Trip C-7

Stratigraphy and Structural Geology in the Harlem Valley, S.E. Dutchess County, New York*

by

James M. McLelland
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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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.

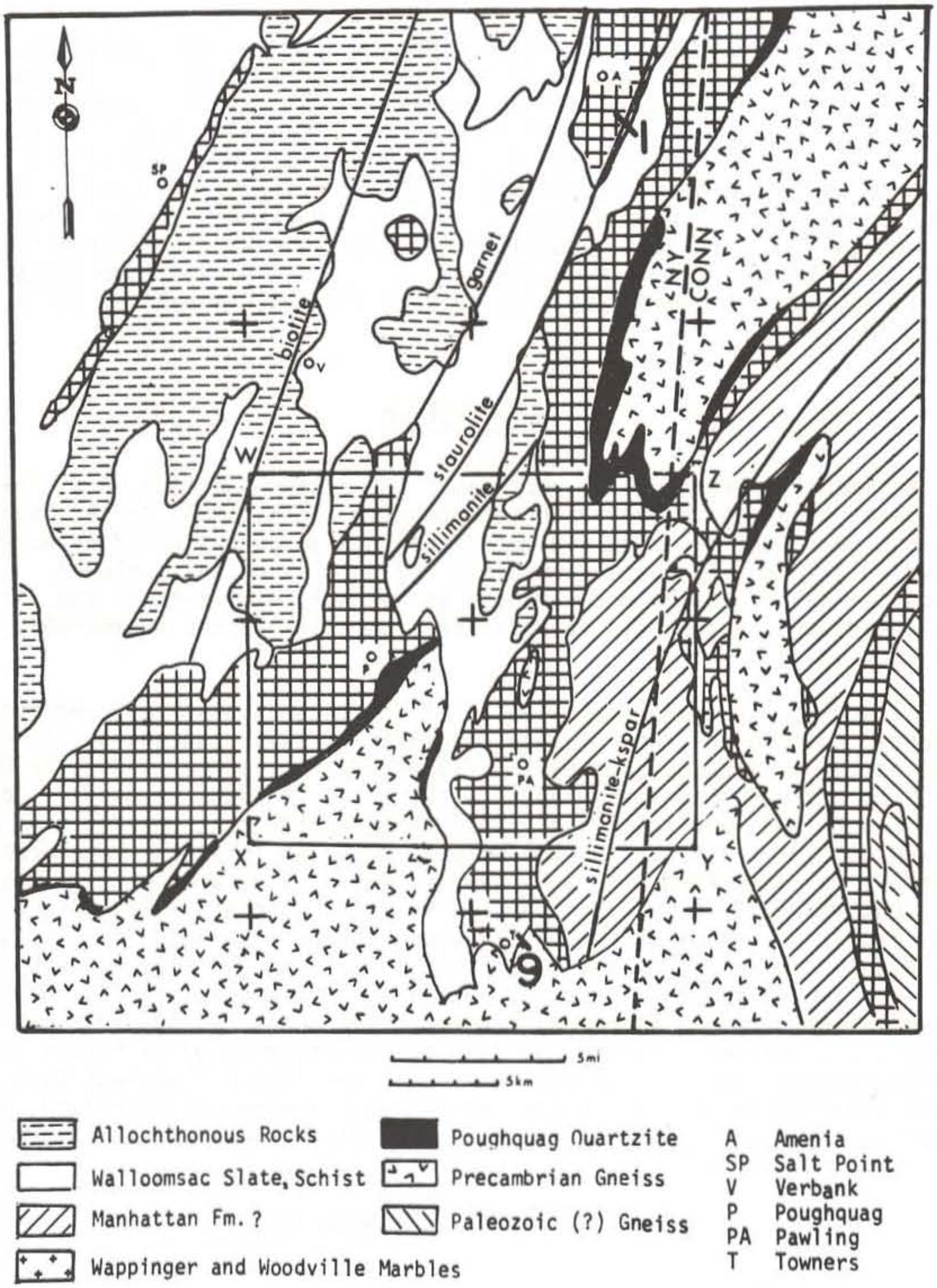


Fig. 1. Generalized geology and isograds of southeastern New York. Stops 1 and 9 indicated. (After Vidale, 1974) Rectangular area in heavy lines refers to Fig. 3 of Bence and McLelland, trip B-7.

