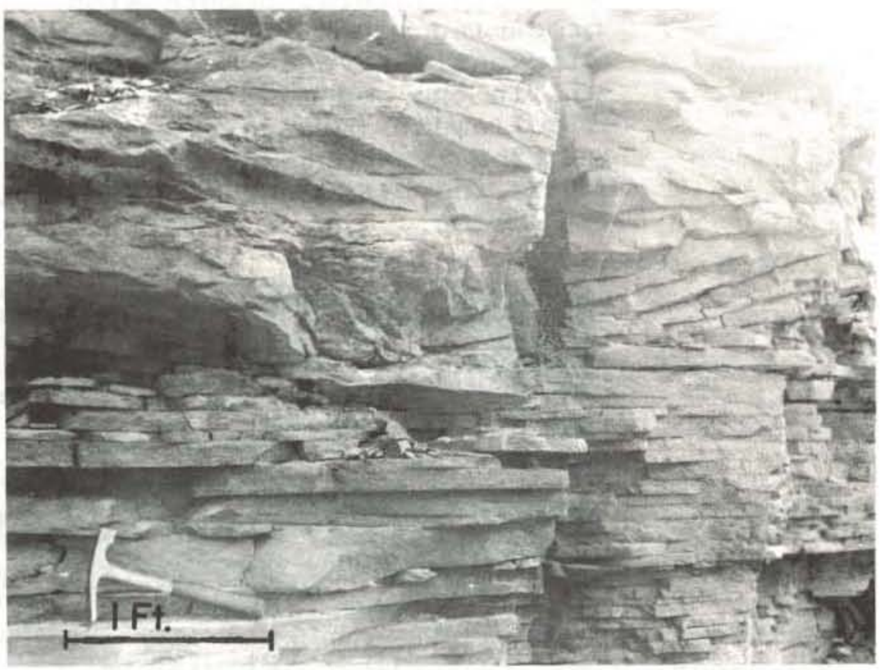

Figure 5. Horizontal-bedded and planar crossbedded subgraywacks sandstones of the Plattekill Formation (Catskill facies - channel environment).

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
58.40	0.90	STOP 5B: Plattekill Formation (Catskill Facies) floodplain environment: Base of outcrop consists of 17 feet (5.2 m.) of knobby red-green mottled mudstone grading upward into 4-6 feet (1.3-3m) of olive green mudstone. Section is disconformably overlain by a sequence of medium-gray, shallow-dipping planar cross-bedded sandstones. The regional paleo-slope across the megarippled erosional surface trends S70°S. The zone of recent differential erosion about 8 feet (2.5m) above the base represents a section of westward lateral compression producing minor folding, slickensides, and thrusting within the red mudstones-a minor decollement (Figure 6.) This section is about 200 feet (61.5 m.) above the base of the Plattekill Formation.

Figure 6. Massive red-green mudstone disconformably overlain by gray crossbedded sandstones of the Plattekill Formation (Catskill facies-floodplain environment). Note zone of compression in lower third of section.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
59.10	0.70	Junction with route 375, continue straight on route 28.
60.90	1.80	STOP 6: Skanneateles-Marcellus Formations (includes the local Ashokan and upper Mt. Marion Formations): Contains features characteristic of the Chemung-Hamilton facies (intertidal environment). Use parking lot of Micrometrics, Inc. on the south side of the road. A. South side of Rt. 28 roadcut - Mottville and Ashokan Sandstones. Major feature is the 8 foot (2.6m) laminated and cross-laminated, moderately sorted, planar cross-bedded sandstones. These occur on a series of enechelon "sand bars" here, over 130 feet (40 m.) wide and interbedded with dark shales and massive, fine-grained, bio-turbated sandstones. These bars strike N70°W and have steep "foreshore" slopes (20°) trending northeast with more gentle (10-15°) "backshore" dips. Over-lying the sandstones is a 5 foot (1.8 m.) succession of dark shales and fine-grained laminated sandstones with abundant plant fragments. This part of the section has been traced to Schoharie Valley (Mottville Sandstone) and is interpreted as a series of river mouth bars, intertidal or shallow subtidal sandbars, and sandflats (Wolff, 1969). These marginal sandstones are steeply truncated by a 40 foot (12.6 m.) section of thick, large-scale trough and planar cross-bedded sandstones with irregular lenses of olive mudstone (Figure 7). Individual beds are 2-4 inches (4-7 cm.) thick and dip at angles of 2-10° to the north-west. Worm burrows, shale chips, and plant fragments are common. This section represents the first major intertidal channel cutting across the sequence (Ashokan

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		sandstone). The paucity of marine fossils may reflect the alien ecologic conditions that would be associated with the rapid lateral and vertical erosion and sedimentation in this environment. However, small crustaceans Estheria (a brachiopod) and Beryrichis (an ostracod) have been collected in several areas at this interval (Goldring, 1943, p. 268) supporting a brackish-water interpretation.

Figure 7. Contact of bar like bipolar crossbedded sandstone and interbedded sandstone-shale sequence of the suggested Mottville Formation (Hamilton facies-intertidal environment) and the planar-crossbedded sandstones with interbedded shales and mudstones of the Ashokan Formation (Hamilton facies-intertidal environment).

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		B. North side of Rt. 28 - upper Mt. Marion Formation. Suggested to be equivalent to Pecksport member of Marcellus Formation (Copper (in Goldring) 1943, p. 260, and Wolff, 1967, 1969). Outcrop consists of 9 feet (2.8 m.) of brown-black interbedded shales and siltstones capped by a 3 foot (1 m.) bed of dark, small scale, planar cross-bedded sandstone (equivalent to base of section on south side of road). Many of the shales exhibit an "oily" iridescent purple sheen. Structures include wave ripples, laminations, cross-laminations, lenticular bedding, flaser bedding, worm burrows, and tidal bedding - all features that can be associated with lagoons and tidal flats (Reineck, 1963, Klein, 1970). Fossils include Schizophoria, Pterinopecten, Paraspirifer, and Tropidoleptus, and are representative though not diagnostic for the uppermost Marcellus (Pecksport member). This area is interpreted as a region of wide sand flats containing barrier base and beaches, lagoons or tidal channels, and marshes or swamps that formed between deltaic laber during a period of general submergence. (Figure 8). After submergence (Pecksport interval - A) there is an interval of transgression, reworking, and nearshore deposition (Mottville interval - B), before the next major pulse of deltaic sedimentation (Ashokan interval - C).

TOTAL MILES	MILES BETWEEN POINTS	REMARKS

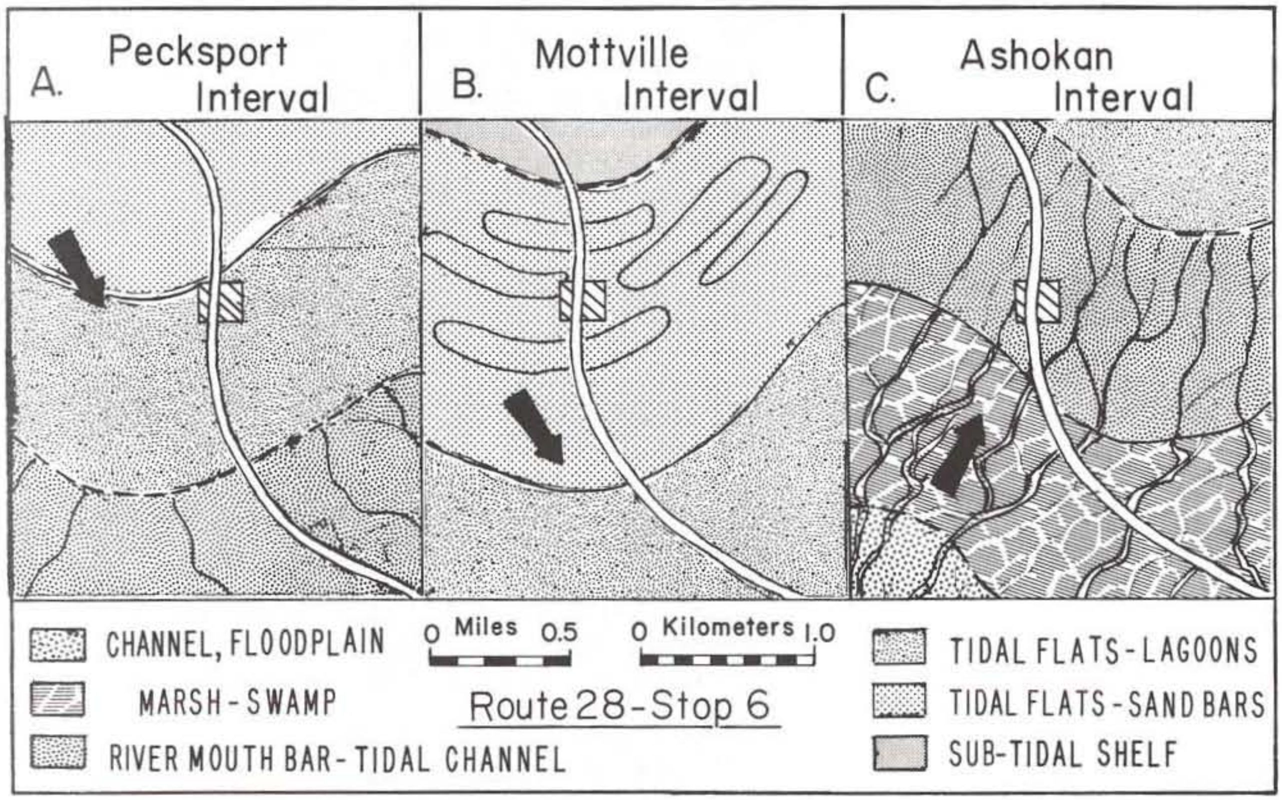

Figure 8. Interpretation of progressive changes during the deposition of Pecksport, Mottville, Ashokan members within the intertidal environment (Hamilton facies) At Stop 6 (see text).

62.00	11	Continue east on Route 28 passing by ball and pillow structure of upper Mt. Marion Formation.
62.60	0.6	Passing dark gray siltstones and shales of middle Mt. Marion (Otsego member) through "Hoogeberge escarpment."

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
64.10	1.5	Passing buff-weathered siltstones of Stony Hollow member.
64.40	0.3	Turn left off route 28 onto Forest Hill Drive near Skytop Motel.
		STOP 7: Marcellus Formation (Portage Marcellus Facies) - Stony Hollow and Bakoven members (distal slope and basin environment): Base of section consists of 22 feet (6.6 m.) of thinly laminated black calcareous shales, commonly drag folded and faulted (underthrusts). The next 8 feet (2.3 m.) also contain black calcareous concretions (frequently slickensided), and compression fractures with quartz veins. The Bakoven is about 100 feet (30 m.) thick, but only the upper portion is exposed here. This unit grades into 8 feet (2.3 m.) of dark gray massive calcareous siltstones. The near vertical joints, trending N60°E are quite characteristic. Upon weathering the buff-colored surfaces exhibit the laminations or cross-laminations commonly associated with this unit. These may represent deposition by waning turbidity, or other marine currents. The siltstones contain some detrital carbonate and a few fossils, and become more massive through this 35 foot (11 m.) section. It is equivalent to the Cherry Valley (Agoniatite) Limestone in central New York and was first described by Cooper (in Goldring), 1943. Return to route 28 and continue south toward Kingston.
64.80	0.4	Junction with route 209 north, bear right onto 209. Pull off just before exit to Sawkill Road.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
67.10	2.3	STOP 8: Marcellus Formation - Portage Facies (locally the lower Mt. Marion Formation or the sandy equivalent of the Chittenango member of east-central New York: Road cut consists of 120 feet (37 m.) of dark gray arenaceous shale with some anomalous interbedded fine-grained sandstones through the lower 20 feet (6.2 m.) of the section. The overlying shales contain light gray concretions and include 5 "coquinite" fossil horizons. Of significance is the *Meristella* - coral zone in the central zone (now covered by the weathered shale) and horizons of brachiopods and pelecypods. Cooper (in Goldring) 1943, traced this horizon from the Berne Quadrangle (S.W. of Albany) into this area. The interval between the Stony Hollow member and the Otsego Shale was designated as the "Berne member" (Cooper, op. cit., p. 249) but it was restricted because of the few known locations. The extension of this member to the Kingston area enables it to be also correlated as the sandy equivalent of the Chittenango Shale (Cooper, op. cit.), and establishes the contact between this shale and the Otsego Shale in this region (Wolff, 1967, 1969). The pull apart and transposition structures at the base of this section (Figure 9) are described in the structure section of this article. Continue on route 209 toward the Kingston-Rhinecliff Bridge.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS

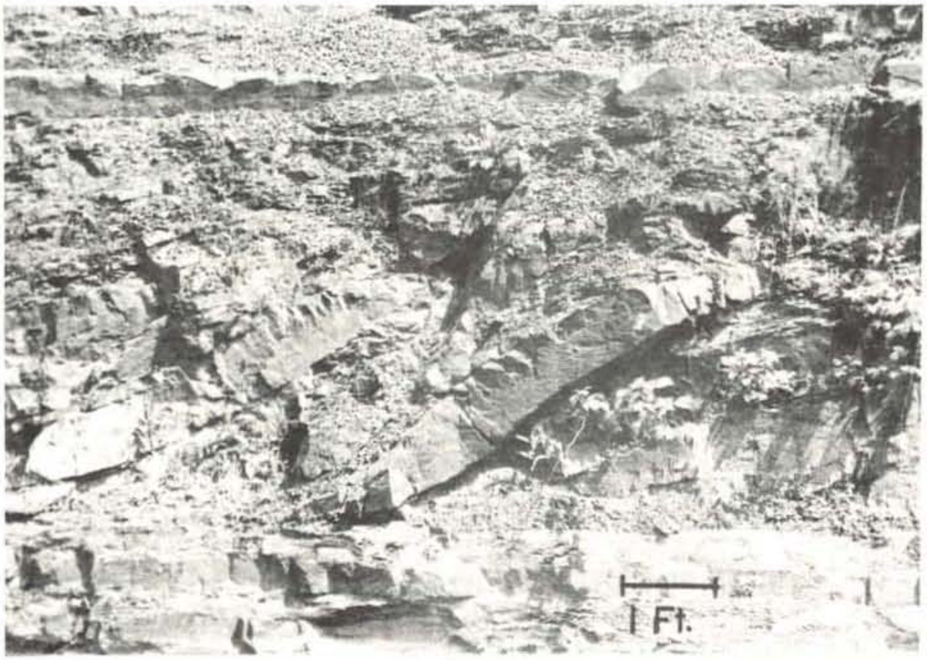

Figure 9. Pull apart and transposition structure (Note: "necked" ends).

68.30	1.2	STOP 9 a, b, c: Gentle folding in the lower Devonian Rocks: Here the gentle anticlines and synclines expose the lower Devonian section almost in its entirety. We are proceeding downward in the column so the rocks encountered are in the following sequence: Schoharie, Esopus, Glenerie, Port Ewen, Alsen, Becraft, New Scotland, Kalkberg, Ravena and Thacher (Waines, 1967). Proceed back to Vassar College.

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TRIP B-5

PLEISTOCENE HISTORY OF THE MILLBROOK, NEW YORK REGION

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LaGrange Junior High School
Pleasant Valley, N. Y.

Location, Physiography, Relief and Drainage

The Millbrook, New York quadrangle is centrally located in Dutchess County, New York, mid-way between the Hudson River and the State of Connecticut (to the east) and New York City and Albany (to the north). The topography of the southern half of the quadrangle is generally hilly with areas of low relief between the hills. These areas appear to be lake plains of ice-marginal lakes formed during the retreat of the continental ice sheet from the Mid-Hudson Valley. Subsequent erosion of the lacustrine deposits has formed flood plains and terraces. The lowest elevation, about three hundred feet above sea level, occurs on the western border of the map area in the flood plain of the east branch of Wappingers Creek. A series of progressively higher rock ridges trending northeast-southwest traverse the quadrangle. The highest elevation, Tower Hill, rises to 1323 feet. The valleys between these ridges are probably pre-glacial in origin but at present are partially filled with glacial deposits. The larger valleys have terraces along the sides.

The area is drained by tributaries of three major creeks. Tributaries of Wappingers Creek on the west and Fishkill Creek on the south, flow into the parent streams and then into the Hudson River. The extreme eastern part of the area is drained by unnamed tributaries of the Ten Mile River, which flows into the Housatonic River in Connecticut. These tributaries originate in elevated bogs and small kettle ponds and lakes.

Geology

The bedrock in the map area varies in age and composition. It consists mostly of folded metamorphosed sediments. The largest area, in the center of the map, is underlain by Ordovician Walloomsac Formation, a mixture of phyllite, schist and metagraywacke. Overlying the Walloomsac in the western and eastern parts of the map area are older Cambrian formations, the Everett Schists in the east and the Everett Schists and the Nassau shales and quartzites in the west. There is a small limestone area in the center of the map and a small area of sedimentary rocks in the extreme northeast corner. Both of these are obscured by glacial and recent deposits. The topography may or may not be structurally related. The relation between the drainage pattern and the nature of the bedrock is not understood. (See map overlay #2)

Evidence of Glaciation

Ice first advancing over the area probably removed a layer of bedrock-derived soil and mixed it with rocks plucked from the bedrock and rocks carried by the ice from the north. This formed the till that seems to blanket most of the area. Typically, the higher, steeper hills are covered with thin till, the lower, less steep hills with thick till. The valleys are partly filled with stratified drift. Evidence of recessional or terminal moraines was not observed.

In the western portion of the map area, glacial striae appear confined to newly exposed rock surfaces and to surfaces of low inclination. These occur mostly on phyllites. The striae indicate that the ice last moved into the area from the northwest from 340°. (See map overlay #1) One groove in the center of the map area and one in the eastern part indicated the same direction but for the most part the rocks in the east were highly weathered and did not exhibit striae. Freshly exposed bedrock, however, was not observed.

Glacial deposits of the following types have been identified in the map area.

<u>Till</u> Thick till has been deposited over the less steep hills. Extensive areas of these rolling hills make up much of the farmland in the area. The till is stony as is the soil developed on it. There are many walls, buildings and piles of stone. These stones vary in size from large cobbles to small boulders. They may have come from lag concentrates resulting from post-glacial sheet-wash of the till. These lag concentrates were probably removed from the fields by the first farmers when they cleared the land for cultivation.

Thin till covers most of the steeper hillsides and some of the hilltops. The bedrock on the higher hills is often exposed or covered with bedrock-derived soil or post-glacial origin.

<u>Deltas, Kettles and Kames</u>

Extensive deltaic deposits occur in several places and at several elevations in the map area. (See map overlay #1) Foreset beds in materials ranging from silts to large cobbles exist at the eastern edges of what were probably once ice-marginal lakes. It is assumed that topset beds of varying thickness overlay these foreset beds in most areas. Where the foreset beds are presently exposed, the topset beds and their soil profiles have been removed as a result of sand and gravel pit operations. In most areas the foreset beds are inclined to a maximum of 30°, generally to the west. In the valley east of the "Hogback" in the northeastern portion of the map, they dip more gently, about 5°, and are extensively cross-bedded. At Glacial Lake Littlerest (See map overlay #1) the formation of large kettles, up to fifty feet deep, may have disturbed the original bedding, making it impossible to distinguish between topset and foreset beds. It is inferred that some of the original beds were deposited against and between large ice blocks. When the ice melted, the bedding collapsed, extensively altering its original position.

Kettles occur in the lake plains of Glacial Lake Littlerest and Glacial Lake Washington but not in the lake plain of Glacial Lake Mabbettsville. It is inferred that these kettles were formed when ice blocks became separated from the retreating ice front and were buried in sediments. When the ice melted kettles remained. Some of these kettles form lakes and ponds, most are dry. They range in depth from a few feet to more than fifty feet. Many are too small to appear on the topographic map; they are more extensively distributed than appears on the topographic map of map overlay #1, but are generally associated with the kettles that do appear on the maps.

A few kames occur on the lake plains. These are generally located marginal on the plains.

In several areas bogs have developed in what were probably shallow glacial lakes. When the ice dams confining pro-glacial lakes melted, these lakes were dammed by residual topography.

Recapitulation of Ice Retreat

Ice retreat westward across the map area is indicated by three major and two minor lake plains. These are inferred from relatively large areas of relatively low relief underlain by deltaic and lacustrine deposits. The major levels occur at 440, 740 and 900 feet. The minor levels occur at 650 and 830 feet.

As the ice sheet began to thin, the high hills, up to 1300 feet, in the eastern part of the map area became exposed and ice probably rose to not more than 1200 feet in the west. The ice front was trapped against the higher eastern topography and forward motion was prevented. The edge of the ice then appears to have formed a dam to the west which trapped melt-water against the hills in the east, forming a lake in a one-sided valley, Glacial Lake Littlerest, with a minimum delta top level at 900 feet. (See map overlay #1 and topographic map) Large ice blocks seem to have become separated from a stagnating ice front and were probably buried in sediments. When the ice blocks melted, they left large kettles. The source of the sediments was probably the till on the hills to the north, east and south, not the base or the top of the ice to the west. The drainage of this lake appears to be eastward through Mutton Hollow into the Housatonic River drainage system.

When the ice sheet thinned to less than 1150 feet and/or the ice front retreated west, melt-water was apparently ponded against the hills west of Lake Littlerest and east of the present South Mabbettsville Road. A narrow lake formed here extended into the valley east of the Hogback. The minimum delta top level of this lake occurs at about 830 feet. The presence of this lake is evidenced by deltaic deposits and kettles along the western slope of this hill. The bottom of the valley east of the Hogback is filled with cross-bedded, gently dipping deltaic deposits. A bog was formed at the lake bottom level, which persists. The deltas occur at several levels in these valleys, indicating that the lake level was not constant. Drainage from this lake was probably to the northeast into the Housatonic drainage system.

The next large lake plain occurs southwest of Mabbettsville at 740 feet. This large lake, Glacial Lake Mabbettsville, has deltaic deposits on the north and east but the hills on the south and west are covered with till over which a layer of clay has been deposited. This lake seems to have been dammed by a relatively small ice plug as it has few of the features usually associated with ice margins. The dam may have been located across Mill Brook northeast of the present village of Millbrook. Ice marginal features associated with this plug were possibly eroded away. The drainage of this lake was probably to the west into the Wappingers Creek drainage system, possibly under the ice in the deep channel that drains the area today. (1) When the lake drained, the part north of Daheim Road on North Mabbettsville Road remained dammed and subsequently evolved into a bog, which persists.

The lake bottom level then lowered to 650 feet where it remained until Mill Brook found what was probably its preglacial channel, cut deep into bedrock, at the northwest edge of the village of Millbrook. This channel was the site of the mills that were the reason for the settlement of the village and from which the creek and the village got their name.

The ice sheet probably continued melting until the ice surface sank to about 740 feet or less to the west. At this time another lake with a delta ((1) It is possible that drainage from this lake followed a channel between the ice and the 740 foot level on the hills east of the village of Millbrook into the drainage system of Fishkill Creek to the south.) top level at 440 feet elevation, Glacial Lake Washington, was formed between the higher ground on the east and the ice on the west. This lake occupied a large area at the west side of the quadrangle and backed up into the valleys to the north, east and south. Stagnant ice was left in the valleys and sediments were washed in around the remnants. When the ice melted many kettles remained. These kettles are concentrated in three areas and scattered elsewhere. Several kames appear along the margins of the lake plain. The presence of this large lake is inferred because of the extensive deltaic deposits found at this level. These deposits consist largely of foreset beds dipping 30° west, overlain by topset beds. Erosion has removed much of the former lake bottom, leaving terraces cut into the deposits on all sides. Some of the remaining sediments are being removed by sand and gravel companies.

As the ice melted off the hills, a ground moraine, the till that exists on them today was left. A soil profile redeveloped and along with the lake plains and the valleys, the hills became reforested and remained so until the arrival of man. Indian artifacts have been found in the western portion of the map area and recently bones believed to be Indian were discovered here.

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Quaternary Geology and Related Topograph, Southern Half, Millbrook Quadrangle, Dutchess County, New York

Unpublished excerpt from the program of the
First Annual New Paltz Science Student Paper Presentation
May 12, 1973 State University College at New Paltz, N. Y.

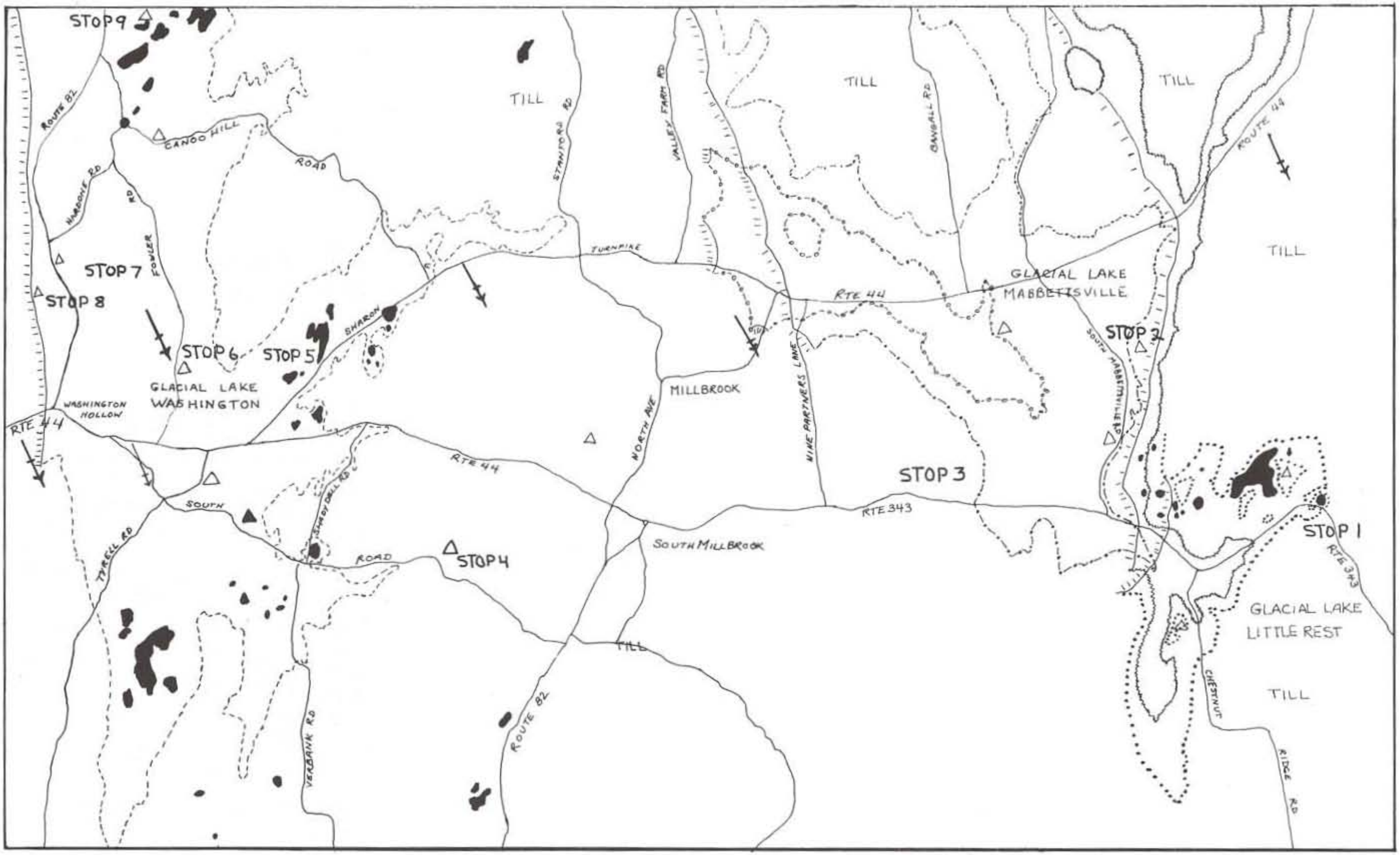
ROAD LOG FIELD TRIP B-5
Leader: David J. Murray

Total Miles	Miles from Last Stop	
0.0	0.0	Assembly Point - Vassar College student parking lot at the corner of Raymond Avenue and Route 376. Departure time: 8:30 a.m. Leave parking lot and turn right (north) on Raymond Avenue.
1.0	1.0	Turn right on Main Street (Route 44).
1.3	1.3	Bear left on Route 44 at Route 44 and Route 55 intersection.
6.8	6.8	Pass through village of Pleasant Valley. Cross Wappingers Creek. This creek provides drainage from field trip area.
12.6	12.6	Pass Dutchess County Farm and Home Center. This site is on the east side of former Glacial Lake Washington.
14.7	14.7	Proceed directly east on Route 343 from Route 44 straight through traffic light. Pass Bennett College.
14.9	14.9	Traffic Rotary with monument. Continue east on Route 343.
		STOP 1 (One hour) Time: 9:05 a.m.
18.4	18.4	Town of Washington Disposal Area. Sanitary Landfill. This is the highest level of the field trip area. Look for massive kettle holes and distorted bedding, due to slumping as buried ice blocks melted. Top elevation 900 feet. Time: 10:05 a.m.
18.4	0.0	Leave Town of Washington Disposal Area. Turn right and proceed west on Route 343.
19.2	0.8	Turn right on Little Rest Road. Proceed north.
20.1	0.9	Turn right on Sutton Road.
20.2	1.0	Dirt Road to Left beyond first House to abandoned gravel pit.
		STOP 2 (15 minutes) Time: 10:15 a.m. Deltaic deposit consisting of foreset and topset beds dipping west indicating source of sediments from east into Glacial Lake Mabbettsville. Time: 10:30 a.m. Leave Stop 2. Return to Little Rest Road.

Total Miles	Miles from Last Stop	
20.5	0.0	Turn left on Little Rest Road. Head south.
21.3	0.8	Turn right on Route 343 (west).
		STOP 3 (30 minutes) Time: 10:35 a.m.
22.5	1.2	Pull into Dutchess Day School Driveway on right. Observe lake plain and lake terrace indicating Glacial Lake Mabbettsville. Time: 11:05 a.m.
22.5	0.0	Leave Dutchess School. Proceed west on Route 343 to Route 44.
26.0	3.5	Go straight ahead on Route 44.
27.3	4.8	Turn left on Shady Dell Road.
27.8	5.3	Note kame and kettle topography on right in field next to swimming pool.
28.2	5.7	Turn right on South Road and proceed west.
28.7	6.2	Turn right into dirt road past white house on right.
		STOP 4 (45 minutes) Time: 11:15 a.m. Large gravel pit. The sand and gravel from this pit is used "as is" as a high grade bank run gravel. It is quite well sorted and fairly free of silt and clay sized particles. Foreset and topset beds visible in this massive deltaic deposit in Glacial Lake Washington. Leave Stop 4. Time: 12:00 noon.
28.7	0.0	Proceed west on South Road.
29.4	0.7	Turn right on Tyrrel Road.
29.6	0.9	Abandoned gravel pit on right.
29.8	1.1	Turn left on Route 44. Turn right on Fowler Road past Cottonwood Inn.
30.3	1.6	Arrive Cary Arboretum Headquarters. Time: 12:10 p.m. Lunch Stop. The Cary Arboretum of the New York Botanical Garden is a 2000 acre tract of land devoted to botanical research, applied environmental science, and education about plants. It was established in 1971 with a grant of land and funds from the Mary Flagler Cary Charitable Trust on an estate owned by the late Mrs. Cary. Time: 1:00 p.m.
30.3	0.0	Leave lunch area. Proceed east on Cary Internal Road to construction site at
31.4	1.4	new headquarters building.

Total Miles	Miles from Last Stop	
		STOP 5 (30 minutes) Time: 1:05 p.m. Level ground underlaid with deep gravel; bedding almost horizontal. Look for fairly well sorted gravels and stagnant ice features. Time: 1:35 p.m.
31.4	0.0	Leave Stop 5. Return west on Cary Internal Road.
32.2	0.8	STOP 6 (10 minutes) Time: 1:40 p.m. Level field is a delta surface at 440 feet elevation. Soil on left side of road is dramatically different from soil on right side of road. Time: 1:50 p.m.
32.2	0.0	Leave Stop 6. Proceed west on Internal Road.
32.5	0.3	Cross Fowler Road.
32.9	0.4	Bear right across Glacial Lake Washington plain.
		STOP 7 (15 minutes) Time: 1:55 p.m.
33.8	0.9	Stop at bridge across Wappingers Creek. Inferred history of Glacial Lake Washington will be discussed. Time: 2.10 p.m.
33.8	0.0	Leave Stop 7.
34.2	0.4	Cross Route 82. Proceed west around greenhouses.
34.4	0.6	Turn right at lathe house to gravel pit.
34.6	0.8	STOP 8 (15 minutes) Time: 2:15 p.m. Gravel pit is an exposure of poorly sorted outwash overlaid with ground moraine on western margin of Glacial Lake Washington. Time: 2:30 p.m.
34.6	0.0	Leave Stop 8. Return to Route 82.
35.0	0.4	Turn left on Route 82 (north).
35.1	0.5	On right side of Route 82 at this point a deltaic deposit was removed for road building material. Bones thought to be those of Indians were found here in 1973 but have not yet been authenticated.
36.3	1.7	Turn right onto Canoe Hill Road.
36.5	1.9	Turn left at Route 82 Sand and Gravel Co. pit.

Total Miles	Miles from Last Stop	
		STOP 9 (One hour) Time: 2:40 p.m. This large gravel pit operated by the Route 82 Sand and Gravel Company has a variety of features that will be discussed here. Time: 3:40 p.m.
36.5	0.0	Leave Stop 9. Return to Route 82.
36.7	0.2	Turn left on Route 82 (south).
38.7	2.2	Turn right on Route 44.
50.9	12.5	Continue straight ahead through Pleasant Valley on Route 44 to Main Street.
51.2	12.8	Turn left off Main Street onto Raymond Ave.
52.2	13.8	Return to Assembly Point.



Drawn from U.S. Geological Survey Map

BY

DAVID J. MURRAY

N MN GN

GLACIAL MAP

SOUTH HALF MILLBROOK
(DUTCHESS COUNTY) N.Y. QUADRANGLE

SCALE 1 MILE

TRIP B-5

LEGEND

- △ DELTAIC DEPOSITS
- ● KETTLES
- INFERRED ICE FRONT

GLACIAL LAKE MARGINS

- .... 900 FEET ELEVATION
- 830 " "
- 740 " "
- 650 " "
- 440 " "
- ICE DIRECTION

- Photograph (Scale 1:130,000) of northern portion of western Dutchess County taken from a U-2 aircraft at an elevation of 20 kilometers (12 miles); resolution of photo is 10 meters. Note especially the NNE alignment of water bodies (black) in the Milan Window, the fold patterns on the west side of the Hudson River in the Quassaic Quartzite, and the topographic break between the Van Buren Slide on the east and the deformed rocks to the west. Wappinger Creek follows this linear for much of its course; Stissing Mountain is in the upper right-hand corner.

Flown April, 1973.

TRIP B-6

STRATIGRAPHIC AND STRUCTURAL GEOLOGY

IN WESTERN DUTCHESS COUNTY, NEW YORK

by

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and

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PROLOG

Sedimentary rocks with deceptively similar but subtly different physical characteristics and yielding rare and hard-to-identify fossils demand exeedingly careful scrutiny. When, however, a further measure of obscurity arises because such rocks are overprinted by polydeformational complex folds, faults, cleavage, and metamorphism, the demands made upon the investigating geologists are, indeed, taxing. This is the situation confronting those who attempt to unravel the geological maze of Dutchess County and eastern New York.

On this trip, our intention is to expose you to some of the knotty problems that beset us and permit you to examine some of the typical rock units and typical structures of the region. Owing to time limitations, we shall confine our visitations to western Dutchess County from Poughkeepsie northward--and not all the rock units nor all types of structures will be examined. If we make you aware of the fascination and frustration of Taconic geology, then we have succeeded in our mission.

ACKNOWLEDGEMENTS

John B. Skiba, Senior Cartographer with the New York State Geological Survey, skillfully prepared the charts and maps which accompany this article and make for better understanding of the perplexing geologic relationships. The pictures taken from the U-2 aircraft and the ERTS satellite image were furnished by Yngvar W. Isachsen of the New York State Geological Survey.

*Published by permission of the Director, New York State Science Service, Journal Series No. 217.

PREVIOUS WORK

Geologic investigations of the Paleozoic rocks in Dutchess County were pioneered by W.W. Mather (1843), J.D. Dana (1872, 1879), and W.B. Dwight (1879-1890). Mather's work was a reconnaissance of a broad area, the "First Geological District", which extended from the southern Champlain Valley on the north to Long Island on the south, and from the state line on the east to the Catskill Mountains on the west. Though rather superficial by design, there is a large amount of useful detail in this monograph. Dana's studies were primarily concerned with carbonates. Dwight's prolific significant disclosures of fossils in Dutchess County formed the groundwork for more exacting age determinations of the carbonates, in particular.

Later, C.E. Gordon (1911) mapped the geology of the Poughkeepsie 15-minute quadrangle, for the first time convincingly demonstrating the structural intricacy of the region. Robert Balk (1936) further elaborated on the petrologic and structural complexities in Dutchess County--chiefly in the eastern part. Vidale (1974) has added new information on the metamorphism in eastern Dutchess County--beyond the scope of our treatment. Eleanora B. Knopf (1962) mapped the stratigraphy and structure of the Stissing Mountain area in northern Dutchess County. This and her earlier work demonstrated the feasibility of subdividing the Wappinger carbonates. No additional paleontologic, stratigraphic, or structural studies have since been published for western Dutchess County.

Work by Holzwasser (1926), Jaffee and Jaffee (1973), Offield (1967), and Ruedemann (1942) in nearby areas to Dutchess County has contributed greatly to our understanding of Hudson Valley geology.

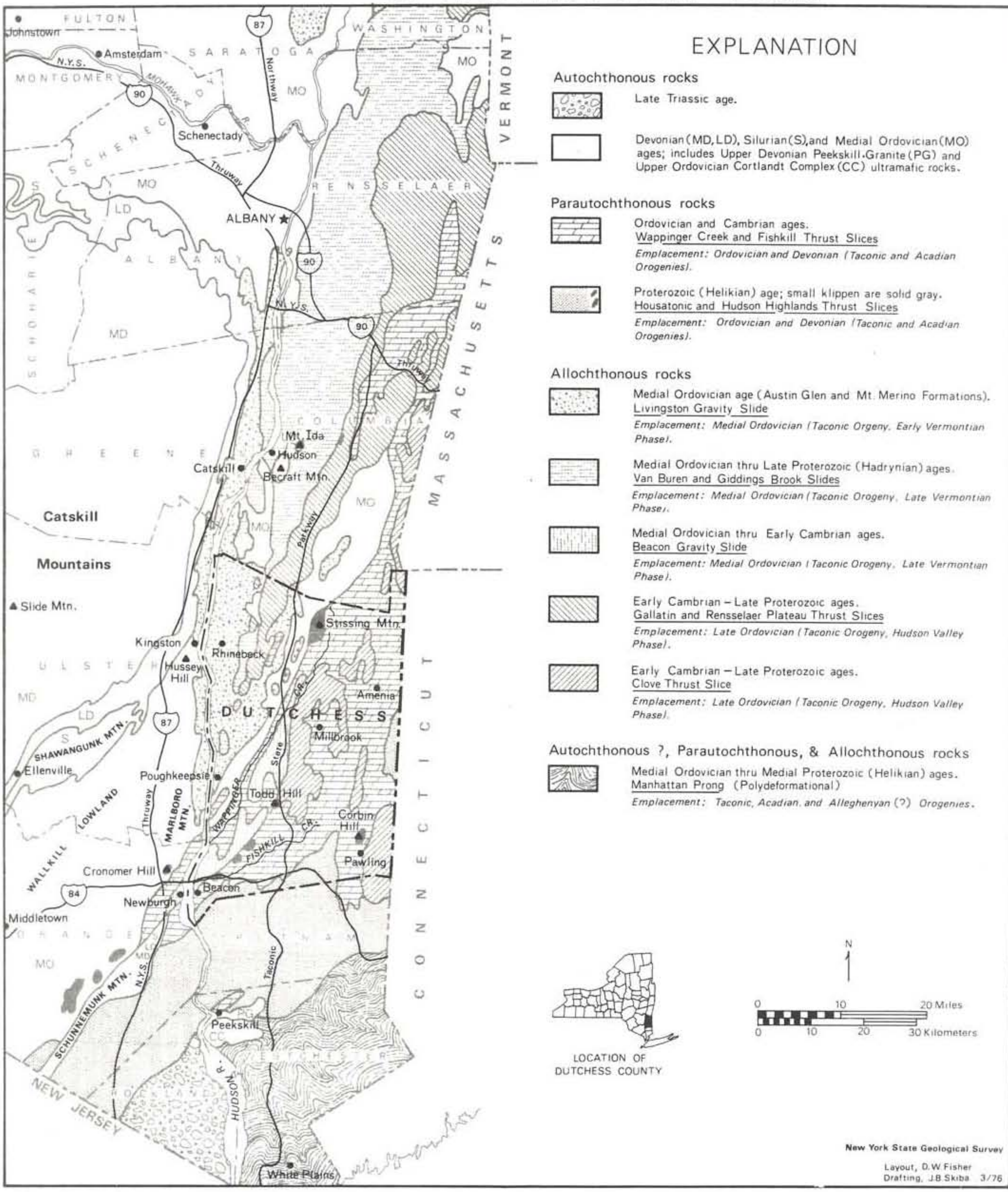
We have conducted a joint effort in order to fill the deficiencies in knowledge on these geological disciplines in western Dutchess County. One of us (A. Scott Warthin) began investigations in the late 1940's with the express purpose of mapping the Rhinebeck 15-minute quadrangle. The other (Donald W. Fisher), during the course of collecting field data for the State Geologic Map of 1960, became interested in the geology of Dutchess County. Jointly, we have completed mapping eight 7.5-minute quadrangles and portions of two others. These will be published in the New York State Museum and Science Service Map and Chart Series in 1977. On the north, Fisher has also mapped three 7.5-minute quadrangles in adjacent Columbia County. On the east, Fisher and Professor James McLelland of Colgate University are mapping portions of six 7.5-minute quadrangles.

And, lastly, Bird and Dewey (1970) and Zen (1967, 1972) have provided modern workable interpretations toward a fuller knowledge of the geologic history of the Taconic region.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

Western Dutchess County is approximately midway between the State Capital at Albany on the north, and New York City on the south (Figure 1). It occupies the portion of the Mid-Hudson Valley where the low

FIGURE 1. INDEX AND GENERALIZED TECTONIC MAP OF EASTERN NEW YORK



Taconic highlands merge with the valley proper. On the east, in eastern Dutchess County are the high Taconics and across the state line, the Berkshire Highlands. On the west, are the dissected Allegheny Highlands (Plateau) known as the Catskill Mountains, with their foothills--the Helderbergs. To the south are the imposing Hudson Highlands. A north-south ridge extending from Kingston on the north to Newburgh on the south, the Hussey Hill-Marlboro Mountain ridge, parallels the Hudson River. A varied array of sedimentary and metamorphic rocks, folds, faults, and other structural features challenge the investigator.

In the Mid-Hudson Valley, rocks range in age from Middle Proterozoic (Helikean) through Late Triassic and an extensive road network provides good coverage for the investigating geologist.

The region is one steeped in early Dutch and Bicentennial History and the unwary geologist is easily distracted by the historical heritage of the region.

ROCK UNITS
(Figures 2, 3)

The rocks of Dutchess County (Figure 2, geologic map) may be conveniently segregated into three categories, based on their degree of structural transport--or lack of it! Autochthonous rocks were deposited where we now see them. Parautochthonous rocks have been transported a short distance from their depositional site but still remain in their general depositional realm (for example, shelf rocks moved westward but still within the shelf realm); amount of transport varies up to about 35 kilometers (22 miles). Allochthonous rocks have been transported a long distance and are now found in a depositional realm alien to their original site (for example, slope or basin rocks moved westward into an area occupied by shelf rocks); amount of transport varies up to about 120 kilometers (75 miles).

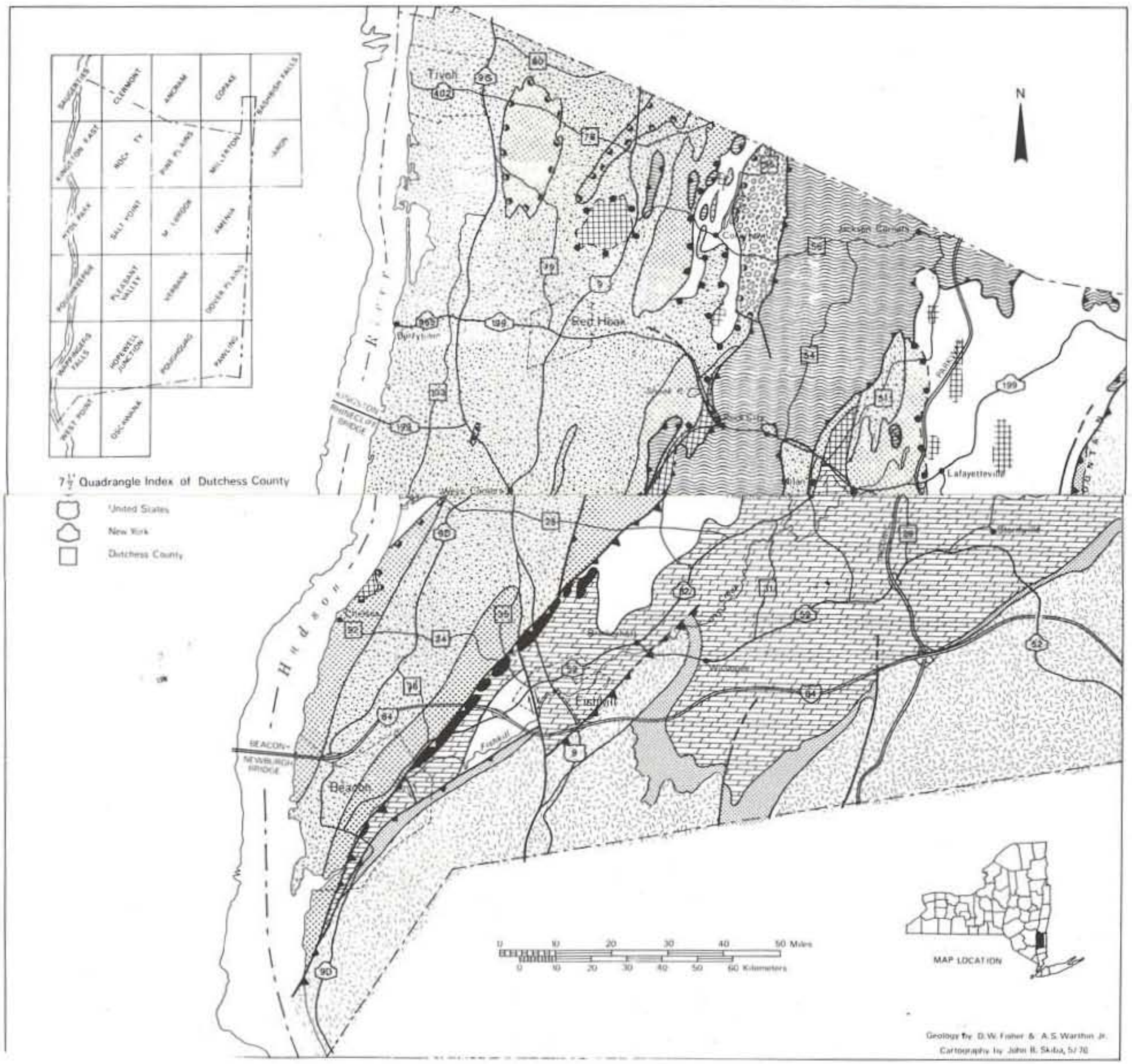
AUTOCHTHONOUS ROCKS

The only certainly identified autochthonous rocks in Dutchess County are the Middle Ordovician Snake Hill Shale and the quasi-autochthonous Poughkeepsie Mélange. In neighboring Ulster and Orange Counties on the west side of the Hudson River, the Middle Ordovician Snake Hill and Quassaic Formations are autochthonous as are the younger Silurian and Devonian strata. In this and succeeding stratigraphic lists, the rocks are listed in order of decreasing age.

Snake Hill Shale (R. Ruedemann, 1912, p. 58) up to 1500 m

Gray-black silty shale, mudstone, and argillite (frequently laminated) alternating with thin-bedded siltstones (frequently laminated and cross-laminated). Siltstones hold benthonic fauna of brachiopods, pelecypods, bryozoans, crinoid stems, and ostracodes; shales, in addition to the benthonic forms, contain graptolites which correlate with the standard

FIGURE 2. GENERALIZED BEDROCK GEOLOGY OF WESTERN DUTCHESS COUNTY, NEW YORK



Diplograptus multidens, Corynoides americanus, and *Orthograptus ruedemanni* zones (Figure 4).

Poughkeepsie Mélange (D.W. Fisher, 1976, in press) 150 m +

Haphazardly oriented clasts of varying angularity, size, and type in an unbedded or poorly bedded gray, argillaceous matrix. Clasts angular to rounded, pebble to mega-block size, principally graywacke but also siltstone, quartzite, laminated argillite, sandstone, chert, limestones, dolostones. The Poughkeepsie Mélange is distributed irregularly in the lower and middle Snake Hill Shale.

Quassaic Quartzite (D.W. Fisher, 1970, map) 650 m +

Lower portion has massive pink and green quartzites with polymict conglomerates having an arkosic, pelitic, red matrix, grading upward into hard green-gray sandstones with few green-gray shale interbeds. Benthonic fauna of brachiopods, gastropods, pelecypods, bryozoans, ostracodes, and rare straight cephalopods. The Quassaic appears to be equivalent to the Schenectady Formation of the lower Mohawk Valley and, like that formation, to represent a molasse, resulting from subaerial erosion of the gravity slides, which filled the Magog (Snake Hill) Trough. The Quassaic is absent in Dutchess County but forms the conspicuous north-south highland extending from Kingston on the north (Hussey Hill) to Newburgh on the south (Marlboro Mountain), on the west side of the Hudson River.

PARAUTOCHTHONOUS ROCKS

Proterozoic Gneisses

Rocks of the Proterozoic (Helikean) Basement occur at Todd Hill (Stop 2), Stissing Mountain near Pine Plains, Cronomer Hill and I-84 roadcut at Newburgh, series of small fault slivers from Beacon to Fishkill, Corbin Hill north of Pawling, and the Housatonic and Hudson Highlands. Geophysical evidence suggests that none of these occurrences are rooted. Quartz-feldspathic gneisses predominate, though varying types occur, some with relatively high biotite or hornblende.

Poughquag Quartzite (J.D. Dana, 1872, p. 250) 10-75 m

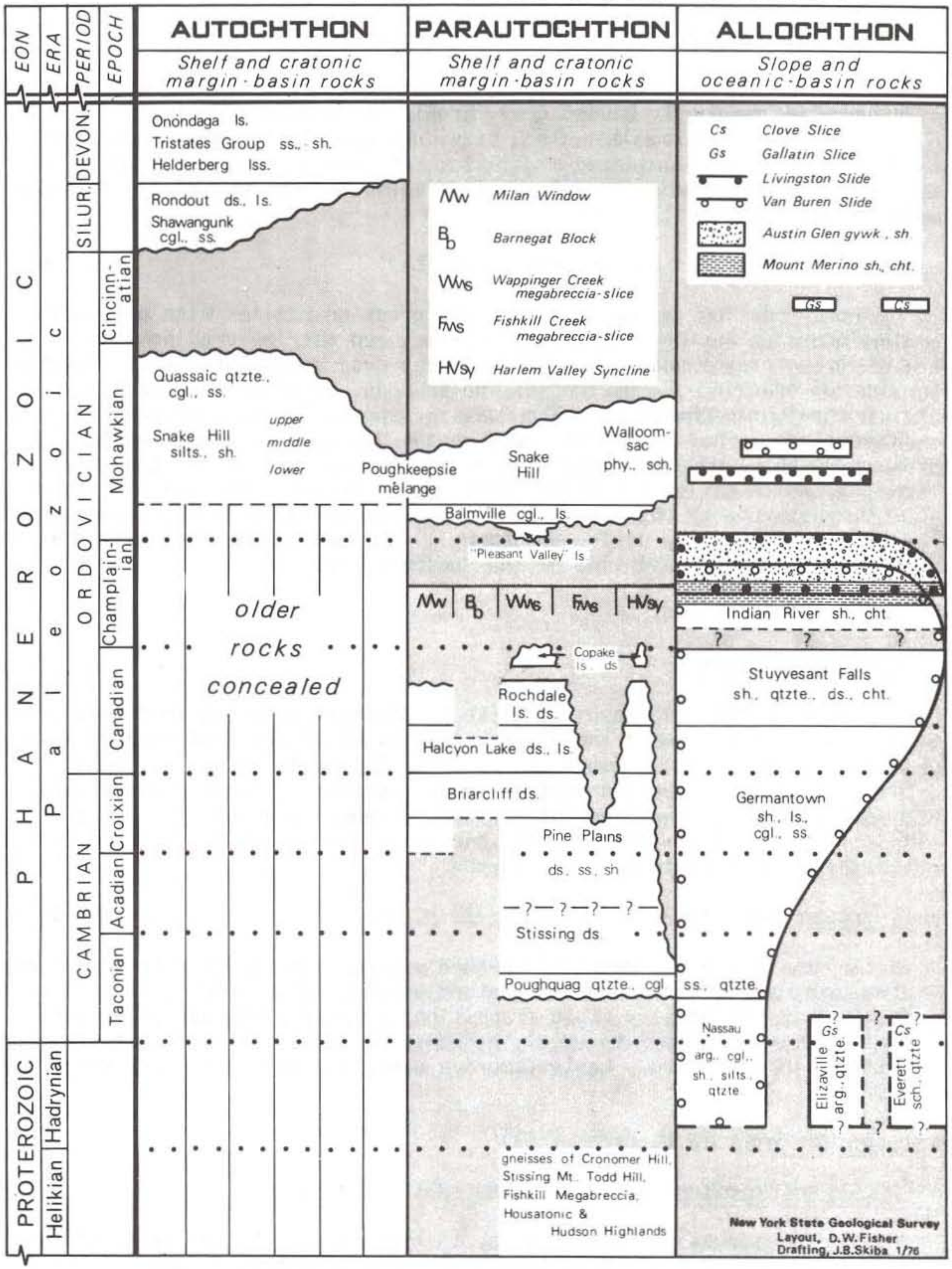
White, tan, pink, massively bedded vitreous quartzite with localized conglomerates at base. Quartz content exceeds 90%. Bedding is difficult to observe. Relatively rapid transition of interlayed quartzites and quartzose dolostones into overlying Stissing Formation over a stratigraphic distance of 10 meters. Early Cambrian olenellid trilobites are very rarely found.

Wappinger Group (J.D. Dana, 1879)

Stissing Dolostone (C.D. Walcott, 1891, p. 360) 150 m

Typically massive, nearly white to light gray, coarse-fine textured dolostones and calcitic dolostones; weathers pale gray. Some intervals

FIGURE 3. STRATIGRAPHY & TECTONICS-MID-HUDSON VALLEY



of gray, green, or red shale. Local chert and quartzose layers. In places has dark gray laminated, conchoidally fracturing, dolostone. Rare fossils denote an Early Cambrian age although the uppermost part may be Medial Cambrian.

Pine Plains Formation (E.B. Knopf, 1946, p. 1212) 350 m

The Pine Plains Formation is characterized by its extreme lithologic variability. Varying colors and textures of dolostone alternate with sandstone or quartzose dolostone beds. Bedding varies from thick to thin; silty, dark gray shale interbeds are common. Cyclical and graded bedding are ubiquitous. Oolites, ripple marks, cross-laminations, and dessication cracks are common. It is obvious that this unit is a product of deposition in the intertidal zone. No fossils, except stromatolites, are known from the Pine Plains.

Briarcliff Dolostone (E.B. Knopf, 1946, p. 1212) 150 m

The Briarcliff is typically a gray-tan weathering, light gray to dark gray dolostone with massive bedding. Detrital quartz is much less frequent than in the underlying Pine Plains. Chert nodules, quartz knots, and vugs with dolomite and quartz crystals are common. Rare trilobites (*Plethometopus, Plethopeltis, Prosaukia*) denote a Late Cambrian (Trempealeauan) age.

Halcyon Lake Dolostone (E.B. Knopf, 1946, p. 1212) 75 m

This is the most elusive of the Wappinger carbonates to find and identify. Where known, it is a calcitic dolostone, slightly quartzose and with chert pods. It is steel-gray, weathering to a medium-dark gray. It is usually medium-thick bedded. It is customarily coarse-medium textured. Rare gastropods (*Ecculiomphalus, Ophileta*) and cephalopods (*Ellesmeroceras*) denote an Early Ordovician (Gasconadian) age (Figure 4).

Rochdale Limestone (W.B. Dwight, 1887, p. 32) 75-125 m

The lower portion consists of interbedded fine-textured, buff-weathering dolostones and calcitic dolostones. The upper portion contains purer limestones, dark gray-black, and bluish-gray weathering. Locally, sandy beds or intraformational conglomerates are common. Laminations and faint cross-bedding are occasionally seen. Dark-gray to black chert pods are rare. The gastropod *Lecanospira compacta*, the trilobite *Hystricurus conicus*, and the cephalopods *Bassleroceras, Dwightoceras*, and *Vassaroceras* are diagnostic of an Early Ordovician and specifically a Medial Canadian (Demingian) age (Figure 4).

Copake Limestone (J.D. Dana, 1879, p. 376-383) 0-10 m

This uppermost unit of the Wappinger Group is better displayed and thicker in eastern Columbia and eastern Dutchess Counties. Because of the pronounced erosional surface atop the Wappinger Group, the Copake is usually eroded away. The unit is medium-light gray weathering, light gray-medium gray, medium-coarse textured limestone, dolomitic limestone, and dolostone; the base is frequently a dolomitic, laminated siltstone. Rare trilobites and cephalopods indicate an Early Ordovician and Late Canadian (Cassinian) age (Figure 4).

Balmville Limestone (F. Holzwasser, 1926, p. 40) 0.5-4 m

In western Dutchess County, the Balmville is a very thin limestone conglomerate and coarse-medium textured light-medium gray limestone. It is fossil-fragmental with whole specimens being very rare. The Balmville fills cracks and pockets in the underlying erosion surface atop the Wappinger Group. The Balmville represents the initial transgressive deposit of a Medial Ordovician (Mohawkian) sea atop the long-eroded Early Ordovician surface. Brachiopods, trilobites (including *Encrinurus cybeliformis*), corals, bryozoans, crinoid debris, ostracodes, conodonts, and algae all demonstrate a correlation with the lower Trenton Limestone Group of the Mohawk, Black, and Champlain Valleys. The physical and organic makeup of the Balmville denotes deposition in a high energy, beach environment; the intertidal zone must have been very restricted or almost non-existent at the time of Balmville sedimentation. Elsewhere, in the Hudson Valley, the Balmville may be absent and the overlying Medial Ordovician shales may rest directly on differing divisions of the Wappinger Group. The Balmville, locally, may reach thicknesses up to 35 m.

