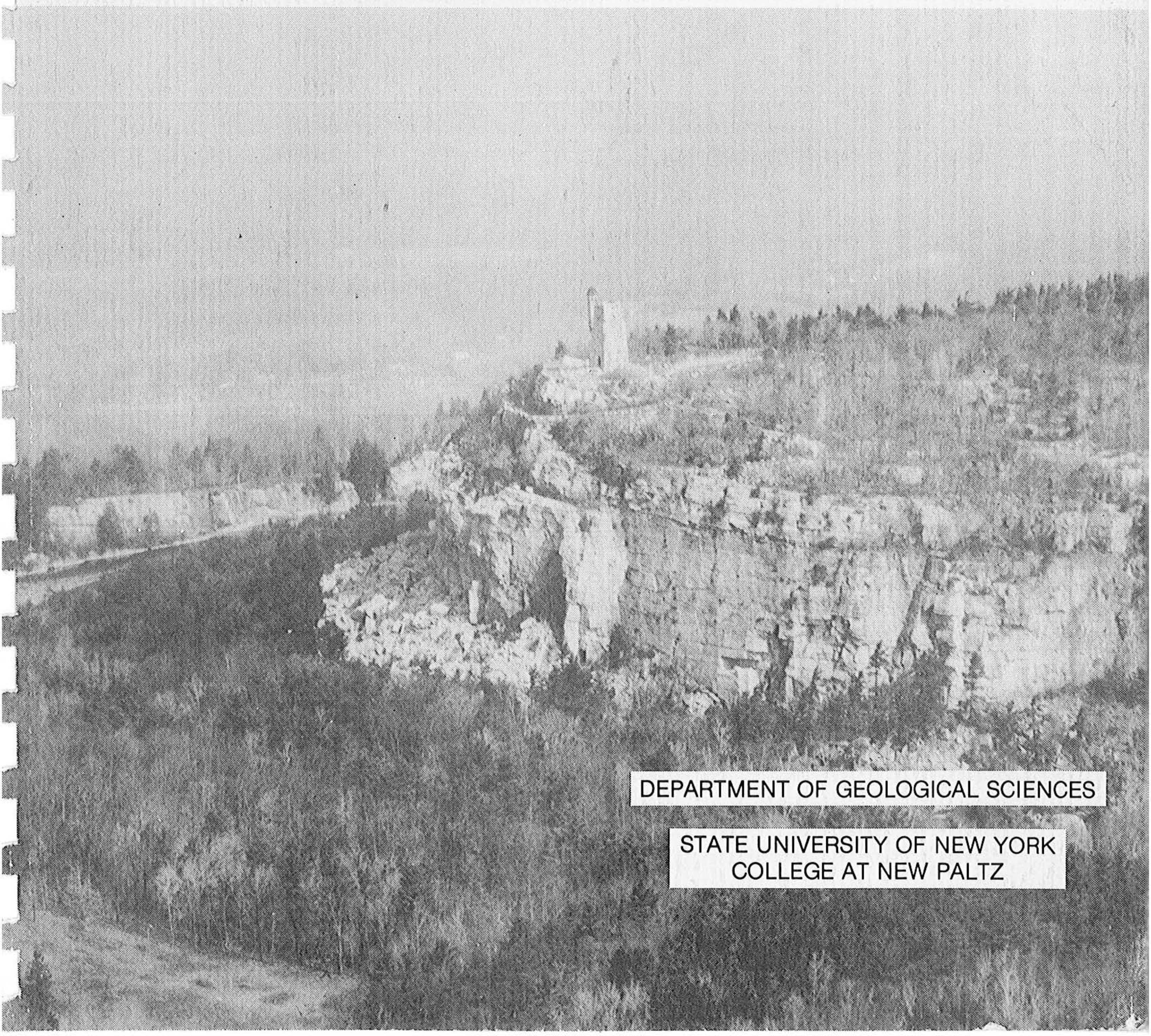
FIELD TRIP GUIDEBOOK

NEW YORK STATE GEOLOGICAL ASSOCIATION

59th ANNUAL MEETING

NOVEMBER 6 - 8
1987



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EDITOR

RUSSELL H. WAINES

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ACKNOWLEDGEMENTS

In rereading the letter of acknowledgements for the 39th Annual New York State Geological Association Guidebook I find little has changed except for the names of most of the participants.

Again I thank the contributors named in the page of contents. Their considerable efforts have provided the 'meat' of the present Guidebook, not only for the moment in this year's trips, but for the anticipated use extending many years into the third millenium.

Additionally, many have labored mightily in other ways to make this year's meeting a success; Diana Parrett, Constantine Manos, Rosario Agostaro and, in many special ways, Robert Cunningham. All of these in one way or another are associated with the Department of Geological Sciences at SUNY, New Paltz and each deserves a special thanks. Many others have given timely assistance; the classes of oceanography and sedimentary petrology at SUNY New Paltz as well as many members of the New Paltz Geological Society who helped with registration, as road guards, and other vital activities and without whose help the work of others would have been much more onerous. Three others at some point in time in this effort have helped in timely fashion; John Johnsen of Vassar College, my wife Dorothy Waines and Martin Rutstein of our Department. Their help is very much appreciated.

Finally, I must mention and thank Todd Leeds of our Department whose excellent oblique aerial photo of the Sky Top Tower at Mohonk Lake graces the Guidebook cover. I should mention also that the tower sits on a fine exposure of a Late Silurian oligomictic orthoconglomerate.

As I wrote twenty years ago "to all these and more, the Guidebook and Annual Meeting owe whatever approbation is deserved".

Russell H. Waines,
Editor

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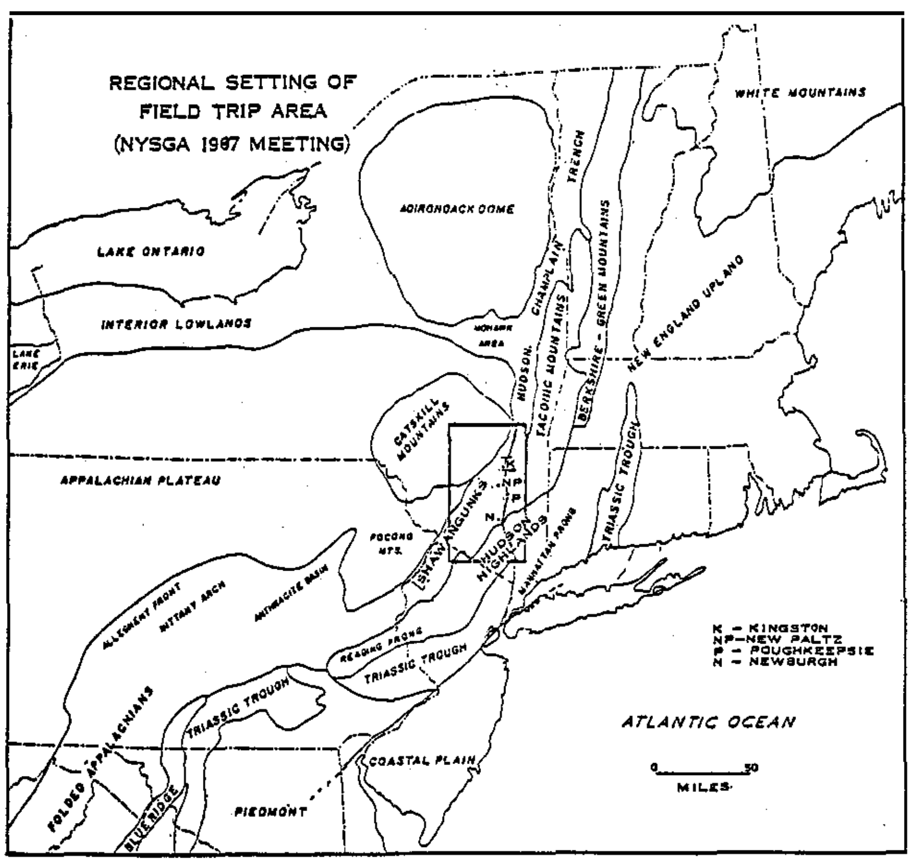

(Adapted from H. A. Meyerhoff, 1963, in NYSGA Guide Book 35th Ann. Meeting, p. 17, fig. 1)

UNUSUAL FEATURES OF THE NEW YORK SECTOR OF THE APPALACHIAN MOUNTAINS

JOHN RODGERS
Yale University
(1967 version, slightly amended)[1]

New York State's peculiar shape provides it with a complete cross-section of the Appalachian chain, from the Atlantic Coastal Plain in Long Island to the Central Lowlands of the continent around the Great Lakes. The cross-section can be complete partly because the Appalachians are particularly narrow here, even when one includes the Appalachian Plateau, whose northeastern extremity is the Catskill and Helderberg Mountains. The narrowness in turn results from a pronounced recess in Appalachian trends between two great salients, one in central Pennsylvania and one in southeastern Quebec and adjacent New England. The New York recess is not the only recess in the Appalachians, although it is one of the most pronounced; others are well displayed around Roanoke, Virginia, and Rome, Georgia, or are hidden under the Gulf of St. Lawrence or beneath the Gulf Coastal Plain in Alabama and Mississippi. All these recesses tend to be angular, in contrast to the smoothly arcuate curves of the intervening salients. Furthermore, the angles seem to be formed by intersecting trends of fold axes or other structural features.

Within the New York recess, the trends outline two separate angles, one from about N 65° E to about N 35° E at and southeast of the Delaware Water Gap, and the other from about N 40° E to about N 10° E at and southeast of Kingston, New York. These angles are well shown in the trends and boundaries of the narrowed Valley and Ridge province here, which extends northeast from the Great Valley of Pennsylvania and New Jersey to include, in New York State, the Wallkill and middle Hudson Valleys and the bounding Shawangunk and Schunemunk Mountains. The province continues to narrow northeastward and seems to disappear near Albany, though an Ordovician Valley and Ridge province is present in the Champlain Valley, mainly in Vermont.

Southeast of the Valley and Ridge province is the line of Precambrian "Highlands" anticlinoria that extends from the Reading Hills (Reading prong) of eastern Pennsylvania to the Green Mountains of Vermont; the New York representative is the Highlands of the Hudson. The trends of these anticlinoria also outline the New York recess and its two subordinate angles, a blunt angle near the Delaware River and a deep reentrant in western Connecticut between the general east-west trend of the Hudson Highlands coming in from New York and the general north-south trend of the Berkshire Highlands coming in from Massachusetts. This reentrant is only slightly larger than a right angle, sharper than any other observable angle in the Appalachians between the Gulf of St. Lawrence and the Gulf Coastal Plain. It is almost exactly centered between the west end of basement outcrops in the Reading Hills and their north end in the Green Mountains -- 275 kilometers (180 miles) from each. Moreover, the

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[1] The Editors of this Guidebook have kindly offered me the opportunity to bring up to date the short summary of Appalachian geology in New York State that I prepared for the guidebook the last time the New York State Geological Association met in New Paltz, in 1967. Rather than have me rewrite it completely, we decided to republish that summary and simply add some paragraphs about new insights reached in the last two decades. I have taken the liberty, however, of correcting a few misprints, incorrect statements, and infelicitous phrases in the original text.

anticlinoria seem to rise higher and higher toward the reentrant from both sides, so that one might expect the Precambrian belt to be highest and broadest there. In fact, however, the reentrant is marked by a 50-kilometer (30-mile) gap between the Hudson and Berkshire Highlands; the gap flares northwestward and is filled mainly with metamorphosed Lower Paleozoic rocks. Because the isograds are not deflected by the reentrant but strike about N 25° E across it, the Paleozoic rocks show a complete gradient from virtually unmetamorphosed along the Hudson River to sillimanite-grade in the throat of the gap. The progressive (Barrovian) metamorphism here was described by Barth and Balk in classic papers and has been studied more recently by Vidale and McClelland. Some Precambrian blocks are also exposed within the gap: Stissing Mountain far to the northwest, the fairly large Housatonic Highlands on the New York-Connecticut border, and others still farther east, where Paleozoic metamorphism has all but obliterated the metamorphic contrast between Precambrian basement and Paleozoic cover.

The Precambrian anticlinorial cores are certainly uplifted relative to the rocks in the Valley and Ridge province and, in accordance with the characteristic Appalachian asymmetry, the uplift was accompanied by relative northwestward transport. In the Green Mountains anticlinorium of Vermont and the South Mountain or Blue Ridge anticlinorium of south-central Pennsylvania, Maryland, and northern Virginia, the northwestward transport has seemed to be rather moderate, associated only with the formation of the asymmetrical anticlinoria and a few discontinuous thrust faults on their oversteepened limbs. Elsewhere, however, evidence is accumulating for recumbent folding involving large-scale horizontal transport. The case is clearest in eastern Pennsylvania, where the whole southeast side of the Great Valley from the Susquehanna to the Delaware has been shown to be the complex middle limb of one or more giant recumbent fold pairs or nappes, and in my opinion gravity data strongly support the interpretation that the Precambrian rocks of the Reading Hills and their eastward extension into New Jersey are the floating basement cores of the nappes. Similarly, Ratcliffe's work in western Massachusetts suggests that the Berkshire Highlands are also completely recumbent, overturned on the Paleozoic rocks to the west and sliced into a stack of thin, roughly horizontal thrust sheets.

To what extent the same overturning and recumbency has occurred in New York State is uncertain; the northwest side of the Hudson Highlands has generally been interpreted as a high-angle reverse fault, although floating blocks of Precambrian basement are known northwest of it. One might suggest instead that some of the high-angle faulting is (Triassic ?) normal faulting, dropping the Precambrian rocks in the core of the recumbent anticline down beside the Paleozoic strata of the underlying middle limb. One might further suggest that the horizontal displacement involved in the recumbent fold is measured by the depth of the western Connecticut reentrant in the line of anticlinoria -- nearly 40 kilometers (25 miles). Indeed, the recess is possibly the locus of maximum overturning and horizontal transport in the entire region from western Massachusetts to eastern Pennsylvania.

Another unusual feature of the New York sector of the Appalachians is the Taconic slate mass, the main body of which lies entirely on the north side of the New York recess. This mass has been the subject of controversy for well over a hundred years because, although its apparent stratigraphic and structural position above surrounding Middle Ordovician carbonate strata demands a Middle or Late Ordovician age, it contains fossils ranging back to Early Cambrian. This mass no longer seems as unusual as it used to, however, for similar masses now recognized from Newfoundland to the Susquehanna River have raised the same problems and have evoked the same answers; i.e., either rapid facies changes in restricted basins surrounded by carbonate shelves or allochthonous thrust sheets or slide masses from another facies realm to the east (either stratigraphic complexity and structural simplicity or vice versa). Comparison with allochthonous slide masses elsewhere, notably in the Alpine chains of Morocco, Italy, and other Mediterranean countries, has convinced many of us of the truth of the latter answer, but I doubt if the debate is over.

The northern and central Appalachian arcs on either side of the New York recess seem to have had rather different orogenic histories. In the central (and southern) Appalachians, the obvious deformation, as in the Appalachian Plateau and Valley and Ridge provinces, is late Paleozoic, post-Pennsylvanian and perhaps post-Early Permian. Recently, however, stratigraphic, tectonic, and radiometric evidence for older orogeny there has slowly been accumulating, suggesting major deformation also in the early Paleozoic, probably in the Ordovician for the most part. The extent of this orogeny southwest of New York State and southeastern Pennsylvania is still quite uncertain, except that it affected mostly the Piedmont region on the southeast side of the chain. In the central and southern Appalachians, therefore, orogeny seems to have migrated northwestward toward the interior of the continent, at least during the Paleozoic. In the northern Appalachians, on the other hand, evidence of multiple deformation is abundant and has long been known. The late Paleozoic deformation, though present, is confined to the southeast side; the early Paleozoic deformation is most obvious along the northwest side; and the most widespread and most intense period of orogeny was middle Paleozoic, largely Devonian. Thus orogency here generally migrated away from the continent. The relative unimportance of the late Paleozoic deformation in the northeren Appalachians is a reason, I believe, for refusing it the title Appalachian Orogeny or Revolution. I prefer to call it by Woodward's term "Alleghany orogeny", so that it can take its proper place beside the Acadian and Taconic among the Appalachian orogenies, of which the roster is probably not yet complete.

Situated between these two different arcs, the New York recess should contain evidence of multiple orogeny, and it does. A Precambrian ("Grenville") orogeny is represented by the contrast between the igneous and metamorphic basement of the Highlands and the overlying sedimentary Paleozoic rocks. The Taconic orogeny is represented by the angular unconformity between the Middle Ordovician and the Silurian along Shawangunk and Schunemunk Mountains on either side of the Wallkill Valley; on the Shawangunk side the Silurian rocks have not overstepped the Middle Ordovician, but on the Schunemunk side they overlap onto the Precambrian. In the absence of Carboniferous rocks anywhere between the Lackawanna syncline in northeastern Pennsylvania and the Narragansett basin in central Rhode Island (except for some granite intrusions in southwestern Rhode Island and southern Connecticut), the Acadian and Alleghany orogenies cannot be clearly distinguished in the New York recess, but both are certainly present in Rhode Island and probably, to judge by radiometry, in Connecticut and the Manhattan prong.

The intersecting trends in the New York recess may provide further clues for unscrambling the effects of the different orogenies. Presumably the trends coming up the northwest side of the Valley and Ridge province out of Pennsylvania must be Alleghany, at least those of the folds in the anthracite basin and their continuations. Evidence in Pennsylvania suggests, however, that the great recumbent folds on the southeast side of the Great Valley are pre-Silurian - i.e., Taconic - and the rapid overlaps of the Silurian strata around Schunemunk Mountain and its southwestward continuation in New Jersey can be interpreted in the same terms. (Indeed, Ratcliffe in western Massachusetts reports evidence for recumbent folding of Lower Ordovician rocks before the deposition of Middle Ordovician.) On the other hand, the broader trends of the northern Appalachians are Acadian, certainly for some distance west of the Connecticut River and quite possibly all the way to the Hudson. Very probably the folding in the Silurian and Devonian west of the Hudson, north of the angle at Kingston, is also of this age, but whether the corresponding folds between Kingston and the Delaware Water Gap are Acadian or Alleghany is debatable. Their trend is also that of the high-angle faults in the New York and New Jersey Highlands; those faults may well be Triassic in part, but as W. M. Davis showed long ago in Connecticut, Triassic faults tend to follow pre-existing strikes. It is even possible that these trends were first marked out in the Taconic orogeny, the western limit of which must trend from Albany to eastern Pennsylvania, well to the west of the eastern edge of the overlapping Silurian and possibly just east of the abrupt eastern termination of the folds in the anthracite basin and along the aberrant trend of the Lackawanna syncline.

To summarize, the New York sector of the Appalachians is unusual because it includes much of a major recess in the chain, notable (like other Appalachian recesses) for the angular intersection of structural trends and also for extreme horizontal transport along the northwest margin of the chain's metamorphic core. One of the first geologists 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 their crossing in the New York recess where, as noted above, the polarity of orogenic migration during the Paleozoic reverses.

(New Material Added in 1985)

There is another way of thinking about the recesses and salients of the Appalachians (or any other mountain chain), by looking at them not from the continental but from the oceanic side. Seen from that side, they would appear molded around promontories and embayments along the margin of the Paleozoic North American continent, which in turn reflect the (post-Grenville) pattern of rifting and subsequent sea-floor spreading that created that margin during latest Precambrian time. A number of features then find natural explanations. The stratigraphic section is generally thinner across promontories than in embayments, because the former tend to rise by isostasy (cf. the high southwestern angle of the Arabian Peninsula in Yemen), whereas the latter tend to sink. Such thinning is clear in the lower Paleozoic shelf sediments on the New York promontory = recess, especially in the Lower Cambrian, both the carbonate strata and the underlying clastics; the latter are almost pure quartzite, in contrast to the "dirtier" sediments in the lower parts of the thicker sequences on either side. When orogeny smashed the Paleozoic sedimentary rocks against the more rigid continent, the thicker strata in the embayments = salients found it easy to deform by classical thin-skinned decollement tectonics, but the thinner strata on the promontories were less fortunate; the projecting parts of the continental basment were stressed more strongly and probably heated up more, so that they played a larger role in the deformation. The contrast between smoothly curved fold trends in the embayments and more angular, commonly intersecting trends near the promontories suggests an analogy with the way ocean waves advancing toward an irregular coastline sweep into bays with smoothly curving crests but beat on headlands in characteristic interference patterns.

The allochthony of the Taconic slate mass and the other masses mentioned above now seems firmly established. Many of us now believe, moreover, that the same rocks can be followed eastward into the high-grade metamorphic rocks of the Manhattan prong and its northeastern continuation in Connecticut, where they form the bulk of the Manhattan schist and its correlatives. Only the lowest part of the old Manhattan would remain autochthonous; now distinguished as the Walloomsac formation, known from a few fossils to be Middle Ordovician, it is unconformable on the underlying (Cambrian to Lower Ordovician) Inwood marble and bevels down across the various members of the Inwood to rest in places on the basal Cambrian clastics or the Precambrian basement. That this unconformity is particularly clear in the New York recess emphasizes once again the tendency of continental promontories to resist subsidence.

The supposed continentward migration of orogenies south of New York is less clear now than it used to seem. Although the Alleghany orogeny certainly deformed the entire Valley and Ridge province from Pennsylvania southwest and played a major role in transporting into their present position the rocks of the present Blue Ridge and Inner Piedmont (and probably also those of the Highlands from New York southwest into the Reading prong), the deformation and metamorphism of the main bulk of those rocks is earlier, largely Ordovician or perhaps in part Devonian. Only at the southeastern margin of the Piedmont does Alleghany deformation and metamorphism reappear, from Georgia to Virginia and again in southeastern Connecticut and southern Rhode Island, and perhaps in some places between (around Philadelphia, for example?). In the northern Appalachians the general retreat from the continent, orogeny by orogeny, is still accepted, though within each orogeny the reverse trend is established or probable. It is still true however, that southwest of New York the outermost folds were formed in the Alleghany orogeny, northeast of Albany in the Taconic. Reflecting on this difference, Shatsky in 1945 suggested that the presence of a great foreland basin -- the Appalachan Plateau or the Alleghany synclinorium -- in the southern and central Appalachians and the absence of anything comparable in the northern Appalachians is related to the change in polarity.

Concerning the fold trends that converge in Europe but cross in the New York recess, I now know that Arthur Holmes got the idea from E. B. Bailey, who got it from Marcel Bertrand, who stated it quite clearly in 1887! The more things change the more they remain the same.

PAC STRATIGRAPHY OF THE BINNEWATER, RONDOUT AND MANLIUS FORMATIONS OF THE HUDSON VALLEY

E. J. Anderson, P. W. Goodwin, T. R. Buggey, S. P. Osborn, L. J. Saraka and W. M. Goodman

TEMPLE UNIVERSITY

INTRODUCTION

The purpose of this trip is to present a demonstration of field application of the PAC hypothesis. Specific objectives include:

1. demonstration of criteria for recognition of PACs in a variety of facies (all STOPS);

2. field checking of stratigraphic columns described in terms of PACs (all STOPS);

3. illustration and discussion of methods of correlation of PACs (all STOPS);

4. demonstration of a major cryptic unconformity at the Manlius-Coeymans boundary (STOPS 1, 2, 3 and 6);

5. demonstration of a minor cryptic unconformity at the PAC 3-5 boundary (STOPS 1, 4 and 6);

6. demonstration of lateral facies change within a PAC (e.g. PAC 9, STOPS 1, 2, 3 and 6);

7. demonstration of episodic onlap over the Ordovician land surface (STOPS 1, 4, 5 AND 6).

THE PAC HYPOTHESIS

The PAC hypothesis (Goodwin and Anderson, 1985) is a comprehensive stratigraphic model which states that most stratigraphic accumulation occurs episodically as thin (less than 5 meters thick), generally shallowing-upward cycles characterized by internal vertical and lateral facies continuity (i.e. conjunct facies relationships). Cycle boundaries, defined by abrupt facies change to disjunct facies, are created by what stratigraphically appear to be geologically instantaneous relative base-level rises. The PAC motif (punctuation and aggradation) is independent of specific facies and therefore a single PAC may be peritidal at one locality and totally subtidal at another locality. The events which produce PAC boundaries are thought to be sea-level fluctuations. Because such events are allogenic, PAC boundaries are essentially synchronous surfaces. PACs are therefore ideal stratigraphic units for intrabasinal correlation and paleogeographic reconstruction.

STRATIGRAPHY OF THE LOWER HELDERBERG GROUP IN THE HUDSON VALLEY

The Binnewater, Rondout and Manlius Formations between Wilbur and Catskill, New York are totally divisible into PACs which can be correlated throughout the study area (Figs. 1 and 2). The general stratigraphic relationships of these formations and their members (Fig. 3) were carefully documented by Rickard (1962). Paleoenvironmental interpretations of these rocks were presented by Waines (1976), Harper (1969) and Laporte (1967 and 1969). An episodic (PAC) stratigraphic interpretation of the formal rock unit boundaries in this area was presented by Anderson, Goodwin and Sobieski (1984) and the cyclic facies architecture and its implications were presented by Osborn (1983), Buggey (1984), Saraka (1984), Goodman (1985) and Goodwin et al. (1986).

In brief summary, the rocks in the study interval represent a diverse set of peritidal and shallow subtidal facies deposited in small-scale allogenic cycles. Correlation and analysis of the distribution of these cycles leads to recognition of a pervasive structure of discontinuities in the lower Helderberg Group. There are not only sedimentologic discontinuities at the bed level but several types of stratigraphic discontinuities (PAC boundaries, small and large scale cryptic unconformities and a traditional angular unconformity).

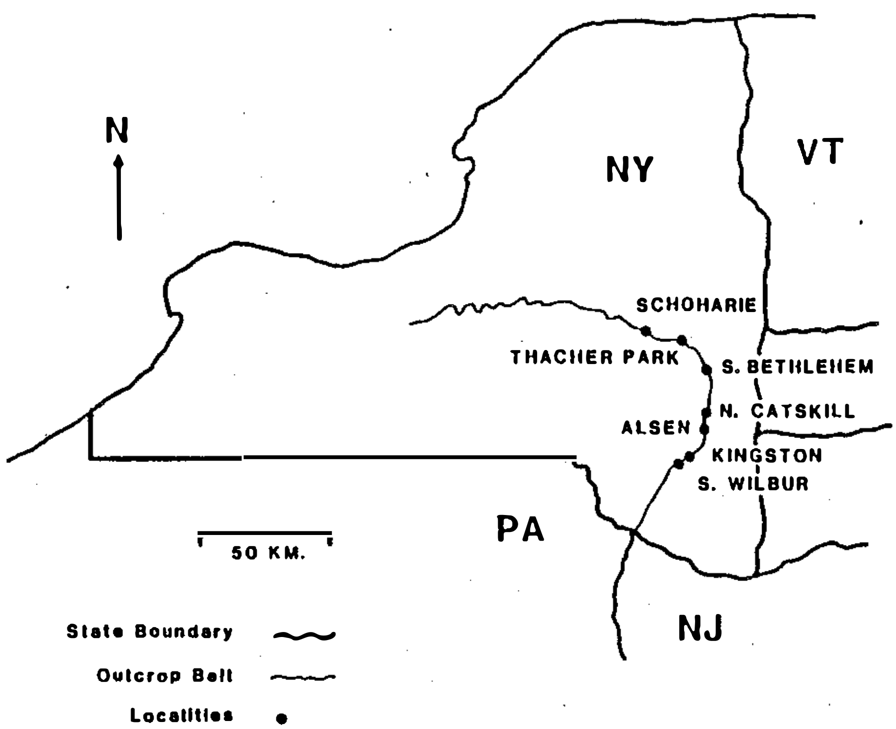


Figure 1. Locality map, Hudson Valley

FIELD TRIP STOPS

STOP 1. NORTH CATSKILL Route 23 exit ramp, .3 miles southwest of New York State Thruway Exit 21.

The Rondout, Manlius, Coeymans and Kalkberg Formations are continuously exposed above an angular unconformity with the Ordovician Normanskill turbidites. The Rondout Formation is made up of 1 PAC and the Manlius contains 10 PACs (PACS 5-14) at this locality (Fig. 2). The Rondout PAC has a subtidal fauna in its base and is topped by a massive supratidal dolomite. The first Manlius PAC has been broken up by tectonism. It is overlain by a peritidal PAC (PAC 6) which is probably similar in facies to the tectonized unit. PACs 7, 8, 11, 13 and 14 are entirely subtidal and PACs 9, 10 and 12 are again peritidal cycles.

In addition to discussing criteria for PAC recognition we would like to focus attention on the following observations at this stop. 1. A major correlation point for Manlius PACs is the facies change from cryptalgal laminites to stromatoporoid bearing calcarenite at the base of PAC 11. We will trace this boundary throughout the study area. 2. The stromatoporoid bearing calcarenite at the base of PAC 9 is replaced laterally by thin-bedded shallow-water carbonate turbidites at Stop 2 and gastropod bearing calcisiltite in the Kingston area (Stops 3 and 6). 3. PAC correlations (Fig. 2) reveal that the Manlius-Coeymans formation boundary is a major cryptic unconformity. To the south at Kingston, PACs 13 and 14 are missing by erosion. To the north and west an additional PAC occurs beneath the unconformity. 4. A minor cryptic unconformity occurs at the boundary between PACs 3 and 5. South of Kingston, PAC 4 is found in this gap. 5. Finally, additional PACs appear below Rondout PAC 3 in the southern localities indicating progressive onlap of the Ordovician land surface.

STOP 2. SOUTH CATSKILL Route 23A, .2 miles southwest of the intersection with Route 9W.

Manlius PACs 6 to 14 are exposed at this locality. The measured section, both overall and cycle by cycle, is nearly identical in thickness to the North Catskill section observed at the last stop (Fig.2). There are two purposes to this stop. 1. We will demonstrate, PAC by PAC, the degree of similarity between two localities two kilometers apart. This analysis is based on PAC correlations. Marked similarity between the two localities is seen in the thick tidal-flat facies in the upper part of PAC 9 and in PAC 10 and in the major facies change to stromatoporoid bearing calcarenite in PAC 11. In addition, the cryptalgal laminite facies with eroded mudcracks on its upper surface at the top of PAC 12 is the same as at North Catskill.

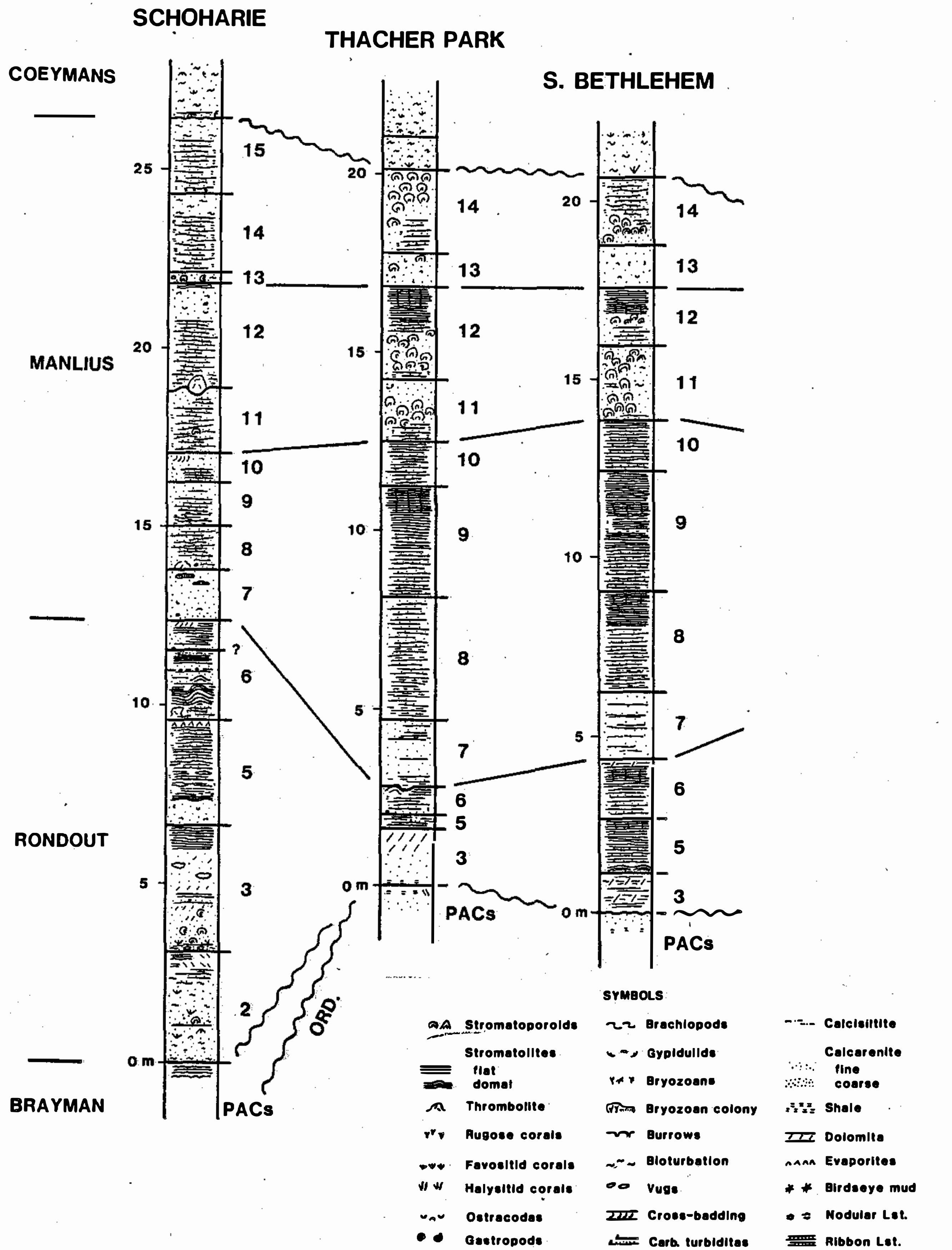
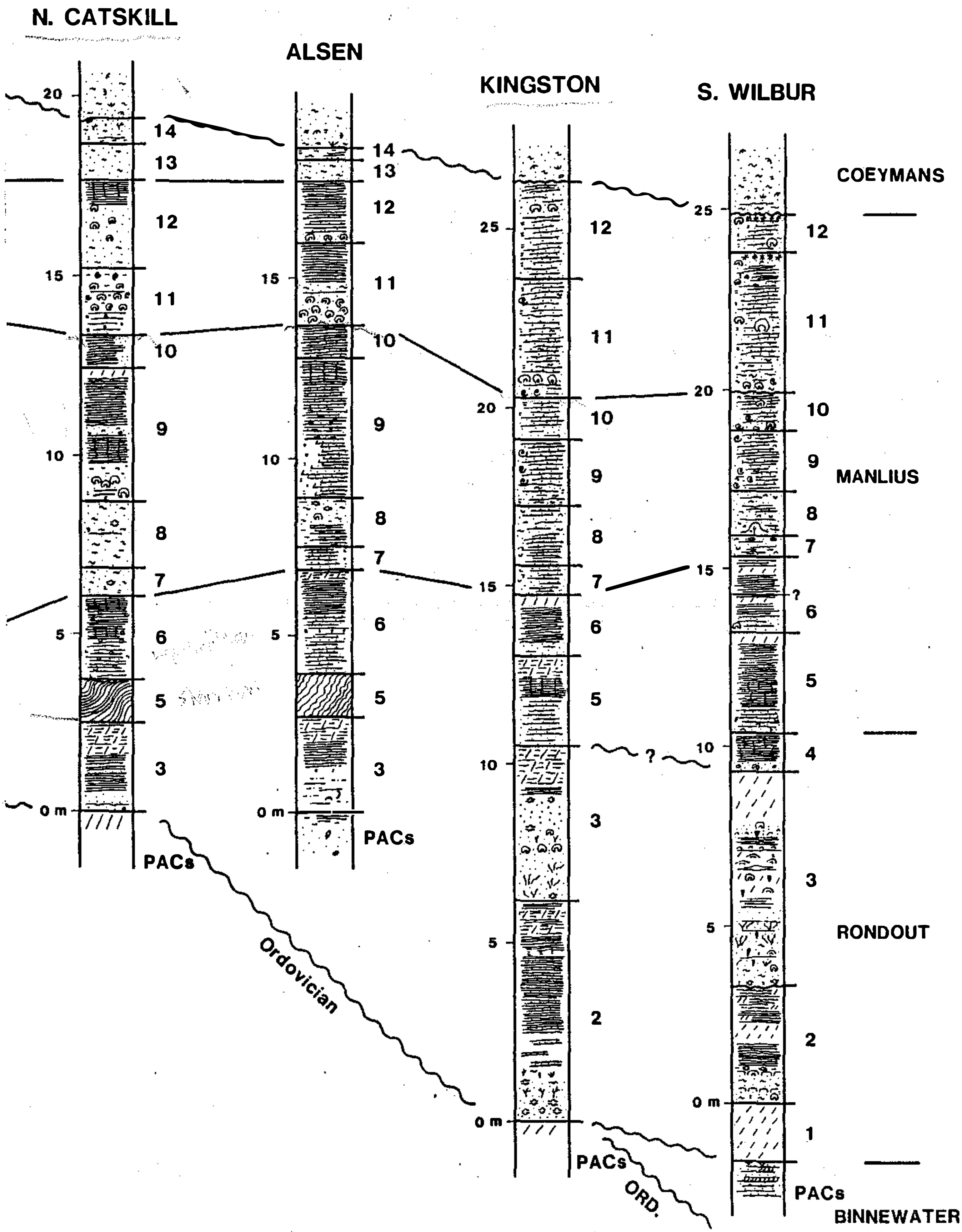


Figure 2. Correlated columns, Hudson Valley, New York (from Goodwin et al., 1986)


N. CATSKILL
ALSEN
KINGSTON
S. WILBUR
COEYMANS
MANLIUS
RONDOUT
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Another primary correlation point is the large facies change from peritidal to subtidal facies at the PAC 5-6 boundary. 2. The second purpose is to demonstrate lateral facies changes within PACs. The boundary between subtidal PACs 7 and 8 is more sharply defined than at the first locality because the calcarenite in PAC 7 is more current washed than at North Catskill. More dramatic lateral facies change within a PAC is illustrated in the base of PAC 9. At this level stromatoporoid bearing calcarenite at North Catskill changes to thin-bedded shallow-water carbonate turbidites.

STOP 3. KINGSTON A Route 199, .5 miles west of the Kingston-Rhinecliff Bridge.

Manlius PACs 7 to 12 are exposed at this locality. In addition to checking PAC definitions, the following observations can be made at this stop. 1. The primary correlation datum is the major facies change to stromatoporoid bearing calcarenite at the base of PAC 11. Also, as at Catskill, a thin cryptalgal laminite facies occurs at the top of PAC 12. 2. If these correlations are correct, PACs 13 and 14 are missing under the first PAC of the Coeymans Formation indicating a progressive enlargement of the cryptic unconformity seen at Catskill. 3. A major lateral facies change has occurred in the PAC 9-10 interval. These PACs are here represented by subtidal gastropod bearing facies while at Catskill we saw two well developed peritidal cycles at this stratigraphic level.

STOP 4. KINGSTON B Route 32, .5 miles south of Route 199.

The top of Rondout PAC 2, Rondout PAC 3 and Manlius PACs 5 and 6 are well exposed at this locality. The following observations can be made at this stop. 1. PACs 5 and 6 are peritidal cycles overlain by the subtidal calcarenite facies of PAC 7. This pattern supports the correlation with the like numbered units at Catskill. 2. As at Catskill, PAC 5 overlies the massive Whiteport Dolomite of PAC 3 (Fig. 4). Also, as at Catskill, PAC 4 is still missing in a minor cryptic unconformity (Fig. 2).

STOP 5. KINGSTON C Route 32, .5 miles south of Stop 4.

Rondout PACS 2 and 3 (the upper part of PAC 3 covered here is fully exposed at the previous stop) overlie Ordovician turbidites of the Normanskill Formation in angular unconformity. PAC 2 (Fig. 2) is represented by the Wilbur and Rosendale Members of the Rondout Formation (Fig. 4) and PAC 3 (Fig. 2) by the Glasco and Whiteport Members (the PAC numbering system, data and interpretations in Figure 4 are taken directly from Osborn's 1983 thesis and differ slightly from those

HELDERBERG STRATIGRAPHY

(modified after Rickard, 1962)

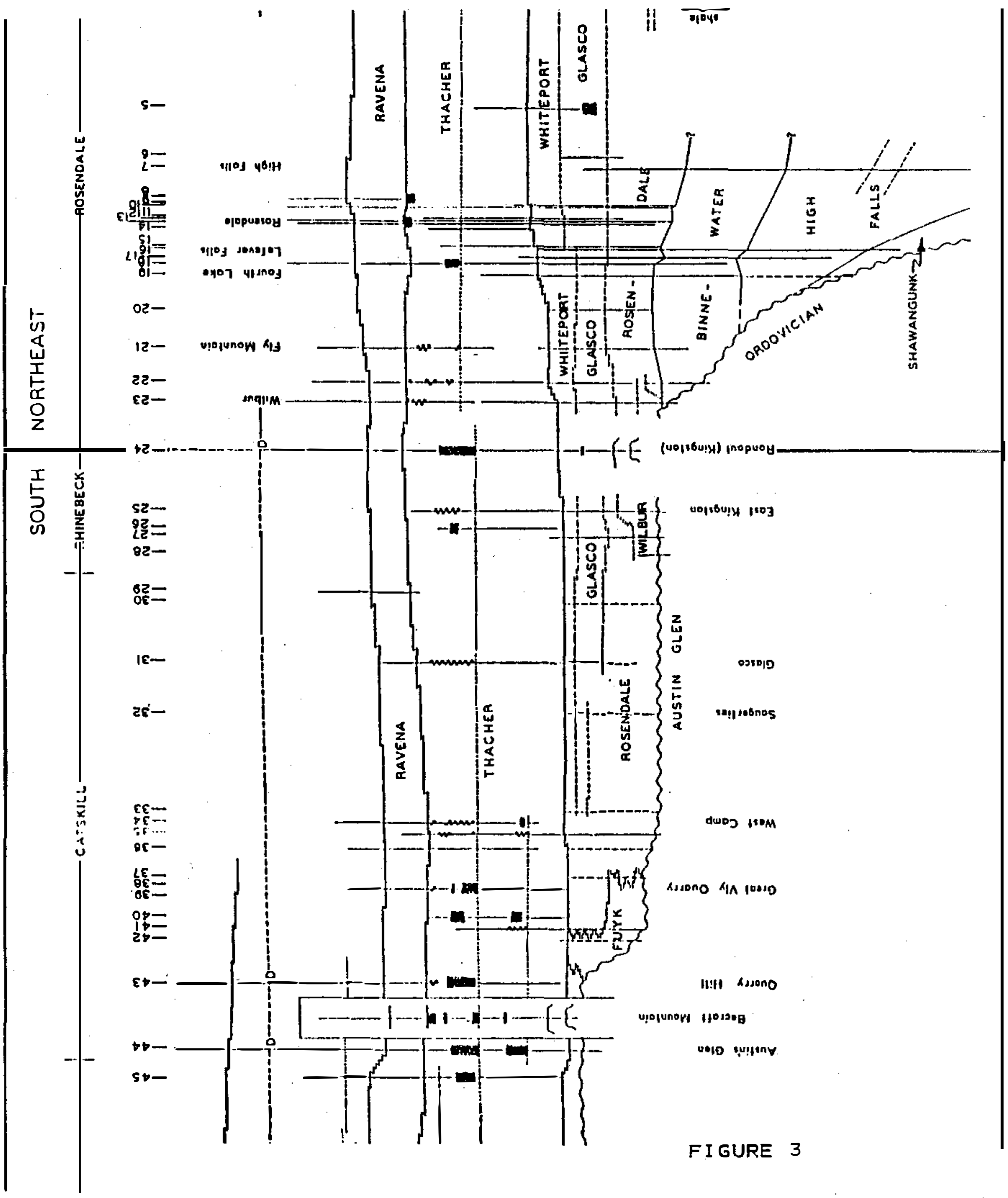


FIGURE 3

presented in the text of this paper and Figure 2). An increase in the number of Rondout PACs at Kingston relative to Catskill indicates progressive stepwise onlap to the north over the Ordovician land surface during Rondout time (Fig.4).