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

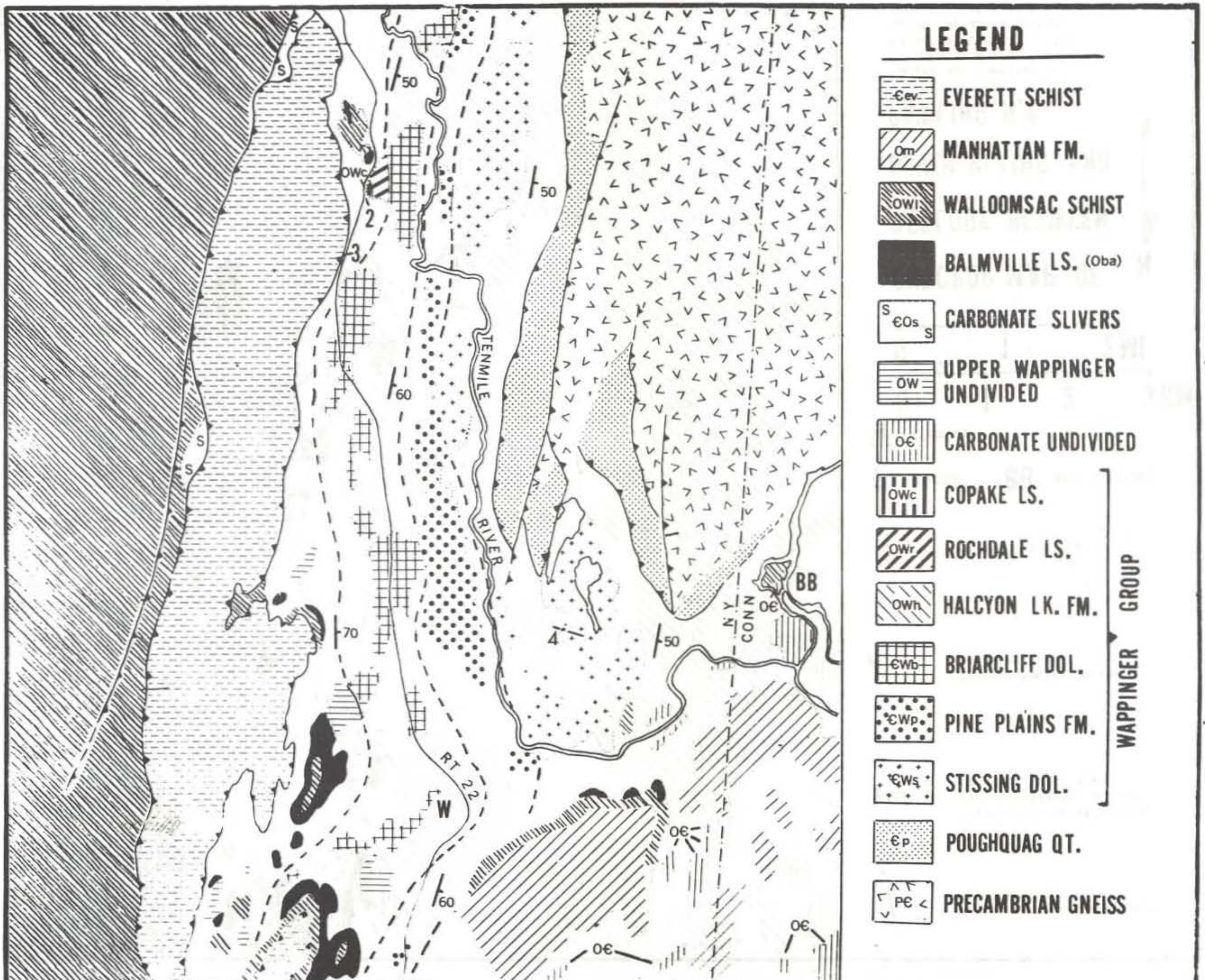
The Amenia-Pawling Valley represents the eastern section of a classic sequence of progressive Barrovian metamorphism (Balk, 1936; Barth, 1936). In recent years the isograds and metamorphism have been studied by Rosemary Vidale (1974) and A.E. Bence (see Bence and McLelland, this volume). The progressive 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
Єev
EVERETT SCHIST
Om
MANHATTAN FM.
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WALLOOMSAC SCHIST
BALMVILLE LS. (Oba)
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UPPER WAPPINGER UNDIVIDED
OЄ
CARBONATE UNDIVIDED
OWc
COPAKE LS.
OWr
ROCHDALE LS.
OWh
HALCYON LK. FM.
ЄWb
BRIARCLIFF DOL.
ЄWp
PINE PLAINS FM.
ЄWs
STISSING DOL.
WAPPINGER GROUP
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POUGHQUAG QT.
PЄ
PRECAMBRIAN GNEISS
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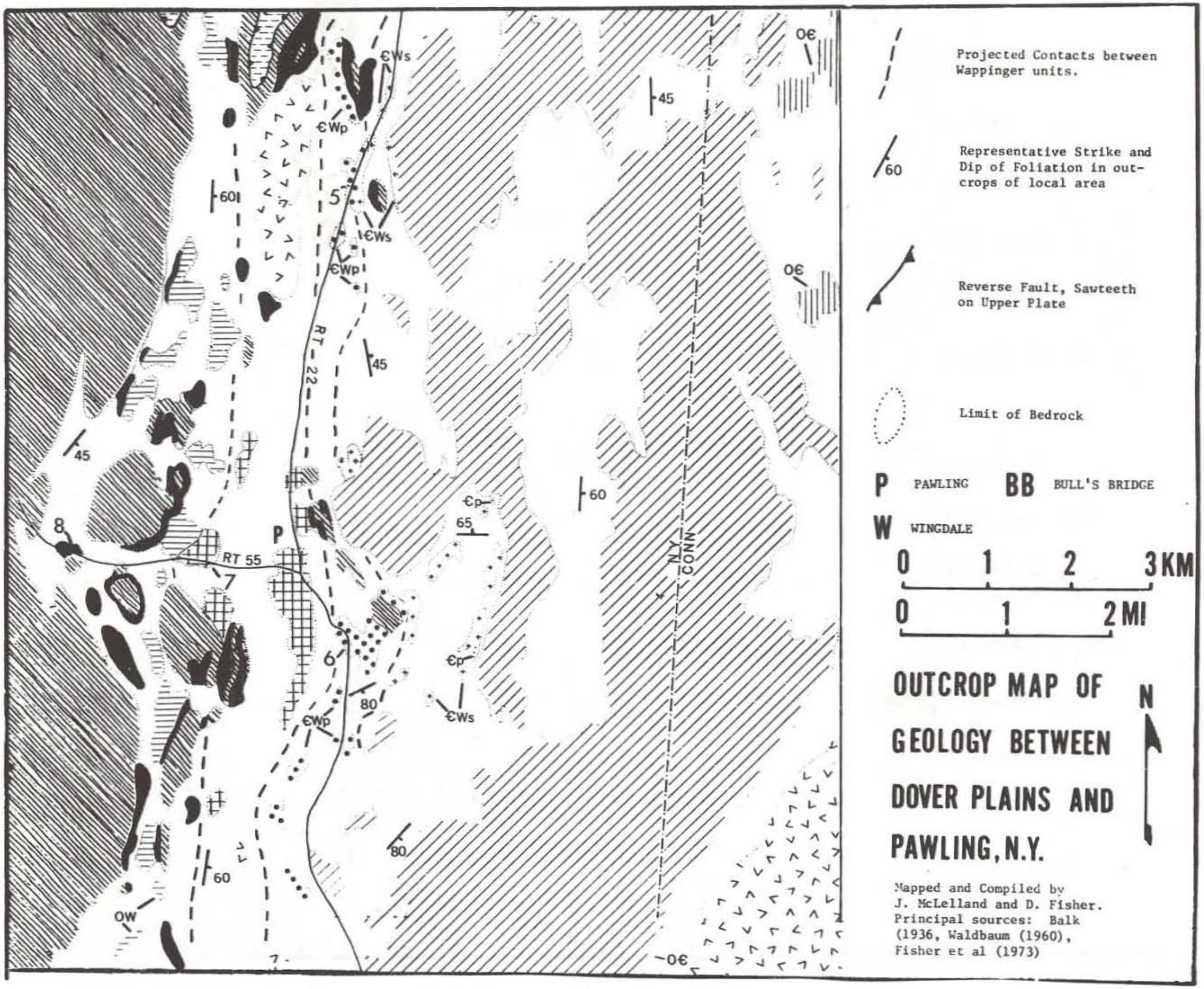

Fig. 2. Geologic map of the Dover Plains - Pawling Valley.