At Pleasant Valley, there are 10-15 m of lighter gray, finer-textured, thinner bedded, argillaceous limestones between the Balmville above and the Wappinger Group below. This interval yields trace fossils very similar to those in the Black River Group Lowville Limestone of the Black River Valley. If this localized pocket at Pleasant Valley is a remnant of the Black River Group, it is the sole occurrence known to indicate that the Black River seas inundated Dutchess County. Chazy Group limestones are absent in the Hudson Valley; if they were deposited here they were removed by erosion prior to the deposition of the Balmville Limestone.

Snake Hill Shale (R. Ruedemann, 1912, p. 58)

On the eastern side of some of the parautochthonous fault blocks, the Snake Hill Shale (previously described under autochthonous rocks) is exposed for a few meters. At Rochdale, for example, Dr. John Riva of Laval University has recovered graptolites, indicative of the *Diplograptus multidens* zone, in the dark gray shales overlying the Balmville Limestone. This is an important find in that it enables a tie-in of the graptolite and shelly faunas and fixes the Balmville as of pre-Canajoharie (Medial Mohawkian) age.

ALLOCHTHONOUS ROCKS

Everett Schist (W.H. Hobbs, 1893), p. 717-736) 500 m

This unit was named for exposures on Everett Mountain in southwestern Massachusetts. Typically, the Everett consists of green-gray, silvery schists and phyllites with local green-tan quartzites. It is strongly cleaved and the cleavage is always folded; bedding is extremely difficult to distinguish. Quartz knots are plentiful. Muscovite predominates over biotite and where the proper metamorphic rank is present, garnet and staurolite are common. The Everett forms the tops of most of the higher hills of the high Taconics in the County and always is in thrust-fault contact with its subjacent units; occasionally, carbonate slivers or quartz zones exist at the fault contact. Perhaps due to its higher metamorphic rank, the Everett has not yielded any fossils; it is presumed to be equivalent to the Elizaville and Nassau to its west and thus of earliest Cambrian or Late Proterozoic (Hadrynian) age.

Elizaville Formation (J.D. Weaver, 1957, p. 739) 300 m +

Lithologically, the Elizaville is quite uniform, consisting of green-gray hard, compact argillite, weathering olive-green, and with interbedded green-gray quartzites; some of the quartzites attain a thickness of 10 m. Cleavage is dominant over bedding, which may be laminated, and the cleavage is unfolded or only slightly folded. The Elizaville is the only rock unit identified in the Gallatin Thrust Slice and is present only in the northern part of Dutchess County, west of Stissing Mountain and east of Rhinebeck. The Elizaville is thought to be correlative to part of the Nassau Formation, although no fossils have been found to substantiate this supposition.

Nassau Formation (R. Ruedemann, 1914, p. 70) 700 m +

In Dutchess County, the Nassau consists of olive-green, micaceous, quartzose shale with local green-gray quartzites up to 10 m thick. To the north, in Columbia and Rensselaer Counties, the Nassau is thicker and has purple and green micaceous, silty shales and thin-bedded quartzites in its lower part and a significant, fossiliferous limestone conglomerate near its summit. The purple strata and the limestone conglomerate have not been found in Dutchess County. No fossils have been discovered in Dutchess County although to the north in Columbia County Early Cambrian trilobites and several types of Early Cambrian phosphatic fossils are known. The Nassau is the oldest unit in the Van Buren Gravity Slide.

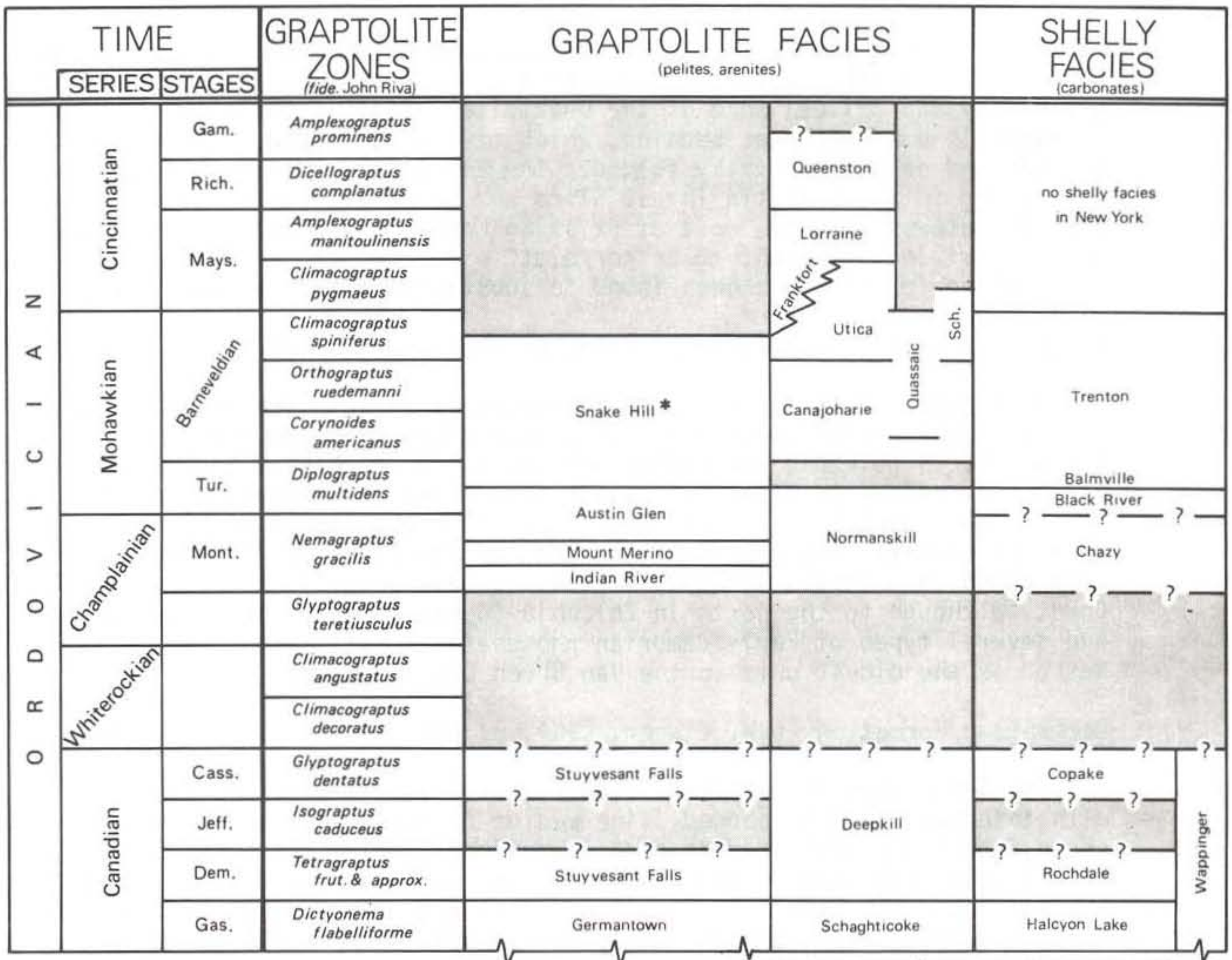
Germantown Formation (D.W. Fisher, 1961, p. D9) 100-300 m

The Germantown is composed of dark gray-black, silty, platey, shale with interbeds of thin-bedded, fine-medium textured medium-dark gray limestone (sometimes laminated or cross-laminated), dolomitic sandstone, thin-bedded to medium bedded tan quartzites, and carbonate-clast conglomerates. The conglomerates have a quartz-sand matrix with large well rounded and frosted grains, black angular phosphate pebbles, and angular-rounded clasts of differing dolostones and fine-textured dark gray limestones. The quartzites are usually basal and believed to correlate with the Diamond Rock Quartzite in Rensselaer County. Some of the conglomerates grade laterally into dolomitic sandstones; both are lensitic. In Columbia County to the north, intensive search has been made for fossils with the result that Early Ordovician graptolites (*Dictyonema flabelliforme*), and trilobites and conodonts of Early Cambrian, Medial Cambrian, Late Cambrian, and Early Ordovician ages have been recognized (Bird and Rasetti, 1968; Rasetti, 1966, 1967; Landing, 1974a, 1974b). The Germantown seems to be a deposit on an ancient continental slope with the conglomerates being lag turbidites.

Stuyvesant Falls Formation (D.W. Fisher, 1961, p. D9) 100-350 m

The Stuyvesant Falls consists of light green shale with interbedded thin beds of orange-tan weathering dolostone and green-gray quartzite and bedded green-gray chert; thin black shale seams and black chert occur occasionally. Rare graptolites (*Diplograptus dentatus* fauna) denote an Early

FIGURE 4. ORDOVICIAN GRAPTOLITE ZONES, APPALACHIAN PROVINCE



New York State Geological Survey; Layout D.W. Fisher, Drafting J.B. Skiba 6/76

Abbreviations: Gam - Gamachian, Rich - Richmondian, Mays - Maysvillian, Tur - Turinian, Mont - Montyan, Cass - Cassinian, Jeff - Jeffersonian, Dem - Demingian, Gas - Gasconadian, frut - fruticosus, approx - approximatus, Sch - Schenectady.

*Much of what we call Snake Hill in Dutchess County (on the Vassar campus, for example) contains only shelly facies.

Ordovician (Canadian) age. The Stuyvesant Falls is a distal slope and oceanic basin deposit.

Normanskill Group

Indian River Shale (A. Keith, 1932, p. 360) 50-300 m

Maroon to bright red and pale green shale with intercalated bedded red and green radiolaria-bearing chert. Local pockets of fine-textured, green-gray limestone, somewhat brecciated, may be turbidite slides. No benthonic fauna; rare graptolites denote the *Nemagraptus gracilis* zone (Figure 4). This is a distal slope and oceanic basin deposit.

Mount Merino Shale (R. Ruedemann, 1942, p. 23) 30-350 m

Dark gray-black mudstone, shale, slate with intercalated bedded dark gray-black radiolaria-bearing chert. No benthonic fauna; scarce graptolites denote *Nemagraptus gracilis* zone. This is an oceanic basin deposit.

Austin Glen Graywacke (R. Ruedemann, 1942, p. 28) up to 300 m

The lower division consists of thin-medium bedded graywacke and sub-graywacke and sandstone interbedded with much bluish dark gray shale. The upper division has thick massive coarse textured graywacke, with some thinner bedded graywacke, graywacke conglomerate, and relatively little shale (mostly as rare seams). The upper portion also displays a great variety of sedimentary features (load casts, climbing ripple marks, cross-bedding, cross-lamination, intra-shale clasts, graded bedding, etc.). No benthonic fauna; graptolites in the lower half are indicative of the *Nemagraptus gracilis* zone whereas graptolites in the upper division are indicative of the *Diplograptus multidens* zone. The graptolites of the upper division of the Austin Glen are the same as those in the lowermost Snake Hill Shale. Graptolite identifications are by Dr. John Riva of Laval University. Austin Glen sedimentation ceased just prior to, during, or shortly after Balmville Limestone deposition. Sufficient time had to elapse for the youngest graywackes to become lithified prior to their transportation westward into the Magog (Snake Hill) Trough--as the Poughkeepsie Mélange. The Austin Glen is a poorly sorted, rapidly deposited sediment on an unstable continental slope and was derived from an adjacent relatively rapidly rising land mass or island arc.

GEOLOGIC AND TECTONIC HISTORY
(Figure 5)

In an area of dense underbush, extensive cover of glacial deposits, ever increasing housing developments, scarce fossils, and complexly deformed rocks, the geologic and tectonic history is not as fully understood as we would like and, thus, many of our statements on the chronology of events must remain equivocal. As we view the past sedimentation and tectonic events, they appear to be as follows:

(1) Deformation, metamorphism, and recrystallization of Middle Proterozoic (Helikean), or older, rocks during the Grenville Orogeny (1100-980 mya).

(2) Rifting of a single tectonic plate during the Late Proterozoic (Hadrynian) and earliest Cambrian with formation of fault-trough deposits of poorly sorted graywackes, siltstones, pelites and volcanics during the initial stages of the Proto-Atlantic Ocean.

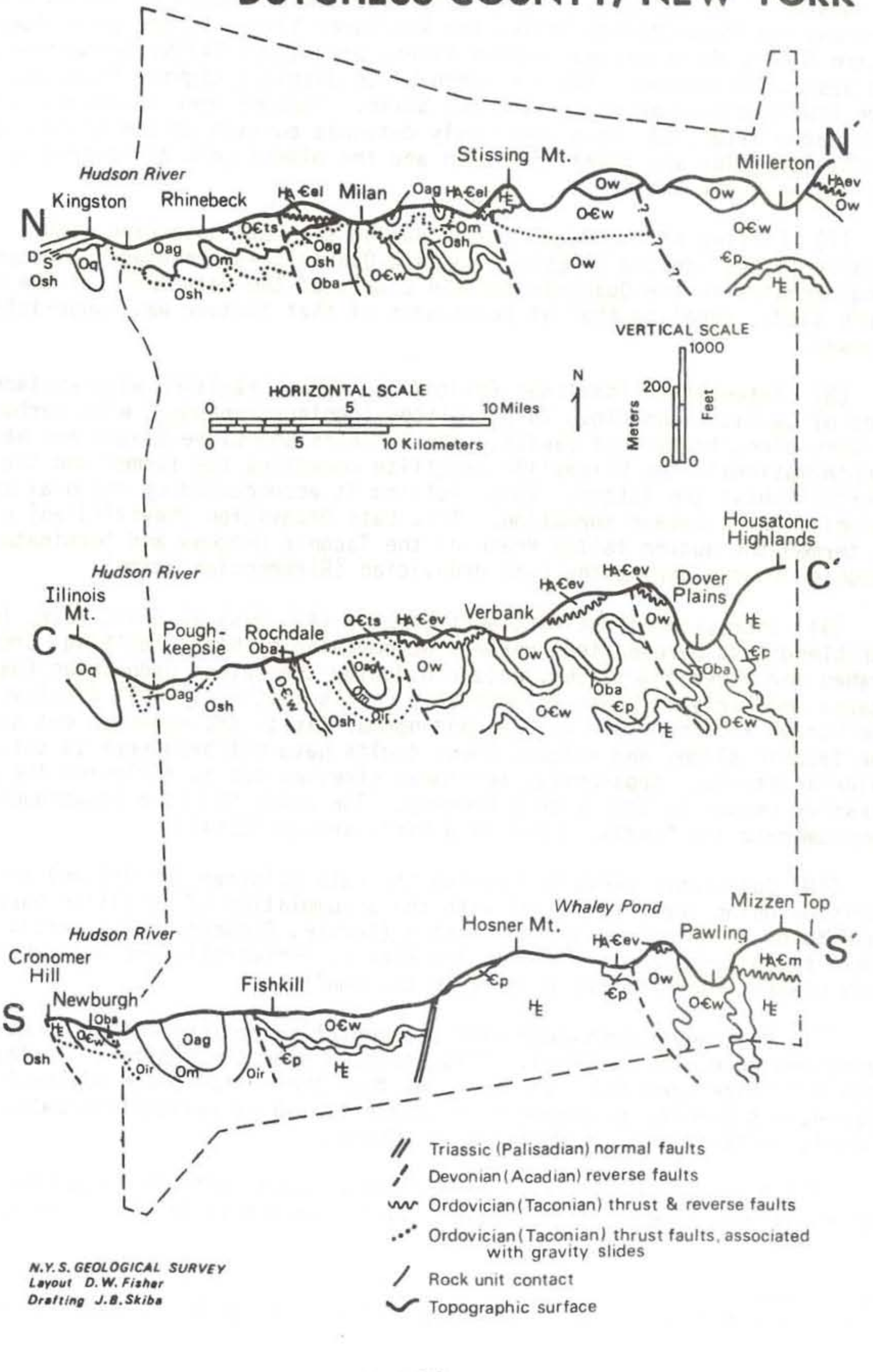
(3) Development of a broad continental shelf on the American stable plate (craton) which continued to receive a seaward-thickening wedge of carbonates throughout the Cambrian and into the Early Ordovician. The initial deposits were clean, quartz sands (Poughquag) whereas the younger carbonates (Wappinger Group) reflected different but similar environments on the broad and enduring shelf. The equivalent deposits on the continental slope were the Germantown (Early Cambrian through Early Ordovician) and in the oceanic basin the upper Nassau (Cambrian) and Stuyvesant Falls (Early Ordovician).

(4) Fracturing by normal and strike-slip tear faults, uplift (accompanied by some folding in the east), and subsequent subaerial erosion (Quebecian or Penobscot Orogeny) closed the Canadian Epoch (Early Ordovician). This represents the change from an expanding to a contracting Proto-Atlantic Ocean. The break atop the Lower Ordovician rocks in North America is one of the most pronounced and widespread in the stratigraphic column and faunally, sedimentologically, and structurally it marks a catastrophic change on the face of the earth.

(5) Compressional stresses, bringing about closure of the Proto-Atlantic Ocean, produced welts and troughs. Accelerated erosion of these welts or island arcs caused the resulting detritus to accumulate rapidly on the steepening slopes and downwarped troughs. These graywackes, pelites, and cherts comprise the Normanskill Group of Early Medial Ordovician age and were formed east of present-day New York--perhaps as much as 100 km east of Poughkeepsie. Partly contemporaneous Chazy carbonates were forming on a relatively narrow continental shelf in what is now the Champlain Valley. This is the early phase of the Taconic Orogeny--called in Newfoundland, the Bonnian Phase. In New York at this time there was little to presage the cataclysmic events that were to follow.

(6) Continued and intensified compressional stresses caused the welts to become greatly elevated and to create new troughs where none had been before (Snake Hill Trough developed on the existing continental shelf). The relief differential caused earlier formed slope and basin rocks (now greatly elevated) to move westward by gravity sliding into the newly created Magog or Snake Hill Trough during the Middle Mohawkian. This westward transport caused westward imbrication of portions of the old shelf, bulldozing carbonate blocks in front of and beneath the moving gravity slides until these blocks came to rest, haphazardly, in the Medial Ordovician Snake Hill mud. Such a northeastern-trending megabreccia of carbonate blocks is superbly shown along the Wappinger Creek Valley. In addition, blocks of the moving gravity slides spalled off and were chaotically mixed with ripped-up sole rocks and newly formed sediment to form a wildflysch or mélange. This gravity sliding event is termed the Vermontian Phase of the Taconic Orogeny, named from the large welt Vermontia, from whence the slides originated. In Dutchess County, at least two principal gravity slides are recognized, the earlier Livingston Slide and the later Van Buren Slide (this may be approximately the same age as Zen's Giddings Brook Slide

FIGURE 5. TENTATIVE STRUCTURAL SECTIONS- DUTCHESS COUNTY, NEW YORK



in the northern Taconics, although it is geometrically discrete). The Livingston Slide consists of both upper and lower members of the Austin Glen and the Mount Merino Shale; the Van Buren Slide is made up of lower Austin Glen*, Mount Merino, Indian River, Stuyvesant Falls, Germantown, and Nassau Formations. The Van Buren Slide displays tighter folding and more imbrication than the Livingston Slide. Another more southerly slide, the Beacon Slide, may be a physically detached portion of the Livingston Slide; its folds are relatively open and the oldest unit discovered is the Indian River Shale.

(7) Filling of the Magog Trough during the Late Mohawkian with a relatively well-sorted molasse (Quassaic Quartzite-Schenectady Sandstone). Conglomerates in the Quassaic contain clasts of the rock units of the Van Buren Slide, denoting that at least part of that feature was subaerially exposed.

(8) Intensified isoclinal folding and thrust faulting with emplacement of Gallatin and Clove Thrust Slices (contemporaneous?) with carbonate slivers along the thrust faults. The Gallatin and Clove Slices are each monoformational--the Elizaville Argillite comprises the former and the Everett Schist the latter. This faulting is accompanied by regional metamorphism and cleavage formation. This Late Ordovician (Maysvillian) episode is termed the Hudson Valley Phase of the Taconic Orogeny and terminates the Taconic Orogeny during the Late Ordovician (Richmondian Stage).

(9) Intrusion of the Cortlandt Complex (435 mya) of mafic rocks (norites, hornblendites, pyroxenites) perhaps accompanied by block faulting, creating graben and horst topography, occurred during the latest Ordovician (Gamachian Stage) and Early Silurian (Llandovery). This rifting is well displayed in the Mohawk and Champlain Valleys and normal faults are known to cut and trim the Taconic slides and slices; these faults have not been seen to cut Late Silurian strata. Apparently, tensional stresses set in following the compressive events of the Taconic Orogeny. The Lower Silurian Shawangunk Conglomerate and Sandstone may be a fault-trough deposit.

(10) Quiescence prevailed during the Late Silurian (Pridolian) and Early Devonian (Helderbergian) with the accumulation of localized basal sandstones (Binnewater) and carbonates (Bertie, Rondout, Helderberg); small patch coral reefs occur in the Glasco, Cobleskill, and Helderberg with blanket stromatoporoid reefs in the Manlius.

(11) Oriskany-Esopus-Schoharie sedimentation reflect influx of quartz sands and much clay material. This, coupled with the erosional surface atop the Helderberg limestones, argues that the intial phase of the Acadian Orogeny was already in progress--as demonstrated by radiometric dates and fossils in Maine and the Maritime Provinces.

(12) A succeeding interval of carbonate-coral reef (Onondaga) deposition was relatively short-lived; however, volcanism persisted as evidenced by

*No upper Austin Glen has been recognized in this or the Giddings Brook Slide.

volcanic ash beds within this limestone interval.

(13) The second more intense phase of the Acadian Orogeny made its presence felt during the deposition of the Hamilton clastics and continued during the Early Late Devonian (Senecan). At this time, tight folding (napping?), thrusting, high-angle reverse faulting (ex. Chatham, Wappinger Creek, Fishkill Creek, Pawling Faults), and metamorphism occurred. The Peekskill Pluton (371 $\pm$ 14 my; Mose, and others, 1976) probably was injected and cooled during the first phase of the Acadian Orogeny--contemporaneous with the White Mountain Magma Series in New Hampshire. At the beginning of Late Devonian (Chatauquan) time, the Acadian Orogeny had ended. The merging of the tectonic plates and the disappearance of the Proto-Atlantic Ocean were completed.

(14) The effect of Late Paleozoic (Alleghenyan) deformations in the Hudson Valley are unknown. A thermal event dated at 225 my is established in western Connecticut but bonafide Alleghenyan folding is unproved in the Hudson Valley.

(15) Late Triassic rifts, diabase intrusion (185 my), and fault-trough deposits (Newark Group) exist a short way to the south in Rockland County. Some of these lengthy, northeast-trending, faults, such as those that bound the Schunnemunk Mountain Graben, can be traced into Dutchess County where they trim earlier gravity slides and thrust slices. Some of this tensional stress probably lasted into succeeding Jurassic time.

(16) Later Mesozoic and Cenozoic history is unrecorded in the Hudson Valley; Late Cretaceous (and possibly Tertiary) sediments occur on Staten and Long Islands.

(17) Pleistocene glaciers have excavated the surface and deposited great quantities of gravels, sands, silts, and clays in the Hudson Valley. This combination of erosion and sedimentation has both exposed and concealed rock for study.

"TWENTY QUESTIONS"

(CONTROVERSIAL MATTERS AND UNANSWERED QUESTIONS
RELEVANT TO DUTCHESS COUNTY GEOLOGIC HISTORY)

1. What is the precise relationship of the graptolite-bearing Normanskill rocks (Indian River, Mount Merino, Austin Glen) to the shelly carbonate sequence?

2. Is the upper Snake Hill Shale unconformable on the rocks of the Livingston gravity slide?

3. What is the relationship between the Poughkeepsie Mélange and the Wappinger Creek megabreccia? And the relationship of the Wappiner Creek megabreccia to the Fishkill Creek megabreccia?

4. Are the Housatonic and Hudson Highlands rooted? or parautochthounous?

5. What is the origin and mechanism for the isolated occurrences of Proterozoic (Helikian) gneisses at Stissing Mountain, Cronomer Hill, Todd Hill, Corbin Hill?

6. Were the slides and slices physically connected during westward transport?

7. Why does the Everett Schist (Clove Slice) always rest on the Walloomsac (metamorphosed Snake Hill) Schist?

8. Does the Everett Schist equate with several rock units that are present in the more westerly slides?

9. What is the precise age of the Pine Plains Formation?

10. Is the Briarcliff an easterly thickening facies?

11. Are the Barnegat and New Hamburg blocks rooted? Is their western contact a high angle reverse fault or an apparent fault?

12. Does the Nassau equate with the Elizaville? with the Everett?

13. Was the Van Buren Slide a single large gravity slide or a series of smaller discrete slides?

14. Are two periods of Acadian deformation recognizable in Dutchess County?

15. Are Late Triassic-Jurassic age block faults really present in Dutchess County?

16. Are the large-scale folds in Orange County (Green Pond, Schunnemunk Mountain, possibly east edge of Shawangunk) continued into Dutchess County? What is their age?

17. Are the pre-Mount Merino beds along the railroad tracks at St. Andrews (now Culinary Institute of America) Germantown? If so, why do they differ from the Germantown elsewhere in the county?

18. Are the apparent strike-slip tear faults of the Milan Window, Wappinger Creek, and Fishkill-Beacon areas pre-gravity sliding in age?

19. What is the significance of the parallelism of the Shawangunk Ridge and the Hudson Highlands? and the northern termination of the Shawangunk conglomerate and sandstone?

20. Is there any napping prior to hard-rock thrusting?

ROAD LOG

T.S.P. - Taconic State Parkway
U.S. - Federal Highway
N.Y. - New York State Highway
D.C. - Dutchess County Highway

Time	Accumulated Mileage	Trip Mileage	Descriptions & Directions
8:15 a.m.	0	0	LEAVE Vassar College South Parking Lot on NE corner of Raymond Ave. and Hooker Ave. (N.Y. 376), N(right) on Raymond Ave.
	1.00	1.00	E(right) on Main St. (U.S. 44).
	1.3	0.3	V-intersection with N.Y. 55. Stay on U.S. 44(left).
	2.1	0.8	Middle Ordovician Snake Hill Shale on left. Proceeding in Lower Ordovician-Cambrian carbonate valley. Megabreccia (?) of carbonate blocks deposited on Snake Hill mud.
	6.7	4.6	Road cut in Rochdale Dolostone.
	7.5	0.8	Village of Pleasant Valley, crossing Wappinger Creek.
	7.9	0.4	Lower Cambrian Nassau pelites; have entered the Van Buren gravity slide.
	8.50	0.6	Lower Ordovician Stuyvesant Falls green shale, and thin quartzites on NW(left).
	8.55	0.05	SE(right) on Rossway Rd.
8:35 a.m.	10.2	1.65	STOP 1 -- Intersection of Drake-Rossway Rds. & T.S.P. Exposures of Cambrian-Lower Ordovician Germantown Formation along both lanes of T.S.P., north of intersection. We shall examine only the western cut on the southbound lane. Here, almost vertical dipping platey, silty shale with very thin-bedded limestones and carbonate-clast carbonates are superbly exposed. Tight drag folding indicates that we are on the eastern limb of a larger synclinorium. Note the quartzose limestone beds. These and the

Figure 6. Carbonate-clast conglomerate in Germantown Formation; west side of Taconic State Parkway near Drake Road. Stop 1 of field trip.

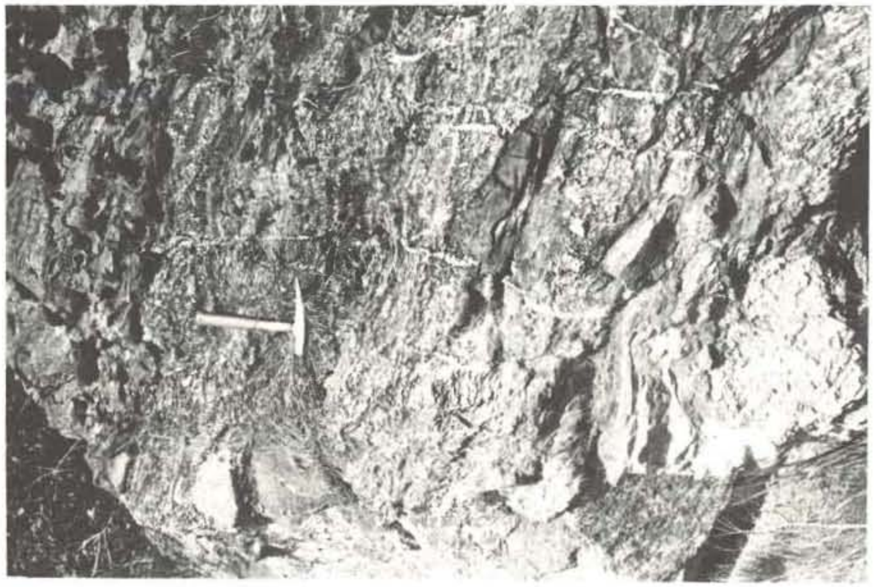


Figure 7. Proterozoic gneiss along east side of Taconic State Parkway and comprising Todd Hill (in center). Stop 2 of field trip.

			carbonate-clast conglomerates have large and well-rounded frosted quartz grains; the clasts consist of fine-textured limestones and differing types of dolostones and black phosphate pebbles. These conglomerates are thought to be lag-turbidites on an ancient continental slope.
9:10 a.m.	10.2		LEAVE STOP 1. SE across T.S.P. on Rossway Rd.
	10.35	0.15	Lower Cambrian Nassau shales and argillites.
	12.65	2.30	E(left) on Mountain Rd.
	12.85	0.20	S(right) on Skidmore Rd., in valley floored with outwash gravels.
	14.3	1.45	Kame terrace on E side of valley.
	14.9	0.6	SE(left) on Velie Rd.
	15.35	0.45	Cross N.Y. 55 on Velie Rd.
	15.7	0.35	Lower Cambrian or Late Proterozoic Everett Schist in hill on left. Everett is thrust-faulted, westwardly, onto Middle Ordovician Snake Hill (=Walloomsac) Shale.
	16.3	0.6	Fork left.
	16.45	0.15	W(right) on Todd Hill Rd.
9:35 a.m.	16.95	0.5	STOP 2 -- Intersection of Todd Hill Rd. and T.S.P. Here we have a geological enigma--an exposure of Proterozoic gneiss in an area far removed from larger masses of Proterozoic gneiss. This orange feldspar-rich granite gneiss does not have a normal shelf stratigraphy (Poughquag Quartzite, Wappinger carbonates) associated with it as does the Cronomer Hill section at Newburgh or the Stissing Mt. section near Pine Plains. Todd Hill and a smaller hill to the SW are flanked on the east by Everett Schist and Mount Merino(?) Shale, respectively. These two gneiss hills are bounded

on the W by a major NE-trending fault. The field relations deny the views that these gneiss hills were islands around which Cambrian and Ordovician sediments accumulated or that the gneisses were up-punched due to doming or normal block faulting (horst). The gneiss owes it position as a result of far-travelled movement--either as a sliver along a low thrust fault or as an erosional outlier of a once larger overthrust mass of gneiss, such as the Hudson Highlands. We prefer the sliver supposition.

10:00 a.m.	16.95		LEAVE STOP 2. W across T.S.P. on Todd Hill Rd.
	17.25	0.3	SW(left) on Stringham Rd.
	18.25	1.0	SE(left) on Old Noxon Rd. at housing development. W(right) into relatively new rock cut on both sides. Park on Old Noxon Rd.
10:05 a.m.	18.55	0.3	STOP 3 -- Noxon Rd. (D.C. 21) rock cut, E of Sprout Creek. Here, we have the Mt. Merino Shale on the west and the Indian River Shale on the east, -- the middle and lower divisions of the Normanskill Group, respectively. The Mt. Merino is a gray to black shale or mudstone locally with gray to black chert; the Indian River is a pale green to red to maroon shale or mudstone with light green to red chert; within the Indian River here is an unfossiliferous dove-tan-gray, fine-textured limestone. Three and possibly four episodes of folding are displayed here. One set has horizontal axial planes, another has westward dipping axial planes with N-plunging folds, and a third are small drag folds which appear to be refolded.. In addition, the penetrative cleavage is folded. The interpretation is that this outcrop exposes a portion of a lower limb of a westwardly overturned fold (nappe). Small discrete bodies of graywacke, more convex upward and to the east, are probably turbidites; they too, are upside down. No fossils have been found at this exposure but

			elsewhere, where less deformed, the Indian River and Mt. Merino yield graptolites characteristic of the *Nemagraptus gracilis* zone of the Early Medial Ordovician.
10:45 a.m.	18.55		<u>LEAVE STOP 3.</u> W on Noxon Rd. (D.C. 21) to Titusville Rd. (D.C. 49).
	21.25	2.7	W(left) on Titusville Rd. (D.C. 49).
	22.25	1.0	S(left) on Red Oaks Mill Rd. (D.C. 44).
	22.95	0.7	W(right) on N.Y. 376 at bridge over Wappinger Creek. Get into left lane for left turn at signal between two gas stations at Red Oaks Mill onto
	23.15	0.2	Spackenkill Rd. (D.C. 76).
	23.75	0.6	Slow, but no full stop. On S(left) side of Spackenkill Rd. is a block of Wappinger (Briarcliff) carbonate in the Snake Hill Shale. This is regarded to be part of an extensive NE-trending megabreccia extending from the Cronomer Hill area at Newburgh, generally following Wappinger Creek and reaching Stissing Mountain near Pine Plains. Although the precise sequence of deformational events is uncertain, this megabreccia is believed to be an early mélange deposit in the Snake Hill mud, created by the ripping-up of underlying shelf carbonates as the pelitic Van Buren gravity slide moved westward. This exposure is but one of many carbonate blocks illustrating various attitudes and differing Wappinger units.
	23.9	0.15	NE(right) on Cedar Valley Rd.
11:00 a.m.	24.4	0.4	<u>STOP 4</u> -- W side of Cedar Valley Rd. (NO ROCK BREAKING OR SAMPLING, PLEASE.) Here, we have opportunity to see the significant Middle-Lower Ordovician contact, -- a profound erosional unconformity on a regional scale. At this exposure, the Middle Ordovician (Mohawkian) Balmville Limestone rests on the Lower Ordovician (Canadian) Rochdale Limestone. In some parts of

the Hudson Valley, the Balmville rests on older rocks--as old as Medial Proterozoic gneisses.

The Balmville consists of medium-dark gray, coarse-fine textured limestone, fossil fragmental, and, locally, with a pebble conglomerate composed of clasts of finer textured, light gray weathering limestone of buff-weathering dolostone. Some "clasts" are colonies of the alga *Solenopora*. The Balmville is relatively fossiliferous but whole specimens are difficult to obtain. Brachiopods, crinoids, and bryozoans are the principal taxa; algae, conodonts, gastropods, ostracodes, and trilobites are secondary taxa. The subjacent Rochdale Formation is fine-textured, bluish-gray to black limestone with interbedded paler bluish-gray, buff weathering dolostones. In some beds, the proportion of calcite to dolomite varies considerably; this produces a fretwork appearance to the weathered surface. The Rochdale is Medial Canadian (Demingian) age as evidenced by the diagnostic discoidal gastropod, *Lecanospira*, the trilobite *Hystricurus conicus*, and the cephalopods *Bassleroceras*, *Dwightoceras*, and *Vassaroceras*. Stromatolites are also occasionally seen. The Rochdale seems to have been deposited in a low-energy, distal intertidal environment whereas the Balmville is a product of extremely high-energy conditions on an ancient beach.

The dip varies from 55° E at the northern end of the exposure to near vertically at the southern end. The observed rocks are on the eastern edge of an elongated carbonate block with Middle Ordovician Snake Hill Shale occupying the lowland to the east and the adjacent lowland to the west of the NE-trending carbonate ridge.

11:25 a.m.	24.4		LEAVE STOP 4.
	24.8	0.4	Return to Spackenkill Rd., turn W(right).

	24.95	0.15	Turn N(right) on Boardman Rd. through area of IBM Research and Development Facility.
	26.65	1.75	W(left) at blinking signal onto Hooker Ave. (N.Y. 376), keeping in left lane preparatory to continuing W through next signal.
	27.35	0.7	S(left) on Cedar Ave. at Sunoco gas station.
11:35 a.m.	28.75	1.5	STOP 5 -- E side of Cedar Ave. (D.C. 74); park cars or buses on W side. This long exposure is in the Briarcliff Dolostone division of the Wappinger Group. Note the variation in textures and colors in the dolostones. Small faults with only a few centimeters displacement and microbreccias are common. A more prominent normal fault across from the parking area trends N70°E and dips almost 90°. A short distance to the east, the Briarcliff abruptly ends in a cliff; Snake Hill Shale occupies the bounding lowland. This is the eastern extremity of the relatively large block of carbonate that is exposed in the large Clinton Point Quarry on the Hudson River. Here, earthquakes have been documented from 1937 to the present. It is speculative whether this Cedar Ave.-Clinton Point block is (1) an exceedingly large block in a megabreccia, (2) an up-punched block bounded by normal faults, (3) the leading edge of a thrust block, or (4) a megabreccia block trimmed by subsequent block faulting. Because of its proximity to known, but smaller, megabreccia blocks, we favor views (1) or (4).
12 noon	28.75		LEAVE STOP 5. S on Cedar Ave.
	28.95	0.2	W(right) on Spackenkill Rd. (D.C. 76). Note gentle dips in Briarcliff Dolostone in every exposure.
	30.30	1.35	N(right) on U.S. 9. Note outcrop of Briarcliff Dolostone just north of Robert Hall Store. Dips are abnormally steep and may record bevelled isoclinal folds or indicate proximity to a fault.

Figure 8. Middle Ordovician Balmville Limestone (darker gray) disconformably on the Lower Ordovician Rochdale Limestone of the Wappinger Group; along west side of Rochdale Road and Wappinger Creek.

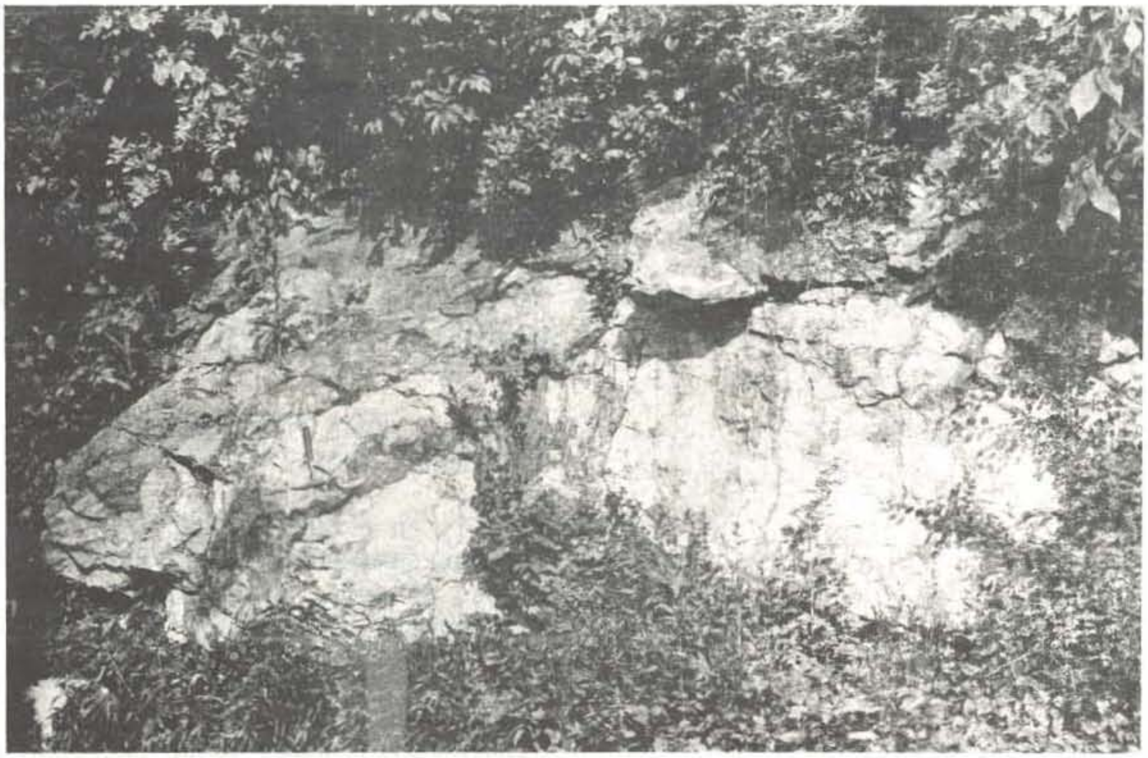
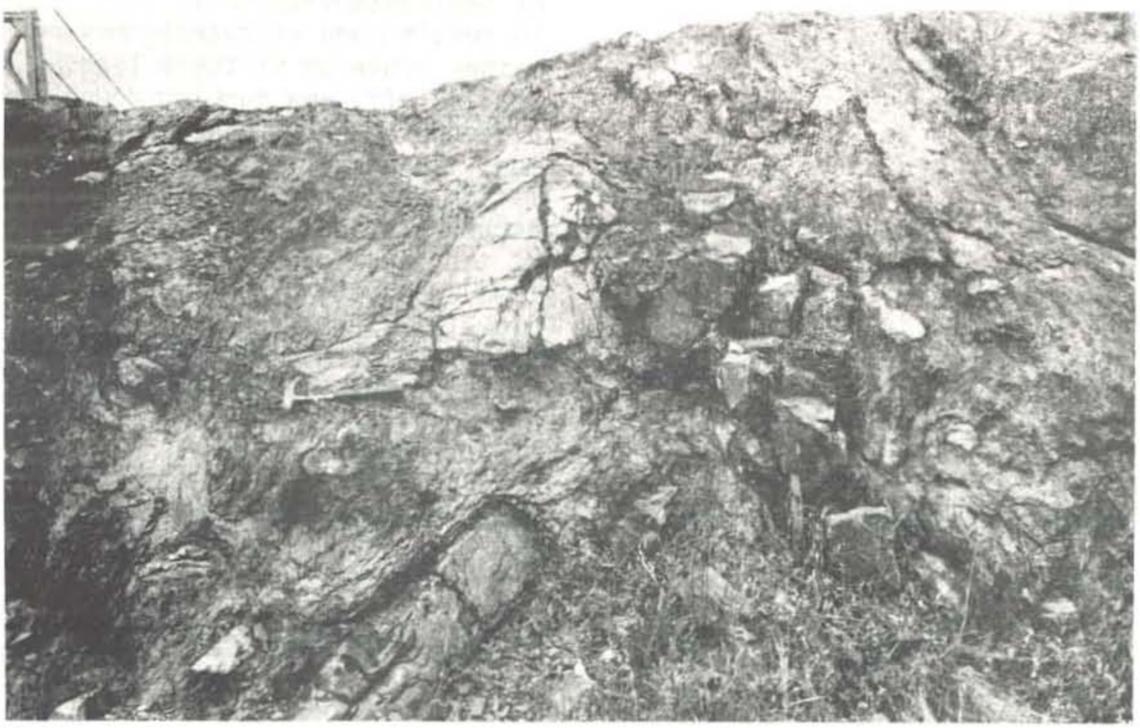


Figure 9. Poughkeepsie Mélange, illustrating exotic blocks of Austin Glen Graywacke in unbedded Snake Hill Shale; Kaal Park under east end of Mid-Hudson Bridge. Stop 6 of field trip.



			This is the western margin of the Cedar Ave.-Clinton Point carbonate block.
	33.75	3.45	Exit from U.S. 9 on access road(right) for Main St.
	33.85	0.1	W(left) on Main St.
	33.95	0.1	S(left) on Rinaldi Blvd., continuing beneath overpass of Mid-Hudson Bridge.
	34.30	0.35	W(right) on entrance road to Kaal Park, turning W(left) 34.40 and downhill into Kaal Park.
12:20 p.m.	34.55		STOP 6 -- KAAL PARK (LUNCH!) NO HAMMERING, THIS IS A CITY PARK.
			This is an exquisite exposure of a tectono-sedimentary unit known as chaos, mélange, olistostrome, or wildflysch. Fisher (1976, in press) has named this unit the Poughkeepsie Mélange. It consists of various sized, angular to rounded clasts of rock (with varying attitudes) in an unbedded or poorly bedded argillaceous matrix. Here, the blocks are almost exclusively Austin Glen Graywacke; elsewhere, there are varying amounts of quartzite, sandstone, shale, and carbonate. This type of sedimentary-tectonic unit is believed to result when westwardly moving rock masses broke up at their leading edge, spalled off, and tumbled downslope into a deepening basin which was receiving mud. Evidences of soft-sediment deformation are widespread. This deposit accumulated during the Vermontian Phase of the Taconic Orogeny (mid-Mohawkian time) when the Livingston and Van Buren Gravity Slides were emplaced into the Magog (Snake Hill-Martinsburg) Trough. Rocks of the Livingston Slide are superbly exposed at the western end of the Mid-Hudson Bridge.
1:20 p.m.	34.55	0.3	LEAVE STOP 6. Exit east via Kaal Park Rd., crossing Rinaldi Blvd. and passing under U.S. 9.
	34.85	0.3	N(left) on access road to U.S. 9.

Figure 10. Cross-section of load casts in Austin Glen Graywacke; north side of St. Andrews Road (Dutchess County 40). Stop 7 of field trip.

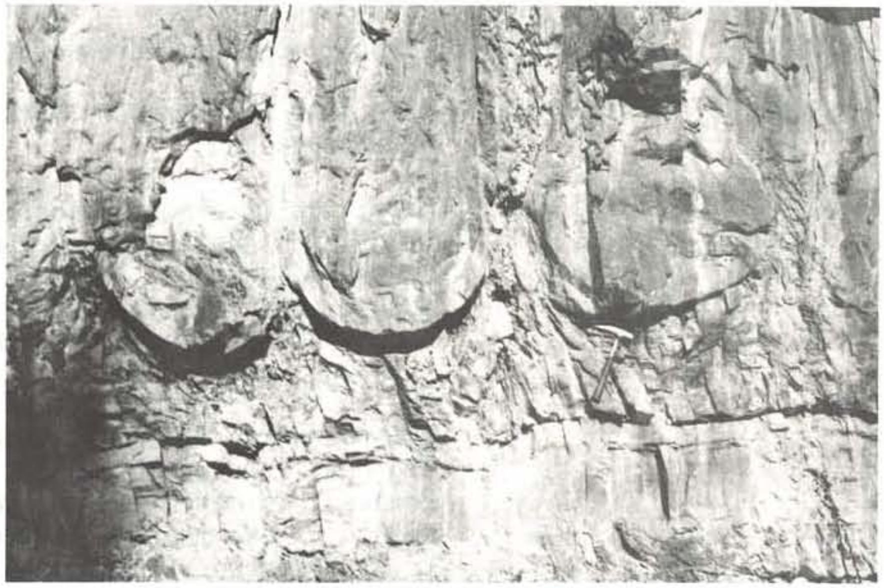
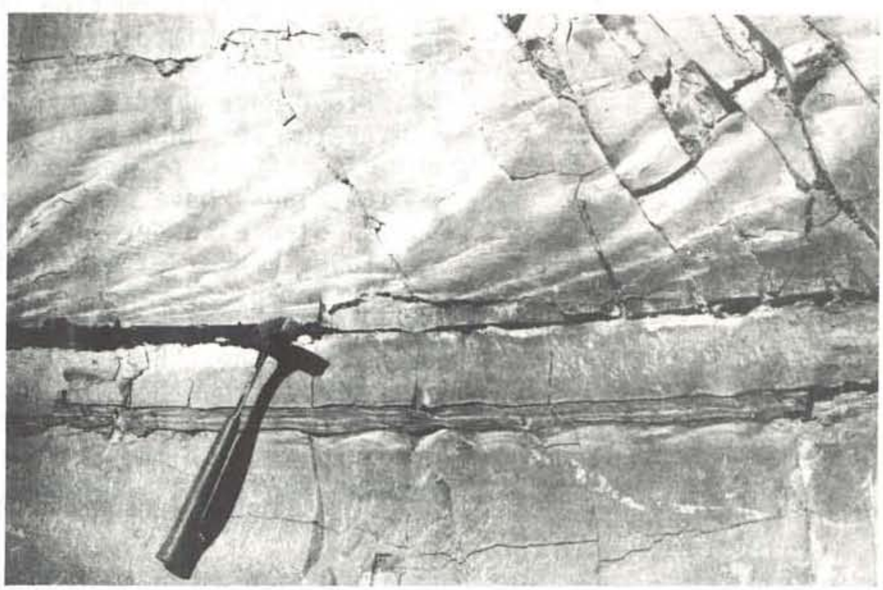


Figure 11. Climbing crossbedding in Austin Glen Graywacke; north side of St. Andrews Road (Dutchess County 40). Stop 7 of field trip.



	35.35	0.5	Numerous exposures of Poughkeepsie Mélange.
	37.05	1.70	Culinary Institute of American on W(left).
	39.30	0.55	E(right) on St. Andrews Rd. (D.C. 40).
1:40 p.m.	39.85		STOP 7 -- Exposures on both sides of St. Andrews Rd.

Here, the uppermost member of the Middle Ordovician Austin Glen Graywacke is deformed into broad, low amplitude folds. The somewhat cyclical shale-graywacke succession is cleaved and the cleavage is slightly bent, denoting that here we are at the western limit of a folding episode which deformed the earlier regional fracture cleavage. This stop, however, is more instructive for the wealth of sedimentary features that are to be observed: load casts, cross-lamination, cross-bedding, graded bedding, intra-bed clasts, climbing ripple marks, etc. Note also, the micro-folding of the thinnest seams. The abrupt change from arenite sedimentation (graywacke) to pelite sedimentation (argillite, shale) is striking. Many of the graywackes, especially the thicker ones, are turbidites as evidenced by the variety of load casts and trapped shale or pelite clasts.

The Austin Glen Formation is thought to have been deposited on an ancient continental slope where the sediments on the sea floor were unstable. This type of substratum was inhospitable to benthonic animals. A few pelagic forms (graptolites, radiolarians) have been recorded from the Austin Glen elsewhere in Dutchess County. The lower member of the Austin Glen belongs to the *Nemagraptus gracilis* zone and the upper member belongs to the *Diplograptus multidens* zone. Because of the absence of a shelly, benthonic fauna from all divisions of the Normanskill Group, its correlation with the shelf carbonates remains equivocal. Outcrop is in the Livingston Gravity Slide.

2:20 p.m.	39.85		LEAVE STOP 7. E on St. Andrews Rd. (D.C. 40).

Figure 12. Interbedded quartzite and argillite, with quartz cross-veining in thicker quartzites in Elizaville Formation; north side of Slate Quarry Road (Dutchess County 19). Stop 8 of field trip.

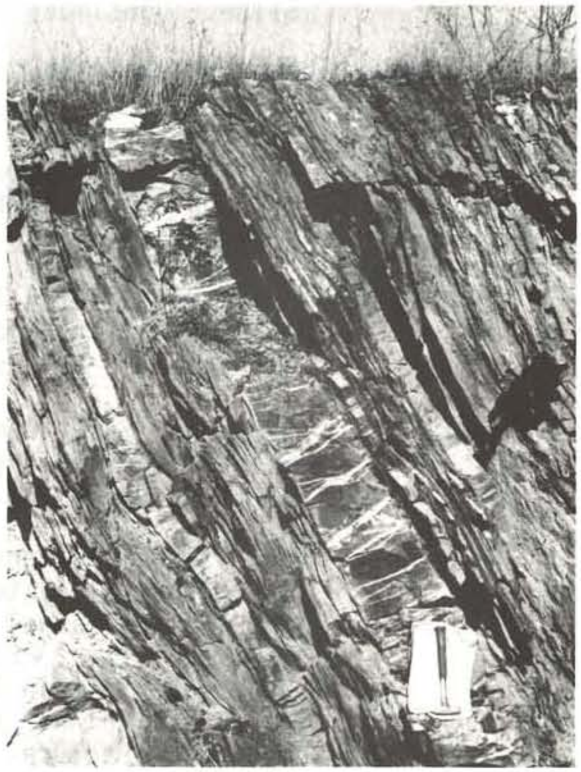


Figure 13. Deformed cleavage ("crinkled layers") in Everett Schist; north side of N.Y. 55, east of the Taconic State Parkway.

	40.45	0.6	N(left) on N.Y. 9G at signal.
	42.30	1.85	Exposures of very massive Austin Glen Graywacke in Livingston Gravity Slide. Continues to 43.2.
	52.20	9.90	E(right) on Slate Quarry Rd. (D.C. 19). Outcrops of mélange near intersection.
	52.65	0.45	Germantown conglomerates, limestone, and shale on N(left) side. Have just entered Van Buren Gravity Slide.
	53.30	0.65	Entering Gallatin Thrust Slice; Elizaville argillite and quartzite in numerous exposures on both sides.
2:50 p.m.	55.05	1.75	STOP 8 -- Early Cambrian or Late Proterozoic Elizaville Argillite and Quartzite on Slate Quarry Rd.

The Elizaville consists of hard, compact greenish-gray slate and argillite (weathering tan to orange) and interbedded greenish-gray quartzite. Elsewhere, some of the quartzites attain 10 meters thickness. Here, the thinner quartzites are traversed by cross-fractures filled with milky quartz and iron carbonate (siderite). NO HAMMERING OR COLLECTING SIDERITE!!! On the west end of the exposure, the strata form a low fold with cleavage dipping 50-60° E. Further east, the bedding and cleavage are parallel (dipping 60° E). Where this coincidence exists, the chances for good quality commercial slate are better; abandoned slate quarries may be found on both N and S sides of the road in the woods. In general, in the Gallatin Slice, cleavage is predominant over bedding. And, cleavage is virtually undeformed.

No fossils have been discovered in the Elizaville Formation. It is presumed to be equivalent to part of the Nassau Formation of the Van Buren Slide.

3:30 p.m.	55.05		LEAVE STOP 8. E on D.C. 19.
	55.70	0.65	Exiting from Gallatin Thrust Slice into Livingston Gravity Slide; Mt. Merino black shale on N(left) side.

3:40 p.m.	56.15	0.45	STOP 9 -- MILAN WINDOW: WAPPINGER (HALCYON LAKE?) carbonate on N side of D.C. 19 near intersection with D.C. 18.
			This is a NNE-trending valley floored by Wappinger carbonates, Balmville Limestone, and Snake Hill Shale. Rimming this sequence of shelf rocks are slope and basin Normanskill graywackes and pelites of the allochthonous Livingston Slide. The window of parautochthonous shelf rocks was produced by differential erosion of part of the covering Livingston Slide and additional covering Gallatin Slice; the Van Buren Slide was presumably eroded prior to the emplacement of the Gallatin Slice. Subsequent normal faulting may have accelerated erosion and the creation of the Milan Window. This stacking of gravity slides and thrust slices is seen to no better advantage than in this region of the Rock City Quadrangle. Mapping of the divisions of the Wappinger Group has disclosed here, and in other lengthy carbonate terranes, the existence of a NW-SE trending fault set (strike-slip faults) which, seemingly predate the gravity slides. These faults may have been the product of stresses in effect during expansion of the Proto-Atlantic Ocean. The slides and slices were formed during contraction of the Proto-Atlantic Ocean.
			Field relations at the Milan Window demonstrate that the parautochthonous carbonates (megabreccia?) were emplaced prior to the transport of the slides and slices--an important criterion in documenting the regional geologic history.
4:00 p.m.	56.15		LEAVE STOP 9. E on D.C. 19 (now named Bulls Head Rd.).
	56.70	0.55	E edge of Milan Window (56.75 Milan Hollow Rd. corner). Several exposures of Mt. Merino black shale on both sides of road almost to T.S.P. (56.90 black shale on S side of road).
	58.55	1.65	Cross T.S.P. Melange exposures on T.S.P. near the intersection. Continue E and SE on D.C. 19.

	62.9	4.35	Everett Schist on both sides of road.
	63.75	0.85	S(right) on N.Y. 82 at Stanfordville.
	64.55	0.8	Everett Schist on E(left).
	65.65	1.1	Crossing into Van Buren Slide near intersection with Knight Rd. Indian River green and red shales and cherts.
	70.45	4.8	W(right) on U.S. 44 at Washington Hollow. State Police Troop K Headquarters on E side of road intersection. Germantown gray-black shale in borrow pit on S side of intersection; Stuyvesant Falls Formation in cliff NW of intersection.
	71.25	0.8	Pass under T.S.P. in a southwesterly direction.
	72.25	1.0	Indian River green and red mottled slates near Tinkertown Rd.
	73.25	1.0	Rossway Rd. intersection.
	74.75	1.5	Re-enter Wappinger carbonate valley at Pleasant Valley.
	75.05	0.3	(Traffic light in Pleasant Valley)
	75.65	0.6	Rochdale limestone and dolostone on both sides.
	78.55	2.9	Delaval Plant on E(left).
	79.05	0.5	Turn SE(left) on DeGarmo Rd. (D.C. 43).
	79.85	0.8	Straight ahead on D.C. 46.
	80.65	0.8	At signal turn W(right) on N.Y. 55 at Manchester Bridge.
	80.70	0.05	After crossing Wappinger Creek and immediately before railroad underpass, turn NW(right) into Page Industrial Park and continue west to westernmost parking lot against hill and near railroad embankment.
4:55 p.m.	81.20	0.50	STOP 10 -- rock cut and fault along Penn Central R.R.

At the western end of the railroad cut is an apparent high-angle reverse fault with Late Cambrian Briarcliff Dolostone on the east and the Middle Ordovician Snake Hill Shale on the west. Note the gouge (mylonitized) zone along the contact. The question here is whether this is a bonafide high-angle reverse fault, east being the overriding block, or rather a carbonate block which has gravity slid into the Snake Hill mud; the illusion of a high-angle fault may have been created subsequent to sliding by rotation of the strata during an Acadian (Middle Devonian) folding episode.

The fault plane dips 75-80° E and there is no apparent drag here or anywhere else along the western margin of this carbonate block. At New Hamburg, along the railroad on the Hudson River, the fault plane dips 35-40° E. The absence of drag and variable dips of the "fault plane" tend to argue for a "block-in-shale" situation.

5:15 p.m.	81.20		LEAVE STOP 10. Return to N.Y. 55 W(right) on N.Y. 55 and merge with U.S. 44.
	83.65	2.45	S(left) on Raymond Ave. at first signal after Howard Johnson's Restaurant.
	84.65	1.00	E(left) into Vassar College South Parking Lot at intersection with Hooker Ave. (N.Y. 376).
5:30 p.m.			END OF TRIP.

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Trip B-7

PROGRESSIVE METAMORPHISM IN DUTCHESS COUNTY, NEW YORK

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1. Introduction

The purpose of this trip is to examine the development of regional progressive metamorphism within southeastern Dutchess County, N.Y. All stops, except the first, lie within the Clove 15' quandrangle (Fig. 1). Localities to be visited have been chosen in order to show a variety of mineral assemblages beginning with rocks at chlorite grade and proceeding eastward through the first sillimanite isograd. The majority of lithologies to be examined are pelitic with interbedded cherts and quartzo-feldspathic rocks. One stop will be made within units of the carbonate shelf sequence where calc-silicates may be seen. The implications of recent geochronological studies will be discussed relative to the geologic history of the area.

2. Previous Work

The general area attracted a number of early workers--e.g. Berkey (1907), Knopf (1927). Modern investigations began with the classic studies of Balk (1936) and Barth (1936). Their research of the structural geology and petrology of Dutchess County laid a groundwork that continues to serve as an important guide for present day investigations. To a large extent, the general geology shown in Figs. 1 and 2 is a result of their mapping. Barth's delineation of several isograds, and his petrochemical work, have provided an early framework from which modern petrological research has been able to build.