STOP 6. SOUTH WILBUR Abandoned quarry above road along Rondout Creek, .5 miles southwest of Wilbur, New York.

Exposed at this locality are two PACs of the Binnewater Sandstone (Fig. 5, taken from Buggey, 1984), four Rondout PACs and eight Manlius PACs (Fig. 2). Several observations and interpretations can be made at this locality. 1. There is an excellent correlation of PACs in the Manlius interval with those observed at Kingston localities A and B. Key correlation points include the major facies change to calcarenite at the base of PAC 7, the thin-bedded gastropod bearing facies which characterizes PACs 9 and 10 and the major facies change to thick-bedded stromatoporoid bearing calcarenite at the base of PAC 11.
2. More erosion at the Manlius-Coeymans cryptic unconformity has reduced the thickness of PAC 12 to about 1 meter. Note the minor paleokarst developed on the unconformable surface. 3. PAC 4 appears between PACs 3 and 5 (Fig. 2). The presence of this PAC to the south and its absence to the north is evidence of a minor cryptic unconformity. In the initial study of this interval Osborn (1983) recognized the facies change which now defines the boundary at the base of PAC 4 but did not set it off as a PAC boundary because it was absent at the northern localities (Fig. 4). Osborn placed this unit in the upper 2-4 feet of the Whiteport Member of the Rondout Formation at the Fourth Lake, Wilbur and Connelly localities. Interpretation of a cryptic unconformity at this level provides an explanation for these facies patterns. 4. The two Binnewater PACs preserved at this locality were shown by Buggey (1984) to be correlated with two PACs in the middle of the Binnewater Formation ten miles to the south at High Falls (Figs. 6 and 7). This correlation leads to the interpretation of the Binnewater-Rondout contact as a cryptic unconformity at which at least two PACs are lost at South Wilbur (Fig. 6). 5. Finally the High Falls and Binnewater Formations progressively and episodically onlap the underlying Ordovician Normanskill Formation as does the Rondout Formation at Kingston and to the north (Figs. 4 and 6).

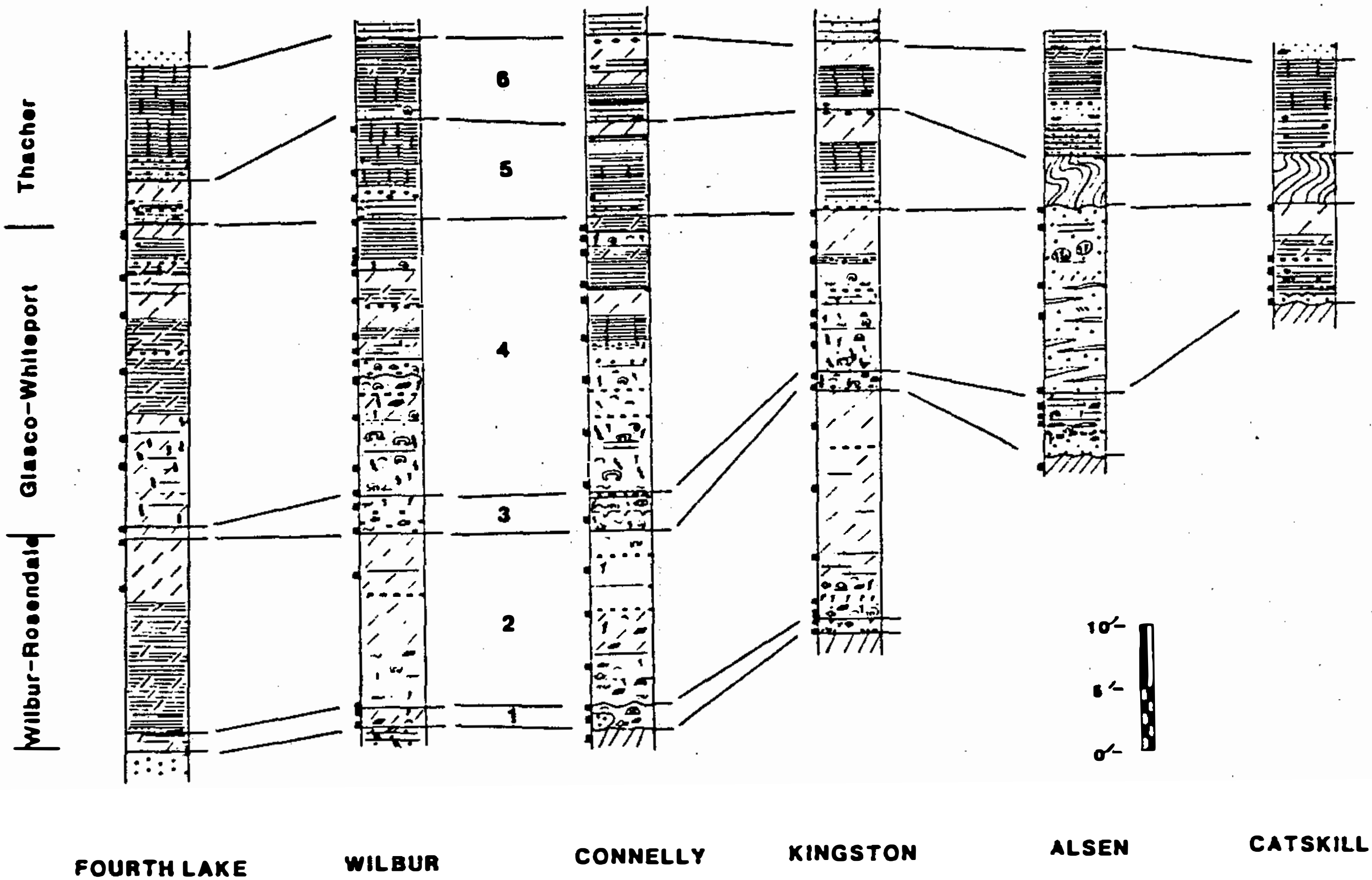
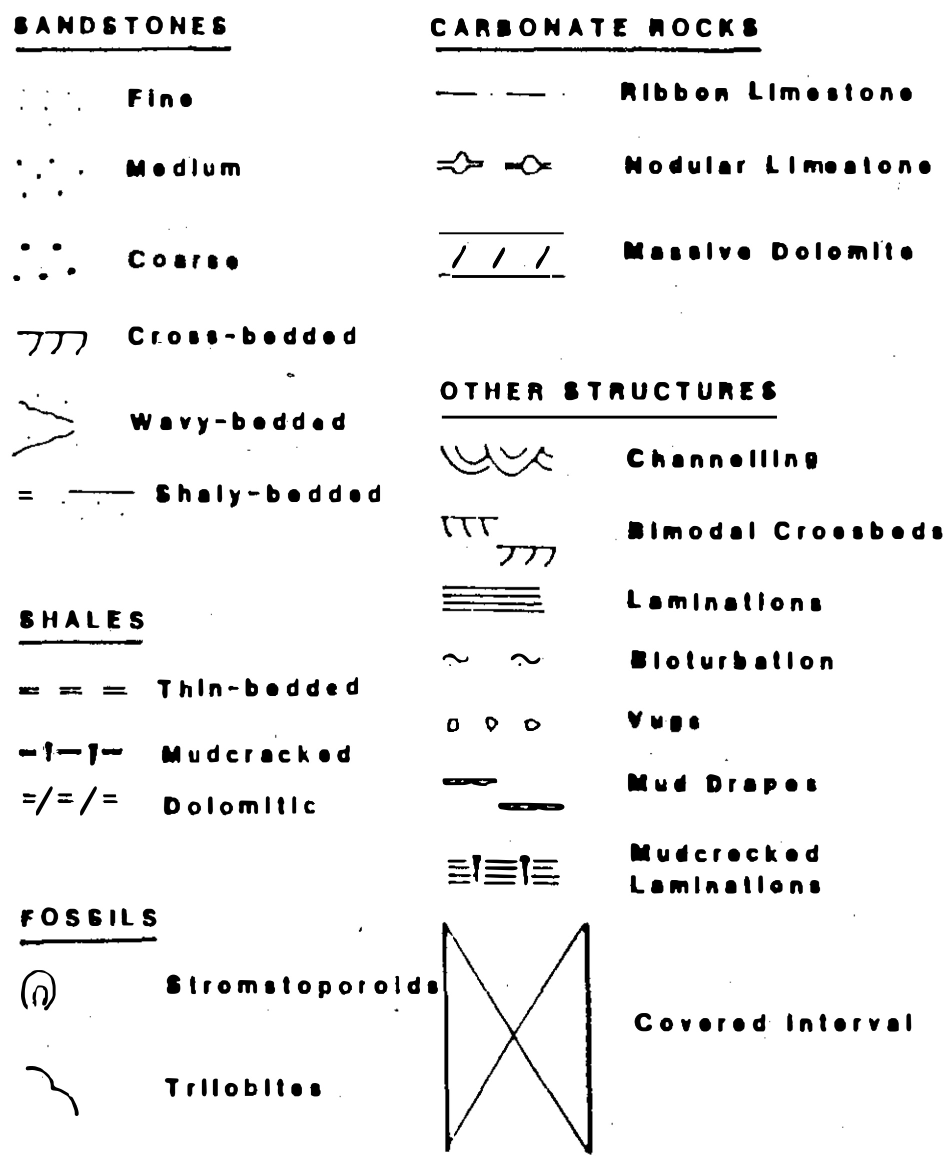


Figure 4. PAC correlations, Rondout Formation, Hudson Valley, New York (from Osborn, 1983)



Legend for figures 5 and 7.

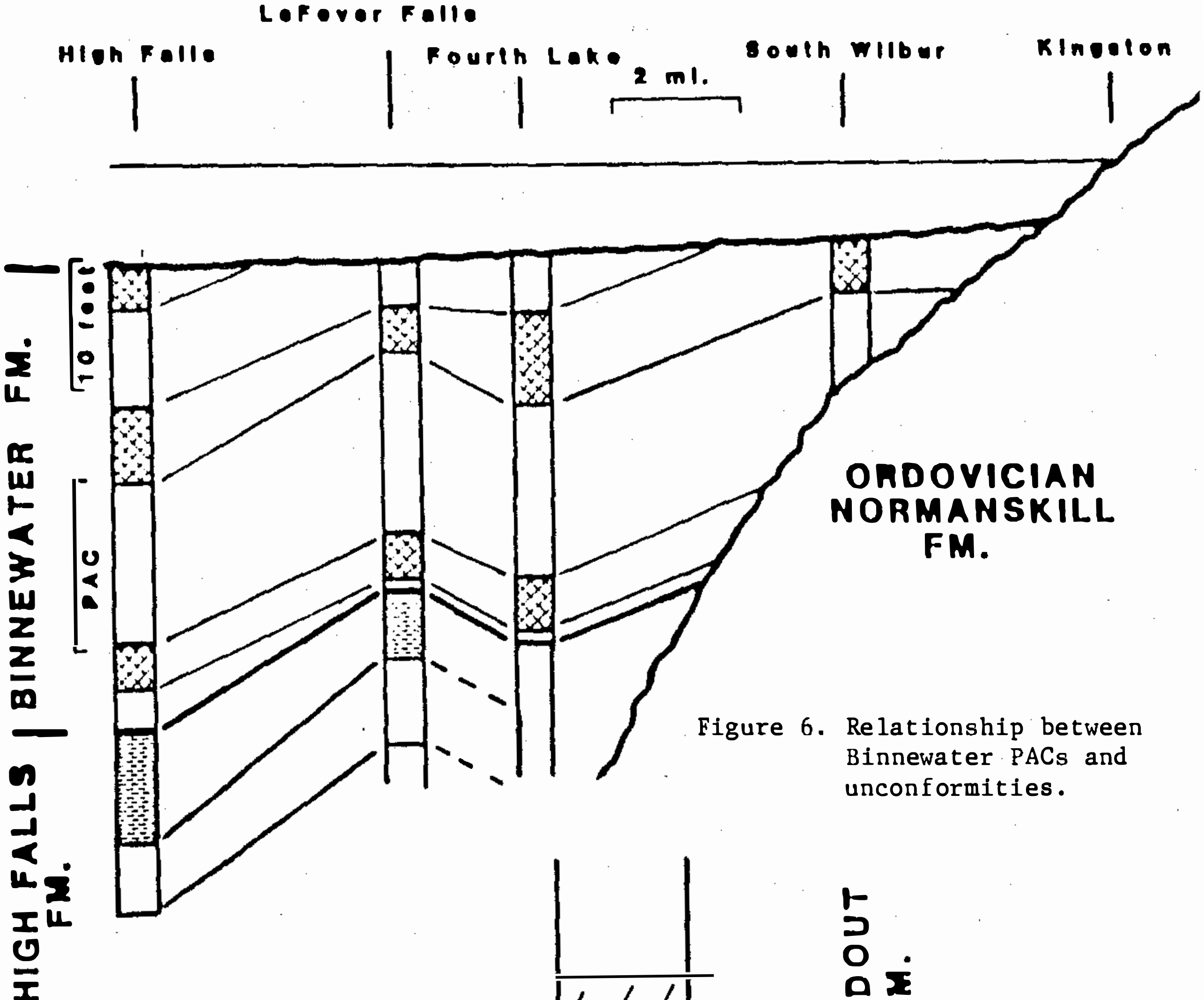


Figure 6. Relationship between Binnewater PACs and unconformities.

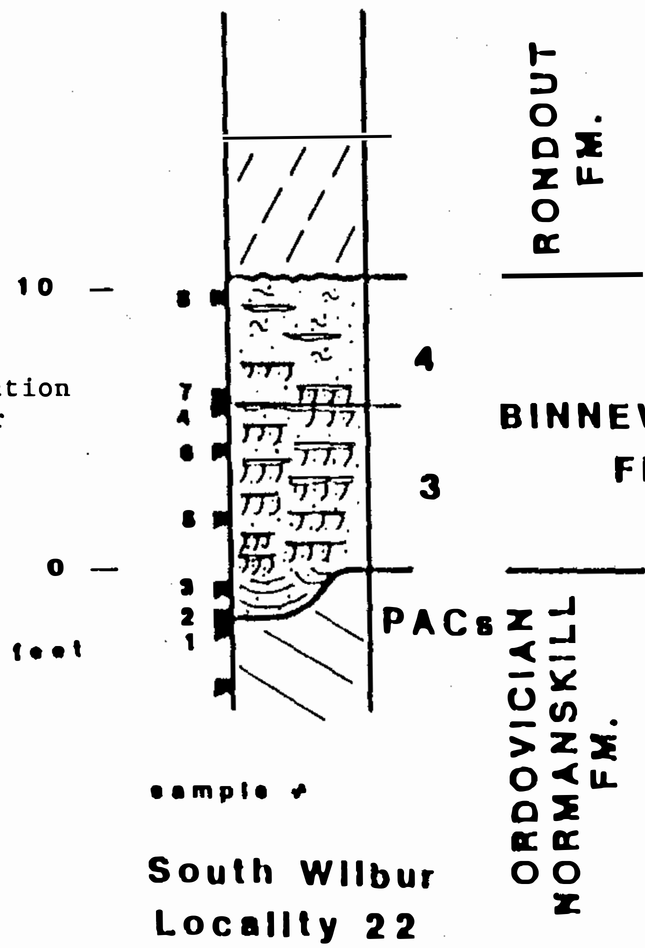


Figure 5. Columnar section South Wilbur locality.

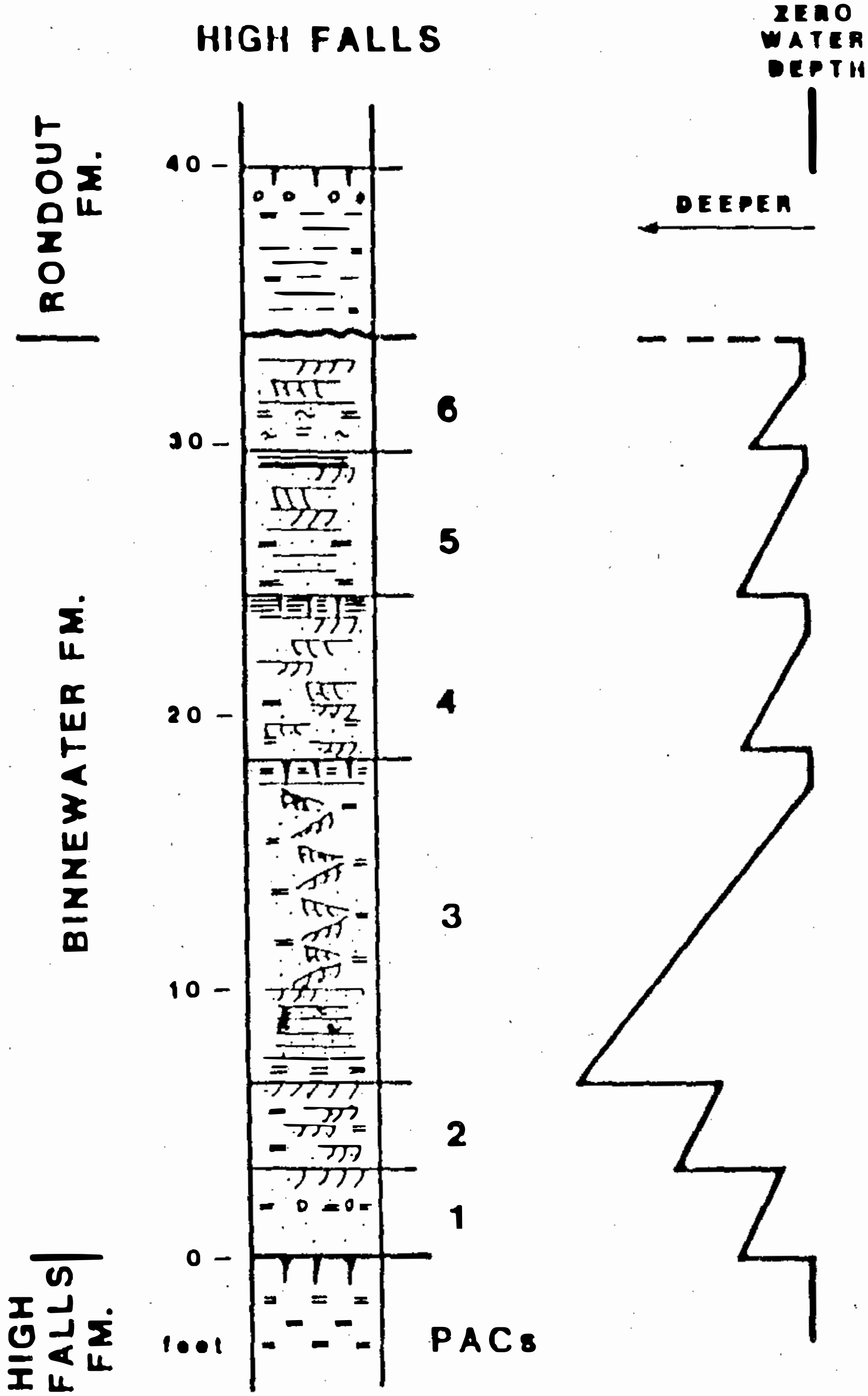


Figure 7. Columnar section, High Falls locality.

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PREGLACIAL AND POSTGLACIAL DRAINAGE OF THE CENTRAL HUDSON VALLEY

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INTRODUCTION

The Problem

The preglacial drainage patterns of the mid-Hudson Valley have not been studied on a regional basis since the early nineteen-forties. These studies dealt with the meso- to macro-scale landscape features and their inferred relationships to Late Mesozoic and Early Cenozoic tectonism. They were limited by their reliance on the small scale and relatively crude maps and by the sparse subsurface information that were available at that time. The Holocene history of the area was only mentioned in passing in those studies because of the lack of information concerning Holocene features throughout the region.

Method

Abundant subsurface and surface data have been assembled during the nineteen seventies and eighties that can be used to illuminate the Late Cenozoic drainage history of the area. The modern topographic map and stereo airphoto data that are available for eastern New York State can be used in combination with Cultural Resource Surveys, archeological studies, engineering reports, historical records, and newspaper accounts to develop a Late Holocene through Recent geologic history of this region. I have used a sampling of such data to prepare this preliminary report on the Cenozoic drainage of the mid-Hudson Valley from Newburgh to Catskill. I have chosen selected sites west of the Hudson River to illustrate key points in this report.

Previous Studies

Several workers have noted peneplains in eastern New York State (Table 1). They have used these erosion surfaces to determine probable Cenozoic drainage systems. Ruedemann (1932) interpreted the regional erosion surfaces as implying westward drainage into the Mississippi Basin during the Early Cenozoic. The erosion surfaces are the Catskill, 2,500 ft, and Helderberg-Rensselaer peneplains. The Helderberg-Rensselaer surface has been correlated with either the Harrisburg Peneplain (Ruedemann, 1932) or the younger Kittatinny or Schooley Peneplain (Happ, 1938; Fenneman, 1938) of the central Appalachian Plateau.

Johnson (1931) surmised that the southeast-draining streams were established during the later stage of the development of the Schooley Peneplain. He noted that the streams presently flow across the major geologic structures and changes in lithology. He theorized that the streams originally flowed across a nearly-flat coastal plain developed on marine sediments that onlapped the older rocks from the present Atlantic coast to the Adirondacks. Streams were entrenched in their present courses during Middle Cenozoic uplift by superposition from the ancient coastal plain.

Ruedemann (1932), Mackin (1933), Fenneman (1938), and Happ (1938) agreed with Johnson's (1931) scenario. Mackin (1933), Fenneman (1938), and Happ (1938) correlated this superposition with the Schooley peneplain. All these workers attributed the absence of Cenozoic marine sediments inland from the present coastal plain to severe Late Cenozoic erosion.

Meyerhoff (1972) noted that the Cretaceous and Early Cenozoic marine rocks, presently preserved along the Atlantic coast, consist of near-shore facies. Consequently, it is unlikely that they extended inland for more than 30 miles. He attributed the present drainage to the normal processes of stream adjustment to structure. The Hudson Valley developed as the Cenozoic Hudson River worked its way westward, along the border of the arched New England thrust sheet. The Hudson undercut the base of the Appalachian Plateau along the Catskill Escarpment. This process was initiated during the Triassic, and was well underway by Schooley time (Meyerhoff, 1972).

Fairchild (1919), Stoller (1920), Ruedemann (1930), and Fenneman (1938) noted that the lowest peneplain in the Hudson Valley lies at an elevation of 200 ft, and is cut by a strath terrace that lies below sea level south of Troy, NY. All the present tributaries hang on the Hudson Gorge and enter the estuary of the Hudson across bedrock sills. Stoller (1920) and Simpson (1949) explained that the flat surface of the Albany Peneplain was more apparent than real; the lack of relief was caused by a thick blanket of glacial lake clays and sand. Deep preglacial valleys underlie the glacial sediment cover (Simpson, 1949; Davis and Dineen, 1969; Dineen and others, 1983).

Chadwick (1944) described the Hudson estuary in the vicinity of the Village of Catskill. He also described a series of abandoned stream terraces in the villages of Saugerties and Catskill that were formed as the Esopus Creek and Cats Kill cut down through the glacial lake deposits during post-glacial time.

Acknowledgements

This field trip is a progress report on projects that started twenty years ago when James F. Davis and I began a study of the bedrock topography of the Hudson Valley. I continued the study after Jim ascended to the post of State Geologist of New York in 1970. Eventually, I was able to determine the bedrock topography by compiling the logs of thousands of water wells gathered from interviews with home owners and drillers, supplimented by

STOP 11: Fawn's Leap (Fig. 10)

Fawn's Leap is a geological feature that was made famous by the Hudson River School painters. It is a waterfall that is cut into the top of the Kiskatom Formation (Fisher and others, 1970). It has formed where one of the major joint sets of the Appalachian Plateau crosses the Kaaterskill Clove (Chadwick, 1944). The Kiskatom Formation is apparently more resistant to erosion than the overlying rocks; the Clove has a distinct V-shaped notch below Fawn's Leap, with a wider, U-shaped valley above (Figs. 11b and c). The Kiskatom Formation also forms steeper slopes along the Catskill Escarpment (Fig. 11a). Seeps and springs are common in the inner gorge, many of the landslides are associated with the seeps (Bonafede, 1980; NYS Dept. of Transportation).

The stream gradient is 0.040 or 211 ft/mile from Fawn's Leap to the head of the alluvial fan. The Kaaters Kill has carved potholes, grooves and a plunge pool at the falls. Bars composed of very coarse-grained, imbricated boulders occur in the stream channel up-and down-stream from Fawn's Leap. Luanne Whitbeck (personal communication, Fall, 1983) noted small trees growing on the bars that were of approximately the same age (~10 to 15 years old). She suggested that the trees indicate that the bars were not active in 1983, and that the trees probably began growing during a drought when the stream flow was low. She also observed active landslides along the channel sides.

The floodplain is still quite thin in this reach. Large alluvial fans or cones have been deposited at the mouths of the high-gradient tributary streams in the Clove. Airphoto analysis and field work by Dineen, Whitbeck, and Lorie Dunn have documented abundant evidence for landslides, rockslides, earthfalls, and earthflows in this reach. Bonafede (1980) cites several nineteenth century maps that document similar features in the Clove.

STOP 12: Tannery Mill and East Hunter (Fig. 10)

This 0.5 to 0.75 mile hike follows the floodplain of the stream. The high embankment of Route 23a is on the right (north). Many examples of earthfalls can be seen in the channel banks. The exposures along the stream show that the floodplain deposits are 1 to 2 meters thick, and are composed of imbricated flat cobbles overlain by a thin veneer of silt. The gradient of the stream in the reach from Haines Falls to Fawn's Leap is 0.046, or 241 ft/mile.

We will pass a large (3 by 4 by 4 meters in diameter) boulder on the bank that was called "Rockefeller Rock" because of an inscription carved into the sandstone (Bonafede, 1980). That boulder had moved 5 to 10 cm away from the bank from 1979 to 1984 (Martha Costello, personal communication, Winter, 1985).

Our trek ends at the defunct East Hunter Tannery. This tannery complex and village were built in 1817 and abandoned by 1866 (Bonafede, 1980). The village is being buried by mass movements. The tannery shows abundant evidence for stream scour and deposition. The milldams that used to serve the tannery have been washed away.

Bonafede (1980) was not able to document the presence of artifacts that were more than 200 years old, in spite of an intensive search that included many shovel test pits. This observation suggests that the Clove gets "flushed out" regularly by the Kaaters Kill, a hypothesis that is strengthened by the evidence for mass wasting and flooding and by Route 23A's severe maintenance problems (NYS Department of Transportation).

The "horseshoe" where the road crosses the Kaaters Kill below Kaaterskill Falls is underlain by over 49 ft of red glacial till, based on NYS Dept. of Transportation test boring data. Landslides occur frequently in the area of the horseshoe (Frank Irving, personal communication, Summer, 1987).

STOP 13: North Lake: Catskill Mountain House (Fig. 10)

The North and South Lake area is a State Park, and is the headwaters for the Kaaters Kill. It is developed on the dipslope of the Onteora Formation, the rock that forms the caprock of the Catskill Escarpment. Glacially striated conglomerates are exposed around the lakes. A major mountain inn served tourists in this area throughout the late nineteenth and early twentieth centuries (Bonafede, 1980). Its abandoned hulk burned about twenty years ago. The inn was built at the edge of the Catskill Escarpment.

The park is on the Helderberg Peneplain. The view from the Escarpment overlooks the Hoogeberg and Albany Peneplains. The Helderberg Plateau-Hamilton Hills are visible to the north. To the east lie the Taconic Mountains, and to the northeast the Rensselaer Plateau can be seen. The Rip Van Winkle and Kingston-Rhinecliff Bridges can also be seen from this vantage point.

The inn and the magnificent scenery lured many geologists into the North Lake area through the years. Darton (1895) suggested that the Kaaters Kill and the Platte Kill to the south have pirated the headwaters of the Schoharie Creek. These high-gradient streams had a major advantage over the Schoharie in that they had only to flow 7 to 10 miles to reach their base level at the Hudson, while the Schoharie waters had to flow 135 miles to reach the same point.

Rodgers (1987) wondered why the piracy took place as late as the Pleistocene. He suggested that the back-tilted edge of the Onteora Formation was so resistant to erosion that it impeded the headward extension of streams in the Hudson Valley for a long time. He also suggested that the Kaaterskill Clove was excavated by the stream in post-glacial time.

The NYS Department of Transportation drilled through 65 feet of compact till along the right-of-way of Route 23A from Intermann's Bridge to Haines Falls, so both the upper, wide valley of the Clove and the narrow gorge below Fawn's Leap are pre-Wisconsinan in age. The till must be studied in more detail to determine whether earlier glacial deposits are present.

hundreds of test- boring logs from the NYS Dept. of Transportation, the US Geological Survey, and various consulting firms. With the aid of Frank Angelloti, Steve Berger, Tom Costello, Pete Knightes, Paul Kopsick, and others, I was able to suppliment the drilling data with seismic refraction lines. The data permitted me to draft a series of 1:24,000 overlays, using a 50-foot contour interval, that show the topography of the bedrock surface in the Hudson Valley of eastern New York State. These maps are in the Open Files of the NYS Geological Survey.

I became intensely interested in the "overburden" of Holocene and Pleistocene deposits during the course of this study. My various studies of the glacial deposits are published elsewhere (Dineen, 1986; Dineen and Duskin, 1987). My fascination with Holocene studies are the result of collaboration with archeologists of the NYS Museum, particularly Patty Bonafede, Martey Costello, Bob Funk, Mark LoRusso, Phil Lord, and Beth Wellman. I have also been helped by Frank Irving and Ed Sees of the NYS Dept. of Transportation, who have shared their observations and data files with me. I wish to thank Bill Rogers and Bob Fakundiny of the NYSGS for their helpful criticism of this paper, and Jack Skiba of the NYSGS for drafting the illustrations.

Geography

The mid-Hudson section of eastern New York State contains parts of three physiographic provinces. These provinces are the Appalachian Plateau, New England Uplands, and the Hudson Lowlands (Fig. 1; Cressy, 1966). The Appalachian Plateau is underlain by gently monoclinally folded marine and non-marine sedimentary rocks of Ordovician and Devonian age. The New England Uplands are metamorphosed sediments and igneous rocks of Cambrian and Ordovician age. The Hudson Lowlands are developed on highly folded and faulted sedimentary rocks of Ordovician age. The physiographic provinces can be divided into smaller sections on the basis of topography and underlying bedrock.

The Appalachian Plateau consists of the Catskill Mountains, Medusa plateau, Mariaville plateau, Helderberg Plateau, and the Hamilton Hills (Fig. 1). The plateaux are underlain by rocks that dip gently to the southwest. The Catskill Mountains are a deeply dissected cuesta that ranges in elevation from 2,000 to 4,500 feet. They are underlain by conglomerates and sandstones of the Upper Devonian Sonyea and Genesee Groups that are capped by the highly erosion-resistant Onteora Formation (Ruedemann, 1930; Fisher and others, 1970). The Medusa plateau rises to 2,000 feet, and is underlain by red sandstones of the Kiskatom Formation of Middle Devonian age (Fisher and others, 1970). The Mariaville plateau overlies gently southwest-dipping sandstones and shales of the Ordovician Schenectady Formation. It reaches elevations of 1,500 feet. The Helderberg Plateau is a cuesta underlain by Lower Devonian carbonates of the Onondaga Limestone and the Helderberg Group. It is moderately dissected, and attains elevations of 1,600 feet. The Hamilton Hills are also 1,600 feet high, and are underlain by Lower Devonian sandstones and shales of the Hamilton (Lower Sonyea) Group (Fisher and others, 1970). A prominent cliff, the Helderberg Escarpment, borders the Helderberg Plateau. A similar cliff, the Wall of Manitou or the Catskill Escarpment, borders the east and north edges of the Catskill Mountains.

The New England Upland can be divided into the Rensselaer Plateau, Taconic Mountains, and the Hudson Highlands (Fig. 1). The Rensselaer Plateau ranges in height from 1,600 to 900 feet. It is underlain by the relatively flat-lying Cambrian Rensselear Quartzite. The Taconic Mountains reach elevations of 2,000 feet and are underlain by intensely folded Cambrian and Ordovician phyllites, marbles, schists, and slates (Fisher and others, 1970). The Hudson Highlands are underlain by highly metamorphosed igneous and sedimentary rocks of Precambrian through Devonian age. The Highlands are 1,100 to 1,600 feet high.

The Hudson Lowlands are a continuation of the Ridge and Valley Physiographic Province (Fenneman, 1938), and include the Rondout-Esopus Valley, Wallkill Valley, Hudson Gorge, Little Ridge and Valley, Slate Hills, Shawangunk Mountains, and Marlboro Mountains (Fig. 1). Homoclinally-folded limestones of the Devonian Helderberg Group underlie the Rondout-Esopus Valley (Fisher and others, 1970). The Wallkill Valley is carved into a belt of intensely folded shales of the Ordovician Martinsburg Formation (Waines and others, 1983). The Hudson Gorge follows the tightly folded Normanskill Group of sandstones and shales of Ordovician age (Fisher and others, 1970). These lowlands lie below the 600 foot contour line. The Little Ridge and Valley is a range of low longitudinal ridges composed of highly folded limestones and shales of the Devonian Onondaga, Marcellus, and Bakoven Formations, and the Helderberg Group (Fenneman, 1938; Chadwick, 1944). This range of hills attains heights of 300 feet. The Slate Hills are an assemblage of low, rounded hills, with heights of 600 feet. They have many outcrops of the moderately metamorphosed Cambrian slates of the Nassau Formation (Fenneman, 1938). The southern extension of the Slate Hills are underlain by Cambrian through Ordovician carbonates of the Wappinger Group (Fisher and Warthin, 1976). The Shawangunk Mountains are a hogback of steeply-dipping beds of the Silurian Shawangunk Quartzite. The white cliffs reach elevations of 2,000 feet. The Marlboro Mountains consist of folded sandstones of the Ordovician Quassaic Formation (Waines and others, 1983) that reach elevations of 700 feet.

The physiographic provinces were molded by weathering and fluvial processes during the Cenozoic era. All of the provinces have been modified by glacial and postglacial erosion and deposition.

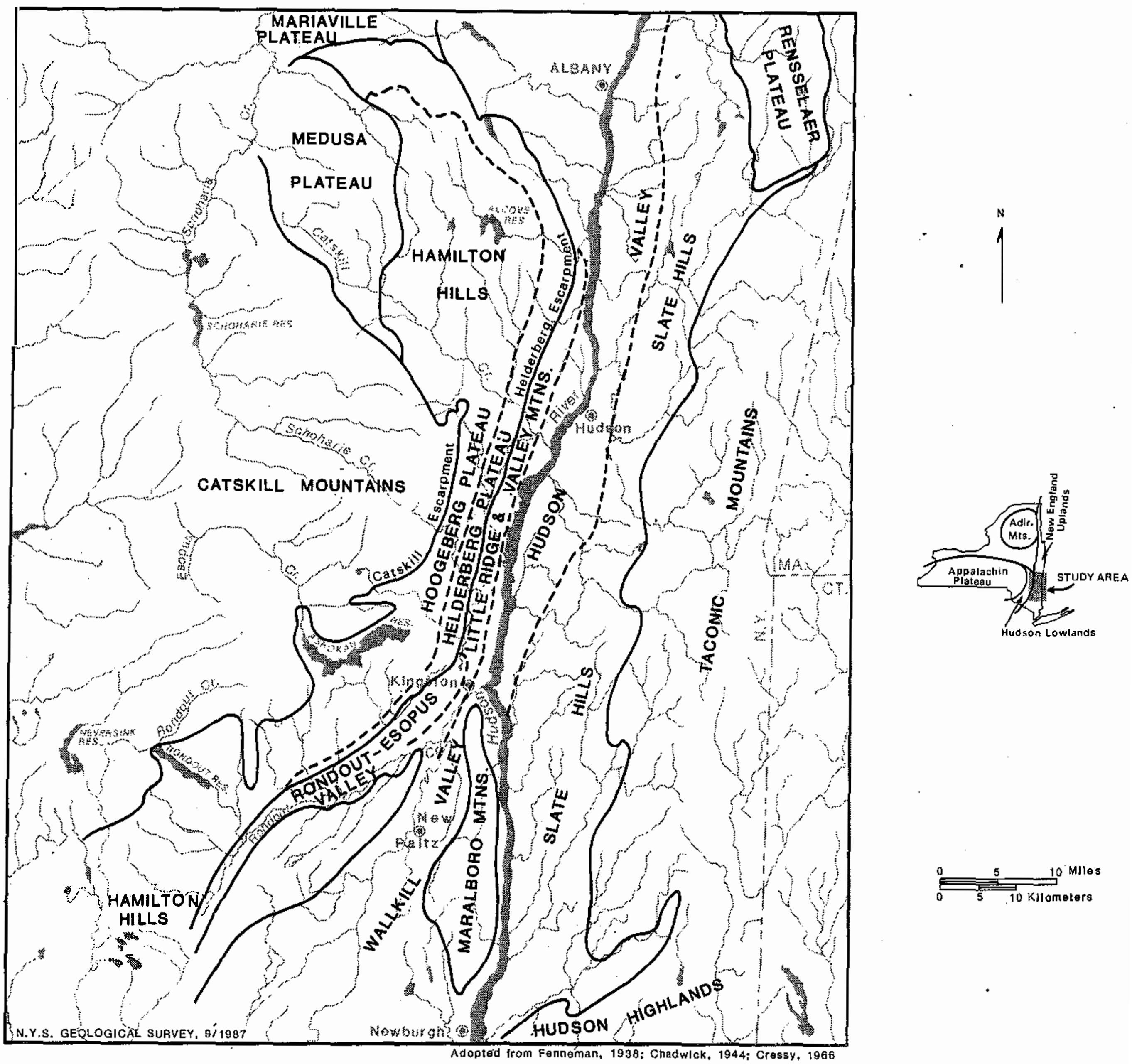

Figure 1. Physiographic Provinces

PREGLACIAL DRAINAGE

Peneplains

Large, nearly planar erosion surfaces developed during long periods of weathering and erosion in the Cenozoic era. These nearly flat to gently undulating plains are peneplains or etchplains. Several have been mapped or described in the mid-Hudson region (Campbell, 1903; Ruedemann, 1930 and 1932; Fenneman, 1938; Happ, 1938; Chadwick, 1944). These erosion surfaces are the Catskill, Helderberg-Rensselaer, and Albany peneplains (Table 1 and Ruedemann, 1930). Each peneplain was developed during long periods of relatively stable base-level control. The peneplains cut across the geologic structure and the bedrock contacts. Monadnocks of more resistant rocks locally rise above the individual peneplains. The development of each peneplain was interrupted by subsequent uplift.

These peneplain surfaces were imperfectly developed or preserved. Development of a nearly flat surface that is graded to a base-level requires that the base-level be stable for millions of years. Thus episodes of uplift can interrupt the peneplanation process. The resulting uplifted surface will preserve features consistant with that peneplain's "maturity."

Erosion surface first form adjacent to the major streams, and then broaden by backwasting of the nearby upland surfaces. Monadnocks form in areas where the bedrock is exceptionally resistant to erosion or along the drainage basin divides. Thus, the incipient peneplain first develop as "strath terraces" (fluvially eroded bedrock surfaces) along rivers and later extend across the entire landscape. This process requires that the peneplains develop by progressive spreading from the trunk streams into the adjacent uplands along upland tributary stream valleys. The peneplain will thereby be most "mature" near the coast, and will exhibit "youthful" strath terraces in nearby uplands.

Multiple episodes of uplift and base-level stability result in the development and preservation of multiple peneplain surfaces. The older peneplains are dissected during the formation of younger peneplains. Frequently the older peneplains will be preserved as accordant elevations of mountain tops or hilltops, windgaps, or as bedrock terraces along the valley sides.

Six erosion surfaces can be mapped in the mid-Hudson Valley. The oldest is the Catskill Peneplain (Table 1 and Fig.2). It was described by Ruedemann (1930) as a highly dissected, 4,000-ft surface that is preserved as accordant mountain tops in the high peaks of the Catskill, Adirondack, and Taconic Mountains. It slopes towards the southwest (see Fig. 6 in Coates, 1974). The Catskill Peneplain is deeply embayed by the headwaters of the Schoharie Creek. These headwater valleys are extentions of the next-youngest erosion surface- the Helderberg Peneplain (Chadwick, 1944).

TABLE 1 PENEPLAINS OF THE MID-HUDSON VALLEY

WORKER: Campbell, 1903	Ruedemann, 1930,1932	Fenneman, 1938	Happ, 1938	Chadwick, 1944	Dineen, this report
PENEPLAIN/ elevation in feet/ regional correlation:					
-	Catskill	-	High Catskills	-	Catskill
-	4,000	-	4,000		4,000
-	-	-	-	-	-
-	-	-	-	-	-
-	2,500	-	-	-	-
-	Kittatinny	-	-	-	-
-	Helderberg-Rennselaer Plateau	-	"2,000 ft Surface"	Helderberg	Helderberg
-	2,000 to 1,600	2,000 to 1,400	2,000	2,000	1,200? to 2,000
-	Harrisburg	Kittatinny (Schooley)	Kittatinny (Schooley)	-	-
-	-	-	Monticello	-	Monticello
-	-	-	1,200 to 1,700	-	1,200 to 1,700
-	-	-	Hamilton Bench	-	Ashokan
-	-	-	900	-	700 to 1,100
-	-	-	Harrisburg (Chambersburg)	-	-
-	-	-	-	Hoogeberg	Hoogeberg
-	-	500 to 400	600 to 500	600 to 400	600 to 400
-	-	Harrisburg	Somerville	-	-
-	Albany	-	-	Kalkberg	Albany
300 to 100	300 to 200	400 to 200	-	400 to 200	400 to 200
Somerville	-	Somerville	-	-	-
-	"Inner Gorge"	"Inner Gorge"	-	-	Castleton
-	-100	100 to -700	-	-	125 to -25
-	-	-	-	-	-

The Helderberg Peneplain is highly dissected but widely preserved throughout the Hudson Valley (Table 1 and Fig. 2). It is best developed in the Helderberg and Rensselaer Plateaus and along the eastern edge of the Catskill Plateau (Fig. 3). It is the Helderberg-Rensselaer Peneplain of Ruedemann (1930 and 1932), the "2,000-ft surface" of Happ (1938), and the Helderberg Peneplain of Chadwick (1944), and ranges in elevation from 1,200(?) to 2,000 ft, sloping northward and southwestward off the Appalachian Plateau (see Fig. 6 in Coates, 1974) and south in the lower Hudson Valley (Figs. 3a to c). The Helderberg Peneplain is deeply dissected by valleys that are part of the modern drainage network and is best developed around the High Peaks of the Catskill Mountains (Fig. 2; see also Fig. 6 in Coates, 1974).

Happ (1938) described the Monticello Peneplain as a late stage of the "2,000-ft surface." He mapped this feature in the Wall Kill and Delaware Valleys. It is developed at elevations from 1,300 to 1,700 ft and blends into the Helderberg Peneplain to the north and southeast (Happ, 1938). The Monticello Peneplain might have developed as a response to 300 to 400 ft of uplift in late Schooley time (Happ, 1938). It can be considered an immature or incipient peneplain that post-dates the Helderberg Peneplain, and can be traced from the Rensselaer Plateau to the Hudson Highlands (Figs. 2 and 3). It blends into the Helderberg Peneplain in many places (note the overlap in elevations in Table 1). It is seperated from the Helderberg Peneplain by sharp escarpments in the Medusa and Helderberg Plateaus (Fig. 2 and 3).