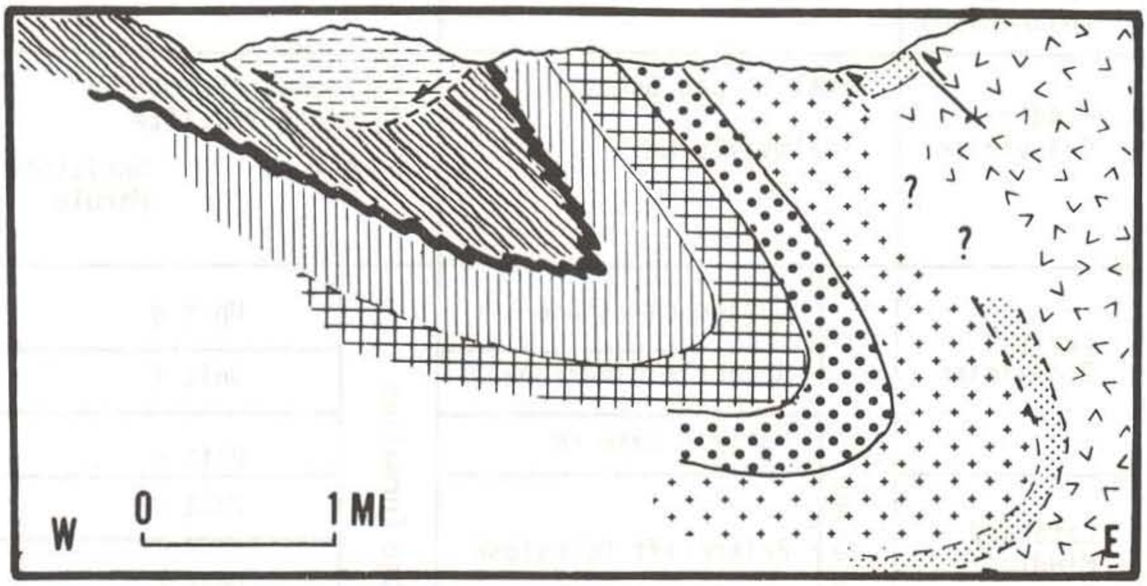

Fig. 3a - Schematic E-W cross section of Harlem Valley Syncline along a line through Nellie Hill. Symbols as in fig. 2.

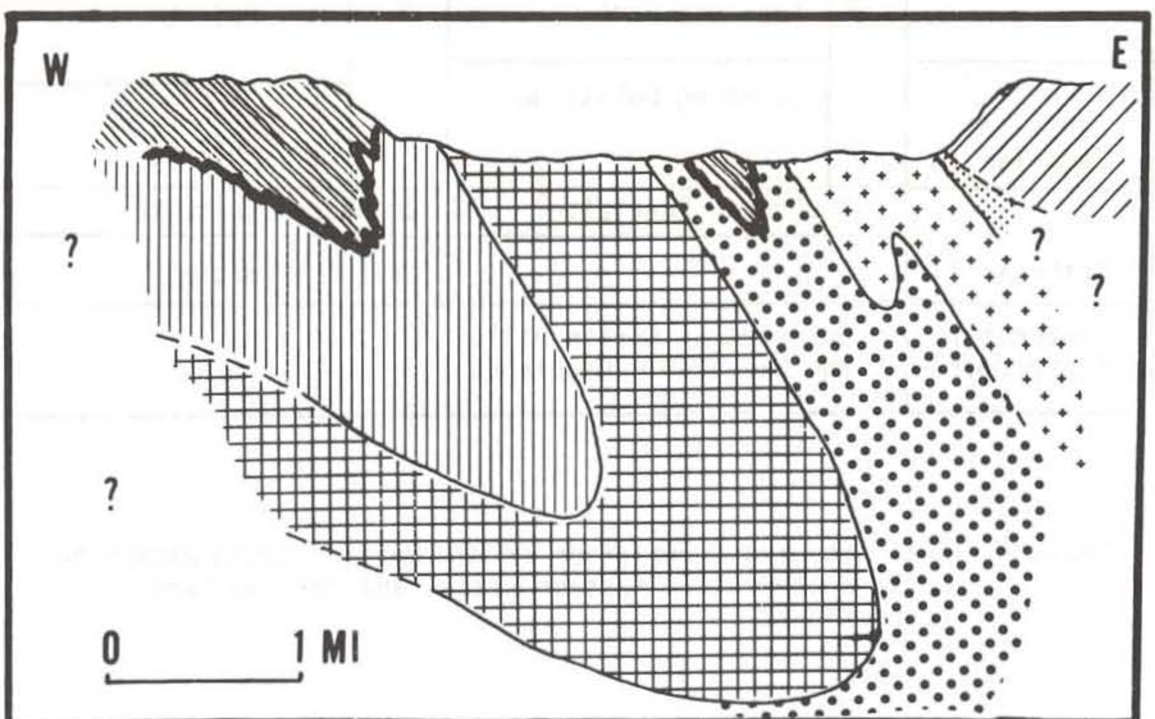

Fig. 3b - Schematic E-W cross section of Harlem Valley Syncline along a line subparallel to NY 55. Symbols as in fig. 2.

<table>
<tr><th>Age</th><th colspan="2">Amenia-Pawling Valley</th><th colspan="2">Bashbish Falls quadrangle
State Line quadrangle
(Zen and Hartshorn, 1966)
(Ratcliffe, 1969)</th></tr>
<tr><td>Earliest Cambrian or Proterozoic (Hadrynian)</td><td colspan="2">Manhattan B, C, Schist
Everett Schist</td><td colspan="2">Everett Formation
Nassau Formation</td></tr>
<tr><td>Middle Ordovician</td><td colspan="2">Walloomsac Schist
Balmville Ls.</td><td colspan="2">Walloomsac Formation
Egremont Phyllite
Limestone Schistose Marble</td></tr>
<tr><td rowspan="3">Early Ordovician</td><td rowspan="7">Wappinger Group</td><td>Copake Limestone</td><td rowspan="7">Stockbridge Formation</td><td>Unit g</td></tr>
<tr><td>Rochdale Limestone</td><td>Unit f</td></tr>
<tr><td>Halcyon Lake Fm.</td><td>Unit e</td></tr>
<tr><td rowspan="3">Late and Middle Cambrian</td><td rowspan="2">Briarcliff Dolostone</td><td>Unit d</td></tr>
<tr><td>Unit c</td></tr>
<tr><td>Pine Plains Fm.</td><td>Unit b</td></tr>
<tr><td>Early Cambrian</td><td>Stissing Dolostone</td><td>Unit a</td></tr>
<tr><td rowspan="2">Cambrian ?</td><td colspan="2">Poughquag Quartzite</td><td colspan="2">Cheshire Quartzite</td></tr>
<tr><td colspan="2"></td><td colspan="2">Dalton Formation</td></tr>
<tr><td>Proterozoic (Helikian)</td><td colspan="2">Gneisses at Corbin Hill
and Housatonic Highlands</td><td colspan="2"></td></tr>
</table>

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 quartzofeldspathic 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

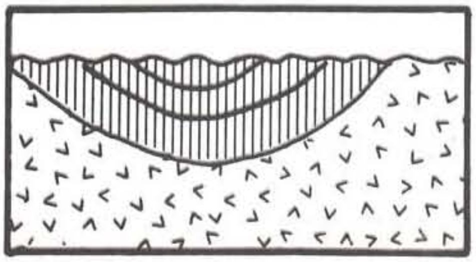

Fig. 4a - Development of early Middle Ordovician unconformity above gently folded shelf.