In recent years the metamorphic petrology of the Dutchess County area has been studied by Bence (1971) and Vidale (1974a,b; 1975). On the basis of microscopic examination, Vidale (1974a) moved Barth's (1936) isograds farther to the west. Bence (1971) determined a similar set of isograds, and these are shown in Fig. 2.

Vidale (1974b, 1974c) studied the nature and origin of veins and vein assemblages in the pelitic rocks of the area. Her results indicate that the vein assemblages: quartz, quartz-calcite, quartz-plagioclase, and quartz-plagioclase-orthclase form at successively higher grades and are probably derived from the surrounding matrix.

Recent field mapping has been undertaken within the Harlem Valley area (McLelland and Fisher, this volume) and within a large area to the west of the Clove 15' quadrangle (Fisher and Warthin, this volume).

Geochronologic studies in the region have been conducted by Clark and Kulp (1968), Long (1969), Long and Kulp (1962), Ratcliffe (1968), Bence and Rajamani (1972) and Mose et al. (1976). Some of these results will be discussed in Section 8 of this paper.

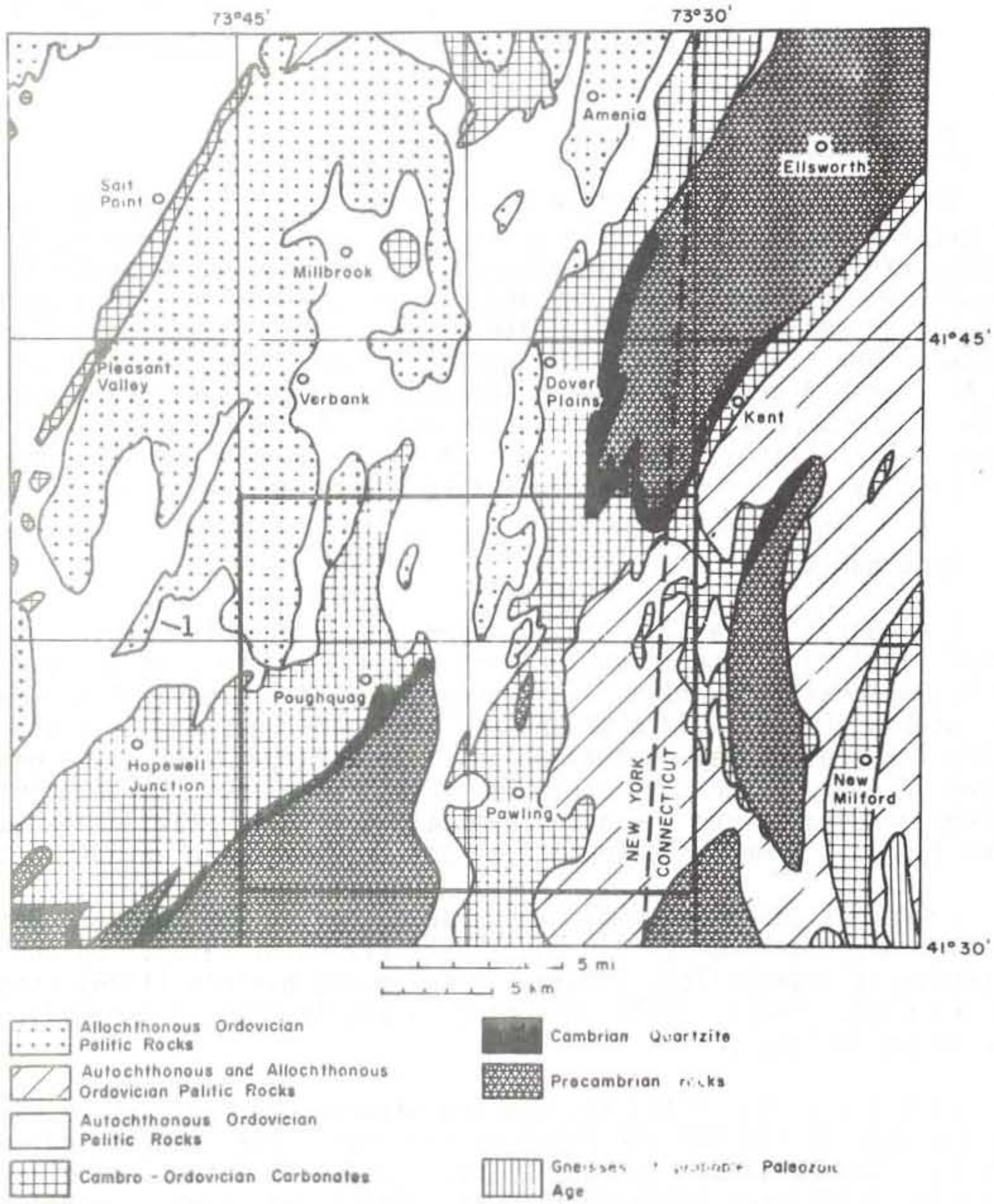


Fig. 1. Generalized Geological map of the Dutchess County region. Location of 7 1/2' quadrangles indicated by town names. The Clove 15' quadrangle includes the following 7 1/2' quadrangles: Verbank, Dover Plains, Poughquag, and Pawling. The area enclosed by the heavy dark line is enlarged in Fig. 3. Stop 1 is identified by the number 1. (After N.Y. State Geological Map, 1973)

3. Stratigraphy and Synopsis of Geologic History

Within the Taconic region stratigraphic relationships have proven to be extremely important in working out the structural relationships of complexly deformed rocks. From the petrological point of view, knowledge of stratigraphy is helpful in relating metamorphism to the regional structural framework and to parent lithologies. We therefore present a brief synopsis of the stratigraphy relevant to the area and its relationship to the regional geologic history as currently understood.

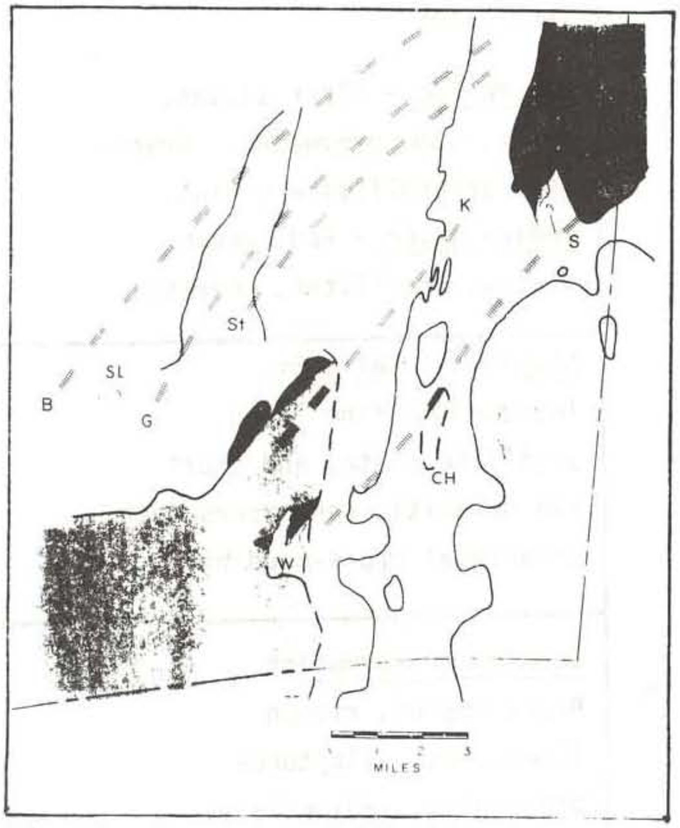


Fig. 2. Isograds: B-biotite, G-garnet, St-staurolite, K-kyanite, S-sillimanite. Locations: SL-Sylvan Lake, W-Whaley Lake, CH-Corbin Hill. Cambrian qzt.-black; Precambrian gn.-dark grey; pelites-stipple at margins; carbonates-unpatterned.

Four general lithologies are easily recognizable within the area: (1) Precambrian gneisses; (2) an orthoquartzite; (3) carbonates; and (4) pelitic masses. No internal stratigraphy has been worked out for the local Precambrian gneisses. The orthoquartzite is of lower Cambrian age and rests unconformably on the Precambrian basement. It is referred to as the Poughquag Quartzite and is correlative with the Hardyston, Potsdam, Lowerre, Chesire, etc. Above the Poughquag Quarzite occurs the carbonate sequence. Its internal stratigraphy has been determined throughout much of the area and is discussed by McLelland and Fisher (this volume). All but one of the carbonate units (Balmville Limestone) lie within the Wappinger Group (= Stockbridge Group). The Poughquag Quartzite and Wappinger carbonates form part of the Cambrian and Early Ordovician shelf that occurs throughout eastern North America.

The success in stratigraphic subdivision and correlation of the shelf carbonates has not been duplicated in the case of all of the pelitic units. To the west Fisher and Warthin (this volume) have established a coherent and detailed stratigraphy within the pelites. However, eastward increases in metamorphic grade have obscured fossil evidence, color differences, and other characteristics that have been utilized for correlation and subdivision

SHELF SEQUENCE

	Schenectady Fm. Sandstone Siltstone Shale	
Middle Ordovician	Walloomsac Fm. Black, sulfidic, graphitic slates Balmville Limestone locally at base.	← Taconic Allochthons
Lower Ord.	Copake Ls.	Wappinger Group McLelland and Fisher (1976).
Lower Ord.	Rochdale Ls.	Wappinger Group
Lower Ord.	Halcyon Lake Fm.	Wappinger Group
M G + U G	Briarcliff Dolostone	Wappinger Group
M G + U G	Pine Plains Formation	Wappinger Group
L G	Stissing Dol.	Wappinger Group
L G	Poughquag Qzt.	
Proterozoic	Precambrian Gneisses	

TACONIC SEQUENCE

Taconic Allochthons

	Normanskill Formation Austen Glen - Tan greywacke with interbedded black slates. Turbidites. Mt. Merino - Black slates, chert, some greywacke. Graphitic, graptolites abundant. Indian River - Red, green slates, argillites, cherts.	
	Stuyvesant Falls Fm. Interbedded fine green argillite slates and chert tan dolomitic sandstones with occasional cross-bedding.	
	Germantown Formation Black shales, ribbon limestones, siltstones brecciolas, sedimentary breccias	
L. Proterozoic - E. Cambrian	Nassau Fm. Green-red slate quartzites (grn.) siltsontes green phyllite Rensselear Greywacke some volcanics	Everett Sch. Silvery muscovite rich schist. At high grade staurolite abundant. Qtz. garnet, feld.

Table 1. Stratigraphic Relationships, Dutchess Co., N.Y.

in other areas. Table 1 summarizes the stratigraphic relationships as established in low grade, metamorphic terrains. Following Rickard and Fisher (1973), we have restricted the term Normanskill Formation to Taconic Sequence rocks.

(a) Evolution of the Shelf Sequence

The geologic evolution of the Shelf Sequence is relatively well understood. As shown in Table 1, the shallow water carbonates of the Wappinger Group are terminated upwards by an unconformity related to the early Middle Ordovician breakup of the shelf. Following erosion, a basal limestone (Balmville) and black, graphitic shales of the Walloomsac Formation (Zen, 1963) were deposited in a deepening Middle Ordovician exogeosyncline (Martinsburg - Snake Hill Exogeosyncline, Rickard and Fisher, 1973). Within upper Middle Ordovician time sandstones and siltstones of the Schenectady Formation were deposited.

(b) Evolution of the Taconic Sequence

The sedimentological history of the Taconic Sequence is less certain than that of the shelf rocks. It is believed that the Taconic Sequence formed in the general vicinity of the continental slope and rise. Beginning in late Precambrian, or Eocambrian, time the opening of Iapetus was accompanied by the deposition of clastics off the eastern margin of North America. These are now represented by the Nassau Formation and its possible correlative, the Everett Schist. The Everett may have been deposited farther out on the continental rise than the Nassau. In Cambrian time the earlier deposits were blanketed by black shales, ribbon limestones, and sedimentary breccias of the Germantown Formation (= West Castleton and Hatch Hill Formations). This unit built up a continental slope down which slumping and gravity sliding took place and gave rise to brecciolas, conglomerates, and various sedimentary structures. The carbonate in the limestone lithologies was presumably provided by lime muds moving down from the developing carbonate shelf. The Germantown Formation is followed upward by a sequence of shales, cherts, and thin dolomitic sands known as the Stuyvesant Falls Formation (= Poultney Slates). These units continued to build up the slope and probably extended out onto the rise.

Following deposition of the Stuyvesant Falls Formation, breakup and erosion of the shelf began in lower Middle Ordovician time. Subsequently, red and green shales and argillites of the Indian River member of the Normanskill Formantion were deposited. These distinctive units were followed upward by black shales and cherts of the Mt. Merino member. Above these were deposited the greywackes and black shales of the Austen Glen member. Rickard and Fisher (1973) place the time of the final deposition of the Austen Glen in the middle of graptolite zone 12 of the lower Middle Ordovician. This places Austen Glen deposition prior to the deposition of the Balmville Limestone and lower Walloomsac black shales. Others (Zen, 1963; Bird and Dewey, 1975) have considered the Austen Glen to be of younger age. The present authors remain agnostic on this controversy and only wish to establish the general stratigraphic relationships of the area.

Within lower Middle Ordovician time (graptolite zone 13), the Taconic Sequence was emplaced westward as submarine gravity slides within the Martinsburg-Snake Hill exogeosyncline. Several of these slides have been recognized in western Dutchess County (Fisher and Warthin, this volume) and allochthonous Taconic Sequence rocks are well exposed along the Taconic Parkway (Stop 1). The early gravity slides were followed by thrust slices of lithified Everett Formation, some low grade representatives of which are recognizable near Millbrook, Verbank, and on the western margin of the Clove Valley (Fig. 1).

Following emplacement of the allochthonous masses, the area was tightly folded and metamorphism overlapped late phases of the regional deformation. Isograds related to this thermal peak trend NNE across the area. The basically contemporaneous nature of the deformation and metamorphism is borne out by fabric-mineral relationships and by geochronological results to be presented in a later section. In thin section, micaceous minerals lie parallel to early foliations and have been kinked by a late deformation. Chloritoids grow across early foliations but have been deformed by kinking. Staurolite grains grow across all deformational fabrics and garnets appear to have grown throughout much of the later deformation.

4. <u>Special Stratigraphic-Structural Problems</u>

Within the area bounded by the Clove 15' quadrangle, and particularly east of the Clove Valley, high metamorphic grade has made it difficult to subdivide the pelitic units. East of the biotite isograd only three broad stratigraphic categories of metapelitic units have been utilized. As shown on the 1973 edition of the New York State Geological Map these are the Walloomsac, the Everett Schist, and the Manhattan Fm. The Walloomsac is characterized by black, graphitic schists rich in biotite. At its base it grades into the thin Balmville limestone. The Everett Schist is generally more aluminous than the Walloomsac and, as a consequence, is richer in muscovite and staurolite. The Manhattan Formation contains lithologies that correspond to both the Walloomsac and Everett.

In Figures 2 and 3, we have generally followed the 1973 edition of the New York State Geological map in designating schist masses as Walloomsac, Everett, or Manhattan. The structural implications of such designations are considerable, because the Walloomsac is thought to be autochthonous, the Everett alochthonous, and the Manhattan may be either. These designations will almost certainly undergo changes in the future. For example, the various schist masses may be internally divided on the basis of high versus low aluminum content, and further research along such lines appears promising. In the meantime, the 1973 New York State Geological Map continues to serve as a standard reference for stratigraphic assignment of the metapelites. Note that schists currently mapped as Everett may possibly contain metamorphosed equivalents of younger Taconic Sequence rocks (i.e. Normanskill, Germantown, Stuyvesant Falls).

5. Folds and Related Cleavages

As in other regions of Taconide Zone, the area has been affected by intense, polyphase deformation. This complex tectonism is reflected by the minor structures that appear in almost every outcrop. Where mapping has revealed major structures they too reflect a history of intense deformation. However, the lack of stratigraphic control within the pelitic units has presented recognition of regional fold patterns to the extent shown by Fisher and Warth (this volume) is similar, but relatively unmetamorphosed, rocks to the west (1976).

(a) Major Folds

Recent work (McLelland and Fisher, this volume) has demonstrated that the entire carbonate sequence underlying the Harlem Valley is overturned to the west and represents the eastern limb of a major NNE syncline (Harlem Valley Syncline). The Housatonic Highlands may represent part of an eastern anticlinal counterpart to this syncline, and the Hudson Highlands may occupy a similar anticlinal structure to the west. The Harlem Valley Syncline is believed to be a second generation Taconian structure that post-dated the emplacement of the allochthons.

The axial trace of the Harlem Valley Syncline passes through the schists lying along the western margin of the Harlem Valley. Continued westward, these rocks lie on the right-side-up, western limb of the syncline. The structure is abruptly terminated by the Precambrian gneisses forming the northern prong of the Hudson Highlands (Fig. 3). Along the eastern contact of this prong, Paleozoic schists rest on top of Precambrian gneisses or Poughquag Quartzite. The Wappinger Group, which should reappear on the western limb of the Harlem Valley Syncline, is completely absent. This discontinuity may be explained by normal faulting, reverse faulting, or the early Middle Ordovician unconformity. The second possibility was favored by Balk (1936) and is supported by minor structures (drag folds, lineations) and by demonstrated westward directed reverse faults near Whaley Lake. Following Balk (1936), we have shown this Precambrian-Paleozoic contact as a reverse fault on Fig. 3.

Within the Clove Valley the carbonate sequence and Walloomsac Slates appear to be right side up but no major fold structure has yet been mapped within these carbonates.

The dominant pervasive cleavage of the region is axial planar to folds of the set represented by the Harlem Valley Syncline. Microscopically this cleavage is represented by strong orientation of platy minerals. It is believed that the folding represents the major deformational pulse of the Taconic Orogeny following the emplacement of allochthonous masses.

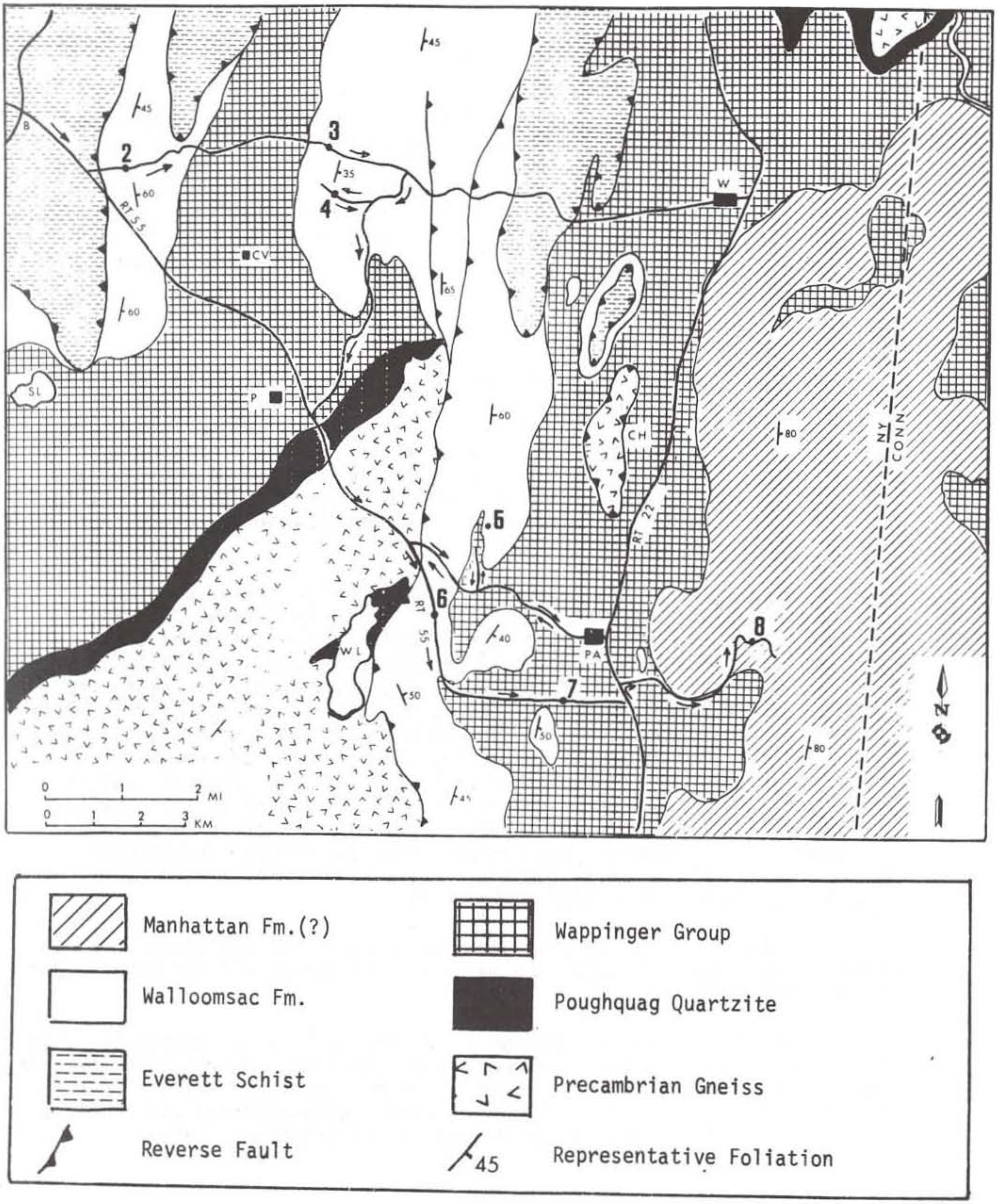


Fig. 3. Enlargement of rectangular area outlined in Fig. 1. Trip route and Stops 2-8 shown. Geology after Balk (1936) and New York State Geological Map (1973). SL-Sylvan Lk., WL-Whaley Lk., B-Billings, W-Wingdale, P-Poughquag, PA-Pawling, CV-Clove Valley, CH-Corbin Hill.

(b) Minor Structures

The metapelitic rocks of the area are replete with excellent minor structures. Early tight folds, kink folds, a variety of cleavages, boudinage, etc. are all recognizable. At least three, and perhaps four, folding events appear to be present in many outcrops. The earliest of these is represented by isoclinal folds usually defined by quartzose layers. These, and an associated early foliation, have been folded about tight NNE folds that are correlated with the event represented by the Harlem Valley Syncline. The dominant cleavage of the region is axial planar to these folds. Following the early episodes of tight folding, a kinking developed in pelitic units and an open, assymetric folding took place in more massive lithologies. The kinking is accompanied by excellent crenulation cleavages. The majority of structures of this type trend approximately NE, but variability is present and may reflect more than a single episode of kink folding.

It is possible that the earliest recognizable fold event was preceded by a still older deformation. This is suggested by the fact that the earliest recognized isoclinal folds occasionally have mica flakes that wrap around early hinges. However, caution must be exercised in interpreting this sort of feature which may be due to mimetic recrystallization of original bedding plane foliation.

Microscopically, foliations associated with the early folds are best represented by aligned micas. Occasionally a microscopic fold may also be seen. Generally these are of the second generation and micas of the first generation event have been rotated abou the later fold hinges. Later kinking and crenulation cleavage is beautifully displayed in most sections. As previously mentioned in Section 3b, all of these fabrics precede the higher grades of metamorphism, i.e. the growth of staurolite and sillimanite.

6. Precambrian Massifs

The two major Precambrian massifs in the area are the Housatonic Highlands and the portions of the eastern Hudson Highlands. Some uncertainty exists with regard to whether or not these masses are anticlinoria rooted at depth or represent thrust sheets (Isachsen, 1964; Harwood and Zeitz, 1974). Field relationships suggest that a rooted hypothesis is likely, although significant reverse faults have caused slivers of the Precambrian to be thrust westward. Faults of this nature have been demonstrated within the Housatonics (Balk, 1936) and in the vicinity of Towners, N.Y. (McLelland and Fisher, this volume). The Precambrian outlier at Corbin Hill in the Harlem Valley appears to be a klippe resting on top of the carbonate shelf sequence (McLelland and Fisher, this volume). In none of these instances has it yet been possible to determine the amount of offset.

7. Metamorphism of the Pelitic Rocks

Early structural and petrographic studies by Balk (1936) and Barth (1936) reveal that mineral assemblages in the pelitic schists reflect a regional metamorphic gradient in which intensity increased from WNW to ESE. The gradient is from chlorite through to sillimanite-K-feldspar zones which is typical of the kyanite-sillimanite facies series of Miyashiro (1961).

Two distinctly different bulk compositions are recognized in the low-grade slates and phyllites and high-grade schists from Dutchess County: (1) an aluminous composition whose assemblage is dominated by muscovite, and (2) an aluminum-poor, graphitic composition characterized by abundant biotite, graphite, and iron sulfides. Both compositions can be traced to the highest metamorphic grades, although phase compositional data are not yet available for both compositions at all grades.

At grades below the stability field of biotite, the phyllites and slates are dominated by aluminous, iron-rich chlorite; quartz; phengitic muscovite; and alkali (sodic) feldspar (Stop 1) (Table 2). Ilmenite, which is abundant in the aluminous composition, has, at some localities, altered to leucoxene.

The first appearance of biotite (Stop 2) appears to be a consequence of the reaction of iron-rich chlorite and phengitic muscovite to form iron-biotite; a more magnesian chlorite; and a more sodic, less phengitic muscovite. At the same time, the feldspar has become more calcic (Table 2). At one locality (Stop 3), characterized by very highly aluminous compositions, chloritoid appears prior to the appearance of biotite, and the assemblage chloritoid + chlorite + muscovite + feldspar + ilmenite + quartz is observed.

The appearance of garnet (Stop 3) is reflected by sharp discontinuities in the compositions of the muscovite and the feldspar. The mica becomes much more sodic and the feldspar more calcic (Table 2). The garnet itself is concentrically zoned. Its core contains a large spessartine component (Table 2 and Fig. 4) which drops off markedly towards the rim. Presumably this zoning reflects the growth rate of the garnet and the diffusion rate of components through the matrix at the time of garnet growth. The shape of the MnO profile suggests that garnet growth follows a Rayleigh depletion model (see Hollister, 1966).

At this grade of metamorphism, the aluminum-rich and aluminum-poor bulk compositions are readily distinguished by the presence of either biotite or chloritoid in the assemblage (Fig. 5a). At slightly higher metamorphic grades there occur a complex sequence of reactions (Fig. 5b) involving the breaking of the chlorite-garnet join on the AKFM projection; the breakdown of chloritoid; and the appearance of staurolite (see Albee, 1973).

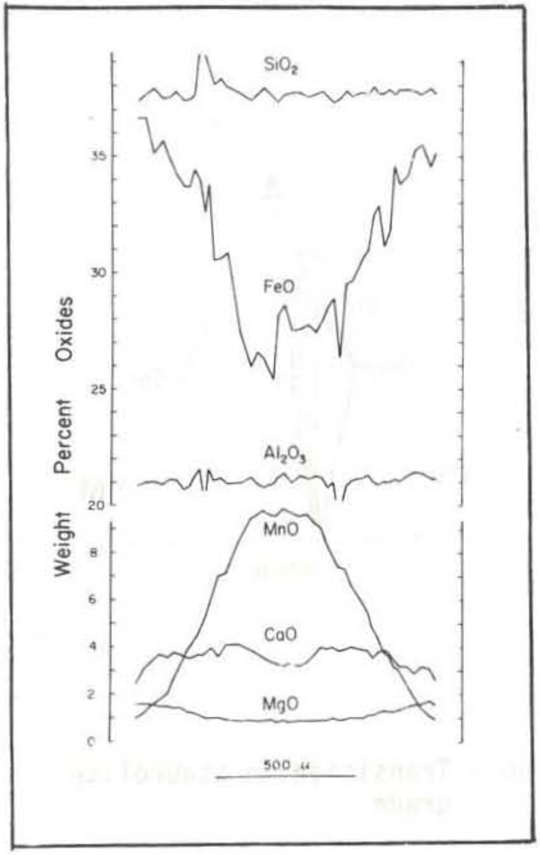


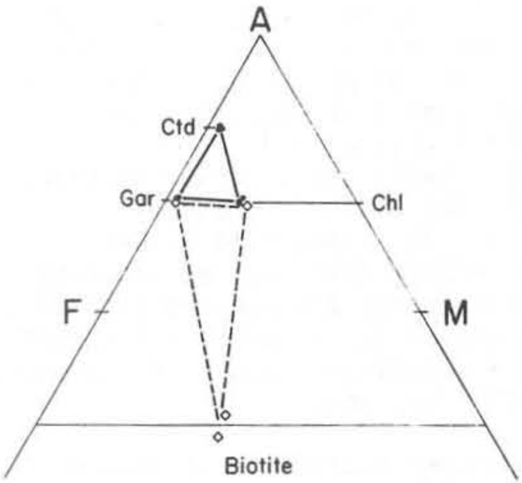
Fig. 4. Electron microprobe traverse across a garnet from Dutchess County. Note the bell shaped profile of MnO. Sample collected from Stop 3.

In the Dutchess County schists one locality has been found (Stop 4) in which the minerals staurolite-chloritoid-garnet-biotite-chlorite (Table 2) (Fig. 5b) are all observed in the same thin section. This clear violation of the Phase Rule appears to be a consequence of reaction kinetics. The first reactions did not go to completion before subsequent reactions involving the daughter products commenced. At metamorphic grades slightly higher than that at locality 4, chloritoid has disappeared (Stop 5), and the assemblage staurolite + garnet + biotite + muscovite + quartz is observed (Table 2) (Fig. 5c).

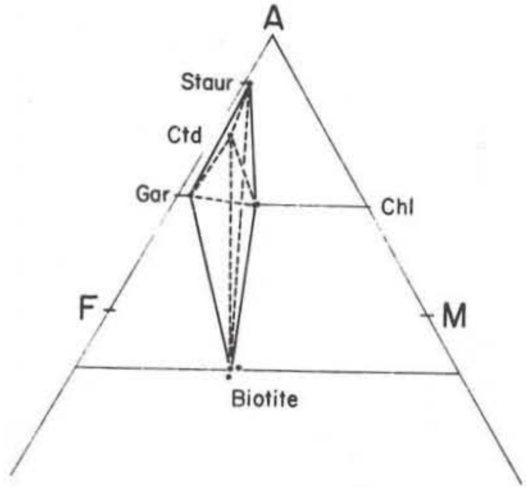
At grades equivalent to Stop 5 (e.g. Stop 6), kyanite coexists with garnet and biotite (Table 2). As shown in Fig. 4c the development of kyanite rather than staurolite may be due to the FeO/MgO of the original sediments. Rarely kyanite and staurolite (with biotite and garnet) are observed in the same thin section. This assemblage violates the Phase Rule and indicates a lack of attainment of chemical equilibrium. Staurolite is not observed in higher grade rocks, and it is likely that its occurrence in the kyanite-bearing assemblages marks the upper limit of its stability field.

Sillimanite is present in the eastern schist masses of Dutchess County and has formed by three reactions: (1) kyanite → sillimanite (lowest grade appearance), (2) staurolite + Na-muscovite ($Mu_{82}Pg_{18}$) + quartz → sillimanite + K-rich muscovite ($Mu_{95}Pg_5$) + albite + biotite + garnet + H_2O (see Guidotti, 1970), and (3) a complicated reaction relationship involving the breakdown of biotite adjacent to garnet prophyroblasts in garnet-biotite-muscovite schist. The polymorphic transition (1) suggests that pressures in excess of about 5 kb obtained if the triple point as determined by a Richardson et al. (1968) is appropriate. In all cases sillimanite occurs as fibrolite.

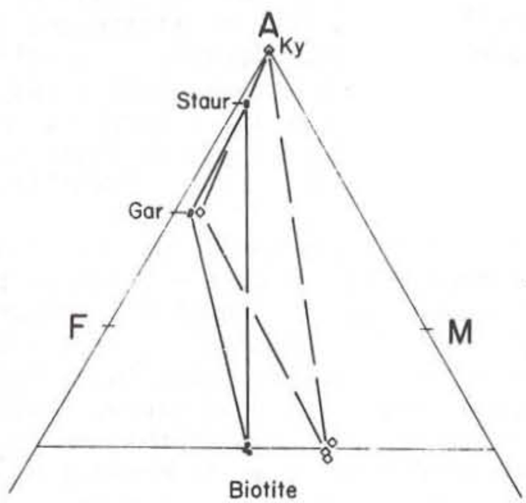
At the highest metamorphic grade observed in Dutchess County, muscovite is absent and sillimanite and K-feldspar coexist. These assemblages occur sporadically near the Connecticut state line where they are surrounded by muscovite-bearing assemblages. This suggests that the reaction surfaces are relatively flat lying in this region with that of muscovite + quartz sillimanite + K-feldspar + H_2O nearly coincident with the present erosion surface.



5a - Garnet-biotite grade



5b - Transition to staurolite grade



5c - Kyanite grade

Fig. 5. AKFM projections at several grades of metamorphism.

8. Geochronology

Whole-rock and mineral istopic ages from the pelitic schists of Dutchess County (Long, 1962) were interpreted to indicate a period of metamorphism at 430 m.y. ago (minimum age) followed by a regional thermal event about 360 m.y. ago. These ages are consistent with the Taconic and Acadian orogenies, respectively. Toward the south and east, K-Ar ages ranging from 480 m.y. to 240 m.y. suggest that three distinct metamorphic events of 460-480, 360, and 255 m.y. affected the region (Clark and Kulp, 1968). In the region between Bridgeport and New Haven, Connecticut, K-Ar ages of 220-280 m.y. are reported (Clark, 1966; Armstrong et al., 1968). These younger ages are thought due to reheating or uplift during the Alleghany orogenic period (Dieterich, 1968).

$^{40}Ar/^{39}Ar$ incremental heating "ages" obtained by Bence and Rajamani (1972) on biotite and muscovite separates from five localities in Dutchess County suggest that metamorphic recrystallization and argon diffusion in this

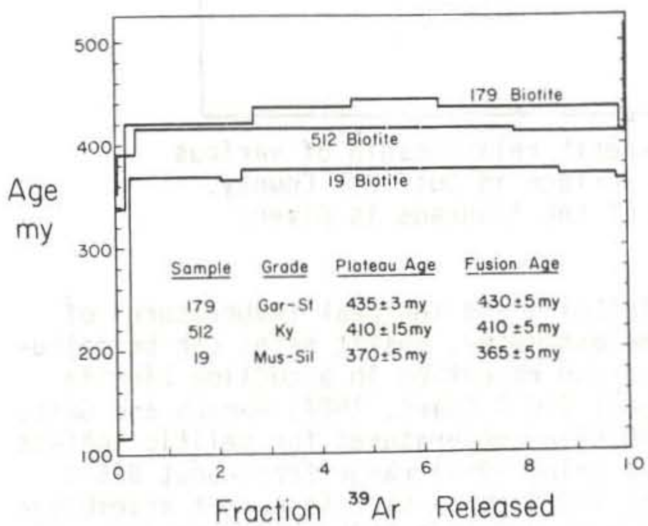


Fig. 6. Argon loss and plateau "ages" for biotites from 3 metamorphic grades in Dutchess County.

region did not occur in two discrete thermal events. All the samples studied had less than two percent argon loss and, consequently, give well-defined plateau "ages" which range from 435 to 370 m.y. (Fig. 6). A direct correlation between increasing metamorphic grade and decreasing gas-retention "age" is noted. If the processes that caused argon loss during the metamorphism are reproduced during the incremental heating of the sample in the vacuum furnace (Hanson et al., 1975), then these ages are most easily explained by continuous rather than episodic argon loss and probably reflect cooling during essentially continuous uplift following the Taconic orogeny. There appears to be no need for a distinct Acadian thermal event to explain the metamorphic recrystallization. This conclusion is consistent with recent Rb/Sr studies by Mose et al. (1976) in the vicinity of Peekskill, N.Y.

If this interpretation of the $^{40}Ar/^{39}Ar$ ages is correct, then a model involving differential uplift is required (Fig. 7). Furthermore, if gas-retention temperatures for biotite and muscovite, the geothermal gradient

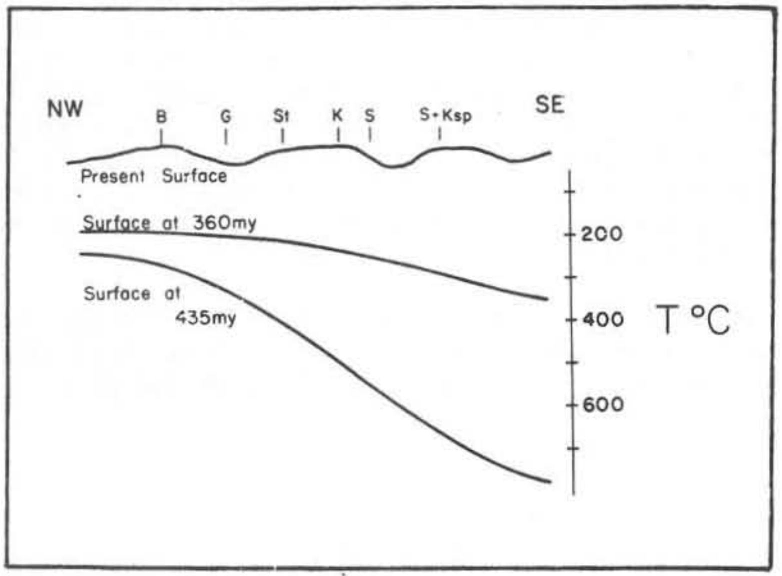


Fig. 7. Temperature-depth relationship of various ages for present day surface in Dutchess County. Approximate location of the isograds is given.

for the region during the lower Paleozoic, and the peak temperatures of metamorphic recrystallization can be estimated, uplift rates can be calculated. Under geologic conditions, argon retention in a cooling biotite occurs at temperatures less than about 300°C (Hart, 1964; Hanson and Gast, 1967; Jaeger et al., 1967). $^{18}O/^{16}O$ paleotemperatures for pelitic schists from Dutchess County (Garlick and Epstein, 1967) range from about 625°C for sillimanite grade assemblages to 480°C for a biotite-garnet assemblage collected at Stop 3. If a geothermal gradient of 25°C/km is assumed, a maximum continuous uplift rate of ~1/3 cm/year is obtained from the sillimanite grade rocks. This uplift rate appears unusually slow and should have resulted in extensive retrograde metamorphism. This apparent discrepancy suggests that the implied assumption that argon diffusion and oxygen isotope equilibration occurred at the same time is not correct.

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Table 2

	Chlorite Grade		Biotite Grade		Garnet Grade	
ALUMINOUS ASSEMBLAGES	Muscovite	$Ms_{95}Pg_5$	Muscovite	$Ms_{80}Pg_{20}$	Muscovite	$Ms_{75}Pg_{25}$
	Chlorite	F/FM = 0.64; Al/Si = 1.13	Chlorite	F/FM = 0.46 - 0.24; Al/Si = 0.77 - 0.9	Chlorite	F/FM = 0.61; Al/Si = 1.20
	Feldspar	$Ab_{99}An_1Or_0$	Biotite	F/FM = 0.5 - 0.21	Chloritoid	F/FM = 0.87
	Ilmenite	$\text{"Fe"}_{3.9}Mn_{0.3}Ti_{3.8}O_{12}$	Feldspar	$Ab_{92}An_7Or_1$	Garnet (core)	$Alm_{82}Sp_9Gr_4Py_5$
			Ilmenite	Not analyzed	Feldspar	$Ab_{80}An_{19}Or_{0.5}$
			and		Ilmenite	$Fe_{3.9}Mn_{0.06}Ti_{4.0}$
			Muscovite	$Ms_{75}Pg_{24}$	*and*	
			Chlorite	F/FM = 0.52; Al/Si = 1.10	Muscovite	$Ms_{79}Pg_{21}$
			Chloritoid	F/FM = 0.87	Chlorite	F/FM = 0.58; Al/Si = 1.17
			Feldspar	$Ab_{82}An_{15}Or_2$	Garnet (rim)	$Alm_{84}Sp_2Gr_7Py_6$
			Ilmenite	$Fe_{3.8}Mn_{0.2}Ti_{4.0}O_{12}$	Biotite	F/FM = 0.58
					Feldspar	$Ab_{70-80}An_{20-26}Or_{0.3}$
					Ilmenite	$Fe_{3.9}Mn_{0.02}Mg_{0.02}Ti_{4.01}O_{12}$
LOW-ALUMINA ASSEMBLAGES	Muscovite	$Ms_{86-98}Pg_{14-2}$	Muscovite	$Ms_{91}Pg_9$	Muscovite	$Ms_{91}Pg_5$
	Chlorite	F/FM = 0.67 - 0.39; Al/Si = 0.96 - 0.70	Chlorite	F/FM = 0.43; Al/Si = 0.98	Chlorite	Not observed
	Feldspar	$Ab_{100-93}An_{0-7}Or_0$	Biotite	F/FM = 0.41	Biotite	F/FM = 0.48 - 0.50
	Ilmenite	$Fe_{3.6}Mn_{0.3}Ti_{4.0}O_{12}$	Feldspar	$Ab_{99-96}An_{1-0}Or_{1-2}$	Garnet (core)	$Alm_{63}Sp_{18}Gr_{12}Py_7$
			Sulfide		(rim)	$Alm_{58}Sp_{18}Gr_{15}Py_8$
					Feldspar	$Ab_{48}An_{42}Or_{10}$
					Sulfide	

Table 2 (cont.)

Staurolite Grade		*Kyanite Grade*		*Sillimanite Grade*		*K-feldspar--Sillimanite Grade*	
Muscovite	$Ms_{80}Pg_{20}$		Not analyzed	Muscovite	$Ms_{89}Pg_{11}$	Garnet (rim)	$Alm_{58}Sp_{21}Gr_{7}Py_{14}$
Staurolite	F/FM = 0.83			Garnet (rim)	$Alm_{85}Sp_{3}Gr_{4}Py_{8}$	Biotite	F/FM = 0.32
Biotite	F/FM = 0.54			Biotite	F/FM = 0.62	Feldspar (plag)	$Ab_{56}An_{43-44}Or_{0-1}$
Garnet (rim)	$Alm_{81}Sp_{5}Gr_{5}Py_{8}$			Feldspar	$Ab_{79}An_{20-21}Or_{0-1}$	(alkali)	Not analyzed
Feldspar	Not analyzed			Ilmenite	$Fe_{3.88}Mn_{0.01}Mg_{0.02}Al_{0.03}Ti_{4.01}O_{12}$	Sillimanite	
Ilmenite	Not analyzed			Sillimanite			
and							
Muscovite	$Ms_{79}Pg_{20}$						
Chlorite	F/FM = 0.57; Al/Si = 1.08						
Staurolite	F/FM = 0.88 - 0.89						
Chloritoid	F/FM = 0.85						
Garnet (rim)	$Alm_{86}Sp_{2}Gr_{3}Py_{7}$						
Biotite	F/FM = 0.58 - 0.60						
Feldspar	$Ab_{79-88}An_{21-12}Or_{0-10}$						
Ilmenite	$Fe_{4.4}Mn_{0.01}Ti_{3.8}$						
Muscovite	Not analyzed	Muscovite	$Ms_{76}Pg_{24}$	Muscovite	$Ms_{96}Pg_{4}$	Not found	
Biotite	Not analyzed	Biotite	F/FM = 0.37	Biotite	F/FM = 0.55		
Staurolite	(Not observed)	Garnet (rim)	$Alm_{61}Sp_{21}Gr_{7}Py_{11}$	Feldspar	$Ab_{64}An_{34}Or_{1}$		
Garnet	Not analyzed	Kyanite		Sillimanite			
Feldspar	Not analyzed	Feldspar	$Ab_{76-80}An_{19-23}Or_{0-1}$				
Sulfide							

Road Log

Mileage

0 Intersection of Taconic Parkway and Rt. 55 at Freedom Plains, N.Y. Head south on the Taconic Parkway.

3 Turn west on Arthursburg Road. Between here and Stop 1 the Mt. Merino member of the Normanskill Fm. is exposed at a number of localities in the surrounding fields.

4.7 <u>Stop 1</u> - <u>Chlorite Grade</u> (See Table 2)

Steep roadcuts along Arthursburg (Noxon) Rd. The purpose of this stop is to display typical pelitic lithologies at low metamorphic grade (i.e. chlorite zone). Similar lithologies, though not necessarily identical stratigraphy, constitute the metapelites to be visited at later stops.

The east end of the cuts consists of typical red and green slates and phyllites of the Indian River member of the Normanskill Fm. At the west end of the cut black slates, phyllites, and greywackes of the Mt. Merino member are exposed. The contact between these two units occurs just at the western end of the red Indian River exposures. Some faulting appears to have occurred along the contact and a later northwestward dipping reverse fault, with associated fracture cleavage, further complicates relationships. These roadcuts are part of a small erosional remnant of a larger allochthon whose principal exposure lies just north of Freedom Plains, N.Y. and is well exposed in the vicinity of James Baird State Park (Fig. 1).

Mineralogically the red phyllites and slates consist of hematite-chlorite-muscovite-plagioclase-quartz. The green lithologies consist of muscovite-chlorite-plagioclase-quartz. These differences imply a variation in oxidation state whose origin is not well understood. Gradations in color occur along strike of the beds and suggest that the variations may be secondary in origin.

The eastern portion of the roadcut consists of several relatively large (λ = 50-60'), upright folds on which are developed a multitude of parasitic chevron folds. Fold axes trend N30-50E and plunge NE at between 10° and 60° with most of the steeper plunges on the north side of the road. The style of folding is of the rounded, chevron type with minor folds reflecting the symmetry of the larger structures. Late flattening appears to have occurred. Associated with these folds is an axial planar crenulation cleavage that strikes N30-50E and dips steeply to the northwest. Close inspection shows that the cleavage intersects an earlier foliation that has been folded by the upright folds. The earlier foliation is usually subparallel to bedding but large intersection angles have been found.

Excellent weathered exposures, and a good overall perspective of the folds in the roadcut, can be found by climbing to the top of the cut.

At the western end of the cut the Mt. Merino slates and phyllites have undergone extensive kink folding with associated axial plane crenulation cleavage which strikes N40-50E and dips steeply to the west. Presumably these kinks are of the same generation as the chevron folds in the Indian River. Greywackes within the Mt. Merino have deformed by buckling rather by kinking.

Sedimentary structures can be seen within the greywackes and suggest that the section is not overturned.

Turn around and return east to Taconic Parkway.

6.4 Taconic Parkway. Turn north after crossing divide.

9.4 Junction with Rt. 55 east. Leave Taconic and proceed east on Rt. 55.

10.3 Roadcut in green phyllites of Everett Fm. (presumed allochthonous) on south side of road. This outcrop exhibits minor structure evidence for at least four phases of deformation. Kink folding and crenulation cleavage are abundantly developed.

10.7 Junction with Rt. 82 at Billings, N.Y. Continue east on Rt. 55.

11.2 Quartz-breccia fault zone.

13.0 Turn north on Wingdale Road.

13.8 <u>Stop 2</u> - <u>Biotite Grade</u> (see Table 2)

Small roadcut in black Walloomsac slates. The slates are highly graphitic and often contain large amounts of pyrite. A strong N20W, 60E cleavage pervades the rocks and is related to N20W minor folds in the outcrop. These folds rotate an earlier foliation. Mineral phases present in the rock are: <u>biotite</u>-chlorite-muscovite and plagioclase-quartz-ilmenite.

The principle reason for stopping at this outcrop is that biotite is developed macroscopically and is easily visible with a hand lens. Here we are very close to the biotite isograd. Note that the biotite flakes grow across the planes of foliation. Be careful to distinguish flakes of biotite from ilmenite grains.

14.5 Large roadcuts in black, graphitic, sulfidic Walloomsac slates. Vein quartz is abundant in the outcrop. Proceeding down the hill, we enter the Clove Valley which is underlain by Wappinger carbonates of the shelf sequence.

15.2 Proceed past small traffic circle and continue eastward up hill (Dutchess County 31 or Blueberry Hill Road). Going up the hill note the cuts on the south side of the road.

16.1 Stop 3 - Garnet Grade (see Table 2)

Pull off into small parking area on south side of road.

(a) Walk back down hill to examine cuts passed as we drove up hill. These consist of black biotite rich schists and cleaved metagreywackes. The observer is asked to compare these lithologies with the Mt. Merino seen at Stop 1. The principal foliation is N60E and dips 45°S.

In coming eastward from Stop 2 we have passed over the garnet isograd. At this locality garnet is sparsely developed in the more westerly (downhill) outcrops of black, graphitic biotite schists. The mineral phases in these rocks consist of garnet-chlorite-biotite-muscovite-feldspar-quartz (Fig. 4a). Proceeding uphill, the amount of graphite decreases while quartz increases, and the rocks begin to resemble greywackes. Within these units garnet is principally developed in thin beds which probably represent pelitic members in a turbidite sequence.

It has not been determined whether these rocks are allochthonous or autochonthonous. They are shown on the New York State Geological Map (1973) as Austen Glen greywackes. This designation, or an assignment to the Mt. Merino, would strongly imply that they are allochthonous. Approximately 1/4 mile south of here the metapelites are found overlying either Poughquag quartzites or the lowermost, quartzite rich, portion of the Stissing. If the rocks are not allochthonous, then the Middle Ordovician unconformity bevelled to the deepest portions of the shelf here, while 1.5 miles to the west the Balmville and Walloomsac rest on the Copake Limestone which occurs at the top of the Wappinger Group. This is by no means an impossible situation, but serves to emphasize the nature of the unresolved structural problems in the area.

(b) Return to parking area and walk north along the old dirt road to the north of the highway. After approximately 200' climb up to the exposures on the east side of the road. These small ledges show an exceptional development of chloritoid. Black chloritoid grains of up to 1/8" in length can be seen growing in seemingly random orientation. Microscopically the chloritoids are clearly younger than the principal foliations but are deformed by kinking and crenulation.

The mineral assemblage in these rocks consists of garnet-muscovite-chlorite-chloritoid-feldspar-quartz. As shown in Fig. 5a, this assemblage is the result of a more aluminous bulk composition than in the rocks at 3a. Here biotite is absent and is separated from chloritoid in an AKFM projection by the garnet-chlorite tieline (Fig. 5a).

At least two major foliations are present in the outcrop. An early N30E, 40S foliations appears to be related to small, attenuated isoclinal folds defined by thin quartz stringers. This foliation is generally parallel to compositional banding. The dominant foliation in the rock appears to be later and trends N80E, 25S. This foliation is axial planar to a sharp disharmonic fold exposed just above the ledge which best displays the chloritoid grains. Note that this fold folds an earlier foliation.

(c) Return to the paved highway and walk east up the hill examining the interlayered schists and quartzose rocks. Chloritoid is still present in some of these units but grain outlines are not as sharp as at 3b. This may be the result of the onset of a chloritoid consuming reaction. Biotite and chloritoid are still mutally exclusive and remain separated by the tie line garnet-chlorite. Although chloritoid is still present in some layers, most of the schists consist of garnet-chlorite-biotite-muscovite-feldspar-quartz. These lithologies are similar to the rocks at 3a, and chloritoid is unable to form because the bulk compositions are not sufficiently rich in aluminum (Fig. 5a). This serves to emphasize the control of rock chemistry on the development of chloritoid in the area.

17.2 Turn south on Pleasant Ridge Road.

17.9 Turn west on Still Road.

18.5 Stop 4 - Staurolite Grade (see Table 2)

Low, rounded outcrop on the north side of the road. These rocks are approximately along strike (N20E, 30E) with the chloritoid bearing schists at Stop 3b. Here we are at somewhat higher grade and staurolite is developed in thin section. The overall mineral assemblage in these rocks is garnet-staurolite-chloritoid-muscovite-chlorite-biotite-feldspar-quartz (Fig. 5b). The presence of five ferromagnesian phases is clearly in violation of the phase rule and this assemblage cannot be in equilibrium. This locality marks the lowest grade at which staurolite is found and the highest grade at which chloritoid is stable. Note the coexistence of biotite and chloritoid both of which are visible in hand specimen. Clearly the tie-line chlorite-garnet is in the process of being broken by biotite-chloritoid. Simultaneously chloritoid is participating in a staurolite forming reaction.

18.7 Dead end and turn around. Proceed back east on Still Road.

19.5 Pleasant Ridge Road. Turn south.

21.5 Y intersection with Gardner Hollow Road. Bear right (west).

21.5 Turn left to stay on Pleasant Ridge Road.

22.7 Junction with Rt. 55. Turn east. Note roadcuts of Poughquag Quartzite on the south side of Rt. 55.

24.4 Turn north onto old Rt. 55.

26.3 Wilkinson Hollow Road.

27.3 Enter Edward R. Murrow Park for <u>lunch</u>. The exposures in the park are Balmville limestones and Walloomsac schists. Following lunch turn back west onto old Rt. 55.

28.3 Wilkinson Hollow Road. Turn north.

28.9 <u>Stop 5</u> - <u>Kyanite Grade</u> (see Table 2)

Park at dead end and walk up the dirt road, past a house, and continue along the footpath. The valley here is underlain by Balmville Limestone. After approximately 1/4 mile the path crosses beneath a power line. Turn east up the hill to exposures of staurolite-garnet-biotite-muscovite-quartz-feldspar schists (Fig. 5c). These rocks are typical of staurolite rich schists in the region. Good penetration twins of staurolite can be found. Kyanite appears to be absent at this locality, and this is probably due to differences in bulk rock composition (Fig. 5c).

The outcrop here contains several large, recumbent isoclinal folds. One of these is dominant and its axial region is exposed near the top of the outcrop. The axial plane strikes N60E and dips 20°S while the axis trends N30W and plunges 10°N, however, the exposure may be out of place. An earlier foliation, defined by micas, has been folded by this structure.

Return to cars, turn around, and proceed south on Wilkinson Hollow Road.

29.5 Turn west on old Rt. 55.

31.4 Intersect new Rt. 55. Turn east and head uphill through Precambrian gneisses of the Hudson Highlands.

32.0 Contact between the Precambrian and black, rusty Paleozoic schists (Walloomsac?). Balk (1936) mapped this contact as a reverse fault. Ratcliffe (pers. comm.) has suggested that the absence of the carbonate section may be due to the lower Middle Ordovician unconformity. Minor structures are consistent with Balk's interpretation.

32.6 Stop 6 - Kyanite Grade (see Table 2)

The rocks in these long roadcuts have been mapped as Walloomsac schists (N.Y. State Geological Map, 1973). Whether they are, or not, is open to question. Regardless of stratigraphic uncertainty, the lithologies are dominantly pelitic with biotite rich schists predominating. Quartzose and granular quartzofeldspathic layers and lenses are interlayered with the schists and serve to define early isoclinal folds. The dominant cleavage trends N30-40E and dips approximately 50°S. This cleavage is axial planar to tight northeast trending folds which fold the earlier isoclinal folds whose general trend is also northeast. An earlier foliation is associated with these isoclines. In places the second generation folds have been flattened into isoclines. Minor folds associated with these give opposing senses of rotation as the roadcuts are traversed along their length and suggest that the entire roadcut has been telescoped by the second generation folds. A third of open N-S folds is present and associated with kinking and crenulation cleavage in the rock.

Mineralogically the schists generally contain biotite-garnet-kyanite-muscovite-feldspar-quartz. The kyanite appears as 1/8" - 3/4" blue blades growing without orientation within the schists, and is particularly concentrated within more pelitic layers, many of which have thickened on the noses of folds. This gives rise to pod like areas that are extremely rich in kyanite. These can be examined to best advantage on the top of the roadcut where weathering has made the kyanites most visible. The metamorphic grade observed here is the same as at Stop 5 but staurolite is rarely observed in these rocks. This may be attributed to bulk compositional differences between the two localities (Fig. 5c). The rocks here are more magnesian than at Stop 5 and staurolite is generally excluded from the phase assemblage.

In addition to kyanite rich layers certain quartzose bands are extremely rich in garnet. Hornblende bearing pods are also present and represent more calcic bulk compositions in the original sediment.

Biotite from a biotite-kyanite assemblage here gives an $^{40}Ar/^{39}Ar$ plateau age of 414 million years.

33.5 Roadcuts in the Walloomsac black schists. A sharp anticline brings the Balmville Limestone to the surface near the east end of the cut. This outcrop is situated near the hinge of the Harlem Valley Syncline.

34.1 Roadcuts in the Balmville Limestone. Here the Balmville is directly overlain by Walloomsac black schists.

34.3 Walloomsac calc-silicates and Balmville Limestone. The Harlem Valley can be seen directly ahead. We are now proceeding into the overturned, eastward dipping, limb of the Harlem Valley Syncline.

34.7 Calcitic marbles of the upper portion of the Wappinger Group are exposed to the south of the highway.

35.2 Stop 7 - Very large roadcuts in the Briarcliff Dolostone. This stop is the same Stop 7 in McLelland and Fisher (this volume), and the structure of the cut is discussed in that article.

Petrologically this stop is of interest because it affords the opportunity to examine the development of calc-silicates at grades approaching the first--sillimanite isograd. Throughout the roadcut diopside, tremolite, and phlogopite are abundantly developed in the appropriate lithologies and are best seen on the weathered surface at the top of the roadcut. The most noteworthy example of calc-silicate development occurs close to the top of the roadcut near its eastern terminus. Here a two foot wide layer consists almost entirely of extremely coarse tablets, blades, and rosettes of white tremolite. The layer can be followed for well over 50 feet. In adjacent layers diopside tablets appear to be the only calc-silicates developed. Presumably this represents a very steep gradient in P_{H_2O} and a local system effectively closed with respect to the water migration across layers.

35.8 Low outcrop of Briarcliff Dolostone on the north side of Rt. 55. This outcrop contains outstanding examples of perfectly formed diopside tablets.

36.1 Interchange for Rt. 55 and Rt. 22. Continue to 22/55 N.

36.5 Enter Rt. 22/55 North.

36.8 Traffic light. Turn east onto Quaker Hill Road. Continue along this road for 2.6 miles. Markers include the "Glen Arden Farm" and a sharp, hairpin turn going up Tracy Hill.

39.4 Stop 8 - Sillimanite Grade (See Table 2)

Roadcuts in coarse, muscovite rich schists. Large garnets are developed. Sillimanite is present in this outcrop but has not been recognized in hand specimen. Tourmaline bearing pegmatities occur and suggest the onset of anatexis (Table 2).

Displayed within the roadcut are numerous examples of disharmonic folding in which the more competent quartzo-feldspathic units have broken and rotated. Early isoclinal folds may be seen. Many of these have attenuated limbs. Rootless isoclinal folds occur.

End Road Log

TRIP B-8

ALLUVIAL AND TIDAL FACIES OF THE CATSKILL DELTAIC SYSTEM

by

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INTRODUCTION

Within the uppermost Middle Devonian and lowermost Upper Devonian rocks of eastern New York State there occurs a remarkably complete spectrum of ancient sedimentary facies (Johnson and Friedman, 1969; Johnson, 1970, 1972, 1976). These beds, which evolved during a transgressive pulse in the building of the great Catskill deltaic system, are part of a 3000 meter sequence that constitutes the standard for the Devonian System of North America (Figs. 1 and 2). They are exposed at the northeastern end of the Allegheny Synclinorium, are essentially undisturbed and, for the most part, very fossiliferous. Laterally transitional between those beds that are clearly of marine origin and those that are clearly non-marine are sandstones and shales that have sedimentary structures, lithology, geometric relationships with adjacent units and biogenic structures that indicate that they evolved in tidal environments generally similar to those of the modern Wadden Sea.