The Hamilton Bench is a narrow bedrock terrace developed on the Hamilton (Sonyea) Group in the Monticello area (Table 1; Happ, 1938). The surface is at an elevation of 900 ft near Monticello and can be traced to the northeast, where it rises from 700 to 1,200 ft (Figs. 2 and 3a to c). I am renaming this surface the Ashokan Peneplain because it is best developed in the Ashokan Reservoir area (Figs. 2 and 3c). It can be traced north to the base of the Rensselaer Plateau (Fig. 3a). This peneplain grades into the Monticello surface on the dipslopes of the Hamilton Hills (Fig. 2).

Chadwick (1944) classified the 600 to 400 ft bedrock terrace that lies at the foot of the Catskill Mountains as a piedmont. It cross-cuts the bedrock structure in this area and makes up the low plateau known locally as the Hoogeberg (Fig. 3b). This surface can be traced into the Wall Kill Valley to the Clintondale area (Fig. 3c). It can be traced north into the Cats Kill Valley (Fig. 2), and up the Hudson Valley to the bases of the Helderberg and Rensselaer Plateaus (Fig. 3a). It is named the Hoogeberg Strath Terrace in this report.

The Albany Peneplain is an incipient peneplain developed adjacent to the Hudson River from Glens Falls, NY to Newburgh, NY (Ruedemann, 1930). It is widest in the Albany area and lies between elevations of 200 and 400 ft (Fenneman, 1938; Ruedemann, 1930). Several immature south-dipping strath terraces in this

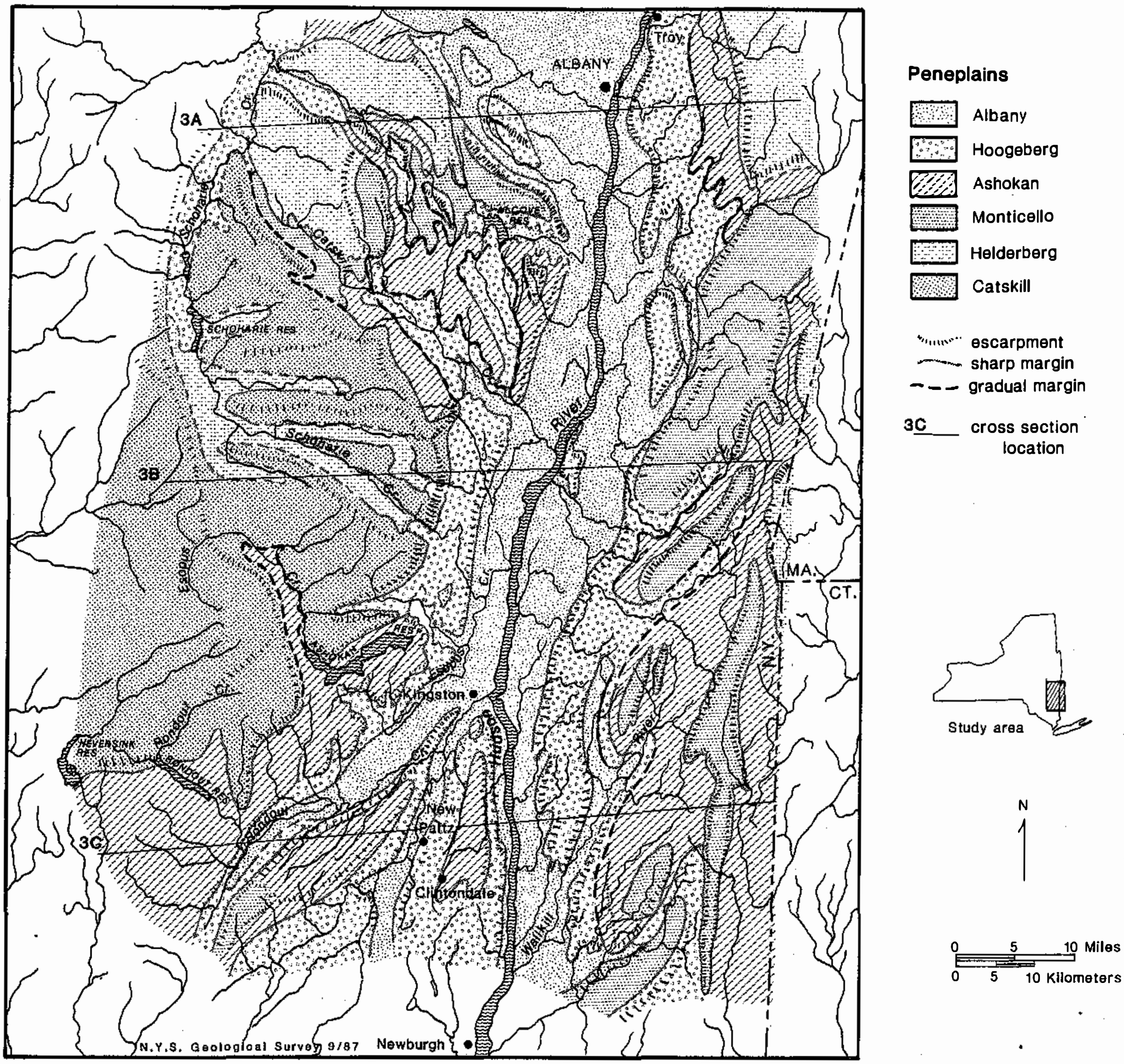

Figure 2. Peneplains

elevation range can be traced in the Hudson Valley near Albany (Fig. 3a; Dineen and others, 1983). The two stongest terraces are the Glenmont and Albany Strath Terraces. The Glenville Strath slopes south from 380 to 370 ft and has a gradient of 0.5 ft/mi. The Albany Strath ranges from 240 to 210 ft in elevation and has a gradient of 1.25 ft/mi. The Albany Peneplain or Strath Terraces can be traced from Albany to Newburgh (Figs. 2 and 3).

The Albany Peneplain is deeply incised by the "inner gorge" of the Hudson (Stoller, 1920; Ruedemann, 1930). The "inner gorge" was carved during the Late Cenozoic and is part of the preglacial drainage network (Table 1 and Fig. 4).

Preglacial Streams

The preglacial drainage pattern of the mid-Hudson Valley can be deduced from the topography of the bedrock surface. Deep valleys underlie the glacial deposits of the region. The connections between the valleys include water gaps (a pass through a rock ridge that a stream drains through), wind gaps (a sag or pass through a ridge that once carried a stream), and dirt gaps (a buried pass or sag in a rock ridge that once carried a stream). Thus, the preglacial drainage of the region can be mapped by connecting the buried valleys using simple rules, such as "water flows downhill" and "the preglacial streams were adjusted to bedrock structure." Deep scouring of lowland areas by glacial ice complicates the interpretation of preglacial drainage somewhat (Kemp, 1915; Dineen and others, 1983). The preglacial drainage map (Fig. 4) traces the late preglacial drainage. The Albany Peneplain had been deeply etched by rejuvenated rivers during the Late Pliocene or Early Pleistocene. Now-buried waterfalls that were paleo-knickpoints are found in the Albany region (Fig. 4; Dineen and others, 1983).

The preglacial river network of the Hudson Valley had a strongly-developed trellis to rectangular drainage pattern (Fig. 4). The pattern in the Hudson Lowlands was influenced by the distribution of belts of folded and faulted shale, limestone, sandstone, and chert. The chert and sandstone underlie the interfluves, while shale underlies the valleys or river channels (Davis and Dineen, 1969). The trunk stream at this time was the Colonie Channel (Simpson, 1949), a buried valley that extends from Coeymans to Glens Falls, NY (Dineen and others, 1983). The present Hudson River was a tributary to the Colonie that rose in the Batten Kill- Hoosic River drainage in the Taconic Mountains. The Batten Kill-Hoosic channel hangs on the Colonie Channel at Castleton (Figs. 5a, 5b and 6). The Castleton Strath Terrace was developed in the Batten Kill-Hoosic channel north of that confluence (Dineen and others, 1983). It lies between elevations of 125 and -25 ft in the Albany area (Dineen and others, 1983), and has a gradient of 1 ft/mi to the south. It can be traced south to the Kingston-Rhinecliff Bridge, where it reaches an elevation of -80 ft (Fig. 6). This strath terrace is incised by a narrow gorge that is carved to a depth of -100 ft at Castleton (Figs. 5a and 6). The Colonie Channel becomes the Hudson channel

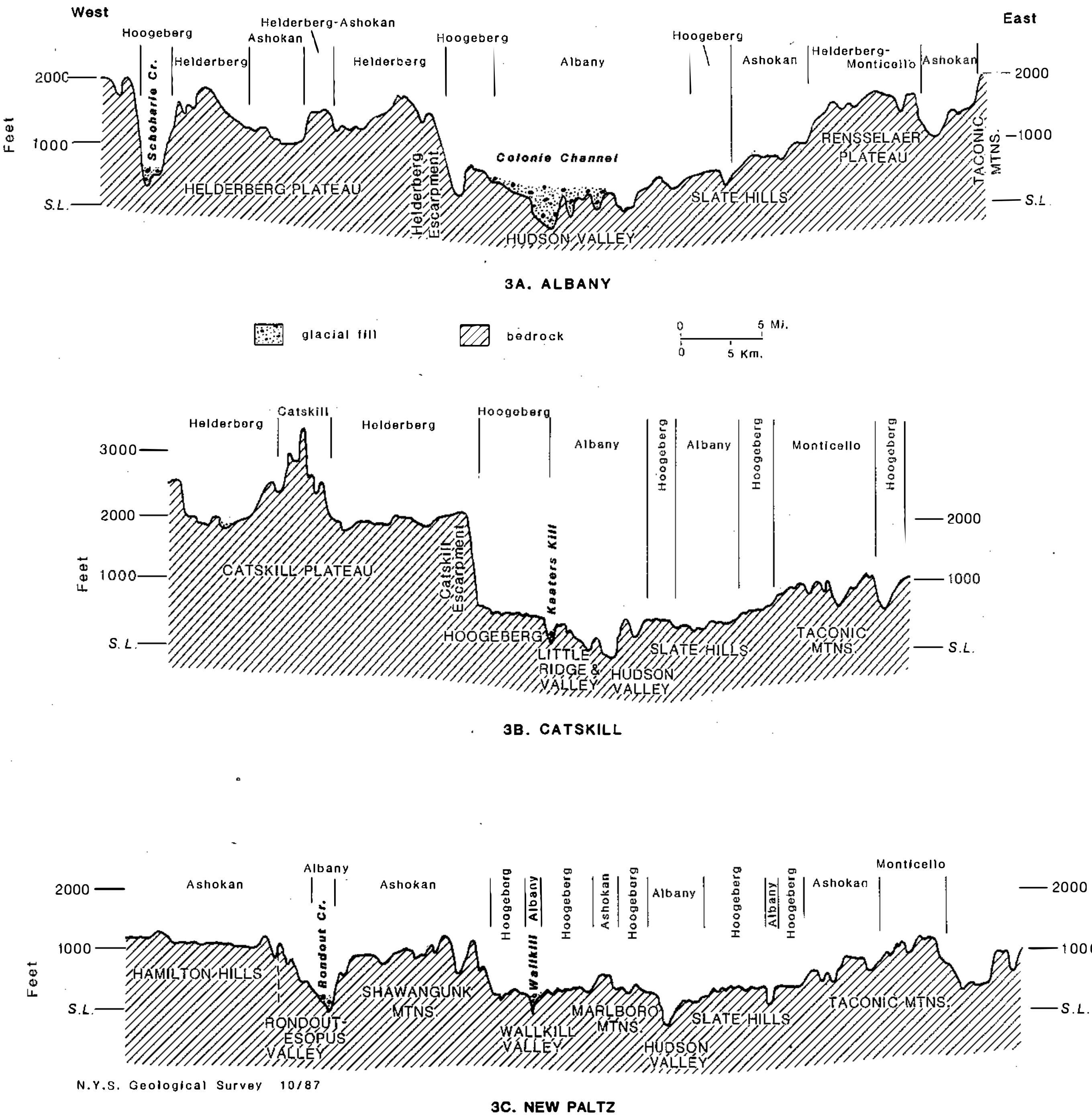

Figure 3.
Physiographic Provinces Cross Sections

south of Coeymans (Fig. 4), and falls to an elevation of -290 ft at the Newburgh-Beacon Bridge (Fig. 5f).

The tributary streams developed a longitudinal drainage pattern that followed the strike of zones of shale, major joint sets, or fault zones. Transverse streams cut across the resistant rock ridges and connected these longitudinal streams with the trunk streams. The drainage pattern that developed along the margin of the Appalachian Plateau was an especially well-developed trellis drainage pattern (Fig. 4). The longer stream segments tended to follow shale belts, while their tributaries were dip-slope streams developed on the major joint sets (Chadwick, 1944).

The Slate Hills were also drained by a longitudinal drainage system that developed parallel to the axes of folded shale belts and along the edges of the Taconic thrust sheets (Fig. 4). The longitudinal drainage in the southern section of the Slate Hills was controlled by the strike of Lower Paleozoic carbonates (Fisher and Warthin, 1976). The drainage pattern of the Wall Kill Valley was controlled by the fold axes in the Martinsburg Shales. The streams in the Rondout-Esopus Valley and the Little Ridge and Valley were controlled by steeply-dipping beds of shales. The adjacent limestones formed ridges. Note that the limestones formed ridges in the Little Ridge and Valley area and formed the caprock of the Helderberg Escarpment, while limestones and dolostones underlie the valleys in the southern section of the Slate Hills. The moderately metamorphosed shales of the Slate Hills were more resistant to erosion than the unmetamorphosed shales in the Little Ridge and Valley and the Helderberg Plateau.

The phyllites of the Taconic section of the New England Uplands were very resistant to erosion. Most of the longitudinal valleys in this section were underlain by marble (Fig. 4; Fenneman, 1938). The valleys in the Hudson Highlands tended to be underlain by either marble or fault zones (Fisher and others, 1970).

HOLOCENE

Sea level was significantly lower during the glacial periods than it is at Present. Much of the Earth's water was "locked up" in the retreating glaciers during late glacial time. This lowered the base level of the streams in the mid-Hudson Valley and allowed them to deeply entrench the glacial deposits that clogged the Hudson Gorge and its tributaries. Sea level was 180 feet below its present level 10,200 years ago (Wiess, 1974). It had risen to 45 feet below present level by 8,000 yr B.P., and was 12 feet below by 4,000 yr B.P. (Averill and others, 1980; W. S. Newman, personal communication, Spring, 1986). The Hudson is now an estuary from the New York Harbor to Troy, NY.

Bridge borings indicate that the Hudson had scoured an inner gorge to 30 ft BSL in the Castleton area (Figs. 5 and 6) and to 120 ft. BSL near Poughkeepsie (Fig. 5e and 6). The tributaries of the Hudson eroded at least 150 feet of glacial sediment out of

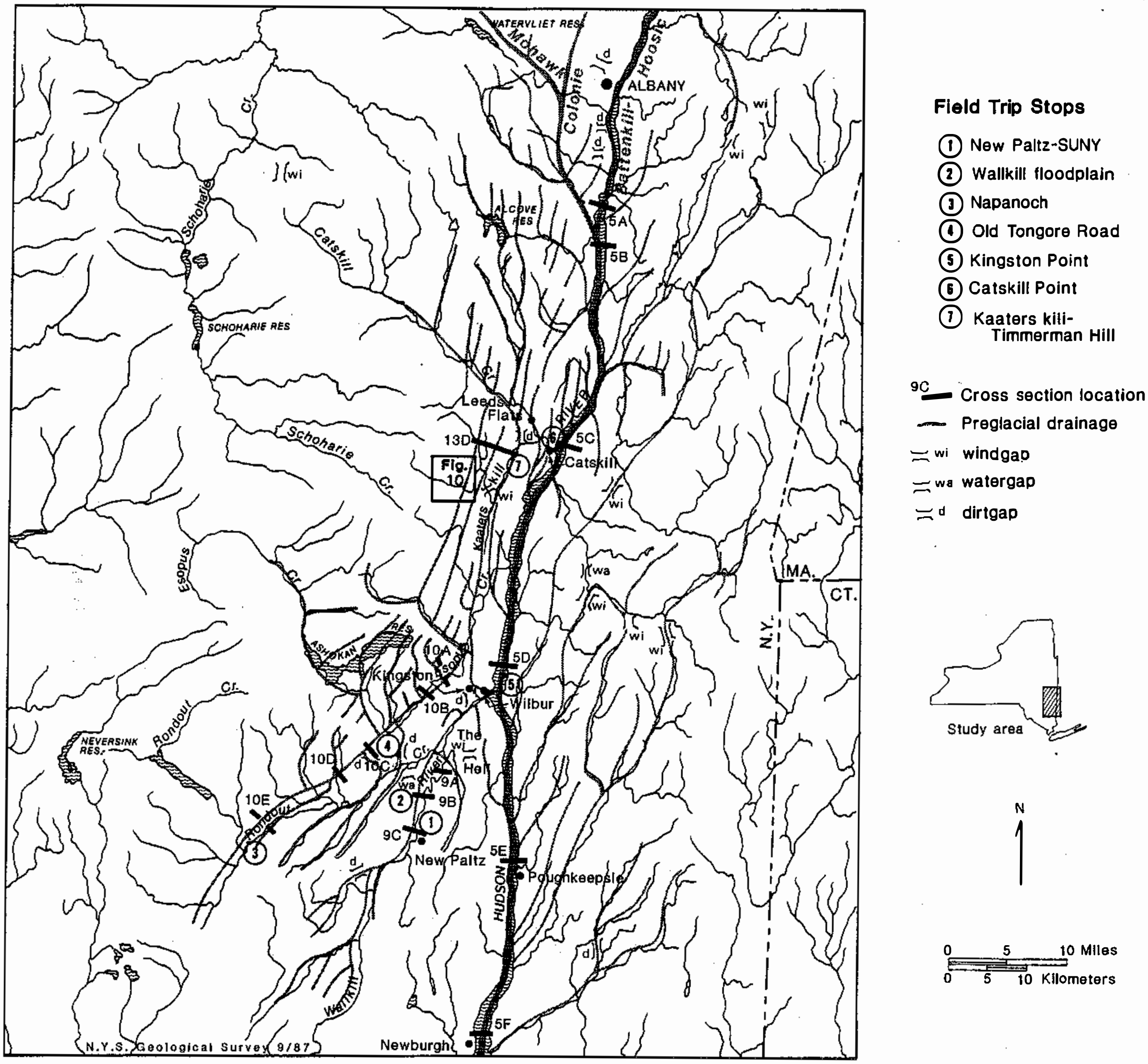

Figure 4. Late Preglacial Drainage & Field Trip Stops

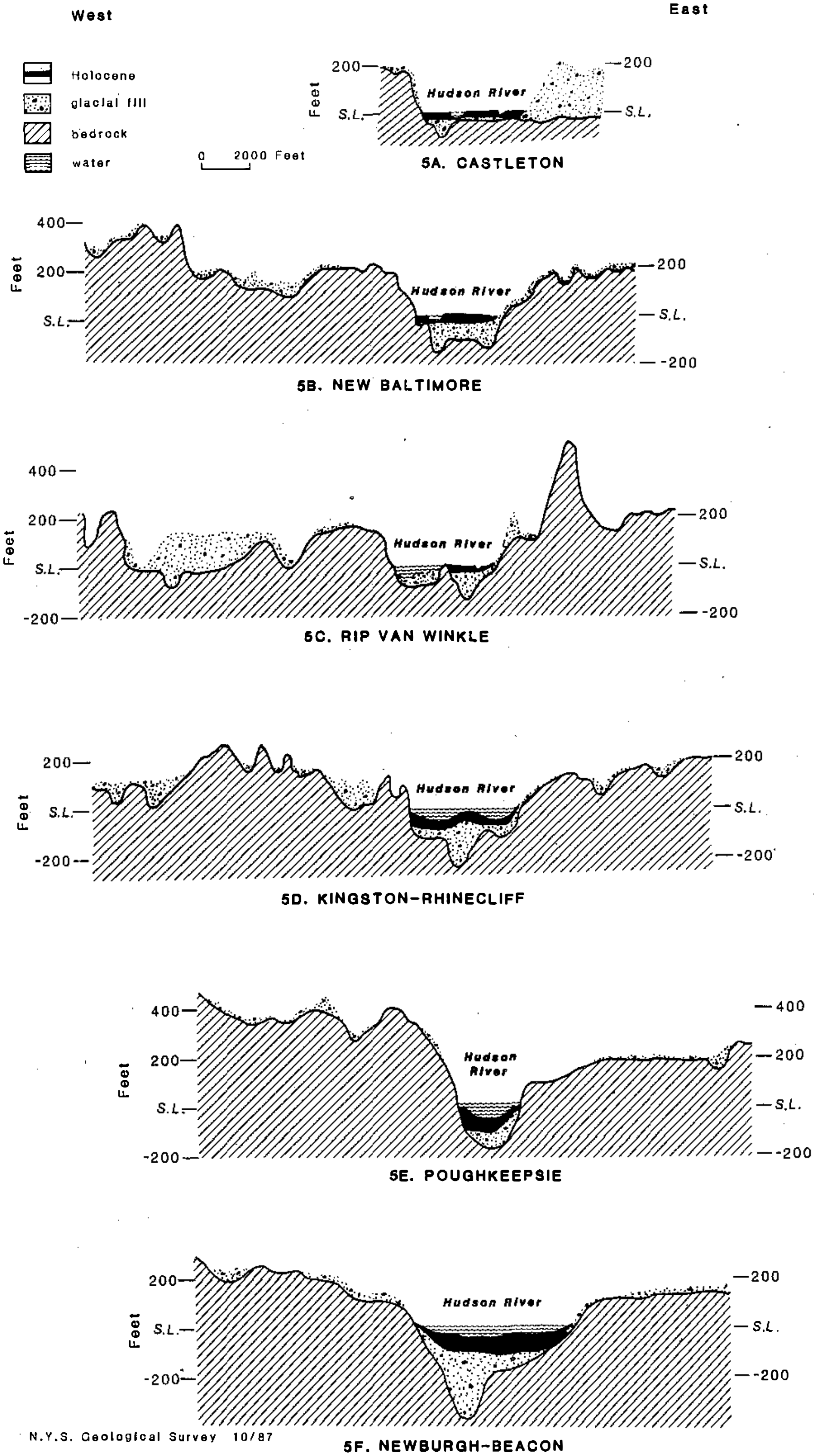

Figure 5.
Hudson River Cross Sections

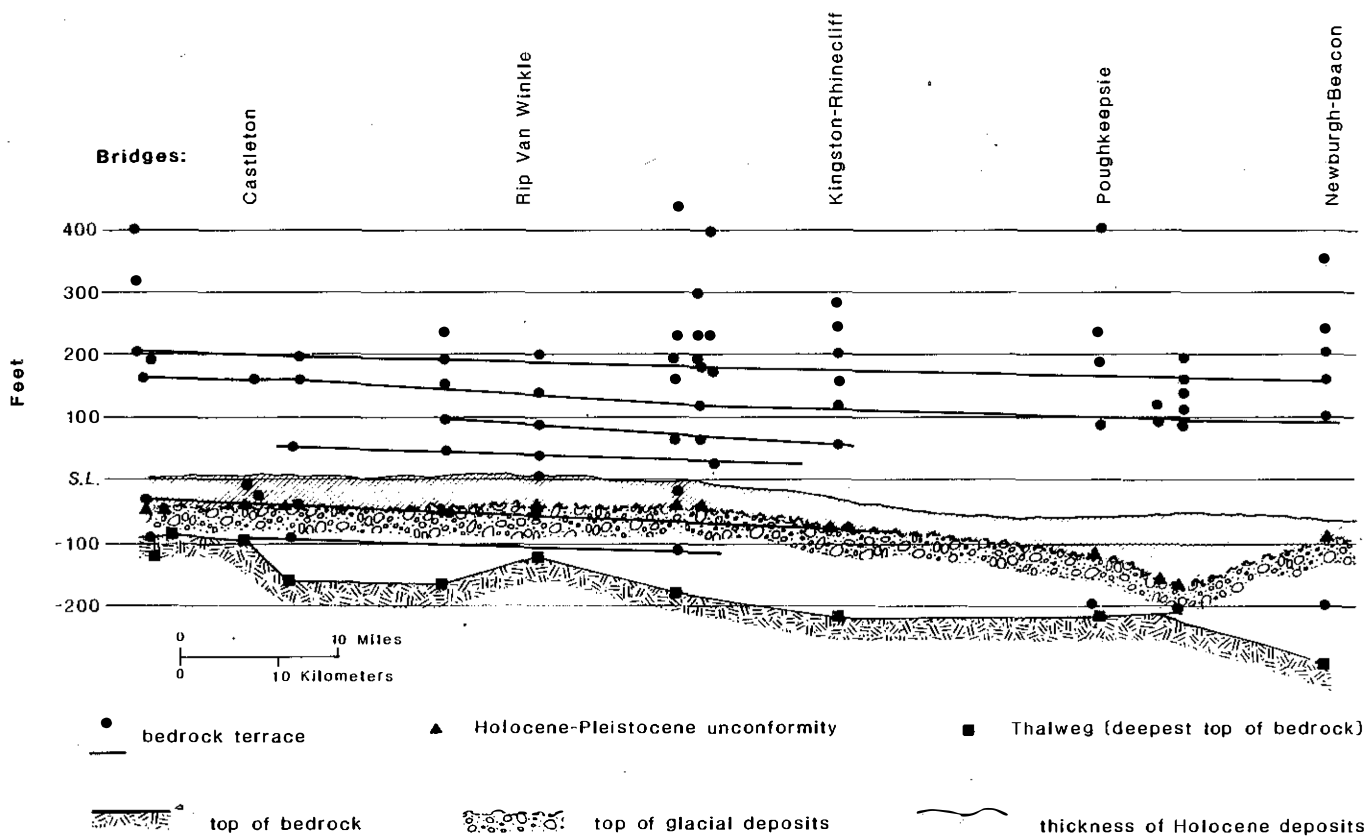

Figure 6.

Longitudinal Section of the Hudson Gorge from Albany to the Newburgh-Beacon Bridge

their lower valleys during Holocene time (Fig. 6; Dineen and Duskin, 1987). Organic-rich silty fine sands have filled the Hudson and its tributary confluences as they were flooded with tidal waters within the past 4,000 years. Many of the tributary streams have deposited large Holocene deltas in the Hudson, these deltas are drowned south of Saugerties (Fig. 7). Rogers Island, under the Rip Van Winkle Bridge, is the southernmost extension of the Hudson River's Holocene delta (Figs. 5c and 7). The Hudson's floodplain and delta is at least 8,000 to 10,000 years old near Albany, based on Spruce Pollen-bearing floodplain deposits that was encountered in test borings (personal communication, Mr. Donald Lewis-NYS Biological Survey, Summer, 1985).

The tributaries of the Hudson River still exhibit a trellis drainage pattern in the upland areas (Fig. 7). Nevertheless, these tributaries form a dendritic drainage pattern where they cross the wide glacial lake plains in the Hudson Lowlands. The deposits of lake clay are significantly thinner and more restricted in the southern Hudson Lowlands and stream pattern is therefore more trellised (Fig. 7).

The tributary streams tend to meander across wide floodplains that are developed on the lake clays. The broad floodplains of the Wappinger Creek, Wall Kill, Rondout Creek, Kaaters Kill, Cats Kill, Normans Kill, and the Kinderhook Creek are all developed upstream from bedrock-defended rapids. Downstream from the rocky knickpoints, they flow in narrow, steep-walled valleys with perched (abandoned) meanders along the valley walls. Almost all of the Hudson's tributaries fall across rock ridges as they reach the Hudson. The waterfalls are developed on the edge of the Albany Peneplain (Stoller, 1920). The floodplain deposits are coarse-grained at their base and tend to become finer-grained towards their top (Dineen and Duskin, 1987).

Large alluvial fans have been deposited at the base of the Catskill Escarpment at West Shokan, Bearsville, West Saugerties, and Palenville (Fig. 7). These fans have fresh surfaces with poor soil development and many abandoned and active braided stream channels. Some have deeply incised their heads and have been reactivated (West Saugerties). Locally they dammed small proglacial lakes, as at Palenville (Dineen, 1986). Thus, they started forming during the Late Pleistocene, but are probably still active. Similar fans lie along the base of the Rensselaer Plateau at Hoags Corners and Poestenkill and at the base of the Hoogeberg Peneplain at Napanoch and Tongore Road (Fig. 7).

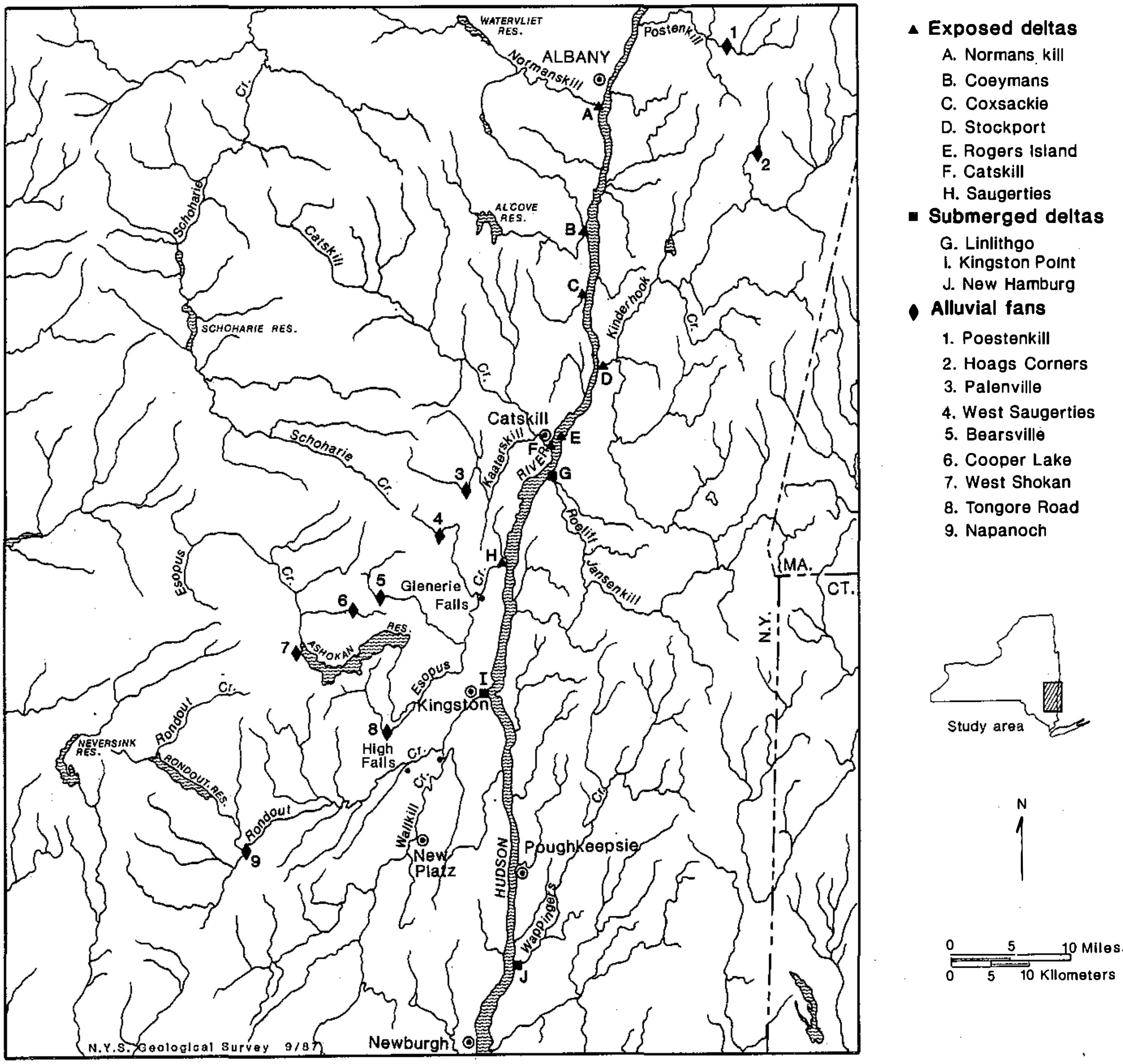

Figure 7. Modern Drainage

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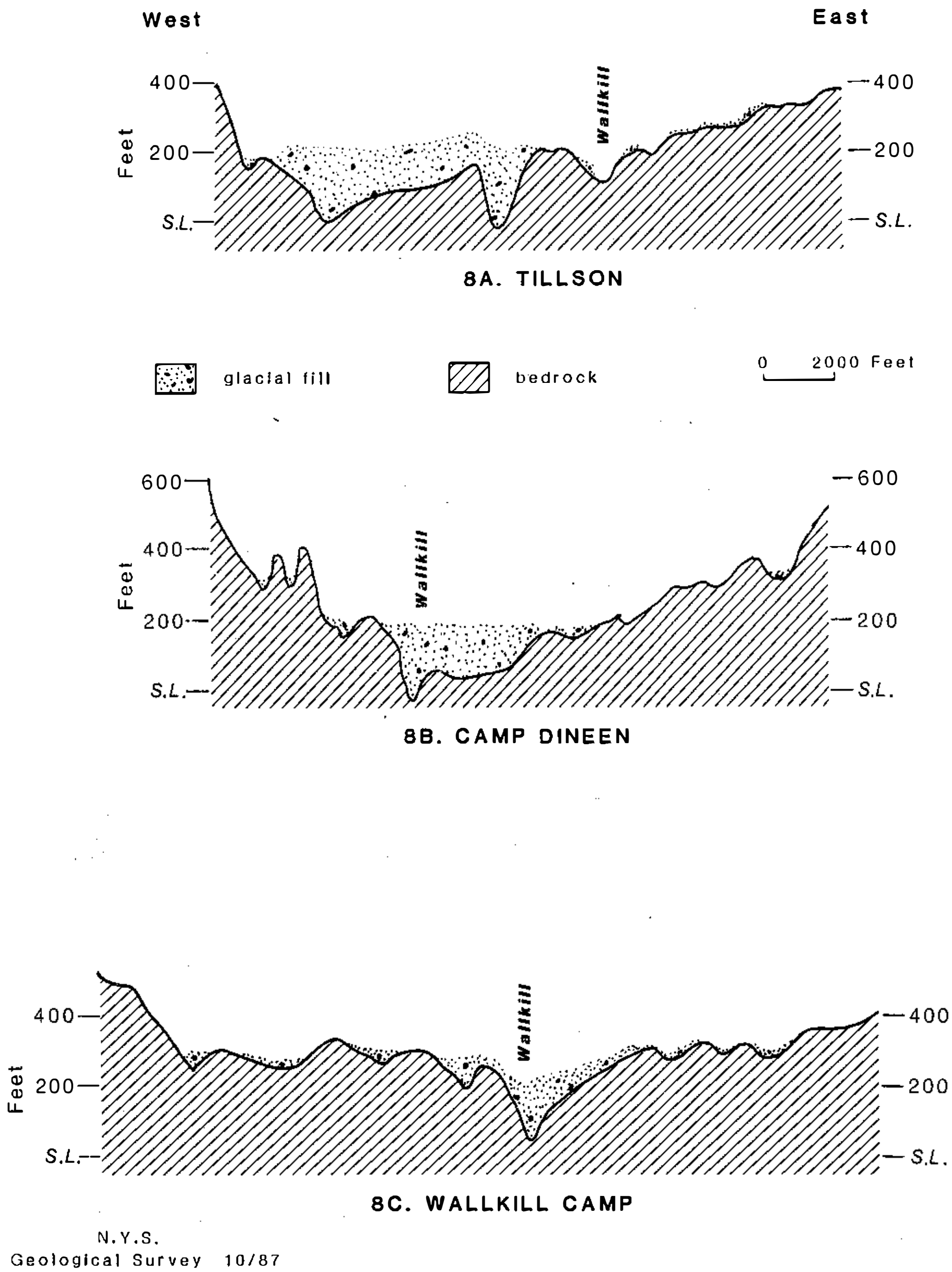

Figure 8.
Wallkill Cross Sections

FIELD STOPS-NYSGA 1987 FIELD TRIP

START: SUNY at New Paltz (Fig. 4)

STOP 1: New Paltz Bedrock Terrace- SUNY at New Paltz Parking Lot Clintondale, Gardiner, and Rosendale 7-1/2 minute quads.

The section of the Wall Kill Valley near the State University College contains a sequence of strath terraces that range in elevation from the Hoogeberg to the Albany Peneplains (Figs. 3c and 8c). Several of these terraces are mappable in the lower Wall Kill Valley. Dissected and glacially scoured remnants of the Hoogeberg Peneplain occur along the western edge of the Marlboro Mountains. This surface is sharply truncated at Clintondale by a 400- to 420-foot surface that can be traced southwest to the State line. The 400- to 420-ft terrace is cut, in turn, by a 340- to 360-ft terrace. This terrace extends through the windgap in the Marlboro Mts known as The Hell (Figs. 2, 4 and 8a). A third terrace lies at 280 to 300 ft (Figs. 8a, b, c). The SUNY at New Paltz campus is built on this terrace. The 280- to 300-ft terrace can not be traced south of Walden. It extends north into the Hudson Valley and west into the upper Rondout Valley.

The Ashokan Peneplain is preserved by the ridge line of the Shawangunk Mts (Figs. 2 and 3c). Monadnocks of the Helderberg and Monticello Peneplains remain as high points along the Shawangunks.

STOP 2: Wall Kill Floodplain: intersection of Mountain Rest and Springtown Roads (Fig. 4)
Rosendale, Clintondale, Gardiner, and Mohonk Lake 7-1/2 minute quads.

The reach of the Wall Kill downstream from New Paltz is underlain by 200 ft of glacial-lacustrine deposits. These sediments fill a gorge that was cut into the Albany Peneplain (Figs. 6 and 8) during preglacial or interglacial time. The gorge narrows and becomes shallower to the south, and disappears between Wallkill Camp and Wallkill Village (Figs. 8b and c). The gorge underlies the Tillson area (Fig. 8a) and passes west of the present Rondout Creek through the Eddyville area (Dineen and Duskin, 1987).

The abrupt widening of the Wall Kill's floodplain between New Paltz and Tillson is controlled by the preglacial topography. The soft glacial deposits allowed the Wall Kill to migrate laterally. Thus, the floodplain of the Wall Kill is 4,000 ft wide in the stream reach between New Paltz and Tillson. It narrows to 500 ft to the south. The floodplain is 15 to 20 ft above the level of the stream channel, and is underlain by 11 to 22 ft of floodplain deposits in the New Paltz area. These deposits tend to become finer-grained towards the surface. The sinuosity of the river in this reach is 1.6. The Wall Kill's floodplain contains

Woodland through Late Archaic Indian artifacts, suggesting an age for the floodplain deposits of 700 to 5,000 yr (Len Isenberg, personal communication, Feb. 1987). The Wall Kill is deflected across a rock sill by the large glacial lake delta at Tillson (Dineen and Duskin, 1987) and flows through a rocky channel to its confluence with the Rondout Creek. The bedrock sill is the base-level control for this reach of the Wall Kill.

<u>STOP 3:</u> Rondout Creek Floodplain at Napanoch (Fig. 4)
Ellenville, Napanoch, and Kerhonkson 7-1/2 minute quads

This section of the Rondout Creek's floodplain was mapped during a Cultural Resource Survey by Mr. Mark LoRusso of the NYS Museum (LoRusso, 1986). The floodplain north of the Eastern Correctional Facility is 2,000 to 3,000 ft wide and 6 to 20 ft thick. Several abandoned meanders are visible on its surface. It is developed downstream from a large alluvial fan that lies at the base of the Shawangunk Mountains. The floodplain deposits were intensely tested during the Cultural Resource Survey, but contained very sparse evidence of Indian occupations, although the meager sample of artifacts suggest an Archaic age (LoRusso, 1986).

The site is downstream from the large alluvial fan of the Rondout Creek at the Village of Napanoch. It was built where the Rondout enters its low-gradient middle valley. The upper Rondout drains the rugged foothills of the southern Catskill Mountains. The base-level of the central low gradient area is controlled by a bedrock sill at High Falls. The stream flows across deeply-incised glacial lake deposits (Dineen, 1986) that fill a preglacial valley (Figs. 2, 3c, and 9e). The preglacial valley is graded to the Albany Peneplain, and is cut into the Ashokan Peneplain. The valley also erodes a section of the Hoogeberg Peneplain (Fig. 2).

<u>STOP 4:</u> Esopus Floodplain at Old Tongore Road Town Park (Fig. 4)
Mohonk Lake, Ashokan, Kingston West 7-1/2 minute quads

This stop is at the alluvial fan of the Esopus Creek that was built where the Esopus flows off of the Ashokan Peneplain and onto glacial lake deposits that clog a valley cut into the Albany Peneplain (Fig. 9b). The Esopus Creek's base-level for this reach is controlled by a bedrock spillway at Glenerie Falls. The stream meanders across a 3,000 ft wide floodplain that is 12 to 20 ft thick (Stop 1 in Dineen and Duskin, 1987). The sinuosity of the stream is 1.2 to 1.3 in this reach. Many oxbows are visible, especially near Kingston. Dr. Len Isenberg noted that many surface finds of Archaic artifacts occur on the surface of the Esopus Creek's floodplain (personal communication, Feb. 1987).

The buried valley contains a narrow inner gorge that is cut to sea level (Fig. 9a and b). The inner gorge extends south into

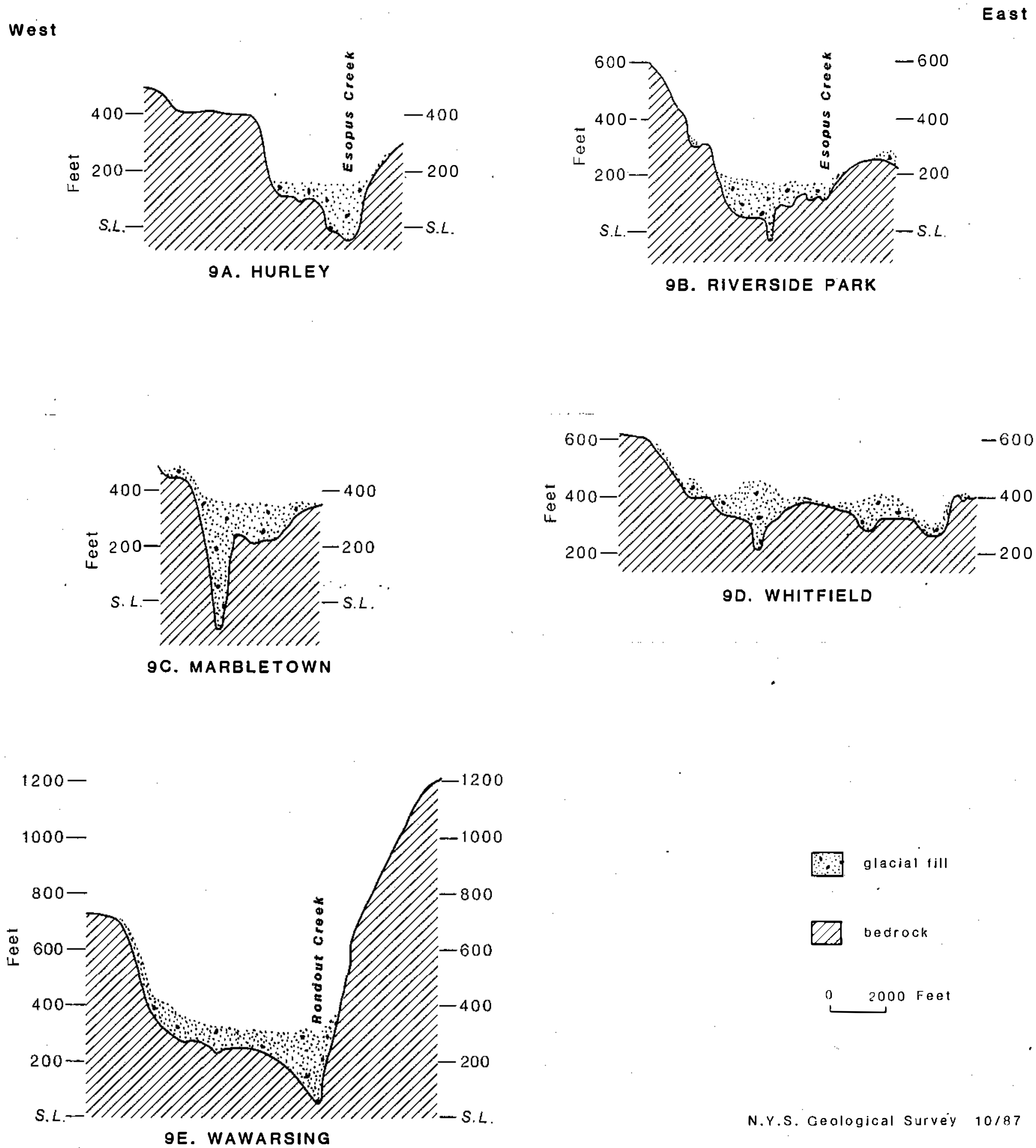

Figure 9.
Esopus-Rondout Cross Sections

the Marbletown area, although it narrows considerably (Figs. 9c and d). The Rondout-Esopus Valley contains a sequence of strath terraces that lie between the Hoogeberg and Albany Peneplains (Figs. 2 and 9d). The Albany Peneplain extends into the middle Rondout Valley through the High Falls water gap (Figs. 2 and 9d).