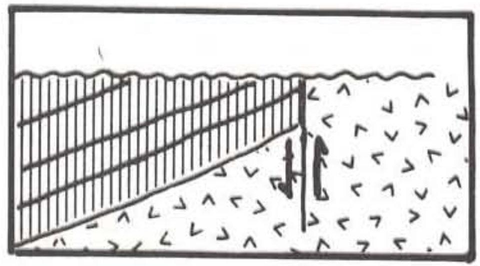

Fig. 4b - Development of early Middle Ordovician unconformity above rotated fault blocks.

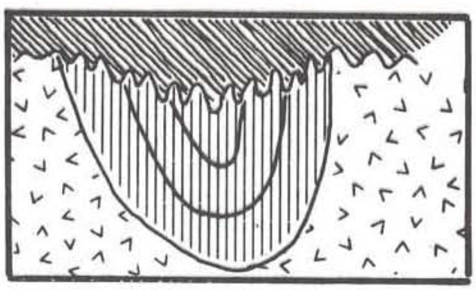

Fig. 4c - Middle Ordovician folding following deposition of Balmville-Walloomsac. Note folding of unconformity.

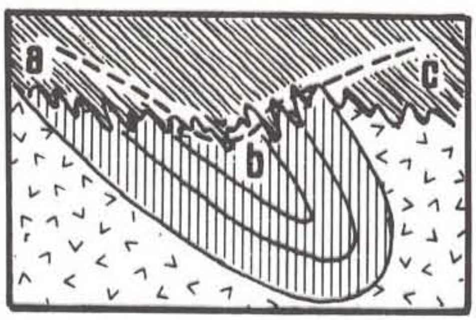

Fig. 4d - Culmination of Middle Ordovician folding and overturning. Unconformity gets in-folded. The dashed line abc represents a present day erosion surface.

(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

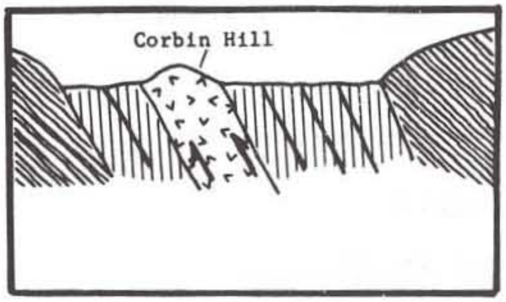


Fig. 5a - Corbin Hill as an upthrust block (Balk, 1936). Inconsistent with stratigraphy.

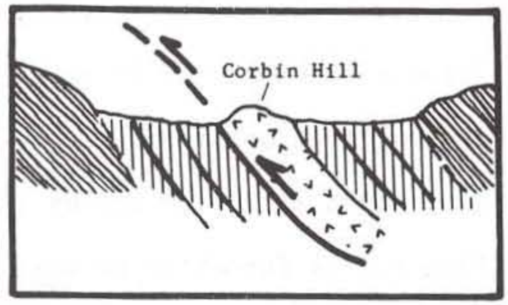


Fig. 5b - Corbin Hill as the basal unit in a large thrust sheet. Inconsistent with stratigraphy.

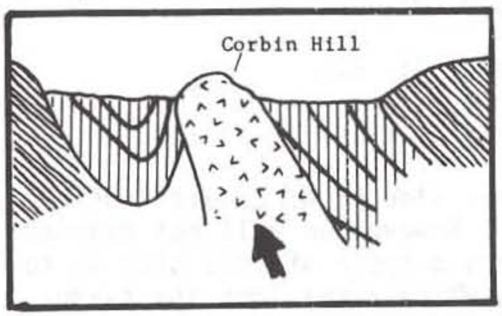


Fig. 5c - Corbin Hill as an up-punched gneiss dome. Inconsistent with stratigraphy.

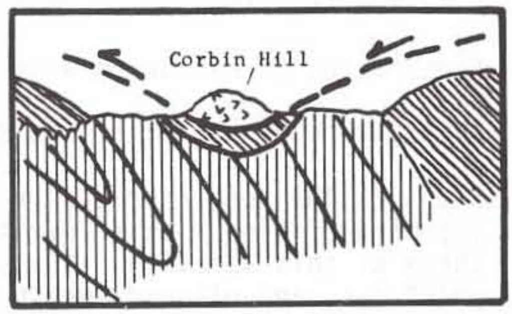


Fig. 5d - Corbin Hill as a far traveled thrust slice.

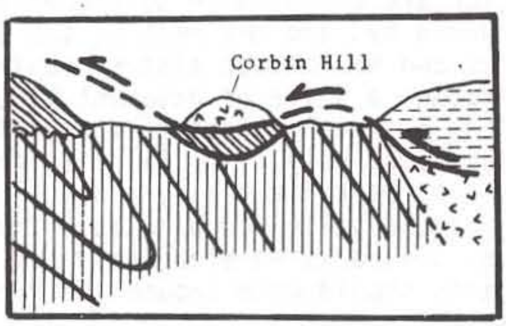


Fig. 5e - Corbin Hill as a tectonic slice on the sole of an Everett thrust sheet.