The purpose of this trip is to outline evidence for assigning depositional environment interpretations to these non-marine and transitional clastics and to offer their associated characteristics as recognition criteria for rock units developed in other tectonic delta complexes (Friedman and Johnson, 1966) at other times in the geologic past.

LITHOFACIES of the MIDDLE AND UPPER DEVONIAN

Three general lithofacies are recognized in the Devonian deltaic system of New York State (Fig. 2). The Catskill lithofacies, which consists of non-marine red and green-gray shales, sandstones and conglomerates, overlies and interfingers westward with littoral and shallow marine, very fossiliferous, gray sandstones and shales of the Chemung lithofacies. The Chemung, in turn, overlies and interfingers westward with deeper-water, sparsely fossiliferous, black shales of the Portage lithofacies.

The rocks of interpreted alluvial origin on which this trip focuses are best exposed along the Catskill Front between Palenville and Haines Falls and, farther northwest, at East Windham. They constitute the northwest Catskill lithofacies (Fig. 2). Rocks of interpreted tidal origin are exposed near Gilboa Dam in the Schoharie Valley, within the easternmost part of the Chemung lithofacies (Fig. 2). These rocks stratigraphically comprise the uppermost part of the Hamilton Group and the basal part of the Genesee Group (Cooper and Williams, 1935).

The interfingering relationship of the Catskill and Chemung rocks is best displayed just east of Schoharie Reservoir. Exposures there consist of interbedded gray, variably fossiliferous, cross-bedded, very fine-grained sandstones and red and green siltstones and mudstones. In places the contact between these two divergent lithologies is marked by a very thin conglomerate zone.

During this field trip, we will briefly examine the characteristics of the Catskill lithofacies between Palenville and Hunter (Stops 1-3). At Hardenburg Falls (Stop 4) we will study the Chemung lithofacies. Along Rt. 30, north of Grand Gorge (Stop 5), we will see both Catskill and Chemung rocks, at Gilboa Dam (Stop 6) Chemung rocks and, finally, at East Windham (Stop 7) a thick section of Catskill beds.

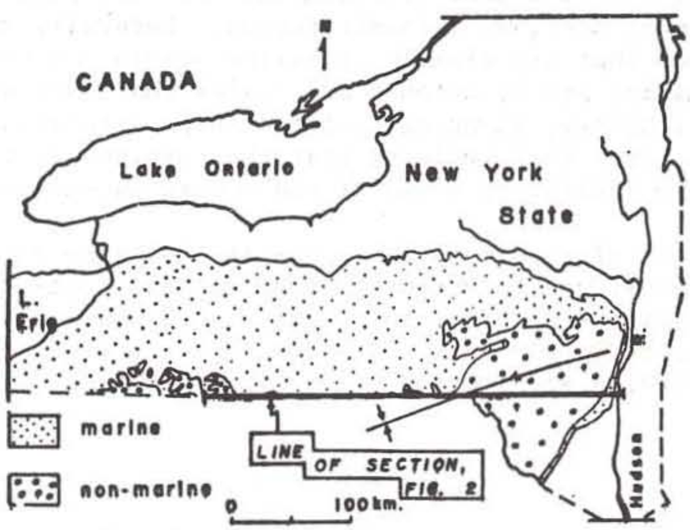


Figure 1 - Devonian bedrock of New York State (after Rickard, 1964).

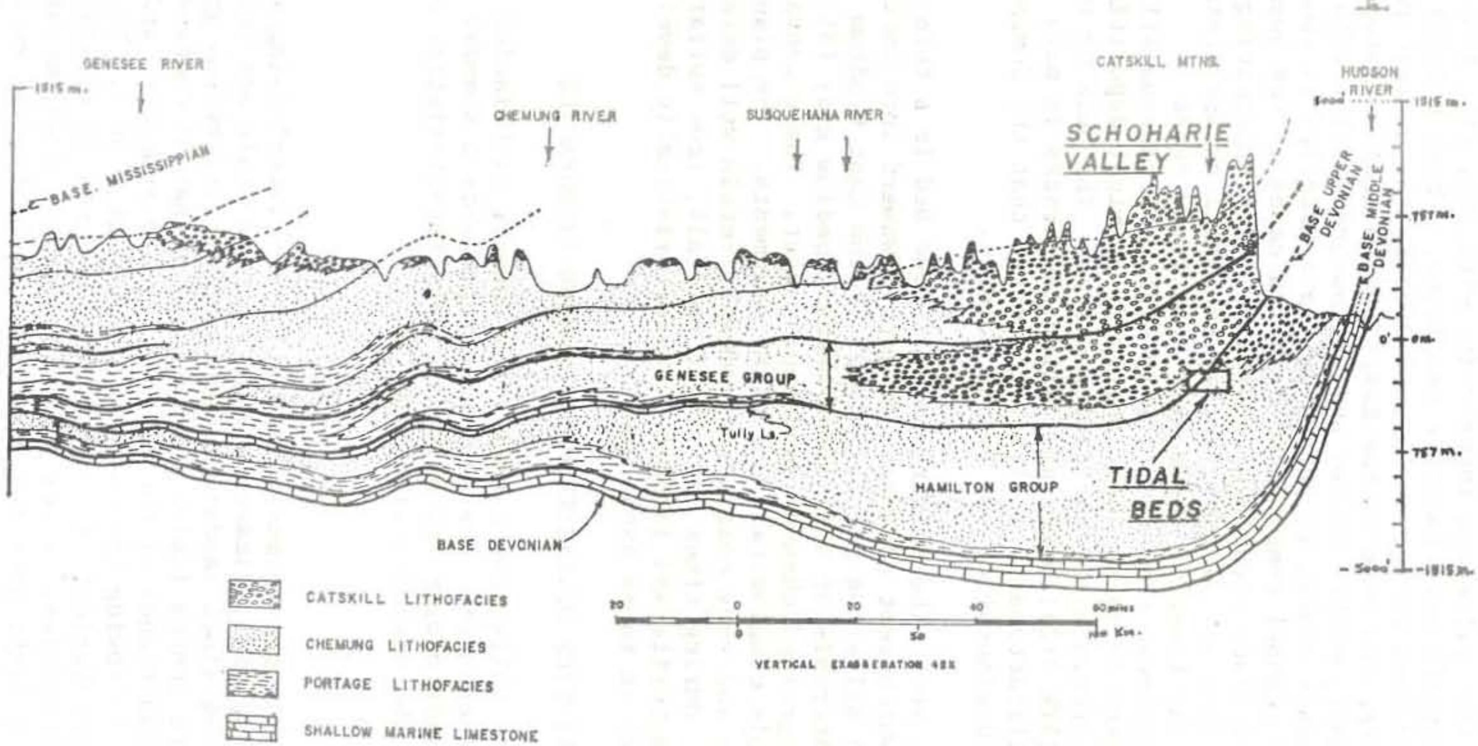


Figure 2 - Cross section of Devonian System along New York-Pennsylvania border (modified after Fig. 17, Broughton and others, 1962), showing geographic and stratigraphic location of Schoharie Valley tidal beds.

CHARACTERISTICS OF CATSKILL LITHOFACIES

Basal Upper Devonian rocks in the eastern part of the Catskill lithofacies consist for the most part of grayish red (5R 4/2) and grayish brown (5YR 3/2) siltstone interbedded with gray (N5) fine to medium-grained, texturally very immature sandstone. Green coloration in these fine-grained beds is not as extensive as in the western part of the lithosome. Near the base of the East Windham section (Stop 7) a large complex channel, mostly of red and yellow-green color with some dark gray highly organic zones, is present. Plant material is abundant in some parts of the channel complex and in a few cases it has been altered to a vitreous black bituminous substance. Two interesting features of the red beds are also present in the section some distance above the channel. The lower of these is a relatively dense bed of persistent thickness composed of very highly calcareous siltstone. The bed appears to be at least partly of chemical depositional origin and is shot through with dessication cracks. The bulk of the rock is pale brown (5YR 5/2); material filling the cracks is pale olive (10Y 6/2). X-ray diffractometer analysis indicates that the dominant constituent carbonate mineral of the bed is calcite.

About one meter above the calcareous siltstone bed is a thin gray (5G 6/1) zone from which root stigmaria project downward into underlying grayish red (5R 4/2) siltstone. Still higher in the East Windham section, numerous intervals of well cross-bedded, medium gray (N5 and N4), fine to medium-grained channel sandstones occur. These contain lenses of shale-pebble conglomerate and plant fragments. The plant fragments are coarse and very coarse and commonly retain well developed cellular structure. During times of slight rainfall, iron sulfate mineralization (melanterite and jarosite) characteristically develops on the organic lenses in these sandstones.

CHARACTERISTICS OF EASTERNMOST CHEMUNG LITHOFACIES

In the Schoharie Valley the Catskill and Chemung lithofacies are interbedded and well exposed. The following represents a summary of the lithologic, sedimentologic and paleontologic characteristics of the Chemung beds in the vicinity of Gilboa Dam.

Lithology

Lithologies within the Chemung lithofacies are interlensing medium gray (N4) to dark gray (N3), micaceous siltstone and shale and medium gray (N5), very fine-grained sandstone with subordinate, medium gray (N5 and N6) coquinite lenses (color terminology is that of Goddard, 1951). All of the sandstones of the lithofacies are submature and immature graywackes following the usage of Folk (1954, 1965). They contain sporadic accumulations of shale pebbles as well as moderately common, small pyrite nodules. A few polymictic pebble conglomerates containing pebbles of light gray and greenish gray quartzite, medium gray slate, red and olive siltstone, and subordinate medium gray limestone are present. Siltstones and shales of the lithofacies are dark gray in color due to a high content of fine organic material. They are very micaceous and variably thinly cross-laminated to occasionally fissile.

The coquinites, or in most examples more correctly coquinoid sandstones, occur as elongate lenses ranging from a few centimeters thick by 1 or 2 m long to 15 to 45 cm thick by lengths of up to some 15 meters. Thickness within a given lens is variable and they rest in channelled contact on underlying beds. Shell material in the lenses consists mostly of large spiriferid brachiopods, which in most fresh exposures are composed of calcium carbonate. Some of the lenses also contain pelecypod fragments as well as red siltstone pebbles. No preferred orientation of valves is apparent in the lenses, although some valves suggest imbrication.

Inorganic Sedimentary Structures

Bedding thickness of sandstones ranges from medium to thick and very thick (terminology after Ingram, 1954). Virtually all of the strata in the lithofacies, with the exception of the fissile shales, are cross-bedded or cross-laminated. Even the very thick-bedded sandstones, which in some cases appear homogeneous, are well cross-laminated. Interference, oscillation and current ripple marks are common. Interference ripple marks are expressed as a low-amplitude unevenness on bedding surfaces. The current and oscillation ripple marks, which have wave lengths of several centimeters and amplitudes of only 2 centimeters or less, provide reliable and plentiful evidence of sedimentary strike and direction of transport. Cross-bedding is of both planar and trough types and in most cases the inclination of foresets is well in excess of the 10 degree lower limit used by Pettijohn (1962) to denote high-angle cross-bedding.

Dessication cracks are well developed in the uppermost part of the Hamilton Group in the Schoharie Valley. Most of these occur as polygonal patterns of medium gray, very fine-grained sandstone infill on bedding surfaces of dark gray shaly siltstone. In one instance numerous sandstone infills extend some 15 cm perpendicular to bedding into a shale ledge.

Biogenic Structures

Biogenic structures in the Chemung lithofacies of the Gilboa Dam area are of three general types - (1) brachiopod and pelecypod body fossils, (2) ichnofossils and (3) fossil seed-ferns.

Brachiopods and pelecypods occur in both sandstones and shales as isolated specimens and as concentrations that appear to be allochthonous. Those found in allochthonous arrangements were considered, for purposes of this study, as biological sedimentary particles occurring in lithified sediment not necessarily that of their life environments. Ichnofossils in the Chemung lithofacies of the Schoharie Valley occur on bedding planes of sandstone as shallow, generally circular and ovoid depressions, which are slightly darker in color than the enclosing lithology. These occur in two sizes; those only about 1 cm in diameter, and those 2.5 cm or more in diameter. The smaller of the two extend downward perpendicular to bedding a distance of up to some 15 cm.

At one locality abundant vertical burrows are 30 cm in length. A few of the burrows have a Y or U pattern.

Fossil seed-fern stumps are present at three stratigraphic levels in the upper Hamilton beds near Gilboa Dam. Over two hundred stumps were taken from the lowest of these levels during quarrying operations just north of the dam (Goldring, 1924, 1927). They occur in light olive-gray (5 GY 6/1), tabular and trough cross-bedded, fine-grained sandstones some of which contain abundant vertical burrows up to 30 cm long. The beds are thick and very thick bedded, are in part slightly calcareous and, at certain levels, contain abundant casts of large spiriferid brachiopods.

ALLUVIAL DEPOSITIONAL SYNTHESIS

During late Middle and Late Devonian time, the Catskill Mountain region was occupied by a very extensive alluvial plain which was composed of sediment derived from a highland or highlands to the east. The general environmental significance of these strata was recognized during early investigations of the Catskill Mountain region and was summarized by Barrel (1913, 1914). The strata interpreted as representing alluvial deposition are all within the Catskill lithofacies.

As a result of intensive study during the last 30 years (Fisk, 1944, 1947, 1952; Allen, 1965a), present-day meandering stream deposits have been found to consist of relatively coarse-grained point bars, channel bars, and alluvial islands that are built in stream channels by lateral sedimentary processes, and of relatively finer-grained levee and flood-basin deposits that accumulate in interfluve areas by vertical sedimentary processes. Cut-off channels, channel fills, and crevasse-splay deposits accumulate by combinations of these two types of sedimentary processes. Subdivision of rocks of the alluvial facies incorporates recognition of the distinction between (1) the coarser, lateral accretion sediments of channel origin and (2) the finer, vertical accretion sediments of overbank origin.

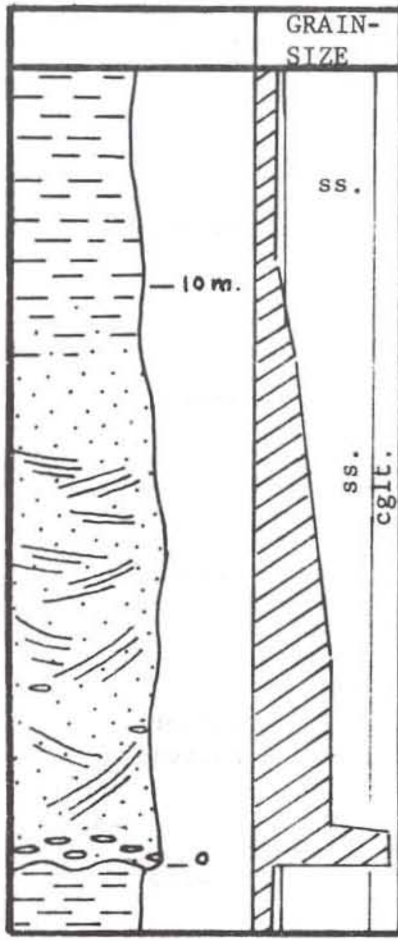
Alluvial Channel Facies

A summary of diagnostic characteristics of rocks of the channel facies is given in Table 1. None of the individual characteristics which are noted is inherently diagnostic; the value of each of them lying only in its being part of a set of characteristics which, in total, is unique to alluvial deposits.

In addition to the beds that will be seen along Route 23A between Palenville and Haines Falls, excellent examples of the channel facies are present in the East Windham section (Stop 7). Here the facies is represented by "multi-story" sandstone bodies that are inter-stratified with red beds of the overbank facies (Fig. 3). At the base, each body (channel) truncates overbank red beds, with the upper contact being one of gradation into red siltstone. This type of cyclic occurrence has been observed to occur commonly in rock sequences of alluvial origin

	Channel	Overbank
Lithology	Gray and greenish gray, fine to medium-grained, immature graywacke with abundant carbonaceous debris and green shale pebbles, especially in lower few feet of sandstone body.	Red and green, locally mottled siltstones, mudstones and shales with sporadic dark gray, locally bituminous lenses and very sparse thin, greenish tan, highly calcareous siltstone beds.
Texture	Variable; poorly sorted with abundant "fines" commonly becoming finer-grained upward in sandstone body.	Silt and clay grain-size with very small admixtures of very fine sand grains.
Sedimentary structures	Cross-bedding ubiquitous, commonly with decreasing foreset thickness and inclination upward in sandstone body. Parting lineation common. Current ripple marks locally well developed.	Very thin parallel laminations which generally are obscure on even slightly weathered outcrops; locally bedding is shaly. Local occurrence of mud-cracks.
Geometry	Truncates strata of underlying unit; upper contact gradational into overbank facies. Sandstone may interfinger with overbank facies or may be lenticular. Many bodies are laterally extensive	Occurs interbedded with channel sandstones. Basal contact with sandstone gradational; upper contact a sharp channelled disconformity. Interfingers with channel facies.
Associations	Sandstone bodies of facies occur as cyclic, "multistory" interbeds in red and green and locally dark gray and black, highly organic siltstones and shales of overbank and marsh facies.	See Geometry. Green coloration occurs in red siltstones and mudstones as mottles, lenses and very thin, persistent layers.
Miscellaneous	Outcrop surfaces commonly iron-stained. Iron sulfates frequently occur on organic, pyrite-rich lenses. Only fossils are plant material, sparse freshwater bivalves and fish plates.	Only fossils are plant material. Locally burrows, green burrow mottling and yellow-green, very slightly calcareous plant stigmaria are abundant.

TABLE 1. Summary of diagnostic characteristics of alluvial channel and overbank facies.



COLOR		LITHOLOGY	STRUCTURES	SEDIMENTARY PROCESS	ENVIRONMENT	
5R 4/2 with 10Y 6/2 mottles	RED	Micaceous silty mudstone and shale; locally very calcareous	Local burrows, plant stigmaria and mud-cracks	Vertical sedimentation	Flood basin	OVERBANK
5R 4/2		Micaceous siltstone	Horizontal lamination to massive		Levee	
	GRAY		Parting lineation	Upper Flow Regime	Point bar	CHANNEL
N5			Low angle (Trough and Tabular cross-bedding)	Low intensity Lower Flow Regime (Lateral sedimentation)		
N4		Immature graywacke	High angle (Trough and Tabular cross-bedding)			
		shale pebble conglomerate		High intensity Lower Flow Regime	Lag concentrate	
5R 4/2		micaceous silty mudst.& sh.	Truncation		OVERBANK	

Figure 3. Alluvial Cycle - Physical characteristics, hydrodynamic zones and environments.

(Bersier, 1959; Allen, 1962, 1964, 1965b; Beerbower, 1964), and Allen has referred to such alluvial successions as "fining-upwards cycles".

Near the base of the East Windham section, a large asymmetric compound channel is well exposed. The compound channel consists of a lower channel sandstone, which truncates overbank siltstone, and an upper channel sandstone, which truncates both the lower sandstone body and laterally adjacent overbank siltstone. A shale-pebble conglomerate in the base of cross-bedded point bar sandstone marks the trough of the oldest (lower) channel element. The bar sandstone can be traced laterally toward the slip-off slope of the channel where it truncates dark, highly organic pyritic lenses of the marsh facies. These lenses contain very abundant, very coarse plant fragments. On the opposite (cut-bank) side of the channel an interval of some 4.5 m of red overbank siltstone is truncated.

In the sandstone bodies higher in the section, foreset thicknesses and inclinations are greater than in the compound channel described in the preceding paragraph, and grain size is fine to medium. Basal shale-pebble conglomerates are very common, as are highly organic, pyrite-rich lenses that during dry periods are commonly encrusted with iron sulfate mineralization. Shale-pebble, or clay gall, accumulations are also scattered through the point bar cross-beds. These have been observed in modern environments to result from (1) undercutting of mudflats on channel-margin point bars and (2) dessication of the surface of mud flats into subangular, flat, disc-shaped plates that were later carried downstream more or less intact and deposited with sand (G. D. Williams, 1966). Although clay galls have been observed to develop in modern marine environments (Trefethan and Dow, 1960), the presence of abundant shale-pebble conglomerate in sandstone is highly suggestive of fluvial deposition. A "fining-upwards" is noted in virtually all of these sandstone bodies and parting lineation was found to be common in the upper, more shallowly cross-bedded portion of the units.

Alluvial Overbank Facies

A summary of diagnostic characteristics of those alluvial rocks of overbank origin is given in Table 1. Rocks of this facies are well exposed at East Windham (Stop 7) and just north of Grand Gorge (Stop 5).

In addition to their very fine grain-size and very thin horizontal bedding, the most striking characteristic of rocks inferred to be of overbank origin is their red and green color. At Stops 5 and 7 the predominant color of the facies is red, with local development of green coloration occurring as thin beds, mottles, and lenses. In places, thin dark gray or black, highly organic zones of limited lateral extent were noted. Just east of the Schoharie Reservoir, green coloration is much more common and is present in some 50 percent of the overbank facies.

The origin and environmental significance of red beds is controversial and has been variously ascribed to (1) color of soil in the source terrain (Krynine, 1949), (2) in place oxidation of iron-bearing minerals in a hot arid climate (Walker, 1967), and (3) variation in oxidation-reduction values at the site of deposition with resultant development of zones in which constituent iron oxides are either in an oxidized (red) or reduced (green or gray) state.

Van Houten (1964) has emphasized that there is no simple explanation for red beds. He points out that they are fundamentally a sandstone, siltstone, or mudstone composed of detrital grains set in a reddish-brown mud matrix or cemented by precipitated reddish-brown ferric oxide, and that there are two basic red bed types: (1) first cycle and (2) second cycle. First cycle red beds are derived from source material weathered deeply enough to supply free ferric oxide, either in chemical solution or colloidal suspension, to the side of deposition. Second cycle red beds are colored by pigment and grains inherited from a pre-existing red deposit.

Friend (1966) who studied the clay fractions and colors of alluvial cyclothems of the Catskill front, which represent the inland flood plain rocks that are generally correlative with the alluvial plain rocks of the present study area, concluded that:

(1) The essential difference between the red overbank rocks and the associated non-red fluvial sandstones is the presence in the red beds of fine-grained hematite that occurs as coatings on silt grains.

(2) The redness developed in place by oxidation of a pre-existing iron oxide, and did not result directly from the presence of red soils in a lateritic source area.

(3) The red/non-red differentiation occurred in the sedimentary environment, as a result of differences in oxidation-reduction potential determined by the position of the ground-water table.

On the basis of the characteristics of rocks in the study area assigned to the overbank facies and the observations of Friend in the generally correlative rocks farther east, it is clear that the beds evolved as interfluve vertical accretion deposits during stream high-water stages. In the areas between channels, oxidizing conditions prevailed in those places where the water table lay some distance below ground level. Here it was possible for any hematite in the sediment to remain in the oxidized state and for any constituent pre-existing iron oxide to be altered to hematite. Plant material included in the sediment was destroyed by oxidation. Where drying at certain times of the year was excessive, desiccation cracks developed, and in local, shallow pans extremely thin accumulations of "evaporites" evolved. In other parts of the interfluve, where the ground water table intersected the surface, reduction of organic material resulted in green or, where organic content was very high, in dark gray or black coloration of the sediment. The westward increase of green coloration within the overbank facies appears to be mainly an expression of environmental change from predominantly oxidizing (well drained) to reducing (poorly drained) conditions.

TIDAL DEPOSITIONAL SYNTHESIS

Although it has long been known that the interbedded Catskill and Chemung lithofacies in the Schoharie Valley are a record of medial and late Devonian shoreline oscillation at the margin of the Catskill deltaic system, it has not been noted that some of the Chemung lithofacies units have characteristics that quite clearly indicate tidal-flat and tidal-channel depositional processes.

Modern tidal sediments accumulate along the margins of protected coastal water bodies such as lagoons, estuaries and bays, and are for the most part alternately submerged and subaerially exposed. They may be subdivided into (1) tidal flats and (2) tidal channels. Most modern tidal-flat sediments consist of material of silt and mud grade-size which is deposited by vertical sedimentary processes, and of somewhat coarser sediment which is deposited by lateral sedimentary processes in channels or creeks that cut across the tidal flats. The lower part of the channel deposits is not necessarily completely exposted during low-tide stage.

In Recent environments, two general types of tidal-flat sedimentation have been recognized (Klein and Sanders, 1964; Klein, 1967): (1) Wadden-type tidal flats and (2) Fundy-type tidal flats. The type area of the first of these is in the Wadden Sea, a part of the Rhine-Ems-Scheldt delta system of northwestern Europe. Van Straaten (1954) subdivided the intertidal sediments of the Wadden Sea into salt marshes, high tidal flats, low tidal flats and tidal channels. Fundy-type tidal flats, which have been studied by Klein (1963, 1964) in the intertidal zone of the Bay of Fundy, have a more complicated association of sediments, attributed to large coastal relief, bedrock cliffs and large tidal ranges. The dominant environment is a wave-cut bench on which a thin veneer of locally derived sediment is being reworked by waves and rising and falling water.

Although modern tidal deposition has been intensively studied in areas of both clastic and carbonate sedimentation, studies of rocks of tidal origin in the geologic record have been for the most part of carbonate sequences (Klein, 1965; Matter, 1967; Braun and Friedman, 1968; LaPorte, 1967, and others). Detailed descriptions of clastic tidal rocks are not well represented in the literature. However, beginning in the last decade a number of papers marked an initiation of considerable interest in ancient clastic tidal sediments.

Tidal Flat Facies

Van Straaten (1950, 1954) subdivided the Wadden Sea tidal flats into (1) a lower seaward part, where meandering tidal creeks cut across and into mud and muddy sand deposits, and (2) a higher landward part composed dominantly of sand. Well-developed incised tidal channels are not present in the high tidal flats and structures in the sediment are lacking due to bioturbation by enormous numbers of sand and mud-dwelling worms and crustaceans. In the lower tidal flats, where sedimentation proceeds at a faster rate, destruction of sedimentary features by organisms is not nearly as complete and fine cross-lamination and flaser bedding is preserved. The origin of interlaminations of sand cross-laminae and mud (flaser bedding) in the Recent tidal flats of the German Bay in the southeastern part of the North Sea has been attributed by Reineck (1967) to alternating current activity and slack water conditions. The lenticular interstratification of mud and very fine sand described by Reineck and Van Straaten appears to be the modern counterpart of the lithological and sedimentological features of those rocks of the Schoharie Valley assigned to the tidal flat facies. These rocks consist of medium dark gray (N4), cross-laminated, muddy siltstone that in most cases contains subordinate medium gray (N5), very fine-grained sandstone. Flaser bedding is commonly well developed, oscillation ripple marks are locally present, plant fragments are abundant, very faint, fine vertical burrows are common, and brachiopods occur sporadically throughout and in lenses. The lenses contain admixtures of pebbles and coarse plant material. In most places the tidal-flat rocks are truncated by over-lying tidal-channel sandstones (Fig. 4). The very close association of these rocks with sandstones of inferred tidal-channel origin indicate that they are of lower tidal-flat derivation. Characteristics of the tidal-flat rocks that are considered diagnostic for recognition of depositional environment are listed in Table 2.

Tidal Channel Facies

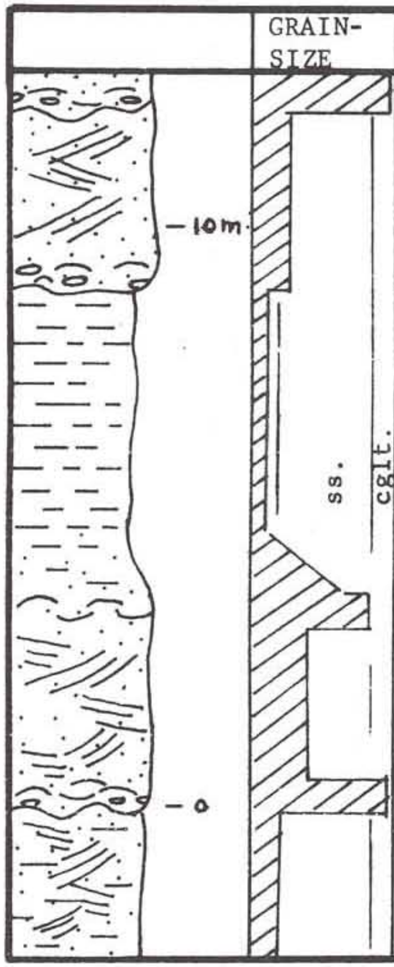
The sedimentary processes operative in modern sinuous tidal channels (Oomkens and Terwindt, 1960) are essentially the same as those found in meandering alluvial channels. In both types erosion cuts back outer (concave) meander banks and sediment is carried downstream and deposited in slack water along the inner (convex) banks of meanders. By this combination of erosion and sedimentation, cross-bedded channel deposits are built laterally and vertically. In the closing stages of channel filling, as flow slackens, parallel laminae of fine sediment are deposited. Thus, virtually all of the sedimentary structures of rocks of alluvial channel origin are found in rocks of tidal-channel derivation.

There would be, of course, a general tendency for Wadden-type channel sandstones to be somewhat finer than equivalent alluvial channel sandstones, and in at least one modern example (Terwindt and others, 1963, Fig. 7) a distinct difference in grain-size has been noted between tidally influenced estuarine sands and adjacent much coarser fluvial sands. This distinction, however, might not be immediately apparent in the geologic record.

Two important characteristics of the tidal type of channel sand body that permit recognition of the facies in the geologic column are (1) close association with strata of marine origin and (2) the unique character of the basal channel lag concentrate. The basal lag concentrates of the Schoharie Valley tidal channel facies consist of a polymictic pebble assemblage and abundant large spiriferid brachiopod valves of subtidal derivation. This type of allochthonous organic sedimentary accumulation has been noted in modern tidal flats and channels of the Wadden Sea, Easter Scheldt (Netherlands), and Bay of Arcachon (France), where the shells are typical open-sea species that are washed into the tidal-flat areas by flood tides (Van Straaten, 1956).

	FLAT	CHANNEL
Lithology	Medium dark gray (N4) finely micaceous, mudy sltst and very subordinate medium gray (N5) very fine-grained ss.	Medium gray (N5) fine-grained immature graywacke containing abundant plant material; coquinoid ss and coquinite with spiriferid brachiopods; polymictic cglt with pebbles of gray, light green, and olive sltst, greenish gray qtzt and red sltst and sh.
Texture	Very fine to fine grade sizes.	Grain-size decreases upward in rock unit from cglt lenses in base to very fine-grained ss at top. Sorting is generally poor.
Sedimentary structures	Featureless to very fine cross-laminated (flaser and ripple bedding). Local well developed polygonal mud-cracks and oscillation ripple marks.	Tabular and trough cross-bedding ubiquitous in basal part of ss, grading upward to generally horizontal bedding at top. Parting lineation common in upper part of body.
Geometry	Basal contact gradational from ss of inferred tidal or near-shore bar origin. Upper contact disconformable with overlying tidal channel ss or nearshore bar ss.	Basal contact truncates strata of underlying inferred tidal flat facies. Upper contact gradational into fine-grained rocks of tidal flat or other facies. In cross section may be lenticular or interfinger with tidal flat facies. In modern environments long axis of sand body generally perpendicular to shoreline.
Associations	Interbedded with ss of inferred nearshore bar and tidal channel origin.	Ss bodies occur as channel deposits in tidal flat facies. Basal lag concentrate is commonly coquinite or coquinoid ss.
Miscellaneous	Contains abundant plant material common allochthonous brachiopods and bases of in situ fossil seed-ferns.	Sedimentary structures same as that of alluvial channel facies. Ss contain local large burrow structures, allochthonous marine fossils and trunks of fossil seed-ferns.

TABLE 2. Summary of diagnostic characteristics of tidal flat and channel facies.



COLOR		LITHOLOGY	STRUCTURES		SEDIMENTARY PROCESS		ENVIRONMENT	
5Y 6/1		coq.pebble cglt.	Truncation	Cross-bedded	High intensity Lower Flow Regime	Lat. Sed.	Lag deposit	CHANNEL
N4	Gray	Immature graywacke	High angle-					
		coq.pebble cglt.	Truncation				Lag deposit	
5Y 4/1	Olive gray	Micaceous siltstone	Flaser bedding			Vertical Sedimentation		FLAT
N5	Gray	coquinoid ss	Current ripple marks & sparse burrows	Cross-bedded	High intensity Lower Flow Regime	Lateral Sedimentation	Lag deposit	CHANNEL
		Immature graywacke						
		coq.pebble cglt.	Low angle- Truncation				Lag deposit	
N5		Silty sandstone			Low intensity Lower Flow Regime			

Figure 4. <u>Tidal Cycle</u> - Physical characteristics, hydrodynamic zones and environments.

The best examples of the tidal-channel facies in the Gilboa Dam area consist of medium gray (N4) and olive gray (5Y6/1), tabular and trough cross-bedded, fine to medium-grained, immature graywacke. The sandstone bodies truncate medium gray, shaly siltstone of the tidal-flat facies and contain well-developed basal lag accumulations, most of which are very rich in large spiriferid brachiopods. In several places vertical burrow structures are present in the uppermost part of cross-bedded sandstone ledges. The tidal channel sandstone bodies occur in cyclic association with the tidal flat facies, in some instances as "fining-upwards cycles" (Fig. 4). Characteristics of the tidal channel rocks that are considered diagnostic for recognition of depositional environment are listed in Table 2.

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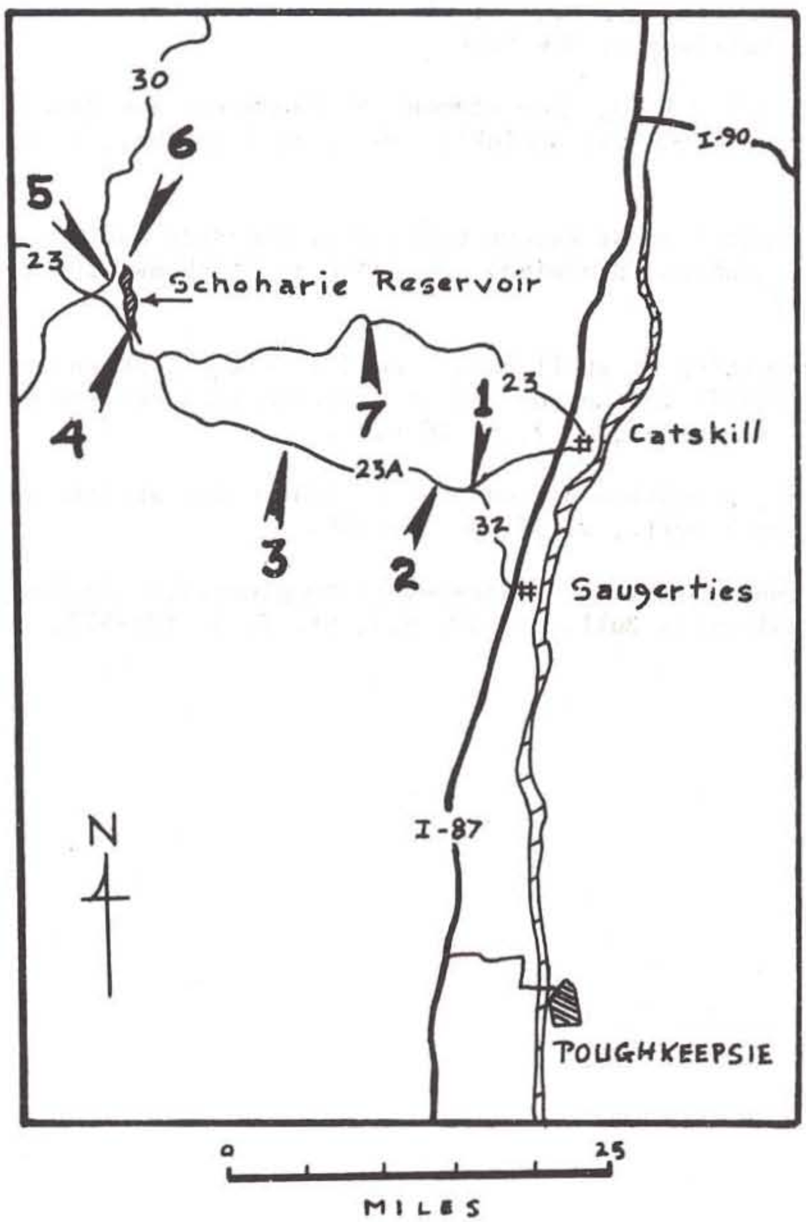


Figure 5. Field trip stop locations.

TRIP B-8

ALLUVIAL AND TIDAL FACIES

OF THE

CATSKILL DELTAIC SYSTEM

ROAD LOG

For purposes of this trip, the intersection of Routes I-87 and 32 at Saugerties are considered the mileage zero-point.

Mileage

0 LEAVE New York State Thruway (I-87) and proceed north on New York Route 32.

0.6 ON LEFT - colonial house, construction material Lower Devonian limestone.

Cherty Onondaga Limestone exposures.

2.2 Deep roadcut in Onondaga cherty, fossiliferous limestone. AHEAD- view of Catskill Front. The Front marks the eastern margin of the Catskill Mountains. It is cut by several narrow stream valleys (cloves) in which there are excellent exposures of Middle and Upper Devonian Catskill lithofacies. We will climb Kaaterskill Clove and observe rocks along the Rip Van Winkle Trail (Route 23A).

3.8 Roadcut in cross-bedded, blue-gray sandstone. Local term for this rock type is Bluestone.

5.1 ON LEFT - Old, inactive quarries in Bluestone.

5.5 ON LEFT - In distance, view of Kaaterskill Clove.

6.4 ROAD FORKS - Bear left on Route 32A.

7.4 Enter PALENVILLE.

7.9 Cross small creek. Rapids and low waterfalls in bed of creek due to well developed, horizontally bedded Bluestone ledges.

8.3 JUNCTION of Routes 32A and 23A (Rip Van Winkle Trail). Proceed west on Route 23A.

8.6 ON LEFT - Gloria Dei Church (Episcopal) STOP 1
This church, constructed in the late 19th Century, was built of fieldstone, most of which is of local bedrock lithologies. The most significant of these are (1) polymictic pebble conglomerate, (2) grayish green, immature, medium-grained, sandstone, and (3)

(3) dark red, very fine grained sandstone and siltstone. In some respects this is as good an outcrop as any that you will see today.

PROCEED west on Route 23A.

9.3 Cross Kaaters Kill and begin climbing clove. Just downstream from this bridge are very well developed pot holes and water falls, where the stream flows over Bluestone ledges.

9.4 Enter Catskill State Park.

9.6 ON RIGHT, across Kaaters Kill - interbeds of red and green Catskill lithofacies.

11.7 ON LEFT, up clove - Twilight Park, a private preserve that was very fashionable in the late 19th and early 20th Centuries. It is still private, but less fashionable. The preserve is the type locality of the Twilight Park Conglomerate, the coarsest of the Catskill lithofacies rocks. The conglomerate appears to represent an ancient mountain front, braided stream deposit. You will see it in outcrop at Stop 3.

11.8 Road swings sharply left. Cascade on right formed where tributary of Kaaters Kill flows over sandstone ledges.

12.0 ON LEFT - Forest Preserve Access Parking Area. STOP 2. From this point it is possible to look east down Kaaterskill Clove. The cross-sectional profile is typical of high-gradient streams that are engaged in active vertical erosion. The Kaaters Kill is considered to be an excellent example of a short, high gradient stream that has managed to capture the headwaters of a longer lower-gradient stream flowing in an opposite direction. The elbow of capture is at Haines Falls, just west of this observation point.

CONTINUE UP CLOVE on Rt. 23A.

13.0 Enter HAINES FALLS

13.2 ON RIGHT - Green County Route 18 leading to North Lake Campsite, former site of Catskill Mountain House. The Mountain House, a resort hotel, was situated near the top of the Catskill Front, some 700 meters above the Hudson River. Exposures of cross-bedded, gray, conglomeratic sandstone and conglomerate may be seen on the trails around North Lake Campsite.

CONTINUE WEST ON Rt. 23A.

14.8 Enter TANNERSVILLE.

AHEAD - Hunter Mountain ski area.

18.9 Enter HUNTER

20.9 JUNCTION Rts. 23A and 296. STOP 3. Outcrop of cobble conglomerate at base of one of Catskill lithofacies alluvial channels. This basal lag concentrate was apparently deposited quite near its source area. It is by far the coarsest exposure that you will see today.

PROCEED WEST ON Rt. 23A.

22.2 Enter SOUTH JEWETT

23.5 JEWETT CENTER

33.5 ON RIGHT - Catskill lithofacies.

34.5 ON RIGHT - Catskill red beds.

35.1 JUNCTION Rts. 23A and 23.
PROCEED west on Rt. 23.

35.7 Pratt Rock Park on outskirts of PRATTSVILLE.

36.6 Cross Schoharie Creek. Leave Prattsville.

36.8 Enter Delaware County.

38.3 ON LEFT - Small power substation. PARK HERE. STOP 4. Walk northeast along unsurfaced side road to Hardenburg Falls. At this point Bear Kill flows into Schoharie Reservoir. Beds here are assigned to the tidal channel and tidal flat facies. The tidal channel facies is represented by gray, cross-bedded, fossiliferous sandstones and the tidal flat facies by very dark gray, very thin-bedded, in part conglomeratic, shales. Lag-concentrates in both facies are rich in shallow marine brachiopod shells.

PROCEED west on Route 23 to Grand Gorge.

41.4 Junction of Rts. 23 and 30 in Grand Gorge. TURN RIGHT AND PROCEED NORTH ON ROUTE 30.

42.4 Enter Schoharie County.

42.9 Top of long hill. PARK ON LEFT. STOP 5A. On east side of road, exposure of alluvial channel sandstone resting on red overbank shale.

PROCEED DOWN HILL.

43.6 PARK ON RIGHT. STOP 5B. On east side of road, exposure of gray, cross-bedded sandstone of tidal channel facies with lag-concentrates of shallow marine spiriferid brachiopods. BE VERY CAREFUL. THIS IS A NARROW SPEEDWAY WITH POOR VISIBILITY.

CONTINUE NORTH ON RT. 30.

43.9 On right, in distance - large quarry from which much of stone for Gilboa Dam was taken. Completion of dam impounded waters of Schoharie Creek, forming Schoharie Reservoir, a part of New York City water supply system.

44.5 Turn right on road to Gilboa.

44.9 View north down Schoharie Valley. Note even crest of hills flanking valley, a result of stream dissection of nearly horizontal Devonian strata.

45.7 Gilboa Bridge across Schoharie Creek. PARK on right at west end of bridge.

STOP 6 - Display of seed-fern stumps taken from quarry just to southwest. Some 200 specimens were found during the quarrying operation. These seed-ferns are thought to have grown to heights of some 18 meters in swamps along the seaward margin of the Catskill alluvial plain during late Medial Devonian time. They were buried during a minor oscillation of the marine shoreline in tidal channel or bar sand deposits.

RETURN TO JUNCTION OF RTS. 23 and 23A VIA GRAND GORGE and PRATTSVILLE.

56.8 Junction of Rts. 23 and 23A. PROCEED EAST ON RT. 23, following Batavia Kill Valley.

58.4 ON RIGHT - Red Falls.

61.1 Enter ASHLAND.

66.1 Enter WINDHAM.

69.4 Enter CATSKILL PARK.

69.9 ON RIGHT - alluvial channel sandstone on overbank shale. Note irregular erosion surface at base of sandstone ledge.

71.9 ON LEFT - Catskill lithofacies, mostly red.

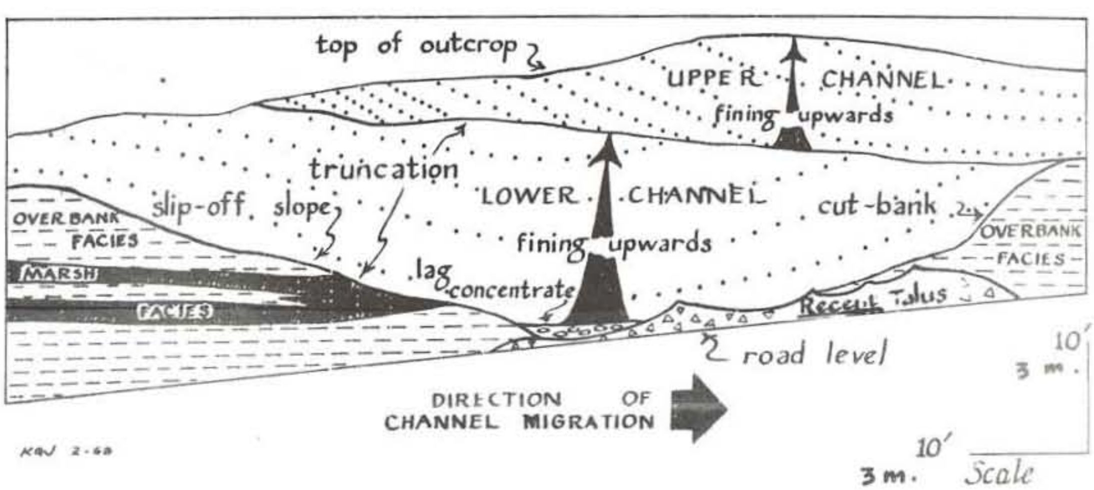
72.6 PARK ON RIGHT SHOULDER, STOP 7A. These alluvial channel sandstones mark the top of an excellent section of some 185 meters, consisting almost entirely of rocks of alluvial origin. Many of these sandstone ledges show an interesting upward progression of change in texture and sedimentary structures.

CONTINUE EAST ON RT. 23. On right - East Windham Post Office. To left (north), in distance, dip slopes of Hamilton Group strata.

74.0 ON RIGHT - high on outcrop - tan sandstone, much lighter in color than sandstone in remainder of exposure, assigned to tidal channel facies.

74.2 Mobil gas station on right.

74.5 Driveway on right. PARK ON RIGHT SHOULDER. STOP 7B. At the driveway are alluvial overbank facies root stigmaria and a highly calcareous overbank "evaporite" bed. A short distance downhill is a compound alluvial channel and laterally equivalent overbank siltstones.



PROCEED EAST ON RT. 23 TOWARDS LEEDS AND NEW YORK STATE THRUWAY (I-87).

82.4 JUNCTION Rts. 23 and 32. CONTINUE EAST On Rt. 23.

82.7 Beginning of series of roadcuts in Catskill lithofacies channel and overbank rocks.

88.9 TURN LEFT on Cauterskill Road.

89.2 TURN RIGHT on Green County Route 23B and cross limestone bridge into village of LEEDS.

90.5 TURN LEFT to NEW YORK STATE THRUWAY toll booths. PROCEED SOUTH on Thruway.

99.0 Thruway Interchange 20 at Saugerties (zero-point for this field trip).

End Road Log

ENVIRONMENTAL GEOLOGY OF THE
LLOYD NUCLEAR POWER PLANT SITE

by

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A History of Site Study

In November 1971 the N.Y. Atomic and Space Development Authority released an anonymous report by Dames and Moore (a consulting engineering firm) entitled: "Consultation and Geologic Evaluation Site Suitability Studies: Hudson River Valley between Albany and Newburgh, New York." The report studied nine sites, two adjacent to the present Lloyd site. Of the nine sites, 5, or more than half, are rated as most favorable for additional study. The Lloyd sites* are described as follows (pp. 12-13):

> Based on recent studies (Salkind, personal communication) lithologies within the region in which Areas 5W, 6W, and 7W are located, can be broken down into three separate formations. The youngest, or highest stratigraphically, is the Quassaic Quartzite. This formation crops out in a linear belt from Illinois Mountain (southeast side of Site 5W) north to Connely, New York. This formation forms the core of a normally faulted, recumbent syncline. Underlying the Quassaic Formation is the Austin Glen Graywacke, also a new formation. It was formerly treated as a member of the Normanskill Formation. This formation crops out west of Illinois Mountain and underlies most of Sites 5W and 6W. The regional strike is N25E with all dips to the southeast. This formation is extensively faulted by repetitive high angle reverse faults which have a north-south trend. All of the lowlying swamps occurring between the more resistant outcrops of Austin Glen and Quassaic are thought to be topographic expressions of faults and/or fault zones.

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*Site 5W is adjacent to and South of the present Lloyd site. 6W is west and adjacent. Site 7W is not adjacent to the present site.

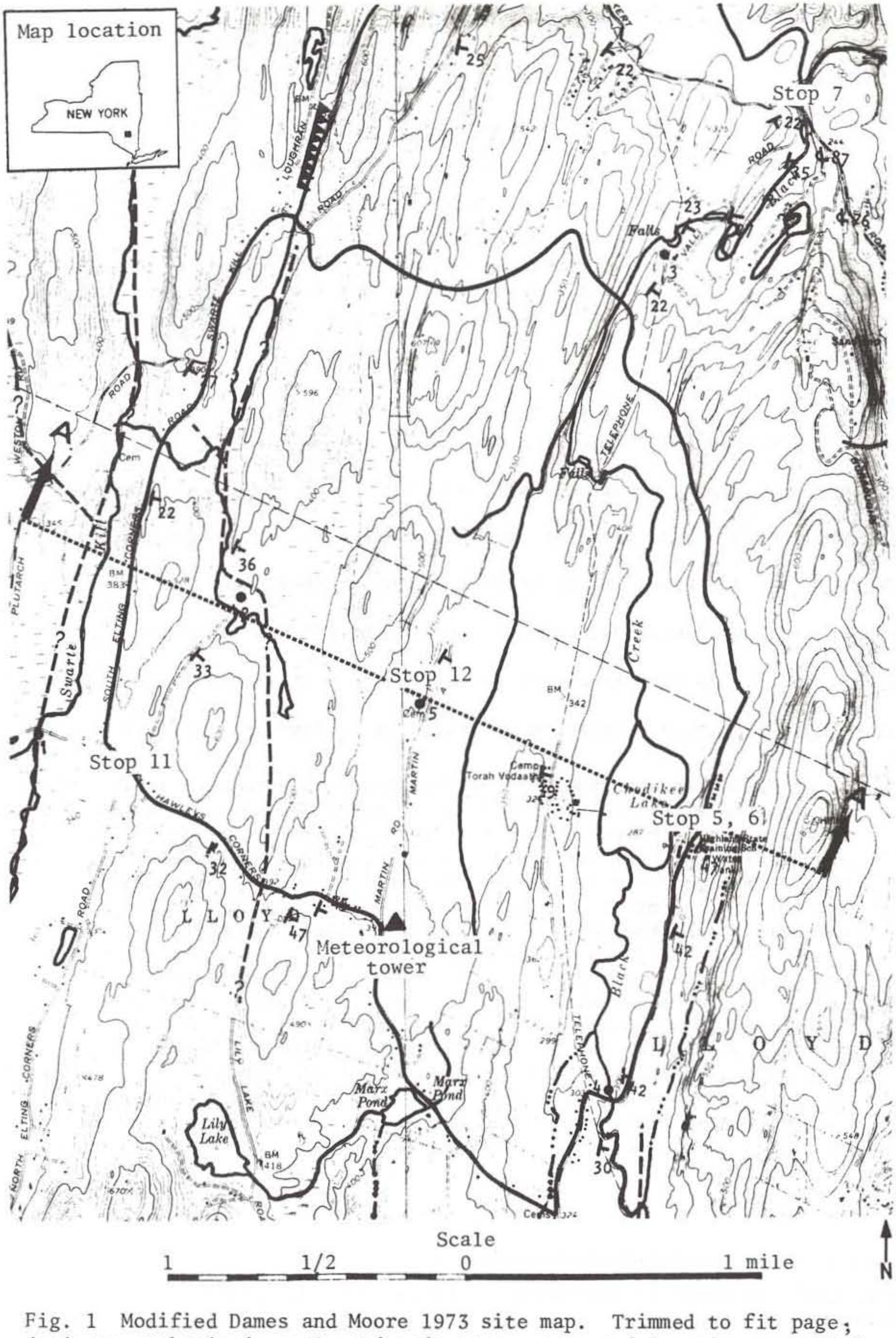


Fig. 1 Modified Dames and Moore 1973 site map. Trimmed to fit page; drainage emphasized; scale reduced; tower, stops and location map added.

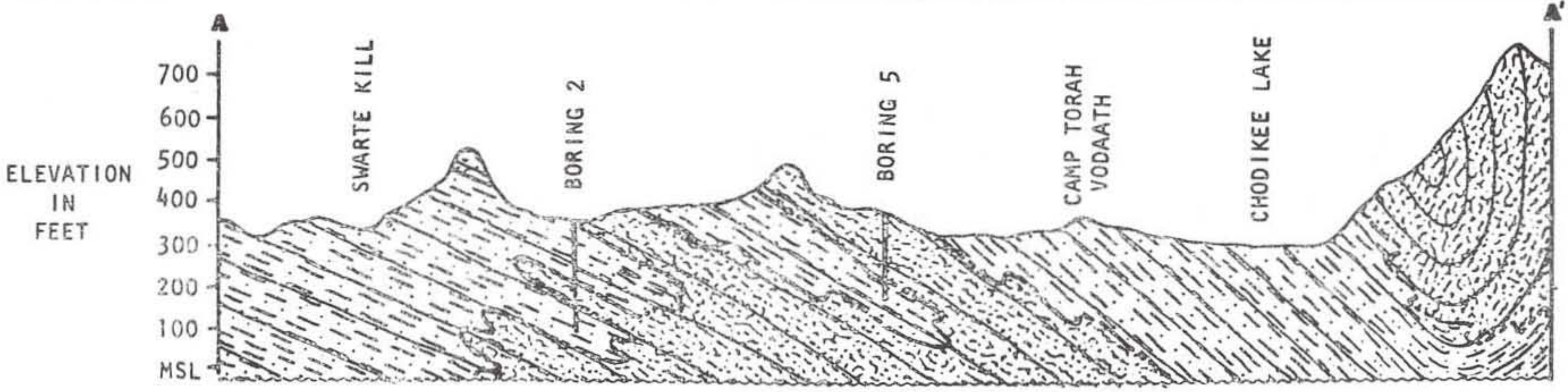
In addition to this information, a 1/250,000 scale Geologic map is provided. The sites are only ¼ inch in diameter at this scale and thus little detail is shown. This report is at best a preliminary reconnaissance of the entire region. It is so preliminary that the choice of best sites is difficult with the meager information available. At least, the description of the Lloyd site is fairly correct as far as it goes.

In June 1973 another report was released by the N.Y. Atomic and Space Development Authority. This report also was generated by anonymous members of the Dames and Moore staff. The Report was called "Report: Site Suitability Geotechnical Studies; Lloyd, New York."

The report is very general. Fig. 1 is a copy of the site geologic map from this report. The cross section A-A' section clearly crosses two faults on the geologic map. However the cross section drawn from the geologic map and reproduced here in Fig. 2 shows no faults. Interestingly, two different vertical exaggerations are claimed for this one cross section. One might seriously question the extremely rapid facies changes shown on the section, for example in one case 500 feet of "quartzite" grades into "Interbedded graywacke/shale" in a horizontal distance of only 2000 ft. There certainly are facies changes in the area but it is doubtful that any are this extreme. Faulting is a more likely explanation.

Dr. Russell Waines and I released to the local press in Oct. 1975 a consistent version of the Dames and Moore cross section. Our modified version is shown in figure 3. The omitted faults are shown and the vertical scale is the same for topography and structure. The facies changes are left as is. In other words we did not at that time change the geologic interpretation we only removed the internal inconsistancies.

There are also problems or questions about interpretation. For



SUBSURFACE SECTION A-A'

VERTICAL EXAGGERATION = 5X
(NO VERTICAL EXAGGERATION OF STRUCTURE)

HORIZONTAL SCALE: 1:24,000

FEET
2,000 0 2,000

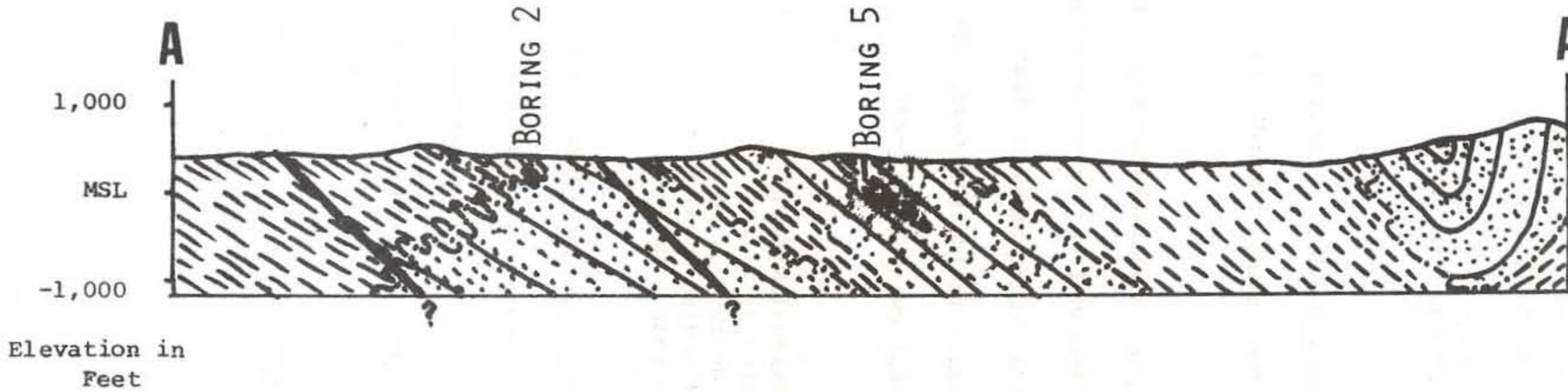
KEY:

APPROXIMATE CONTACT OF LITHOFACIES

QUARTZITE

INTERBEDDED GRAYWACKE/SHALE

Fig. 2. Lloyd Site cross section after Dames and Moore, 1973.



SCHEMATIC SUBSURFACE SECTION A-A'

(Data from Dames and Moore; Field data not included)

(No vertical exaggeration)

Horizontal Scale: 1:24,000

KEY

Quartzite

Interbedded Graywacke/Shale

Fault

Approximate contact of Lithofacies

Fig. 3

Waines & Egemeier

example, several site bore holes logs hit possible fault zones (Dames and Moore, 1973, plate 2-6a):

> "1' Zone showing contorted bedding and several calcite veins with samll offsets; slickensides also occur at right angle to dip at 129' and 129.5'.
> The zone from 126'-131' clearly shows evidence for at least 3 episodes of deformation, 1) folding, 2) jointing and/or fracturing with vein filling by quartz and calcite, 3) offset of veins."

There is a short discussion in the report of bore hole data. The report concludes that the faults are "healed faults". Presumably "healed" is roughly synonomous with inactive.

In October 1973 anonymous staff members of Stone and Webster Engineering Corporation did a site study entitled the "Metropolitan Transportation Authority Plant Site Study". They studied some 32 sites between Albany and N.Y.C. 21 sites were considered to be suitable including Lloyd. The geologic suitability of Lloyd was based on the following (pp. 2-29).

> "(1) Physical and Environmental Features
>
> Geology: Possibly shallow organic and residual material overlies shales and graywackes of Ordivician (sic) Age. This formation strikes N15 degrees to 20 degrees E, paralleling the regional structure with easterly dips of ± 30 degrees. Pre-Mesozoic faulting lies more than 5 miles west, paralleling the regional structure."