STOP 5: Kingston Point (Fig. 4)
Kingston East, Hyde Park, and Saugerties 7-1/2 minute quads.

The "inner gorge" of the Hudson is deeply incised into the Albany Peneplain in the Kingston area (Fig. 5d and 6). The inner gorge attains depths of 205 ft below sea level. The Castleton strath terrace lies at -80 to -100 ft in this area (Fig. 5d). The irregular surface of the Albany Peneplain is probably caused by glacial scour of the weak shale beds that lie between the relatively resistant sandstone and limestone layers. The Albany Peneplain clearly extends south as far as the Newburgh-Beacon Bridge (Fig 5f).

The Holocene deposits of this section of the Hudson's estuary are predominently silty sand to sandy silt with abundant organic matter (Figs. 5 and 6). The deposits overlie an unconformity that was carved into glacial deposits by the Hudson during the long period of lower sea level (12,000 to 4,000 yrs ago). The organic-rich silts and sands were deposited by the Hudson during the later stage of sea level rise. The Holocene unconformity lies at -20 to -30 ft at the Castleton Crossing of the Thruway, at -40 ft at the Rip Van Winkle Bridge, at -80 ft at the Kingston-Rhinecliff Bridge, at -120 ft at Poughkeepsie, and at -90 ft at the Newburgh-Beacon Bridge (Figs. 5 and 6). The excessive depth at Poughkeepsie is somewhat puzzling, it might be caused by either the presence of a glacial kettle hole, by catastrophic floods during deglaciation (Dineen and Duskin, 1987) or by tidal scour.

STOP 6: Catskill Point (Fig. 4)
Hudson South, Cementon, and Hudson North 7-1/2 minute quads

The bottom of the Hudson gorge is over 122 ft BSL at the Rip Van Winkle Bridge (Fig. 5c). It has been scoured into the Albany Peneplain. Remnants of the Hoogeberg Peneplain might exist at Mount Merino and the Becraft Mts., beyond the east end of the bridge.

The tidal flats and swamps south of the Village of Catskill are the Holocene delta of the Cats Kill. The tidal flats around Rogers Island are the southernmost extent of the Hudson's Holocene delta. Both of these deltas are composed of silty sand.

STOP 7: The Kaaters Kill at Timmerman Hill (Fig. 4)
Cementon, Hudson South, Saugerties, and Kaaterskill 7-1/2 minute quads.

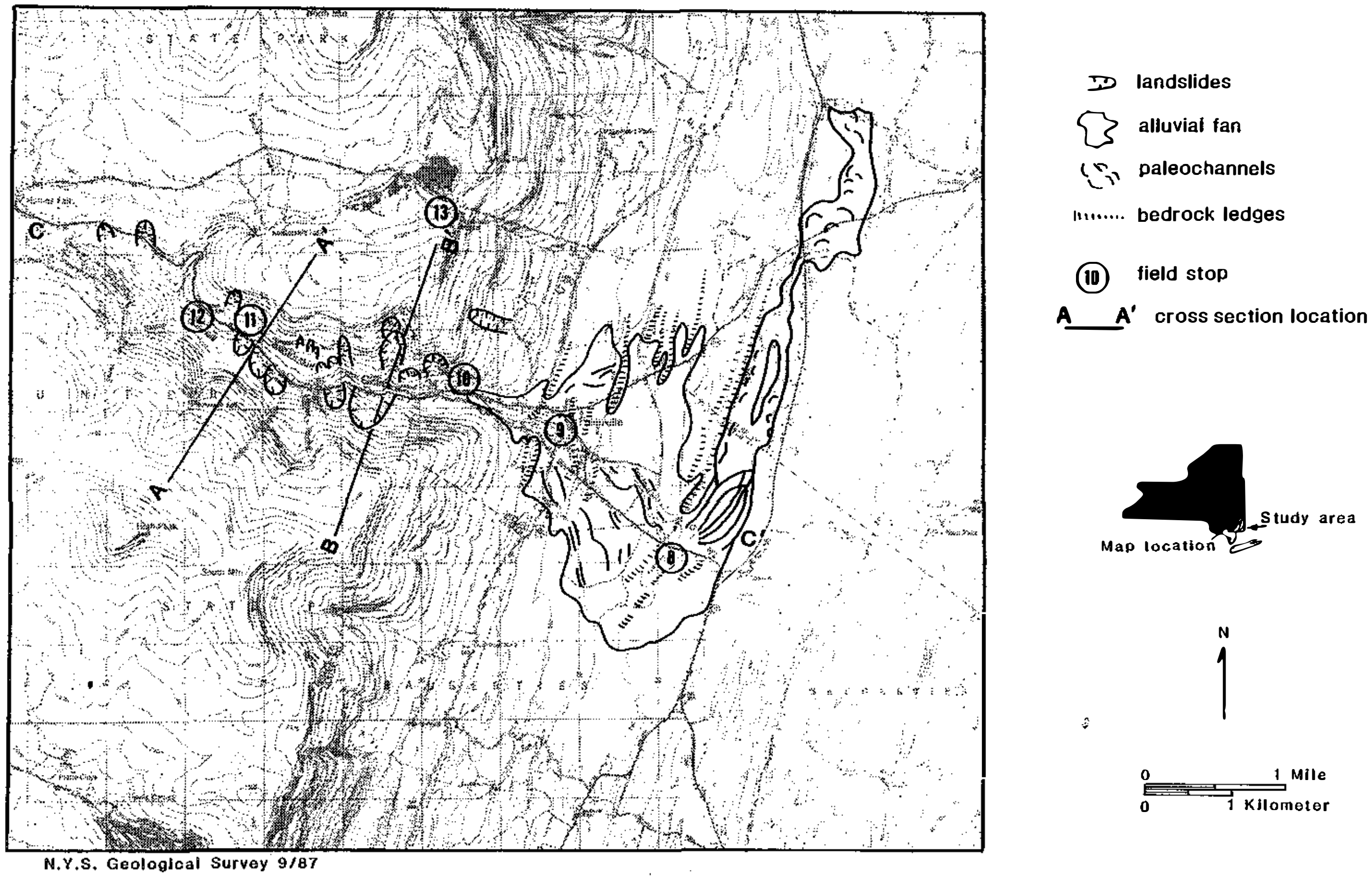

Figure 10. Kaaterskill Clove & Palenville Alluvial Fan

The Kaaters Kill's headwaters are in the eastern edge of the Catskill Mountains. The stream flows across the remnant of the Hoogeberg Peneplain and into the Bakoven valley at High Falls. The Hoogeberg is underlain by sandstones of the Mount Marion Formation. The Bakoven valley is underlain by the Bakoven Shales and is bordered on the east by the relatively resistant carbonates of the Onondaga Formation and the Helderberg Group that underlie the Kalkberg (Chadwick, 1944). The Bakoven valley was eroded to sea level by the late preglacial Cats Kill (Figs. 2, 4, and 11d). The Cats Kill entered the Bakoven valley through the dirt gap at Leeds Flats, flowed into the Esopus Valley at Mount Marion, and entered the Hudson's inner gorge through a dirt gap at Wilbur, near Kingston (Fig. 4).

The Kaaters Kill flows between deeply incised clay bluffs. These rounded bluffs resemble Dutch colonial baking ovens, hence the name "Bakoven" for the valley (Chadwick, 1944). The bluffs are failing by a myriad of landslides as the Kaaters Kill undercuts their base when it overflows its narrow floodplain every spring. The clays are over 80 ft thick in the Bakoven valley and overlie shale-pebble rich esker gravels. The base-level of this reach is controlled by the bedrock sill in the water gap at the Thruway's crossing of the Kaaters Kill.

<u>STOP 8:</u> Lower Palenville Fan (Fig. 10)
Kaaterskill, Woodstock, and Cementon 7-1/2 minute quads

The next four stops will give us an opportunity to examine several features of the Kaaters Kill as it leaves its upland headwaters and debouches onto the Hoogeberg Peneplain or piedmont. The stream begins near North Lake (STOP 13) on the dipslope of conglomerates that are part of the Onteora Formation (Fig. 11a). It spills over the edge of the Helderberg Peneplain at Kaaterskill Falls and enters the Kaaterskill Clove. It has a high gradient in the Clove (Fig. 11a). The Clove is carved into the sandstones and shales of the Kiskatom Formation. Many knickpoints have developed on the sandstone beds in the Clove (STOPS 10 and 11). The gradient flattens somewhat when the stream exits from the Kaaterskill Clove and flows across the surface of the Hoogeberg Peneplain. A large alluvial fan has been deposited at the mouth of the Clove (Fig. 10).

The Village of Palenville is built at the head of the fan (Fig. 10 and STOP 9). Abandoned braided stream channels (distributaries) traverse the fan's surface. The soil development is very poor on the surface of these sandy, cobbly gravels. The stream abandons its braided habit at the foot of the fan and meanders across the lake clays that mantle the Kiskatom Valley (Fig. 10). The stream's gradient across the alluvial fan is 0.034 or 180 ft/mile.

STOP 8 is near the distal edge of the fan (Figs. 10 and 11). The stream cut next to the the road exposes clean, open-work,

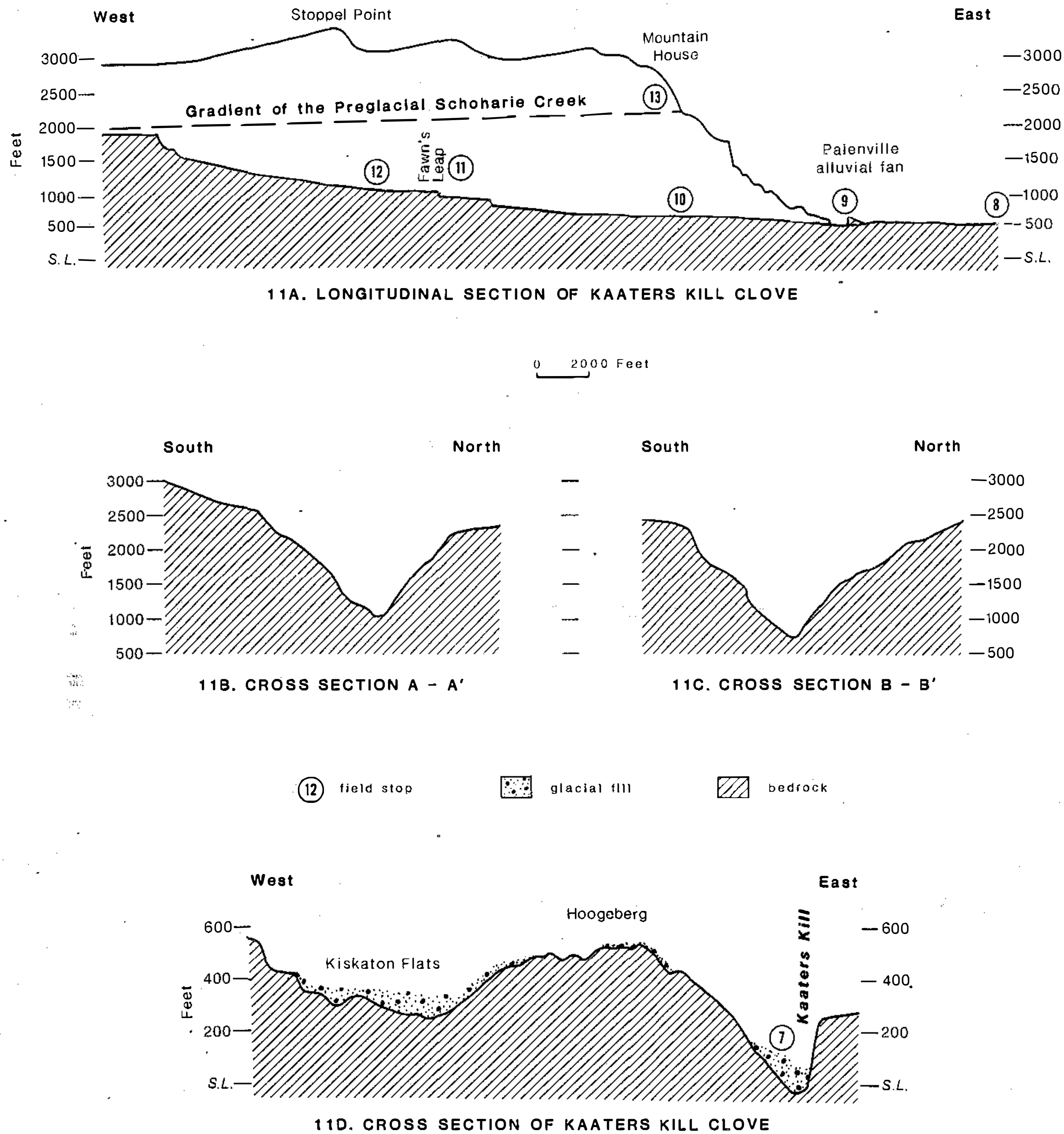

Figure 11.

Kaaters Kill Clove Longitudinal Section and Cross Sections

imbricated cobbles that are interbedded with muddy matrix-supported cobbly gravels. During low stream flow stages, the stream disappears into the open-work cobbles exposed in the streambed. Rock is exposed in the streambed and the stream flows across a rock ledge upstream at the bridge. Large swampy areas lie along the foot of the fan, thus many of the camps in that region are built on stilts.

The muddy gravels were probably deposited as either wet sediment flows during catastrophic floods or as sieve deposits left as the stream waters flowed into the highly permeable channel deposits, and the open-work cobble beds are probably channel deposits of more "normal" flows. The outcrops of ledge rock are "mini-hogbacks" of Mount Marion sandstones that have been incompletely covered by the fan. The stream channel is approximately at the the same height as the adjacent road, so the stream could break through the intervening levee and to spill onto the roadway, thus creating a new distributary!

STOP 9: Red House at Head of Fan, Village of Palenville (Fig. 10)

The head of the Palenville alluvial fan can be examined at this stop. The Kaaters Kill crosses a bedrock ledge as it exits from the Kaaterskill Clove. The stream gradient is abruptly reduced, causing the stream to deposit the coarse bedload that it carried in the Clove. Many 1-meter diameter clasts are deposited each Spring in the backyards of the people that live next to the creek. A significant number of these boulders are composed of limestone, a lithology that is not native to the Clove. The primary upstream source of limestone appears to be the rip-rap that is emplaced along the roadbed of Route 23A. These limestone clasts might have traveled a mile from their origin in the roadbed! The fan head is deeply trenched by the stream channel. It is composed of coarse-grained material.

STOP 10: Intermann's Bridge (Fig. 10)

The stream flows in a steep-walled valley upstream from STOP 9. The floodplain is thin in this section, exposures are less than 6 ft thick. The floodplain deposits are also very ephemeral in the Clove- they have been deeply scoured several times since 1890. The bridge and local houses have been swept away in those floods (Bonafede, 1980). The bridge's 1850 foundations are on rock and usually survive the floods, so they are reused in succeeding bridges. Landslides and rockfalls are common in the Clove (Fig. 10; Bonafede, 1980).

The records of the NYS Dept. of Transportation identify many landslides and seeps along the road from Intermann's Bridge to Moore's Bridge (the bridge near Fawn's Leap). The roadbed crosses a buried valley with over 100 ft of "hard to compact red clayey silt with angular gravel" (till) approximately mid-way between the two bridges. The records also note that the road was severely washed-out during a hurricane in 1935.

STRUCTURE AND STRATIGRAPHY ABOVE, BELOW, AND WITHIN THE TACONIC UNCONFORMITY, SOUTHEASTERN NEW YORK

By

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Reston, Virginia

INTRODUCTION

In the early Paleozoic, carbonate banks lay along the east coast of the ancient North American continent. In Ordovician time, plate convergence commenced the closing of the ancient proto-Atlantic ocean (Iapetus) and a deep basin developed into which thick muds and dirty sands were deposited. These were later to harden and become the Martinsburg Formation. Later still, with continued compression, the sediments were folded and faulted during the complex deformation of the Taconic Orogeny. In the field trip area the trend of these folds and faults is about N. 20° E. These structures become less intense westward. Following Taconic deformation, mountains rose to the east and coarse sediments were transported westward and deposited as sandstones and conglomerates of the Shawangunk Formation across beveled folds of the Martinsburg Formation. However, a thin diamictite with exotic pebbles records a heretofore unreported geologic episode which occurred during the Taconic hiatus. As the mountains were worn down, finer clastic sediments and carbonates were deposited more or less continuously through the Middle Devonian. Clastic influx during the Middle Devonian records a later orogeny, the Acadian. It is probable that the structural effects of this orogeny did not extend as far west as this field trip area; the limit of Acadian folds, faults, and igneous intrusions lies to the east. Finally, near the end of the Paleozoic, continental collision deformed all rocks, down to and below the Martinsburg. The trends of these later (Alleghanian) structures are more northeasterly.

On this field trip we will develop new interpretations of Ordovician and Silurian stratigraphy, demonstrate structural zones at the limits of Taconic deformation, investigate the relative effects of Taconic, Acadian, and Alleghanian deformation in southeastern New York, and discuss the strange goings-on in a thin enigmatic unit at the unconformity between the Martinsburg and Shawangunk Formations. We will see a variety of complex structures within three Taconic tectonic zones (Stops 1, 2, 5, 6, 7, and 8), examine the nature of, and deposits at, the Taconic unconformity (Stops 2, 5, and 8), review some of the proposed facies relationships in Silurian rocks (Stops 3, 7, and 8), and, weather permitting, look out over the regional geology from high atop the Shawangunk Mountains during lunch (Stop 4).

In the case of disastrous weather, alternate Stops 1A and/or 1B may be substituted for Stop 1. These stops would allow a brief look at a melange zone of Taconic age, albeit not as spectacular as at Stop 1, and a thrust fault zone of Alleghanian age, both in the Martinsburg Formation.

STRATIGRAPHY

A generalized description of the stratigraphic units in the field trip area is given in table 1. Because we will concentrate on rocks just above and below, as well as "within" the Taconic unconformity, certain details of these rocks are described below.

Table 1. Generalized stratigraphy in field trip area. Please note that stratigraphic terminology for rocks above the Onondaga Limestone is not well established in this area (see Rickard, 1964).

PLATTEKILL FORMATION of Fletcher (1962) (Middle Devonian): Red and gray shale, siltstone and sandstone. 500+ feet thick.

ASHOKAN FORMATION (Middle Devonian): Thin- to thick-bedded, olive-gray sandstone, and minor siltstone and shale. 500-700 feet thick.

MOUNT MARION FORMATION (Middle Devonian): Olive-gray to dark-gray, platy, very fine- to medium-grained, sandstone, siltstone, and shale. Probably more than 1000 feet thick.

BAKOVEN SHALE (Middle Devonian): Dark-gray shale. 200-300 feet thick.

ONONDAGA LIMESTONE (Middle Devonian): Cherty fossiliferous limestone. From top to bottom, Moorehouse, Nedrow, and Edgecliff Members. 100 feet thick.

SCHOHARIE FORMATION (Lower Devonian): Thin- to medium-bedded, calcareous mudstone and limestone; more calcareous upwards. From top to bottom, Saugerties, Aquetuck, and Carlisle Center Members as redefined by Johnsen and Southard (1962). 180-215 feet thick.

ESOPUS FORMATION (Lower Devonian): Dark, laminated and massive, non-calcareous, siliceous, argillaceous siltstone and silty shale. 200 feet thick; thickens to southwest.

GLENERIE FORMATION of Chadwick (1908) (Lower Devonian): Siliceous limestone, chert, and shale, thin- to medium-bedded. 50-80 feet thick.

CONNELLY CONGLOMERATE (Lower Devonian): Dark, thin- to thick-bedded pebble conglomerate, quartz arenite, shale, and chert. 0-20 feet thick.

PORT EWEN FORMATION (Lower Devonian): Dark, fine- to medium-grained, sparsely fossiliferous, calcareous, partly cherty, irregularly bedded mudstone and limestone. 70-125? feet thick; 180 feet thick near Port Jervis, N. Y.

ALSEN LIMESTONE (Lower Devonian): Fine- to coarse-grained, irregularly bedded, thin- to medium-bedded, argillaceous and partly cherty limestone. 20 feet thick.

BECRAFT LIMESTONE (Lower Devonian): Massive, very light- to dark-gray and pink, coarse-grained, crinoidal limestone, with thin-bedded limestone with shaly partings near the bottom in places. 30-50 feet thick; thins towards High Falls; 3 feet thick near Port Jervis, N. Y.

NEW SCOTLAND FORMATION (Lower Devonian): Calcareous mudstone and silty, fine- to medium-grained, thin- to medium-bedded limestone. May contain some chert. 100 feet thick.

KALKBERG LIMESTONE (Lower Devonian): Thin- to medium-bedded, moderately irregularly bedded limestone, finer grained than Coeymans Formation below, with abundant beds and nodules of chert and interbedded calcareous and argillaceous shales. 70 feet thick.

RAVENA LIMESTONE MEMBER OF THE COEYMANS FORMATION (Lower Devonian): Wavy bedded, fine- to medium-grained and occasionally coarse-grained, limestone with abundant thin shaly partings. 15-20 feet thick.

THACHER MEMBER OF THE MANLIUS LIMESTONE (Lower Devonian): Laminated to thin-bedded, fine-grained, cross-laminated, graded, microchanneled, mudcracked, locally biostromal limestone with shale partings. 40-55 feet thick.

RONDOUT FORMATION (Lower Devonian and Upper Silurian): Fossiliferous, fine- to coarse-grained, thin- to thick-bedded limestone and barren, laminated, argillaceous dolomite: Limestone lentils come and go, and the more persistent ones have been named (from top to bottom): Whiteport Dolomite, Glasco Limestone, and Rosendale Members. 30-50 feet thick.

BINNEWATER SANDSTONE of Hartnagel (1905) (Upper Silurian): Fine-grained, thin- to thick-bedded, crossbedded and planar-bedded, rippled quartz arenite , with gray shale and shaly carbonate. Probably grades southwestwardly into the Poxono Island Formation. 0-35 feet thick.

POXONO ISLAND FORMATION (Upper Silurian): Poorly exposed gray and greenish dolomite and shale, possibly with red shales in the lower part. 0-500 feet thick.

HIGH FALLS SHALE (Upper Silurian): Red and green, laminated to massive, calcareous shale and siltstone, occasional thin argillaceous limestone and dolostone. Ripple marks, dessication cracks. 0-80 feet thick.

BLOOMSBURG RED BEDS (Upper Silurian): Grayish-red and gray shale, siltstone, and sandstone. 0-700 feet thick.

TONGUE OF THE BLOOMSBURG RED BEDS: Grayish-red siltstone and shale and slightly conglomeratic, partly crossbedded sandstone with pebbles of milky quartz, jasper, and rock fragments, and gray sandstone. 0-300 feet thick.

SHAWANGUNK FORMATION (Middle Silurian): Crossbedded and planar-bedded, channeled, quartz-pebble conglomerate (rose quartz conspicuous in upper part), quartzite, minor gray, shale and siltstone, and lesser red to green shale. Lower contact unconformable. 0-1,400 feet thick.

TONGUE OF THE SHAWANGUNK FORMATION: Crossbedded, cross-laminated (distinctive very-light and medium-dark-gray laminae), and planar bedded, thin- to thick-bedded, medium-grained quartzite and conglomerate with quartz pebbles as much as 2 in long and greenish-gray silty shale and siltstone. 0-350+ feet thick.

"WEIRD ROCKS" (Lower Silurian or Upper Ordovician): Diamictite (colluvium and shale-chip gravel with exotic pebbles) and fault gouge of sheared clay and quartz veins. Lower contact unconformable. Less than 1 foot thick.

MARTINSBURG FORMATION (Upper and Middle Ordovician): Greater than 10,000 feet thick.

SHALE AND GRAYWACKE AT MAMAKATING: Dominantly thick sequences of thin- to medium- bedded, medium dark gray shale interbedded with very thin to thick-bedded graywacke (as much as 6 ft thick) alternating with thinner sequences of medium-bedded graywacke interbedded with less thin- to medium- bedded shale. Grades downward and laterally into the sandstone at Pine Bush.

SANDSTONE AT PINE BUSH: Medium-grained, medium- to thick-bedded, medium gray, speckled light-olive-gray- and light-olive-brown-weathering quartzitic sandstone interbedded with, and containing rip-ups of, thin- to medium-bedded, medium-dark-gray, greenish gray-weathering shale and fine-grained siltstone. Lower contact with Bushkill Member is interpreted to be conformable, but in many places it is marked by a thrust fault. Grades upward and laterally in the shale and graywacke at Mamakating.

BUSHKILL MEMBER: Laminated to thin-bedded shale and slate containing fine-grained graywacke siltstone. Bed thickness of shales does not exceed 2 in and bed thickness of graywackes rarely exceeds 12 in. Lower contact conformable with underlying Balmville Limestone of Holzwasser (1926), but often disrupted by thrust faulting.

Ordovician Rocks
(Rocks below the Taconic unconformity)

There has been, and continues to be, a great deal of confusion when dealing with the Ordovician clastic sediments of southeastern New York State. A brief (and by no means exhaustive) review highlighting some of the earlier work in these rocks is helpful to emphasize the complex history of names, and establish proper correlation of units. The rocks that we concentrate on in this guidebook, all of which are considered to be members of the Martinsburg Formation, underlie the Wallkill Valley from south of Rosendale, New York, to the New Jersey border (fig. 1).

In the Wallkill Valley, a thick section of glacial deposits covers much of the bedrock. In so far as this makes structural analysis of the rocks in places difficult, if not impossible, this has a definite influence on resolving the stratigraphy. The tracing of faults and sometimes folds in the Ordovician rocks is extremely difficult, which explains why we and other geologists such as Vollmer (1981) and Kalaka and Waines (1986) have chosen to divide map areas into structural domains that can be defined in general descriptive terms. Added to this is the century-old problem regarding which Ordovician clastics in the Hudson Valley region are part of the far-traveled Taconic allochthon and which are part of the parautochthonous flysch that rests conformably on Middle Ordovician carbonates of the North American shelf. This is a problem which seems to be satisfactorily resolved to the southwest in New Jersey and Pennsylvania (Lash and Drake, 1984; Lash, 1985; Perissoratis and others, 1979; Lash, Lyttle, and Epstein, 1984) but remains a critical problem in parts of southern New York State, particularly along the Hudson River. There is an irony to this, since the existence of the far-travelled rocks was recognized much later in Pennsylvania (Stose, 1946) than in New York.

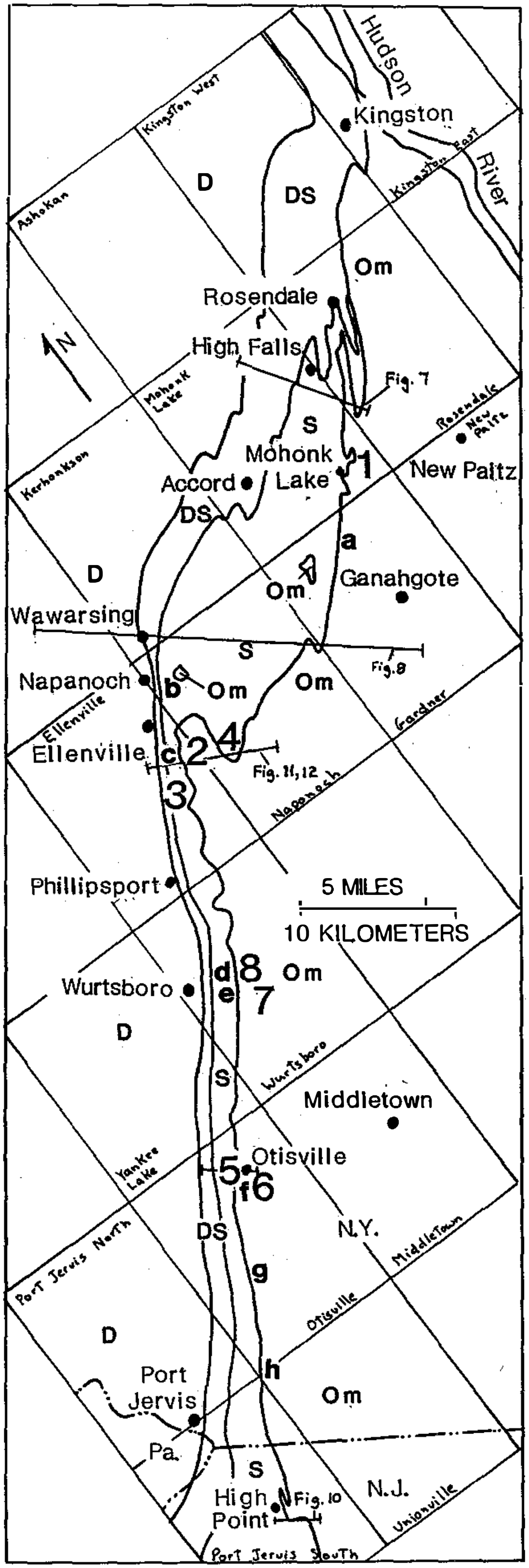


Figure 1. Generalized geologic map of part of southeastern New York showing field trip stop numbers, localities where the unconformable contact between the Martinsburg and Shawangunk Formations have been studied (small letters), location of cross sections, and 7.5-minute-quadrangle coverage.

a. Trapps
b. Napanoch
c. Mt. Meenahga
d. N.Y. Route 17
e. Abandoned railroad tunnel
f. Otisville
g. Guymard prospect
h. Interstate 84

D Rocks of the Hamilton Group (Plattekill, Ashokan, Mount Marion, and Bakoven Formations) and younger

DS Rocks between the Onondaga Limestone and Binnewater Sandstone-Poxono Island Formation

S High Falls Shale, Shawangunk Formation, Bloomsburg Red Beds, and tongues of the Shawangunk and Bloomsburg

Om Martinsburg Formation

Mather (1840) first proposed the name "Hudson River slate group" for rocks that he had previously referred to as "transition argillite" (1839). Subsequently, this name has seen at least 7 variants including Hudson River Series, Hudson River Group, and Hudson River Formation. In addition to the variations in the name, the use of these names has been extended north into Canada and as far west as Wisconsin. Holzwasser (1926) gives a useful account of the tortured history of Hudson River nomenclature; unfortunately, she also decided to use the name Hudson River formation for the shales and graywackes of the Newburgh Quadrangle. Although the name has generally been abandoned since Ruedemann's work in the beginning of this century, it is still loosely used and misused in a variety of publications to this day. Ruedemann (1901, p. 561) first used the name Normanskill Shale for rocks in the gorge of the Normans Kill near Kenwood, New York. This type locality turns out to be one of the more spectacular exposures of melange in the northern Appalachians, as attested to by the extremely detailed mapping of the structures by Vollmer (1981). It should not be too surprising, therefore, that there has also been considerable confusion in the use of this geologic name. Later, when mapping the Catskill quadrangle, Ruedemann (1942) recognized two belts of rock that he included in the Normanskill Shale. The western "grit belt" was named the Austin Glen Member and the eastern "chert belt" was named the Mount Merino Member. Most geologists today would agree that both of the type localities for these members are within the Taconic allochthon (sensu stricto); that is, the rocks are part of the far-traveled slope-rise sequence. The name Snake Hill Shale was first used by Ulrich (1911), although he based his discussion on the work of Ruedemann who later published a number of papers using this name (1912, for example). The type locality for this unit is on the east side of Saratoga Lake. Berry (1963) suggested abandoning the name because restudy of this region showed that what was mapped as Snake Hill contains three different lithic units all of which contain elements of the distinctive fauna which Ruedemann used as the unit's diagnostic feature. This points to yet another problem in the nomenclature of the clastics of the Hudson Valley region. Ruedemann and others often failed to discriminate between biostratigraphic and lithostratigraphic units, making it extremely difficult for later workers to fully appreciate the problems inherent in using a particular name.

More recently, Fisher (1962) and Offield (1967) have used the names Mount Merino Shale, Austin Glen Graywacke, and Snake Hill Shale for the lower, middle and upper units of the parautochthonous Middle and Upper Ordovician shales and graywackes that are found west of the Hudson River in the Wallkill Valley. Later, Fisher (1969; 1977; in Fisher and others, 1970) made a number of modifications to the mapping and naming of Ordovician clastic units in the vicinity of the Hudson River at the latitude of our field trip, but very little new work closer to the unconformable contact with the Silurian Shawangunk to the west has been published. For a summary of the most recent work near the Hudson River, particularly in the region underlying Marlboro and Illinois Mountains, see Waines (1986).

Offield (1967) produced a wealth of new stratigraphic and structural information in the Goshen 15-minute quadrangle (Middletown, Goshen, Warwick, and Pine Island 7.5-minute quadrangles) and recognized that his units might correlate with Behre's (1933) tripartite subdivision of the Martinsburg Formation in Pennsylvania. This subdivision was later refined by Drake and Epstein (1967) who recognized a lower thin-bedded slate unit called the Bushkill Member, a middle graywacke-rich unit called the Ramseyburg Member, and an upper thick-bedded slate unit called the Pen Argyl Member. Berry (1970) was one of several people to recognize significant similarities between the Delaware Valley sequence of Drake and Epstein and the sequence of rocks in the Wallkill Valley (Fisher, 1962; Offield, 1967). We feel that all of the names that Offield (1967) chose for the units of what he refers to as "the shale sequence" in the Wallkill Valley should be discontinued. One reason to do this is to avoid unnecessary confusion with the Normanskill Shale and its members that are clearly part of the far-traveled Taconic allochthon. Another reason, which is even more important, is that a better correlation can be made with units mapped in Pennsylvania and New Jersey. We have not done all of the detailed mapping that is necessary to establish these correlations in detail, but we feel confident that the correlations proposed herein are correct overall.

We believe that it is appropriate to refer to all of the parautochthonous Ordovician clastics in the Wallkill Valley as the Martinsburg Formation of Middle to Upper Ordovician age. Virtually all of the Ordovician clastics in the Great Valley from eastern Pennsylvania through northern New Jersey to the New York State border have been mapped in detail (1:24,000 scale) in the last 20 years, and much of it in the last 10 years. The parautochthonous sequence west and southwest of Albany, New York, is not contiguous with the rocks of the Wallkill Valley; nor has the stratigraphy of the rocks near Albany been done in sufficient detail to warrant using the names established for that area in the Wallkill Valley.

There has been debate in eastern Pennsylvania over whether the Martinsburg is a tripartite sequence with a lower slate member, a middle graywacke member, and an upper slate member, or a bipartite sequence with an upper graywacke member and a lower slate member (see Lash, Lyttle, and Epstein, 1984, for a summary of this debate). We feel strongly that the published detailed mapping, which ultimately must answer all questions of this sort, supports the tripartite subdivision first discussed by Behre (1933) and later named along the Delaware Valley by Drake and Epstein (1967). The question that must now be answered, is how far away from the Delaware Valley can the three members of the Martinsburg be mapped? The upper Pen Argyl Member, which contains thick-bedded slates (up to 25 ft thick), has been extensively quarried in Pennsylvania from the New Ringgold 7.5-minute quadrangle in the west to the Stroudsburg 7.5-minute quadrangle in the east where it disappears beneath the Silurian Shawangunk Formation. Based on our mapping and that of other geologists, it is not found in northern New Jersey and southern New York. However, the Pen Argyl correlates in part with rocks that we have mapped in the western Wallkill Valley unconformably beneath the Shawangunk, and that we are herein informally naming the shale and graywacke at Mamakating, subsequently called the Mamakating (fig. 2, table 1, and the discussion at Stop 7). The Mamakating represents the upper part of the Martinsburg in the western Wallkill Valley and is named for the excellent exposure seen at Stop 7 along Route 17 (just east of Wurtsboro exit) in the eastern part of the Mamakating Township.The Mamakating first appears from beneath the Shawangunk in the Otisville 7.5-minute quadrangle, New York and extends northeastward. All of the Martinsburg we shall be seeing on this field trip is within the Mamakating. The Ramseyburg Member extends from the New Tripoli, 7.5-minute quadrangle, Pennsylvania to the Middletown 7.5-minute quadrangle, New York. To the northeast it correlates for the most part with a unit that we are herein informally calling the sandstone at Pine Bush, subsequently called the Pine Bush (fig. 2, table 1). The sandstone at Pine Bush extends from the High Point area of New Jersey through the Middletown and Pine Bush 7.5-minute quadrangles, New York, where it is thickest, and appears to die out somewhere in the vicinity of the southwest corner of the Gardiner 7.5-minute quadrangle. There are excellent exposures of the Pine Bush along Route 17K that underlie the unnamed hills 1.6 miles west of Montgomery, New York, in the Pine Bush 7.5-minute quadrangle. Since the details of the facies changes in the middle and upper Martinsburg have not been sufficiently mapped in southern New York State, it is safest to say that the combined Ramseyburg and Pen Argyl correlates with the combined Pine Bush and Mamakating. It may eventually be determined that the Pen Argyl correlates with all of the Mamakating and the uppermost Pine Bush. The lower Bushkill Member of the Martinsburg has, by far, the greatest areal extent of the three members of Drake and Epstein (1969). It extends as far southwest as Reading, Pennsylvania (and probably considerably farther) and northeast at least as far as the Newburgh, New York area. We have not done sufficient detailed mapping in the central part of the Wallkill Valley to confidently work out precise stratigraphic relations of the Mamakating and the Pine Bush, nor do we know in detail how these units correlate with the Pen Argyl and Ramseyburg Members of the Martinsburg. Figure 2 portrays our current state of understanding.

The Mamakating is everywhere unconformably overlain by the Shawangunk Formation. It grades conformably downward and laterally into the Pine Bush, and the contact is arbitrarily put where beds of medium-grained, clean protoquartzite make up more than 5% and are thicker than 2 inches. In most places in the Wallkill Valley the Pine Bush grades upward into the Mamakating,

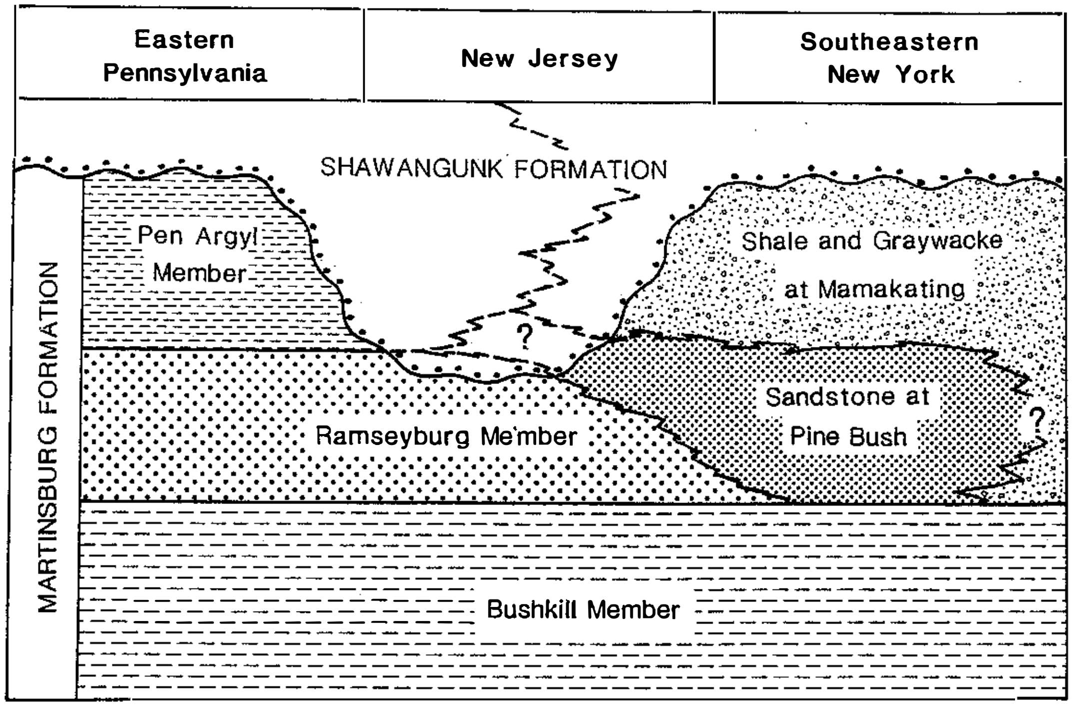


Figure 2. Preliminary correlation diagram showing members of the Martinsburg Formation of Ordovician age from eastern Pennsylvania to southern New York. The shale and graywacke at Mamakating and the sandstone at Pine Bush are named informally for the first time in this guidebook. Evidence for the facies relations between the Pen Argyl and Ramseyburg Members to the southwest and the Mamakating and Pine Bush to the northeast has been removed by erosion beneath the Taconic unconformity or may lie beneath the Shawangunk Formation to the northwest of the outcrop area of the Martinsburg. These inferred relations are shown by dashed lines.

but to the southwest near High Point, New Jersey, it is unconformably overlain by the Shawangunk Formation. We have not done enough detailed mapping in the Pine Bush, Walden, and Gardiner 7.5-minute quadrangles, New York, to resolve what happens to the Pine Bush to the northeast. From reconnaissance, it would appear to pinch out and grade laterally into the Mamakating somewhere near the northeast corner of the Pine Bush quadrangle.

Several very general points can be made about the Martinsburg Formation. From eastern Pennsylvania to the field trip area in southern New York, the composite thickness of the Martinsburg appears to remain fairly constant with ranges estimating from about 8,000 to 12,800 feet. It is possible that the thickness decreases going towards the northeast, perhaps by as much as 3,000 feet. All thickness estimates may be on the generous side, because of the large number of thrust faults that duplicate portions of the unit, particularly the lower Bushkill Member.

The sedimentology of the lower part, or Bushkill Member, of the Martinsburg remains remarkably constant along strike from eastern Pennsylvania through southern New York. However, the middle part of the Martinsburg shows considerable facies variation along strike. To the southwest in Pennsylvania, the Ramseyburg Member rarely contains more than 20% medium- to very thick bedded graywacke beds. Also going up-section in the Ramseyburg, the thickness of slate beds increases dramatically near the contact with the Pen Argyl. From High Point, New Jersey northward, the Pine Bush commonly contains up to 50% clean, medium- to very thick bedded sandstone, and as best as we can tell from reconnaissance, the thickness of shale beds does not increase going up in section. Both of these factors would appear to suggest that the middle part of the Martinsburg is becoming more proximal to the northeast. The upper part of the Martinsburg also shows dramatic facies changes along strike. Although this part of the section is dominated by shales or slate everywhere, in eastern Pennsylvania, slate beds in the Pen Argyl Member are commonly 12 feet thick, and can be as thick as 25 feet. In New York, the shale beds in the Mamakating rarely exceed 3 inches in thickness.