(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

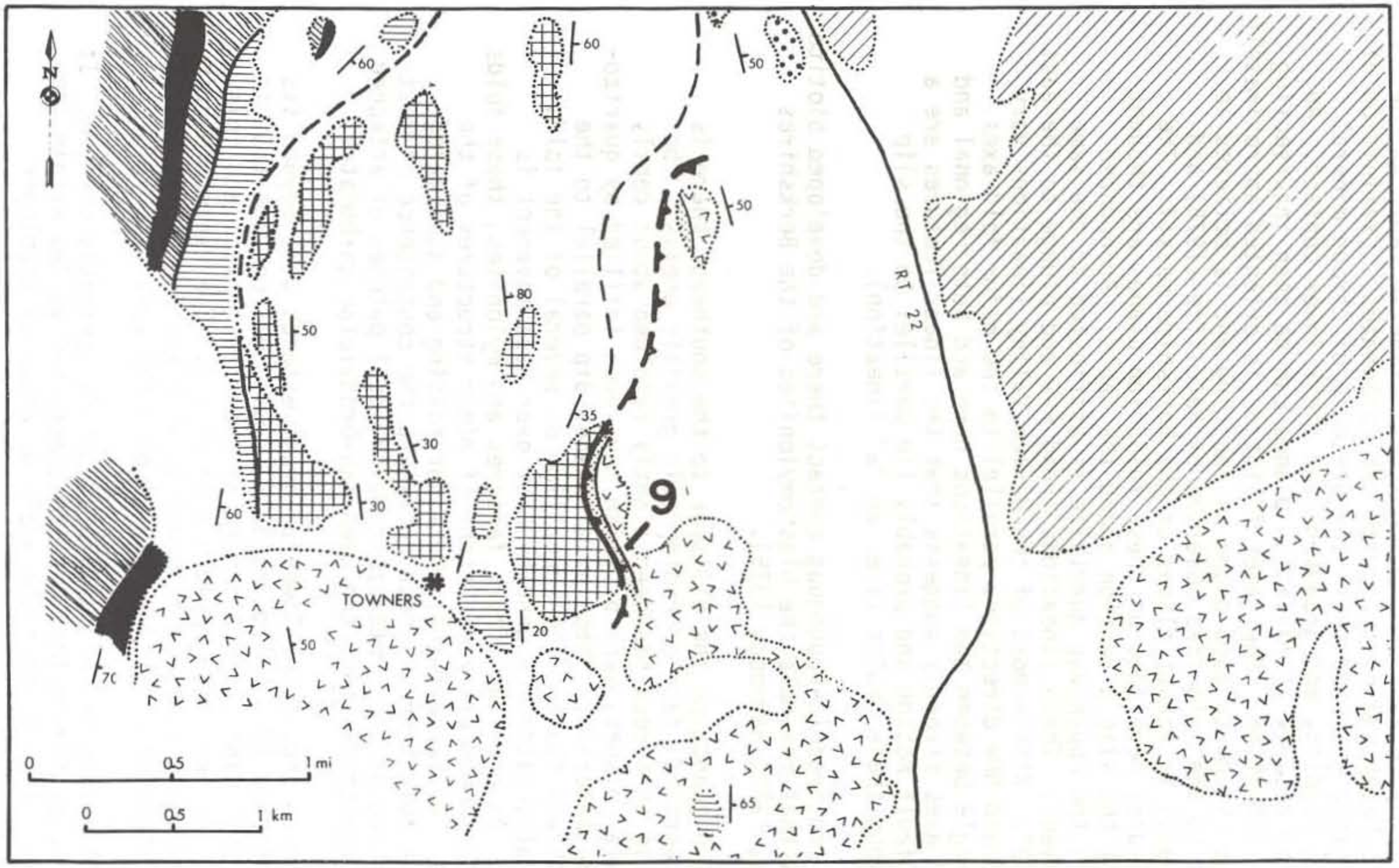


Fig. 6. Geology in the vicinity of Stop 9, near Towners, N.Y. Symbols the same as in Fig. 2.

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).

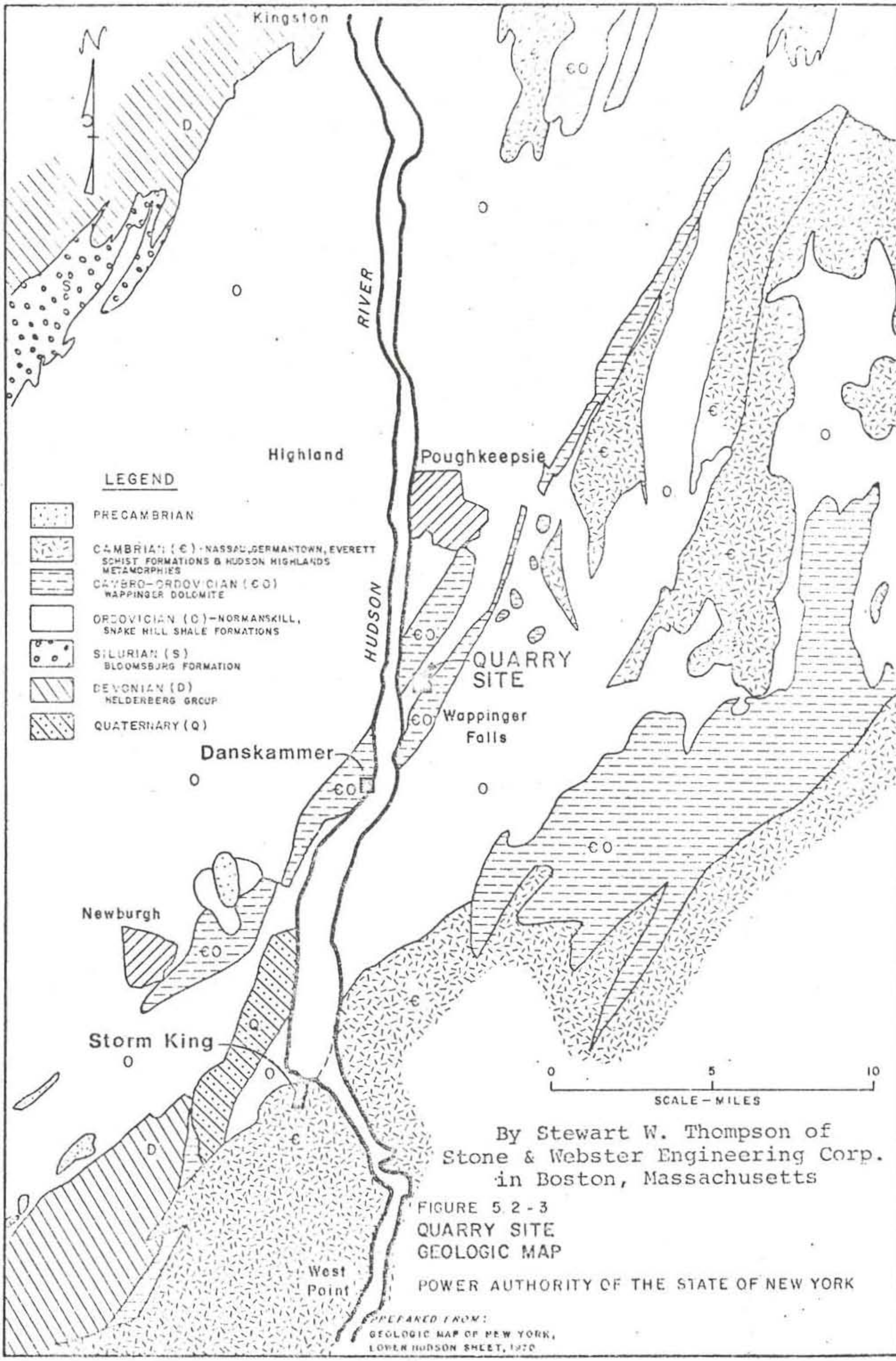
A short distance up the hillside to the southeast there is exposed a vertical face of Proterozoic granitic gneiss. The foliation in this rock has been tightly refolded about gently dipping axial planes, many of which have been infilled by quartzo-feldspathic material. These axial planes dip parallel 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).