The quality of the geological information not just its sparcity is a problem. I accept the misspelling of Ordovician as a typographical error, but the statement about ± 30 dips to the east may represent a lack of adequate geologic review of this document. It's quite clear that very little was known about the site.

The weakness of the geologic information may not be significant as Stone and Webster's conclusions on the site did not use any geologic information. They said:

"The Lloyd site is not recommended for detailed study because the cost of a nuclear power plant at that location exceeded the costs at other sites."

A need for the site is not obvious. The executives of Central Hudson Gas and Electric Corporation, the local utility, have publically stated that they have no interest in the site. No utility has indicated an interest in the site. Even so there is strong local opposition to the site.

The local opposition to the site proved effective enough to influence the state legislature. The legislature abolished ASDA, the state agency that was promoting the site and set up the New York State Energy Research and Development Authority (ERDA). ERDA's authority is to site new energy systems only, and hence it does not have authority to site nuclear power plants. ERDA has, however, finished the Lloyd Site study to complete ASDA's last project.

In November 1975 ERDA released another Dames and Moore report on the site. This anonymously authored report is titled "Report of Investigations Lloyd, N.Y." ERDA has revealed that two participants in the project were Joseph A. Fischer, a Civil Engineer, and Dr. Matthew L. Werner, a geologist.

According to the report, page A-1 field procedures were

> "* * * initial field efforts were directed toward developing a quick, but detailed geologic understanding of the area within a five mile radius of the site. This was achieved by 18 circular mapping traverses, evenly distributed over the area, of about 6 miles in length each of which was covered in one man day * * *.
>
> "On each traverse, the mapping geologist was required to establish 5 hard stations at which the following were observed:

lithology and bedform
bedding attitude
fracture cleavage
mineralized veins
faulted surfaces
a sample of 10 fracture attitudes
one oriented sample taken

> "In addition, intermediate running stations were established at which all of the above were noted, except fracures and oriented samples. In practice, difficult terrain or cover occasionally made it impractical to establish 5 hard stations per traverse: however, 77 hard stations and 111 running stations were uniformly distributed over the area."

The report also notes that photointerpretation and consultation was used to add to the field data.

The irregular area mapped is 75-80 square miles. Thus one hard station and 1.5 running stations were recorded per square mile. This is one observation per 260 acres. As you see the site you might consider the adequacy of this spacing.

The report included a new cross section which is reproduced in Fig. 4. As this new section is longer, A and A' have been located so this section can be directly compared with all others.

Starting in March 1975, R. Waines and I decided to have a quick look at the regional geology of the site. We started by walking the Dames and Moore cross section and studying all outcrops within a few hundered feet of the trace of the section. Many man days were spent and over 100 observations recorded for the 3 mile section. We then checked critical outcrops mentioned by Dames and Moore and did a general reconnaissance of the area. A broad picture has emerged and is shown in our tentative cross section in Fig. 5.

The aim of this field trip is to show you some of the major points of geologic interest and also show some of the areas of controversy. There is

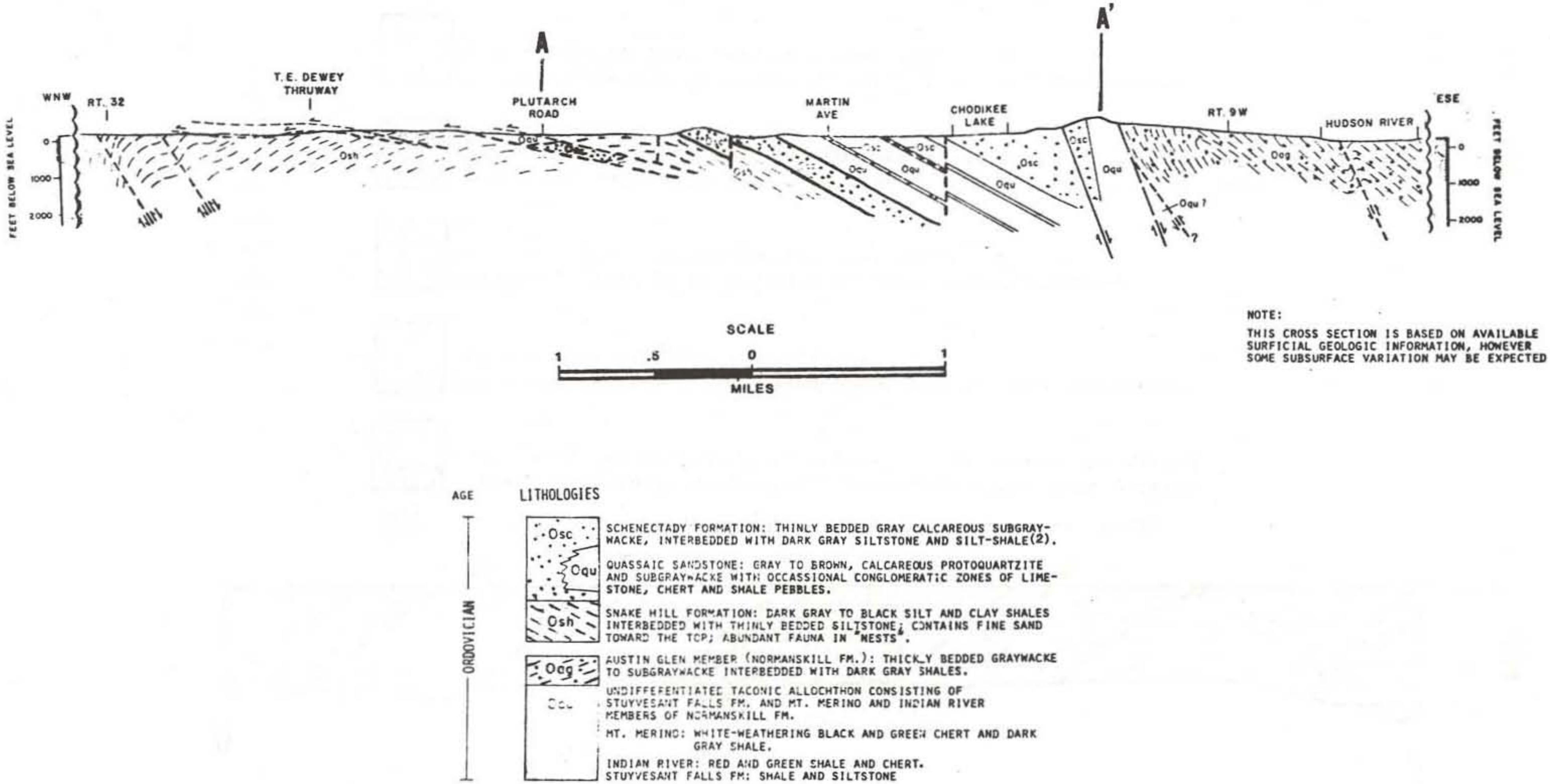
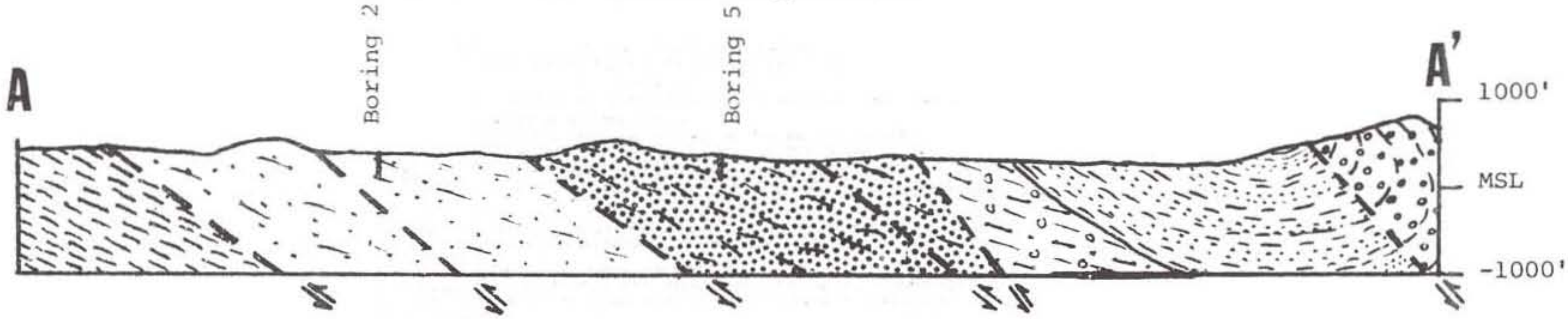


Fig. 4. Cross section from Dames and Moore 1975 geologic map. Section trimmed along wavey lines at ends to fit page. Color on original section not reproduced.

TENTATIVE SUBSURFACE SECTION A-A'

Actual dip of faults uncertain. Numerous minor faults omitted.
Scale 1:24,000. No vertical exaggeration.



KEY — Stratigraphic Contact — Fault

ORDOVICIAN

A — Graywacke laminated, massive weathering, rare chert pebbles; most graywacke beds 1-10 ft. thick. A may correlate with 2.

1 — Shales-graywackes interbedded about 50-50. Graywacke beds often a foot or more in thickness.

2 — Graywacke, laminated, occasional large chert pebbles. Generally beds one to several feet thick.

3 — Graywacke, laminated, occasional small chert pebbles or no chert pebbles. Generally beds one to several feet thick. Fifty foot shale marker? near base of unit.

4 — Shales-graywackes interbedded, more shale than graywackes. Most graywacke beds less than one foot thick.

5 — Shale, occasional siltstone. Siltstone beds generally half foot or less in thickness.

Fig. 5.

ample room for supposition and argument until adequate study is completed.

The site geology is difficult to determine due to a lack of good marker beds, a lack of diagnostic fossils, and lack of continuous outcrop. Recently, many people have started working out the geology, however, a considerable effort will be required to gain a detailed understanding of the site geology. There is still a lot to be done, for example, as yet there is no published detailed stratigraphic column of the site area. Up until now there had been no economic reason to study this area.

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TRIP B-9

VISUAL POLLUTION OF THE PROPOSED NUCLEAR REACTOR SITE IN THE TOWN OF LLOYD, ULSTER COUNTY, NEW YORK

by,
Harvey K. Flad
Vassar College

Introduction

The analysis of the environmental impact of a noxious facility implies the need for assessment of aesthetic and social impacts as well as the physical impact upon the land, air, water, and biota. Aesthetic impacts, such as upon the visible scene, have not been studied in detail for the environmental impact statement of the siting of a nuclear power plant at Lloyd, N.Y. although the U.S. Nuclear Regulatory Commission, Regulatory Guide 4.2, Revision 1 : Preparation of Environmental Reports for Nuclear Power Stations (January 1975) notes in Table 4 "Environmental Factors to be used in comparing alternative Plant Systems," that "People (aesthetics") are to be considered where "The local landscape as viewed from adjacent residential areas and neighboring historical, scenic and recreational sites may be rendered aesthetically objectionable by the plant facility." (U.S.N.R.C, 1975, p. 42-62)

This lack of detailed concern is unfortunate: the changes due to the viewscape are obvious and of a degree of magnitude which demand their attention. Although the assessment of aesthetics is complex and fraught with problems of subjectivity, nevertheless transmission tower and power plant design and siting must be implemented in consonance with the overall human environment; indeed, Federal and State legal rulings reflect an increased awareness and justification for aesthetics as a form of environmental control.(Flad, 1974) Measurement of aesthetic impact of nuclear power plants is possible (Burnham, 1974). This paper and field trips will deal with some of the outstanding aesthetic concerns (cooling tower height and plume, transmission pylons and rights-of-way, and historic and cultural sites) with respect to varying viewsheds of the Lloyd site viewscape.

Aesthetics and Environmental Policy

The National Environmental Policy Act (NEPA) of 1969 mandated that all constructions using Federal funds for any part are required to file an assessment of the environmental impact of the facility. This policy has been followed by most State and some local governmental agencies. Such projects as reservoirs, stream channelization, highways, mining buildings, dams and power plants are required to file an Environmental Impact Statement (EIS) according to section 102(c) of NEPA. Using such guidelines, a typical outline would include descriptions of the following: (i) present conditions, (ii) proposed action; (iii) probable impact; (iv) unavoidable adverse impacts; (v) alternatives; (vi) short term vs long term impacts; and (vii) irretrievable and irreversible impacts. Environment impacts are both physical and social, and may include qualitative as well as quantitative assessment. Guidelines from various agencies, environmental interest groups, and scientific or technical consultants have discussed aesthetic considerations with reference to social, physical, psychological and visual indicators.

Aesthetic impacts are those which change the cultural landscape in ways that are visible, experiential and psychologically meaningful. The cultural landscape and its component elements (skyscape, landscape, and townscape) are in constant change as a result of ongoing social process, so that the impact of any particular induced change is somewhat relative; neverthless, criteria which can create an assessment of qualitative change are possible. (Flad, 1976)

Overall environmental categories which have been discussed as being subject to aesthetic or visual impact have included (i) scenic resources; (ii) urban design; (iii) noise; (iv) air quality; (v) water quality; (vi) fauna and flora; and (vii) land use. Social impacts, which may also be considered to relate to aesthetic interests, include: (i) cultural resources; (ii) historical resources; (iii) leisure and recreation resources; and (iv) health factors (psychological, physiological, safety, and hygenic). Examining a potential change through the construction of a proposed facility at a particular site according to such aesthetic and social concerns, then, would attempt to seriously evaluate specific criteria for each of these categories as well as some of the interactions between them. (Bagley, 1973) A recent handbook for writers and reviewers of EIS (Hopkins, 1973) suggests that general categories of the environment be assessed according to the following viewpoints: (i) land, includes geologic surface material, relief, and topography; (ii) air, includes odor, visual, and sounds ("noise is considered a physical/chemical" impact, whose elements consist of intensity, duration and frequency),(iii) water, includes flow, clarity, the interface between land and water, and floating materials; (iv) biota, includes both wild and domestic animals and type and diversity of vegetation, (v) man-made objects, includes their presence, as structures, and their consonance with the environment; and (vi) composition, includes the composite effect, unique composition, and the resulting mood or atmosphere at the place or in the scene.

The assessment of aesthetic impact implies that criteria similar to that used in art criticism can be used in judging a landscape. Each landscape may be considered according to its expression of balance, form, shape, growth, space, light, color, texture, movement, tension, and expression. Elements of pattern (such as points, line, or area), have distinct reflections in a specific landscape; for example, edges create distinctions between locales, and give definition to places. Patterns, of course, can be too complex and therefore be viewed as chaotic; while some may be too simple and be seen as monotonous. Psychological assessment of design has shown that both order and diversity are important in the creation of a harmonious and appealing landscape.

The element of surprise is necessary in breaking up an otherwise routine pattern, but singular, emphatic points in the landscape may disrupt the overall quality of the scene. Hence, a 500 foot vertical cooling tower may visually intrude upon the other lines, curves and patterns of the composite whole, just as a series of electric power transmission line towers can disrupt an otherwise pastoral scene. The power line pylon or the cooling tower create too much contrast with the visible scene, and may also be interpreted as urban expansion into a rural landscape.

The landscape unit in its entirety, characterized by generalized impressions of a topographic and cultural region, and the setting of the particular proposed structure on its site, which gives details to the viewer, are seen by different observers from different physical positions, at varying distances and directions, under changing visual conditions. Taking into account different cultural values and social perspectives, some attempts have been made to assign relative weights onto various aesthetic criteria in a community assessment process. (Burnham, 1974). In judging viewscape quality, viewsheds were analyzed according to their "intactness", "vividness", and "unity". A viewscape is simply a scene where elements may include both natural landscape features and man-made objects, while the viewshed also includes that which surrounds the area and is impacted by the facility's introduction. In the case of the Lloyd nuclear power plant site, both the magnitude of change and the cooling towers, are viewed as having a detrimental aesthetic impact upon the mid-Hudson valley region.

Cooling Tower Impact

The proposed nuclear power plant facility at Lloyd would have either two or four cooling towers, which will rise 137.3 meters (450 ft.) from a base a bit less than half that in diameter. Built on a site of deep muck soils and peat bogs, the tower would start at 320 feet and rise to 770 feet in altitude. Surrounding the general center of the site are hills and ridges over 600 feet; Illinois Mountain to the south is over 1000 feet at its crest, and Shaupeneake Mountain to the north is 850 feet. However, many breaks in these surrounding peaks, such as saddles and valleys, allow visible access toward the general site from the surrounding area. Especially important are the viewsheds from across the Hudson River on the east bank. Here, at places of special historical and cultural interest such as the Vanderbilt and Franklin Delano Roosevelt mansions in

Hyde Park, N.Y., the aesthetic impact will be notable. Sight line analysis (Burnham, 1974 pp73-79) for these viewsheds of the proposed site, along with population estimates of over a quarter of a million visiters annually to these historic homes plus the Poughkeepsie SMSA population of a quarter million, and the additional dimension of the social significance of the west bank view from these National Historic Landmarks, present an overwhelming case against the visible intrusion of such towers upon the viewscape.

Even more noticeable than the towers themselves will be the visible plume, or smoke, from the operation of the power plants. The planned towers are closed cycle evaporative natural draft cooling towers which will be used to dissipate heat from the electric generating units; each tower is expected to dissipate 8.12×10^9 Btu/hr of heat. Since the air is coming from an evaporative unit, it will also contain a lot of water vapor, thus producing a warm and moist plume visibly emenating from the stacks.

According to the Dames and Moore Cooling Tower Report;

> Due to the bouyancy of the plume, it will usually rise several hundred feet into the air in the immediate vicinity of the tower...
>
> Since an elevated flow of warm moist air is emitted from cooling towers, a visible plume up to a few hundred feet in length is normally observed in the immediate vicinity of the towers. A small percentage of the time, the plume will extend downwind of the towers for a distance of two or three miles. On very infrequent occasions, the plume will extend to distances over five miles downwind. (Dames & Moore, 1975,pp.2-3)

Data from the ASDA/ERDA meteorological station on site, as described in this report, suggest that visible plume lengths of less than four miles in length will be seen 96.3% of the time, particularly in the SSW sector, while visible plumes greater than 20,000 feet (4 miles) would exist only 3.7% of the time; plumes in the winter months are to extend beyond 20,000 feet 9.5% of the time. Such percentages obscure four interesting facts: (1) plumes will exist at some length and duration for 365 days of the year; (2) plumes of a length greater then 4 miles will exist on at least 13½ days of the year, most of which will be during the winter; (3) winter plumes can be expected to produce the greatest hazards as a result of increased ground fogging or icing, especially since the Hudson Valley is an area of high relative humidity (Dames & Moore, 1975 p.47; Konigsburg, 1976, p.32) Calculations by Egemeier (n.d.) project perhaps two days of plumes reaching as far as 16 miles. Since the height of the ASDA/ERDA meteorological tower is only 90 meters, local wind conditions may be obscuring the general westerlies that will tend to bring this high and long plume down over the heavily populated Poughkeepsie urban area, where it will be both a more visible aesthetic insult as well as a potential hazard to air and surface transportation.

To put it another way, using their own data as well as data from other existing power plants (Appendix D), it can be noted that plumes will exist every day, although at different lengths and for varying duration, and be an omnipresent observable change in the Mid-Hudson skyscape.

Transmission Tower Impact

The transmission of electrical energy from the site of the electric utility production plant to the substations for eventual dissemination to the private and public users has had an enormous impact upon the visual landscape of North America. Federal and State regulations now require the utility company to site their rights-of-way so as to do minimal damage to the visual environment (Howlett & Elmiger, 1969), and to encourage the more ecological use of the rights of way. (Goodland, 1973)

Nevertheless, there remains great damage that increased mileage of higher voltage lines (345kv and 765kv) will do irreparable harm to the biota, including man (Young, 1973), while the extension of 345 kv, 500 kv, and 765 kv lines begins to dominate the skyline. According to the most recent reports of the NYS Power Pool, the Mid-Hudson Valley is projected to become an area of increasing density of such lines. The Pleasant Valley substation is particularly noted as a growing node in the electricity transmission network.

Transmission lines carrying electricity from the Lloyd nuclear power plants would create aesthetic impacts upon three areas: (1) the rural area immediately surrounding the site of power generation; (2) the Hudson River as they cross from the west bank to the east bank; and (3) the Valkill historical site of Hyde Park.

In the immediate vicinity of the Lloyd power plants, the towers and lines which carry the electricity would create a very strong visual imprint upon the rural region. Not only is this an obvious visual contrast of texture, pattern, and balance; but, also the imprint of the "meaning"of the power line as a linkeage to urbanization (Gussow and Lowenthal, 1973)

The aerial crossing of the Hudson River strikes severely at the importance of the River as a "place"in the history of artistic expression throughout the eighteenth, nineteenth, and twentieth centuries. How, one might well ask, would Thomas Cole have painted such a scene? Just as the river begins to become a clear, less polluted, and more important amenity, it would be subject to another aesthetic insult. As the right-of-way stretches from the east bank to the Pleasant Valley substation it will be in view of the famous "cottage" owned by Eleanor Roosevelt. At this time a citizens committee has been formed to purchase and preserve Valkill as an integral part of the Roosevelt Hisorical Site.

Conclusion

A concern for the aesthetic impact of a nuclear power generating facility is not a secondarymatter. Not only is it mandated by the Nuclear Power Regulatory Commission in pursuance of the goals of NEPA, but it is an appropriate measure of the goals and purpose of the electric utility or state agency which originates the proposal for a site and employs a consulting firm to do the EIS. Some concern was shown for the biotic impact upon the John Burroughs Sanctuary (National Audubon Society, 1974), but its aesthetic impact on this historic site and on the historic sites along the Hudson River (Roosevelt, Vanderbilt and Ogden

Mills Estates) was less apparent. The accompanying road log to the field trip details some of the viewsheds and aesthetic amenities of the Lloyd site and its impacted Mid-Hudson region.

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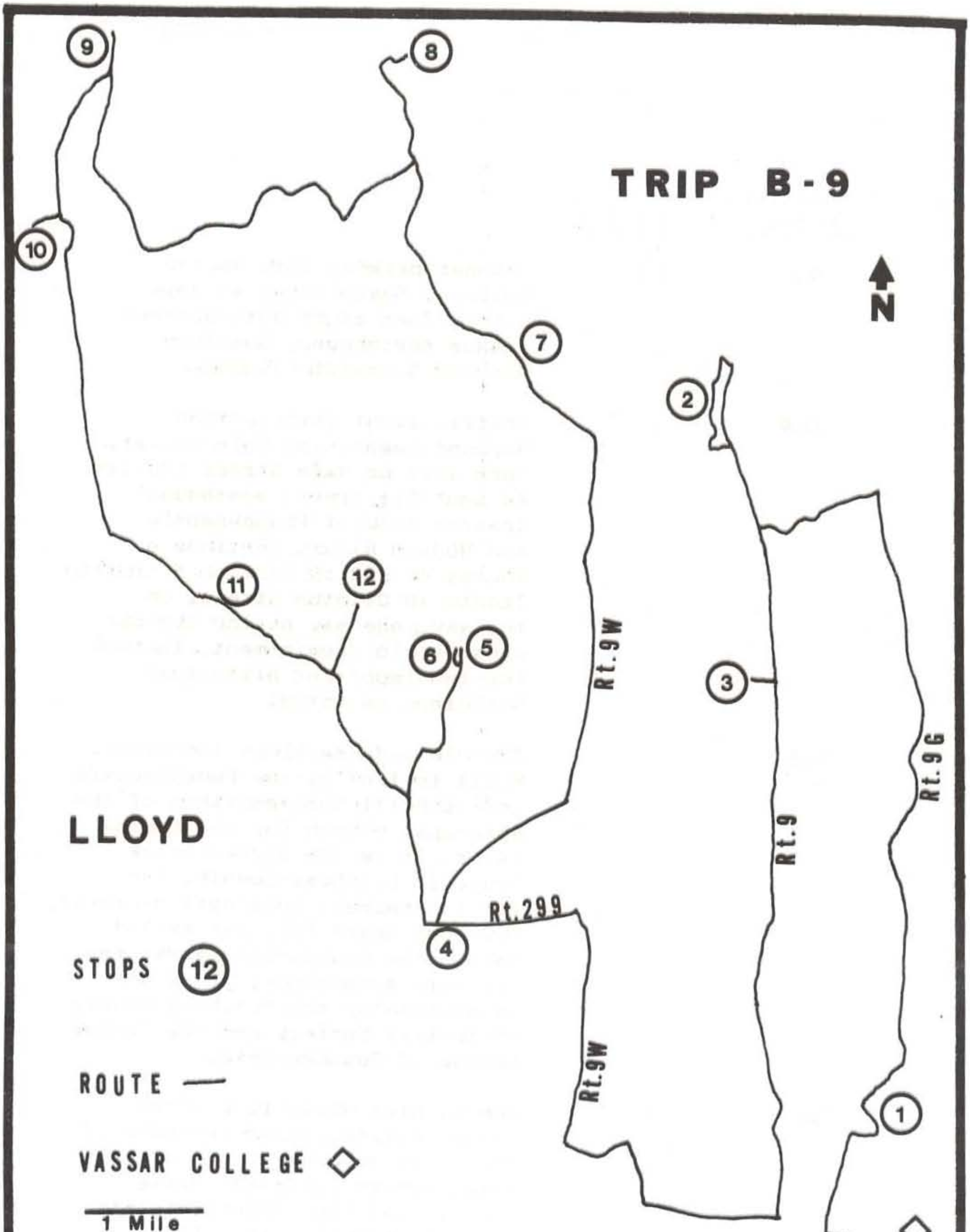
TRIP B-9
N
LLOYD
Rt.9W
Rt.9
Rt.9G
Rt.299
Rt.9W
STOPS 12
ROUTE
VASSAR COLLEGE
1 Mile
1
2
3
4
5
6
7
8
9
10
11
12

TRIP B-9

ROAD LOG
(First Leg)

Cumulative Miles	Miles from last point	
0.0	0.0	Skinner parking lot, Vassar College. Board buses at this point. Turn right onto Raymond Avenue northbound. Continue through 5 traffic lights.
0.9	0.9	Traffic light intersection Raymond Avenue and Main Street. Turn left on Main Street (Routes 44 and 55); travel westbound towards city of Poughkeepsie and Hudson River. Continue on Routes 44 and 55 through 5 traffic lights to Clinton Street. On the way, one may notice typical urban strip development, including two important historical buildings as noted.
1.5	0.6	The Glebe House is on the right. Built in 1767 by the Poughkeepsie and Fishkill congregations of the Episcopal church for their minister, it is the oldest brick house in Dutchess County. The first permanent Episcopal minister, Reverand Beardsley, was exiled during the Revolutionary War for his Tory sympathies. It is now maintained by the Dutchess County Historical Society and the Junior League of Poughkeepsie.
1.8	0.3	The Clinton House is a State historic site, named in honor of the first governor, who made his headquarters in Poughkeepsie when it was the temporary state capital from 1777 to 1783. Originally built c.1765, it was rebuilt and enlarged in 1783 by

Cumulative Miles	Miles from last point	
		Udny Hay, purchasing agent for the state, with assistance from artisans from the Continental Army sent by General Washington.
1.9	0.1	The West Indian grocery on the right is an urban landscape indicator of ethnic change in the Poughkeepsie Central Business District.
2.0	0.1	Traffic light, intersection of Main Street and Clinton Street. Turn right on Clinton. Keep straight on Clinton (bear towards left fork). Continue north on Clinton Street through two traffic lights.
2.7	0.7	Turn right into College Hill Park. Go up hill to park.
2.9	0.2	In College Hill Park, keep to right fork.
3.0	0.1	Keep to left fork. Views west and south excellent.
3.3	0.3	Top of College Hill Park.

STOP 1

The largest park in the city of Poughkeepsie, College Hill Park is located on the highest point in the city (375 feet). Excellent views south and southwest of Poughkeepsie and its environs, as well as the bridge and the Hudson River; farther south the Fishkill or Breakneck Ridge can be seen. West and northwest lie the Catskills; the Lloyd power plant site lies among the hills to the northwest. The park is named for a school which existed at this site in the mid-nineteenth

Cumulative Miles	Miles from last point	
		century. After the school and subsequent plans to use the buildings had failed, William W. Smith, of Smith Brothers cough drops in Poughkeepsie, donated the land to the city in 1892. The Greek Doric designed stone solarium on the crest of the hill was built in 1935-6.
3.5	0.2	Keeping to left around the hill, take right fork and begin to descend the hill.
3.6	0.1	Open reservoir on left. This open area affords the best view northwest across the Hudson River towards the Lloyd site. The open reservoir was formerly the main water supply of the city. Continue down the hill.
3.9	0.3	Exit onto North Clinton Street. Turn right, northbound.
4.0	0.1	Traffic light at intersection of Clinton Street and Parker Avenue (Route 9 G). Turn right onto 9 G.
5.1	1.1	Violet Avenue school on left. Continue north on Route 9 G (Violet Avenue).
5.8	0.7	Entering Town of Hyde Park.
7.6	1.8	Michael's Restaurant on right. This building was used as the tea room for Val-Kill Industries, established in 1927 by Mrs. Eleanor Roosevelt. Eleanor Roosevelt's cottage (Val-Kill) still exists one quarter of a mile east of this point (on a dirt road 150 feet north of the intersection of Route 9 G and Creek Road). At the cottage Mrs. Roosevelt organized a cottage crafts industry which attempted

Cumulative Miles	Miles from last point	
		to reintroduce the crafts of furnture making, pewter smithing and hand-weaving as a local economy. The cottage is presently under consideration for inclusion in the Federal Register as a National Historic Landmark.
		If a power plant is built at Lloyd, the electricity will be shipped by high tension transmission lines along a powerline corridor that traverses this property; the lines and pylons will dominate the Val-Kill skyscape.
8.7	1.1	Homestead Market on the right. This property until recently was the last remaining dairy farm in the Poughkeepsie-Hyde Park urban area.
9.5	0.8	William Stoutenburgh House, on left. One of the only two remaining early Dutch stone houses, built probably in 1750 by William, son of Jacobus Stoutenburgh, the first settler of Hyde Park. It was fired upon by British ships in October 1777. Otto Berge, who was foremost maker of antique reproduction furniture at Mrs. Roosevelt's Val-Kill furniture shop, lived in this house for over forty years until 1975.
9.6	0.1	Traffic light at corner of Route 9G and the East Park-Hyde Park Road. Turn left travel westbound towards Hyde Park. Road follows Fallkill for part of way.
10.9	1.3	Traffic light at intersection of Hyde Park Road and Route 9 in center of Hyde Park village. Turn right on 9 going north.
11.1	0.2	Turn left into Vanderbilt National Historic Site.
11.7	0.6	Parking lot, Vanderbilt Estate.

Cumulative Miles	Miles from last point	
		STOP 2
		The Vanderbilt Estate was built by the grandson (Frederick) of Cornelius (Commodore) Vanderbilt in 1895. The building is a classic by the architectural firm of McKim, Mead & White.
		A short walk from the parking lot to the mansion and surrounding lawns. From the edge of the bluff a magnificent view west across the Hudson River.
		Viewing southwest, one can have a clear sight-line towards the Lloyd site, exactly 3 miles away. All four stacks will be visible.
12.0	0.3	On the exit road, a view west and northwest of the Catskills.
12.1	0.1	Exit onto Route 9. Turn right, southbound. Directly across the exit are the former estate horse-barns, now the Hyde Park Playhouse, famous for summer theater.
12.9	0.8	Traffic light in village center. Continue south on Route 9.
13.6	0.7	Bergh-Stoutenburgh House on left. The second of the two remaining stone houses in Hyde Park, built before the Revolutionary War. Its gambrol roof is unusual. Now recycled and occupied by the Green Frog dress shop.
13.9	0.3	On the left (next to Gasland gas station) is a cleared lot...all that remains of the third of the previously three existing pre-Revolutionary

Cumulative Miles	Miles from last point	
		stone houses.
14.5	0.6	Entrance to Franklin D. Roosevelt National Historic Site.
14.8	0.3	Parking lot for F.D.R. home and museum.

STOP 3

The birthplace of the 32nd President of the United States, and home for himself and family. The 94 acre site contains a museum and library as well as the graves of both Franklin and Eleanor Roosevelt. Originally built c. 1826, the wings were added in 1915 by F.D.R.

The view from this home of 3.1 miles of the Lloyd site is only slightly obscured by a range of hills in the Lloyd region. Stacks numbered 3 and 4 of the proposed Lloyd site plan would definitely be seen in any case.

Buses return to Route 9 exit.

15.1	0.3	Right turn to Route 9, southbound.
15.6	0.5	Barkers shopping center on right. After intensive discussion, stone walls were preserved.
16.9	1.3	Culinary Institute of America on right. Formerly St. Andrew's Novitiate, a Jesuit seminary since 1903. American Trappist Monk Fr. Thomas Merton, author of <u>The Seven Storey Mountain</u> and numerous poems and essays, is buried here. Purchased by the C.I.A. in 1970 as a college for fine chefs.

Cumulative Miles	Miles from last point	
18.0	1.1	Hudson Valley Psychiatric Hospital on the left.
18.6	0.6	Marist College on the right.
18.7	0.1	Keep right on Route 9 by-pass.
19.9	1.2	Turn <u>left</u> onto ramp for bridge to follow Routes 44 and 55 westbound across Hudson River.
		RESET ODOMETERS for Second Leg of Trip B-9.

TRIP B-9

ROAD LOG
(Second Leg)

Cumulative Miles	Miles from last point	
0.0	0.0	RESET ODOMETERS. The Second Leg of the trip starts at the East side of the Mid-Hudson Bridge (City of Poughkeepsie) at the entranceof Route 9 By-Pass to the Bridge. Cross the Bridge, view northward along Hudson River. Road (routes 44&55) climbs steeply through ridge on west bank. Passes by toll booths to Route 9-W. The curved road cut just west of the bridge reveals a section inter-bedded shales and graywackes mapped as Austin Glen formation on the 1970 N.Y. State geologic map and by Dames and Moore, 1975. On the west (left) side of the cut several faults are visible. Note that an individual bed may vary in thickness even over short distance. We will see a lot of out-crops that are frustratingly similar to this one. Good marker beds are non-existent and what poor markers there are are useful only in very small areas. Fossils are rare and usually non-diagnostic. Thus geologic mapping in the Lloyd area is a slow and arduous task. All the rocks in the Lloyd area are Ordovician in age.
1.9	1.9	After crossing bridge, turn right, proceed North on Route 9-W (and routes 44 & 55). Remain on 9-W.

Cumulative Miles	Miles from last point	
3.4	1.5	Turn left onto Route 299. Follow signs towards New York Thruway.
4.6	1.2	Riverside Road on right. Stop alongside Route 299 just before reaching Riverside Road.

STOP 4

This outcrop consists mainly of steeply dipping graywackes. On the 1970 N.Y. State Geologic map this is mapped as Quassaic although this sequence differs from the map's description of the Quassaic. Dames and Moore map this outcrop as Schenectady Formation, just south of here, along strike, they map the same rocks as Quassaic Sandstone. These rocks may be Quassaic or may overlie the Quassaic.

This outcrop is a section of the east limb of an assymetric syncline with its east limb overturned. On the east end of the outcrop the rocks dip east steeply and are overturned. On the west end of the outcrop the rocks dip steeply west and are right-side-up. The fold axis is just west of here, perhaps along the Black Creek (i.e. near the bridge).

If we were to travel to the west we would not see a repeat of the strata exposed here, but would see mostly shale. Thus it is assumed that a fault is buried beneath the fill along Black Creek. The fault could be a thrust dipping east that formed contemporaneously with the folding or it could be a steeply dipping normal fault dipping east as shown by Dames and Moore, 1975. Minor faults in this outcrop might suggest this.

Cumulative Miles	Miles from last point	
		I prefer the former interpretation and Dames and Moore prefer the latter. As the fault is buried neither answer can be proven at this time.
4.8	0.2	Continue west on Route 299 to Chodikee Lake Road (at sign to Highland Training School, follow road to school). Note shales on right side of road, gently dipping towards east, also outcrops on left in pasture of east dipping shales.
5.4	0.6	Hawleys Corners Road and revolutionary age cemetary on left. Proceed straight on Chodikee Lake Road.
5.9	0.5	Right turn. Follow signs to Highland Training School.
6.0	0.1	Cross Black Creek. Note waterfall on right. Outcrops of gently eastward dipping shales with interbedded graywacke.
6.8	0.8	On grounds on Highland Training School. Take right fork.
7.2	0.4	Park in Highland Training School parking lot. Walk to various outcrops in area. Poisonous snakes are found in this area. Use appropriate caution.

STOP 5

We will stop on the east shore of Chodikee Lake and hike to the east across the west limb of a syncline to the axis of syncline. Stop 4 was on the east limb of this same fold.

To the west of where we will park the busses is Chodikee Lake. Based on outcrop along the south shore of the lake (near the waterfall for example)

Cumulative Miles	Miles from last point	
		it appears that the bedrock under the lakes is mainly shale with some interbedded graywacke. The low ridge just west of the lake is mainly massive graywacke. The ridge is bounded on the east by a shear zone that follows a swampy valley.
		As we walk east you will note that the exposed bedrock is mostly graywacke. Shales are found in some of the valleys beneath the soil. The axis of the syncline is just west of a cliff formed by graywackes of the east limb of the fold. If we were to continue to the mountain summit we would climb valley and ridge topography with very little shale. Thus the shales beneath Chodikee Lake do not seem to repeat on the east limb. This again suggests that the fold is faulted. The extreme assymmetry of the fold and the general pattern of thrusting from the east suggest that the fault would be a reverse fault.
		The rocks that crop out at the axis of the fold at this point are the youngest rocks of the Lloyd site. Their exact age is not certain as diagnostic fossils have not been found in this area. I have found fossils in float and am hopeful that I will find some in place.
7.6	0.4	Return to bus for short loop from parking lot to Administration Building on shores of Chodikee Lake.

STOP 6

View stop across lake towards site of nuclear power plants and cooling towers, less than one mile NW of east shore of Chodikee Lake. Notice meteorological tower directly west (at southern end

Cumulative Miles	Miles from last point	
		of site). The tower is 90 meters tall; thus the cooling towers will be almost two times as tall, as well as much more massive. Return along Chodikee Lake Road to Route 299.
8.7	1.1	Immediately past waterfall (on left) take a left turn at intersection; continue towards Route 299.
9.7	1.0	Turn left onto Route 299.
10.0	0.3	Just after crossing the bridge over Black Creek, turn left onto Riverside Road.
10.4	0.4	As examples of the agricultural land use that may be affected by land pressures due to growth, or to climatological change; note the vineyards and orchards to right side of road.
10.7	0.7	Outcrop on left. Outcrop shows slightly metamorphosed slatey shales and siltstones, with foliation steeper than the eastward dip. Continue on Riverside Road.
11.2	0.5	Stop sign. Turn left onto North Road (Old Route 9-W north). This runs parallel to new Route 9-W north.
11.6	0.4	Agricultural land use typical of region; note new plantings of apple orchard on left.
11.8	0.2	Examples of architectural individualism; note house with sculptured gargoyles on left, and building with used car parts sign on the right side of Route 9-W.
12.5	0.7	Stop sign, Turn left onto Route 9-W northbound. Outcrop on immediate left at stop sign is another good example of shales.

Cumulative Miles	Miles from last point	Description
12.7	0.2	Town of Esopus sign on right side of highway. Two nuclear plants are projected to be sited on the town line between Esopus and Lloyd, less than two miles directly west. Such exact siting is to spread the economic impact over two towns.
13.0	0.3	Mother Cabrini Retreat House on right. Many former Hudson River estates have been converted to monestaries, seminaries, or retreat housed by various churches and orders, such as the Holy Cross, Christian Brothers, and Marist Brothers. Excellent views of the Hudson River valley looking eastward from these properties.
14.3	1.3	After crossing a railroad bridge, enter the village of West Park and immediately turn left onto Floyd Ackert Road. (Although marked on the right side, it is unmarked on the left. Turn left just before the Post Office.)
15.1	0.8	Outcrop on right. Extremely steeply dipping. Excellent example of an overturn, note ripple marks overturned.
15.5	0.4	At driveway (entrance) to Cabin of John Burroughs, noted Catskill naturalist and author of many books on natural history in the 19th Century, stop for short walk to lunch stop area.

STOP 7

LUNCH STOP - Bus will stop briefly to offload passengers for a short walk alongside outcrops alongside road and will meet us a Gordon Preserve Park (along Black Creek

Cumulative Miles	Miles from last point	Description
		in the Gordon Memorial Woods). Watch it -- Poison Ivy is abundant in this area.
		The buses will stop near the crest of the ridge where the bedrock is clearly overturned. We will walk down the road to the Black Creek where several ledges in the stream dip south. Just west of the stream bedrock dips east. The Black Creek is following the axis of the syncline along this reach. We are on the axis of the syncline at a point stratigraphically much lower than at the Highland Training School, Stop 5. This is one of the most accessible places to view the syncline. Even so, we cannot trace beds from one side of the fold to the other because of a fault.
		Southeast of here on the road that parallels the creek is Villa Valley. At Villa Valley another fault is exposed in outcrop. It dips east at a slight angle to bedding and is apparently a thrust. It strikes north and crosses Floyd Ackert Road about half a mile east of here.
		Lunch can be eaten along the banks of Black Creek or the dammed up swimming pool on the creek. Tour participants are encouraged to seek additional evidence from neighboring outcrops, or commune with nature in the manner of John Burroughs.
		Reboard buses and continue on Floyd Ackert Road.
16.2	0.7	VanderWater Road on left; continue straight on Floyd Ackert Road.

Cumulative Miles	Miles from last point	Description
16.8	0.6	Stop sign at Swarte Kill Road. Keep straight on Floyd Ackert Road.
17.5	0.7	Stop sign at Old Post Road. Floyd Ackert Road ends here. Turn left onto Old Post Road.
17.7	0.2	Keep straight onto Popletown Road. (Old Post Road continues after a 90 degree turn left.) Popletown Road becomes a gravel road as it steeply climbs 350 feet to the peak of Shaupeneak Mountain. Note very gentle dips on outcrops.
18.7	1.0	Keep right, up fork to Radio Tower.
18.9	0.2	Summit of Shaupeneak Mountain.

STOP 8

From the clearing afforded by the Western Union communications tower facilities, note the view South and Southwest of the Lloyd nuclear site. The nuclear plants and cooling towers will be approximately four miles directly south from this peak, in the center of the presently relatively unspoiled and aesthetically pleasing view.

There is an OUTHOUSE available at this stop.

A short walk to various outcrops on peak; especially noteworthy are the red cherts. Return to bus for trip back down mountain to Old Post Road.

This stop is at the northern end of the syncline we saw at Black Creek and the Highland Training School. We are several thousand feet stratigraphically lower than we were at the training school.

Cumulative Miles	Miles from last point	Description
		The stratigraphically lower part of the fold is far more gently folded and is not overturned. Several north striking shear zones cut the structure and at least one can be seen in outcrop along the cliff to the east.
		Just north of a former community antenna system rocks crop out that fit the description of Quassaic Quartzite as given on the Geologic Map of New York, 1970. They are overlain by thousands of feet of rocks that do not fit the description. The description from the 1970 N.Y. State Geologic Map key is as follows: "Quassaic Quartzite - thick bedded red and green quartzites and greenish-gray sandstones, conglomerates with pebbles of red and black chert, shale and limestone."
		Dames&Moore in their 1975 report have changed the description of Quassaic. Their map key states: "Quassaic Sandstone: Grey to brown calcareous protoquartzite and subgraywacke with occasional conglomeratic zones of limestone, chert and shale pebbles."
		The point of this trip is not to pick bones over stratigraphic nomenclature, but to get a general idea of the environmental geology of the Lloyd Site. The proposed nuclear power plant complex represents the first time there has been significant economic reason to work on the geology of this region.
19.1	0.2	Road from communications tower feeds in - to Popletown Road. Keep left, continue down the mountain on Popletown Road.

Cumulative Miles	Miles from last point	Description
20.0	0.9	Stop sign. Turn right onto Old Post Road. Note historic one room school house building on right which has been recycled into a home.
20.9	0.9	Loughran Lane on left; keep right on Old Post Road.
23.1	2.2	Dashville Road on left. Keep right on Old Post Road.
24.9	1.8	Route 213 enters on left, continue north on route 213.
25.4	0.5	Sturgeon Pool of the Wallkill River.

STOP 9

Sturgeon Pool is part of a hydroelectric installation of Central Hudson Gas and Electric Corporation.

Dames & Moore 1975 have mapped the northern half of the pool as Snake Hill Formation. The eastern shore of the pool is massive graywacke and the hill on the west is largely shale. Thus on the 1970 N.Y. State Geologic Map the eastern shore is mapped as Austin Glen and the west as Normanskill (Snake Hill).

As an example of the visual imprint of electric power transmission lines and pylons in the skyscape, note the 345kv lines across the lake at the spillway. Lines which carry greater loads (765kv) require higher pylons and are therefore even more apparent in the landscape and skyscape. Return south along Route 213.

Cumulative Miles	Miles from last point	Description
25.8	0.4	Old Post Road enters on left. Keep right and continue straight ahead on Main Street (Route 213).
26.0	0.2	The village of Rifton.
26.3	0.3	Outcrops on left of shales with interbedded thin graywackies.
26.6	0.3	1876 stone Church on right.
27.2	0.6	As we drive south along Sturgeon Pool, you will note thic graywacke beds interbedded with shale. Dames & Moore show a thrust fault relationship between the graywackes and shales.
27.3	0.1	Dashville Road on left. Keep right on 213.
27.5	0.2	Central Hudson Gas and Electric Corporation electric power substation on right. Pull into parking lot.

STOP 10

Offload from busses in the C-H parking lot and walk down Route 213 on left side of road. WATCH FOR TRAFFIC. A small fold is in evidence, as well as interesting facies changes of graywacky and shale. Note as you walk along to road cut that at least one 2 ft. thick massive graywacke bed develops shale interbeds tothe west. Generally, there is a facies changes in the Lloyd area with graywackes on the east and shales to the west.

We will walk up the bank and through the woods to get to a unique outcrop. There is no trail so watch your step.

Cumulative Miles	Miles from last point	Description

This outcrop is described by Dames and Moore in the 1975 report on page 31 as follows:

"4.1 Dashville Thrust"

Perhaps the most spectacular and (from a classical viewpoint) unexpected structure in the region is the Dashville thrust. This feature is exposed along Rt. 213 between Rt. 32 and Rifton, and is best preserved in the hillside below the Woodcrest School. There, upward form road level, occur (1) moderately folded Snake Hill sandy shale, (2) 20 ft. of thrusted slices of schenectady Formation and Quassaic sandstone,(3) three feet of tectonically mixed Snake Hill and Quassaic and, (4) about 200 ft. of Snake Hill Formation. The investigators feel that (1) the amount of evident thrusting (2) the observed intermixing of Quassaic and Schenectady, (3) the thinness of the characteristically thick Quassic-Schenectady section, and (4) the overlying zone of mixed Quassic.

Snake Hill all argue for a tectonic sliver of Quassaic and Schenectady caught in a major thrust of Snake Hill over Snake Hill."

The names used by Dames and Moore refer to lithology as follows (abstracted from their map key):

Schenectady formation: thinly bedded subgraywacke interbedded with siltstone and silt-shale.

Quassaic sandstone: Protoquartzite and subgraywacke with occasional conglomerate zones.

Snake Hill Formation: Silt and clay shales interbedded with thinly bedded siltstone.

Cumulative Miles	Miles from last point	Description
		Look at the outcrop and come to your own conclusions. Is what you see due to thrusting or some other cause?
		Continue to "Perrines Bridge", an old covered bridge across the Wallkill circa 1844 (Ulster County Historical Site). Buses will pickup at pulloff across from covered bridge.
28.0	0.5	Return north along Route 213 to Dashville Road.
28.7	0.7	Turn right onto Dashville Road. Immediately turn right onto Cow Hough Road.
28.9	0.2	Dubois Lane on left. Keep straight on Cow Hough Road.
29.5	0.6	Turn left onto Van Nostrand Road. (Cow Hough Road ends at this intersection and becomes North Ohioville Road straight ahead.)
30.2	0.7	Stop sign at Plutarch Road in the hamlet of Plutarch. Continue straight ahead (east) on Van Nostrand Road.
30.8	0.6	South Eltings Corners Road on left. Continue straight ahead on Van Nostrand Road.

STOP 11

Events similar to earthquakes have been reported by several homeowners in this area. The reports are only from those who live along a line parallel with the base of the ridge just east of the road intersection.

The reports seem to be aligned along a N-S linear feature that shows up on landsat photography. The linear also shows up on topographic maps and on the ground as

Cumulative Miles	Miles from last point	Description
		a series of aligned valleys. This linear is one of the more noticeable of several subtle N-S linears that cross the site. This linear is apparently at least 8 miles long. Where one of the linears crosses Shawpeneak Summit sheared graywackes crop out on the southeast side of a valley that marks the linear. Dames and Moore drill hole 2 is 500 ft. east of the linear. The hole was drilled to 249 ft. and several broken zones were reported. It seems most reasonable to conclude that his linear is a fault. People who live along this alignment have reported events that may be earthquakes. The linear passes through one of the proposed nuclear power plants. A summary of the reported events are listed in the appendix.
30.9	0.1	North Eltings Corners Road on right. Continue straight ahead. (Van Nostrand Road becomes Hawleys Corners Road at this junction. Continue straight ahead east on Hawleys Corners Road.)
32.0	1.1	Turn left onto Martin Road.
32.1	0.1	Just after turning onto Martin Road (north) will be seen the ASDA (ERDA) Meteorological Station on the right. Climatological data is gathered at ground level and from the 90 meter tower noticeable from the road.
32.4	0.3	Truck farms on right.

Cumulative Miles	Miles From last point	Description
		STOP 12 Situated on the deep rich muck soils, Sorbello's greenhouses and onion farms are located in the very heart of the proposed nuclear site at Lloyd. The land use plan proposes the first two plants and cooling towers to be located just to the north in the same swampy soils. View south and notice the height of the ASDA-ERDA meteorological tower (90 meters) and recall that the cooling towers planned for this site are almost two times as tall and massive enough at their bases to essentially fill the valley east-west. Return back along Martin Road.
32.8	0.4	Turn left (more or less straight ahead) onto Hawleys Corners Road.
34.1	1.3	Turn right onto Chodikee Lake Road. (Cemetary on left at corner)
34.7	0.6	Turn left onto Route 299. Return to Route 9-W southbound, Routes 44 and 55 eastbound, across the Mid-Hudson Bridge to Poughkeepsie and Vassar College.

APPENDIX

Possible Earthquakes at or Near the Lloyd Site

Date	Time	Description	Reported By	Location of Observation
1950's	1950 and 1952	House shakes few seconds (house now owned by Metro's)	Dorothy Yess and Emma Grand	1.1 mile WSW of meteorological tower
1975		Several events reported but dates and times unknown	Rosemary Esposito Irene Metro	1 mile WNW 1.1 mile WSW
1-11-75	8:00 a.m.±15'	House vibrated and thumping-grinding noise from beneath driveway. Not like sonic boom or blasting	Rosemary Esposito	1 mile WNW of meteorological tower
2-20-76	7:15 a.m.±2'	Thumping and grinding noise like boulders colliding. Lasted six seconds. Floor vibrated; dog went berserk.	Frederick and Rosemary Esposito	1 mile WNW of meteorological tower
		Con Ed stations ... recorded a small emergent event coming from the north at 7:16 a.m.	Mary M. Golisano (Lamont-Doherty Geological Observatory)	Indian Point. 37 miles south of meteorological tower
3-16-76	11:09 p.m.±3'	2-3 seconds of loud noise like a blast; little rattling	Irene Metro	1.1 mile WSW of meteorological tower
4-7-76	6:20 a.m.±2'	Thumping and grinding noise, lasted a few seconds	Rosemary Esposito	1 mile WNW of meteorological tower

Date	Time	Description	Reported By	Location of Observation
4-13-76	2:30-3:30 p.m.	Noise heard while outside.	Elaine Dillahunt	1.2 miles WSW of meteorological tower
5-13-76	10:45 p.m.±2'	Rocks sliding and rubbing	Frederick Esposito	1 mile WNW of meteorological tower
6-16-76	5:00 p.m.±2'	Loud thump first, sound of rocks falling and rolling	Rosemary Esposito	1 mile WNW of meteorological tower
6-22-76	2:45 p.m.±2'	Loud thump first, sound of rocks falling and rolling	Rosemary Esposito	1 mile WNW of meteorological tower
7-5-76	11:10 a.m.±2'	A lot of vibration	Rosemary Esposito	1 mile WNW of meteorological tower
7-25-76	7:40 p.m.±15'	Vibration in ground (in concrete patio)	Thomas Spinard Betty Spinard Frederick Esposito Rosemary Esposito	1 mile W of meteorological tower
8-2-76	12:30 a.m.±15'	House vibrated, medicine chest doors rattled	Fred Vincent Esposito	1 mile WNW of meteorological tower
8-10-76	2:07 a.m.±3'	Awakened by loud noise sounds like a heavy tram crossing a joint in the tracks. Bed vibrated strongly for 3 seconds.	Frederick Esposito Rosemary Esposito	1 mile WNW of meteorological tower

Trip B-10

Engineering and Environmental Geology of the Hudson Valley Power Sites

William D. Lilley*

and

Claudia Assini**

I. Introduction

The four main types of electric generation facilities that will be available in the next 25 years are coal, oil, nuclear and hydro. Each type has significant environmental impacts requiring detailed geologic and environmental studies. The purpose of this field trip is to identify some of the geologic and environmental considerations involved with siting various types of facilities.

II. Siting Controls

(1) The responsibility for licensing of nuclear plants is shared by both the Federal and State governments. At the Federal level the major responsibility for nuclear health and safety is in the Nuclear Regulatory Commission (NRC) under the terms of Section 161 of the Atomic Energy Act of 1954 and the Energy Reorganization Act of 1974. The individual States discharge their responsibilities in a variety of ways.

Figure 1 shows the steps associated with obtaining approval of the NRC for a nuclear plant. The NRC application (PSAR and ER) requires at least one year to prepare and the hearings usually take at least another year. The geologic and seismic analysis required of nuclear sites is outlined in 10 CFR, Part 100, Appendix A - Seismic and Geologic Siting Criteria for Nuclear Plants.

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(2) Federal licensing of hydroelectric facilities and associated transmission lines is the responsibility of the United States Federal Power Commission (FPC) pursuant to the Federal Power Act. The FPC process is outlined in the flow chart in Figure 2. Application requires at least a year of studies. Hearings last at least a year. In the Storm King case the hearings have lasted ten years and will start again this fall.

(3) In addition to traditional licensing requirements, Federal agencies are required to submit environmental impact statements under the National Environmental Policy Act of 1969 (NEPA). On July 23, 1971, the United States Court of Appeals rendered a historic decision in two suits jointly filed against the Atomic Energy Commission (AEC) (predecessor of the Nuclear Regulatory Commission) by the Calvert Cliff's Coordinating Committee, Inc., the National Wildlife Federation and the Sierra Club. The suits sought review of regulations adopted by the AEC for implementation of NEPA in AEC licensing proceedings and the application of those regulations to the Calvert Cliff's Nuclear Power Project, a Maryland facility licensed for construction prior to NEPA enactment. The court's decision upheld the petitioner's contentions in each respect and ruled the following:

> "1. The AEC was wrong in providing that in uncontested licensing proceedings consideration need not be given to non-radiological environmental issues. The Court held that environmental issues must be considered at every important decisionmaking stage; and that at each stage of the process there must be a case-by-case balancing (through a cost-benefit assessment) of environmental and non-environmental factors with alterations made in the facility which would minimize environmental costs. In uncontested cases the licensing board must examine the staff's environmental statement to determine whether the latter's review was adequate and the board must independently consider the final balance among conflicting factors that is struck in the ultimate staff recommendation.
>
> 2. In its implementation of NEPA, AEC must make an independent assessment of water quality and other non-radiological environmental factors. The Commission cannot rely on certification by Federal or State agencies of compliance with water quality standards established under the Federal Water Pollution Control Act or on Federal or State standards in other environmental areas. The Commission

must be prepared to set more stringent requirements of its own in light of the overall balance of project benefits and environmental costs resulting from the NEPA cost-benefit assessment.

3. The AEC was tardy in its implementation of NEPA following the statute's enactment. Even if a delay in implementing the statute was necessary for administrative reasons, the AEC was not relieved of responsibility to consider, and hold public hearings on, the environmental consequences of licensing actions taken between January 1, 1970, and the final adoption of the Commission's NEPA regulations. AEC must thus give prompt NEPA consideration to facilities for which permits and licenses were issued after January 1, 1970, where NEPA matters were not substantively considered in the original licensing determination.

4. With respect to construction permits issued before January 1, 1970 (e.g., the Calvert Cliffs Nuclear Power Plant), AEC must promptly consider, on its own initiative, any significant non-radiological environmental impact and order such facility alterations as may be indicated thereby. This NEPA consideration, including a hearing thereon, may not be deferred until the operating license review."[5]

The NEPA procedures followed by the NRC are lined in Figure 3.

(4) In 1972 New York State enacted a one-stop power plant siting law in which all laws, codes, and permits had formerly been the responsibility of separate State and local agencies. The purpose of the "one-stop" siting law was to both expedite power plant siting decisions and provide for a full exposition of all issues. A certificate of environmental compatibility and public need must be issued by the New York State Board on Electric Generation Siting and the Environment prior to the construction of any steam-electric generating facility 50 MW and greater. The procedure for siting a major steam-electric generating facility in New York State under Article VIII of the Public Service Law is outlined in Figure 4.

III. Future Power Generation

At least one fossil plant, two nuclear plants, and one pumped storage facility are being proposed for the Hudson Valley (Figure 5). One new 700 MW coal unit is being considered for alternative Athens, Quarry or Arthur Kill sites by the Power Authority of the State of New York (PASNY). Consolidated Edison's proposed pumped storage at Cornwall-Storm King is still in hearings. PASNY has filed an Article VIII application for its Cementon nuclear site and New York State Electric and Gas Corporation is studying the Stuyvesant site for two nuclear units.

IV. Major Siting Considerations

(1) Coal

The impacts of coal facilities relate to the combustion of the fuel and the control and disposal of the combustion waste produces. The sulfur content of the fuel is critical in determining the SO_2 impact on the region. Present air quality regulations require low-sulfur fuels or SO_2 stack gas scrubber equipment on all new plants. Most coal contains about ten percent ash, after the coal is burned there are several hundred thousand tons of ash waste per year for disposal. As a result of the amendments to the Clear Air Act of 1970 requiring the reduction of SO_2 from new plants the SO_2 gas scrubbers produces millions of tons of toothpaste-like SO_2 sludge for disposal. Although there are means of stabilizing the SO_2 sludge, the cost will be millions of dollars per year.

(2) Pumped Storage

A pumped storage facility has a reservoir that is pumped full during off-peak hours and then released during peak load periods. Pumped storage requires three units of energy for every two units it returns, but it is still considered the most economical method, now available, for storing energy.

Pumped storage facilities cause no air pollution in the vicinity of the facility or heat to the water bodies utilized. Heaviest impacts are on terrestrial habitats, land use, and the general aquatic ecology of affected water bodies. The fossil or nuclear steam-electric units which provide off-peak power impact the environment in which they are located.