Silurian Rocks
(Rocks above the Taconic unconformity)

The stratigraphic relations of Silurian rocks, especially in the lower part,in southeastern New York, especially in the lower part, have been poorly understood (Fisher, 1959, Rickard, 1962,). The presently accepted sequence is, from the base upwards, the Shawangunk Formation, High Falls Shale, Binnewater Sandstone of Hartnagel (1905), and Rondout Formation (See Table 1 for a general description of these rocks). The stratigraphic identification and regional relations of rocks between the

Rondout Formation and Onondaga Limestone are fairly well known. The sequence of Shawangunk-High Falls-Binnewater in the northern part of the field trip area is firmly established. However, our recent mapping suggests that the facies mosaic of most of the Silurian rocks is a bit more complex than previously envisioned, and a revision of some stratigraphic interpretations is necessary. Figure 3 shows the present stratigraphic interpretation. Work is still in progress, so some details will most certainly be changed.

Regionally, the Silurian sequence thins dramatically between eastern Pennsylvania and southeastern New York, (fig. 4). The Shawangunk Formation of eastern Pennsylvania consists of three quartzite-conglomerate units (Weiders, Minsi, and Tammany Members) and a unit containing appreciable shale and some red beds (Lizard Creek Member) (Epstein and Epstein, 1972). Farther southwest, only a basal quartzite (Tuscarora Sandstone) and shale-sandstone sequence (Clinton Fomration) can be recognized (Lyttle, Lash, and Epstein, 1986). In New Jersey, the shales of the Lizard Creek become less abundant and the unit can no longer be mapped in the middle of the state, but scattered beds and intervals of shale persist into southeastern New York. These shales are generally not mappable and appear to be present at various levels within the Shawangunk (fig. 3). Recent mapping in the Ellenville and Naponoch area has allowed us to divide the quartzites and conglomerates of the Shawangunk into lower and upper units, separated by a "shale" unit about 100 feet thick. Actually this unit contains more sandstone and siltstone than shale, but it is distinctive and mappable. It thins to the northeast to where it is generally unmappable. Locally it may contain red beds, just as in the Lizard Creek Member in eastern Pennsylvania. Friedman (1957) divided the Shawangunk in the Ellenville area into three members. Our "shale" unit may be his Minnewaska member, separating his Mohonk conglomerate below from his Ellenville member above. The exact relation between his and our units is uncertain, however. It is possible that his Ellenville member may contain some rocks that we place in the tongue of the Bloomsburg and the tongue of the Shawangunk. Some shales in the Shawangunk were believed by Swartz and Swartz (1931) to be abundant enough near Otisville that they named the interval the "Otisville Shale". The "Otisville Shale", however, fails the test of mappability. In the type area, which we shall see near Stop 5, the Shawangunk consists predominantly of quartzites and conglomerates with scattered interbedded shale. Nowhere are the shales concentrated enough to form a separate mappable unit. As a matter of fact, Clarke (1907) measured the Shawangunk in great detail west of Otisville, and of the 420 feet measured, less than three percent were shale, and these beds were scattered throughout the sequence.

The Bloomsburg Red Beds overlies the Shawangunk in eastern Pennsylvania and New Jersey (fig. 4). The contact is transitional, in places through about 700 feet of rock, as at Delaware Water Gap at the New Jersey-Pennsylvania border

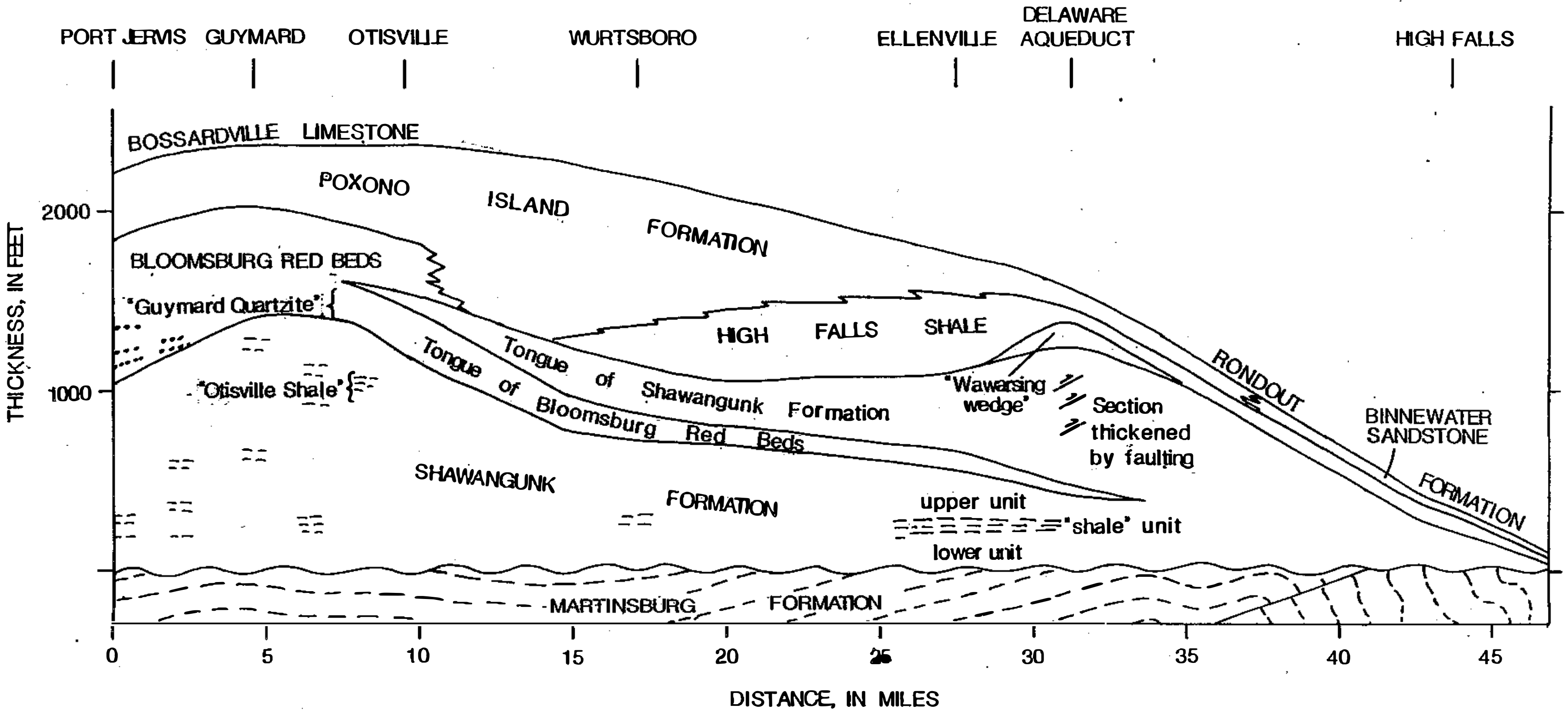


Figure 3. Preliminary stratigraphic section of Silurian rocks from the Poxono Island Formation and Binnewater Sandstone of Hartnagel (1905) to the Shawangunk Formation in southeastern New York.

(Epstein, 1973). The contact has been traced without complication to Guymard, N.Y. Between Wurtsboro and Ellenville redbeds followed by gray sandstone and shale overlie the Shawangunk. Because of a similar sequence of red and gray rocks at High Falls, several workers have identified these rocks as the High Falls and Binnewater, respectively (Darton, 1894; Sims and Hotz, 1951, Friedman, 1957, Gray, 1961, Smith, 1967). Younger rocks are not generally exposed. Detailed and reconnaissance examination suggests, on the contrary, that the red bed sequence between Wurtsboro and Ellenville is a tongue of the Bloomsburg, and not the High Falls, and the overlying gray sandstone and shale are a tongue of the Shawangunk, and not the Binnewater. The High Falls, which is very poorly exposed, crops out above both of these units near Wurtsboro (roadlog milage 99.0). Future detailed investigations will allow redefinition of these mappable units. The tongue of the Bloomsburg disappears northeastward by gradual change in color of the rocks from grayish red, through olive gray, into gray. This lateral change in color is similar to the changes seen along the transitional contact at Delaware Water Gap. The name "Guymard Quartzite" was applied to a portion of the tongue of the Bloomsburg between Guymard and Otisville by van Ingen (Bryant, 1926, p. 259). We feel that this name, like the "Otisville Shale", should not be used to define the stratigraphy of these rocks.

The rocks in the tongue of the Shawangunk are somewhat different from those in the main part of the formation in that they contain quartzites that are more distinctly crossbedded (seen along U.S. 44, roadlog mileage 33.8; north of Ellenville, mileage 41.5; and along N.Y. Rte 17 just south of Wurtsboro, mileage 98.5), and contains scattered red beds and polymictic conglomerates. Some of the conglomerates are similar to those in the Green Pond Conglomerate of the Green Pond outlier, about 25 miles to the southeast. One can easily envision a stratigraphic section between the main outcrop belt and the outlier that shows the Shawangunk tongue becoming thicker and encompassing more of the lower part of the section going eastward. In the outlier most of the Green Pond Conglomerate would be included in the tongue.

The High Falls Shale at High Falls not only contains red shales, similar to those of the Bloomsburg, but also abundant dolomite, fine-grained limestone, and green shales. Ripple marks and desiccation cracks are abundant. In the Delaware Aqueduct Bird (1941) reported 95 feet of gray limestone between the Shawangunk and his "High Falls". He named this unit the "Wawarsing wedge", alluding to the fact that the longitudinal shape of the unit must be wedge-like--it is not seen in exposures to the northeast or southwest. In all likelihood, it is predominantly dolomite, similar to the "powerhouse limestone" within the High Falls Shale at High Falls (Rickard, 1962, p. 129). The dolomite, green and red shale, limestone, and sandstone within the High Falls interval are very similar to rocks within the Poxono Island Formation of eastern

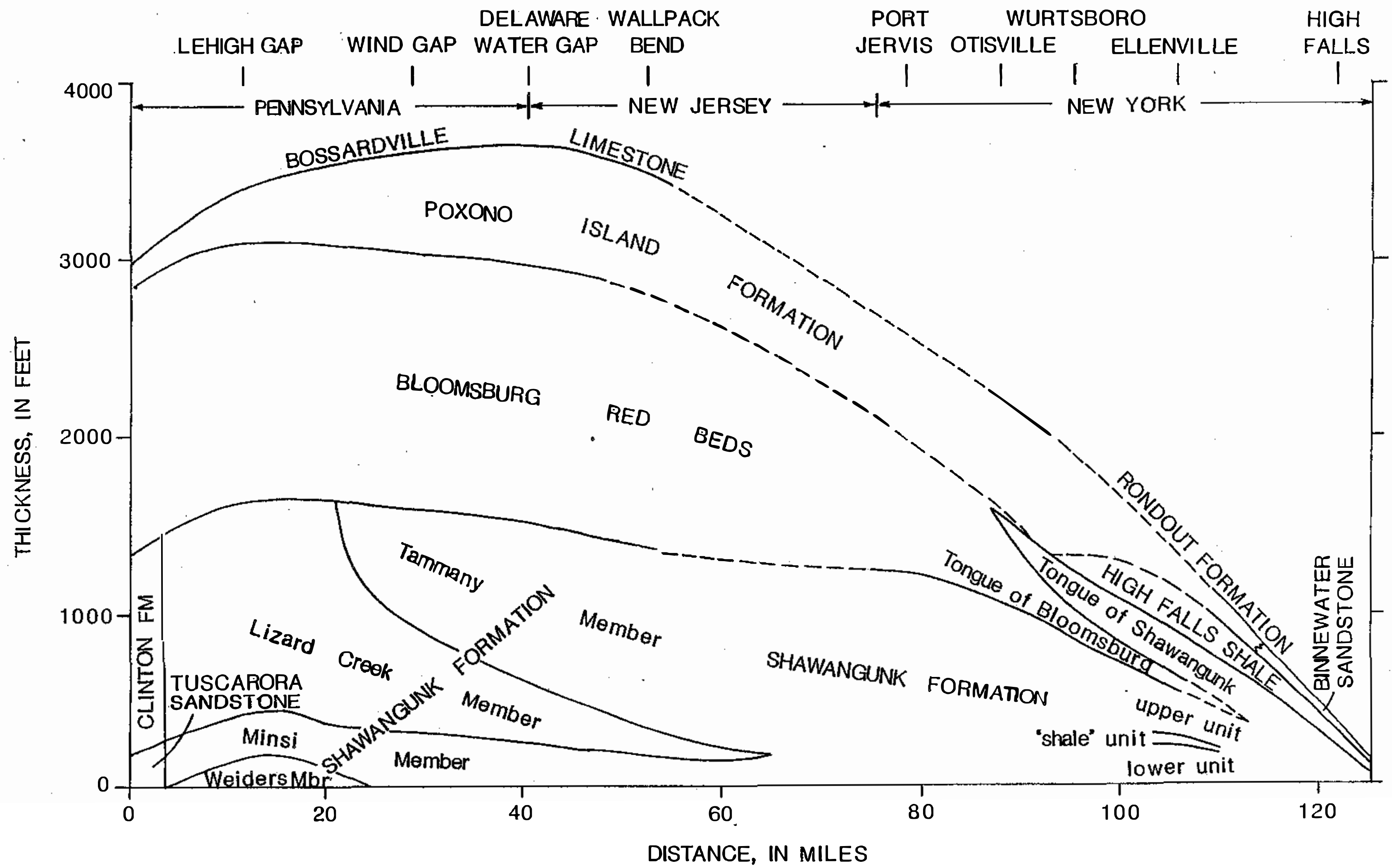


Figure 4. Generalized stratigraphic section of Middle and Lower Silurian rocks from Lehigh Gap, Pennsylvania, to High Falls, New York.

Pennsylvania. As a matter of fact, in the Delaware Aqueduct Fluhr and Terenzio (1984, p. 73) referred to the Wawarsing wedge of Bird (1941) as the "Wawarsing Limestone in Poxino Island Shales". (Note that "Poxino" has been misspelled by several authors ever since the original error by Wilmarth, 1957, p. 1724). For this reason the Poxono Island and High Falls are shown to grade into each other in figure 3. These rock units are generally not exposed and the location of the contact between them is speculative. This contact has not been defined, but a logical choice for its location would be where redbeds exceed a certain percentage, perhaps 50 percent (High Falls), and where they are less abundant (Poxono Island). The Binnewater Sandstone, which consists predominantly of crossbedded sandstone, at and north of High Falls, loses its character to the southwest (Rickard, 1962, Waines, 1976), becoming more dolomitic and shaly, so that at Accord, Fisher (1959) named the interval the "Accord Shales". This shows that even the Binnewater takes part in the complex carbonate-clastic facies mosaic of the Poxono Island-High Falls interval.

The complex Silurian sequence in southeastern New York described above is capped by the Bossardville Limestone near Otisville (Epstein and others, 1967), but somewhere to the northeast that unit disappears under glacial cover and the Binnewater is overlain by the Rondout Formation.

The consequence of these studies has been to better define the stratigraphic variations in Silurian rocks in southeastern New York. It demonstrates that the name "High Falls Shale", shown on the New Jersey State geologic map (Lewis and Kummel (1912), should not be used for rocks that should be referred to as the Bloomsburg Red Beds.

Weird Rocks
(Rocks "within" the Taconic unconformity)

The uppermost rocks of the Martinsburg Formation are near the Middle and Late Ordovician boundary in age, and the lowest rocks in the Shawangunk Formation are probably Middle Silurian in age. Thus, the Taconic hiatus in southeastern New York is about 20 to 30 million years, nearly as long as the entire Silurian Period itself. An interesting question is, what went on during that long period of time?

At the contact between the Martinsburg and Shawangunk Formations in the field trip area there is an interval, generally less than one foot thick, of diamictite (nongenetic term for a poorly sorted terrigenous deposit), clay, and at one locality, a deposit of Martinsburg shale fragments, which resembles a mass-wasting, terrestrial deposit (shale-chip gravel). The diamictite is interpreted to be a colluvial deposit. The clay with its slickensided quartz veins is believed to be tectonic (fault gouge). The deposit of shale fragments resembles a mass-wasting, terrestrial deposit (shale-chip gravel).

Some aspects of these rocks have been discussed before and alternative interpretations made. Waines and Sanders (1968) believed that the clay at the contact is a paleosol. Lukas, Rutstein, and Waines (1977) and Waines and others (1983) interpreted the clay as a hydrothermally altered Silurian shale and certain structures at the base of the Shawangunk as runnels produced by backflow on a beach. As discussed below, we believe that these structures are tectonic in origin. In eastern Pennsylvania, a similar clay layer is found between the Martinsburg and Shawangunk. Liebling and Scherp (1982) believe that this layer in Pennsylvania is a separate stratigraphic unit, in contradiction to the fault gouge hypothesis of Epstein and others (1974).

The diamictite is dark yellowish orange and consists of a variety of clasts in a sand-silt matrix. The clasts consist of fragments of the underlying Martinsburg, quartz pebbles (similar to those found in the overlying Shawangunk), and exotic rounded to subangular pebbles (dissimilar to rock types immediately above or below the unconformity). Sorting is poor (fig. 5A). There is a sharp contact with the Shawangunk above and also a sharp contact with the Martinsburg below. In places, such as at Otisville (Stop 5), it appears that parts of the Martinsburg have been bodily lifted from the underlying bedrock and incorporated in this diamictite. We do not believe that this deposit is a fault breccia, because there does not appear to be a foliation in it, although it may have been affected by movement to some degree. It looks more like a product of mass wasting, that is, a colluvium. Moreover, it contains a large variety of pebbles, which could have only been brought in as a sedimentary deposit.

The exotic pebbles are rounded to subangular and as much as 4 inches long. They consist of graywacke, orthoquartzite, feldspathic and chloritic sandstone, cross-laminated feldspathic conglomeratic quartzite, red fine-grained sandstone and siltstone, vein quartz, coarse-grained quartzite with pyrite, graywacke, medium-gray siliceous siltstone, laminated micaceous siltstone, and medium dark-gray shale. The pebbles are found at the Taconic unconformity near Otisville (Stop 5), Wurtsboro (Stop 8), and Otisville.

Martinsburg fragments are also found within the colluvium and consist of angular fragments derived from the immediate underlying bedrock, and rounded clasts that were transported for some distance. Angular Martinsburg fragments are also found in the gouge, presumably incorporated during fault movement.

Many pebbles are rounded and have weathering rinds a few millimeters thick. A few laminated samples have small ridges weathered out in relief. The oblate shape of others appears to have formed by erosion in running water. Clearly, these cobbles were exposed to the air, weathered, and incoporated in the diamictite, which we believe to be a colluvium.

We have collected samples for petrographic analysis from sedimentary rocks that may have been the source for the exotic pebbles. The work is still in progress, but we can make some guesses. The graywacke pebbles could have been derived from the Martinsburg. The pebbles of quartzite are similar to quartzites fairly high up in the Shawangunk, but obviously the Shawangunk could not have been the source of the pebbles. The dirtier sandstones, red sandstone and siltstone, as well as the quartzite pebbles, may have come from the Quassaic Formation of Waines (1986) of the Marlboro Mountains, presently 5-15 miles east of the Taconic unconformity. The age of the Quassaic is somewhat speculative, but it probably ranges from lower Martinsburg through the Upper Ordovician (Waines, 1986), so some of it, at least, could have supplied the pebbles and cobbles to the colluvium. Similar rocks are found in Little Mountain in the Friedensburg quadrangle of eastern Pennsylvania, between the Susquehanna and Lehigh Rivers, as well as possibly at the Spitzenberg a bit farther northeast. Some of the sandstone could have been derived from the sandstone at Pine Bush (informally named in this report). Some possible problems remain: (1) the shape of the pebbles suggests short transport, but similar rocks are not presently found in the Martinsburg immediately below; (2) the possible source terrane for these pebbles was probably not similar to the one which supplied the graywacke sandstone presently in the Martinsburg; and (3) few (if any) of the pebbles like those described are found in the conglomerates of the immediately overlying Shawangunk Formation.

The occurrence of angular slickensided vein quartz fragments that are oriented in all directions within the colluvial diamictite presents a problem in interpretation. The fact that the gouge and quartz veins are found uniquely at the Martinsburg-Shawangunk contact suggests that the movement is post-Taconic, probably Alleghanian, in age. The colluvium with exotic rounded pebbles unconformably overlies the Martinsburg and unconformably underlies the Shawangunk. It is therefore post-Martinsburg and pre-Shawangunk in age, a product of Taconic uplitt. The problem is that angular fragments of vein quartz (Alleghanian ?) is incorporated within the colluvium of Taconic age. The resolution to this dilema may be that there has been multiple movement along the fault at the Shawangunk-Martinsburg contact, and that the "weird rocks" is a composite deposit, made up of both Taconic colluvium and fault breccia. Therefore, the angular fragments of vein quartz were incorporated in the colluvium during later fault movement. Alternatively, the fragments of vein quartz could have been derived from vein quartz produced during Taconic faulting and incorporated in the colluvium as sedimentary clasts.

The clay within the zone between the Martinsburg and Shawangunk occurs as discontinuous light bluish-gray layers that have been weathered to moderate red and grayish orange. The clay

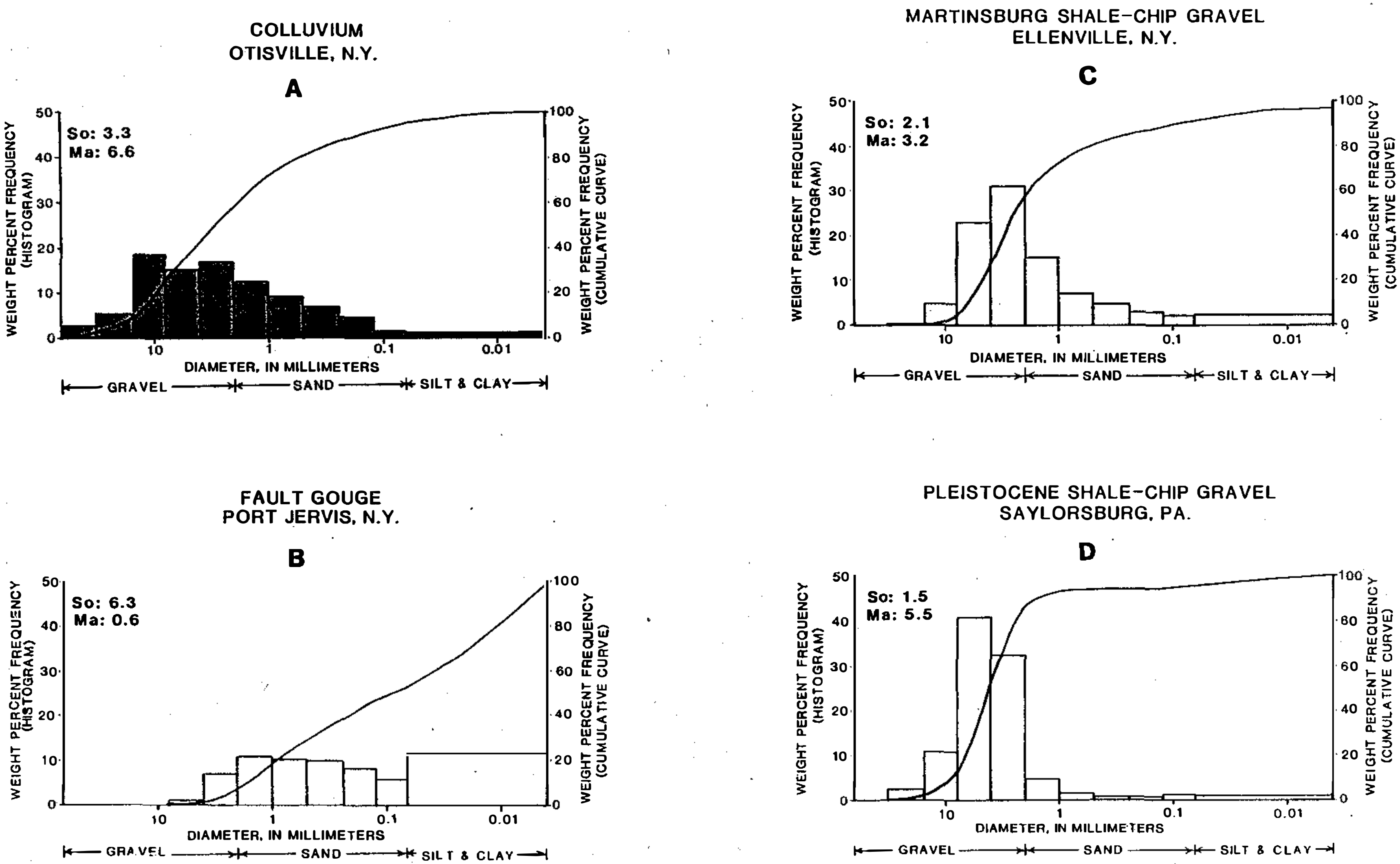


Figure 5. Histograms and cumulative curves for deposits between the Martinsburg and Shawangunk Formations. These deposits are interoreted to be colluvium (A), fault gouge (B), and shale-chio gravel (C). A Pleistocene shale-chip gravel is shown in D for comoarison with C. So, coefficient of sorting; Ma, median diameter, in mm.

is internally folded and contains both continuous and disrupted quartz veins. In places, closely spaced fractures extend down from the clay into the underlying bedrock. In other places the lowest few millimeters of the Shawangunk is sheared. At Stop 8 the upper few inches of the Martinsburg is rotated. The clay is clearly a fault gouge. The vein fragments are slickensided, indicating repeated movement along the zone.

One question that needs to be asked is why the clay in the fault gouge has remained a sticky clay, whereas surrounding rocks have been lithified? The answer may be that the contact is a zone of alteration. This area of the Shawangunk Mountains contains several abandoned lead-zinc mines and there are many prospects and mineralized localities throughout the area. The lower few inches of the Shawangunk here at Otisville is similarly altered.

The shale-chip gravel just below the Shawangunk Formation and above solid Martinsburg bedrock at Ellenville (see description for Stop 2) is remarkably similar in appearance to Pleistocene shale-chip gravels elsewhere in the northern Appalachians. Figure 5 compares a size distribution analysis of the gravel at Ellenville (fig. 5C) with a Pleistocene shale-chip gravel in eastern Pennsylvania (fig. 5D). The coefficient of sorting, So, of the Ellenville gravel is 2.1, indicating a very well sorted sediment, similar to sorting found in alluvial sands. This suggests water washing of the sediment. The mean grain size, Ma, is 3.2 mm. The Pleistocene shale-chip gravel is remarkably similar, both in sorting and mean grain size, suggesting a similar origin. On the other hand, colluvium between the Martinsburg and Shawangunk at Otisville, New York (Fig. 5A), which we will see at Stop 5, is much more poorly sorted. Fault gouge between the Martinsburg and Shawangunk, such as at Port Jervis, New York, is even more poorly sorted and contains a much larger percentage of silt and clay (fig. 5B).

These data add an interesting hitherto unrecognized chapter to Late Ordovician paleogeography in the central Appalachians. It seems likely that following the deposition of the marine Martinsburg shales and graywackes, the Martinsburg was uplifted during the Taconic orogeny. But later as the Martinsburg surface was subaerially exposed, diamictic colluvium and shale-chip gravels were spread out on the exposed surfaces, and exotic pebbles and cobbles were incorporated in the diamictite. Much of this material was subsequently removed during pre-Shawangunk erosion and only scattered occurrences remain. The clasts were derived from a source that is no longer exposed nearby. The only evidence for that source is from the few pebbles that we have found. It might be suggested that thrusts brought these exotic rocks close to the site of deposition, and that thrusts sheets were subsequently eroded. If this is true, these thrusts must have been Taconic in age. These deposits were later covered by conglomerates and sandstones of the Shawangunk Formation during Middle Silurian time.

Therefore, these "weird rocks" indicate a fairly complex geologic history that has not been previously suggested. We welcome your comments.

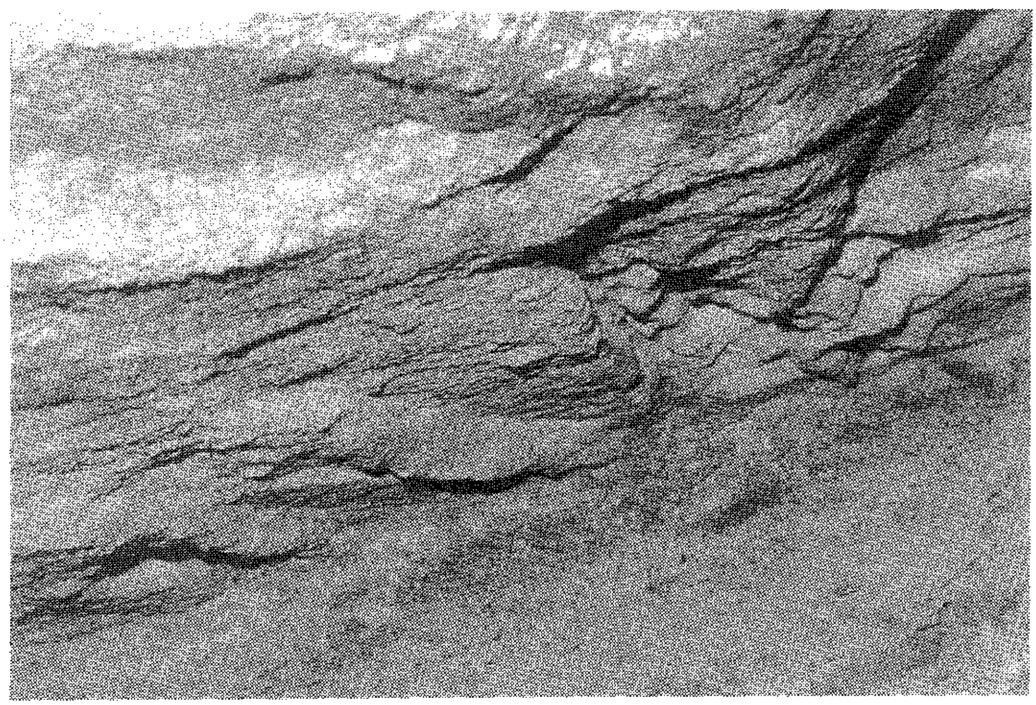
Mullions at the base of the Shawangunk

"Mullion" is an architectural term borrowed by structural geologists to describe elongate fold-like or prism-like forms developed at the boundary between rocks of different mechanical properties. They may be very regular in spacing and geometry and extend for considerable distances, or they may be irregular and short. They may originate by differential folding of rocks of contrasting properties or by disruption of competent rocks along foliation that is well developed in surrounding less competent rocks. They may be either parallel or perpendicular to the structural transport direction. These characteristics are discussed in many structural geology texts.

Mullions were seen at the base of Shawangunk Formation at seven localities in southeastern New York. These are Interstate 84 south of Port Jervis, in a prospect near Guymard, at the abandoned railroad cut in Otisville (Stop 5), along NY Route 17 south of Wurtsboro (Stop 8), in the abandoned railroad tunnel just south of Route 17, along the creek just east of the prison at Wawarsing, and a few hundred feet south of NY 55-US46 (the "Trapps", Waines and others, 1983).

The mullions are straight to slightly irregular downward-projecting structures at the base of the Shawangunk (fig. 6). They tend to have an asymmetrical wave-like form, and extend about two inches below the Shawangunk contact. The mullions trend subparallel to the strike of the Shawangunk. In a few places faint slickenlines trend about perpendicular to the trend of the mullions. At the creek behind the prison at Naponoch, the mullions bow down the slightly sheared bedding in the upper few inches of weathered Martinsburg, suggesting that they were not eroded into the underlying shales, but are a tectonic loading feature. We do not believe that they are "runnels" formed on a beach face (Waines and others, 1983) because they are found only at the Martinsburg-Shawangunk contact, a boundary of extreme mechanical disharmony (they are not seen at the bases of beds elsewhere in the Shawangunk) and their trend is not parallel to current directions indicated by trough crossbedding (see fig. 15). We interpret the Shawangunk as a fluvial (braided stream) deposit, not a beach deposit.

A



B

Figure 6. Mullions at the base of the Shawangunk Formation at Otisville, Stop 5 (A), and the Guymard prospect (B). The mullions are 1-2 in deep and asymmetrical. They vary from straight (left side of B), to irregular (right side of B). At Otisville, fragments of Martinsburg bedrock and exotic pebbles can be seen in the diamictite between the Shawangunk and Martinsburg.

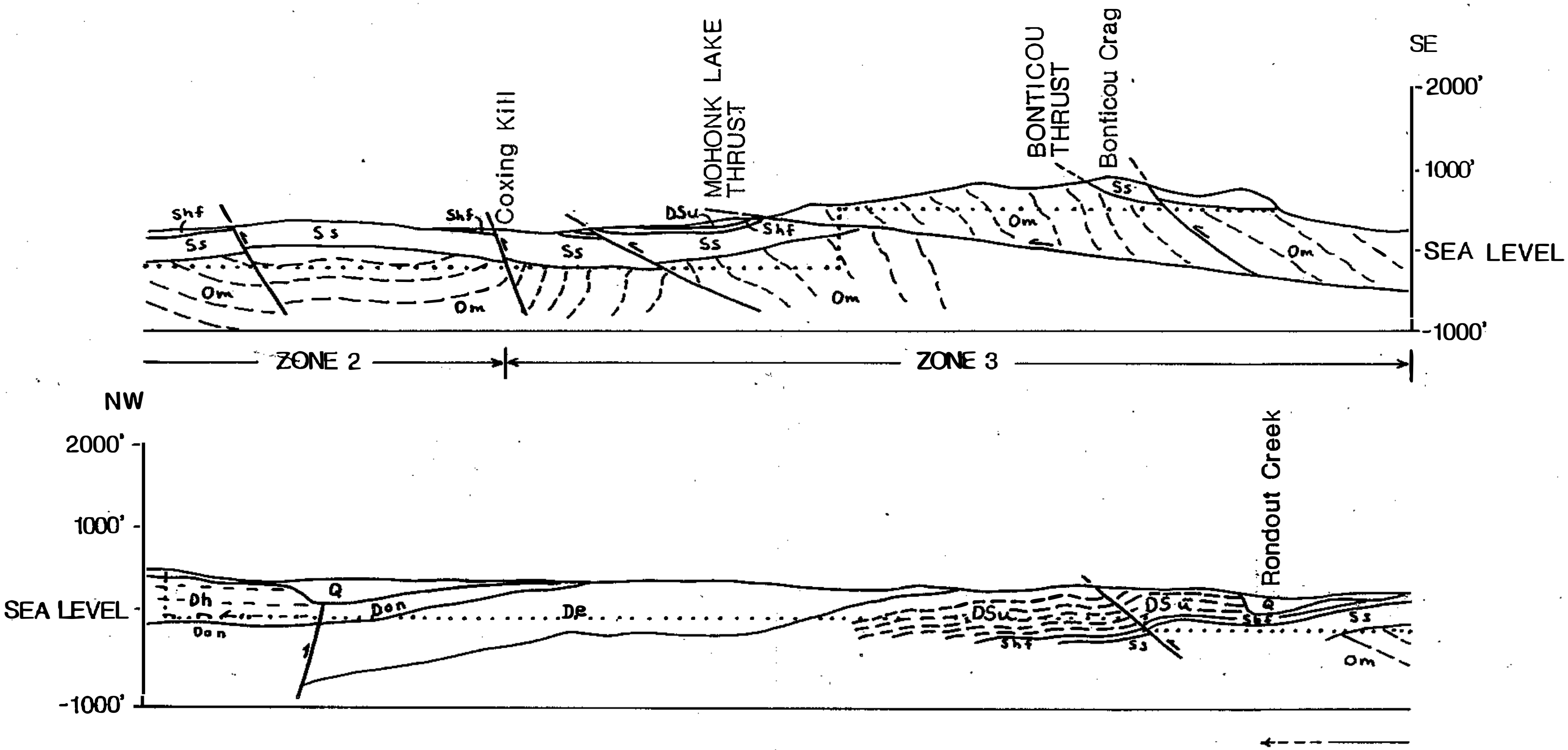


Figure 7. Cross section through Bonticou Crag showing location of Taconic tectonic zones. See figure 1 for location.

Q, Quaternary surficial deposits; Dh, Hamilton Group; Don, Onondaga Limestone; De, Schoharie and Esopus Formations; DSu, Glenerie Formation through Binnewater Sandstone; Shf, High Falls Shale; Ss, Shawangunk Formation; Om, Martinsburg Formation.

From surface mapping and data modified from New York City Water Board, unpublished data of the Catskill Aqueduct. Compare with Berkey (1911, fig. 22) and Brown (1914, fig. 2). Dotted line is the position of the aqueduct tunnel, in places projected into the line of section.

STRUCTURAL GEOLOGY

Both Ordovician and younger rocks in the field trip area are more highly faulted and tightly folded in the eastern part of the area than to the west. Timing and degree of deformation of these rocks has been the subject of considerable long-standing debate.

The three most important problems are: (1) what is the geographic distribution of Taconic structures in pre-Silurian rocks; (2) what are the intensities of Taconic and post-Taconic deformations in pre-Silurian rocks (and what is the age of the folds, faults, melange, and cleavage in these rocks); and (3) is the post-Taconic deformation Acadian or Alleghanian, or both?

On this field trip we will suggest that (1) zones of Taconic deformation can be recognized which decrease in intensity from east to west; (2) west of "Ruedemann's Line" the Ordovician rocks were more severly affected by post-Taconic deformation than by Taconic deformation; (3) the age of the later deformation is Alleghanian, (4) Alleghanian deformation along the Taconic unconformity decreases in intensity from Pennsylvania into southeastern New York, 5) the regional slaty cleavage in this area, where present, is Alleghanian in age, (6) more intense, later, Alleghanian deformation overlaps the earlier Alleghanian deformation in the eastern part of the area, and (7) the strike of Taconic structures is more northerly (by as much as 20°) than Alleghanian structures.

Taconic Tectonic Zones

Compilation of geology in the Delaware and Catskill aqueduct tunnels, and comparison with surface exposures in southeastern New York, allows us to identify tectonic zones of Taconic age. (figs. 7 and 8). These zones strike about N. 10-20° E. and progressively emerge to the southwest along the contact with the overlying Shawangunk Formation. The structure is more complex to the east. The zones are, from west to east: (1) zone 1 which has broad open folds in slight angular unconformity with the overlying Shawangunk Formation, (2) zone 2 that is a belt of less severe folds and faults with bedding in high angularity with overlying Silurian rocks; and (3) zone 3 with thrusts, steep dips, overturned folds, and melange. Many melanges have been mapped in the Ordovician rocks of the Hudson Valley, such as one on Rondout Creek near Rosendale, New York. These structures are definitely Taconic because in places the Silurian rocks truncate the scaly cleavage in them. The Taconic thrust faults that produced these melanges are abundant to the southeast of the unconformity and appear to become rarer as the unconformity is approached. The contact between zones 1 and 2 may be the extension of Ruedemann's Line which trends southerly and is overlapped by Silurian rocks southwest of Albany (Bosworth and Vollmer, 1981). This line passes under the Catskill Plateau and

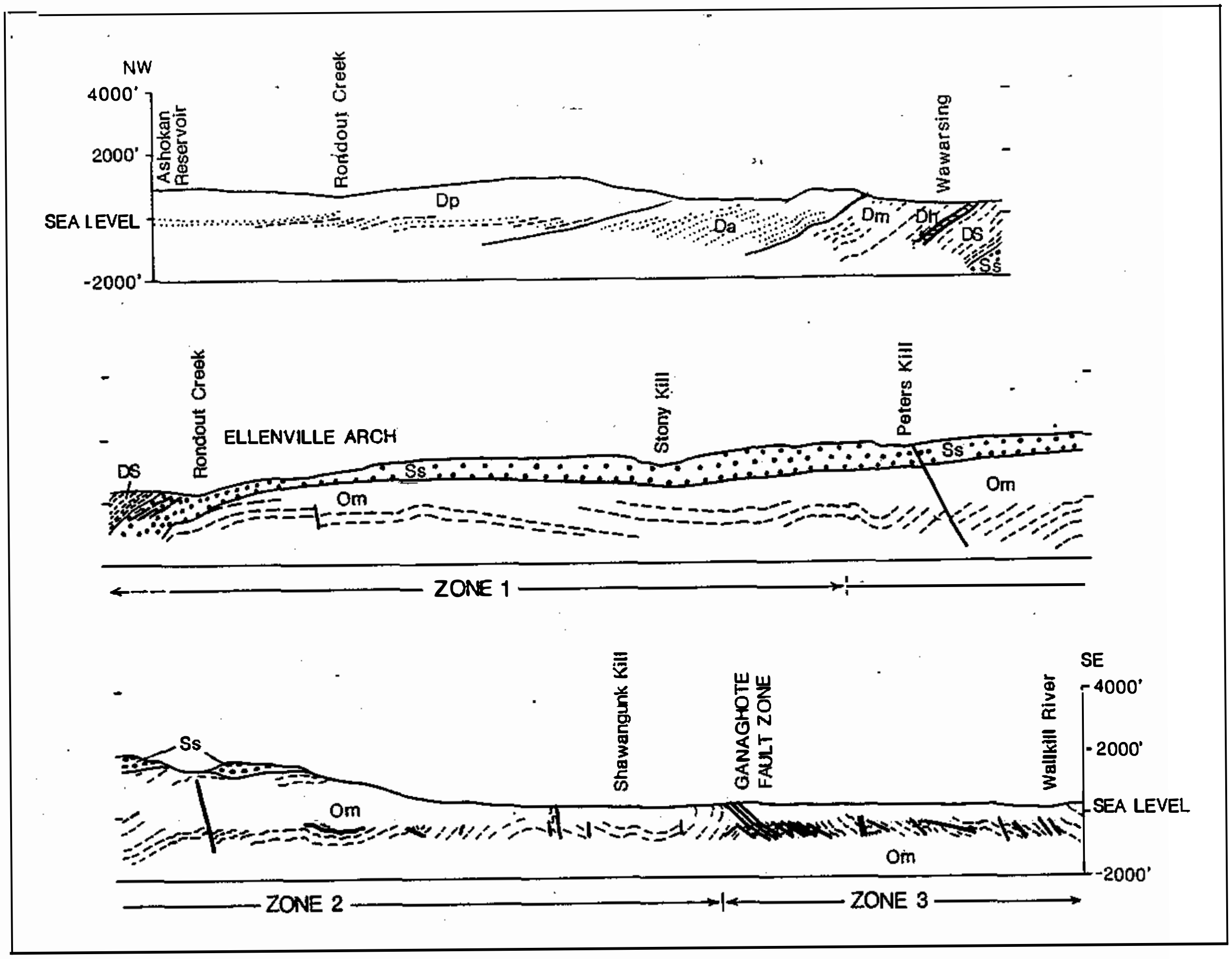


Figure 8. Cross section along the Delaware Aqueduct from the Ashokan Reservoir, through Wawarsing, to the Wallkill River (see Figure 1 for location), showing location of the Taconic tectonic zones and the Ellenville arch.

Dp, Plattekill Formation; Da, Ashokan Formation; Dm, Mount Marion Formation; Dh, shales and siltstones of the Hamilton Group; DS, Onondaga Limestone through the Binnewater Sandstone; Ss, High Falls Shale, Shawangunk Formation, and tongues of the Shawangunk Formation and Bloomsburg Red Beds; Om, Martinsburg Formation.

From surface mapping and underground data modified from the Delaware Aqueduct (New York City Water Board, unpub. data, 1945).

emerges from beneath the Shawangunk Mountains about 5 miles east of Ellenville (fig. 9). To the east of zone 1 lie the complex structural terrane of the Taconic klippen. To the west of zone 3, such as in central Pennsylvania, angular unconformity gives way to a conformable Ordovician-Silurian sequence, and orogenic uplift is reflected only by the Taconic clastic wedge.