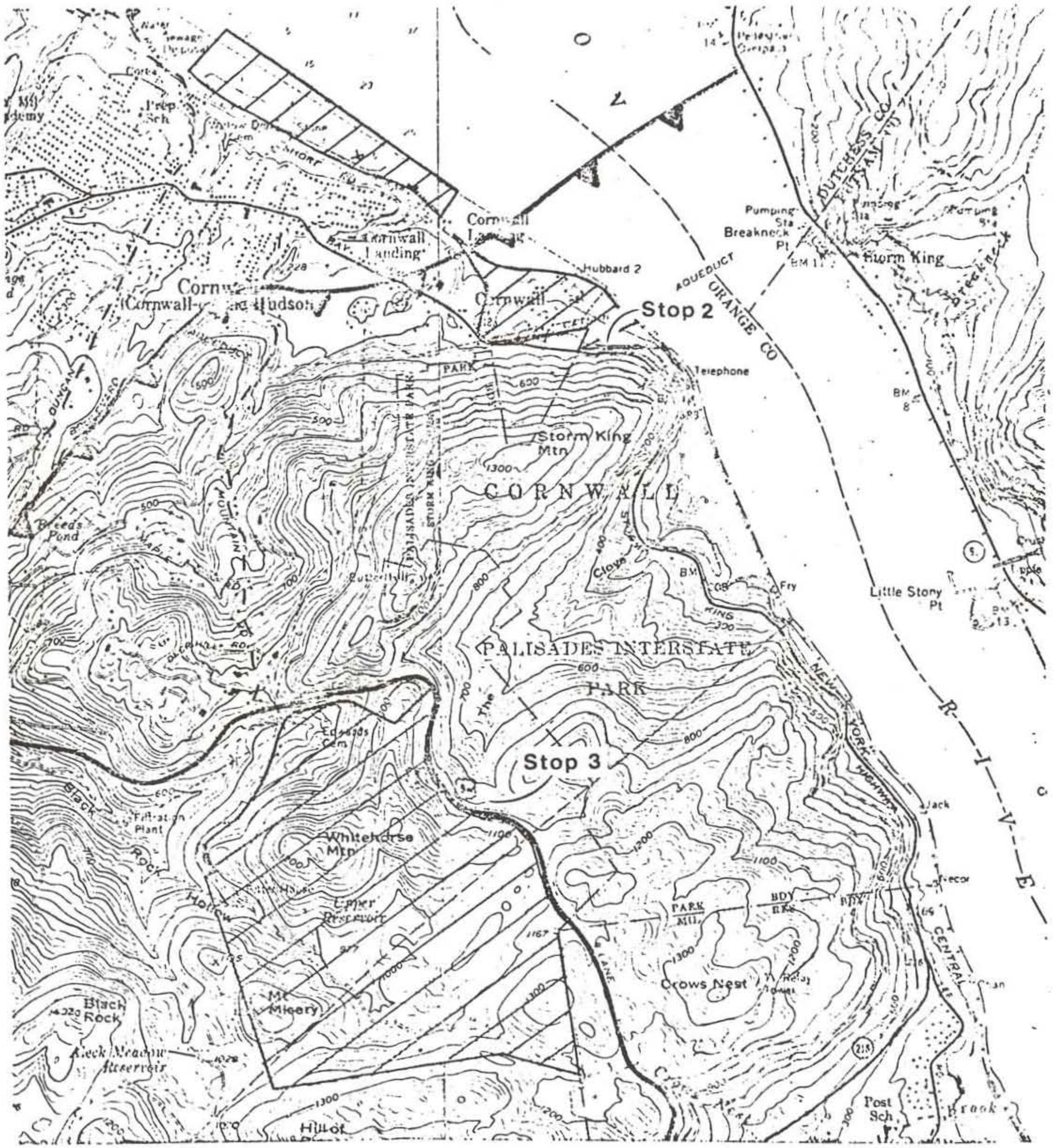
End Road Log



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

C-8-2

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.