(3) Nuclear

Nuclear plants play a large role in New York Power Pool's future generation plans. Nuclear plants do not approach the major air quality impacts of fossil plants, but have a greater heat discharge than fossil plants. Long-term nuclear waste disposal has not yet been resolved. Even with the recent rise in construction costs and uranium fuel prices, experts say that the historical price advantage of nuclear over coal will remain. Finally, the nuclear safety question has been discussed and debated by experts. For geologists, the seismic safety is the key question.

Stop 1 - Danskammer and Roseton, Marlboro, New York

(1) Danskammer - Central Hudson Gas & Electric Corp. Plant - Oil Fired - 531.9 MW - 66.3 Acres Plant Site

Units 3 and 4 of the Danskammer Point Generating Station are the subject of a notice of intention by the Federal Energy Administration to issue a prohibitive order that would require conversion of those units from residual oil to coal.

Unit 3 was first placed in commercial service in October 1959 and Unit 4 in September 1967. Central Hudson currently has $57,000,000 invested in the two units; $5,000,000 represents the cost of converting these units from coal-firing to oil-firing in 1970 and 1971.

These units were originally designed with coal as their primary energy source. In the late 1960s, however, because of the rapidly rising cost of coal, the deteriorating quality of the coal economically available, coal delivery problems, increasing costs associated with coal unloading and handling and ash disposal, increasing concern about the environmental impact of coal burning, and the very attractive prices for fuel oil being offered by some of the major oil companies, the decision was made to convert these units to oil-firing. At that time the oil companies indicated to the company that oil prices would be stable for a long time and that ample oil supplies would be available. Indeed, after competitive bidding, the company entered into an advantageous contract for fuel oil at a fixed price; that price prevailed from 1968 to the oil embargo in 1973.

Because of the foregoing factors and the severe space limitations at the station, the company decided that the conversion from coal to residual oil would be permanent, with no consideration for reconversion to coal-firing. Consequently, major modifications were made that resulted in these units becoming exclusively oil-fired.[6]

The major problems of air quality impact and waste disposal associated with conversion have not yet been resolved. At present there are air quality violations in the area of the plant, and conversion to coal could only worsen this situation. The Environmental Protection Agency has yet to make a decision on the FEA coal conversion notice.

(2) Roseton - Central Hudson Gas & Electric Corp. Plant - Oil Fired - 1242 MW - 133 Acres in Land Use

Environmental Impacts:

(a) Aquatic and Water Quality - The plant is under EPA orders requiring cooling towers. The company has requested a variance to prepare studies to prove the impact of cooling water intake and discharge location and operation is insignificant.

(b) Air Quality - Violations of the Federal primary ambient SO_2 standards have occurred in the vicinity of the plants. The New York State Department of Environmental Conservation has ordered Central Hudson to burn lower sulfur fuel costing $8 million more per year. Public Service Commission staff believes that the severe downwash problems due to the short stacks, compounded by the high terrain at these facilities, are creating the air quality problems. The stacks were designed in response to a State agency request to limit the aesthetic impact of the facility.

(c) Noise - Numerous complaints have been made about noise generated by the Roseton Station. The noise problem is a result of the short stacks. The company has attempted to increase exit velocity of the stack gas to improve air quality. The company has failed to solve the air problem, and now has a noise problem.

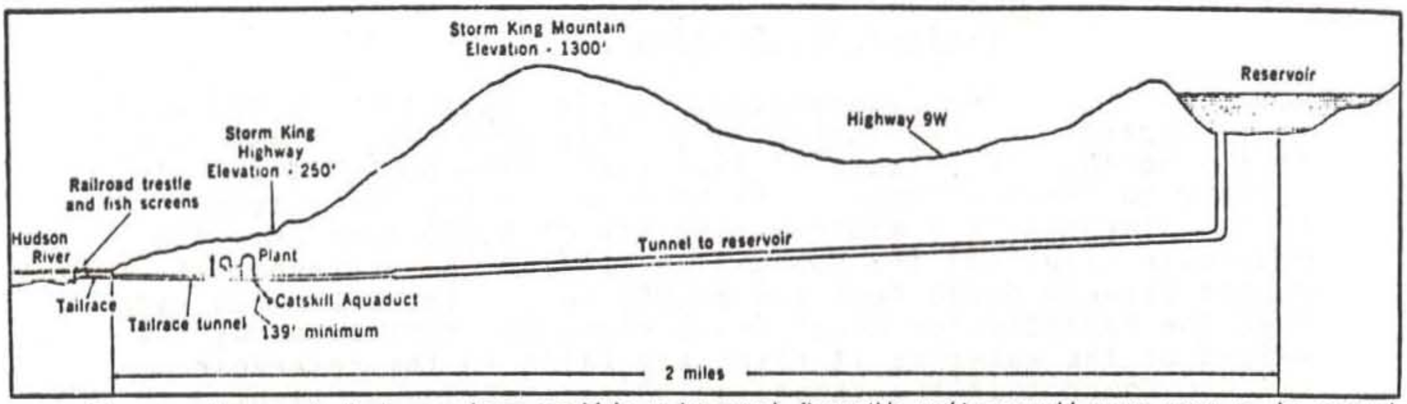
Stop 2 and 3 - Storm King-Cornwall Project, Cornwall, New York

(1) Storm King-Cornwall - Consolidated Edison Company of New York, Inc. - Pumped Storage - 2000 MW - Proposed 1965, Planned Operation 1988

History

The ten-year legal battle between the Scenic Hudson Preservation Conference and Consolidated Edison Company of New York, Inc. over the Storm King project anticipated the environmental litigation that developed in the late 1960s and early 1970s, resulting in NEPA and subsequent Federal and State

CROSS SECTION OF CORNWALL PROJECT



The pumped-storage facility's powerhouse would be underground. Reversible turbines would pump water to the reservoir during hours of low demand. Hydropower would be generated at hours of peak demand.

legislation governing air and water quality. It also highlighted a new area in the legal practice--environmental law.

The turning point in the Storm King case came in late 1965 when the United States Court of Appeals for the Second Circuit ordered the FPC to reopen proceedings after granting Consolidated Edison a license to build. The FPC was instructed to weigh aesthetic and other environmental values in the utility's proposal and to explore alternative means for meeting the project's objectives. In 1966 Consolidated Edison amended its plans to put the powerhouse entirely underground, thus eliminating the cut in the face of Storm King Mountain, and making the trail race less visible.[1]

Since licensing hearings before the FPC have been suspended until after October 1, 1976, it is not possible to accurately predict what constraints may arise from these hearings. Constraints could include possible reduction of biological impact of the plant. This may require fish protection devices or other mitigating measures, and continuation of present environmental studies or the addition of new studies to determine plant impact on aquatic population may be required.[4]

In March 1976, at the request of the New York State Public Service Commission, Consolidated Edison submitted a report of a restudy of the need for, and economic justification of, the Cornwall project. The report says the underground pumped storage plant's capital cost would be about $1 billion and alternatives to the project would require an investment of $1.4 billion to $3.2 billion.

Engineering Geology

The Pagenstecher Creek fault lies to the northwest, separating the Highland's granite from sedimentary rocks to the north. This fault strikes northeast-southwest and dips steeply to the southeast. The surface and the Pagenstecher fault intersect at a minimum distance of 8,000 feet from the reservoir site; and the fault dips beneath the reservoir at depths between 6,000 feet and 29,000 feet. The claim was made that the Pagenstecher Creek fault might be reactivated by the weight of the water as it rises and falls in the reservoir. The FPC found that the thousands of feet of sound, tight, granite rock and gneisses underlying the project are capable of sustaining any loading without movement of the Pagenstecher Creek fault.[9]

The hazards to the Catskill Aqueduct from powerhouse excavation and vibrations caused by blasting were raised by New York City and Scenic Hudson. Construction of the powerhouse would require removal of approximately 254,000 cubic yards of rock. After several geologic studies and witnesses were heard on the subject of rock stress, the FPC concluded that the evidence in the record indicates that the probability of damage to the Catskill Aqueduct is remote.[9]

Stop 4 - Ramapo Fault System, Stony Point, New York

The Ramapo Fault System, shown in Figure 7, extends for more than 50 miles northeast from Peapack, New Jersey to the Hudson River at Stony Point, New York, just west of Indian Point. Along this trend, to at least the New York State border, the Ramapo Fault System is a zone in the Newark Basin. The term Ramapo Fault has been applied to the structure north of the New York State line where the fault system continues northeastward, but is divided into several major splays trending subparallel to each other and passing into the Precambrian Hudson Highlands on both sides of the Hudson River.[7]

Stop 5 - Indian Point, Buchanan, New York

Nuclear Unit 1 - Operational 1962, 260 MW (the second commercial reactor in the United States) - Shutdown in 1974 due to inadequate emergency core cooling system.

Nuclear Unit 2 - Operational 1976, 873 MW, has applied for its full operational license. Owned by Consolidated Edison Company of New York, Inc.

Nuclear Unit 3 - Operational 1978, 965 MW, has applied for its testing operational license. Owned by PASNY.

Seismic Analysis

The hearings on seismic safety of Indian Point have been held before the Atomic Safety and Licensing Board. The New York State Atomic Energy Council, Citizens Committee for the Protection of the Environment, Consolidated Edison, and NRC were parties in the proceeding. The following issues are in controversy:

(1) Does the Cape Ann earthquake of 1975, or any other historic event, require the assumption, in accordance with 10 CFR, Part 100, Appendix A, of a Safe Shutdown Earthquake for the Indian Point site greater than a Modified Mercalli Intensity VII?

(2) Should the ground acceleration value used for the design of Indian Point Unit 1, 2 or 3 be increased?

(3) Is the Ramapo Fault a capable fault within the meaning of Appendix A, 10 CFR, Part 100?

These hearings were completed this summer and decisions on these issues are expected this fall. The decision could effect the seismic analysis used in siting all nuclear plants.

At present, Consolidated Edison is undertaking extensive geologic and seismic studies of the Ramapo Fault System.

Environmental Impact

The major fishkills at Indian Point plants in the winter of 1964-1965 served to high-light the potential impacts of power plants on aquatic life. These fishkills added controversy to the Storm King hearings and the requirement for cooling towers at many power plants to protect aquatic life. At present, Consolidated Edison is under orders from NRC, at the request of EPA, to install cooling towers at Unit 2 by 1979 and at Unit 3 by 1981. Consolidated Edison has requested a variance on the tower requirement. The people of Buchanan, New York and local officials have opposed cooling towers due to the noise, visual impact and impacts on salt drift. Consolidated Edison has requested time to prepare impact studiés.

Stop 6 - Quarry Site, Wappingers Falls, New York

Proposed Coal Plant - 700 MW - Power Authority of the State of New York

The quarry site is an alternative to the Arthur Kill site on Staten Island, New York. The plant would supply for the MTA. This would relieve some of the load carried by Consolidated Edison. This site is subject of an as-yet-to-be-docketed Article VIII application pending before the New York State Public Service Commission.

Engineering Geology

This site is located next to one of the largest limestone aggregate quarries in the United States. On June 7, 1974 an earthquake of magnitude 3.3 occurred at the quarry site. All available evidence indicates that this earthquake sequence, and possibly past earthquakes in the same area, may have been triggered by crustal unloading associated with quarrying operations in the presence of high horizontal stress.[8]

Environmental Geology

The coal plant proposed to be built will have SO_2 stack gas scrubbing equipment. The only type of SO_2 scrubbing equipment the engineers consider reliable enough to meet present air quality standards is a nonregenerable scrubber system, would produce over one million tons of toothpaste-like material requiring stabilization and disposal. The disposal options are quarries, the ocean or the Bahamas. The economic and environmental impacts of each option have yet to be fully explored.

References

(1) Mid-Hudson Pattern for Progress, Inc., Electrical Energy Facility Planning in the Mid-Hudson, prepared for the Mid-Hudson Inter-County Council, 61 Livingston Street, Poughkeepsie, New York, HUD Project No. CPA-NY-02-00-1039, August 1975.

(2) Talbot, Allan R., Power Along the Hudson, "The Storm King Case and the Birth of Environmentalism," E. P. DuHon and Company, Inc., New York, 1972.

(3) New York State Public Service Commission, Draft Report on the Hudson River Valley/Long Island Pilot Area Site Survey, Office of Environmental Planning, Empire State Plaza, Albany, New York, July 1, 1974.

(4) Report of Member Electric Systems of the New York Power Pool and the Empire State Electric Energy Research Corporation, Pursuant to Article VIII, Section 149-b of the Public Service Law, Volume 2, Albany, New York, April 1, 1976.

(5) Joint Committee on Atomic Energy Congress of the United States, Selected Materials on the Calvert Cliff's Decision, Its Origin and Aftermath, United States Government Printing Office, Washington, D.C., February 1972.

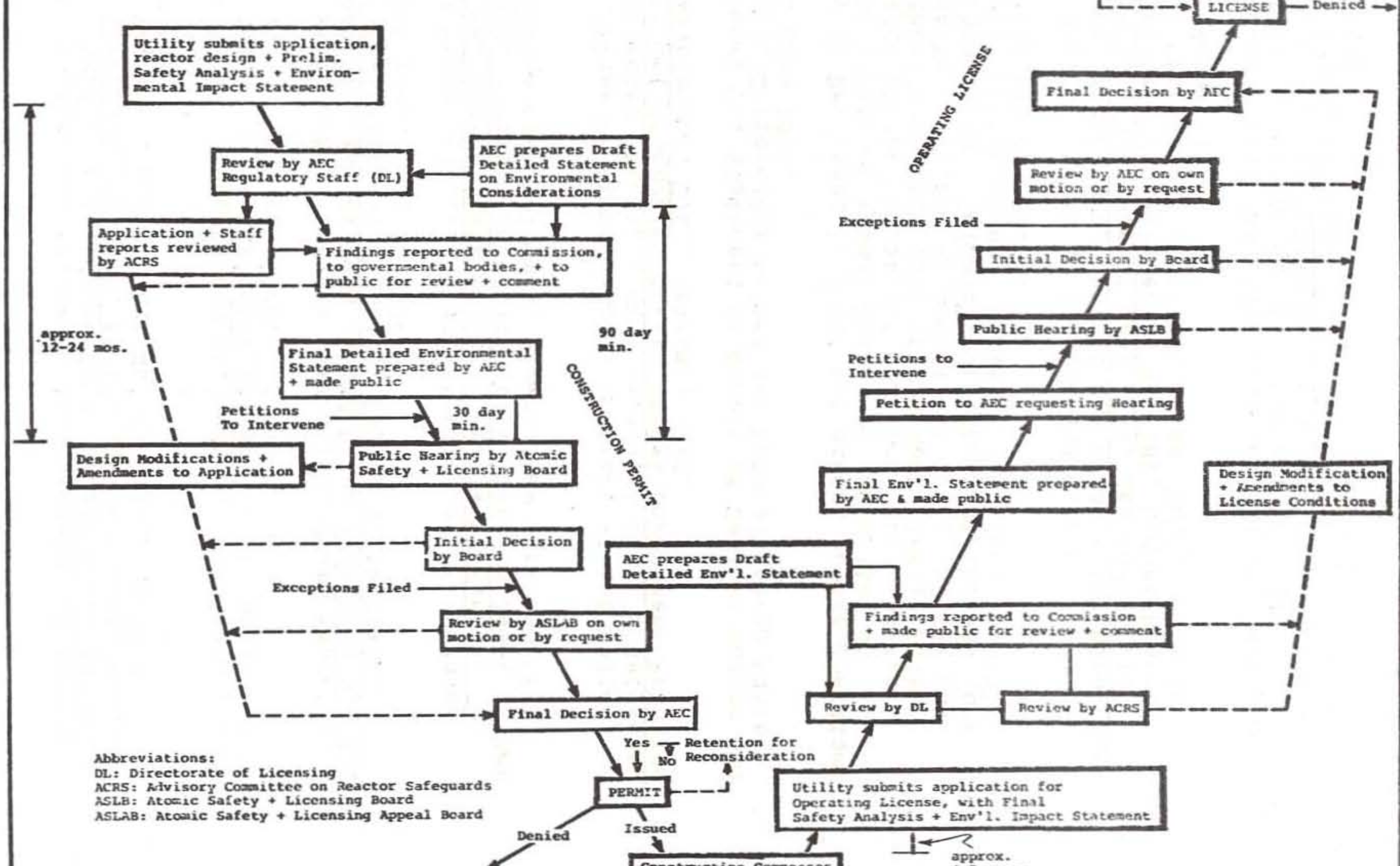
(6) Walker, Henry L., Statement on Behalf of Central Hudson Gas and Electric Corporation before the Federal Energy Administration, June 1975.

(7) Testimony of Dr. James F. Davis and others before the Atomic Safety and Licensing Appeal Board, in the matter of Consolidated Edison Company of New York, Inc. and the Power Authority of the State of New York, Indian Point Station Units 1, 2, and 3, Docket Nos. 50-3, 50-247 and 50-286 (Show-Cause - Seismic), on behalf of the New York State Atomic Energy Council on Issue III, June 18, 1976, pp. D1-2 and Exhibit No. 2.

(8) Pomeroy, Paul W., David W. Simpson and Marc L. Spar, Earthquakes Triggered by Surface Quarrying - The Wappinger Falls, New York Sequence of June 1974, New York State Science Service, Journal Series No. 189, LaMont-Doherty Geological Observatory Contribution No. 0000, Palisades, New York, August 1975.

(9) Federal Power Commission, "Consolidated Edison Company of New York, Inc., Opinion No. 584, Project No. 2338, August 19, 1970," Environmental Reporter Cases, The Bureau of National Affairs, Inc., 1970, Washington, D.C. pages 1ER 1526-1558.

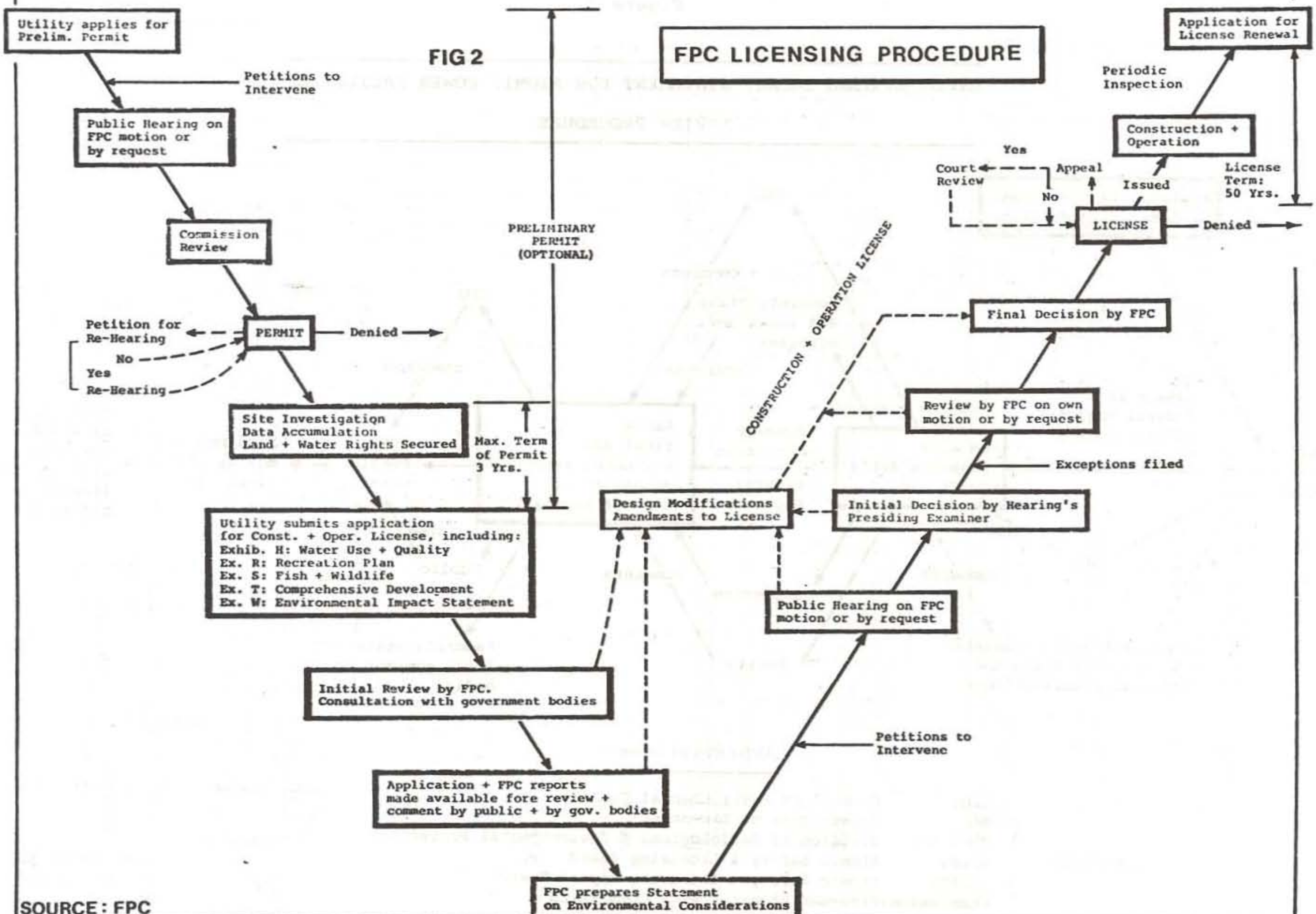
FIGURE 1
NRC (FORMER AEC) LICENSING PROCEDURES



SOURCE: AEC

FIG 2

FPC LICENSING PROCEDURE

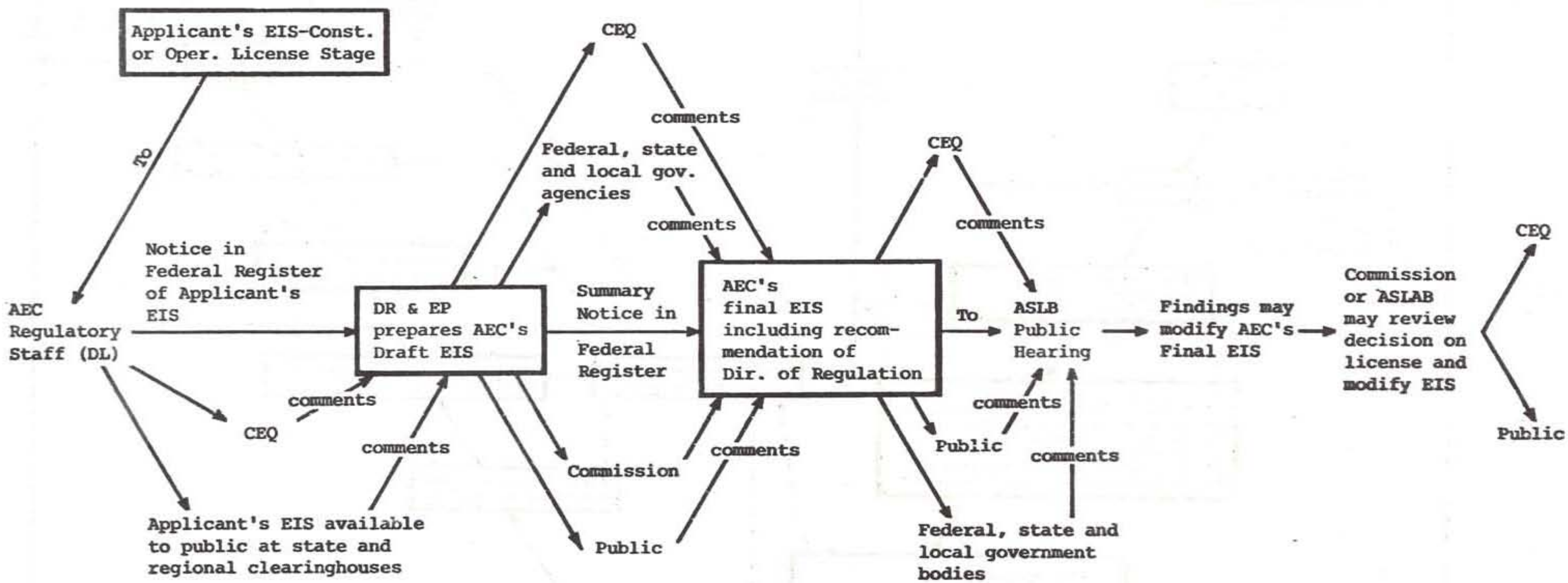


SOURCE: FPC

Figure 3

ENVIRONMENTAL IMPACT STATEMENT FOR ATOMIC POWER FACILITIES

REVIEW PROCEDURE



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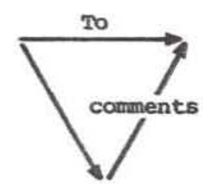
Abbreviations

AEC Staff:

CEQ:	Council on Environmental Quality
DL:	Directorate of Licensing
DR & EP:	Division of Radiological & Environmental Protection
ASLB:	Atomic Safety & Licensing Board
ASLAB:	Atomic Safety & Licensing Appeal Board
Commission:	Five-man Atomic Energy Commission

Symbols



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SOURCE: AEC

FIGURE 4

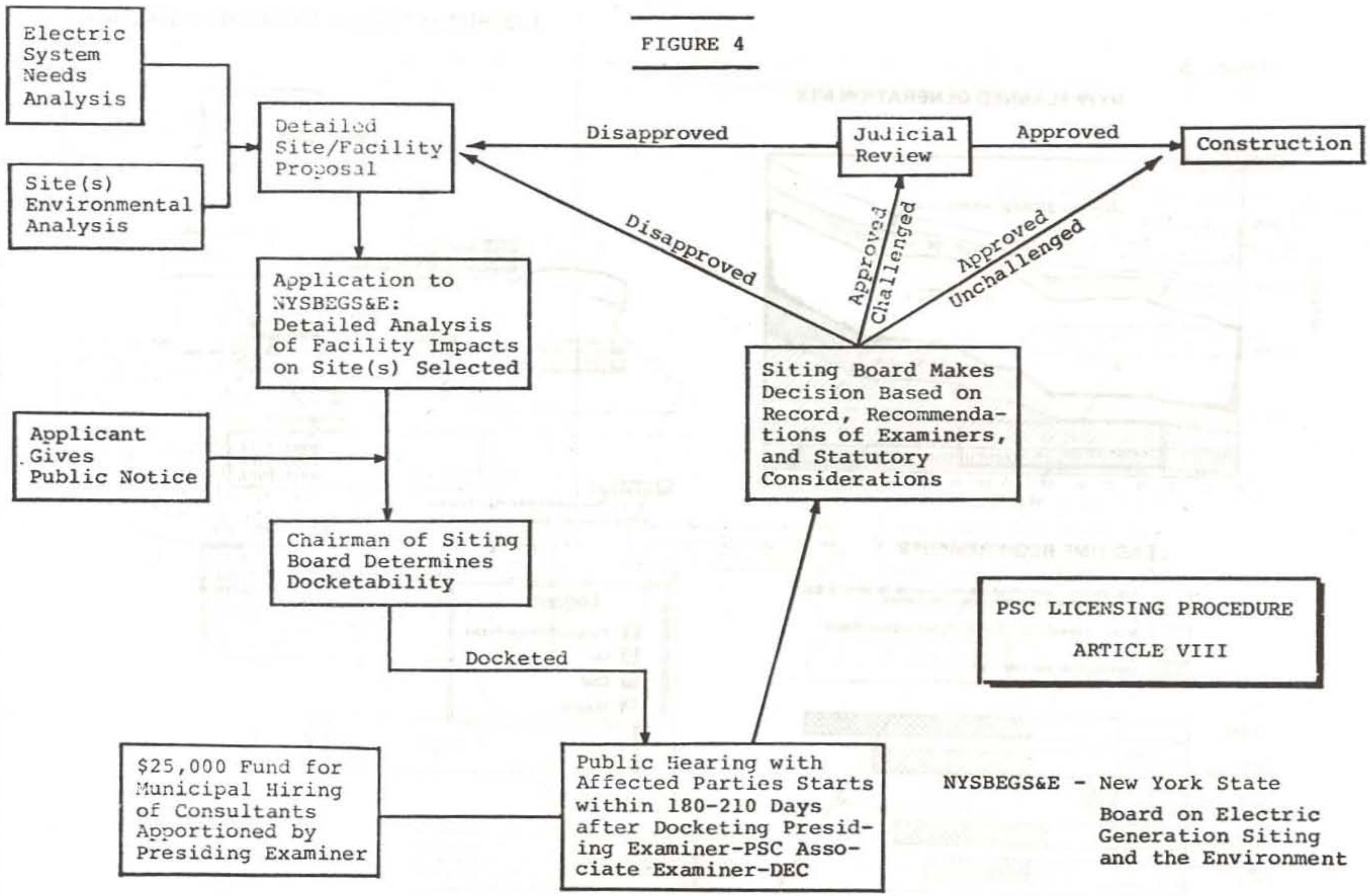
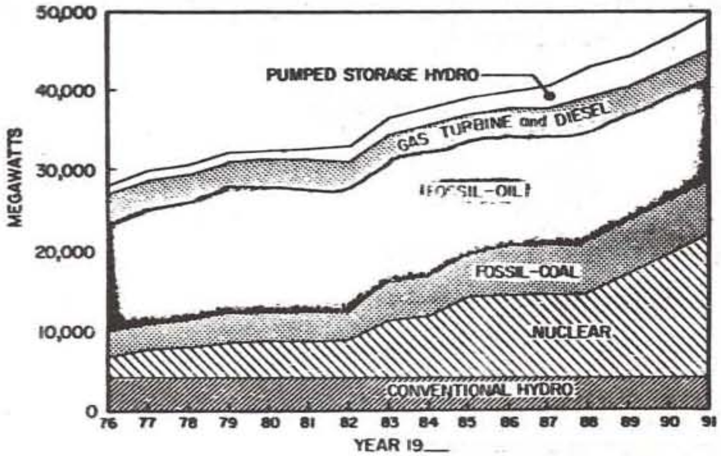
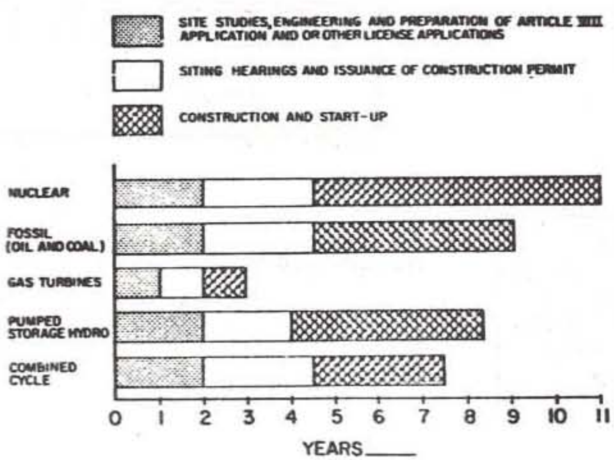

Electric System Needs Analysis
Site(s) Environmental Analysis
Detailed Site/Facility Proposal
Application to NYSBEGS&E: Detailed Analysis of Facility Impacts on Site(s) Selected
Applicant Gives Public Notice
Chairman of Siting Board Determines Docketability
Docketed
$25,000 Fund for Municipal Hiring of Consultants Apportioned by Presiding Examiner
Public Hearing with Affected Parties Starts within 180-210 Days after Docketing Presiding Examiner-PSC Associate Examiner-DEC
Siting Board Makes Decision Based on Record, Recommendations of Examiners, and Statutory Considerations
Disapproved
Approved Challenged
Approved Unchallenged
Judicial Review
Disapproved
Approved
Construction
PSC LICENSING PROCEDURE
ARTICLE VIII
NYSBEGS&E - New York State Board on Electric Generation Siting and the Environment

Figure 5

NYPP PLANNED GENERATION MIX



LEAD TIME REQUIREMENTS



Location of Major Generating Additions

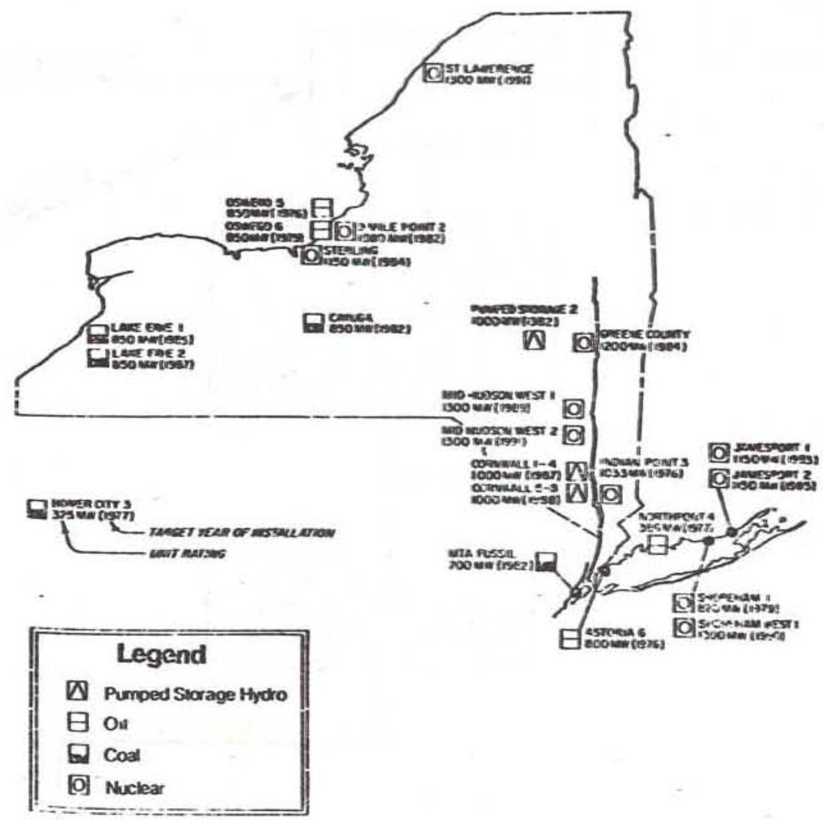


Figure 6

COMPARATIVE ENVIRONMENTAL PROFILE OF BASE-LOAD ALTERNATIVES*

(Note: All quantities shown are approximations and relate to a multi-unit power station of 2300-2400 MW installed capacity.)

	OIL-FIRED	COAL-FIRED	NUCLEAR
A. Fuel Supply			
1. Production	Production and refining of sufficient crude oil to yield 80,000 barrels of fuel oil per day. This roughly corresponds to the fuel-oil output of two large oil refineries.	Mining of 16,000 tons of coal per day.	Mining and milling of 400 tons of uranium ore per day. Processing and fabrication of one ton of uranium metal per day.
2. Transport	One supertanker delivery of crude oil every 2 weeks, or, in the case of the larger tankers now serving U.S. ports, 1 delivery every 2nd day.	Two collier deliveries every 3 days.	12 truckload deliveries per year.
3 Storage	Storage of a 45 day fuel-oil supply would require 4 large oil storage tanks (1 million barrels each) occupying 55 acres.	75-acre coal pile, assuming 45 days reserve.	Nominal
B. Power Plant			
1. Installation	150-acre plant site, assuming cooling towers used (Site size might have to be increased to meet allowable offsite noise levels).	400-acre plant site (assuming cooling towers used).	500-acre plant site, mostly undeveloped.
2. Operation	Discharge of 240 billion BTU of waste heat per day; emission of 25 tons/day of sulfur or SO_2 (assuming low-sulfur fuel oil being burned), 60 tons/day of nitrogen oxides and other gaseous effluents, and 1 ton/day of particulates.	Discharge of 240 billion BTU of waste heat per day; limestone scrubbers are used to remove sulfur from coal to avoid SO_2 emissions. This process creates limestone sludge as a by-product. 120 tons/day of nitrogen oxides and other gaseous effluents and 18 tons/day of particulates (assuming use of highly efficient precipitators and scrubbers).	Discharge of 320 billion BTU of waste heat per day; emission of trace amounts (a few hundred thousandths of a gram per day) of radioactive substance containing 4 curies of comparatively long-lived radioactivity. Shipment of 120 casks of spent fuel per year (120 truckloads or 20 railroad flat car-loads).
C. Waste Disposal	Minor problems.	Disposal of 800 tons/day of fly ash and 430 tons/day of sulfur based on 3% sulfur coal and assuming 90% stack gas desulfurization efficiency.	"Perpetual" storage of solidified high-level radioactive waste concentrates from spent fuel reprocessing, which, in calcined form and with inert diluents, accumulate at a rate of 200 cubic feet per year. Also, land burial of 400 cubic feet per year of miscellaneous low-level radioactive waste materials.

*This exhibit lists the principal ways in which the fueling and operation of base-load power generating facilities interact with the natural environment. Some details, such as the release of modest quantities of chemicals used to prevent fouling of tube surfaces in the steam condenser portion of the turbine-generator system, are not shown. Also, the transmission and distribution of the power produced are not covered.

Fuel Costs

Type of Generation	1985 Fuel Cost–¢/10^6 BTU
Nuclear	60*
Coal	
Eastern high sulfur	240
Western sub-Bituminous	240
Western low sulfur	300
Oil	
.3% Sulfur	360
.75% Sulfur	330
2.8% Sulfur	300
Intermediate Range & Gas Turbine	
#2	410
Kerosene	435

*Components of Nuclear Fuel Cost 1985

Ore $34/lb.
Enrichment $100/SWU
Fabrication $120/KG
Recovery & Disposal $200/KG
Plutonium Credit $14/gm

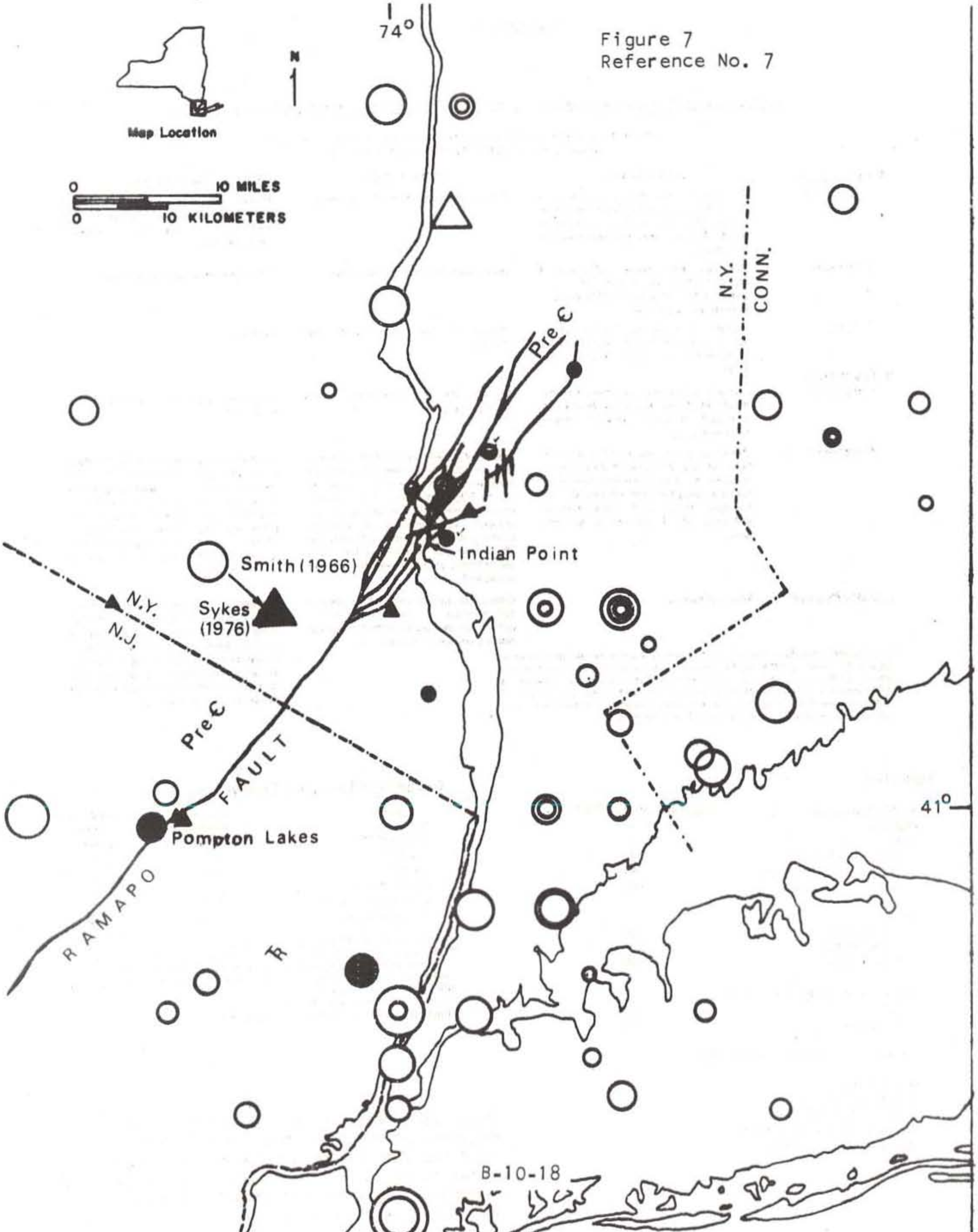
Capital Cost Excluding Transmission

Type of Generation	Nominal Size MW	1985 Cost $/KW
Nuclear***	1100	1060*
Coal***	800	820**
Oil***	800	630****
Gas Turbines	--	305
Intermediate Range	500	530
Pumped Storage Hydro	250	400

*Includes cost of $85/KW for cooling tower
**Includes cost of $55/KW for cooling tower Excludes cost of sulfur removal equipment ($180/KW) since it was assumed higher cost low sulfur western coal would be used as fuel in expansion coal plants for the purposes of this study.
***Cost based on two units at a site.
****Includes cost of $55/KW for cooling tower.

From the: Report of Member Electric Systems of the New York Power Pool and the Empire State Electric Energy Research Corp., Pursuant to Article VIII, Section 149-b of the Public Service Law, Volume 2, April 1, 1976.

Figure 7
Reference No. 7



Explanation of Figure 7

Historical Earthquakes

Modified Mercalli Intensity Scale

I ○

II ○

III ○

IV ○

V ○

VI ○

VII ○

Epicenters are located at the centers of symbols. The numbers correspond to an accompanying event list. A question (?) after the number indicates an uncertainty in the epicenter location.

Instrumentally Located Event*

▲ Lamont-Doherty Geological Observatory Network.

△ Wappingers Falls events.

● Consolidated Edison Network

Probable earthquakes

* Size of △ or ○ is relative to Modified Mercalli intensity.

1 **Shaker Museum, Old Chatham** — [illegible] 1774. Buildings [illegible] textiles and blacksmithing.

2 **Olana, Hudson** — a 19th century [illegible] in the style of a Moorish [illegible] villa built by artist Frederick Edwin Church.

3 **Hunter Mountain Sky Ride, Hunter** — [illegible] ride to summit of Colonel's Chair. Panoramic view of northeast, picnic area, hiking trails, lodge.

4 **Clermont, Clermont** — Livingston manor house built by Robert L. Livingston 1730. Burned by British in 1777 and rebuilt, contains paintings and priceless Duckman Library.

5 **Senate House, Kingston** — America's oldest government building, 1676, where the first New York State Senate met in 1777.

6 **Ogden Mills Estate, Staatsburg** — furnished 65-room French Renaissance mansion.

7 **Vanderbilt Mansion, Hyde Park** — 54-room Italian Renaissance marble mansion built in 1898 by Frederick Vanderbilt.

8 **Franklin Delano Roosevelt Home, Hyde Park** — [illegible] of 32nd President and adjoining library with personal and Presidential papers.

9 **Clinton House, Poughkeepsie** — state owned historic site; stone colonial home used by staff members of Gov. George Clinton when Poughkeepsie was Capitol.

10 **Glebe House, Poughkeepsie** — Built in 1767 as rectory for Episcopal church, it is restored to its appearance as a middle class home in early 19th century.

11 **Huguenot Street, New Paltz** — nation's oldest street with original stone houses, built between 1692 and 1712 by French Huguenots.

12 **Resnick Motor Museum & Doll House, Ellenville** — Collection of classic cars, model racing cars, and 750 dolls.

13 **Ice Caves Mountain, Ellenville** — Registered Natural Landmark: caves with ice and snow, tunnels, rock formations, trails and five state view from Sam's Point.

14 **Washington's Headquarters, Newburgh** — Washington's headquarters, 1782-1783, where he created the Order of the Purple Heart.

15 **New Windsor Cantonment, Vails Gate** — restored final camp of Washington's Army includes reconstructed log "Temple".

16 **Storm King Art Center, Mountainville** — Permanent and loan art shows in a French chateau in a beautiful garden setting. Home of collection of sculpture by David Smith.

17 **Brotherhood Winery, Washingtonville** — free tours and wine tasting at America's oldest winery, site of the country's largest underground wine cellars.

18 **Putnam County Historical Society Museum, Cold Spring** — Permanent exhibits featuring lore of the Hudson River and the West Point Foundry. Special displays change monthly.

19 **Boscobel, Garrison** — restored 19th century mansion in the style of Scottish architect Robert Adam.

20 **U.S. Military Academy, West Point** — where future officers of the United States Army are educated, site of fascinating military museum.

21 **Old Museum Village of Smith's Clove, Monroe** — re-created village of 19th century America, composed of some 35 buildings which include a smithy and apothecary.

22 **Marian Shrine, West Haverstraw** — called "America's Most Beautiful Rosary Way" with its 15 statue groups of the Mysteries.

23 **Hammond Museum, North Salem** — museum of humanities presenting [illegible] changing exhibitions of international art and beautiful Oriental stroll gardens.

24 **John Jay Homestead, Katonah** — state owned historic site, home of first Chief Justice of U.S. Supreme Court, period furnishings.

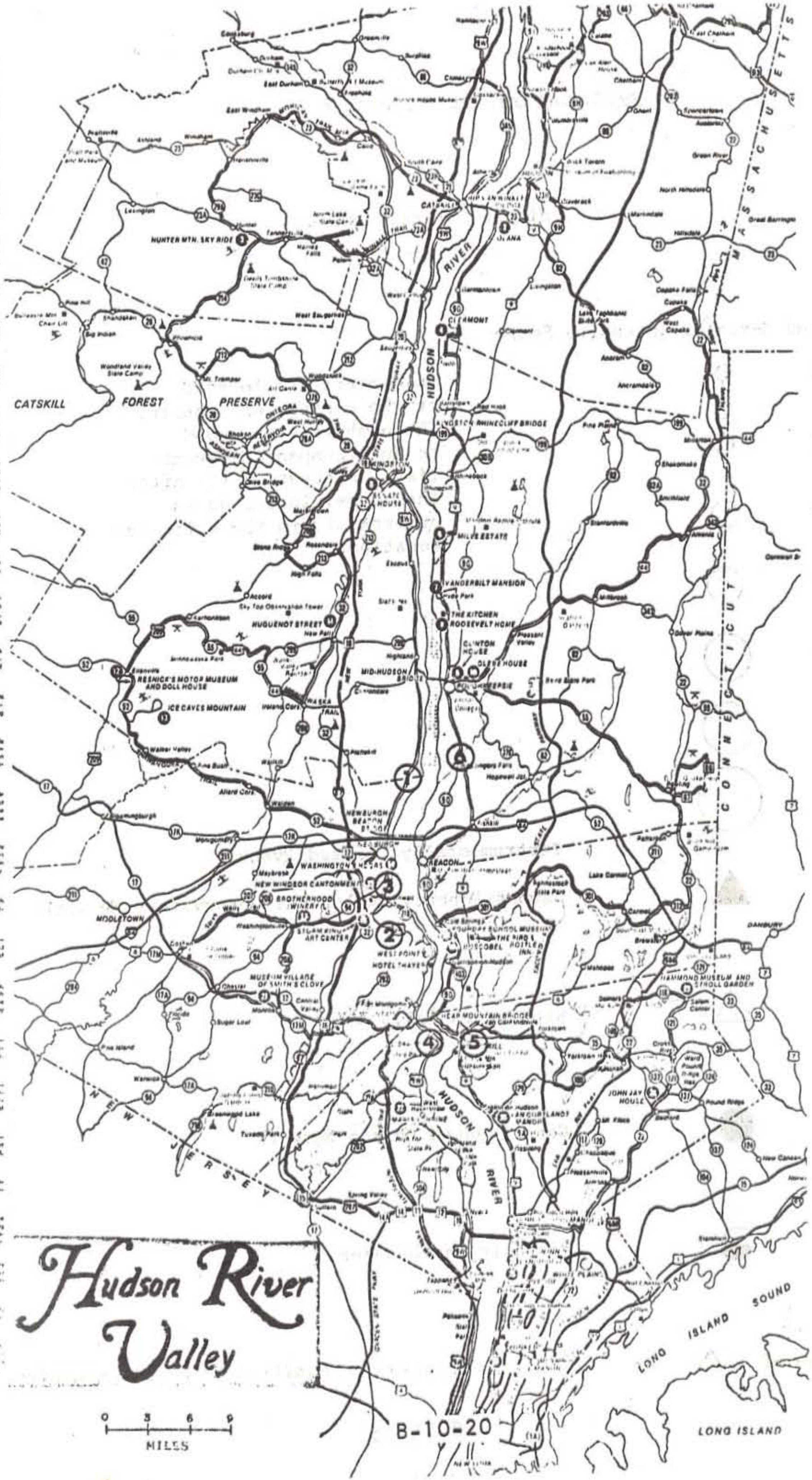
25 **Van Cortlandt Manor, Croton-on-Hudson** — late 18th century Dutch-English manorial estate.

26 **Philipsburg Manor, North Tarrytown** — Early 18th century Dutch trading center [illegible] water-powered gristmill [illegible]

27 **Lyndhurst, Tarrytown** — 19th century [illegible] with art gallery and [illegible]

28 **Sunnyside, Tarrytown** — 19th century [illegible]

29 **Philipse Manor, Yonkers** — [illegible]



TRIP C-6

WALKING TOUR OF HISTORIC FISHKILL, NEW YORK

by

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The village of Fishkill was the scene of a number of important events during the Revolutionary War, and remained a serene rural village until the recent suburban growth of southern Dutchess County. Settled by the Dutch a few years after the granting of the Rombout Patent of 1685, Fishkill soon became an important center of local agricultural activities.

In 1731 the Dutch residents of the nearby area built the First Reformed Church which, during the war, was converted into a military prison for Tories, deserters, and British prisoners-of-war. It was from this prison that the famous patriot spy Enoch Crosby made his "escape"; he had helped capture a group of Loyalists by posing as one of their number. The American writer James Fenimore Cooper's novel The Spy was based on this incident and included scenes using buildings from the Fishkill area.

The strategic value of the Fishkill area was apparent at the outbreak of the Revolutionary War. It lay at the junction of routes eastward to New England, across the river to West Point, and connected the Hudson Valley north towards Lake Champlain with New York City through Wiccopee Pass. General Washington fortified this pass just south of Fishkill and established troop barracks and storehouses for supplies. It remained a major supply depot throughout the war.

The English church (Trinity Church) was established in 1768 and also played a part during the war. When the New York Provincial Convention evacuated New York City in August 1776 before the threatened invasion of the British, it came to Fishkill and convened its first sessions on September 5 in Trinity Church. The church was found to be unsuitable so the sessions were moved to the more useful nearby Dutch Reformed Church. Trinity Church was then used as a military hospital where victims of smallpox and men wounded in the Battle of White Plains, October 28, 1776, were cared for. According to the reports of one eye-witness, after the White Plains engagement "the dead were piled like cordwood in the Fishkill street between the two churches."

Early constitutional affairs also took place in the village. The first copies of the Constitution of the State of New York, drawn up by John Jay, as well as many of General Washington's military orders were printed by Samuel Loudon in the house of Robert Brett, son of Madam Brett. Madam Brett (Catharyna Rombout) was the daughter of the original patentee; her policies of land development and land tenure were unusually advanced for the time. Her grave, formerly in the cemetery, was enclosed under the pulpit of the Dutch Reformed Church when the church was rebuilt and enlarged (1786) due to its active wartime use. Many houses from the Revolutionary period still exist in the immediate area; in them slept such personages as George Washington, Alexander Hamilton, Baron von Steubon, and John Jay.

After the Revolutionary War the village grew slowly, but a disastrous fire in 1873 destroyed many of the historic buildings. The village remained a small rural community until a recent spurt of growth in the post World War II period as a result of the location of IBM facilities in the East Fishkill and Poughkeepsie. The population of the village remains at about 1,000 persons, while the town has grown from 7,000 in 1960 to about 12,000 in 1970; East Fishkill's growth was even more dramatic, adding over 6,000 persons during that decade, or a growth rate of over 132 per cent. Present population growth should continue, although at a slower rate, in the area. Under such pressures of development, Fishkill village attempts to retain its "sense of place".

Participants of the walking tour will have a chance to enjoy the human scale of heritage that remains in historic Fishkill.

ROAD LOG FIELD TRIP C-6

Cumulative Miles	Miles from Last Point	
0.0	0.0	START OF TOUR. Skinner Parking lot, Vassar College. Turn left onto Raymond Avenue.
0.1	0.1	Stop light. Turn left on Route 376.
0.5	0.4	Blinking light. Turn right onto IBM Road. Road leads to IBM Development Laboratory, Homestead, and Kenyon House. On right is Vassar Farm, a 541 acre "island" of open space in the rapidly developing area. A concept master plan by Sasaki Associates, 1975, is presently underway to create a conservation area of over 300 acres.
1.6	1.1	IBM Development laboratories on the former Boardman-Kenyon farm.
2.2	0.6	Stop sign. Turn right onto Spackenkill Road. From this height one can view the Catskill Mountains across the Hudson River to the west. As one proceeds west on Spackenkill, note the development of single family dwellings on the left known as Hagantown. Vassar Farm property on right.
3.1	0.9	Cedar Avenue enters on right; continue straight on Spackenkill Road.
3.4	0.3	Spackenkill High School on left. A confusion of architectural styles of the single family dwellings is evident (for example the peculiar "mansard" roof lines), as well as a lack of concern for appropriate front yard plantings along a busy highway. "For Sale" signs indicate continued growth.
4.2	0.8	Oakwood School on left. This school is the oldest private coeducational boarding school in the United States, begun by Quakers in 1796.
4.4	0.2	Spackenkill Road crosses Route 9 (South Road). Keep to right as you cross the bridge. After crossing Route 9, turn right down ramp to enter Route 9. As

Cumulative Miles	Miles from Last Point	
		you cross the bridge ahead is the South Road plant of IBM, where much of IBM's hardware is constructed. IBM is the largest single private employer in Dutchess County. The summer home of Samuel F. B. Morse, inventor of the telegraph, is just to the north of this plant (see: River Guide).
4.6	0.2	Turn right onto Route 9; travel south.
5.4	0.8	I.B.M. Country Club on left, followed by Hudson Valley Block aggregate.
6.3	0.9	Turn Right onto Sheafe Road, just past Camelot Inn on left; sign on right to Camelot Village, low cost modular homes.
7.0	0.7	Poughkeepsie Asphalt, Inc. (bituminous concrete) on right.
7.4	0.4	Lone Star Industries, New York Trap Rock Corporation Clinton Point Plant; Dutchess Quarry and Supply, on right. Major source of crushed stone (dolomite) (see: River Guide); also mentioned as potential site for nuclear power plant, although small earthquakes have been noted here.
7.8	0.4	Entrance to estate owned and occupied 1804-1812 by George Clinton, then vice-president of the United States. No longer existing; owned by Lone Star Industries.
8.4	0.6	Turn Left onto DeLavergne. Note Mt. Alvernia seminary of the Franciscan Friars on the right.
8.5	0.1	Left turn onto Merrywood.
9.0	0.5	Right turn onto Sherrywood Drive; drive to end.
		<u>STOP 1</u>
		View south. View of Fishkill plains nestled at foot of Highlands; a strategic staging and transport center for the Continental troops.
9.2	0.2	Retrace back to Merrywood. Turn left onto Merrywood.

Cumulative Miles	Miles from Last Point	
9.7	0.5	Turn right onto DeLavergne.
9.8	0.1	Turn left onto Sheafe Road. Continue south on Sheafe Road.
10.3	0.5	Dutchess County Park on right. Recently purchased by the county from Children's Aid Society in New York City, it was known as the Bowdoin-Vanderbilt Camp. During the past year geography students from Vassar College, landscape architecture students from Cornell, and ecology students from S.U.N.Y. Purchase studied the environment and social uses and created plans for the consideration of the county legislature. The work was coordinated by the Dutchess County Cooperative Association and County Planning.
11.0	0.7	Stop sign. Turn right onto Channingville Road. Channingville Road becomes Main Street.
11.6	0.6	Stop sign. Turn left onto Bridge Street. Bridge Street becomes New Hamburg Road (Dutchess County Road #28).
11.9	0.3	Cross bridge over Wappingers Creek. On right is Wappingers Creek estuary; across railroad tracks and Hudson River see Danskammer power plant. The mouth of Wappingers Creek was an important loading dock for produce from the farms of Dutchess County during the period just before the Revolutionary War. Dutchess County supplied much of the wheat for the Continental army.
12.1	0.2	Immediately after crossing the bridge over Wappingers Creek, turn left onto Market Street. Follow Wappingers Creek up towards the falls.
13.4	1.3	Stop cars on Market Street just before entering East Main Street.

STOP 2

Walk from cars to bridge on E. Main Street overlooking Wappingers Falls. The falls was a major source of power for textile dying firms (the bleachery); the village retains many fine nineteenth century facades.

Cumulative Miles	Miles from Last Point	
		Return to cars. Turn right onto E. Main Street. Travel south, up hill through village.
13.5	0.1	Mesier Park. Turn left into parking area at sign for police station. Mesier Homestead, c.1750. Peter Mesier, a New York City merchant, bought the grist mills originally built by the Brewer brothers in 1777. Because Mesier held Tory sympathies, his store (operated from part of this house) became the scene of several "Wappingers Tea Parties" where Whigs and patriots broke into Mesier's house and store and "protested" his price of tea by "consuming large quantities of liquor."
13.7	0.2	Exit back onto E. Main Street; turn left and continue south to Route 9.
14.0	0.3	Red light at Route 9 and E. Main Street. Turn right onto Route 9 and travel south.
14.6	0.6	Red light intersection Route 9 and Myers Corners Road. Continue south on Route 9.
15.3	0.7	Red light intersection Route 9 and New Hamburg Road. Continue south on Route 9.
17.3	2.0	Enter Village of Fishkill. Note view south from rise of village center.
18.4	1.1	Red light, intersection Route 52 and Route 9 in center of Village of Fishkill. Drive through the green light on Route 9 and immediately turn right into parking lot behind King Kone.

<u>STOP 3</u>

Assemble for "Walking Tour of Historic Fishkill" (approximately 1½ hours).

Of the many interesting buildings, two are of greatest interest: the First (Dutch) Reformed Church and Trinity Church.