Ignoring for the moment all faults and folds of Taconic age, the structure of the Martinsburg belt in eastern Pennsylvania can be characterized as a northwest-dipping sequence. The oldest member is always on the south side of the Great Valley and the youngest on the north side. Lyttle and Epstein (1987) show that this monoclinal sequence is actually the north limb of a very broad anticline that involves rocks as far south as the Pennsylvania Piedmont and that this structure is probably Alleghanian in age. Going northeastward into New Jersey the middle member of the Martinsburg is found in the trough of several smaller scale synclines, but still the very broad and general structure is one of a northwestward-dipping monocline. In southern New York State, the Wallkill Valley has long been recognized as a very broad open anticline (e.g., Offield, 1967; Kalaka and Waines, 1986). This anticline is highly faulted in the Mohonk Lake area (figs. 1 and 7). Many of these faults cut Silurian rocks and we interpret them to be Alleghanian in age.

Post-Taconic structures
Relative effects of Alleghanian and Taconic deformation

The tectonic effects in rocks above and below the Taconic unconformity in the central Appalachians has been the subject of considerable discussion and debate ever since the unconformity was recognized by H. D. Rogers in 1838. We have been mapping selected areas along 120 miles (200 km) of the unconformity from eastern Pennsylvania through New Jersey, and into southeastern New York (fig. 10). We have chosen areas where exposures are abundant enough to be able to determine structural relations in rocks on both sides of the contact. In general, going from Pennsylvania to New York, structures become simpler, from highly faulted and folded at Hawk Mountain, where the Tuscarora Formation rests on both the Martinsburg Formation and rocks of the Hamburg klippe, to overturned and faulted rocks at Lehigh Gap, to oversteepened folds at Delaware Water Gap, and upright to slightly overturned folds at High Point, New Jersey, and finally into a fairly simple arch at Ellenville, New York. Slaty cleavage in both Ordovician and younger rocks is common, particularly in the southwestern part of the study area.

The geology of the area near Ellenville, where Alleghanian and Taconic structures are relatively simple, is an excellent place to distinguish the effects of Taconic and later deformations. The Ellenville arch is a northeast-plunging fold with a half wavelength of about 4.2 miles (6.8 km). Folded rocks include the Martinsburg in the Great Valley, the Shawangunk in

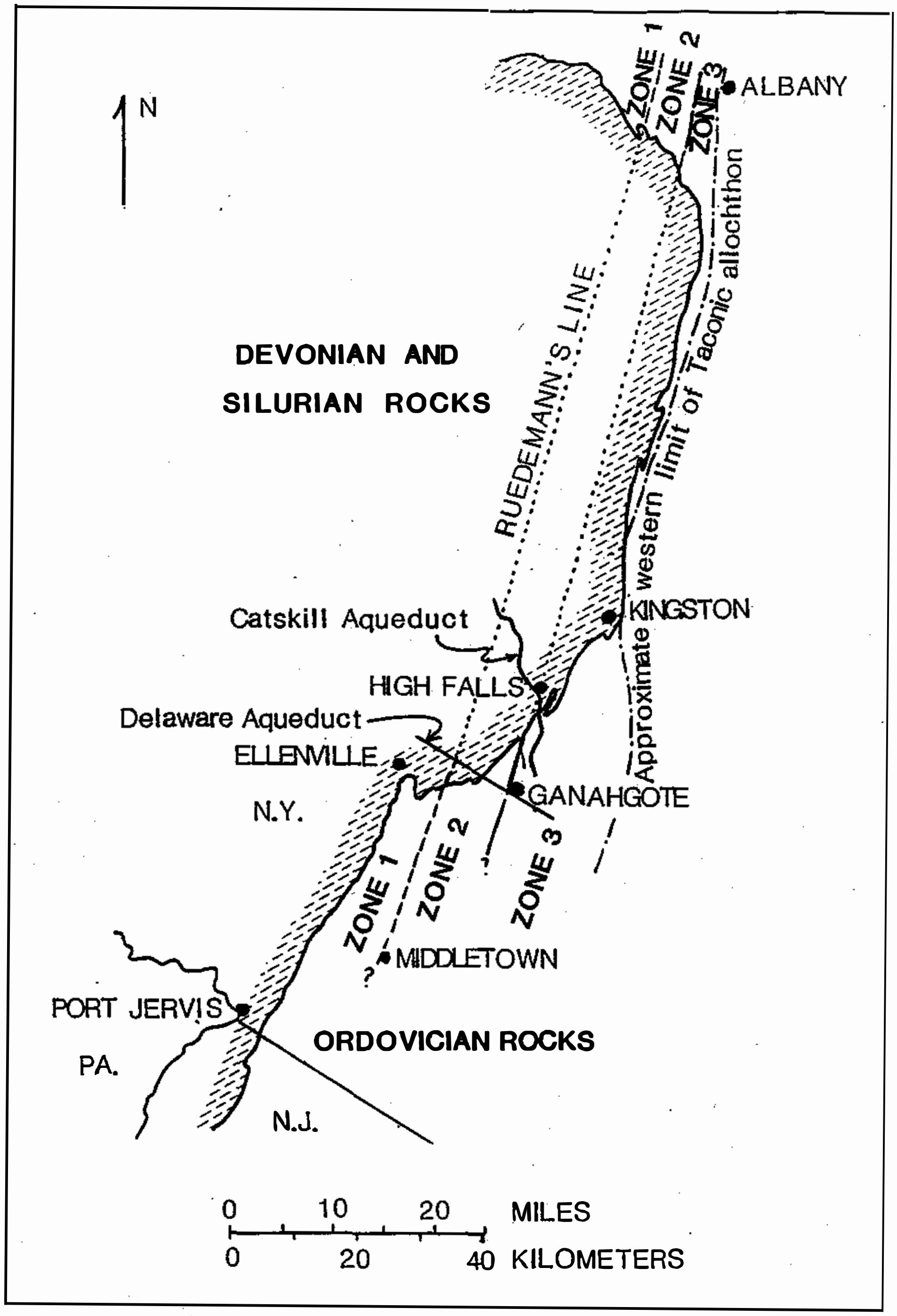


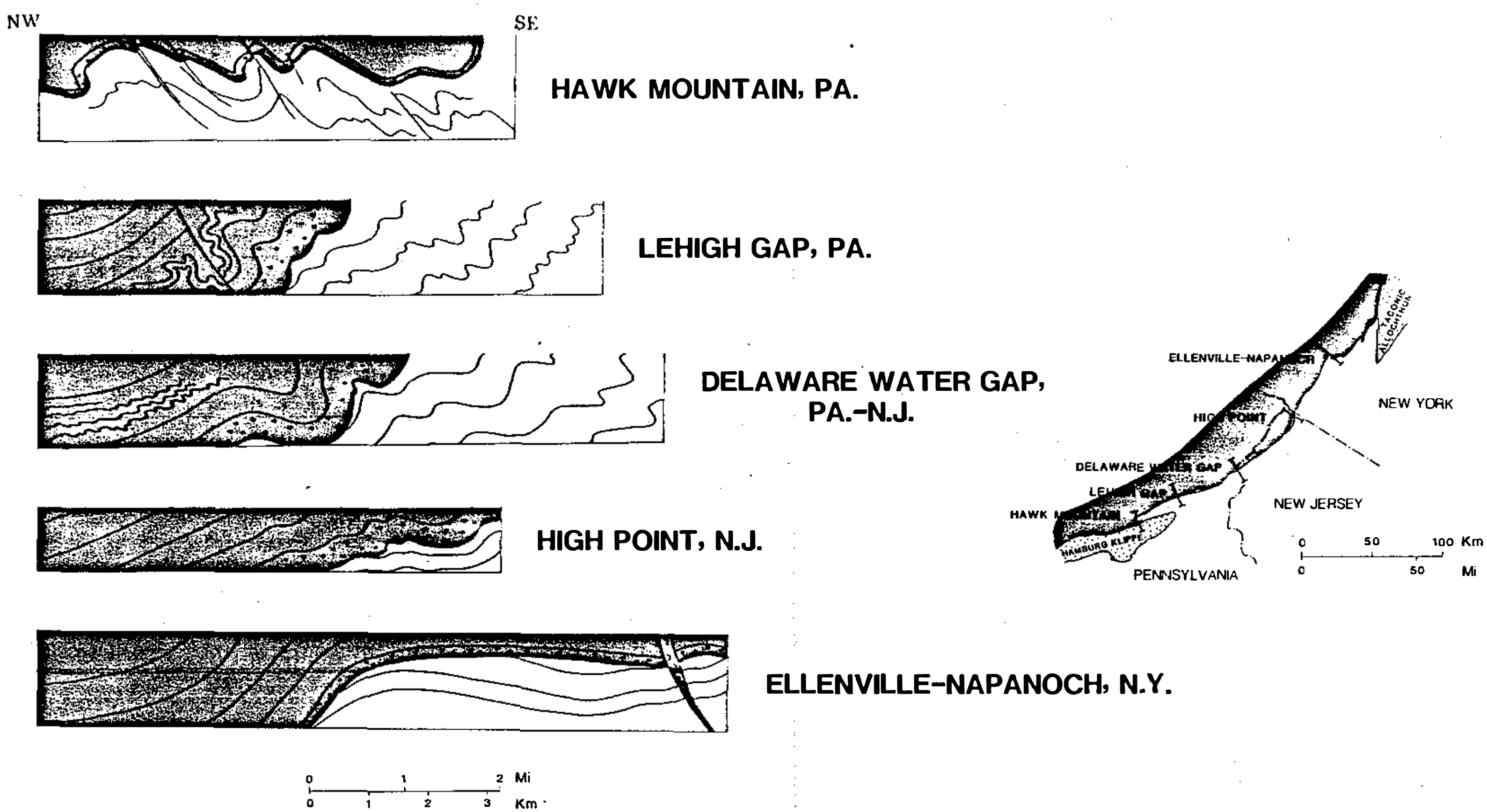
Figure 9. Map of southeastern New York showing the Taconic tectonic zones within the parautochthonous flysch, the boundary of overlapping Devonian and Silurian rocks, and the approximate western limit of allochthonous rocks of the Taconic allochthon. The zone boundaries are dotted beneath the Devonian and Silurian rocks. ZONE 1, broad open folds; ZONE 2, tight folds and thrust faults; ZONE 3, overturned folds, thrust faults, and melanges. Faults and some overturned folds are found in zone 1, and some areas of open folds are found in zone 3. Zones in the Albany area are from Vollmer (1981) and Bosworth and Vollmer (1981).

the Shawangunk Mountains, and rocks of Silurian and Devonian age in the Rondout Valley and Catskill Plateau (fig. 8). The broad arch is prominent in exposed cliffs of the Shawangunk Formation in the Ellenville area. The shales and graywackes of the Martinsburg are fairly well exposed in this area. The Martinsburg rarely exhibits slaty cleavage in this area. We are therefore able to draw an accurate cross section which shows that the crest of the arch differs in position in the Martinsburg and in the Shawangunk (fig. 11). It is clear that this geometry is the result of the folding of an unconformable sequence. If we unfold the folds in the Shawangunk, we can reconstruct the pre-Alleghanian folds in the Martinsburg on the bottom of the diagram. Note that the Ellenville arch has been eliminated and we are left with only a broad syncline, Taconic in age.

We have also done a similar reconstruction by rotating bedding in the Shawangunk back to horizontal using a stereo net and determining the retrodeformed Taconic attitudes in the Martinsburg. Figure 12 shows the position of the Alleghanian Ellenville arch. The heavy lines are isogons showing angles of dip and dip directions in the Shawangunk. These isogons were used to determine the amount of rotation necessary for the Martinsburg structural readings. The dips shown in the Martinsburg are these retrodeformed dips, that is, the Alleghanian folding has been eliminated. Therefore, this is a composite map, showing Alleghanian structure in the Shawangunk and Taconic structure in the Martinsburg. Note that the rotated beds in the Martinsburg dip consistently and gently to the southeast in the western part of the area and that the Ellenville arch has disappeared. The fold axes in the Martinsburg are thus Taconic in age. Also note that east of the Lake Awosting deformed zone, beds in the Shawangunk, shown by the isogons, strike ENE (average N. 76° E.), but that the Martinsburg underneath strikes more northerly by about 16° (averages N. 60° E.).

Using the data shown in the map, a cross section that is similar to the one shown in figure 11 was constructed (section A-A′, fig. 12). The solid line is a cross section showing bedding derived from our stereographically rotated Martinsburg. Note that it agrees almost perfectly with the pattern derived from the simple unfolding of the cross section shown in figure 11, the dashed line. It seems clear that Taconic folds in this area are broad and open, and the Ellenville arch is a later structure superimposed on the Taconic folds.

Figure 13 shows equal area plots of bedding in the Shawangunk, in the Martinsburg, and in the stereographically rotated Martinsburg. The girdle in the Shawangunk defines a fold whose axis plunges 5° N. 32° E. The Martinsburg trends, as we see them now, are more northerly, by about 10°, than trends in the Shawangunk. Interestingly, when the retrodeformed Martinsburg bedding is plotted, the Taconic folds plunge to the southwest. Therefore, we conclude that Taconic folds trend more



CROSS SECTIONS OF THE TACONIC UNCONFORMITY

Figure 10. Taconic unconformity study area between Hawk Mountain, Pennsylvania, and Napanoch, New York, showing decreasing Alleghanian deformation in the Shawangunk Formation and younger rocks (dark area) from southwest to northeast, and refolding of open Taconic folds (zone 1) in the Martinsburg Formation (light area).

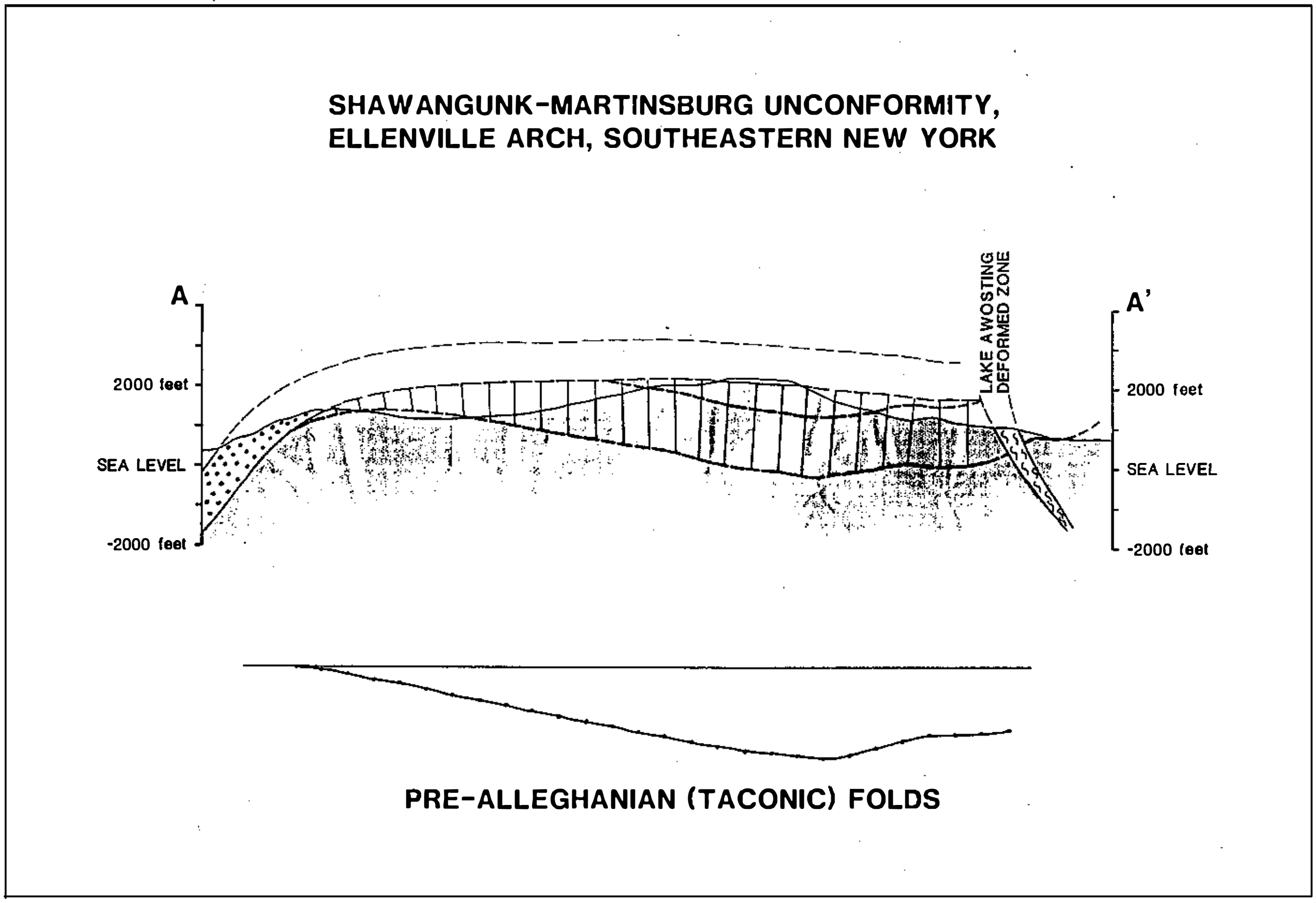


Figure 11. Cross section through the Ellenville arch east of Ellenville, showing the angular unconformity between the Shawangunk Formation (dotted) and the Martinsburg Formation (shaded), and the different position of the fold crest in the two units. By measuring the orthogonal distance between the base of the Shawangunk and a marker bed in the Martinsburg (near vertical lines), we can reconstruct the configuration of Taconic folds in the Martinsburg, shown on the lower part of the diagram. See figure 1 for location of cross section.

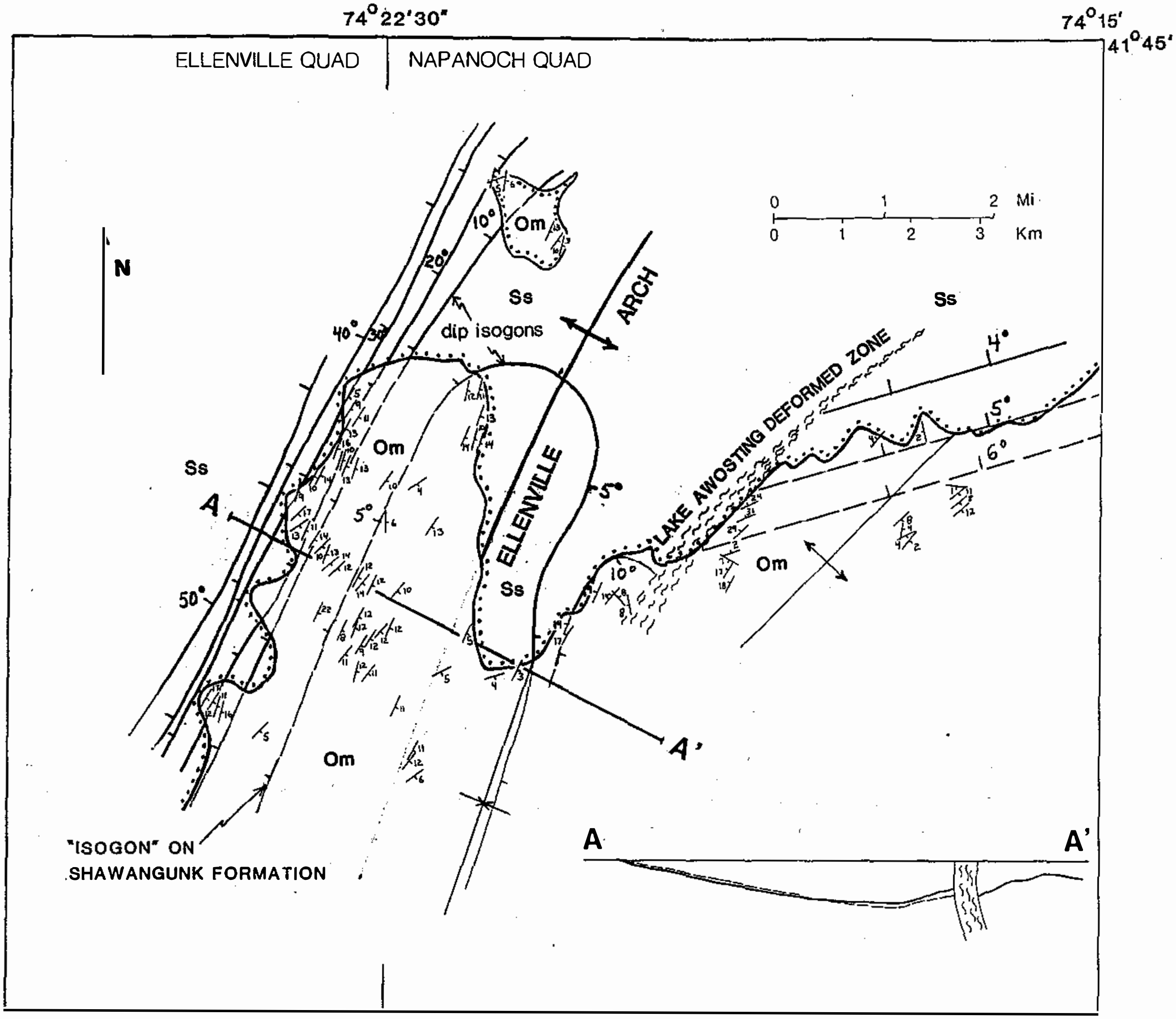


Figure 12. Geologic map of parts of the Ellenville and Napanoch 7.5-minute quadrangles showing the unconformable contact between the Shawangunk Formation (Ss) and the Martinsburg Formation (Om), lines of equal dip (dip isogons) in the Shawangunk (solid lines), and areas where the Shawangunk has been removed by erosion (dashed lines), dips in the Martinsburg that have been rotated to eliminate Alleghanian folding shown by the dip isogons, and the position of the reconstructed Taconic folds in the Martinsburg. The cross section A-A' compares the retrodeformed Taconic structures derived from the construction from the map (solid line) and from the exercise in figure 11 (dashed line).

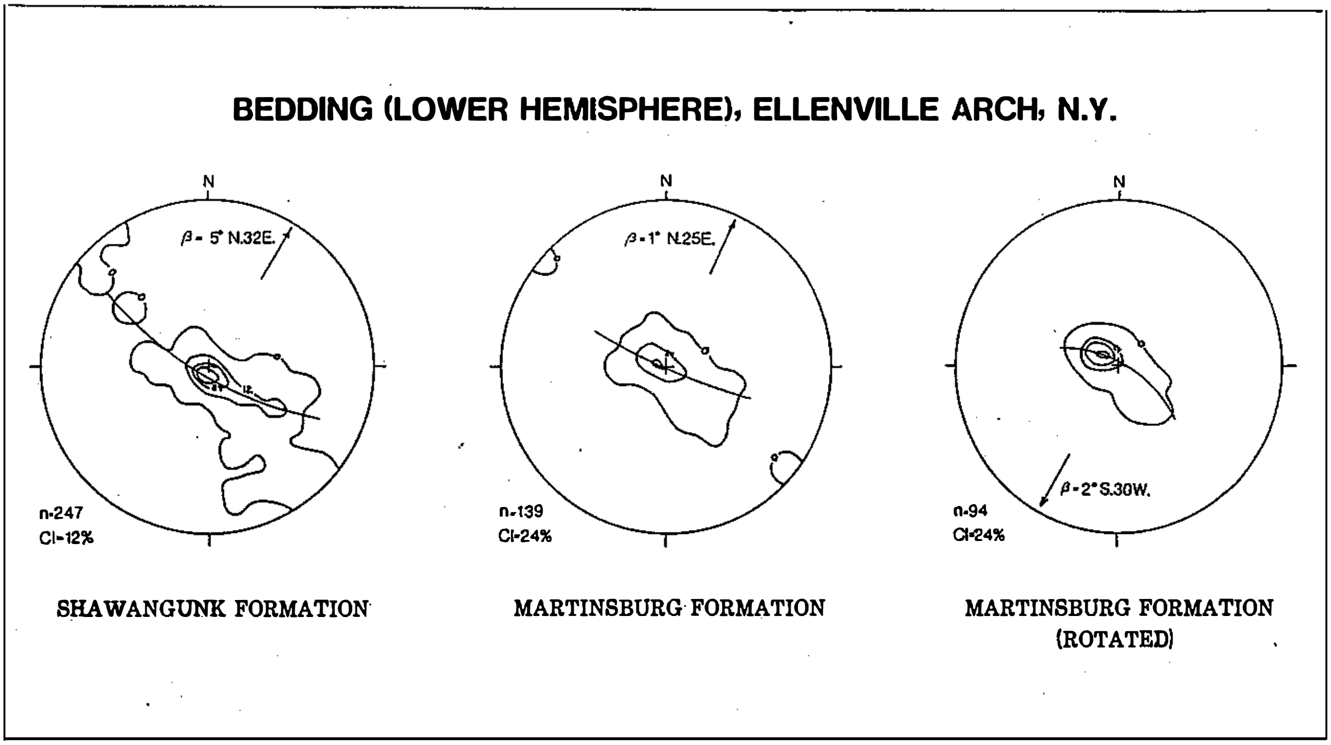


Figure 13. Equal-area projections (lower hemisphere) of the present attitudes of bedding in the Shawangunk and Martinsburg Formations in the area shown in figure 12, and the bedding in the Martinsburg that has been rotated so as to eliminate the effects of the Ellenville arch.

northerly than Alleghanian folds in this area, and plunge in the opposite direction. Thus, in the Ellenville area, we have been able to distinguish Taconic from Alleghanian folds, both in amplitude and trend.

From the data presented above, and from other considerations (Epstein and Lyttle, 1986), we draw the following conclusions for the area from Ellenville to northeastern Pennsylvania <u>near the Taconic unconformity</u>:

1. With only a few exceptions, the Shawangunk and equivalent Tuscarora Formation overlie the Martinsburg Formation with an angular unconformity that ranges between an angle that is barely discernible, to about 15°.

2. The dominant regional folding in all rocks along the contact is Alleghanian in age.

3. The regional slaty cleavage is Alleghanian in age.

4. Taconic folds in the Martinsburg Formation below the unconformity are mostly broad and open along the entire 120 mile length of the contact that we have studied southwest of Ellenville. To the north in zones 2 and 3 the structures become more intense and the angular disparity between beds above and below the unconformity is greater.

5. The strike of Taconic structures trend a bit more northerly (by about 3-20°) than later structures.

Age of post-Taconic deformation

Was the entire sequence of rocks exposed in the field trip area affected by Acadian or Alleghanian deformation, or both? Marshak (1986, p. 366) gives a succinct summary of the controversy. An Acadian age was favored by Woodward (1957), Ratcliffe and others (1975), and Murphy and others (1980), based on the age of the youngest rock that has been deformed. Structures in Early Devonian and Upper Silurian rocks were believed to be Acadian in age by Chadwick (1944) and Woodward (1957) because these structures were thought to be different in style and trend from structures known to be Alleghanian in age in Pennsylvania. On the other hand, Schuchert (1930), Sanders (1969), and Geiser and Engelder (1983) argued that secondary structures could be traced from Pennsylvania into New York, and the structures in the Hudson Valley area are Alleghanian in age. An Acadian age was inferred by Ratcliffe and others (1975) and Sutter and others (1985) from dating of cleavages east of the Hudson River. We favor an Alleghanian age for the following reasons:

1. The Ellenville arch is a structure at the northeast end of a series of structures that extend from tight folds with abundant faults in east-central Pennsylvania, through tight folds with less-abundant faults in easternmost Pennsylvania, through upright folds in New Jersey, and into simple folds and monoclinal dips in southeastern New York (fig. 10). Since these folds in Pennsylvania involve rocks of Pennsylvanian age, the Ellenville arch is therefore believed to be Alleghanian in age. In New York rocks at least as young as the Plattekill Formation of Middle Devonian age are affected by the arch. Possibly even younger rocks, now eroded away, were involved in the folding. To the east in New England the age of Acadian intrusion and deformation is generally believed to be Middle Devonian in age (Naylor, 1971). Clearly the Ellenville arch is a post-Acadian structure.

2. The structures of the Hudson Valley trend in the Silurian and Devonian rocks in the Kingston area (Marshak, 1986) may extend southwest into structures that we have mapped in the Shawangunk Mountains of the field trip area. We believe that these structures cross cut and post-date the Alleghanian

Ellenville arch, and therefore formed during a later Alleghanian event. A possible example of one of these later structures in the field trip area is the Bonticou thrust (fig. 7).

3. Many workers have suggested that the youngest rocks that have been folded or faulted are in the Hamilton Group, thus limiting the time of deformation to Middle Devonian (the Acadian orogeny). Two such fault zones, one in the Bakoven Shale and one in slightly younger rocks of the Mount Marion Formation, are discussed at roadlog mileage 0.3. Slickenlines and verging of folds at these localities indicates northwestward translation along these faults. Similar faults have been reported in equivalent rocks in central New York as much as 100 miles west of Albany (Schneider, 1905; Long, 1922, Rickard, 1952, Bosworth, 1984a, b). Thus, there is evidence for detachment within Middle Devonian shales under the rocks of the Catskill Plateau. Bosworth (1984b) suggested that this movement may be linked to detachment in Salina salt under the Appalachian Plateau of central New York and Pennsylvania, described earlier by Prucha (1968) and Frey (1973). Bosworth placed no age constraints on the age of this movement, except to say that it is post-Middle Devonian, and could be Acadian or Alleghanian. If it is linked to the Salina horizon, and all the rocks of the Catskill Plateau have moved on this decollement, then an Alleghanian age would be indicated.

Similar fault horizons are found in rocks even higher than the Middle Devonian shale interval. For example, one such fault was discussed by Pedersen and others (1976, p. B-4-16). It is in the Plattekill Formation, located in the Woodstock 7.5-minute quadrangle, along NY Route 28, 7 miles west of Kingston. The fault zone is a duplex about two feet thick in which slickenlines, the verging of folds, and overlapping of structural blocks indicates translation of the overlying beds towards N. 23° W. Well-developed cleavage is found just below the fault. All these data suggest that there has been movement of rocks of the Catskill Plateau above the Hamilton shale horizon as well as within younger rocks. Perhaps many more similar faults zones are waiting to be discovered. If the structures within the Hamilton shales really mark the limit of Acadian deformation, as a number of geologists have suggested, then younger rocks should lie on the Hamilton with angular unconformity. So far as we know, no evidence for such an unconformity has ever been presented. If one recognizes structures such as small thrust zones or detachment horizons within the Hamilton shales, and does not see this sort of structure in any overlying unit, it is meaningless to say that the Hamilton is the youngest unit affected by these structures. There is plenty of evidence to suggest that these structures formed when the rocks were at least partially lithified. Therefore, some rocks younger than the affected beds <u>must</u> have been present and were transported to the west in the overlying block or thrust sheet. Therefore, we feel it is very important to examine the type of structure being discussed when important generalizations about the ages of regional deformations are being made.

4. Lineaments, which have a trend of about N. 20° E., are very apparent on radar imagery and topographic maps. They extend northward into rocks as young as the Plattekill Formation of Middle Devonian age and probably extend into the Oneonta Formation of Late Devonian age. They also parallel faults that we have mapped in the Shawangunk Mountains to the south. In the Catskill Plateau, they are aligned along valleys (seen from mileage 1.3 and Stop 3), which preliminary investigations suggest are controlled by minor faulting and very closely spaced joints. The structures that cause these lineaments are post-Acadian in age, since they cut Upper Devonian rocks. The parallelism with the faults in the Shawangunk Mountains suggests, but does not prove, an age equivalence.

5. Finally, the Acadian orogeny in New England involved deformation, metamorphism, pluton emplacement, and uplift. Dating of the late orogenic plutons places a minimum date of 380 million years (middle Middle Devonian) for the orogeny (Naylor, 1971). Therefore, Acadian deformation ceased by at least the time that the basal part of the Hamilton Group (Bakoven Shale) was being deposited, if not sooner. Thus, the response in the field trip area to Acadian deformation going on to the east was subsidence to form a basin in which Hamilton sediments were deposited. This was followed by shoaling and finally terrestrial deposition ("Catskill Formation") as the Acadian mountains to the east were uplifted. Acadian folding may never have extended as far west as the field trip area! Faill (1985) likewise suggested that evidence for Acadian deformation of rocks in the Catskill depositional basin are either absent or ambiguous, at best. Catskill sediments are the result of Acadian orogenic uplift, and were not deformed during Acadian tectonism. Faulting in the Plattekill and Hamilton must therefore be the result of later (Alleghanian) deformation. This suggests that the flat-lying and gently dipping rocks of the Catskill Plateau may lie with fault contact on the highly deformed Upper Silurian and lower Middle Devonian rocks of the Hudson Valley. Alternatively, the severe deformation of these Silurian and Devonian rocks may not have extended as far west as the present Catskill front (Marshak, 1986, p. 366).

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is internally folded and contains both continuous and disrupted quartz veins. In places, closely spaced fractures extend down from the clay into the underlying bedrock. In other places the lowest few millimeters of the Shawangunk is sheared. At Stop 8 the upper few inches of the Martinsburg is rotated. The clay is clearly a fault gouge. The vein fragments are slickensided, indicating repeated movement along the zone.

One question that needs to be asked is why the clay in the fault gouge has remained a sticky clay, whereas surrounding rocks have been lithified? The answer may be that the contact is a zone of alteration. This area of the Shawangunk Mountains contains several abandoned lead-zinc mines and there are many prospects and mineralized localities throughout the area. The lower few inches of the Shawangunk here at Otisville is similarly altered.

The shale-chip gravel just below the Shawangunk Formation and above solid Martinsburg bedrock at Ellenville (see description for Stop 2) is remarkably similar in appearance to Pleistocene shale-chip gravels elsewhere in the northern Appalachians. Figure 5 compares a size distribution analysis of the gravel at Ellenville (fig. 5C) with a Pleistocene shale-chip gravel in eastern Pennsylvania (fig. 5D). The coefficient of sorting, So, of the Ellenville gravel is 2.1, indicating a very well sorted sediment, similar to sorting found in alluvial sands. This suggests water washing of the sediment. The mean grain size, Ma, is 3.2 mm. The Pleistocene shale-chip gravel is remarkably similar, both in sorting and mean grain size, suggesting a similar origin. On the other hand, colluvium between the Martinsburg and Shawangunk at Otisville, New York (Fig. 5A), which we will see at Stop 5, is much more poorly sorted. Fault gouge between the Martinsburg and Shawangunk, such as at Port Jervis, New York, is even more poorly sorted and contains a much larger percentage of silt and clay (fig. 5B).

These data add an interesting hitherto unrecognized chapter to Late Ordovician paleogeography in the central Appalachians. It seems likely that following the deposition of the marine Martinsburg shales and graywackes, the Martinsburg was uplifted during the Taconic orogeny. But later as the Martinsburg surface was subaerially exposed, diamictic colluvium and shale-chip gravels were spread out on the exposed surfaces, and exotic pebbles and cobbles were incorporated in the diamictite. Much of this material was subsequently removed during pre-Shawangunk erosion and only scattered occurrences remain. The clasts were derived from a source that is no longer exposed nearby. The only evidence for that source is from the few pebbles that we have found. It might be suggested that thrusts brought these exotic rocks close to the site of deposition, and that thrusts sheets were subsequently eroded. If this is true, these thrusts must have been Taconic in age. These deposits were later covered by conglomerates and sandstones of the Shawangunk Formation during Middle Silurian time.

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ROAD LOG AND STOP DESCRIPTIONS

Total Miles	Miles Between Stops	
0.0		Leave parking lot of Ramada Inn Motel. Locality is on blacktop of Holocene age, unconformably overlying stream and lake-bed deposits of Pleistocene (Woodfordian) age, unconformably overlying either the Onondaga Limestone or Bakoven Shale of Middle Devonian age. Turn right at traffic light heading west on NY 28.
0.3	0.3	Turn right onto US 209 South towards Ellenville. About one-third mile straight ahead on the north side of NY 28 is a fault in the Bakoven Shale (noted by Pedersen and others, 1976, p. B-4-21). The fault zone is about 5 feet thick and consists of crumpled and slickensided black shale with abundant quartz veins. The slickenlines and verging of the folds indicate that the overriding beds moved to the northwest. Some workers believe that these are the youngest rocks deformed in the area and therefore date the folding in Silurian and Lower Devonian rocks as Acadian. However, we believe that there is evidence to suggest that this deformation is Alleghanian (see section on Age of Deformation). 2.1 miles northeast of the fault in the Bakoven is a fault duplex about 5 feet thick, slightly higher in the section in the Mount Marion Formation. Slickensides in the duplex indicate that the overriding beds moved N. 70° W. Pedersen and others (1976, p. B-4-6, 7, 22,23) consider these structures to be soft-rock "pull aparts". However, a 1-foot-thick sandstone bed is deformed into mullions and is surrounded by slickensided surfaces and sheared shale. Tectonic shortening is estimated to be 50-60 percent, judging from the overlapping of the mullions.
0.6	0.3	Fault in Bakoven Shale described above can be seen to right. For the next 8 miles we will be riding along a flat plain underlain by floodplain and stream-terrace deposits of Esopus Creek and glacial lake-bed sediments of Pleistocene Lake Stone Ridge (Dineen and Duskin, 1987).

1.3	0.7	The hills in foreground to right are underlain by shales and sandstones of the Mount Marion Formation. In the hills above are sandstones of the Ashokan Formation. Valleys which trend N. 20° E. are parallel to lineaments that are very apparent on radar imagery and topographic maps. The valleys, seen for the next two miles, are controlled by very closely spaced joints and minor faulting. The lineaments extend northward up into rocks as young as the Plattekill Formation of Middle Devonian age and may extend into the Oneonta Formation of Late Devonian age. Southward, these lineaments parallel faults that have been mapped in the Shawangunk Formation of Silurian age. This is one of the reasons for suggesting that the deformation in the area is Alleghanian, rather than Acadian, in age.
1.8	0.5	Cross Esopus Creek. For the next several miles we will see scattered exposures of the Onondaga Limestone poking through glacial cover.
4.7	2.9	Entering Marbletown.
8.9	4.2	Traffic light. Continue straight on US 209 South.
9.6	0.7	Junction with NY 213 West. Continue straight on US 209 South and NY 213 East.
10.4	0.8	Turn left on NY 213 East.
11.0	0.6	View of Mohonk Lake tower on Shawangunk Mountain at 2 o'clock. The tower affords an excellent view of the Catskill Mountains, Walkill Valley, and surrounding region. It overlooks a gorgeous lake at the Mohonk Mountain House which is situated at the crest of a faulted anticline.
11.3	0.3	Enter town of High Falls.
11.5	0.2	Outcrops of the Schoharie Formation.
11.6	0.1	Traffic light. Continue straight.
11.7	0.1	Cross Rondout Creek. Classic section of High Falls Shale, Binnewater Sandstone, and Rondout Formation to left.
12.1	0.4	Exposures of uppermost Shawangunk Formation in low cliff one block ahead. Turn right onto Bruceville Road (Ulster County 6A) between antique store and pizzeria.

12.2	0.1	Canal Museum on left.
12.3	0.1	Continue straight on Hill Road.
13.1	0.8	"Y" in road. Bear left.
13.4	0.3	Cross Coxing Kill.
13.7	0.3	"Y" in road. Continue right on Ulster Co. 6A.
14.0	0.3	Exposure of High Falls Shale, Binnewater Sandstone, and Rondout Formation in steep slope to left.
15.0	1.0	Intersection with Clove Road. Continue straight.
15.4	0.4	Mossy Brook Road on right. If you hike about 0.5 mile down this road, which is on private land belonging to the Mohonk Mountain House, you will find an old log cabin. Nearby, the Mohonk Lake thrust fault is beautifully exposed in Mossy Brook. This gently southeast dipping fault carries Ordovician Martinsburg Formation northwestward over the Silurian Shawangunk.
15.6	0.2	Exposure of red beds of High Falls Shale on right.
15.7	0.1	Exposure of Shawangunk on right.
15.8	0.1	Cross Mohonk Lake thrust fault, which carries shales of the Martinsburg Formation, here dipping moderately to steeply towards the southeast, northwestward over quartzites and conglomerates of the more gently southeast dipping Shawangunk Formation. This fault is not exposed where it crosses the highway.
16.0	0.2	For the next 0.7 mile we pass outcrops of the Martinsburg, consisting of thin-bedded shale, minor siltstone, and very rusty weathering, fossiliferous, fine-grained graywacke in beds up to 3 inches thick. Cleavage is poorly developed.
16.9	0.9	Pass through one-lane underpass, then immediately turn to right at gatehouse.
17.0	0.1	Stop sign at gate house.

ROUTE TO ALTERNATE STOP 1A (If it is raining hard, we may choose to take the bus to this stop instead of walking to Stop 1.):

0.0	0.0	Stop sign at gate house. Turn right on Huguenot Drive heading towards main entrance of Mohonk Mountain House.
0.1	0.1	Exposures of slumped Martinsburg on left. View of Catskill Mountains on right.
0.8	0.7	Road intersection at Woodland Bridge. Straight ahead, and following the stream valley, is the Kleine Kill thrust fault. To the right are exposures of deformed Shawangunk and the slope to the left is underlain by deformed Martinsburg.
		Make abrupt left turn on Terrace Road heading back towards gate house.
0.9	0.1	Martinsburg in bank on right. For most of this outcrop the southeast dipping shales and graywackes are right side up; however, there are several zones about 3 feet wide that are very tightly folded. The azimuth of these folds vary from N-S to N. 10° E. and they plunge gently to both the north and south.
1.0	0.1	Turn right into shale pit.

ALTERNATE STOP 1A.

FAULT ZONE IN FOSSILIFEROUS MARTINSBURG

The Martinsburg in this outcrop is dominantly medium dark-gray shale interbedded with fine grained graywacke. The graywacke beds are commonly less than 5 inches thick, and exhibit graded bedding, and parallel and cross laminations. The graywackes are fossiliferous (mostly brachiopods and crinoids) and contain a fair amount of pyrite. The fossils are most easily seen in the very rusty weathering pyrite-bearing graywacke beds. A cleavage is poorly to moderately well developed in the shales, although not enough to call these rocks slates.