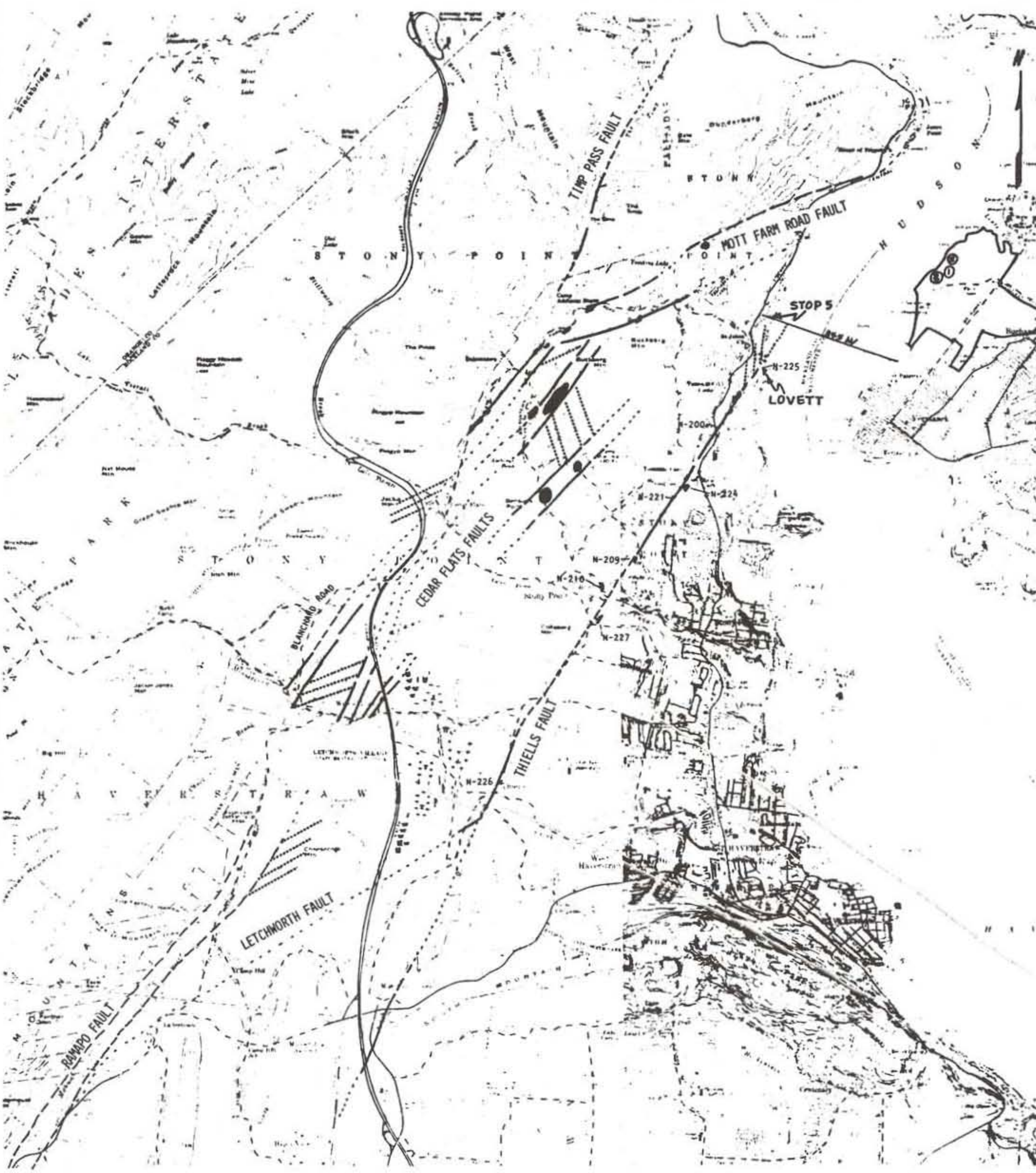
A1.3.3 Outcrop N-224

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

DAMES & MOORE

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
- ₮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

1 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 3 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.