The Dutch Reformed Church was originally built in 1731 although it was substantially rebuilt in 1786 after its active use during the Revolutionary War. During

Cumulative Miles	Miles from Last Point	
		the Revolutionary War it served as the seat of the Provincial Congress from September 1776 to February 1777, after it had fled from New York City and White Plains, making Fishkill the capital of New York for that period. Later in the war the church was used as a military prison and was the scene of the "escape" of Enoch Crosby, patriot spy, which became the basis for John Fenimore Cooper's novel <u>The Spy</u>.
		Trinity Church, built in 1768, is the county's oldest church building still in use. During the Revolutionary War it was first used for a meeting of the Provincial Congress; later it became a military hospital.
		At end of walking tour, reboard cars and proceed to the last stop. From the parking lot, return to Route 9; turn right and drive south on Route 9.
18.6	0.2	Cross railroad tracks. Continue south on Route 9.
18.9	0.3	Traffic light at entrance to IBM plant. Continue south on Route 9.
19.3	0.4	Holiday Inn on left. Continue south on Route 9. Drive under Interstate 84.
19.5	0.2	Turn left into Van Wyck Homestead, immediately after the entrance ramp to I-84 eastbound.
		<u>STOP 4</u>
		Van Wyck-Wharton House, at Interstate 84 and Route 9, was built in 1733, with a major addition twenty years later. During the Revolutionary war the house was used by the Continental army and quartermaster department officers stationed at the Fishkill camps, and was also the scene of several courts martial. Built by the

Van Wycks, it has also had the name Wharton attached to it as it was the inspiration for the Wharton House in James Fenimore Cooper's novel <u>The Spy</u>.

End of tour of historic Fishkill.

Trip C-7

Stratigraphy and Structural Geology in the Harlem Valley, S.E. Dutchess County, New York*

by

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Colgate University

and

Donald W. Fisher
New York Geological Survey

Introduction

The purpose of this field trip is to provide familiarity with the stratigraphy and structure of the Amenia-Pawling portion of the Harlem Valley in eastern New York State. Emphasis is placed upon stratigraphic relations of the Wappinger Group (Dana, 1879) which represent the Cambrian-Ordovician carbonate shelf sequence in this portion of the Appalachians. Additional stops will be made to examine the Poughquag Quartzite, the Walloomsac Schist, the Everett Schist, and Precambrian units of the Hudson Highlands, all of which are integrally related to the regional geology.

It should be understood that the structural framework and geologic history of this area have not been clearly deciphered. As in other parts of the Taconide Zone (Zen, 1972), complex polyphase deformation, regional metamorphism, and limited exposure have combined to leave scanty evidence of a protracted geologic history. A great deal more detailed work is required before the Harlem Valley area is well understood. It is our hope that this trip may arouse sufficient interest in the regional geology so that others will decide to undertake further field studies in the area.

Acknowledgments

We thank the following individuals for their roles in enhancing our understanding and interest in the local geology: John Rodgers, Yngvar Isachsen, and Rosemary Vidale. One of us (JMM) was supported by a NSF Science Faculty Fellowship during the summer of 1971.

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* In large part reprinted from NEIGC Guidebook, 67th Annual Meeting, 1975, with permission of editors.

Previous Work

Early work concerning the carbonate stratigraphy was conducted by Dana (1879), Dwight (1887), Mather (1843), Merrill (1890), Walcott (1891), and Dale (1923). Dana (1879) named the Cambrian-Ordovician carbonate units the Wappinger Group. Although the term Stockbridge Formation (Emmons, 1842) has precedence, Dana's terminology has generally been applied within New York State. We shall adhere to this tradition.

Dale (1923) mapped the carbonate rocks of western Connecticut and eastern New York and showed that units of the Harlem Valley could be carried through to the Stockbridge Valley of western Massachusetts. He divided the carbonates into lower dolomitic and upper calcitic sequences.

The most important contribution to the stratigraphy of the carbonate rocks was carried out by Knopf (1927, 1946, 1962) in the terrain around Stissing Mt., New York. Her subdivision of the Wappinger Group is the one adopted in this study and is presented in correlation chart form in table 1.

Balk (1936) carried out an extensive study of the structural geology of Dutchess County. He considered subdividing the carbonates but ultimately decided not to do so on the ground that intense deformation and metamorphism made the attempt impractical.

Carroll (1953), working in the Dover Plains 7 1/2' quadrangle recognized an upper (western) calcdolomite and dolomite section and a lower (eastern) dolomite section.

Waldbaum (1960) mapped the valley carbonates between Dover Plains and Wingdale, N.Y., and his subdivisions correspond approximately to Knopf's (1927, 1946, 1962). For the most part, his contacts approximate our own (fig. 2).

The pelitic rocks of the area were investigated by Balk (1936) who classified them as Hudson River pelites of Cambrian-Ordovician age. He was unable to subdivide these units, and, to a great extent, this stratigraphic uncertainty remains today. As a result, tentative correlations are made to less metamorphosed, or better understood units, outside of the area--i.e. Walloomsac Slate (Prindle and Knopf, 1932); Everett Schist (Hobbs, 1893); Manhattan A, B, C (Hall, 1968).

The structural geology of the area was considered in detail by Balk (1936). He concluded, largely on the basis of minor structures, that none of the rocks in the area were allochthonous, but that numerous reverse faults brought older rocks up against younger ones. Both Carroll (1953) and Waldbaum (1960) reached similar conclusions, but held open the possibility of far-traveled thrust slices. Carroll (1953) considered the presence of retrograde metamorphism in some of the metapelites to be suggestive of an allochthonous history.

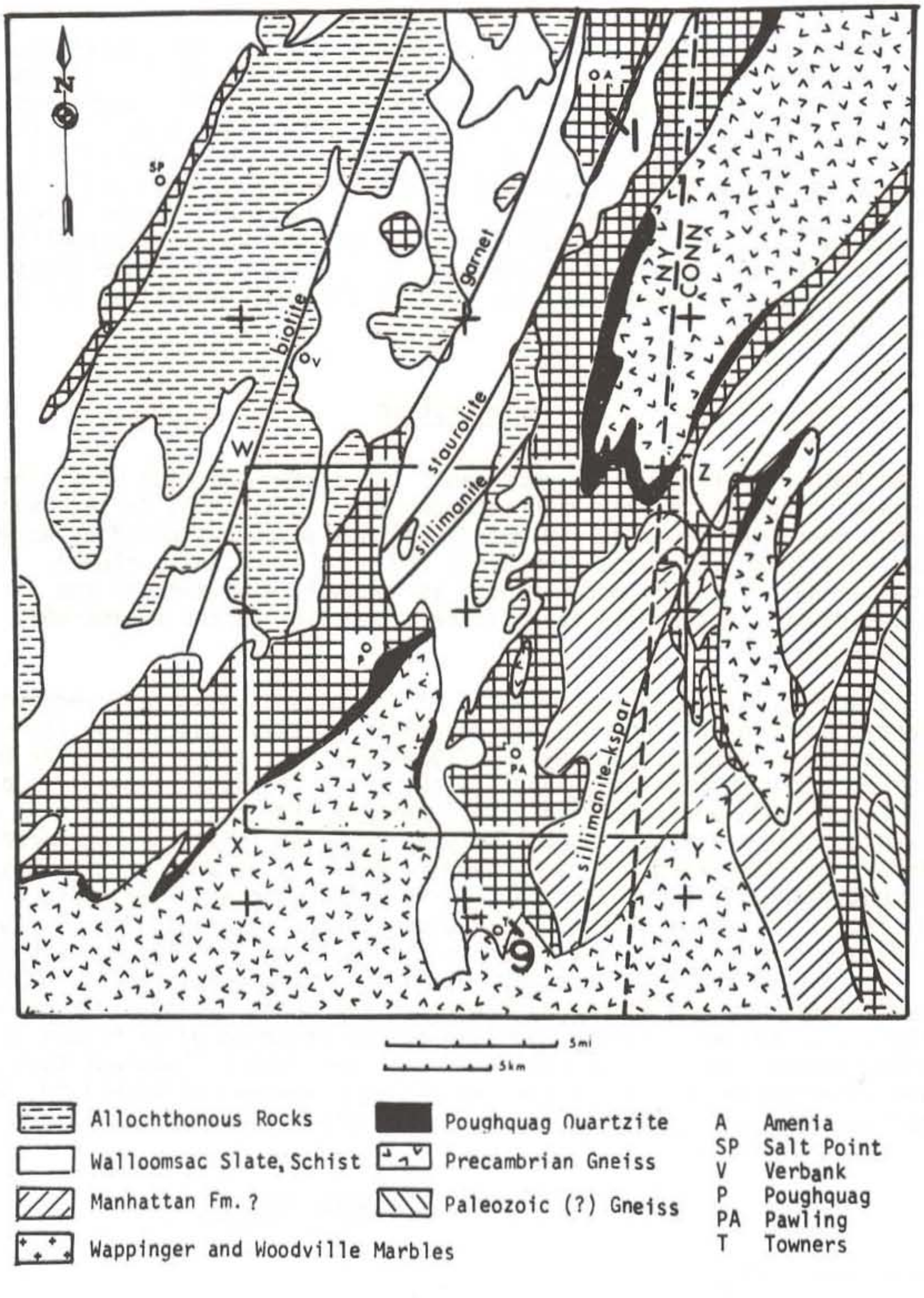


Fig. 1. Generalized geology and isograds of southeastern New York. Stops 1 and 9 indicated. (After Vidale, 1974) Rectangular area in heavy lines refers to Fig. 3 of Bence and McLelland, trip B-7.

In preparing the 1961 and 1973 editions of the New York State Geological Map, Fisher demonstrated the existence of Taconic "soft-rock" allochthons (gravity slides) to the west in the general vicinity of the Poughkeepsie, N.Y. "Hard rock" slices of Everett Schist were recognized in the Dover Plains and Millbrook 15' quadrangles (Fisher et al., 1973). It thus appears that allochthonous rocks are widely represented in the surrounding area and extend into the region considered in this report (fig. 2). Parautochthonous carbonate rocks and gneisses are also recognized by Fisher and Warthin (unpublished) in western Dutchess County. D.W. Fisher and A.S. Warthin, Jr. have prepared, for this volume, a text and geologic maps of the western half of Dutchess County, New York.

Metamorphism

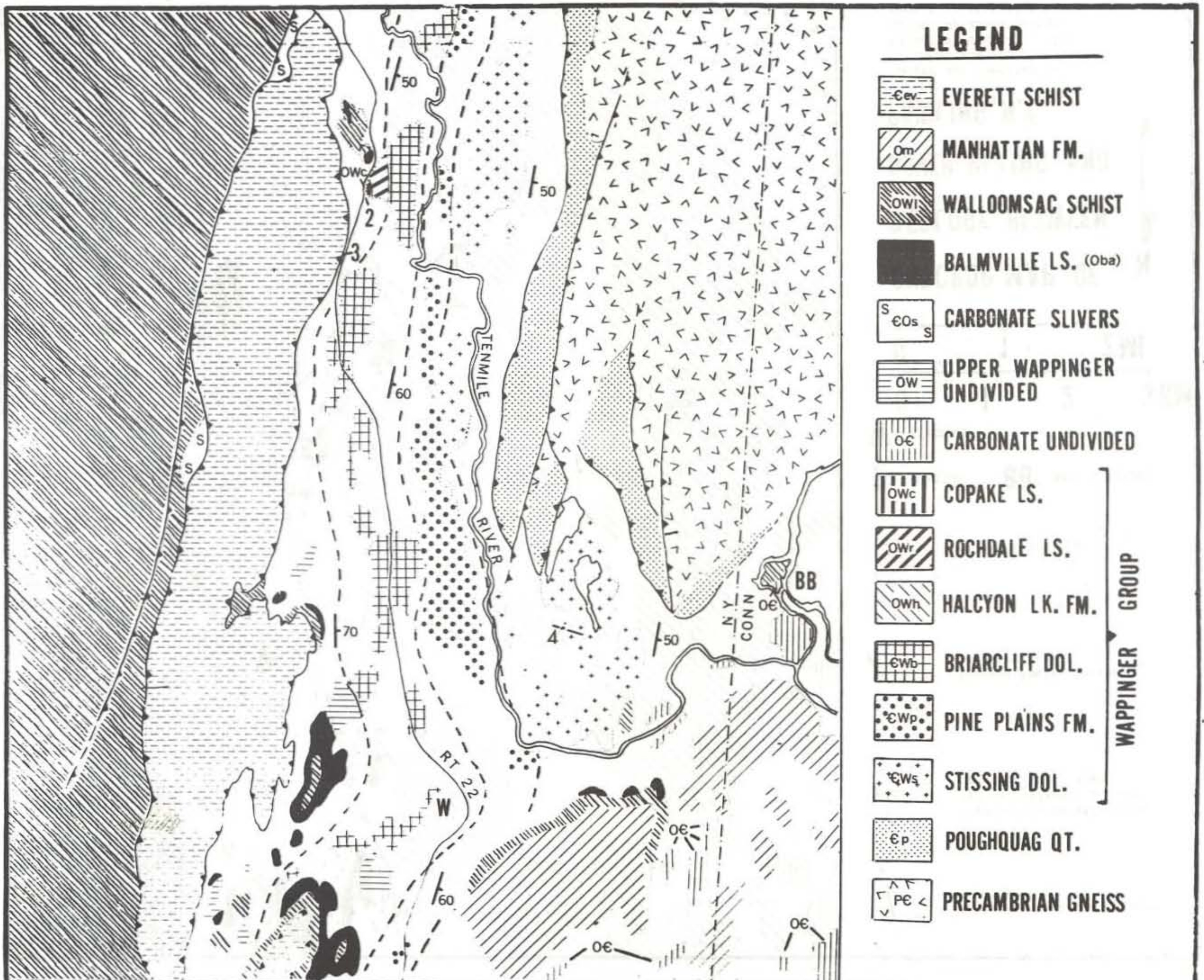
The Amenia-Pawling Valley represents the eastern section of a classic sequence of progressive Barrovian metamorphism (Balk, 1936; Barth, 1936). In recent years the isograds and metamorphism have been studied by Rosemary Vidale (1974) and A.E. Bence (see Bence and McLelland, this volume). The progressive nature of the metamorphism is not well displayed in the Harlem Valley, because its trend is approximately parallel to the metamorphic isograds (fig. 1).

Although the petrological aspects of the metamorphism have received considerable attention, uncertainty continues to exist concerning its age. To the north, in areas mapped by Zen (1969) and Ratcliffe (1969), the higher grade isograds have been assigned a Devonian age (Acadian Orogeny). To the south, Long (1962) and Ratcliffe (1967) demonstrated that the 435 m.y. old Cortland Complex transects the metamorphic rocks and that the metamorphic events may be associated with a Taconian (~450 mya) metamorphism. This is consistent with ~400 mya Rb/Sr ages in the Walloomsac near Verplank, N.Y. (Long, 1962). A set of younger Rb/Sr ages clustering around 350 my suggests an Acadian overprinting of the Taconian metamorphism. According to Long (1962), this overprinting increases eastward in its intensity. In considering similar problems in the Manhattan Prong area; Hall (1968) left open the possibility of either a Late Ordovician (Taconian Orogeny) or Middle Devonian (Acadian Orogeny) age for the peak metamorphism. Within Dutchess County similar uncertainty exists. Argon heating ages (Bence and McLelland, this volume) suggest that the metamorphism may be wholly Taconian in age.

Rock Units and Stratigraphic Detail

(I) Precambrian Basement

Rocks of the Proterozoic (Helikian) basement are exposed in three areas (1) Corbin Hill, (2) Housatonic Highlands, and (3) Hudson Highlands. Quartzofeldspathic gneisses, biotite-quartz-feldspar gneisses, and amphibolites dominate these units, although other lithologies are present.


LEGEND
€ev EVERETT SCHIST
Om MANHATTAN FM.
OWl WALLOOMSAC SCHIST
BALMVILLE LS. (Oba)
€Os CARBONATE SLIVERS
OW UPPER WAPPINGER UNDIVIDED
O€ CARBONATE UNDIVIDED
OWc COPAKE LS.
OWr ROCHDALE LS.
OWh HALCYON LK. FM.
€Wb BRIARCLIFF DOL.
€Wp PINE PLAINS FM.
€Ws STISSING DOL.
WAPPINGER GROUP
€p POUGHQUAG QT.
P€ PRECAMBRIAN GNEISS
TENMILE RIVER
RT 22
N.Y.
CONN.
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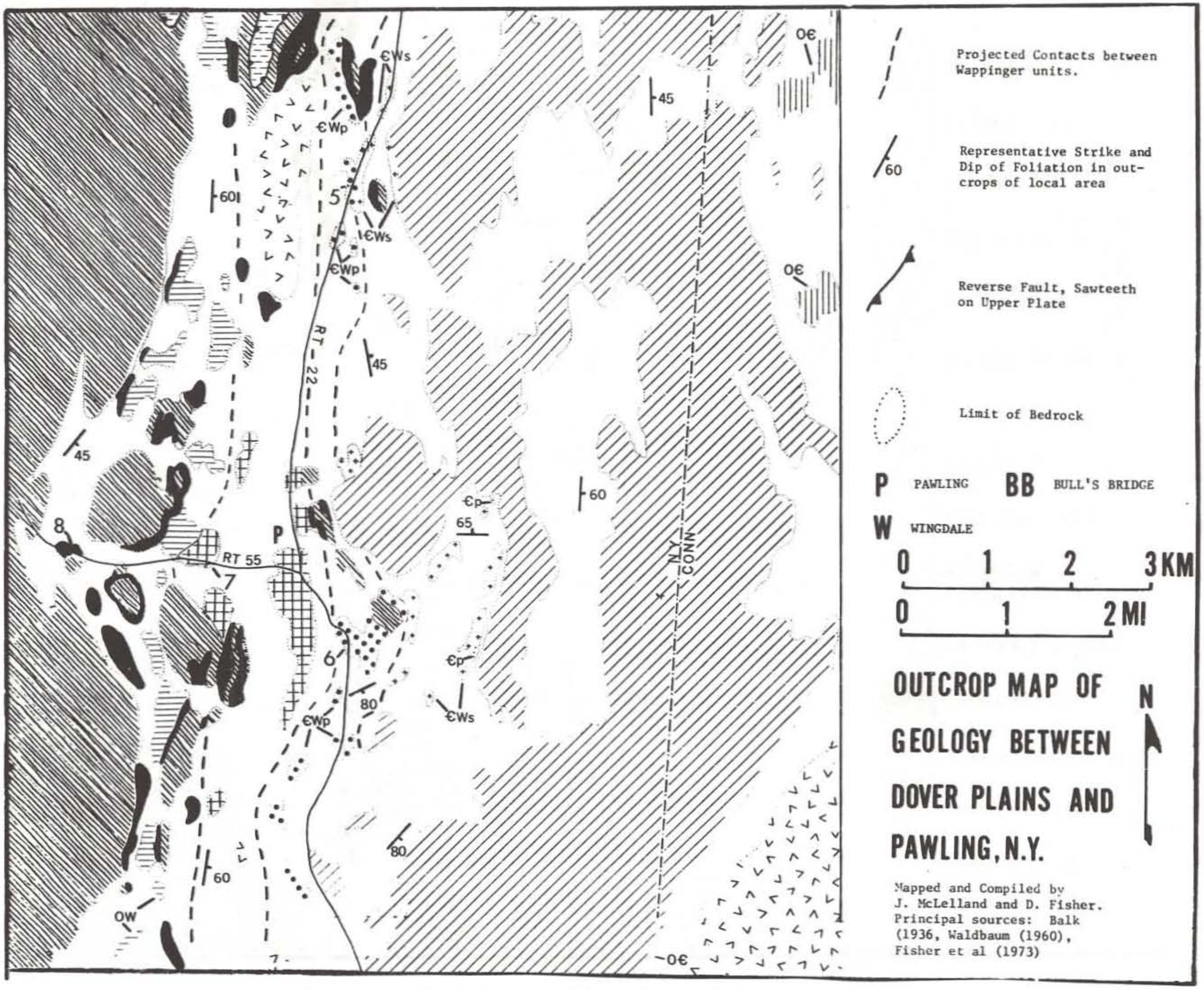

Fig. 2. Geologic map of the Dover Plains - Pawling Valley.

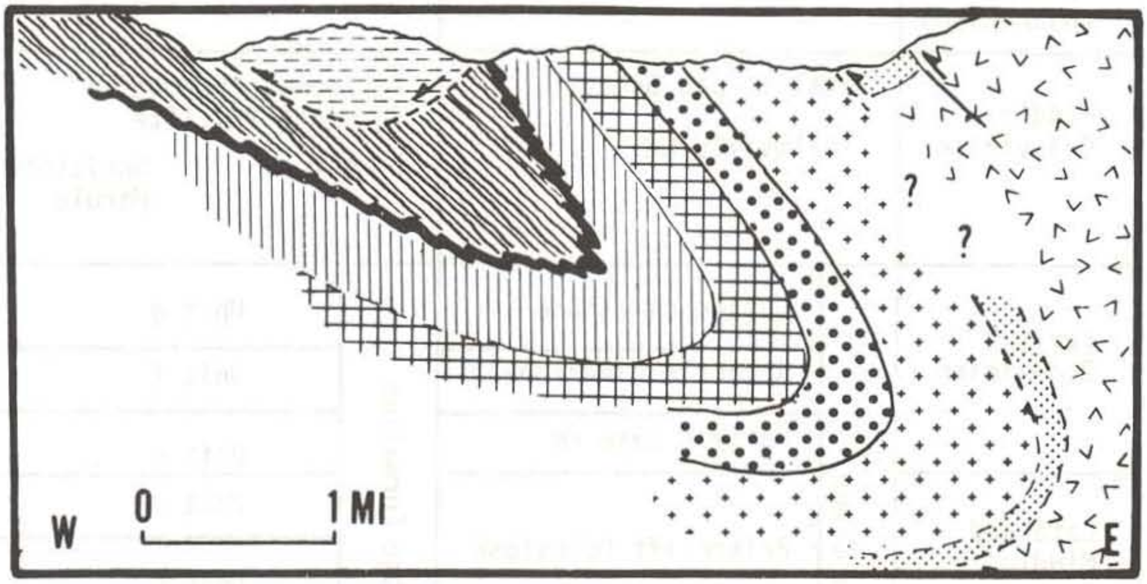

Fig. 3a - Schematic E-W cross section of Harlem Valley Syncline along a line through Nellie Hill. Symbols as in fig. 2.

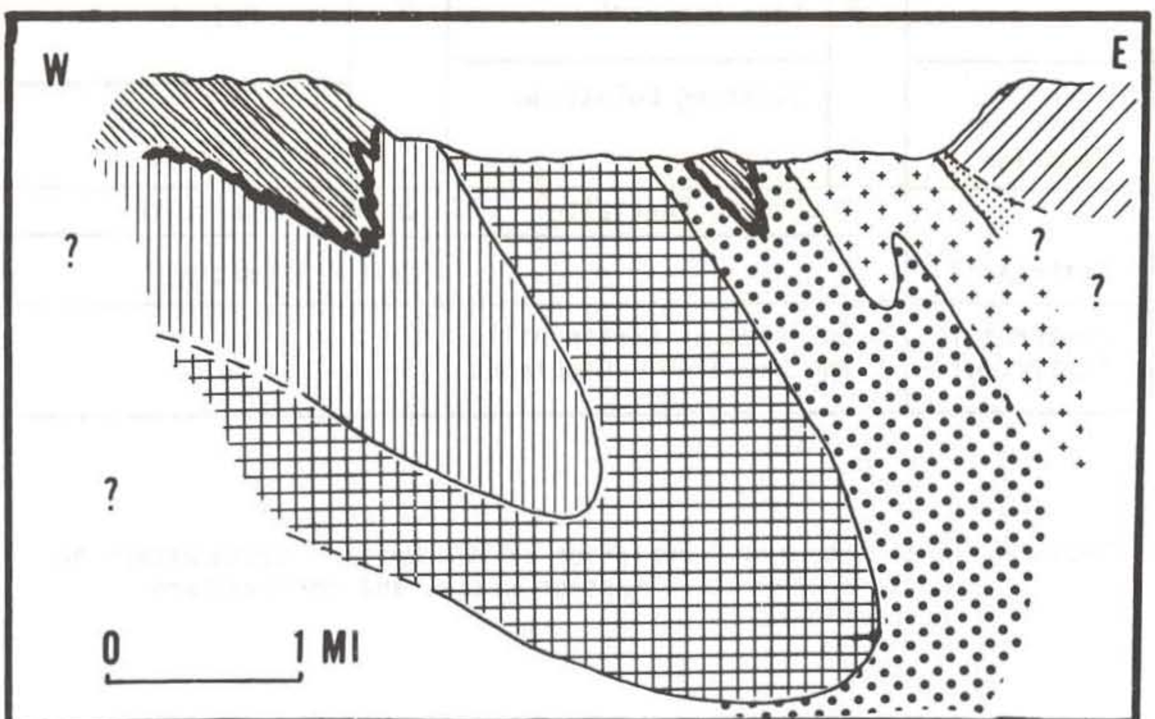

Fig. 3b - Schematic E-W cross section of Harlem Valley Syncline along a line subparallel to NY 55. Symbols as in fig. 2.

Age	Amenia-Pawling Valley		Bashbish Falls quadrangle State Line quadrangle (Zen and Hartshorn, 1966) (Ratcliffe, 1969)	
Earliest Cambrian or Proterozoic (Hadrynian)	Manhattan B, C, Schist Everett Schist		Everett Formation Nassau Formation	
Middle Ordovician	Walloomsac Schist Balmville Ls.		Walloomsac Formation Egremont Phyllite Limestone	Schistose Marble
Early Ordovician	Wappinger Group	Copake Limestone	Stockbridge Formation	Unit g
		Rochdale Limestone		Unit f
		Halcyon Lake Fm.		Unit e
Late and Middle Cambrian		Briarcliff Dolostone		Unit d
				Unit c
		Pine Plains Fm.		Unit b
Early Cambrian		Stissing Dolostone		Unit a
Cambrian ?	Poughquag Quartzite		Cheshire Quartzite	
			Dalton Formation	
Proterozoic (Helikian)	Gneisses at Corbin Hill and Housatonic Highlands			

Table 1. Chart Showing Correlation of Map Units - southeastern New York, southwestern Massachusetts, and northwestern Connecticut.

(II) Poughquag Quartzite (Dana, 1872) (~50-200 m)

White, tan, and pink, massively bedded vitreous quartzite. Throughout the area it appears to be relatively clean, but lower conglomeratic horizons have been recognized. Quartz content generally exceeds 90%. Bedding is rarely visible. Near contacts with the overlying Stissing carbonates rosettes of tremolite are developed. Rapid gradation into the Stissing is achieved by interlayering of quartzite and quartz bearing dolostones over a stratigraphic distance of 10-15 meters. In places the Poughquag lies unconformably upon Proterozoic basement gneisses--i.e. East Mt. (Waldbaum, 1960). Often the contact is marked by reverse or high angle normal faults. Early Cambrian olenellid trilobites have been identified in western Dutchess County, N.Y.

(III) Wappinger Group (Dana, 1879) (~1000-1500 m)

The Wappinger Group comprises the Cambrian-Early Ordovician carbonate shelf sequence in the Hudson Valley of New York State. It is equivalent to the Stockbridge Formation (Emmons, 1842) in Massachusetts and Connecticut (Table 1). The following subdivisions can be recognized. They are listed in order of decreasing age.

(A) Lower Wappinger Dolostone Sequence

(a) Stissing Dolostone (Walcott, 1891) (~300 m)

Typically massive sparkling white dolostones and calcitic dolostones that show a limited reaction with dilute HCl; weathers a pale gray and readily decomposes into white dolomitic sands. Local horizons are rich in yellow to white bands of chert and quartzite which are usually boudinaged. Within the lower 10-20 meters increasing quantities of quartzite layers mark the transition into Poughquag Quartzite. Tremolite and diopside develop near the chert and quartzite beds. Pelitic intervals occur and Mrs. Knopf (1946) recognized a 20 m layer of red shale in the vicinity of Stissing Mt. Fossils in western Dutchess County denote an Early Cambrian age; the uppermost strata may be of Middle Cambrian age.

(b) Pine Plains Formation (Knopf, 1946) (~300 m)

The Pine Plains Formation is characterized by its extreme variability. It is predominantly composed of dolostone but dark grey phyllite layers are common and lavender to purplish mica-rich mottlings are widespread. Layers of dolostone, dolomitic siltstone, and dolomitic sandstone alternate providing a distinctive array of extremely well bedded strata. The thickness of individual beds is variable, ranging between 3 m to 0.5 m. The most characteristic color of the weathered surface is buff to brown or tan. Gray weathering, relatively pure, siliceous dolomites also appear in the section and are marked by the development of diopside and tremolite. Chert and quartzite beds are common in the well bedded portions and give rise to excellent examples of boudinage. At lower metamorphic grade, oolites, cross-bedding, ripple marks, and dessication cracks can be found in the Pine Plains Fm. Local graded bedding is associated with quartz grains in the dolostone.

(c) Briarcliff Dolostone (Knopf, 1946) (~300-400 m)

A gray weathering, massive, light gray to dark gray dolostone containing abundant, and boudinaged, yellow to white chert bands. Minor pelitic mottling is present in some layers. Within this area the Briarcliff is relatively free of quartz sand and calcite. Weathers to rounded pavement outcrops in the field. Weathered-out knots of quartz are common and diagnostic. Diopside tablets and tremolite rosettes show abundant development parallel to siliceous layers. Disharmonic folding occurs between dolostone and cherty layers. Rare fossils near Pine Plains indicate a Late Cambrian (Trempealeau) age. The Briarcliff Dolostone is the thickest unit within the Wappinger Group.

(B) Upper Wappinger Sequence of Calcitic Marbles (~300-400 m)

Poor outcrop and unconformable overlap by the Walloomsac/Balmville lithologies, have made it difficult to subdivide these units in the field. As a result, they are mostly mapped together as a single Upper Wappinger unit in fig. 2. Fortunately, Stop 2 at Nellie Hill provides an excellent cut through portions of, what are believed to be, the Copake and Rochdale Limestones.

(a) Halcyon Lake Formation (Knopf, 1946)

Fine to medium grained calcitic dolostone with some chert. The base is usually sandy or silty. The Halcyon Lake Formation has proven exceedingly difficult to find and map in this area, and we have not yet recognized any lithology that can be definitely assigned to the Halcyon Lake Formation. The possibility exists that cherty dolostones assigned to the uppermost briarcliff are, in fact, Halcyon Lake. The local absence of fossils precludes an early resolution of this problem. Elsewhere in Dutchess and Orange Counties, fossils indicate an Early Ordovician (Gasconadian) age.

(b) Rochdale Limestone (Dwight, 1887)

The lower portion consists of interbedded buff-weathering, fine textured dolostones and calcitic dolosontes. The upper portion contains purer, only slightly dolomitic limestones; some of these possess coarse textures. Buff to fair weathering sandy-beds are common, frequently displaying sedimentary textures. In western Dutchess County, fossils denote an Early Ordovician (Roubidouxan) age.

(c) Copake Limestone (Dana, 1879)

Gray to white weathering dolomitic limestone, coarse textured limestone, and dolostone. Basal portion contains sand and silt that tends to occur in pods and lenses giving the rock a mottled appearance. Cross-bedding is frequently developed in the sandy layers. Rare fossils elsewhere in Dutchess County are of Early Ordovician (Cassinian) age.

(IV) Balmville Limestone (Holzwaswer, 1926) (0-30 m)

The Balmville consists of a coarse textured, blue-gray weathering calcite marble that is free of dolostone layers. Conglomeratic clasts of underlying Wappinger carbonates are relatively common. Locally the marble is schistose. It grades upward by interdigitation into the black Walloomsac phyllites. Layers of calcite bearing calc-silicate-biotite-quartz-plagioclase rocks are commonly developed in the transition zone. The Balmville Limestone is not everywhere present at the base of the Walloomsac Schist, and this absence is probably due to local non-deposition. Elsewhere, the Balmville Limestone has been found resting upon different Wappinger units. Balmville fossils indicate correlation with Middle Ordovician Mohawkian (Rockland) units farther to the west.

(V) Walloomsac Schist (Prindle and Knopf, 1932) (~500 m?)

The original name of Walloomsac Slate was given to certain black slates overlying the Trenton-equivalent limestones in Rensselaer County, N.Y. In Columbia and Dutchess Counties the term Walloomsac is applied to phyllite and schist equivalents of the Snake Hill shales farther to the west. Zen (1969) included the Balmville Limestone as the basal member of the phyllite/schist sequence and referred to the entire mass as the Walloomsac Formation.

The Walloomsac schists are typically jet black to rusty weathering phyllites that contain graphite and pyrite. Biotite tends to dominate over muscovite in the mode (see below). Many sections contain abundant quartz and plagioclase and tend to be more granulitic than schistose in texture.

Everett Schist (Hobbs, 1893) (~700 m?)

This unit was named for exposures on Everett Mt. in southwestern Massachusetts near the New York line. Typically the Everett consists of green-gray and silvery schists, phyllites, and green-tan massive quartzites. It tends to be quartz rich and to show abundant development of moscovite, garnet, and staurolite at high grade. Coarse muscovite dominates over biotite in almost all sections assigned with certainty to the Everett.

Within the Amenia-Pawling Valley the Everett Schist is the only allochthonous Paleozoic unit that has been recognized. Presumably it represents a hard-rock slice of later Taconian thrusting (Hudson Valley Phase of Taconian Orogeny). It is believed to be correlative with the Elizaville Argillite and Nassau Formation (Late Hadrynian or Early Cambrian) further west in Dutchess County.

Manhattan Schist (Merrill, 1890; Hall, 1968) (thickness indeterminable)

We have used this designation for rocks that cannot be placed with certainty within either the autochthonous Walloomsac Schist or the allochthonous slices of Everett Schist. These lithologies, which are exposed in the highlands to the east of Pawling and Wingdale, consist of micaceous schists containing abundant stringers and veins of quartz and quartzo-feldspathic material.

In its type area the Manhattan is divisible in a Lower (A) and Upper (C) unit separated by an amphibolite unit (B) (Hall, 1968). The lower unit consists of a dark, biotite rich, graphitic member. The presence of basal carbonate rich rocks strongly suggests that the lower Manhattan correlates with the Walloomsac Schist. The upper Manhattan consists of coarse, light colored muscovite schists. Garnet and staurolite are common. Ratcliffe and Knowles (1969) conducted modal analyses on 46 samples of Manhattan Schist. They report that out of 22 samples of Upper Manhattan (C), 19 show muscovite more plentiful than biotite; of 24 samples of Lower Manhattan (A), 19 show an excess of biotite over muscovite. Staurolite is present in 13 samples of upper Manhattan and is present (as small amounts) in only 6 samples of lower Manhattan. Opaques are much more abundant in the lower Manhattan than in the upper Manhattan unit. Hall (1968) believed the upper Manhattan to be allochthonous.

It is believed, but unproven, that within the local area certain schists correlate with upper Manhattan and are therefore probably allochthonous. Further clarification of the age, stratigraphic correlation, and tectonic relationships of the Manhattan Schist is currently being undertaken by Hall (personal communication).

Structural Geology and Geologic History

(A) Chronology

As with other examples of Taconic geology, the region exhibits at least two, and frequently three significant deformational events of Paleozoic age. Following the terminology and scheme of Ratcliffe (1969), we have:

Deformational Event	Foliation	Tectonic style
D_0-pre-Walloomsac Mid-Ordovician unconformity bevels down through, at least, the Stissing	None Recognized	Unknown. Possibly high high angle faulting, folding, or both. Possible overturning of shelf sequence
D_1-Post Mid-Ordovician Unconformity Locally recognizable as refolded isoclinal minor folds cut by D_2 foliation. Vermontian Phase of Taconian Orogeny	None Recognized	Isoclinal recumbent minor folds. Related to emplacement of early allochthons (gravity slides)

Deformational Event	Foliation	Tectonic style
D_2-Post and Pene-allochthonous Hudson Valley Phase of Taconian Orogeny	Major NE foliation (S_2)	Large recumbent folds that dominate structural framework, includes and post-dates hard-rock thrusting
D_3-Post-S_2 Foliation Folding of S_2 Foliation. Possibly Acadian in age.	Crenulation cleavage (S_3) and associated chevron folds. Trend varies from N-S to NNW.	Chevron folds, kink banding, microlithons along slip cleavage

A fourth folding event is suggested by changes in plunge of lineation from north to south in several areas. They may be seen on Balk's 1936 geologic map of the Clove 15' quadrangle. Waldbaum (1960) mapped an E-W trending fold axis on this basis just south of Nellie Hill. These changes in plunge may reflect synchronous E-W cross-folding associated with the rise of the Proterozoic gneissic massifs (D_2). The changes in plunge of lineations are less likely to be due to intersecting elements of the D_0-D_3 fold sets since these possess axial traces that lie subparallel to one another. If the E-W trends are a separate event, they reflect a second post-D_2 deformation.

(B) Broad Structural Framework

Relatively detailed, but still incomplete, mapping in the Harlem Valley has demonstrated the presence of all units of the Cambrian-Ordovician shelf sequence between the bordering western and eastern pelitic highlands. As shown in fig. 2, the carbonate stratigraphy can be traced from Nellie Hill to south of Pawling, N.Y.--a distance of nearly 30 km. Fig. 2a extends this stratigraphy another 10 km to the vicinity of Towners, N.Y. It is certain that continued investigation will modify fig. 2 in detail, but the larger implications of the current map pattern are not likely to undergo substantial changes. In particular, we note that the entire valley is underlain by a complete--and overturned--section of the Wappinger Group. As shown in fig. 3, we consider this section to represent the eastern, overturned limb of a large, westward verging syncline related to the D_2 event. The axial trace of the folding is N10°-20°E. A reasonable name for this structure is the Harlem Valley Syncline. The Housatonic Massif may be an anticlinal complement to the syncline and appears to be a westward verging, doubly plunging anticlinorium whose overturned, lower limb passes into the overturned carbonate sequence of the valley. Almost certainly the Proterzoic gneisses of the massif have been locally thrust out over the carbonate shelf sequence in the manner described by Ratcliffe (1975) for the northern Berkshires. This thrusting may be multiple and of large throw (Harwood and Zeitz, 1974). Corbin Hill may be a relict klippen of this mechanism. It is also possible that the Housatonic massif is unrooted at depth and has been emplaced by thrusting from the east (Harwood and Zeitz, 1974).

Both figs. 2 and 3 fail to show any complicating effects of early/late high angle faulting. As of the moment, this faulting has not been studied in detail, but it does not appear that it could markedly change the outcrop patterns as currently determined within the Harlem Valley.

The regional S_2 foliation parallels the axial trace of the major overturned fold, and these two elements are taken to be genetically and temporally related. Since this foliation transects metapelites of the presumably allochthonous Everett formation, the foliation is considered to be post-allochthonous.

The major folding and emplacement of local "hard-rock" allochthons are believed to be penecontemporaneous. The major folds and cleavage are thought to have formed during, or shortly after, the westward thrusting of the so-called "hard rock" or "High Taconic" slices. This conclusion is based upon analogy with other better understood, portions of the Taconide Zone (e.g. Zen, 1967, 1972). However, Acadian folding is known to the west (Green Pond outlier) and we must reserve the possibility that this deformation resulted in some major structures in this area (see Hall, 1968, p. 126).

When considered from a broad, regional point of view it is not difficult to envisage reasonable mechanisms leading to the formation of the Harlem Valley Syncline. Assuming a plate tectonic model broadly similar to that of Bird and Dewey (1969) or Zen (1972), we suppose that the Middle Ordovician inversion of sea floor relief was accompanied and followed by syntectonic flysch sedimentation and the emplacement of gravity slide allochthons now exposed farther west around Pleasant Valley and Fishkill, N.Y. Continued underthrusting of oceanic crust led to increasingly severe westward directed compression that culminated in hard-rock thrust slices and the rise of Proterozoic basement units along a zone dipping to the east (fig. 2). As the basement rose from the east the overlying carbonate shelf rocks responded by overturning to the west. This overturning is most pronounced near the Proterozoic structural front. A final phase in this sequence was represented by late westward thrusting of the Proterozoic massifs (Ratcliffe, 1969). This thrusting may have been of major dimensions in Southeastern New York and Western Connecticut.

The foregoing sequence of events provides a broadly acceptable conceptual framework within which to understand the regional geology. However problems arise when the geology of the valley is examined in detail. Some of these problems are discussed in a later section.

(C) Outline of Geologic History

Within the context of the foregoing regional setting, and notwithstanding some of the noted uncertainties, we suggest the following summary of events for the geologic history of the region that includes the Amenia-Pawling Valley.

Because of multiple overprints of deformation and metamorphism, portions of this history and timing are, of necessity, speculative.

(1) During Middle Proterozoic (Helikian) time a sequence of sedimentary and volcanic rocks was deposited and then metamorphosed during the Grenvillian Orogeny (1100-850 mya).

(2) In Late Proterozoic (Hadrynian) time rifting of continental dimensions led to the initial opening of Iapetus (Proto-Atlantic Ocean). Eastward of the continental margin marine fault-trough deposits began to accumulate (Rensselaer Graywacke, Nassau Fm.). These thick units were deposited within an age bracket of 850-570 mya.

(3a) In Early Cambrian time marine waters began to transgress the craton from southeast to northwest. This incursion is marked by the development of orthoquartzites (Poughquag Quartzite), which grade upward into the Stissing Dolostone.

Continued marine transgression resulted in the development of an extensive carbonate shelf throughout Cambrian and Early Ordovician time. This shelf is now represented by the Wappinger Group (Stockbridge Formation).

(3b) To the east of the shelf there formed a series of black shales and limestone conglomerate beds (Germantown Formation). These were followed by green shales, siltstones and cherts (Stuyvesant Falls Formation). It is believed that these units were formed on, or near, the continental slope. The presence of carbonate conglomerates and brecciolas support this contention.

(4) Near and at the close of Early Ordovician (Canadian) time, there occurred widespread high angle faulting and regional uplift. Some folding and fault block rotation may have accompanied this event (Quebecian or Penobscot Taphrogeny). The cause of the shelf breakup is not well understood, but its occurrence resulted in the discontinuous development of an Early Ordovician erosional surface on top of which residual, iron rich soils were developed. The erosional surface bevelled to all units in the Cambrian-Ordovician shelf sequence and probably to the Proterozoic basement itself. The unconformity may have extended into portions of the continental slope. Presumably the expansion of Iapetus ended at this time.

(5) As Iapetus began to diminish in size, compressional forces of the Taconic Orogeny (Bonnian Phase) resulted in a series of welts and troughs, some of which were probably off shore island arcs (Bronson Hill Anticlinorium?). Early Normanskill pelites and bedded cherts (Indian River, Mt. Merino) accumulated at this time and were deposited in the deeper portions of the troughs. Younger Normanskill graywackes, siltstones, and silty pelites accumulated on the slopes of the troughs. Farther to the east the island arc helped feed the eugeosynclinal sequence now represented by the Missiquoi Fm., Ammonoosuc Fm., Hartland Fm., etc.

(6) Continued compressional forces resulted in a relatively large land mass (Vermontia) during the Middle Ordovician (Mohawkian). Erosion of this landmass produced the muds, sands, and graywackes that were deposited in the trough to the west (Snake Hill-Martinsburg Trough). Presumably, the source rocks for this flysch sequence were the uplifted slope and eugeosynclinal sediments to the east. As Vermontia continued to grow, slope and basin sediments located near the axis of the uplift became gravitationally unstable and

slid westward into the deepening trough (Vermontian Phase of the Taconic Orogeny). Sedimentation continued during this submarine sliding and some of the allochthonous rocks were eventually buried in younger Snake Hill-Martinsburg muds and silts. Some of these sediments may have been derived from the allochthons themselves. The emplacement of the allochthons resulted in the development of a chaotic melange in the soft pelites at the base of the slide. This melange, or wildflysch, is well developed in western Dutchess County but has not been recognized in the metamorphic terrain of eastern Dutchess County.

(7) During the Late Middle Ordovician (Late Mohawkian) time the Snake Hill-Martinsburg Trough filled with fairly well sorted clastics of the Schenectady-Quassaic molasse. Clasts in the Quassaic conglomerates near Illinois Mt., New York denote derivation from units comprising the gravity slides--demonstrating at least partial subaerial exposure of some of these allochthons.

(8) Tectonism continued into the early Late Ordovician (Maysvillian) time and produced hard-rock thrust slices with associated carbonate and Walloomsac slivers torn from the older, subjacent shelf. In Dutchess County these slices are represented by the Everett Schist and by some plates of Proterozoic (Helikian) gneiss. Accompanying, or immediately following, the hard-rock slices there developed westwardly overturned folds and regional development of cleavage. Mineral ages of ~400 mya suggest that a pulse of regional metamorphism occurred at this time (Long, 1962). These ages are most prevalent in western Dutchess County but appear to have been overprinted in eastern Dutchess County.

(9) During the Late Ordovician (Richmondian) mafic igneous bodies were emplaced at Cortland and Bedford (~435 mya, Long, 1962).

(10) During the latest Ordovician (Gamachian) and early Silurian (Llandoverian, Wenlockian) there occurred a widespread episode of normal, block-faulting. This is particularly well displayed in the Mohawk and Champlain Valleys and the faults are observed to cut Taconian thrust sheets. Evidence strongly suggests that these Silurian faults were accommodated along reactivated Proterozoic basement fractures. Uplands produced by this post-Taconian block-faulting provided erosional debris for the Shawangunk-Fernon-Bloomsburg clastics.

(11) During Late Silurian (Ludlovian) time evaporite deposits accumulated in central New York. Corresponding events in eastern New York and westernmost New England are uncertain. Some renewed compression may have occurred.

(12) In the latest Silurian (Pridolian) and Early Devonian (Helderbergian), crustal stability prevailed with attendant carbonate and reef development. Uplift followed, but the nature of this is uncertain. The succeeding Oriskany sands and Esopus-Carlisle Center silts and pelites suggest renewed deformation in eastern New York (Phase I of Acadian Orogeny). Brief crustal stability with Onondaga carbonates and reefs ensued. The intense Phase II of the Acadian Orogeny followed with westward overturned folding and with probable high-angle reverse faulting and metamorphism in easternmost New York. East of Wappinger

Creek Valley earlier Taconian cleavage was folded. Vigorous erosion of uplifted land created the thick and extensive Catskill clastic wedge during the Middle Devonian (Erian) and early Late Devonian (Senecan). By late Late Devonian (Chautauquan) time, the Acadian Orogeny was over.

(13) The effects of Late Paleozoic deformation, (if present) in eastern New York are vague. A thermal event of about 250 mya is known in western Connecticut and it is reasonable to assume that its presence was felt in southeastern New York.

Major Problems of Local Interest

For the moment, at least, the most severe problems in the area are:

(1) The angular relationship between the Balmville Limestone-Walloomsac Schist and the inverted Wappinger units below the early Middle Ordovician unconformity. Related to this are implications concerning the nature of the pre-Walloomsac, D_0, event.

(2) The subdivision and correlation of the Manhattan Schist, that forms the eastern wall of the Amenia-Pawling Valley from south of Pawling to the Wingdale-Bull's Bridge gap. Stratigraphic assignment will help determine whether these schists are allochthonous, autochthonous, or parautochthonous.

(3) The nature of the basement rocks underlying the schist mass referred to in (2)--i.e. is the schist directly underlain by Proterozoic gneiss or Wappinger carbonate units?

(4) The structural relationships, and origin, of the isolated masses of Proterozoic gneiss exposed at Corbin Hill and Pine Island, as well as the nature of the Paleozoic-Precambrian contact near Towners, N.Y.

(5) The relationship of the Harlem Valley to the regional setting comprising the various Precambrian massifs of the area; the presence of Wappinger carbonates east of Precambrian gneisses; and the ever problematical Cameron's Line. Unravelling of the regional geology in southeastern New York and Western Connecticut represents a fundamental key to the understanding of the evolution of the Appalachians. We shall not pursue this major undertaking within this report.

Discussion of Problems

In what follows we will briefly discuss problems (1) - (3). Problem (4) (Corbin Hill) is treated in the text for Stop 6. Problem (5) must await further research.

1. Middle Ordovician Unconformity

A Middle Ordovician unconformity is widely recognized throughout eastern North America (Rodgers, 1970). Most workers have agreed that the unconformity

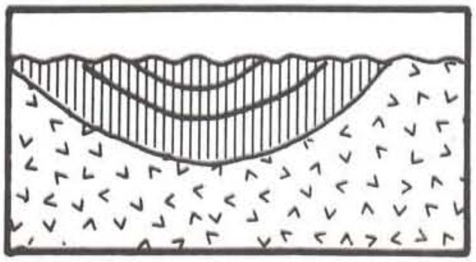

Fig. 4a - Development of early Middle Ordovician unconformity above gently folded shelf.

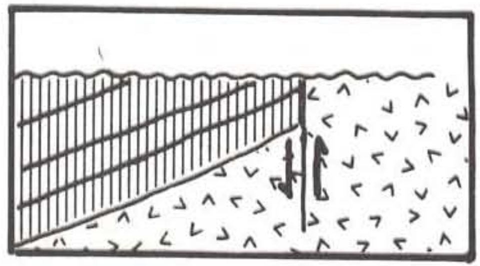

Fig. 4b - Development of early Middle Ordovician unconformity above rotated fault blocks.

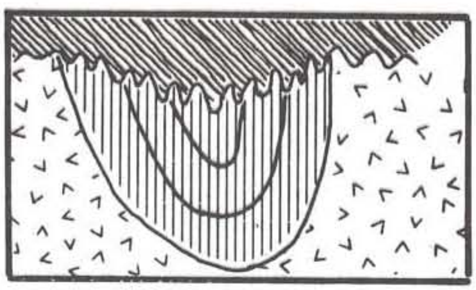

Fig. 4c - Middle Ordovician folding following deposition of Balmville-Walloomsac. Note folding of unconformity.

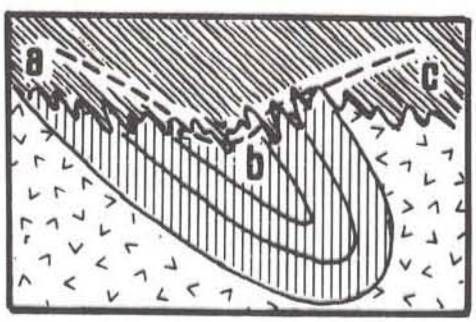

Fig. 4d - Culmination of Middle Ordovician folding and overturning. Unconformity gets in-folded. The dashed line abc represents a present day erosion surface.

(Symbols as in Fig. 2)

developed following the Early Ordovician (Canadian) breakup of the shelf sequence by N-S block faulting. The faulting appears to step up the Pre-cambrian basement near the eastern margin of the shelf and represents events immediately preceding the emergence of Vermontia and the deepening of the Snake Hill-Martinsburg Trough. Just prior to this deepening an erosional surface formed on subaerially exposed blocks. Subsequently, Balmville Limestone and Walloomsac flysch were deposited above the locally developed erosional surface. Presumably sedimentation continued unimpeded in non-exposed basins (grabens).

The foregoing exposition of the pre-Walloomsac tectonism (Penobscot or Quebecian Taphrogeny) has much to recommend it. Zen (1968), Thompson (1959), as well as numerous others, have shown that block faulting was the most probable mode of deformation at this time. However, local compressional events have been recognized and Thompson (1959), Zen (1961, 1967, 1968), and Ratcliffe (1969) have demonstrated that reality of pre-Walloomsac folding within the shelf sequence. Neumann and Rankin (1966), Ayrton (1967), and Hall (1969) have demonstrated strong compressional events of pre-Walloomsac age in Penobscot County, Maine; the Gaspe Penninsula; and the Notre-Dame-Sutton Mt. Anticlinoria. It appears as if compressional tectonics were more intense in off-shelf than in on-shelf environments.

The importance of understanding the pre-Walloomsac event is emphasized when dealing with overturned Wappinger carbonates. Thus, Ratcliffe (1969a, p. 2-12) was able to demonstrate at No Bottom Pond Window in the State Line Quadrangle in eastern Columbia County, N.Y., that an angular discordance of 70° existed between the Balmville Limestone and the underlying Stockbridge carbonates. Because of the detailed field evidence, Ratcliffe concluded that the Stockbridge had been folded, and overturned, prior to deposition of the Balmville Limestone.

Within the Amenia-Pawling Valley the Balmville-Walloomsac sequence is found in patchy exposures lying above overturned Wappinger carbonates. It appears from field relationships that this situation need not imply inversion of the Wappinger Group prior to deposition of Balmville-Walloomsac units. It is equally possible that gentle folding and even tilted block faulting, could have provided a westwardly dipping Wappinger section which was bevelled down and then overlain by the younger lithologies (fig. 4). Subsequent over-turned folding could have brought the units into their present configuration. The preservation of patches of Balmville and Walloomsac would be enhanced if the major folding episode that overturned the Wappinger Group deformed the Middle Ordovician unconformity also. In so doing there could have resulted in-folded keels of Balmville-Walloomsac which escaped later erosion (fig. 4). Only detailed field investigations of the angular relationships on either side of the unconformity can resolve this situation. Unfortunately critical out-crops are lacking. In the absence of information to the contrary, we choose to regard the local Pre-Walloomsac event as primarily non-compressional, and we attribute the formation of the overturned folds to later Taconian or Acadian events.

As a final observation on this matter, we note that the possibility exists that, locally, the Balmville and Walloomsac were thrust into their present positions relative to the overturned carbonate sequence. This possibility appears ad hoc and is not favored.

2. Subdivision and Correlation of the Manhattan Formation (?)

The problem of subdividing and correlating Taconide pelitic masses constitutes one of the historical pivot points in the Taconic controversy. The difficulties inherent in this undertaking are complicated by high metamorphic grade. In the western gravity slides fossil control, color differences, textural differences, bedding characteristics, etc., have been helpful in providing stratigraphic control. However, these criteria are not generally present in the later, hard-rock slices lying to the east. Here the stratigraphic divisions have usually been reduced to the recognition of two major units: the autochthonous Walloomsac Fm. and allochthonous slices which, in much of Dutchess County, N.Y., have been referred to as the Everett Schist (Hobbs, 1893). The distinction between Everett Schist and Walloomsac phyllites is not usually obvious. Often, the Walloomsac is darker, rustier, and more graphitic than the Everett; the latter tending to have a greenish or silvery hue. As metamorphic grade increases, these distinctions become less obvious.

The 25 mile long ridge that defines the eastern margins of the Amenia-Pawling Valley from near Towners to the Wingdale-Bull's Bridge gap is underlain for 5-6 miles to the east by enigmatic schists of the type described in the preceding paragraph. On the 1973 edition of the New York State map these are shown as Manhattan Fm., and we have retained this nomenclature for the purposes of this field guide. For the most part these rocks consist of coarsely micaceous sillimanite-staurolite-garnet-muscovite-quartzo-feldspathic schists. They resemble units mapped as hard-rock slices of Everett Schist on the northwestern side of the carbonate valley (see Stop 3). The strongest argument for correlation of these rocks with the Everett rests with their lithologic similarity to high grade Everett in other areas. In general, workers have tended to regard the Everett as more aluminous than the Walloomsac, and this difference is reflected in a greater ratio of muscovite to biotite in the former. Relatedly the Everett generally displays more staurolite, chloritoid, and alumino-silicates than does the Walloomsac. These criteria suggest that the rocks in question should be assigned to the Everett rather than to the dark, rusty weathering, graphitic Walloomsac. However, this assignment rests on no quantitative, or unequivocal, evidence.

The distinction between Walloomsac and Everett is analogous to that between the Lower and Upper Manhattan (Manhattan A and C of Hall, 1969) as reported by Ratcliffe and Knowles (1969), and as discussed in the stratigraphy section of this report. While it is not at all certain that the main mass of the schist in question here is correlative with Manhattan C, the lithologic similarities are pronounced, and we adopt this correlation as a preferred alternative. Hall (1968) and Ratcliffe and Knowles (1969) have suggested that the Manhattan C may be allochthonous. We suggest here that a similar possibility exists for the schists underlying the metapelite ridges east of Pawling, New York.

Evidence favoring an autochthonous history for the eastern schist mass derives principally from the presence of Balmville Limestone and dark, rusty, and calcitic Walloomsac schists underlying the main schist mass at its northern margin in the Wingdale-Bull's Bridge gap (Balk, 1936; Waldbaum, 1960). However, this data is in no way inconsistent with the general Taconic situation in which allochthonous masses overroad the black shales of the exogeosyncline.

At the base of the schist mass directly east of Pawling the basal Walloomsac and Balmville are not present and the coarse, muscovite rich schists lie directly upon Stissing Dolostone and even Poughquag Quartzite. Inspection of the maps in figs. 2 and 2a shows that the schist transects the Stissing contact and even cuts the Stissing and Pine Plains out entirely near the southern end of the valley. The fact that the Stissing is here overturned is further suggestive of a tectonic contact, but such a contact could also be the result of the early Middle Ordovician unconformity, or of local westward thrusting of Walloomsac, and need not indicate a far traveled hard-rock slice of Everett.

While we prefer an Everett assignment--and an allochthonous history--for these rocks, we re-emphasize that the matter remains equivocal.

3. Nature of the rocks underlying the Manhattan Schist

It is not possible to know with any certainty whether the mass of Manhattan Schist is underlain by units of the carbonate shelf or by Proterozoic gneisses. It is conceivable that beneath the Manhattan there exists an eastward dipping, right-side-up sequence of carbonates that represent the eastern limb of the southern extension of the Housatonic Anticlinorium. It is equally likely that the schists are underlain, at least in part, by Proterozoic gneisses near the axis of the anticlinorium. This possibility is favored by the fact that the western margin of the schist overlaps the Stissing Dolostone, and the Proterozoic basement can be at no great depth. Furthermore, the schists are surrounded on their southern and southeastern margin by Proterozoic gneisses of the Hudson Highlands.

One reason for preferring at least a partial Proterozoic gneiss sequence below the Manhattan Schist is that its presence provides a reasonable local source area for the Proterozoic gneiss outlier at Corbin Hill (see Stop 6).

4. Structural Relationship between the Paleozoic and Proterozoic at Corbin Hill and at Towners, N.Y.

These problems are examined in detail at Stops 6 and 10 of the Road Log.

Summary

Although important unresolved problems remain in the Amenia-Pawling Valley, we are able to conclude with reasonable certainty that the valley is underlain by the overturned, eastern limb of a large NNE trending syncline. In the western limb of this fold the carbonate shelf remains hidden beneath

Walloomsac and Everett schists. This structure is termed the Harlem Valley Syncline and is thought to be complementary to the Housatonic Highland massif and its southern extension. It is suggested that the Proterozoic gneisses at Corbin Hill are a relict klippen of a hard-rock thrust slice emplaced in the late Taconian Orogeny (Hudson Valley phase). Local allochthons of Everett Schist were emplaced at the same time. Penetrative cleavage and metamorphism followed these events, probably, in late Ordovician time. A Devonian overprinting of Ordovician metamorphism is probable.

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Road Log

This trip begins on N.Y. Route 22 just north of Dover Plains. Stop 1 may be reached by driving northeast from Poughkeepsie on Rt. 44. After approximately 16 miles take Rt. 343 east to Dover Plains. At the junction with Rt. 22 in Dover Plains turn north on Rt. 22 for 6 miles to Stop 1.