The Martinsburg in this shale pit contains fault-related structures interpreted to be of two different ages. A melange or broken formation, best seen at the far north end of the pit (at least at the time of this writing), is part of the same melange zone seen at Stop 1. The melange zone is Taconic in age and has a strike of N. 5-10° E. It has been carried westward over the Silurian Shawangunk in the hanging wall of the younger Kleine Kill thrust (fig. 14). Most of the small faults and slickensided

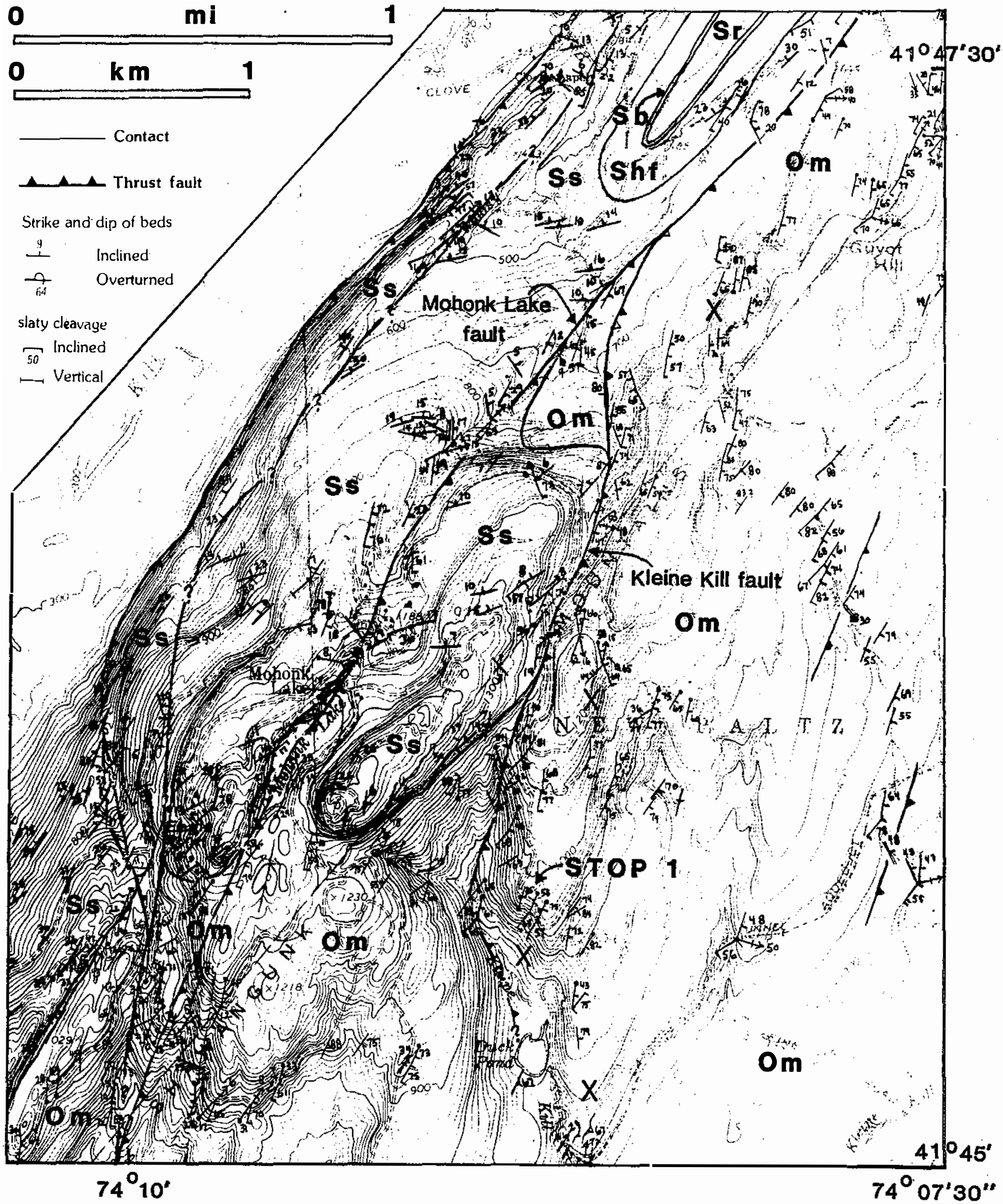


Figure 14. Preliminary geologic map of the Mohonk Lake area, N.Y.

Sr, Rondout Formation; Sb, Binnewater Sandstone; Shf, High Falls Shale; Ss, Shawangunk Formation; Om, Martinsburg Formation. X marks exposures of melange.

surfaces that are common in this pit are probably related to this younger thrust fault. The trace of the Kleine Kill thrust nearby has a strike of N. 15° E., and is interpreted to be Alleghanian in age.

Based on our mapping, several generalizations can be made about Taconic and Alleghanian fault-related structures. The fault zones in the Martinsburg which clearly do not cut Silurian and younger rocks generally have: a) a trend more northerly than the northeast-trending folds and faults in the Silurian rocks, b) a diagnostic scaly cleavage (see Stop 1 for a fuller discussion), c) tightly folded "floating" knockers of graywacke whose axes plunge predominantly to the northeast with variable azimuth, and 4) very little, if any, vein quartz. The faults that definitely cut both the Ordovician Martinsburg and the Silurian Shawangunk, and which we interpret to be Alleghanian in age, generally have: a) a slightly more easterly strike, b) well-developed "pencils" in the shales formed by the intersection of bedding and cleavage, and c) vein quartz parallel to bedding and/or cleavage that commonly contains shale fragments.

An example of a good Taconic melange can be seen at Stop 1, and an example of an excellent Alleghanian fault zone can be seen at Alternate Stop 1b.

		Reboard bus, leave shale pit, turn right toward gate house.
1.4	0.4	View of Wallkill Valley to right (southeast).
1.8	0.4	Rejoin roadlog at Milage 17.0.

17.0	0.1	Stop sign at gate house. (NOTE: THIS IS PRIVATE PROPERTY; ACCESS CAN ONLY BE GAINED BY CONTACTING DAN SMILEY AT THE MOHONK MOUNTAIN HOUSE). Drive a few feet past the gatehouse and turn left down Lenape Lane (a dirt road) past the "Do Not Enter" sign.
17.9	0.9	Excellent exposures of Martinsburg shales to right and at bend in road. Thin-bedded, graphitic shale interbedded with thin- to medium-bedded, parallel-laminated, fine-grained, pyritiferous graywacke. Cleavage is poorly to moderately well developed and oriented nearly parallel to bedding.
18.2	0.3	STOP 1. Park on right and disembark. Climb hill along dirt road with switch back. After walking approximately 1,000 feet you will reach the intersection of Forest Drive and Oakwood Drive; continue straight ahead on Oakwood Drive. Between here and Stop 1 Oakwood Drive marks the boundary between the lands of the

Mohonk Mountain House and the Mohonk Preserve, which is also a hunting boundary.

PLEASE BE AWARE THAT BOW AND ARROW HUNTERS MAY BE LURKING IN THE WOODS. NO DEER IMITATIONS ALLOWED.

After about 1,800 feet you will cross Kleine Kill Road. Continue another 50 feet on Oakwood Drive and follow it around a sharp bend to the right (northwest). For the next 750 feet until we reach Stop 1, pay attention to the outcrops of Martinsburg on the right. You should be able to find tight folds, overturned bedding, slickensided fault surfaces with and without vein quartz, and tension gashes in sandstone beds. We will not spend much time discussing these rocks until we reach Stop 1.

STOP 1

MARTINSBURG MELANGE

At this stop we will see a good example of a tectonic melange within the Martinsburg Formation. As there are no identified "exotic" blocks in this melange, it perhaps should be called a broken formation (Hsu, 1968). As you can see by looking to the northeast, we are very close to the Shawangunk clitts beneath Skytop Tower. Although there are no exposed contacts showing unfaulted Shawangunk resting unconformably on Martinsburg melange in the field trip area, there are several localities in the Rosendale quadrangle to the east where Silurian rocks directly on strike with Martinsburg melange zones show no comparable deformation or offset. In addition, mapping by Vollmer (1981) just southwest of Albany, New York (fig. 9) documents a beautiful exposure of unfaulted Rondout Formation resting unconformably on top of Taconic melange in the Normanskill Shale. For these reasons we feel that this melange zone, as well as similar ones nearby in the Martinsburg, must be Taconic in age. In the Kleine Kill valley down the hill and less than 1,000 feet to the west of Stop 1, is the main trace of the Kleine Kill thrust fault, which a short distance to the north offsets and folds the Shawangunk. This fault is part of an imbricate splay, or perhaps a duplex (fig. 14). It would appear that the melange zone seen at Stop 1 and several other places along strike is always contained in the hanging wall of the Kleine Kill thrust fault. Since there are thrust faults that postdate and transport these melange zones, it is particularly important to document structures that appear to be diagnostic for the melanges. The most important feature which can be seen at this stop is a scaly, anastomosing, phacoidal cleavage that commonly exhibits shiny and smeared surfaces. In addition, bedding is very disrupted and many tight folds are rootless and "floating" in the phacoidally cleaved shale and siltstone. Both of these features are most easily seen by examining the two to six inch graywacke beds. As one might expect, the hinge lines of the rootless folds show a significant range in orientation; however, they generally plunge moderately to steeply to the NNE. By carefully examining small scale structures such as asymmetric folds, minor offsets, and slickensides, it is possible to determine the sense of movement on some of the faults. What is difficult, if not impossible, to prove is whether an individual fault formed during the Taconic melange-forming episode or is related to the later, probably Alleghanian thrust system. It is possible, however, to show that although most small-scale structures show an east-over-west sense of rotation and a west-northwest transport direction, there are quite a few examples of thrusts with the opposite sense of movement.

There are two good exposures of the Kleine Kill thrust fault in the bed of the Kleine Kill just west of this stop. These outcrops are remarkably different from the melange seen here. They show sharp, planar, knife-edge faults with minor brecciation but no wholesale bedding disruption. They also contain many quartz slickensided surfaces. Most of these slickensides show an east-over-west thrust sense; however, a number of slickenlines are subhorizontal and suggest that there is a component of strike-slip displacement. The sense of movement is ambiguous, but appears to be left lateral. The shales near the fault commonly show an excellent cleavage (they are almost slates) and are beautifully pencilled.

		Return to bus, continue straight on Lenape Lane.
20.3	2.1	Turn right on Butterville Road. Excellent view to right of cliffs of the Shawangunk Formation and the Mohonk Tower. The hills in the middleground are underlain by shales and graywackes of the Martinsburg Formation, trending northerly with angular discordance under the Shawangunk.
20.6	0.3	Turn right on NY 299 heading west.
21.6	1.0	Overturned shales and thin graywackes of the Martinsburg Formation on right. There are a number of narrow fault zones with vein quartz. This outcrop is roughly on strike with Alternate Stop 1B.
22.0	0.4	World-renowned New York State orchards.
22.4	0.4	Steeply dipping and overturned Martinsburg shales and thin graywackes on right. View of the Shawangunk cliffs at the Trapps straight ahead.

22.9	0.5	Martinsburg with 2.5 ft graywackes on right. Bedding appears to be right-side-up, however, the poorly developed cleavage in the shales dips steeply to the west suggesting that both bedding and cleavage have been rotated by faulting.
24.2	1.3	Stop sign. Intersection with US 44-NY 55. Turn right, heading west.

ROUTE TO ALTERNATE STOP 1B

0.0	0.0	Stop sign. Turn left on US 44- NY 55 heading east.
2.2	2.2	Benton Corners. Intersection with Libertyville Road. Continue straight on US44-NY55.
3.2	1.0	Exposures of Martinsburg Formation of Alternate Stop 1B to left.
3.4	0.2	Park on shoulder at intersection. Walk west, back to outcrop of Martinsburg Formation.

ALTERNATE STOP 1B

FAULT ZONE AT GANAHGOTE--MARTINSBURG FORMATION

The shales and graywackes of the Martinsburg in this long roadcut have been severely faulted. This locality was chosen as an alternate stop in order to show the small-scale structures related to what we and others (Kalaka and Waines, 1986) interpret as a major thrust fault of Alleghanian age. Several difficulties arise when trying to document this age: 1) The extent and thickness of glacial materials in the Wallkill Valley prevents the reliable tracing of structures over great distances. 2) This locality contains no rocks younger than the Martinsburg of Ordovician age. Therefore, at this specific locality it is impossible to prove the fault is younger than Taconic. This fault was first referred to by Kalaka and Waines (1986) and they will probably visit this locality on Trip H (this guidebook).

There are at least two ages of quartz slickensides at this stop. The oldest slickensides are parallel to bedding, show movement to the northwest, and were later folded by the tight folds produced during faulting. Unfolded slickensides also formed along these late faults and again show east-over-west movement. In addition, vein quartz found along faults can contain broken pieces of shale. The faults vary in strike from N. 10° E. to N. 50° E. and dip gently to moderately to the southeast. Cleavage, though present throughout the outcrop, is more intensely developed near the NE-trending thrust faults. It is in these localities that the rock is intensely pencilled.

Based on our mapping in this region, the best examples of pencil shales occur near the younger faults that cut both Ordovician and Silurian rocks. At this outcrop it is common to find bedding and folds abruptly truncated by faults, but the total disruption common to the melange seen at Stop 1 is missing. While one can find smearing along cleavage planes and some anastomosing fabrics at this outcrop, the pervasive scaly cleavage so beautifully developed at Stop 1 is also missing.

About 0.5 mile southwest of Stop 1B along the Shawangunk Kill are a series of excellent exposures of the middle part of the Martinsburg that we are informally calling the sandstone at Pine Bush (see section on Ordovician stratigraphy). For a distance of at least 2,000 feet along Shawangunk Kill the entire section is overturned. These outcrops appear to be in the footwall of the thrust fault seen at this stop. However, the total width of the fault zone is not known and there appears to be some faulting at the west end of the Shawangunk Kill exposures. In addition, data from the nearby Delaware aqueduct suggests that the 2,000 feet of overturned Pine Bush might be a sliver caught in the fault zone (see fig. 7). About 3.2 miles to the north of Stop 1B on Route 299 (Roadlog mileage 21.6 to 22.4) a minimum of 4,000 feet (perhaps as much as 6,000 feet) of Martinsburg is overturned or close to vertical. Also, it would appear that the thrust is cutting up section towards the north since it is approaching the contact with the overlying Shawangunk Formation. It is most likely that this fault is the same as the Mohonk Lake thrust fault (see figs. 7 and 14). They both have minimum offsets of several thousand feet. In the Mohonk Lake area, the stiff and thick-bedded Pine Bush is virtually absent and the thinner bedded shales and graywackes of the upper Martinsburg (Mamakating) do not appear to be regionally overturned. Locally, for distances of a few tens of feet the rocks may be tightly folded and overturned.

		Return to bus, reverse direction heading west on US44-NY55.
5.5	2.1	View of Shawangunk Formation on cliff face straight ahead.
6.7	1.2	Intersection with NY 299. Pick up road log at 24.2

24.2	1.3	Stop sign. Intersection with US 44-NY 55. Turn right, heading west. For the next mile we will be climbing to the top of the Shawangunk Mountains.
24.4	0.2	Martinsburg on left

24.8	0.4	From here to the unconformable contact with the Shawangunk near the top of the mountain the Martinsburg is well exposed. The rocks are predominantly shale interbedded with thin-bedded (up to 5 in), crossbedded to planar laminated siltstone, and minor fine-grained sandstone. Soft-sediment slump folds are common in the siltstones. Cleavage is absent or very poorly developed, except near tight folds and narrow fault zones. Most of these folds and faults do not affect the overlying Shawangunk and must be Taconic in age. They trend from N. 5° E. to N. 20° E., while structures in the overlying Shawangunk trend moreeasterly.
25.2	0.4	To the left is a turn off with a nice view of Wallkill Valley.
25.3	0.1	Buried contact of Martinsburg and Shawangunk. This area of the "gunks" is very popular with rock climbers, often as "thick as pigeons" (R. Waines, oral commun., 1983). The contact is exposed at two spots about 400 feet southwest of the road at the base of the cliffs. Fairly regular and linear mullions are seen in the basal Shawangunk at the contact.
25.4	0.1	Pass under Trapps bridge. Conglomerates and quartzites of the Shawangunk dipping moderately to the west.
26.6	1.2	Cross Coxing Kill. Here the Coxing Kill valley coincides with the trough of a broad open syncline that plunges gently to the northeast. It is also the site of much nude bathing. For the next 0.5 mile we will begin to cross a broad open anticline that exposes a window of Martinsburg that is approximately 2 miles long.
27.1	0.5	Poor exposure of Martinsburg to left.
27.4	0.3	Exposure of basal Shawangunk to right with unconformably underlying shales of the Martinsburg exposed about 40 feet away. Dips in both units are very gentle and the angle of unconformity is as little as 2°. However, the divergence in strike is as much as 38°, with the strike in the Martinsburg being more northerly. The Martinsburg here is in the broad open-fold Taconic tectonic zone (zone 3, fig. 9).
28.0	0.6	Cross Peters Kill.

28.5	0.5	Entrance to Lake Minnewaska State Park on left.
28.7	0.2	Parking lot on left; entrance to trail leading to Lake Awosting.
29.4	0.7	Cross Sanders Kill.
30.4	1.0	Upturned beds in Shawangunk mark a fault here.
30.5	0.1	Overview on right of Rondout Valley, underlain by Upper Silurian through Middle Devonian rocks which are buried by a variety of glacial sediments, and the Catskill Mountains, underlain by Middle and Upper Devonian clastic rocks of the "Catskill Formation". Moderately dipping quartzites and conglomerates of the upper part of the Shawangunk on left.
31.5	1.0	Cross Stony Kill
33.8	2.3	Roadcut in tongue of the Shawangunk (figs. 3 and 4) consisting of distinctive light- and dark-gray, crossbedded, slightly conglomeratic quartzite.
34.2	0.4	Cross Rondout Creek.
34.3	0.1	Stop sign. Intersection with US 209. Turn left. U.S. 209 follows the Rondout Valley, here underlain by rocks from the uppermost part of the Shawangunk Formation, then through a sequence of Upper Silurian through Middle Devonian limestones, shales, sandstones, and siltstones. Exposures are poor because of cover by glacial drift.
36.5	2.2	Enter Town of Wawarsing.
37.1	0.6	Cross Vernooy Kill.
37.4	0.3	Gravel pits in glacial delta to right and lake clays of glacial Lake Wawarsing under flat plain to left (Rich, 1934; Heroy, 1974). Glacial Lake Wawarsing was dammed in the Rondout Valley between the recessional moraine at Phillipsport (mileage 65.2) and the retreating ice front. The top of the deltaic deposits are at approximately 600 feet altitude, showing that the lake was about 300 feet deep here. The lake enlarged during recession, it dropped as lower outlets were uncovered, and finally drained as the ice retreated past the northeast end of the Shawangunk Mountains near Rosendale.

37.9	0.5	Sand and gravel pit to right.
38.1	0.2	Eastern New York Correction Facility, a maximum security prison, servicing many gentlemen from the New York City area, to left. There is an excellent exposure of the Martinsburg-Shawangunk contact, about 20 feet long, at an altitude of 600 feet. The angular discordance between the two formations is 4^{o}; the Martinsburg here is in Taconic tectonic zone 3 (fig. 9). The Shawangunk dips 22^{o} NW. in the northwest limb of the Ellenville arch. Mullions are prominent on the basal Shawangunk surface, and there is a shear fabric in both the Martinsburg and Shawangunk.
38.4	0.3	View of the Shawangunk Mountains in the northwest-dipping limb of the Ellenville arch to left.
38.8	0.4	Cross Rondout Creek.
39.2	0.4	Exposures of shaly siltstone to very fine-grained sandstone of the Mount Marion Formation, dipping 56^{o} NW., to right. Field to left covered by glacial deposits except for one exposure of Onondaga at airfield.
39.8	0.6	Enter Village of Ellenville.
40.4	0.6	Cross Beer Kill. A fine example of a slump deposit with disrupted bedding in the Mount Marion Formation is exposed 800 feet up the creek to the right. This outcrop may be within the Alcove Conglomerate of Wolff (1977).
40.5	0.1	Turn left on Liberty Street. View of North Gulley in Shawangunk Mountain straight ahead.
40.6	0.1	Stop sign. Turn left on Canal Street.
40.9	0.3	Cross Sandburg Creek.
41.1	0.2	Pass Berme Road. The Ellenville zinc-lead mine and a rock quarry in the tongue of the Shawangunk are located at the base of the mountain to the left. See Sims and Hotz (1951) and Rutstein (1987, p. 116) for descriptions.
41.5	0.4	Cross North Gully, joining NY 52. Exposures of the tongue of the Shawangunk in roadcuts and tongue of the Bloomsburg in the creek bed of North Gully to the left (fig. 3).

41.8	0.3	Turn left on blacktop road towards Mt. Meenahga.
42.0	0.2	Red beds of tongue of the Bloomsburg to left. Till and moderately NW-dipping Shawangunk higher along road towards Mt. Meenahga.
42.2	0.2	View to right of the valley of Sandburg Creek, the Nevele Country Club, and the Catskill Mountains.
42.6	0.4	Turn left. Conglomerates of basal Shawangunk on left. (Bus will return to this spot after letting group off at top).
42.7	0.1	Uppermost Martinsburg on left.
42.9	0.2	Contact between Martinsburg and Shawangunk at base of low cliff on left.
43.0	0.1	Pull into parking area of abandoned ski slope. Disembark. Bus will return to mileage 42.6.

STOP 2

CONTACT OF MARTINSBURG AND SHAWANGUNK; SHALE-CHIP GRAVEL AT TACONIC UNCONFORMITY; UPPERMOST MARTINSBURG IN TACONIC OPEN-FOLD FRONTAL ZONE; CLEAVAGE IN SHAWANGUNK

Take a peek to the northwest through the bushes at the broad glacial valley of Sandburg Creek and the Catskill Mountains beyond. The valley is underlain by glacial lake sediments, deposited in glacial lake Wawarsing between the morainal dam at Phillipsport, 5 miles to the southwest, and the receeding ice front. Also note the graffiti-covered, unevenly and planar bedded conglomerates with low-amplitude channels in the lower Shawangunk Formation. The contact with the underlying Martinsburg Formation is near the base of the low cliff. In this area the strike of the two formations is similar, but the Martinsburg dips 10 to 15 degrees less than the Shawangunk.

Locality A:

Walk 300 feet down the road to the exposed contact of the Martinsburg and Shawangunk.

The Shawangunk consists of planar bedded, quartz-pebble conglomerate with rounded to subangular vein quartz pebbles as much as 2.5 inches long, and planar bedded and crossbedded, conglomeratic, medium- to coarse-grained, feldspathic quartzite. Chert pebbles are rare. There are no pebbles derived from the underlying shales and graywackes of the Martinsburg Formation.

The Shawangunk forms a two-foot overhang above the underlying rock, which is at least 1.5 feet thick and consists of a mass of shale chips with an openwork texture. The chips are up to about 1 inch long and form a crude foliation approximately parallel to the overlying contact with the Shawangunk, although this foliation is interrupted in places. It might be suggested that these rocks were jammed by man under the Shawangunk, but the unit below the Shawangunk is clearly in place. The only explanation for this unit that we can think of is that it is a shale-chip gravel, deposited on and derived from a sloping Martinsburg surface. The shale chips are flat and generally equidimensional on their flat surface. There is no secondary cleavage in the chips, as far as we can tell. This suggests that cleavage was not imposed upon the Martinsburg prior to the deposition of the gravel. Thus, slaty cleavage at this locality did not form during Taconic deformation.

The gravels in the Martinsburg are remarkably similar to Pleistocene shale-chip gravels derived from Paleozoic shales in the central Appalachians, both in physical appearance and size-distribution characteristics (see section on "Weird rocks" and fig. 5 C,D).

If this is indeed a colluvial deposit, the geologic relations in this area indicate that the Martinsburg was gently folded during Taconic deformation, it was uplifted and exposed with a steep enough slope to develop a colluvial shale-chip gravel, and was later covered by conglomerates (believed to be fluvial) of the Shawangunk Formation.

Locality B

Walk another 700 feet down the road to exposures of uppermost Martinsburg bedrock.

The Martinsburg here consists of thin-bedded grayish black shale with some thin beds of olive-gray, very fine grained, crossbedded graywacke, capped by thin Pleistocene till. Note the lack of cleavage in the shales. The Shawangunk 40 feet above has the same strike, but dips 10^{o} more steeply. This gentle angular discordance between the two units is typical not only for the Ellenville area, but for many miles to the northeast (to Ruedemann's Line, fig. 9) and to the southwest through New Jersey into eastern Pennsylvania (Epstein and Lyttle, 1987). This relationship is typical of the open-fold Taconic frontal zone (fig. 9).

Locality C

Walk another 600 feet downhill to the road intersection and the Shawangunk outcrop.

Bedding in the Shawangunk dips 40^{o} NW here, getting steeper as we head farther northwestward into the steep limb of the Ellenville arch. The conglomerates in Shawangunk contains closely spaced fractures cutting through the quartz pebbles and sand matrix. In places a residual thin film of mica and opaque minerals along the cleavage folia shows that it is a pressure-solution phenomenon. This type of cleavage is common in the Shawangunk in New Jersey and New York. Because bedding-plane slickensides are not common in this area, it is hypothesized that shortening during folding of the Shawangunk was taken up by development of cleavage. In eastern Pennsylvania, where folding is tighter and there has been much accomodation by bedding-plane slippage, there is little cleavage in the conglomerates and quartzites.

43.4	0.4	Reboard bus and retrace route back to NY 52.
44.2	0.8	Stop sign. Turn left on NY 52.
44.3	0.1	Tongue of the Bloomsburg Redbeds on left. The road follows this unit for several hundred feet.
44.8	0.5	Outcrops of uppermost Shawangunk in flatirons on northwest limb of Ellenville arch.
44.9	0.1	Cross South Gully.
45.6	0.7	Site of Stop 3 on left.
45.7	0.1	Pull off on shoulder to right. Cross road and walk 0.1 mile down to Stop 3.
		CAUTION--WALK ONLY ON SHOULDER. THIS ROAD IS HEAVILY TRAVELLED! NO REFUNDS IF YOU ARE HIT.

STOP 3

STRATIGRAPHY AND SEDIMENTATION OF THE SHAWANGUNK FORMATION

The upper half of the Shawangunk Formation is exposed here and consists of crossbedded and planar-bedded conglomeratic quartzite and pea-gravel conglomerates, with minor thin, lenticular light-olive-gray shale. Channels are abundant and many beds pinch out along strike. Shale drapes in crossbeds are common. Flattened silty shale balls up to 8 inches long are seen on the lower exposed bedding surface. Crossbed trends throughout the area of this field trip are to the northwest (fig. 15). The sedimentary structures, current trends, and petrographic characteristics suggest a fluvial, braided stream environment of deposition, similar to the interpretation for the Shawangunk in eastern Pennsylvania (Epstein and Epstein, 1972).

We will discuss some of the regional stratigraphic correlation shown in fig. 3.

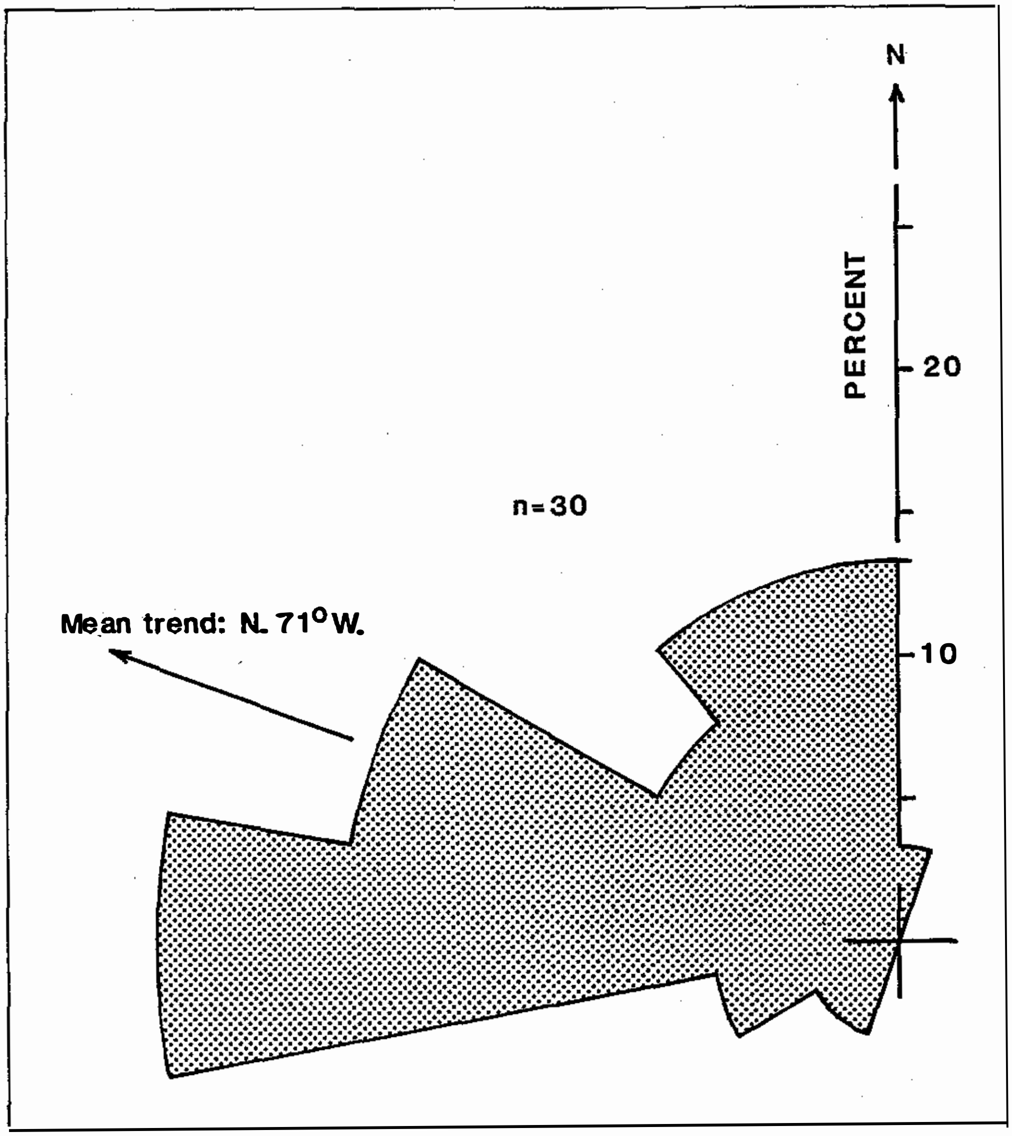


Figure 15. Histogram showing current trends from axes of trough crossbedding in the Shawangunk Formation, southeastern New York. Grouped in 20 percent intervals.

The beds dip about 45^{o} NW. They are interupted by a kink fold whose axis trends 18^{o} S. 56^{o} W., a more easterly trend than the regional strike of the beds. This fold, and scattered others in this part of the Appalachians, may represent a later stage of Alleghanian folding.

If the leaves are off the trees, you may be able to see the linear valleys in the Catskill Mountains to the north. These are discussed under "Age of post-Taconic Deformation".

If parking of the bus for this stop does not work at this locality, proceed to mileage 46.8 for alternate Stop 3.

Return to bus and continue uphill on NY 52.

45.9	0.2	Small thrusts in Shawangunk to left. These have a strike similar to the kink axis at Stop 3 and may also be later structures.
46.2	0.3	Upper quartzite member of Shawangunk. Launch site for hang gliders straight ahead.
46.5	0.3	Shale unit of Shawangunk on left.
46.6	0.1	Back into overlying quartzite unit.
46.8	0.2	Shale unit of Shawangunk to left, nice view at turn off to right. Pull off for Alternate Stop 3.

ALTERNATE STOP 3

To the right (northwest) is the flat-floored valley of Sandburg Creek underlain by glacial lake clays. In the far distance to the north the hills are underlain by sandstones of the Ashokan Formation, and in the far distance to the north are the higher Catskill Mountains underlain by Middle and Upper Devonian rocks of the "Catskill Formation". The valleys in the Catskills are aligned along linears that are presumably controlled by structural weakness (see section on age of deformation).

CAREFULLY CROSS THE ROAD

In this area we have been able to divide the Shawangunk into lower and upper units (fig. 3), separated by a shale-bearing sequence about 100 feet thick. The shale unit underlies topographic lows, generally allowing for easy mapping. This unit can be seen at the base of the exposed section, and consists of more than 80 feet of interbedded, laminated, ripple laminated, olive-gray silty shale and moderate-brown and light-olive-gray very fine to medium-grained, crossbedded, lenticular sandstone, slightly conglomeratic in places. Many of the sandstones have sharp channeled bases and some are ripple-topped.

The shale unit is overlain by several hundred feet of thin- to medium-bedded, medium-grained, partly conglomeratic, partly feldspathic, crossbedded, channeled quartzite with scattered thin and lenticular olive gray shale. The quartzites appear to be evenly bedded from a distance, but closer scrutiny shows that they are channeled, lenticular, and unevenly bedded.

Return to buses and continue uphill along NY 52.

47.9	1.1	Turn left on road to Cragsmoor and Ice Caves Mountain. Between here and the next stop, the road will be mostly on glacial till, with a few scattered exposures of the Martinsburg.
48.3	0.4	Village of Cragsmoor. Bear right at Post Office.
48.4	0.1	Turn right on Sams Point Road following signs to Ice Caves Mountain.
48.6	0.2	Cragsmoor Fire Dept. on right. Martinsburg exposure on left. This exposure and a few more up the road are in the Taconic tectonic zone of broad open folds. Views of continuous cliffs of the Shawangunk Formation in the broad top of the Ellenville arch may be seen at several places along this road.
48.7	0.1	Borrow pit on right in Martinsburg.
49.7	1.0	Entrance to Ice Caves Mountain National Landmark. Stop sign. Continue straight ahead on loop road to left. If you are quick you might read the educational (??) signs as the bus proceeds. It is possible that we will not drive to the top of the mountain at Sam's Point. If so, pick up a lunch and take a liesurly 15-minute stroll to Sam's Point along the road to the right. The basal Shawangunk is nicely exposed near the end of the journey.
49.8	0.1	Slot Rock, a crevasse in the Shawangunk, on your right.
50.0	0.2	Martinsburg on right. At this locality the Martinsburg dips 5° more steeply to the southeast than the Shawangunk exposed in the low cliffs above.
50.5	0.5	Cross Martinsburg-Shawangunk contact.

50.7	0.2	Microwave tower on left. Lake Marentanza on right. Many of the Shawangunk surfaces contain glacial striae.
51.1	0.4	Lake Maratanza, partly dammed by till in a structural depression, on right.
51.3	0.2	Sign: "There are no fish in this lake. This is Lake Marentanza. It is the water supply for Ellenville. There are no fish because the rocky bottom does not grow plant life to give off enough oxygen to support fish life. It is a mystery where the water comes from since the lake is on a mountaintop. What do you think?"
51.7	0.4	Road to Ice caves on left. Continue straight.
52.1	0.4	Turn right to Sam's Point.
52.2	0.1	Park in lot and walk out to Sam's Point.

STOP 4

SAM'S POINT
REGIONAL OVERVIEW
BASAL SHAWANGUNK; TROUGH CROSS BEDDING
GLACIAL STRIAE
ICE CAVES AND JOINTS
LUNCH

The highest point in the Shawangunk Mountains (2,289 ft) lies 2,000 feet north of this point. From southeast (left) to north (right), you can see (if the day is clear), the New York Highlands underlain by Precambrian rocks thrust on top of Cambrian and Ordovician carbonates and shales of the Wallkill Valley. In front of the Highlands are Schunnemunk and Bellvale Mountains underlain by conglomerates and sandstones of the Middle Devonian Schunnemunk Conglomerate in the Green Pond outlier. The rocks of the outlier are in fault and sedimentary contact with the Precambrian. The details of these structures are far from fully known. Shawangunk and Kittatinny Mountains, held up by the Shawangunk Formation, upon which we stand, next wiggle to the southwest with Tristates Monument marking the highest elevation in New Jersey at High Point (1,803 ft). We already know about the glaciated valley northwest of the mountain. The large white buildings 17 miles due west near Monticello make up the Concord Hotel, the site of several past GSA meetings. Beyond that are the Pocono Mountains of Pennsylvania that blend into the Catskill Mountains of New York to the northeast, underlain by flat-lying rocks of the "Catskill Formation".

The Shawangunk at Sam's Point dips very gently to the northeast, near the broad crest of the Ellenville Arch. Trough crossbedded is well exposed. These indicate current trends ranging between S.80°W. and N.70°W. Glacial striae with chatter marks on the bedding surfaces show that the Wisconsinan glacier flowed over the mountain moving S. 16° W.

The lower 80 feet of the Shawangunk here consists of medium- to thick-bedded conglomerate with quartz pebbles as much as 2 inches long. Channeled bases are common. Nowhere do we see any pebbles from the underlying Martinsburg, a peculiarity that exists throughout New York, New Jersey, and eastern Pennsylvania, and one which eludes a good sedimentologic explanation.

The Shawangunk is separated into huge blocks tens of feet wide. These have moved apart along the soft shales of the underlying Martinsburg, probably forced apart by frost action and wedging of boulders that fall into the cracks, producing a "moveoutite". This process has gone to a joyous extreme at the Ice Caves, one-half mile to the east, where the joints parallel the cliff face of the mountain. Cold air is trapped in the maze of blocks, and snow may persist throughout the summer, hence their name.

		Return to bus. Turn right out of parking lot and proceed down over cliff of Shawangunk conglomerates, crossing buried contact with Martinsburg Formation.
52.4	0.2	Note the breaking away of large blocks of the Shawangunk along joints.
52.8	0.4	Entrance to park. Retrace route back to Ellenville.
54.2	1.4	Post Office in Cragsmoor. Bear left downhill.
55.7	1.5	Stop sign. Turn right on NY 52 towards Ellenville.
57.2	1.5	At 11 o'clock are linear valleys in the Catskill Mountains that mark lineaments seen on radar imagery and described under mileage 1.3.
59.7	2.5	Bear left on Center Street.
60.5	0.8	Stop light. Intersection with US 209. Turn left.
61.3	0.8	Moderately northwest dipping gray shale, siltstone, and sandstone of the Mount Marion Formation. We will be paralleling these rocks for the next 18 miles. On the left are lake deposits of Lake Wawarsing. This lake was dammed by the moraine at Phillipsport, four

		miles to the southwest.
64.4	3.1	Bear Hill to left in Ellenville arch.
64.8	0.4	Cross Sandburg Creek.
65.1	0.3	Cross Homowack Kill. Leave Ulster County; enter Sullivan County.
65.2	0.1	Moraine at Phillipsport on left.
68.5	3.3	Leave moraine.
69.6	1.1	Parking area on right from which to see gliders on lazy summer days.
70.1	0.5	Wurtsboro airport on left. Shawangunk mine (zinc-lead) on top of Mountain to left (Ingham, 1940; Gray, 1961).
71.8	1.7	Enter Village of Wurtsboro.
72.4	0.6	Stop light. Danny's Restaurant on left is excellent place for pastrami and corned beef sandwiches. Continue straight on US 209.
73.6	1.2	Overpass with NY 17. Continue straight on US 209. Exposures of Mount Marion to right.
78.8	5.2	Entering Village of Westbrookville.
79.1	0.3	Turn left on Otisville Road (Sullivan Co. Rt 163).
79.2	0.1	Enter Orange Co (Orange Co. Rt 61).
79.5	0.3	Cross Basher Kill.
79.7	0.2	Large erratics of Catskill sandstone on left.
80.0	0.3	Quarry in New Scotland Formation on left.
81.0	1.0	Beginning of exposures of Shawangunk Formation on left.
81.2	0.2	Stop sign. Intersection with NY 211. Turn left. Northwest dipping Shawangunk straight ahead. In quarry to left are thin shales interbedded with typical Shawangunk quartzites and conglomerates. These are on line with exposures 1.2 miles to the southwest to which Swartz and Swartz (1931) applied the name "Otisville Shale Member of the Shawangunk Formation". This unit is out to lunch, that is,

it is poorly defined, it is unmappable, and should be discarded. Clarke (1907) measured the rocks in the quarry and showed that shale makes up less than 3 percent of the section.

Turn immediately right onto dirt road of abandoned railroad track. Walk to stop 5.

STOP 5

TACONIC UNCONFORMITY AT OTISVILLE

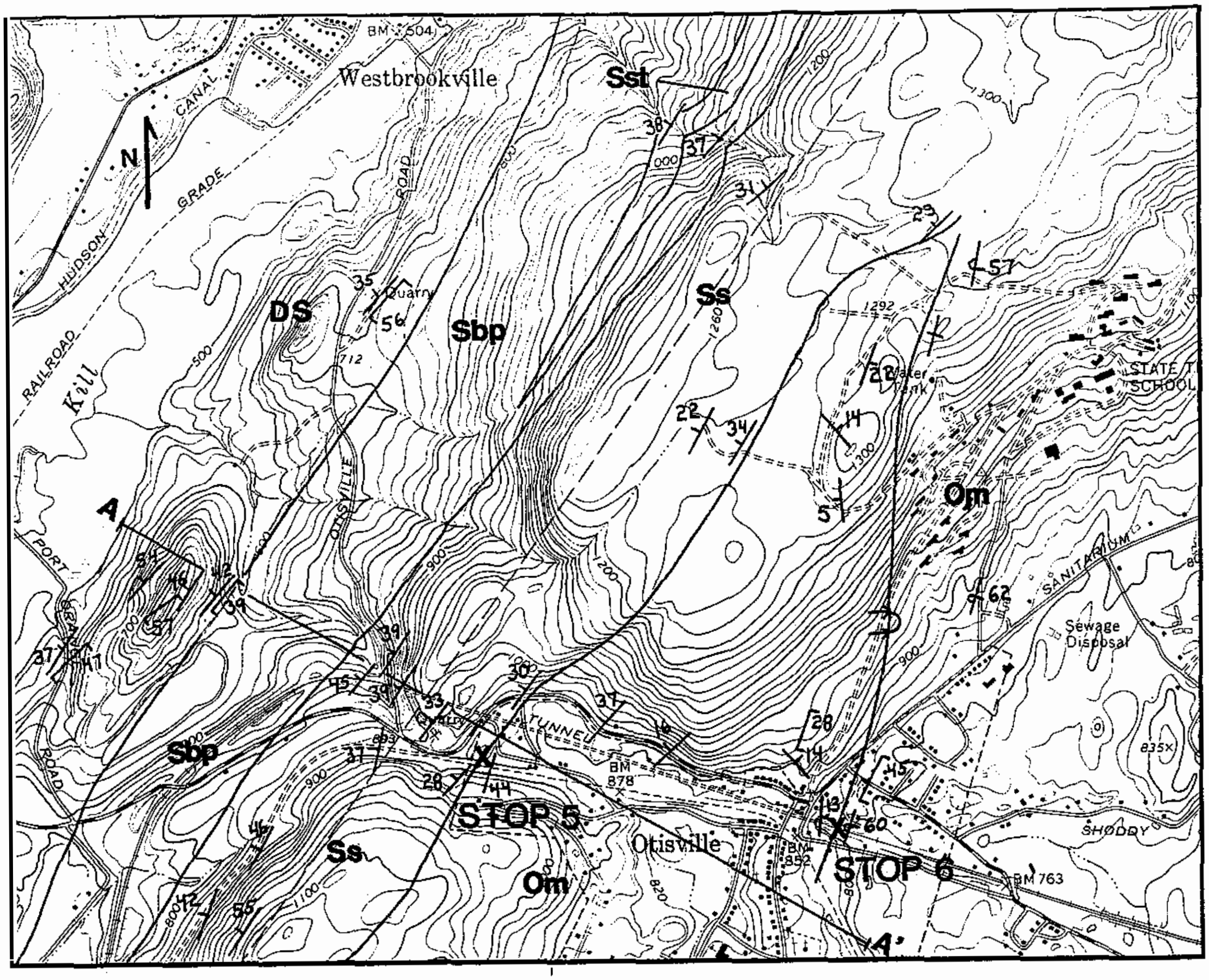
This is a classic exposure, discussed by many geologists in the past (Clarke, 1907, Schuchert, 1916, others), and visited by the 34th Meeting of the NYSGA (Fink and others, 1962). All have recognized the angular discordance in bedding between the Martinsburg (N.16^{o}E., 44^{o}N.W.) and Shawangunk (N.36^{o}E., 28^{o}N.W.). In this area we are in the broad open-fold zone of Taconic deformation, although these gentle structures are interrupted locally by a faulted overturned fold, seen at the next stop (fig. 16).

The basal Shawangunk conglomerates contain quartz pebbles as much as 2 inches long. No pebbles from the underlying Martinsburg were seen. The lowest few inches is pyritized. The Martinsburg comprises shale with minor thin graywacke siltstones and contains no obvious secondary cleavage.

The basal surface of the Shawangunk is irregular, with downward-projecting mullions that have a relief of about one inch and are about 3 inches to two feet apart. These have a general trend of N. 32^{o} E., about parallel to the strike of the beds and perpendicular to the regional transport direction. Note that these mullions are found only at the Martinsburg-Shawangunk contact and are not found on any surface higher up in the section. Some of the lowest Shawangunk is sheared parallel to bedding.

Between the solid Martinsburg bedrock and the Shawangunk there is an unusual zone, as much as one foot thick, containing light-gray to light-bluish gray clay gouge with slickensided quartz veins. This gouge, and the associated mullions in the overlying conglomerates, are typical of most Martinsburg--Shawangunk contacts exposed in southeastern New York (fig. 1) and shows that the unconformity is also a plane of movement, the displacement along which is not known.