IV

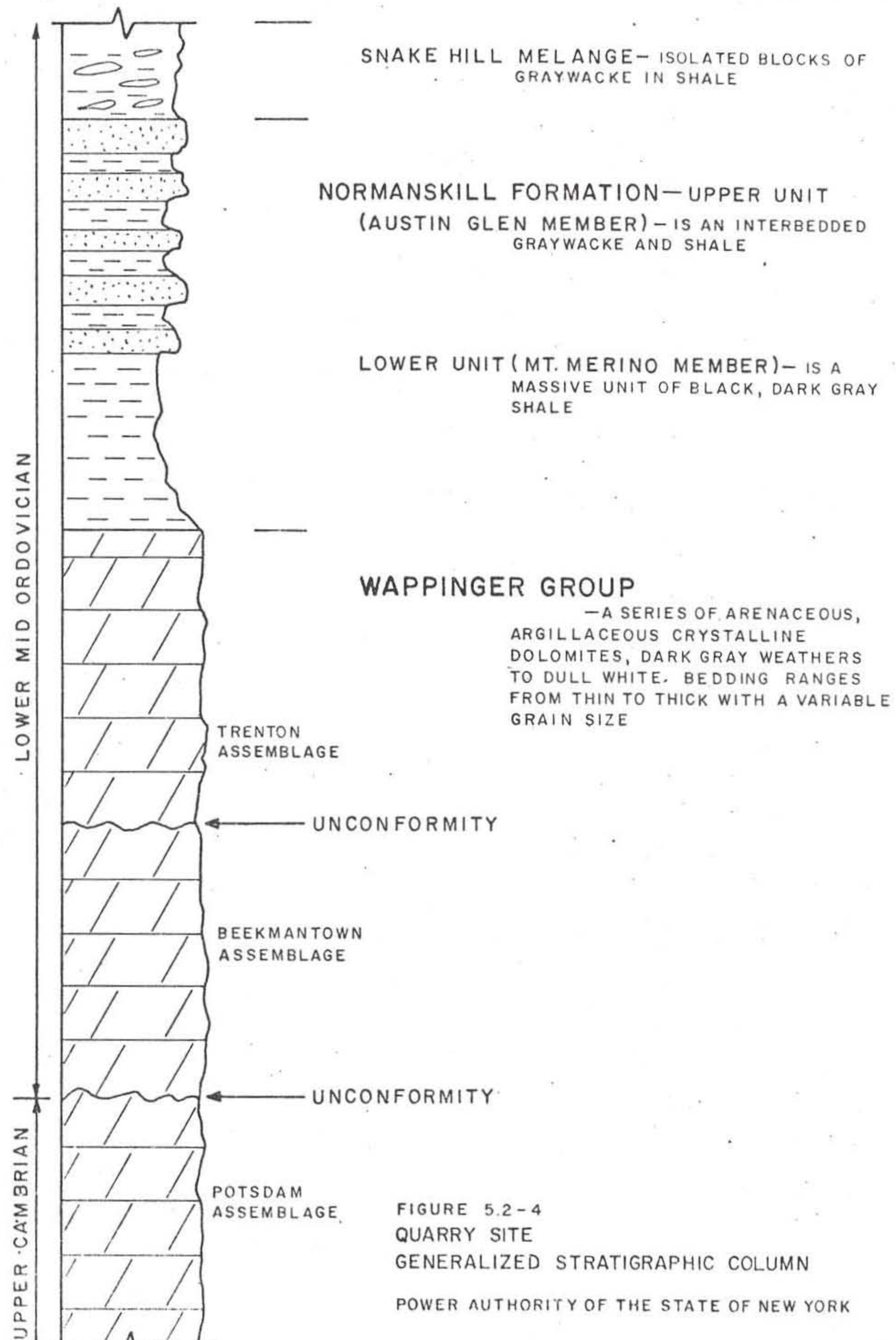


FIGURE 5.2-4
QUARRY SITE
GENERALIZED STRATIGRAPHIC COLUMN

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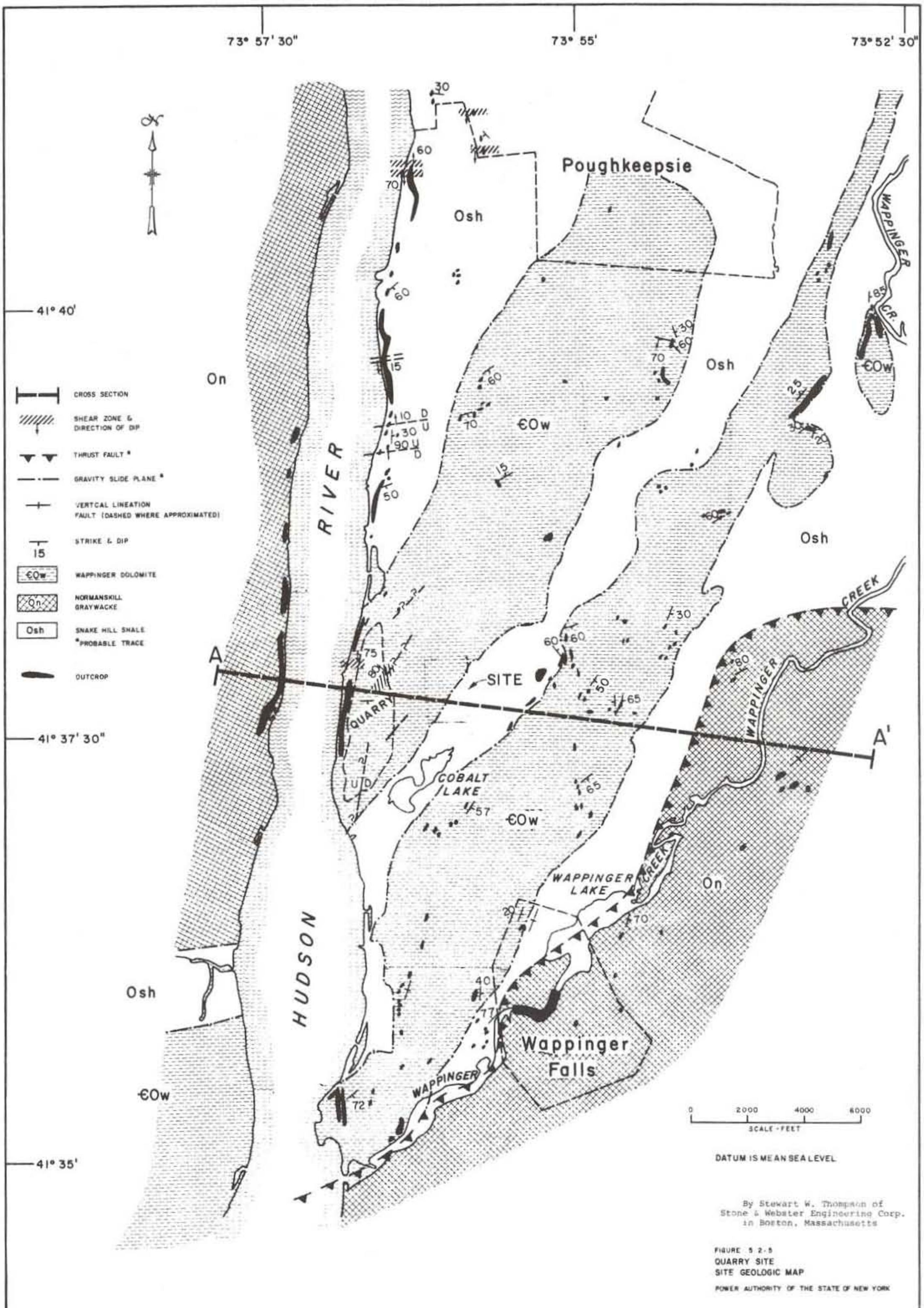

By Stewart W. Thompson of Stone & Webster Engineering Corp. in Boston, Massachusetts

FIGURE 5 2-5
QUARRY SITE
SITE GEOLOGIC MAP

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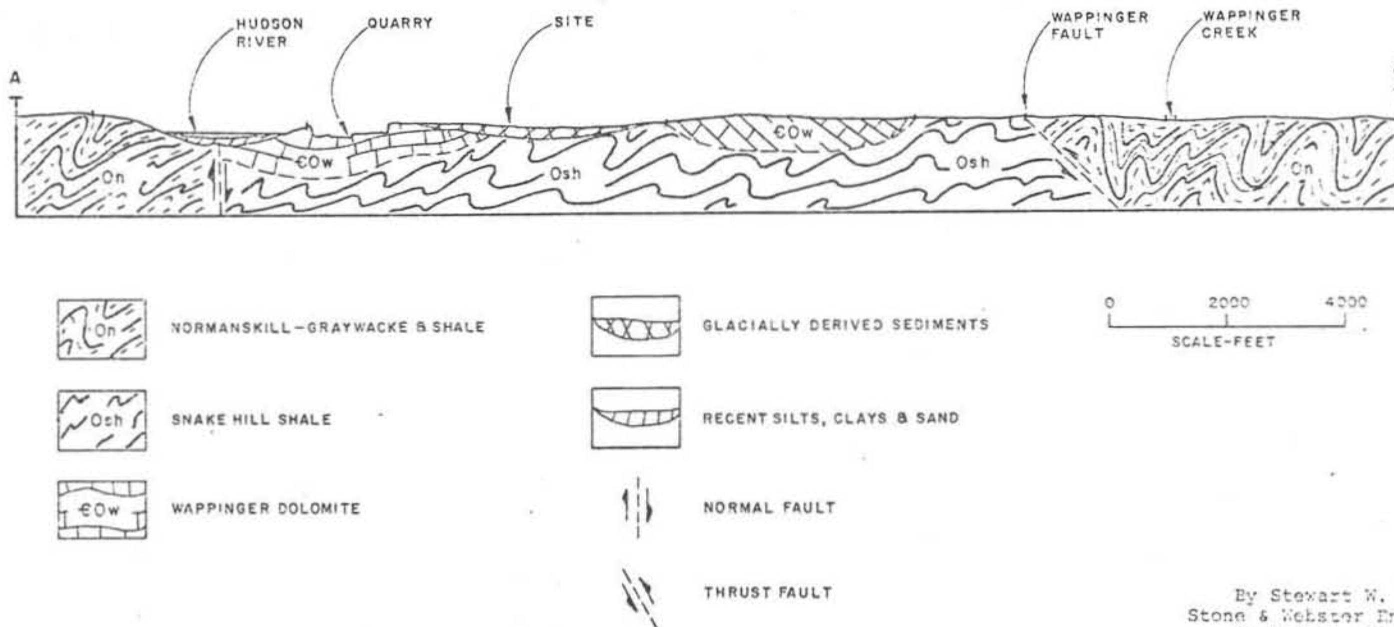

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in Boston, Massachusetts

FIGURE 5.2-6
QUARRY SITE
GEOLOGIC & SUBSURFACE SECTION A-A'

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