Mileage

0. Stop 1. Roadcuts in Walloomsac schist and Wappinger carbonates on both sides of NY 22. Here the Walloomsac schist overlies calcitic and dolomitic limestones of the upper Wappinger--possibly the Copake Limestone. The presence of brown and tan weathering dolostone beds in the carbonates preclude their being Balmville. Probably this was a site of non-deposition of the Balmville. At or near the contact, there is developed tectonic interleaving of schist and carbonate. This interleaving could result from at least two causes: (1) differing mechanical properties of the schists relative to the carbonates; (2) the shearing off of original irregularities along the old erosional surface. Within the outcrop, the foliation and bedding surfaces strike N40E and dip 50°W. The stratigraphy is right side up. Tight folding takes place about N10-15E axes and the folds verge westward. Near the south end of the outcrop there exist good examples of the relationship of fold wavelength to bed thickness. Note that the principle foliation has been refolded representing, probably, the D_2 and D_3 events. A thin section of Walloomsac from this outcrop shows abundant quartz and biotite as well as garnet, feldspar, muscovite, graphite, and metallic opaques. Two generations of biotite can be seen megascopically.

5.9 State Police headquarters in Dover Plains, N.Y.

7.4 Stop 2. Nellie Hill. Large roadcuts in upper Wappinger carbonates. The beds strike N10-20E and dip 30°-40°E. In the fields beyond the west side of the road are outcrops of Balmville Limestone and Walloomsac Schist that also dip to the east. If one proceeds eastward over the top of the roadcut and onto the next ridge (~300 m), Briarcliff Dolostone is encountered. Still further to the east the Pine Plains Formation, Stissing Dolostone, and Poughquag Quartzite crop out successively until the proterozoic gneisses of the Housatonic Highlands rise in the ridge defining East Mt. Except for minor folding, the strata dip consistently to the east and the entire section must be regarded as overturned. Chestnut Ridge, immediately to the west on Rt. 22, consists of Everett Schist and is regarded as an allochthonous hard-rock slice.

The southern portion of the outcrop is thought to consist of Copake Limestone that has been pervasively folded about N10-20E axes, plunging 10°-15°N. Excellent examples of transposed bedding and thinned out fold limbs can be seen. The rock consists of dark, pure calcitic metacarbonate interbedded with coarser sandy dolostone. Possible crossbedding can be seen in the steep walls of the roadcut.

At its northern end, the outcrop shows the development of well layered buff and brown dolostone beds interlayered with dark, massive calcite rich beds. These units are thought to belong to the upper portion of the Rochdale Limestone. Bedding averages around 0.5-1 m in thickness. Some of the dolostone beds are quartzose and show thin bedding laminations. No cross-bedding or graded bedding has been recognized and discoveries of the same will be welcomed.

Above the road level, and within the tree cover, there are developed coarse, gray, massive limestones that extend to the top of the hill. These are considered to be part of the Rochdale. Between the hilltop and the Briarcliff dolostone, limestone bearing units of possible Halcyon Lake assignation crop out.

A problem with the correlations as given above is that the resulting thickness of the Rochdale Limestone is less than would be expected. Warthin (pers. comm.) reports approximately 125 m of Rochdale near Poughkeepsie. If the Halcyon Lake is present in the section above the Briarcliff here, it does not appear possible to have 125 m of Rochdale. Perhaps faulting has cut out some of the section. Alternatively the Halcyon Lake Fm. may not have been deposited locally. A further possibility is that the beds assigned here to the upper Briarcliff are actually Halcyon Lake.

8.1 Stop 3. Park on east side of NY 22 near bend in road. Walk southward along railroad tracks, for approximately 150 meters. Excellent outcrops of Everett Schist are exposed in a small railroad cut. NO HAMMERS PLEASE. Large (1/8" - 1/4") staurolite and garnet crystals are developed in coarsely micaceous muscovite schists which display the typical silver sheen of the Everett at this grade. Quartz and feldspar are plentiful with quartz predominating. Some graphite is present. The foliation has been refolded.

8.8 Briarcliff Dolostone in roadcut.

8.9 Briarcliff Dolostone in roadcut.

9.4 Briarcliff Dolostone on hill to west of road.

10.6 Briarcliff Dolostone on east side of road.

10.8 Briarcliff Dolostone on east side of road.

10.9 Leave NY 22 and turn east on Crickett Hill Road (unmarked).

11.2 Abandoned quarry in Briarcliff Dolostone to south of road.

11.4 Cut in Briarcliff Dolostone.

11.7 Cut in Briarcliff Dolostone.

12 Cut in Pine Plains Formation.

13 Junction with N-S road. Turn north.

13.3 Turn east on Bridge across Ten-mile River.

14.2 Entrance to Peckham Industries Quarry. Park cars in quarry yard.

Stop 4. The quarry is within Stissing Dolostone and the broad expanse of dazzling white dolostone reflects the purity of this lowermost carbonate. During World War II, this quarry was utilized as a source for magnesium. Within most units the rock consists almost entirely of dolomite and calcite. The structure within the quarry seems to be fairly straightforward. Bedding dips steeply around an anticline that trends N10-20E and plunges 10°-15°S. The core of this anticline is preserved in the lower quarry level where pelitic beds of Stissing are also exposed. Presumably these are related to the red shale horizons recognized by Mrs. Knopf (1946) near the middle of the Stissing. At the stratigraphic level of the pelite rich zones, the Stissing is difficult to distinguish from portions of the Pine Plains Formation.

At the south end of the quarry beds of Pine Plains dolostones overly the Stissing. The Pine Plains appears to overly the Stissing around the entire margin of the quarry, reflecting its overall anticlinal structure. Because its regional extent is unknown, the Pine Plains in this area has been mapped in Undivided Carbonates (Of) in fig. 2.

In terms of regional structure, note that the quarry lies within the Wingdale-Bulls Bridge gap. Within this gap the Stissing Dolostone appears to wrap around the southern end of the Housatonic Highlands. Moreover, Stissing within the gap appears to be structurally and stratigraphically continuous with Stissing to the west in the Harlem Valley. This strongly suggests that the gap represents the south plunging nose, and upper limb, of the westward verging anticlinorium cored by the Proterozoic gneisses of the Housatonic Highlands. The possibility exists that this anticlinorium is developed on an eastward dipping thrust plate (Harwood and Zeitz, 1974).

Return to cars. Leave quarry and turn south at entrance.

15.1 Cross Ten-mile River. Turn south on west side of bridge.

15.7 Intersection with NY 55 at Webatuck.

16.5 Intersection of NY 55 and NY 22. Turn south on NY 22.

17.1 Stop light at Harlem Valley State Hospital.

17.8 Pine Plains Formation on west side of Rt. 22.

18.2 Pine Plains Formation on east side of Rt. 22.

18.5 Manhattan Formation of the schist mass comprising the east side of the valley.

18.8 Pine Plains Formation on west side of Rt. 22.

19 Pine Plains Formation on west side of Rt. 22.

19.3 Stissing Dolostone on both sides of Rt. 22.

19.7 Stop 5. The long roadcuts on either side of NY 22 are fine examples of Pine Plains Formation. However we will not examine these at this location. The primary purpose of this stop is to point out, and discuss Corbin Hill which rises from the swampy fields to the west of NY 22.

Corbin Hill consists of Proterozoic (Helikian) gneisses whose bedding and foliation are conformable to the valley trends. These gneisses are surrounded by, and may rest on top of, interlayered Balmville limestones and Walloomsac slates. Balk, 1936, considered Corbin Hill to represent a slice of basement brought to its present erosional level along a steeply dipping reverse fault block that involved Precambrian rocks only (fig. 5a). If this mechanism is correct, then it should be reflected by a break in the stratigraphic succession of the valley carbonates. Similarly, if Corbin Hill punched its way upward as an elongate domal mass, then the carbonate stratigraphy should wrap around the Precambrian gneisses (fig. 5c).

Mapping around Corbin Hill has shown that the caronbate stratigraphy is unaffected by the gneiss body. Units of the Wappinger Group can be followed down the valley and "through" Corbin Hill with no signs of displacement or "wrapping-around". As shown in fig. 2, the Briarcliff Dolostone is the Wappinger unit underlying Corbin Hill. This is inconsistent with an upunched or upthrust origin of this feature. Similarly the presence of Balmville Limestone, Walloomsac Schist, and even Everett Schist in close

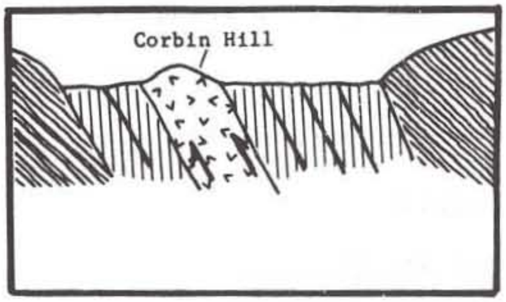


Fig. 5a - Corbin Hill as an upthrust block (Balk, 1936). Inconsistent with stratigraphy.

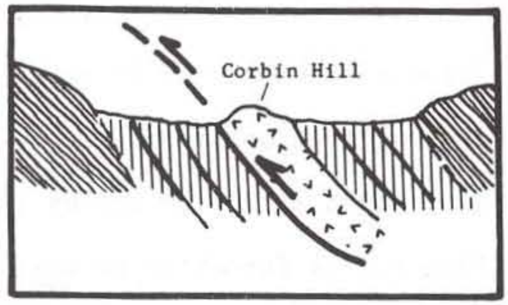


Fig. 5b - Corbin Hill as the basal unit in a large thrust sheet. Inconsistent with stratigraphy.

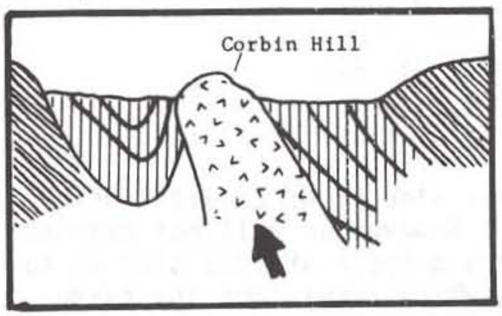


Fig. 5c - Corbin Hill as an up-punched gneiss dome. Inconsistent with stratigraphy.

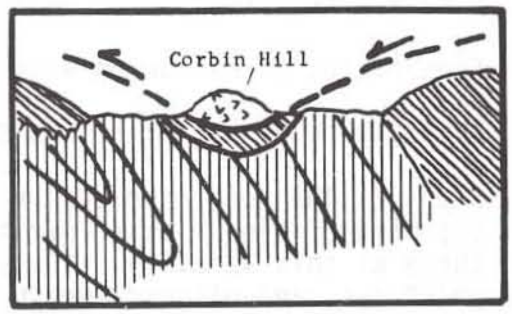


Fig. 5d - Corbin Hill as a far traveled thrust slice.

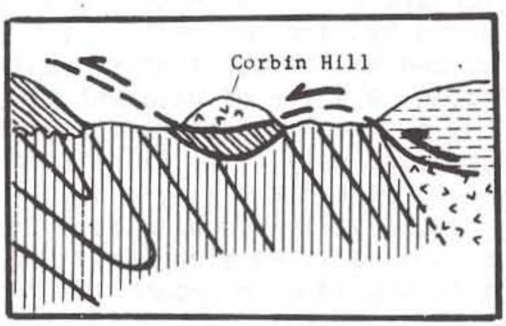


Fig. 5e - Corbin Hill as a tectonic slice on the sole of an Everett thrust sheet.

(symbols as in Fig. 3)

proximity to the western margin of the Precambrian gneisses makes it difficult to account for Corbin Hill by essentially autochthonous mechanisms. The stratigraphic continuity of the carbonate shelf units, and their overturned attitudes, cannot tolerate vertical movement models for Corbin Hill. In effect, the gneisses on Corbin Hill do not appear to be rooted through the valley carbonates. While this conclusion cannot be made firm without further evidence it does represent our preferred interpretation of the field data.

In the absence of further data, we are unable to offer any convincing, detailed history relating to the origin of Corbin Hill. Our preferred model is that these gneisses represent an erosional outlier of a low dipping hard-rock slice that transported Proterozoic rocks from east to west. Rather than suppose the existence of extensive Proterozoic rocks in this slice (fig. 5d), we prefer to attribute the rocks of Corbin Hill to tectonic slivering of basement rock by an overriding slice of Everett Schist (fig. 5e). This slivering could have occurred in the basement rocks that underly the Manhattan Schist terrain, forming the ridge on the east side of the valley. While other source areas exist, this one appears to be the most economical of long distance transport. Similarly, slivering of the Proterozoic offers the simplest explanation for the restricted outcrop of Corbin Hill.

The foregoing model is consistent with the recent aeromagnetic interpretations of Harwood and Zeitz (1974) for rocks of the Housatonic massif. Here, eastern, weakly magnetic Precambrian rocks are thrust westward along low angle faults rooting in the east. This thrusting occurred late in the Taconian Orogeny and involved the various hard-rock slices of the High Taconics and the Precambrian massifs. Note that just to the north of Towners, New York, Balk (1936) mapped Precambrian and Poughquag Quartzite thrust over carbonate units. Lying north of this is the small Pine Island mass of Precambrian and Poughquag which, presumably, is also thrust in (see Stop 9).

20.1 Pine Plains Formation on east side of NY 22.

21.8 Trinity-Pawling School.

22.4 Briarcliff Dolostone on east side of NY 22.

22.8 Briarcliff Dolostone on east side of NY 22.

23.1 Signal. Briarcliff Dolostone in large roadcut on east side of NY 22. Abundant diopside and tremolite are developed in the outcrop.

23.4 Pass under NY 55.

23.5 Briarcliff Dolostone on west side of NY 22.

24.1 Slow down and turn left across divider. Head back north.

24.2 Stop 6. Road cut in the Pine Plains Formation. Excellent example of the highly variable lithologies that characterize this unit. Brown and buff sandy dolostones alternate with quartzites and relatively pure, massive white dolostones. Tan colored units often shows typical rotten weathering. Punky, asphalt bearing layers give off H_2S upon breaking open. Bedding is of variable thickness. The beds of quartzite and chert have undergone boudinage and pinch and swell of textbook quality. Reaction rims and selvages exist between the carbonates and the quartz rich layers. In the brown to purplish pelitic zones phlogopite, sphene, diopsidic pyroxene, and tremolite are developed. Within the more massive beds of grey weathering, white colored dolostones diopside tablets attain dimensions approaching 3 cm across.

On the east side of NY 22, the Pine Plains units strike subparallel to the road and dip steeply to the east. On the west side the strike has turned E-W and dips are steeply to the south. This represents a fairly open, dextral type of fold that swings the carbonate units and the Manhattan Schist westward for about 0.8 km at which point strikes return to NNE trends (see fig. 3).

The contact between the Briarcliff dolostones and the Pine Plains Formation is thought to occur just to the west of NY 22. The low hill rising from NY 22 is known to be underlain by Briarcliff Dolostone and this unit is beautifully developed just to the south of the NY 55 underpass (0.5 km along strike to the north). Perhaps some of the massive, pure dolostone at the north end of the cut should be assigned to the Briarcliff.

Minor folds in the outcrop suggest that we may be observing here the limbs of larger isoclinal folds. Two foliations exist and are best manifested by micaceous bands.

24.9 Turn onto entrance ramp for NY 55 west.

25.3 Briarcliff Dolostone with excellent diopside crystals on north side of NY 55.

25.9 Stop 7. Very large roadcuts in the Briarcliff Dolostone. The Briarcliff consists typically of grey weathering, light colored rather pure dolostones with yellow to white and even black chert layers (1"-2") abundantly developed in some units. Knots and nodules of vitreous quartz are locally present and weather out above the dolostone surface. At the east end of the cut some dirty portions of the Briarcliff exhibit moderate development of phlogopite. At the western end of the beds of dolostone are massive and pure. This difference appears to be reflected in the more open style of folding associated with the pure thick layered (5-7 m) beds.

A large number of different structural styles and phenomena can be seen in the roadcut. Folds range from fairly open flexural styles to isoclinal folds that may involve flowage and/or significant flattening. In many areas of the cut disharmonic folding is pronounced with the dolostones undergoing extensive flowage while t·e much more brittle chert layers show rupturing and extensive separation of blocks. Examples of the folded boudinage are beautifully developed at the eastern end of the roadcut.

There appear to be at least four major compressional events recorded in the outcrop. The earliest of these is manifested by only an early foliation (flakes of phlogopite) that lies within the surfaces rotated by the earliest recognizable folds. These folds are generally very tight to isoclinal and their axial planes display a variable attitude. In general the axes of these folds do not plunge steeply but exceptions are common due to later refolding. These tight folds are then refolded about NNE axes with relatively steep plunges (50-60°). This leads to an interesting set of geometrical relationships wherein the early isoclinal folds are well exposed in vertical faces of the cut while the steeply plunging folds are best seen on horizontal erosional surfaces. A final set of upright, open, and gently plunging folds that trend approximately N-S. These are best exposed near either end of the large road cut.

Fold interference patterns are best seen at three places. The first is on the north side of the road and near the east end of the roadcut just prior to the beginning of the cut's really steep faces. Here upright isoclinal folds are clearly refolded by steeply plunging, tight folds. Close examination of the folded surfaces of the isoclinal folds indicates phlogopite mica growing parallel to them. Folded boudinage also appears to be present.

A second vantage point for observing fold interference is on the north side of the cut just beyond the large saddle nearly 2/3 of the way up the cut. Here several pelitic layers define the core region of early gently plunging isoclinal folds. These can be clearly seen to be folded by a later, steeply plunging fold set.

A third example of fold interference lies on the south side of the cut almost directly opposite the case cited immediately above.

Numerous high angle faults cause observable offsets in the dolostones. Some of the fault stones contain serpentine. These faults appear related to a larger fault zone that causes a topographic saddle about half way along the roadcut.

Of particular petrologic interest are layers of tremolite and diopside in the Briarcliff. These are best observed on the top of the roadcut at its southeastern end. Massive beds of tremolite and diopside areas are mutually exclusive and seem to reflect the relative immobility of the vapor phase during metamorphism. Note that the diopsides, especially, appear to post-date any severe orogenic events.

26.8 Calcitic Walloomsac schists containing calc-silicates, calcite, and overlain by a calc-silicate bearing calcitic dolostone. The latter may be a tectonic sliver similar to those seen at Stop 1.

27.0 Stop 8. In this small roadcut we are afforded a view of the contact between the Balmville Limestone and the Walloomsac Schists. At the north end of the outcrop the schists overly the Balmville, but at the south end, units dip steeply to the east, and, if outcrop were preserved, the Balmville would overly the schists. We consider this relationship to be due to proximity to the hinge line of the overturned Harlem Valley Syncline whose upright, western limb is entered as NY 55 is followed to the west (see fig. 3). The roadcut itself probably represents a minor fold near the hinge line since black Walloomsac calcitic schists are found farther to the east at mileage 26.8.

Turn around and head back east on Rt. 55.

29.0 Intersection with Rt. 22. Head south on Rt. 22 for 5.5 miles.

34.5 Junction NY 164. Turn east towards Towners.

35.7 Turn north on Cornwall Hill Road. Mendel pond on right.

36. Stop 9. Thrust contact between the Proterozoic gneiss and the Cambrian-Ordovician shelf sequence. Balk (1936) mapped the Towners Thrust through this area. As he indicated, the upper thrust plate consists of Proterozoic gneisses overlying Poughquag quartzites. Beneath the Poughquag there appears a much deformed and cleaved impure dolostone. Because of the impurity of this unit (particularly the number of chert stringers in it), we have tentatively correlated these dolostones with the Briarcliff. The possibility remains that future work will result in a revision of this correlation and the dolostones may be incorporated into a dirty, lower facies of the Stissing. At this grade of metamorphism, and with lack of fossil control, it is difficult to make stratigraphic assignments with absolute certainty. However, the present correlation is preferred.

If the dolostones at this stop are accepted as Briarcliff, then the stratigraphy itself necessitates a reverse fault between the Proterozoic/Poughquag and the underlying Briarcliff. Such stratigraphic control would demonstrate thrusting, and fix its minimum

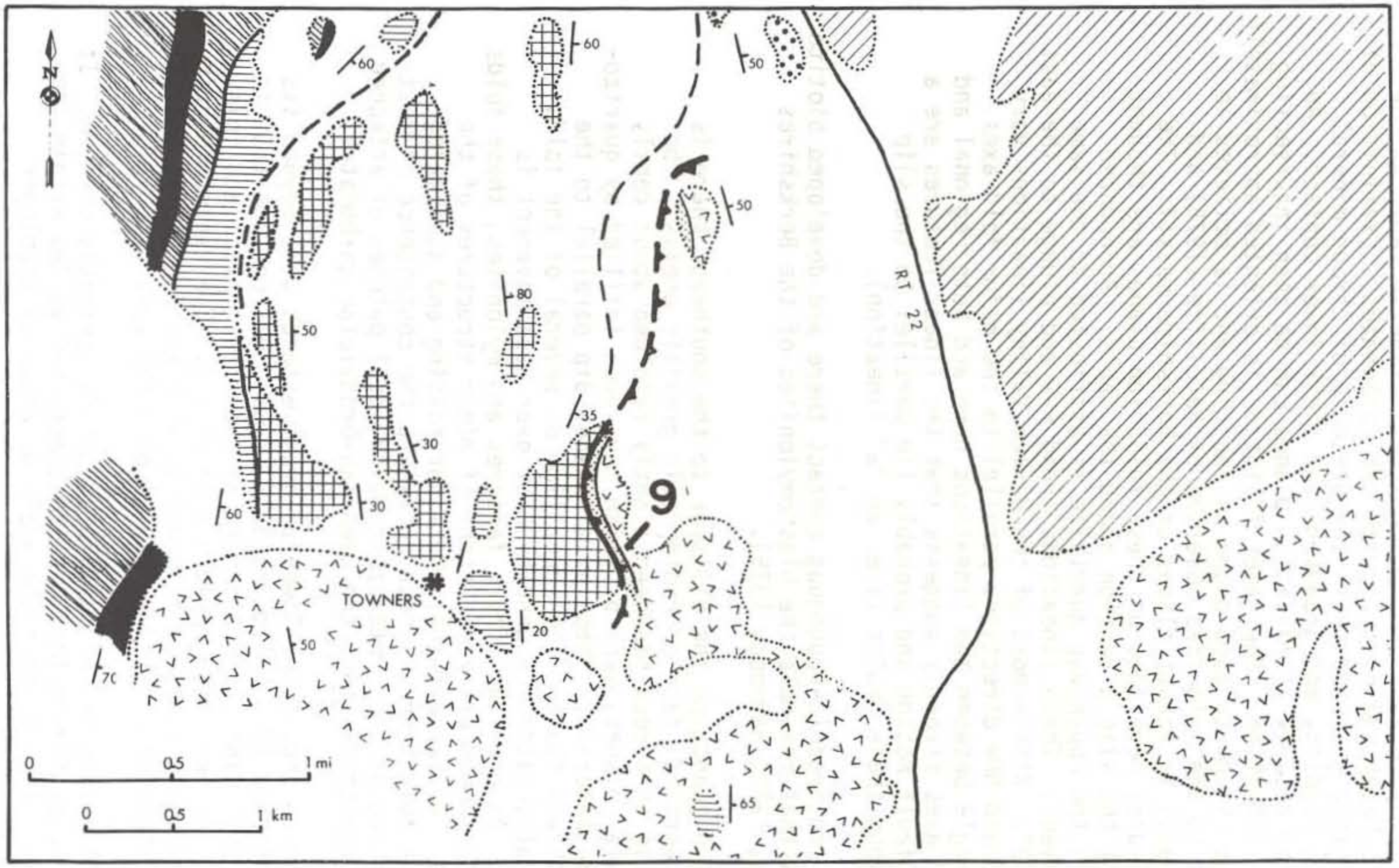


Fig. 6. Geology in the vicinity of Stop 9, near Towners, N.Y. Symbols the same as in Fig. 2.

displacement. However, this control is not necessary in order to demonstrate that low angle faulting was extremely likely in this area. Balk (1936) concluded that fabrics and minor structures in the surrounding rocks strongly suggested a reverse fault at the Proterozoic/Poughquag contact with the carbonates. Examination of the Proterozoic gneisses shows the presence of strong mineral lineations, rodding, and grooving near their lower contact. An anastamozing network of foliation planes can be seen intersecting an earlier foliation. The later foliation is oriented approximately parallel to the postulated plane of faulting and is believed to be similar to the mylonites observed by Ratcliffe (1975) and Harwood (1975) in thrust slices of the Berkshire massif. The linear features developed on these foliation planes are thought to manifest the slip direction along the fault. Pronounced grooving in the Poughquag quartzite is attributed to the same tectonic event. These lineations trend E-W and plunge to the east at about 40°. Within most of the Harlem Valley lineations vary around NNE and NNW directions parallel to the major fold axes. The high angle between the lineations here and both regional and local fold axes strongly suggests that the linear features are a result of fault motion and probably lie parallel to the slip vectors along these faults (i.e. an "a" lineation).

At the Proterozoic-Poughquag contact there are developed biotite rich seams that resemble the blastomylonites of the Berkshires (Ratcliffe, 1975; Harwood, 1975).

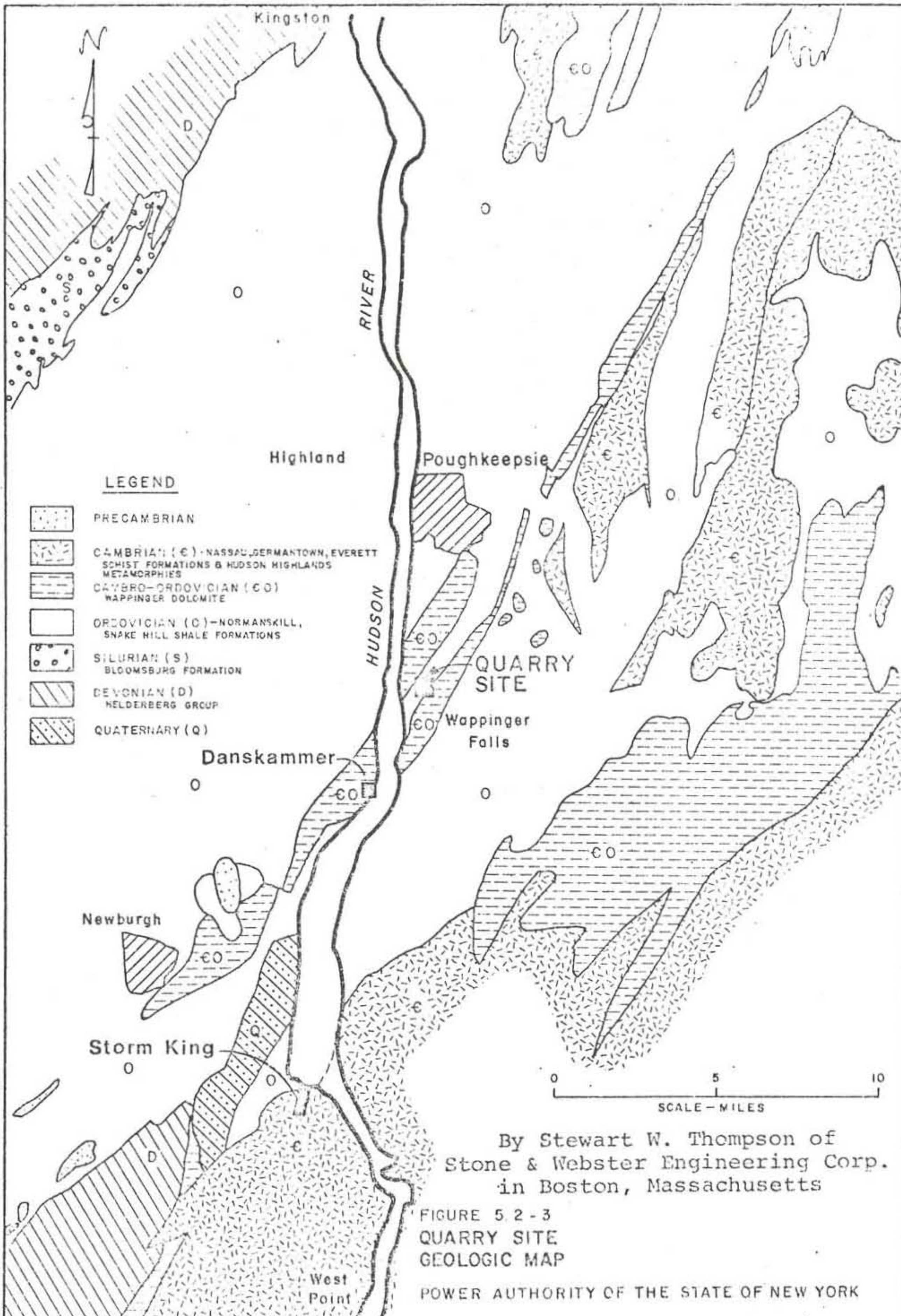
A short distance up the hillside to the southeast there is exposed a vertical face of Proterozoic granitic gneiss. The foliation in this rock has been tightly refolded about gently dipping axial planes, many of which have been infilled by quartzo-feldspathic material. These axial planes dip parallel to the presumed thrust fault. The lower limb of several of the folds have been attenuated. A general East over West movement is indicated. As with the linear features and mylonites, these folds and granitic seams are reminiscent of minor structures of the Berkshires. We believe that the minor folding and associated axial plane foliation in these rocks are the consequence of westward thrusting of the Proterozoic, with local patches of attached Poughquag quartzite, over the Cambrian-Ordovician carbonates.

As shown on fig. 6 the Towners Thrust extends well beyond its exposure at Stop 10. Following Balk (1936), we conclude that it is likely that Pine Island is part of the thrust plate and this hypothesis has been incorporated into fig. 6. The eastern margin of the thrust plate cannot be drawn in with any certainty, and we have not attempted to extrapolate beyond Pine Island.

The full extent of the Towners Thrust is presently unknown. It may continue southward into the pronounced N-S valley within the Proterozoic. In this case the small outcrops of Wappinger carbonates in this valley may represent tectonic slivers along the sole of the thrust. Alternatively the trace of the thrust may pass along the Proterozoic-Paleozoic contact west of Towners (fig. 6), and then swing to the south at the western margin of this Proterozoic block. This is essentially the pattern shown on the 1973 edition of the New York State Geological map. Such a trace would explain the abrupt truncation of the carbonate shelf sequence by the Proterozoic just to the west of Towners. It would also explain the fact that, along its western contact, this mass of Proterozoic appears to overly shelf carbonates. A third possibility is that the abrupt termination of the Paleozoic stratigraphy west of Towners is due to a WNW high angle fault that connects the thrust at Cornwall Hill with its continuation along the N-S Proterozoic-Paleozoic contact west of Towners. In this case the small carbonate bodies referred to above as possible tectonic slivers might possibly lie within erosional windows through the overlying Proterozoic thrust sheet.

The regional extrapolation of the Towners Thrust remains a major research problem in the area. Together with Corbin Hill, it raises the possibility that portions of the Hudson Highlands may be parautochthonous, as in the Berkshires, or even allochthonous, as suggested by Isachsen (1964).

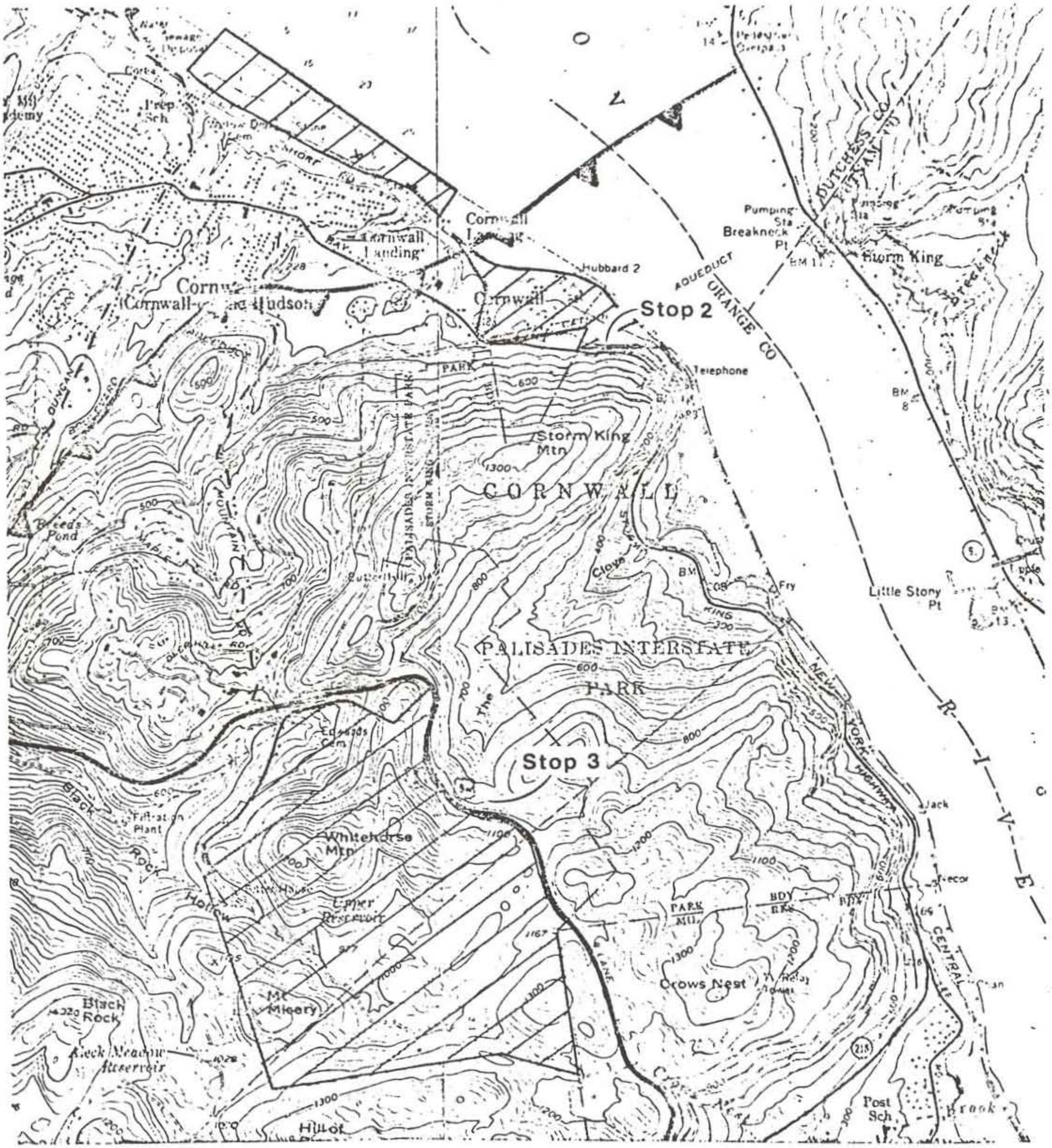
End Road Log



By Stewart W. Thompson of
Stone & Webster Engineering Corp.
in Boston, Massachusetts

FIGURE 5.2-3
QUARRY SITE
GEOLOGIC MAP

POWER AUTHORITY OF THE STATE OF NEW YORK



CORNWALL

Property Acreage - 700

WEST POINT, N.Y.

NW/4 WEST POINT 15' QUADRANGLE

N4122.5—W7352.5/7.5

1957

AMS 6266 IV NW—SERIES V821

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

In the Matter of CONSOLIDATED EDISON COMPANY OF NEW YORK, INC. and POWER AUTHORITY OF THE STATE OF NEW YORK (Indian Point Station, Units 1, 2 and 3)	))))))	Docket Nos. 50-3 50-247 50-286 (Show Cause - Seismic)

TESTIMONY OF DAMES & MOORE (PANEL) ON BEHALF OF LICENSEES ON ISSUE NO. 3

PANEL:

Joseph A. Fischer
Samir G. Khoury
Bernard Archer
Jerry Szymanski
Todd M. Gates
Umesh Chandra

FILED: July 2, 1976

A1. RAMAPO FAULT AND FRACTURE ZONE

A1.1 INTRODUCTION

The Ramapo Fault is considered in the literature to extend from Peapack, New Jersey to the vicinity of Ladentown. It is well defined from Oakland, New Jersey to about Ladentown, New York (see Plate A1-1). Along this extent it has a strong topographic expression and its trace generally follows the Ramapo and Mahwah Rivers and the eastern escarpment of the Ramapo Mountains. The Ramapo Fault also serves as the northwestern border of the northern end of the Newark-Gettysburg Basin. Northeast of Ladentown, the trend of the Ramapo Fault departs from the western border of the Triassic Basin and branches into a wide zone of less well-defined faults. The faults within this northeastern extension are part of the Ramapo fracture zone. The faults of the fracture zone, together with the Ramapo Fault, are here collectively referred to as the Ramapo system of faults.

The following sections describe the character of some members of the fault system that have been identified to date. The segments described are illustrated on Plate A1-1 and include the Ramapo Fault, the Letchworth Fault, the Thiells Fault, the Cedar Flats Fault, the Mott Farm Road Fault, and the Timp Pass Fault. A regional geologic map was also compiled from the published literature (Plate A2-1) showing the distribution of the major rock types and prominent structural features in the region.

A1.2 THE RAMAPO FAULT

The mapped trace of the Ramapo Fault trends between N30° to 40°E (Plate A1-1). Along its entire length, the Ramapo Fault separates the Hudson Highlands from the Triassic Basin. Several large bodies of Mesozoic diabase are spatially related to it at Ladentown, and Union Hill, New York.

The main brecciation of the Ramapo Fault occurs in Precambrian gneiss that lies just to the east of the base of the eastern escarpment of the Ramapo Mountains. This area is poorly exposed and covered by flood-plain sediments. A traverse from the Highlands into the Triassic Basin at Suffern, New York, reveals that the intensity of fracturing and shearing increases toward the fault zone.

Two localities within the fault zone were examined during this phase of the investigation. At the mouth of Stag Brook dark cataclastic rocks and healed breccia within the Precambrian gneiss have been densely refractured. The predominant shear orientations are N30°E and N60°E with both strike-slip and dip-slip slickensides and NNE to NNW shears with strike-slip slickensides. The youngest feature examined appears to be a gouge oriented N20°E, 75°SE that has dominantly horizontal slickensides and one set of possibly younger dip-slip slickensides.

Just south of Antrim, near the New York Thruway, healed, brecciated gneiss and dark cataclastic rocks occur (striking northeast and dipping to the south). The predominant younger

shears at this location strike ENE and dip greater than 10° to the south with dip-slip slickensides.

At an exposure in Antrim, EW, 25°S thrust faults are crosscut by N45°W vertical shears. A N45°E, 75°SE diabase dike truncates both of these features and in turn is cut by parallel northeast shears. The slickensides on the sheared dike pitch 30° to 50° NE. Another dike (N40°E, 47°SE) is truncated by a north-south vertical fault.

In addition to the early (Precambrian) brecciation and cataclasis, thrusting, strike-slip and dip-slip movement have occurred along this fault.

A1.3 THE THIELLS FAULT

The Thiells Fault is well defined between Tompkins Cove and Thiells, New York (see Plate A1-1). The following paragraphs describe key outcrops that serve to define this fault and the preliminary conclusions that have been drawn from each. Outcrop locations are shown on Plate A1-1, and a comparison between outcrop observations is given in Table A1-1.

A1.3.1 Outcrop N-225

Wappinger Limestone and Annsville Phyllite of Cambro-Ordovician age occur in a large exposure adjacent to the Lovett Power Plant. The phyllite is infolded and infaulted with the limestone, but, in general, lies to the west of it and east of the Precambrian Gneiss. A thrust surface that is subparallel to the near horizontal limestone bedding dips gently to the southeast and climbs section to the northwest. The rock types and the structures are markedly different across this surface. A

large N35°E vertical shear plane with a healed breccia and three sets of slickensides (0-20°, 30°, 60° SW) forms the southeastern face of this exposure. The near horizontal slickensides are the strongest and most common set. A series of second-order NS vertical shears extends north from this main shear. These crosscut the thrust plane and have breccia "pockets" developed along them, and near-horizontal slickensides.

Based on these observations, it appears that:

1) The Wappinger Limestone is thrust from SE to NW over the Annsville Phyllite at this locality.
2) This thrusting episode was followed by NE strike-slip faulting with NS second-order shears.

A1.3.2 Outcrop N-200

A fault-line scarp extends from N-225 for 3000 feet to N-200, where a mylonite occurs that appears to be on the easternmost exposure of Precambrian rocks. The mylonitic fabric is oriented N45°E, 60°SE and has a strong down-dip lineation. Although relatively intact, the mylonite does exhibit minor brittle deformation in the form of N35°E fractures.

The observed characteristics suggest that:

1) Large confining pressures were required to develop the mylonite.
2) Conditions of formation of the mylonite suggest that its development is not a recent event.

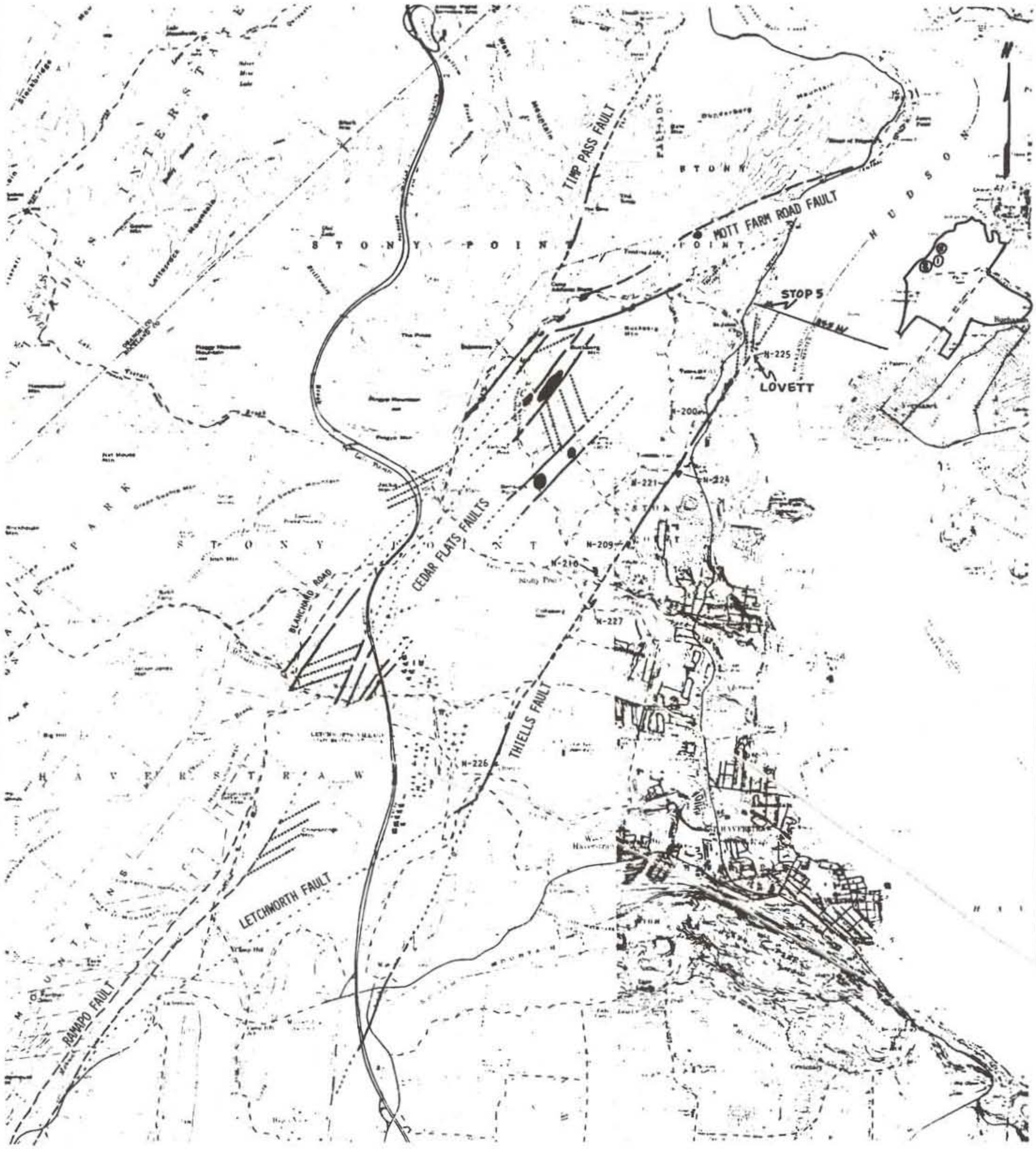
A1.3.3 Outcrop N-224

The same escarpment extends 2000 feet farther to the southwest to a point across a small valley from a limestone

TABLE A1-1

THE THIELLS FAULT: OBSERVATION FROM KEY OUTCROPS

Outcrop	Faults	Slickenside Orientation	Inferred Movement Shears	Character and Relationships
N-225	NE thrust dip <30°SE	≈90°pitch	parallel to dip	Decollement
	NE vertical shears	0-20°,30°,60° SW	strike-slip (several episodes)	Main Shear
	NS vertical shear	near horizontal	left-lateral strike slip	Second-order shear to NE shears Cross-cuts thrusts
N-200	N45E 60SE mylonite	down dip lineation	possible thrust?	Healed
	N35E vertical fractures			Cross-cut mylonite
N-224	N10E to 10W, 60-80 SE breccias		thrust	Bedding plane breccias
	N10-20E vertical shear	near horizontal	strike slip	Cross-cut bedding plane breccias
N-221	N30E 45SE mylonite		thrust	Healed
	N25E vertical shear		right lateral? strike slip	Main shear cross cuts mylonite
	N50E, 60°NW fractures			Second-order shear
	N20E, 40SE breccias		thrust	Solution breccia along bedding plane thrust
	EW, vertical breccias		dilation-tear fracture	Solution breccia



LOCATION MAP OF THE RAMAPO AND ASSOCIATED FAULTS

SCALE

MILES 0

0 KILOMETERS

KEY:

— — - - -	FAULTS, FAULT ZONES (SOLID WHERE KNOWN DASHED WHERE APPROXIMATE DOTTED WHERE INFERRED
....	"SECOND ORDER" SHEARS AND FRACTURE
●	BRECCIA EXPOSURE
N-208	LOCATIONS MENTIONED IN TEXT

PLATE A1-1

STRUCTURAL SYMBOLS

NORMAL FAULT

FAULT DASHED WHERE APPROXIMATE

STRIKE-SLIP FAULT

SHEAR ZONE

LITHOLOGIC CONTACTS DASHED WHERE APPROXIMATE

KEY

TRIASSIC-JURASSIC

TRIASSIC-JURASSIC NEWARK GROUP

TR D - TRIASSIC DIABASE

DEVONIAN

PEEKSKILL PLUTON

CAMBRO-ORDOVICIAN

ROSETOWN COMPLEX

CORTLANDT COMPLEX

MANHATTAN FORMATION (SCHIST) - ANNSVILLE PHYLLITE

INWOOD FORMATION (MARBLE) WAPPINGER LIMESTONE

LOWERRE - POUGHQUAG QUARTZITE

PRECAMBRIAN

FORDHAM FORMATION (GNEISS)

CANOPUS PLUTON

UNDIFFERENTIATED GRENVILLIAN METAMORHIC
AND IGNEOUS ROCKS

GENERALIZED GEOLOGICAL MAP

SCALE

1/2 0 1 MILE

0 1 KILOMETER


MANHATTAN PRONG

QUARRY

5.5 SUMMARY

The Quarry site is approximately 1.5 miles south of Poughkeepsie, New York, and geographically in the Hudson Champlain Valley Province, a low-lying, moderate-relief terrain that is underlain by moderate to highly deformed, partially metamorphosed Cambrian and Ordovician shales and carbonates. The site will be situated on thick glacial overburden consisting of an upper layer of silts and clays underlain by denser sands and gravels. The bedrock underlying this overburden is the Wappinger Dolomite, a very hard, crystalline carbonate, and the Snake Hill shale, a highly deformed shale.

This region has been subjected to multiple periods of deformation that terminated by the middle Mesozoic era (approximately 180 million years ago). Since that time, the region has been tectonically inactive with the exception of crustal adjustments resulting from Pleistocene glaciation. The proposed plant facility, with grade elevation 50 feet, will be founded on piles driven into the dense sands and gravels. The upper 50 to 60 feet of soil are too weak to support the plant loads.

Seismic risk evaluation for the site, as determined from a study of historical earthquake events within a 200-mile radius of the proposed site, characterizes this region as having earthquakes of normal focal depth of low to moderate magnitude and intensity. The highest intensity earthquake felt at the site occurred on two occasions, both with an intensity V (MM). These earthquakes occurred on August 10, 1884, 70 miles from the site, and on June 7, 1974, near the western site boundary. The resultant horizontal groundmotion at the site is estimated to have been approximately 0.04g. From this determination it was recommended that a fossil fuel plant in this area be designed for a maximum horizontal goundmotion of 0.08g. 3

IV

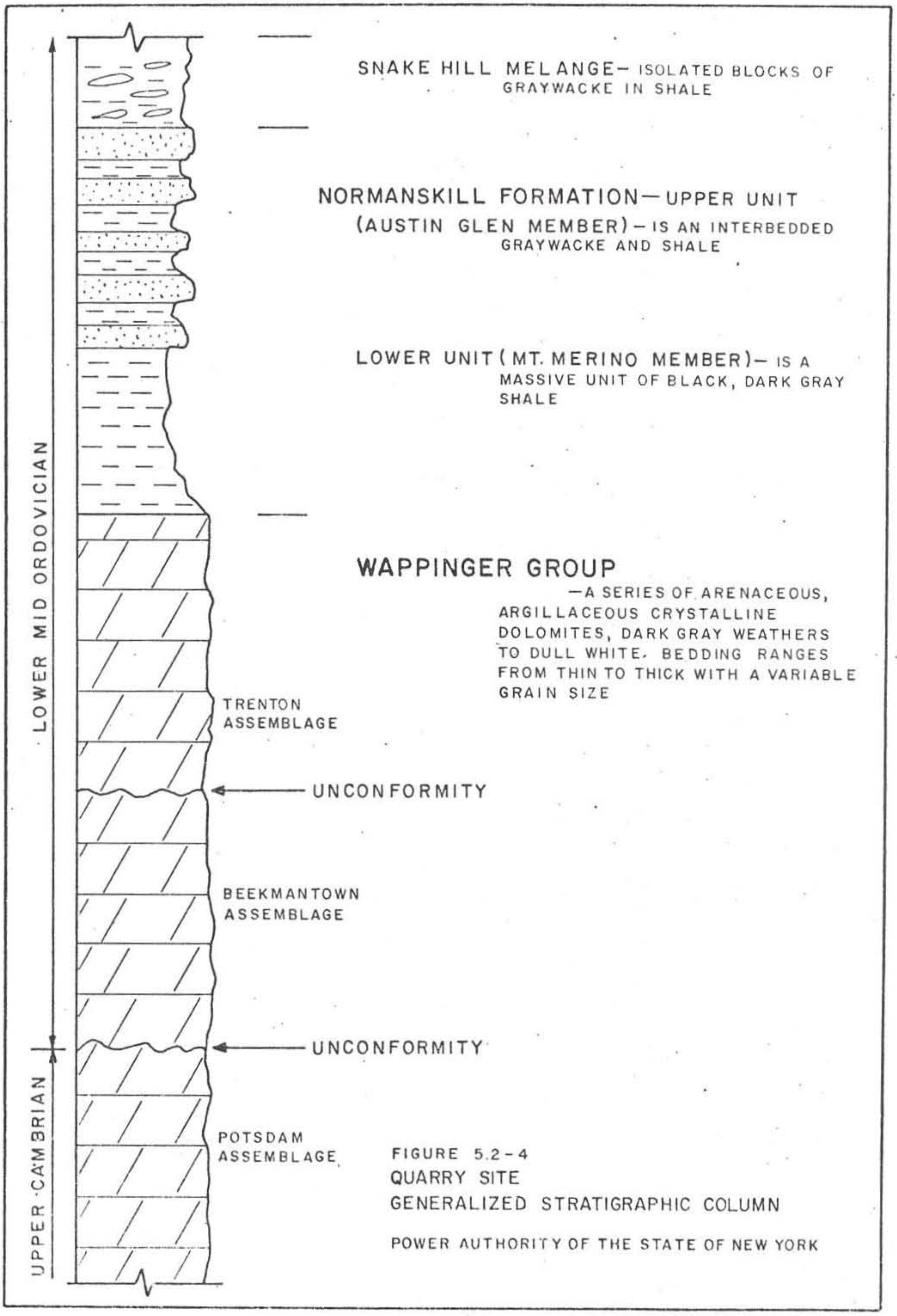


FIGURE 5.2-4
QUARRY SITE
GENERALIZED STRATIGRAPHIC COLUMN

POWER AUTHORITY OF THE STATE OF NEW YORK

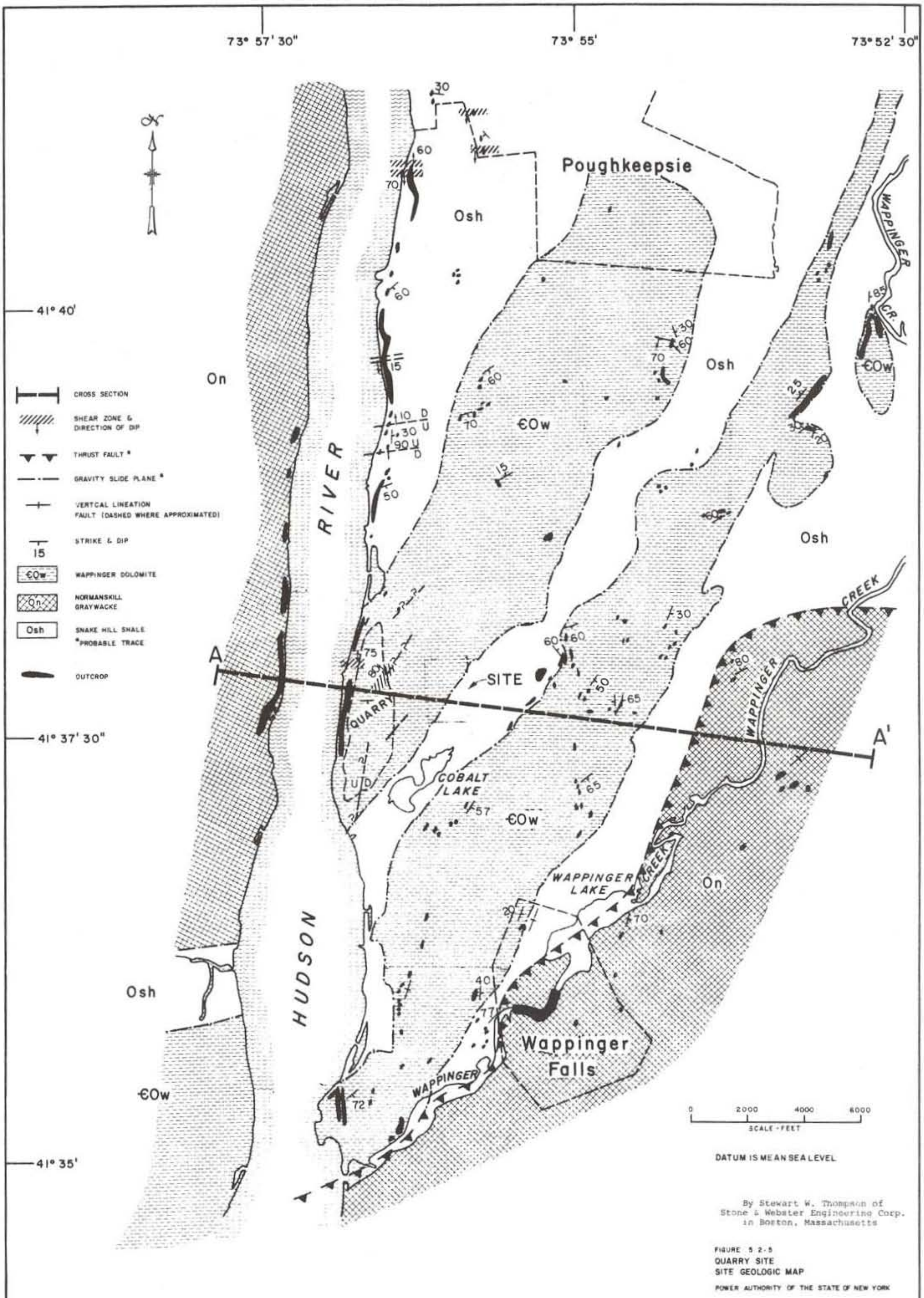


FIGURE 5.2-5
QUARRY SITE
SITE GEOLOGIC MAP

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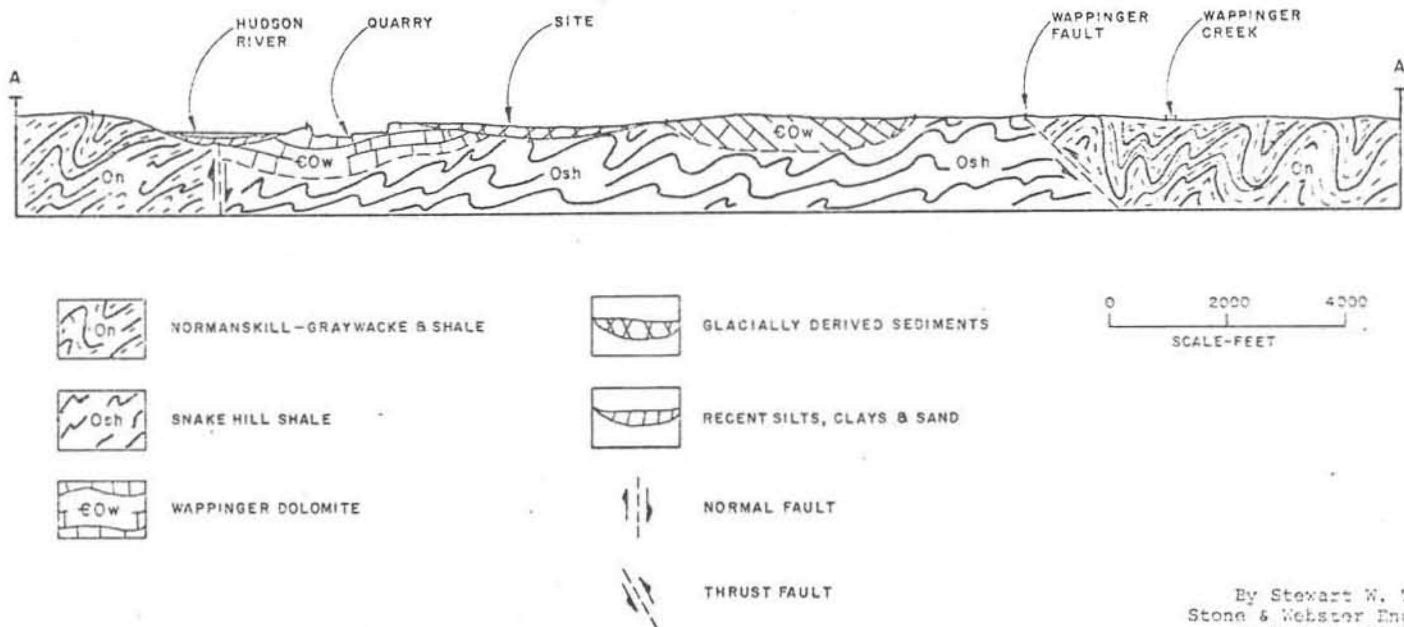

By Stewart W. Thompson of
Stone & Webster Engineering Corp.
in Boston, Massachusetts

FIGURE 5.2-6
QUARRY SITE
GEOLOGIC & SUBSURFACE SECTION A-A'

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