Also in this zone is a poorly sorted and vaguely bedded diamictite (a nongenetic term referring to a poorly sorted sedimentary rock with a wide range of particle sizes) containing angular to rounded pebbles of exotic types, as well as clasts from the Martinsburg, in a clay-silt matrix. Bedding is generally poor, but some samples collected from the northeast



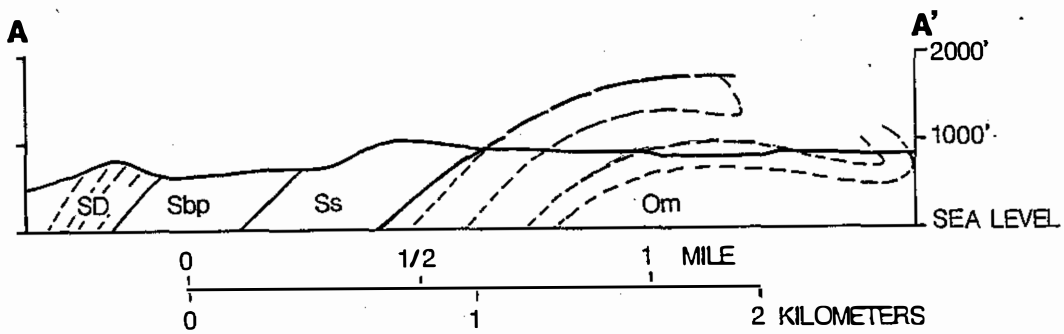


Figure 16. Preliminary geologic map and section of the Otisville, N.Y. area showing the angular unconformity between the Shawangunk and Martinsburg Formations, the overturned syncline overlapped by the Taconic unconformity, and location of stops 5 and 6. Standard structure symbols used for bedding, cleavage, and axial trace of syncline. DS, Schoharie Formation through Bossardville Limestone; Sbp, Poxono Island Formation and Bloomsburg Red Beds; Ss, Shawangunk Formation; Om, Martinsburg Formation. Base from U.S. Geological Survey topographic quadrangle: Otisville, N.Y., 1969.

side of the cut show reasonably decent bedding. There is a sharp contact with the Shawangunk above and also a sharp contact with the Martinsburg below; both are unconformable. In places it appears that parts of the Martinsburg have been bodily lifted from the underlying bedrock and incorporated in this diamictite. There are several possibilities for the origin of this unit. We do not believe that it is fault related, because there is no foliation in it. It looks more like a product of mass wasting, and is interpreted to be a colluvial gravel.

The pebbles include types foreign to the immediately underlying bedrock. They are composed of fairly clean quartzite, some of which are pyritic, fine-grained protoquartzite and subgraywacke, red siltstone, medium-gray siliceous siltstone, laminated micaceous siltstone, medium dark-gray shale, graywacke, and vein quartz. Many are rounded, some have a thin weathering rind, and others have surfaces that are weathered in relief. Clearly, these cobbles were exposed to the air, weathered, and incoporated in the diamictite.

One question that needs to be asked is why the clay has remained a sticky clay, whereas surrounding rocks have been lithified? The answer may be that the contact is a zone of alteration. This area of the Shawangunk Mountains contains several abandoned lead-zinc mines and there are many prospects and mineralized localities throughout the area. The lower few inches of the Shawangunk here at Otisville is similarly altered.

Another puzzlement is that the colluvium contains many disoriented clasts of slickensided vein quartz. This indicates fault movement prior to incorporation in the colluvium. Possibly the Martinsburg nearby was faulted and slickensided during Taconic deformation and the slickensided fragments were later incorporated in the colluvium. Another possibility is that the diamictite is a fault gouge and not a colluvium, and there has been several periods of movement, the latest one of which fractured earlier slickensided rocks. The problem with this interpretation is that it does not account for the exotic pebbles nor does it explain the lack of foliation in the diamictite.

WHAT DO YOU THINK?

		Return to bus, turn right, and continue east on NY 211 towards Otisville.
81.4	0.2	Enter Village of Otisville.
81.5	0.1	Covered contact of Martinsburg and Shawangunk.
81.8	0.3	Exposures of Martinsburg shale and graywacke on left, dipping moderately northwest.
82.2	0.4	Turn right on Kelly Hill Road. Follow road to left paralleling railroad tracks..

82.6 0.4 Stop on right shoulder. Cross over to railroad tracks and walk westward to Stop 6.

STOP 6

OVERTURNED TACONIC FOLD IN MARTINSBURG FORMATION

The Martinsburg in the Otisville area is generally within the open-fold Taconic frontal zone. However, this locality is complicated by a faulted overturned fold (fig. 17). The Martinsburg here consists of shale and interbedded thin- to thick-bedded graywacke. Sole marks (grooves, flutes, and loads) are prominent on the undersurfaces of bedding in the overturned limb. Cleavage is well developed and is axial-planar to the fold. The axis of the fold trends about N.10°E. and is overlapped by the Shawangunk about 1.3 miles to the north. Beacuse the Shawangunk does not appear to be folded at the unconformity, the fold, faults, and cleavage in the Martinsburg at this locality must be Taconic in age. Outside the area of this fold, cleavage is generally not developed. While the map is believed to be accurate, critical parts lie within the boundaries of both a State and a Federal maximum security prison. These areas have not as yet been mapped. The criminal instincts of the senior author of this guidebook may allow him to set up residence here in the near future in order to complete the mapping.

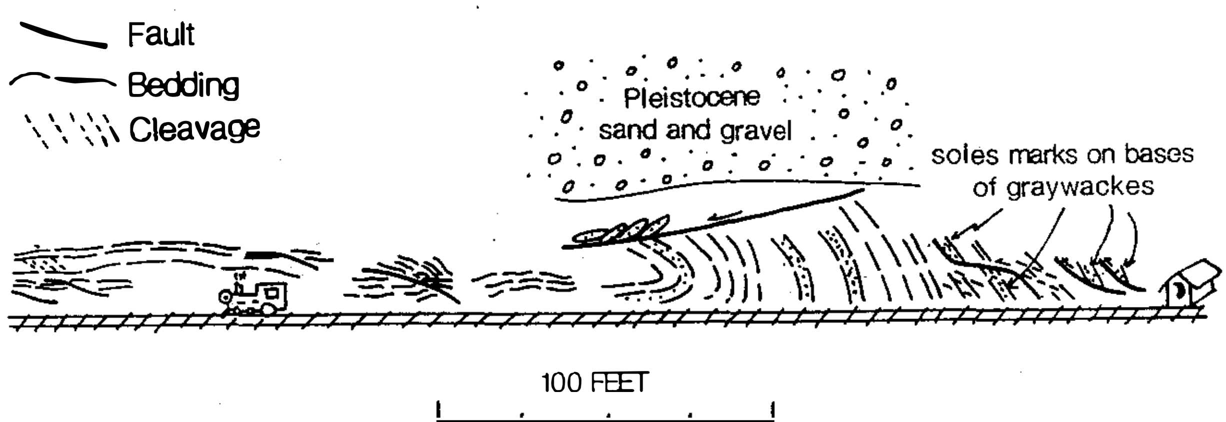


Figure 17. Field sketch (looking north) of faulted overturned syncline along Erie-Lackawanna Railroad, Otisville, New York. Stop 6.

		Reboard bus and continue straight ahead.
83.2	0.6	Stop sign. Turn left on N.Y. 211, passing under railroad bridge.
84.3	1.1	Stop sign. Turn right on Sanitorium Avenue (Orange Co. Rt 90).
84.4	0.1	Road to Federal Correctional Institution to left.
84.6	0.2	Otisville Correctional Facility of the New York State Department of Correctional Services to left. At this point, all those who have disagreed with the interpretations presented on this field trip will be dispatched.
86.3	1.7	Graywackes of the Martinsburg Formation on left.
87.1	0.8	Entering Sullivan County. Continue straight on Sullivan Co. Rt 65.
87.5	0.4	Continue straight on Sullivan Co. Rt 65.
88.3	0.8	Continue straight on Sanitorium Road towards High View.
88.7	0.4	Bear left at "Y" on Mountain Road.
89.4	0.7	Lake Altemont on left; gently dipping Martinsburg shales on right.
92.0	2.6	Stop sign. Turn left on Rt 17K.
92.2	0.2	Thick bedded graywacke and shale of the Martinsburg on left.
92.3	0.1	Turn left just before overpass of Rt 17 towards High View Terrace.
92.4	0.1	Martinsburg graywacke and shale on right.
92.5	0.1	Stop sign. Turn right.
92.6	0.1	Do not turn left; pull into parking area straight ahead.
		Walk out to overlook above NY Rt 17.

STOP 7

ROUTE 17 ROADCUT: STRATIGRAPHY AND STRUCTURE OF THE UPPERMOST MARTINSBURG, THE TACONIC UNCONFORMITY, AND LOWERMOST SHAWANGUNK.

CAUTION. DO NOT FALL OFF ROADCUT.
DEATH WILL RESULT

A fine view may be seen from this point. Far to the east (right) are the Schunnemunk and Bellvale Mountains, underlain by the Schunnemunk Conglomerate of Middle Devonian age in the Green Pond outlier. The lowland immediately to the east is the Walkill Valley, underlain by carbonate rocks of Cambrian and Ordovician age, as well as the Martinsburg Formation. Directly under us is a marvellous 3000-foot-long exposure demonstrating the stratigraphy and structure within the Martinsburg. To the west (left) you can see the overlying Shawangunk conglomerate (STOP 8), as well as the tongue of the Bloomsburg and overlying tongue of the Shawangunk. Beyond the bend in the road, and not seen, is the High Falls Shale. Off in the distance are the Catskill Mountains with rocks as young as the Plattekill Formation of Middle Devonian age.

This outcrop offers the best look at the uppermost 600 feet of the shale and graywacke at Mamakating of the Martinsburg exposed anywhere in the Wallkill Valley. Some of the more interesting sedimentologic and structural features are described below and located on figure 18, so that at some future date the field tripper can return and look at the outcrop at his or her leisure. As mentioned in the section on Ordovician stratigraphy, the Mamakating in southern New York differs from both the Ramseyburg and Pen Argyl Members of the Martinsburg that have been mapped in eastern Pennsylvania and northern New Jersey. The Mamakating consists dominantly of thick sequences (hundreds of feet) of medium dark-gray, thin-bedded shale interbedded with with very thin to medium-bedded (1/4 to 15 in), very fine to fine-grained, graywacke. These thick sequences alternate with thinner sequences (generally less than 100 feet) of thin-bedded shale interbedded with medium- to thick-bedded (up to 6 ft), fine-grained graywacke. Locally in both sequences, graywacke makes up more than 50 percent of the outcrop, but a more common average would be less than 25 percent. Only seen at this outcrop, but probably present elsewhere in the Mamakating, is a 40 foot thick olistostrome (fig. 19, near location B, specifically all rocks at ground level between station 50 and 300; fig. 18) with slump folds, flute casts, randomly oriented fissile shale chips, and imbricately stacked thin graywacke beds in a dominantly shale matrix, all of which suggest westward flowing currents. The olistostrome is dominantly shale, but contains some coherent graywacke beds which have incorporated some folded shale rip-ups. Perhaps earthquakes triggered slurries of slump deposits which were then immediately followed

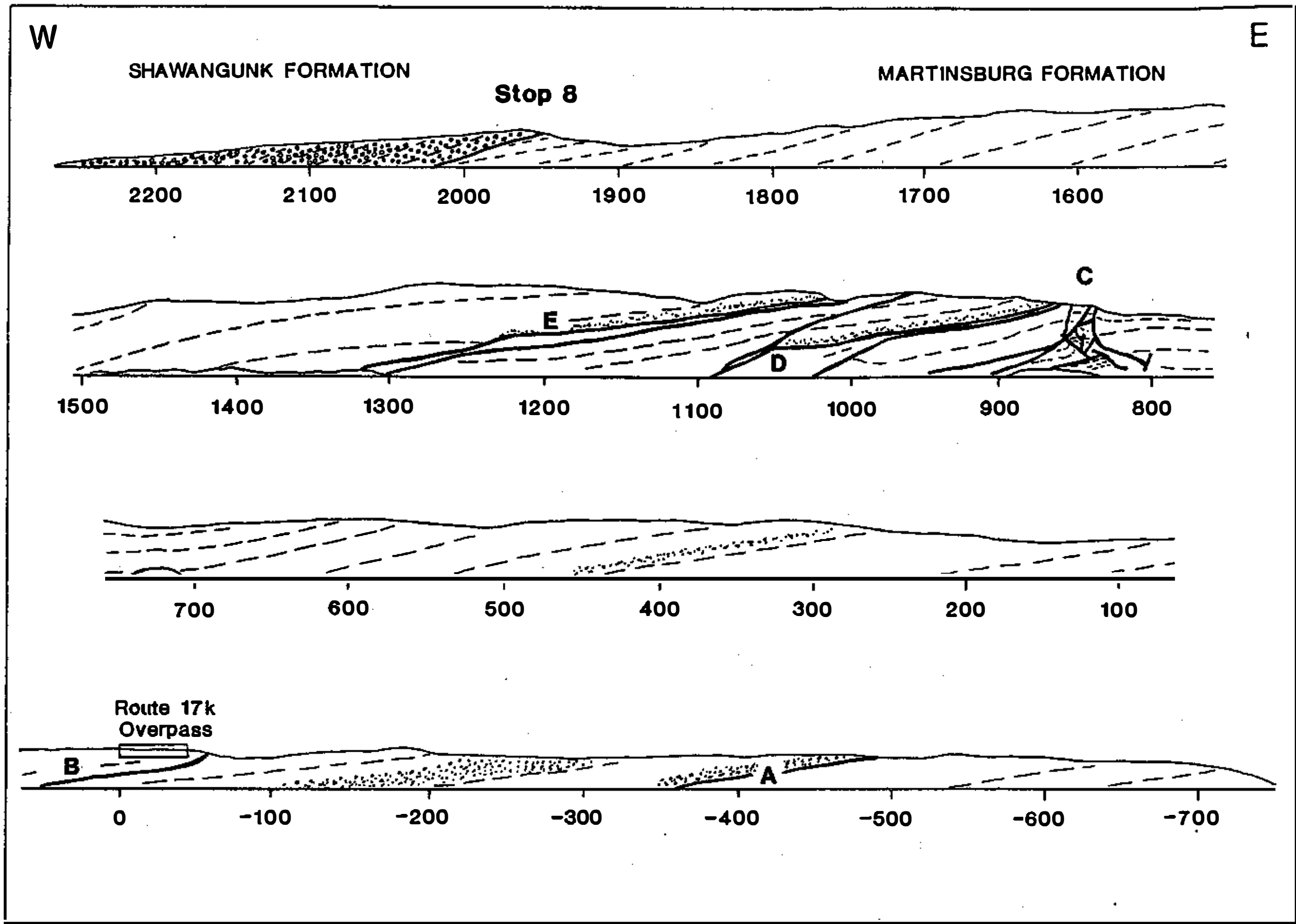


Figure 18. Field sketch from photographs of the 3,000 foot long roadcut along N.Y. Route 17 seen at Stop 7. Numbers beneath sketch indicate distance in feet. Pacing was arbitrarily begun directly beneath the west side of the Route 17K overpass; all distances to the east are shown as negetive numbers and to the west as positive numbers. See Stop 7 for detailed descriptions of structures marked by letters A-E. This long roadcut exposes the uppermost Martinsburg Formation exposed in southeastern New York State and the unconformable contact with the overlying Shawangunk Formation (Stop 8).

Figure 19. Olistostromal deposits within the shales and graywackes at Mamakating of the Martinsburg Formation at Stop 7. Picture location is directly under the west side of the Route 17K overpass on the south side of Route 17 roadcut (see fig. 18, locality B). To the right of the hammer handle is a good example of tightly slump-folded graywacke in a shale matrix. To the left of the hammer and above the foot-thick graywacke lens are imbricately stacked and broken thin graywackes. At the top of the picture is a thick graywacke turbidite which contains folded shale rip-ups near its base. Not visible are randomly oriented fissile shale intraclasts in the shale matrix.

by turbidites which ripped up the shale. This olistostrome appears to be in the hanging wall of a back thrust of unknown displacement. A return to this exposure at a later date would be well worth the effort.

Near locality A on Figure 18 is a minor 2 inch thick bedding plane fault at the base of a foot thick graywacke bed. Another 60 feet east (at station 480 on fig. 18) is a graywacke bed with breccia at its base. The breccia contains quartz and calcite crystals and slickensides at its base. The upper block appears to have moved to the southeast.

The most obvious features seen from this vantage point are a number of faults (fig. 18, location C) directly across the highway. All of these structures trend in a more northerly direction than bedding in the overlying Shawangunk, and comparable disruption is not seen in the Shawangunk. Therefore, it seems most probable that these structures are Taconic in age. The thrust fault on the east (right) side of this tepee-like structure has an east-over-west sense of motion, and has produced an excellent cleavage in the gently arched adjacent rocks of the hanging wall. This is all the more evident because cleavage is not well developed, if at all, at Stop 7, except near faults. It is difficult to prove, but this fault is probably the one with the greatest displacement. Framing the west side of this tepee-like structure is a back thrust with unknown, but probably less, displacement. This back thrust cuts a bedding plane fault that probably has had minor movement with most of the strain taken up in little buckle folds, narrow breccia zones, and fractures. In between the two are a host of accommodation faults, which are trying heroically to solve the room problem. With a little patience it is possible for the field tripper to work out a chronology of movement among the many little faults in this area.

About 250 feet to the west (fig. 18, location D) is a complex area with faults of three different ages. From our vantage point across the road it is impossible to see these details, but it is worth discussing. The earliest movement is parallel to bedding and produces quartz slickensides. These slickenlines plunge N. 60^{o} W. and show that the upper block moved northwest. The bedding plane faults are cut by a very steep fault oriented N. 83^{o} E., 80^{o} SE. which has a 6-12 inch gouge. Down-dip slickenlines show that the south block moved up in this case. This steep fault is in turn cut by a third fault oriented approximately N. 70^{o} E., 50^{o} NW. This cross structure may be a much later Alleghanian feature similar to the late kinks seen at Stop 3. Movement on this youngest fault folds the second steep fault and shows down-to-the-northwest movement.

At the 1,175 foot marker on Figure 18 (near location E) are beautiful fractures filled with calcite, brecciated shale fragments, quartz, and a brownish-orange carbonate mineral (probably ankerite). These vertical fractures, seen at road level, are oriented N. 11° E. and appear to be caught up in a fault zone about 20 to 25 feet above road level. This fault reaches road level at station 1,300 on Figure 18. We interpret this thrust fault as a backthrust, based on folding of bedding in the upper block (presumed hanging wall) and the sense of rotation of the vertical fractures. Some of these fractures were the locus of later movement as evinced by slickenlines oriented 11° N. 11° E.

From station 1300 (fig. 18) west to the contact with the unconformable contact with the overlying Shawangunk at Stop 8, the Mamakating dips gently northwest and is devoid of any complex structures.

D. W. Fisher made three collections of graptolites from the Martinsburg shales of this outcrop, which were reported on by W. B. N. Berry (1970). The species reported by Berry are: Climacograptus spiniferus Ruedemann and Climacograptus typicalis Hall from 16 feet below the contact with the Shawangunk; Climacograptus sp., Dicranograptus nicholsoni var. minor Bulman, and Orthograptus quadrimucronatus var. approximatus (Ruedemann) from 49 feet below the contact with the Shawangunk; and Dicranograptus nicholsoni var. minor Bulman from 138 feet below the contact with the Shawangunk. These fossils are of critical importance to the dating of Taconic events (see section on Ordovician stratigraphy in text) and in establishing the length of the hiatus represented by the Taconic unconformity in southern New York State. Berry puts these graptolites in his upper subzone of zone 13, which suggests the rocks are late Middle Ordovician to early Late Ordovician in age.

Just to the south of where we are standing and approximately 240 feet beneath us is an old abandoned railroad tunnel that Russell Waines kindly suggested we visit. The southeastern 3,400 feet of this tunnel is in the Martinsburg, while the northwestern 400 feet offers excellent exposures of Shawangunk. The mineralized unconformable contact is especially well exposed (for details see Stop 8). Interestingly, a long section of the tunnel that is bricked over so that no rocks can be seen coincides with the most faulted section of the Martinsburg (fig. 18, between localities C and E). A thirty foot wide thrust fault zone (located about 400 feet in from the southeastern end of the tunnel) which, if projected along strike, would be located about 1,000 feet east of the long roadcut of Stop 7. For anyone enterprising enough to visit this tunnel, we would highly recommend a hard hat, and even more importantly, a pair of chest waders at least 5 feet tall; there is always a great deal of water in the north end of the tunnel.

Reboard buses and retrace route back to NY 17K.

92.8	0.2	Turn right on NY 17K.

93.8	1.0	Entering Bloomingburg.
94.3	0.5	Stop light. Continue straight.
94.7	0.4	Turn left on NY 17K towards Newburgh.
95.2	0.5	Turn left on NY 17 East towards Wurtsboro.
97.5	2.3	Beginning of long Martinsburg exposure described at Stop 7 on right.
97.7	0.2	Excellent exposure of olistostrome showing slump folds in thick graywacke on left beneath overpass.
98.0	0.3	Pull off on shoulder to right.

STOP 8

MARTINSBURG-SHAWANGUNK CONTACT
STRATIGRAPHY OF THE SHAWANGUNK-BLOOMSBURG INTERVAL

BE VERY CAREFUL OF HIGH-SPEED TRAFFIC.

This is another fine exposure of the Taconic unconformity in southeastern New York. The rocks of the Martinsburg and Shawangunk are similar to those we have seen elsewhere. The basal foot of the Shawangunk contains much pyrite. The Martinsburg at the contact dips 16° to 31° NW., whereas the Shawangunk dips 25° NW. The angular discordance at eye level is 15°. No secondary cleavage is seen in the Martinsburg at this spot. Graptolites of Zone 13 age (late Middle to early Late Ordovician) were identified by Berry in the Martinsburg within 135 feet of the overlying Shawangunk (Offield, 1967, p. 53; Berry 1970; see Stop 7).

The character of the zone between the Martinsburg and Shawangunk varies from place to place. Near road level, the zone contains rotated shale fragments with some quartz veins. This is probably a shear zone. Also included in this zone are disrupted shale fragments and a medium dark-gray sticky clay, a fault gouge. To the southeast, where the contact rises to about 20 feet above road level, we found rounded to subangular pebbles and cobbles up to 4 inches long of graywacke, chloritic sandstone, crosslaminated feldspathic conglomeratic quartzite, and red very fine-grained sandstone. Small ribs on the surface of one pebble prove that the clast was weathered prior to emplacement, and is not a fault-breccia fragment. Several pebbles also have distinct weathering rinds. The shape of the pebbles suggest transport of short distances.

As indicated in the section on stratigraphy at the beginning of this guidebook, these findings suggest that there were a series of Upper Ordovician and possibly Lower Silurian rocks that were deposited upon the Martinsburg following Taconic uplift and folding. These were derived from source rocks that are now gone. The potential source areas are presently under investigation.

About 1,000 feet to the west we can see fine exposures of the tongue of the Bloomsburg (called High Falls by Gray, 1961, and Otisville Shale and High Falls by Smith, 1967), overlain by the tongue of the Shawangunk (called Binnewater by both Gray, 1961, and Smith, 1967). About 2,000 feet farther west are rocks which we believe to be part of the High Falls Shale. See the section on stratigraphy for an understanding of these interpretations. The conclusions were based on tracing the various facies in the Shawangunk and Bloomsburg eastward from New Jersey.

		Return to buses and continue north on NY 17
98.3	0.3	Uppermost Shawangunk on left.
98.5	0.2	Contact between tongue of the Bloomsburg Redbeds and tongue of the Shawangunk on right.
99.0	0.5	High Falls Shale dipping moderately northwest.
100.2	1.2	Turn off at Exit 113 towards US 209.
100.6	0.4	Stop sign. Turn right on US 209 North.
101.9	2.0	Stop light. Danny's Restaurant on right. Good place for pastrami and corned beef sandwiches. Continue straight on US 209 and retrace route back to Kingston.
103.7	1.8	Shawangunk Mine high on northwest slope of Shawangunk Mountain to right.
111.2	7.5	View of Ellenville Arch straight ahead.
113.8	2.6	Junction with NY 52 at traffic light in Ellenville. Continue straight on US 209 North.
115.1	1.3	Enter Naponoch.
115.7	0.6	View of eroded Ellenville arch producing flatirons in northwest limb of fold on right.
116.2	0.5	Eastern New York Correctional Facility to right.
116.9	0.7	Entering Wawarsing.
120.0	3.1	Junction with US 44 and NY 55. Continue straight on US 209.

120.8	0.8	Traffic light in Kerhonkson.
122.5	1.7	Granit Hotel to right and water tower at Minnewaska at top of Shawangunk.
124.8	2.3	Town of Accord.
129.4	4.6	Dark gray shales of Bakoven Shale on left.
130.4	1.0	Schoharie on left.
131.0	0.6	Entering Stone Ridge.
140.4	9.4	Turn right onto NY 28 East heading towards Kingston.
132.8	0.5	Turn left into Ramada Inn Parking lot.
		END OF TRIP.
		HAVE A SAFE JOURNEY HOME.

PALEOGEOGRAPHY AND BRACHIOPOD PALEOECOLOGY OF THE ONONDAGA LIMESTONE IN EASTERN NEW YORK

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New York, New York 10036

INTRODUCTION

During the three plus decades since Oliver (1954) formally divided the Middle Devonian Onondaga Limestone into its Edgecliff, Nedrow, Moorehouse and Seneca Members, the formation has been the focus of considerable attention. However, with the exception of subsurface investigations, research has concentrated on the formation as seen in outcrop (Fig. 1) between Buffalo and the Helderberg/Catskill area. Few geologists have ever examined the Onondaga south of its classic exposure in Leeds Gorge. As an arbitrary measure of this, we note that between 1962 and 1986 more than ten NYGSA field trips concentrated on the Onondaga while only one (Oliver, 1962) was sited in southeastern New York. As a result, stratigraphers and paleontologists alike tend to have a somewhat skewed impression of Onondaga paleogeography, a situation we hope this field trip will partially rectify.

LITHOSTRATIGRAPHY

In the central New York type area the Onondaga unconformably overlies Lower Devonian carbonates of the Helderberg Group. In that area the formation's members are lithologically distinct from one another. The lowermost Edgecliff bed(s) is a calcareous and phosphatic quartz arenite which grades upward into the typical thick-bedded, light-gray, Edgecliff biosparites. The typical Nedrow lithology is a thin-bedded, dark-gray, argillaceous, fine-grained limestone. This grades upward into the coarser grained, thin to medium-bedded, dark-gray, cherty and argillaceous limestone typical of the Moorehouse. The Moorehouse is overlain by the (a) Tioga Bentonite which is succeeded by dark gray, fine to medium-grained limestones of the Seneca Member. While the uppermost Seneca becomes increasingly argillaceous, it includes a regionally extensive "bone bed" and shows signs of erosional truncation prior to deposition of the overlying Union Springs Shale.

Type lithologies of the four members do not extend into eastern New York. Oliver (1954, 1956) found that the lower Edgecliff beds are gradational with the Schoharie Formation in the east and that the contact is best recognized based on fauna. The argillaceous Nedrow beds extend eastward only to the approximate longitude of Cherry Valley, beyond which they grade into an Edgecliff lithology. Similarly, the Moorehouse is much like Edgecliff in the Helderberg area. The Seneca Member pinches out east of Cherry Valley, though Rickard (personal communication, 1980) found it to be present in the subsurface of southeastern New York.

Oliver (1956, 1962) found that lateral facies changes into eastern New York necessitated the use of faunal criteria in recognizing the individual members. He also found a pronounced thickening of the formation into eastern, and to an even greater degree into southeastern, New York (Table 1). Oliver recognized the eastern Edgecliff beds by the presence of large crinoid columnals, the Nedrow on the basis of numerous platyceratid gastropods and the Moorehouse by its brachipod-dominated fauna and abundant black chert. However, Lindemann (1979, 1980) found platyceratids to be more common in the cherty Moorehouse beds than in the Nedrow. Be that as it may, fossils remain the best criteria for correlation, particularly in southeastern New York where outcrops are small and few and the entire formation is fine-grained. There, at least, the Edgecliff's crinoid columnals persist despite the non-typical lithology. These can be traced into the Buttermilk Falls Formation of Pennsylvania (Oliver, 1962). Pronounced facies changes in the Onondaga-equivalent strata of southeastern New York prompted Rickard (1975) to assign those strata to the Buttermilk Falls. While this is prudent lithostratigraphy, we will refer to them as Onondaga due to their significance in paleogeographic reconstruction.

Table 1. Representative thicknesses (in feet) of the Onondaga Limestone and its members in eastern New York.

	Syracuse	Helderbergs	Leeds	Saugerties	Port Jervis
Seneca	25	-	-	-	-
Moorehouse	25	70	37+	100+	190+
Nedrow	15	15	43	34	?
Edgecliff	22	30	36	36	30?
Total	87	115	116	170	200+

LITHOFACIES

To facilitate the interpretation of depositional environments, Lindemann (1980) identified six carbonate lithofacies on the basis of relative abundances of calcisiltite, bioclasts, cement, argillaceous mud and pyrite as pointcounted in thin section. While all of the lithofacies are described below, only three are well-represented in eastern New York and figure directly in this discussion. As the

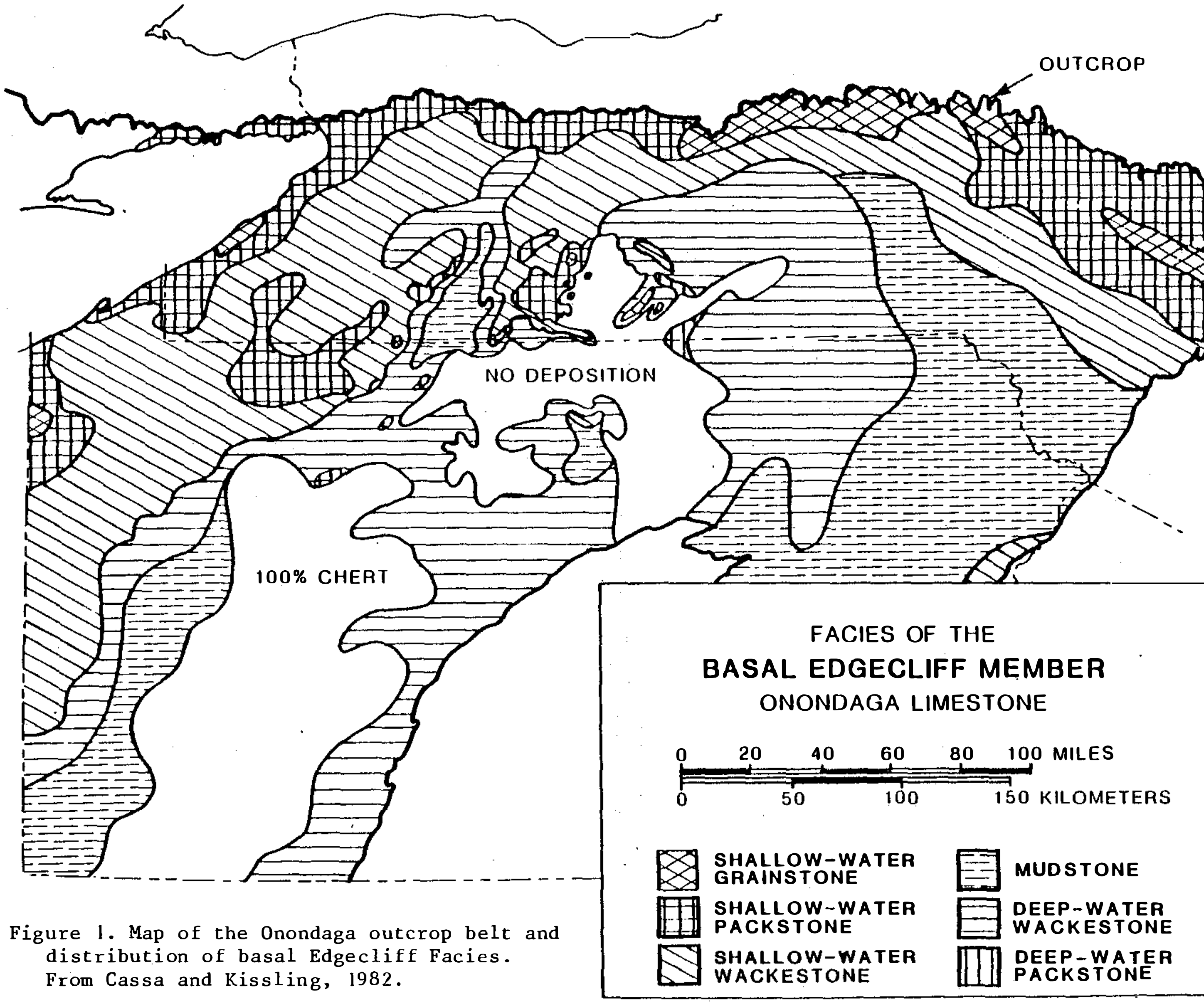


Figure 1. Map of the Onondaga outcrop belt and distribution of basal Edgecliff Facies. From Cassa and Kissling, 1982.

lithofacies do not exactly correspond to formally named carbonate lithologies, they are referred to by Roman numerals and mean abundances of their constituents are shown in Table 2. Note that the Roman numerals used herein do not correspond to those of Lindemann (1979) but do correspond to those of Lindemann (1980) as well as Feldman and Lindemann (1986).

Lithofacies I. Lithofacies I consists of thick-bedded to massive, medium-gray, sparce and packed biocalcisiltites. Terrigenous mud tends to be concentrated in styolites and is otherwise scarce. While crinoids and fenestrate bryozoans are dominant fossils in thin section, the ramose bryozoan Fistulipora dominates the fauna as seen in outcrop. Some specimens are encrusted by a calcareous alga similar in morphology to Sphaerocodium. Chondrites, small vertical burrows, and calcarenite-filled grooves on bedding surfaces dominate the ichnofauna. Intimately associated with Lithofacies II and VI, Lithofacies I occurs most commonly in the Leeds to Saugerties area. Except for occurrences in the Moorehouse of the Helderbergs and westernmost New York it is not commonly encountered.

Lithofacies I is interpreted as having been deposited in fairly quiet, slightly turbid waters. Occasional reworking of the sediment by storm waves is indicated by thin shell-layers and by the presence of spar cement in some samples. At Leeds this lithofacies alternates with Lithofacies VI and both are associated with a Fistulipora-dominated community which persisted from early Edgecliff to late Moorehouse time. As will be more thoroughly discussed later, the Onondaga in this area is interpreted as a sequence of bryozoan bafflestone biostromes which grew at a rate comparable to that of basinal subsidence.

Lithofacies II. Lithofacies II consists of medium-bedded to massive, medium-gray packed bioclacisiltites. Crinoids and bryozoans dominate the fossils in thin section and in the field. Intimately associated with Lithofacies I and VI, and occurring in the Edgecliff throughout the state and the upper Onondaga to the east and west, Lithofacies II differs from the former and latter in abundances of fossil debris and spar cement respectively. There are additional faunal differences, particularly in western New York, but these do not figure in this description.

Lithofacies II is interpreted as having been deposited under nonturbid carbonate shelf conditions quieter than, but similar to, those of Lithofacies VI. Stratigraphic distribution and association with other moderate energy lithofacies indicate that II was generally deposited just offshore from, or in slightly deeper water than VI. With the possible exception of occurrences in the Clarence Member of western New York, lagoonal conditions are not indicated.

Lithofacies III. Lithofacies III consists of laminated to medium-bedded, dark-gray, argillaceous calcisiltite, fossiliferous calcisiltite and sparse biocalcisiltite. The pyrite content of this lithofacies does not exceed one percent in central New York.

Comminuted crinoids and trilobites dominate the megafossils in thin section and the microfossil Styliolina fissurella reaches its maximum abundance. Fossils are occasionally concentrated in thin stringers associated with argillaceous laminae. However, most fossil fragments were scattered by intense bioturbation. This lithofacies predominates in the Nedrow of central New York and in the Moorehouse elsewhere in the state. It does not occur east of Cobleskill.

Lithofacies III is interpreted as having been deposited in quiet, moderately turbid water offshore from Lithofacies VI and II. Restricted circulation and low oxygen levels are not indicated. The sediment's fine grained nature suggests a flocculent or soupy sediment-water interface, a condition not particularly conducive to colonization by the larvae of sessile organisms. This accounts for the relative abundance of calcisiltites and planktonic styliolines.

Lithofacies IV. Lithofacies IV consists of thin to medium-bedded, dark gray, moderately argillaceous fossilferous to sparse biocalcisiltites. Fenestrate bryozoan and crinoid debris dominate the fossils seen in thin section while brachiopods and trilobites dominate the fauna seen in outcrop. The ichnofauna includes a diverse set of small horizontal burrows and Chondrites. Relatively coarse-grained lag deposits and cross laminae are present in some beds. Lithofacies IV is common only in the Clarence Member of western New York and the Moorehouse of the Cherry Valley-Schoharie area.

Lithofacies IV is interpreted as having been deposited in quiet, moderately turbid waters. Though calcisiltite abundances far exceed those of fossils, it appears that bottom conditions were not as quiet as those of Lithofacies III and that storm-generated waves often reworked the sediment. Occurrences of Lithofacies IV in the Clarence Member are interpreted as lagoonal deposits while occurrences in the Moorehouse at Cherry Valley are interpreted as shelf margin or transitional deposits between the shallow shelf to the east and the Appalachian Basin to the west.

Lithofacies V. Lithofacies V consists of laminated to medium-bedded, dark-gray, highly argillaceous fossiliferous calcisiltites and sparse biocalcisiltites. Trilobites dominate the fossils in thin section and share dominance with brachiopods in field observations. Chrondrites and general signs of bioturbation are abundant. This facies is virtually restricted to the Moorehouse and Seneca members of central New York where it is intimately associated with Lithofacies III. It differs from III in containing about twice as much argillaceous mud and slightly more pyrite (Table 2).

Lithofacies V is interpreted as having been deposited in quiet, relatively deep and turbid water in or near the subsiding axis of the Appalachian Basin. Because this facies occurs in the area representing the lowest rate of sedimentation for the formation, (probably less than half that of some sites to the east for example) the magnitude of real day-to-day turbidity required to attain its approximately 20 percent argillaceous content is uncertain. While fluctuations in argillaceous influx are evident as shale laminae, it appears that the depositional conditions of Lithofacies V differ from those of III primarily in geographic proximity to the relatively carbonate-starved and more restricted axis of the Appalachian Basin.

Lithofacies VI. Lithofacies VI consists of thick-bedded to massive, light-gray, poorly washed to sorted biosparites. Varying abundances of quartz sand, glauconite, and phosphorite nodules are present in samples from the lower beds of the Edgecliff Member. Comminuted crinoids and bryozoans dominate the fossils seen in thin section and macrofossils vary as this lithofacies occurs with both coral- and bryozoan-dominated communities. Rare cryptalgal laminae and calcareous algae are present. While evidence of bioturbation is rarely observed, vertical burrows are common as are shell lag concentrations and cross-laminae. This lithofacies is characteristic of the Edgecliff throughout the state and also occurs higher in the formation in eastern and western New York. It dominates the Nedrow and lower half of the Moorehouse in the Helderbergs and alternates with Lithofacies I at Leeds. It has not been observed at any horizon in the Onondaga south of Leeds.

Lithofacies VI is interpreted as having been deposited under shallow shelf conditions in wave-agitated waters of very low turbidity.

Table 2. Mean percent abundances of Onondaga lithofacies constituents.

Facies	Calcisiltite	Bioclasts	Cement	Detrital Mud	Pryite
I	50	38	2	7	1
II	38	53	3	4	1
III	84	2	0	10	2
IV	74	16	<1	7	1
V	67	10	0	21	2+
VI	15	61	21	4	1

THE ONONDAGA/BAKOVEN CONTACT

Contacts between the Onondaga Limestone and overlying black shale units are few and far between, only one (Locality 7) is known in the area of this field trip. This horizon is deserving of detailed consideration as conclusions drawn from it have far-reaching significance. Oliver (1956) judged the Moorehouse/Bakoven contact to represent only a minor break in deposition. However, Chadwick (1944, p. 103) described the contact as a "calcarenyte of tiny crinoidal fragments, black in color like the shale and containing also comminuted fish remains with an occasional brachiopod shell seemingly reworked from the limestone beneath. The basal (Bakoven) contact here shows this bed bonded into solution pitting in the limestone, indicating a distinct break and disconformity."

The uppermost Moorehouse bed is a medium dark-gray, sparse to packed bioclacisiltite containing trilobite, brachiopod, and crinoid fragments along with a few phosphatic particles. Authigenic quartz and silicified brachiopods are common, while unquestionably-detrital quartz silt is uncommon. Terrigenous mud constitutes less than six percent of the rock's weight and organic matter makes up an additional three to six percent. Typical of the upper Moorehouse in the mid-Hudson Valley, terrigenous mud is concentrated in microstyolites, giving weathered exposures a "shaly" appearance. This is the case at Locality 7 where this uppermost Onondaga bed is a Lithofacies I limestone typical of the area. It is significant that this does not resemble Lithofacies V of the upper Onondaga in central New York.

Chadwick's crinoidal "calcarenyte" abruptly overlies the Moorehouse. This horizon is approximately 1 cm thick and bears little resemblance to the Onondaga below or the Bakoven above. While the rock is packed with crinoid fragments, it is unlike Onondaga lithologies in that both spar cement and calcisiltite are absent. About 7% of the rock volume consists of fish remains; quartz silt and sand constitute an additional 5%. It is worth noting that quartz sand does not occur above or below this horizon. The original thickness and terrigenous percentage of this horizon remain uncertain due to an unusually intense intergranular pressure solution between crinoid particles. What does this "bone bed" represent?

The upper Onondaga of the central Hudson Valley is a sequence of bryozoan bafflestones interbedded with normal sparse to packed biocalcisiltites, deposited marginal to a carbonate shelf. Open circulation in a fairly quiet environment near wave base are indicated by both fauna and lithology. The Bakoven, on the other hand, is a black, carbonaceous shale which emits a petroliferous odor from freshly broken specimens. The fauna is dominated by planktonic forms including *Styliolina fissurella* and *"Tentaculites"* cf. *gracilistriatus*. Signs of bioturbation are absent, to the extent that current-oriented styliolines were not disturbed. These characteristics are consistant with deposition in a stratified, dysaerobic, quiet-water environment. Pedersen, et al. (1976) interpret the Bakoven as a distal basin deposit consisting of the first and stratigraphically lowermost muds of the Catskill Delta complex. They also note that there is a problem with this interpretation. If there is validity to Walther's law of the correlation of facies (Middleton, 1973), as applied to vertical sedimentary sequences, the lithologically abrupt contact between a shallow-water to moderate-depth carbonate and a distal basin black shale facies must represent a disconformity of pronounced magnitude. It is certain that the contact is disconformable and clear that the "bone bed" was deposited on an already lithified Onondaga. However, many Bakoven styliolines contain pyritic steinkerns indicating that they settled to the bottom with their cellular material intact. While we have no data on what might be a soft tissue compensation depth for styliolines, the extremes of distal basin habitat would almost certainly exceed it. We suggest that the Onondaga/Bakoven contact is a disconformity representing a relatively brief time span during which rapid crustal subsidence, to a shallow or proximal basin depth position beneath storm-wave base, resulted in stratification of the water column and a dysaerobic benthic condition conducive to the eradication of a benthic fauna and deposition of black shale. Savarese, et. al. (1986) suggest a deepening event starting at 20-25m and finishing at 100-150m for roughly similar limestone/shale contacts in the Hamilton group of central and western New York. Further interpretation of the contact is presently premature.

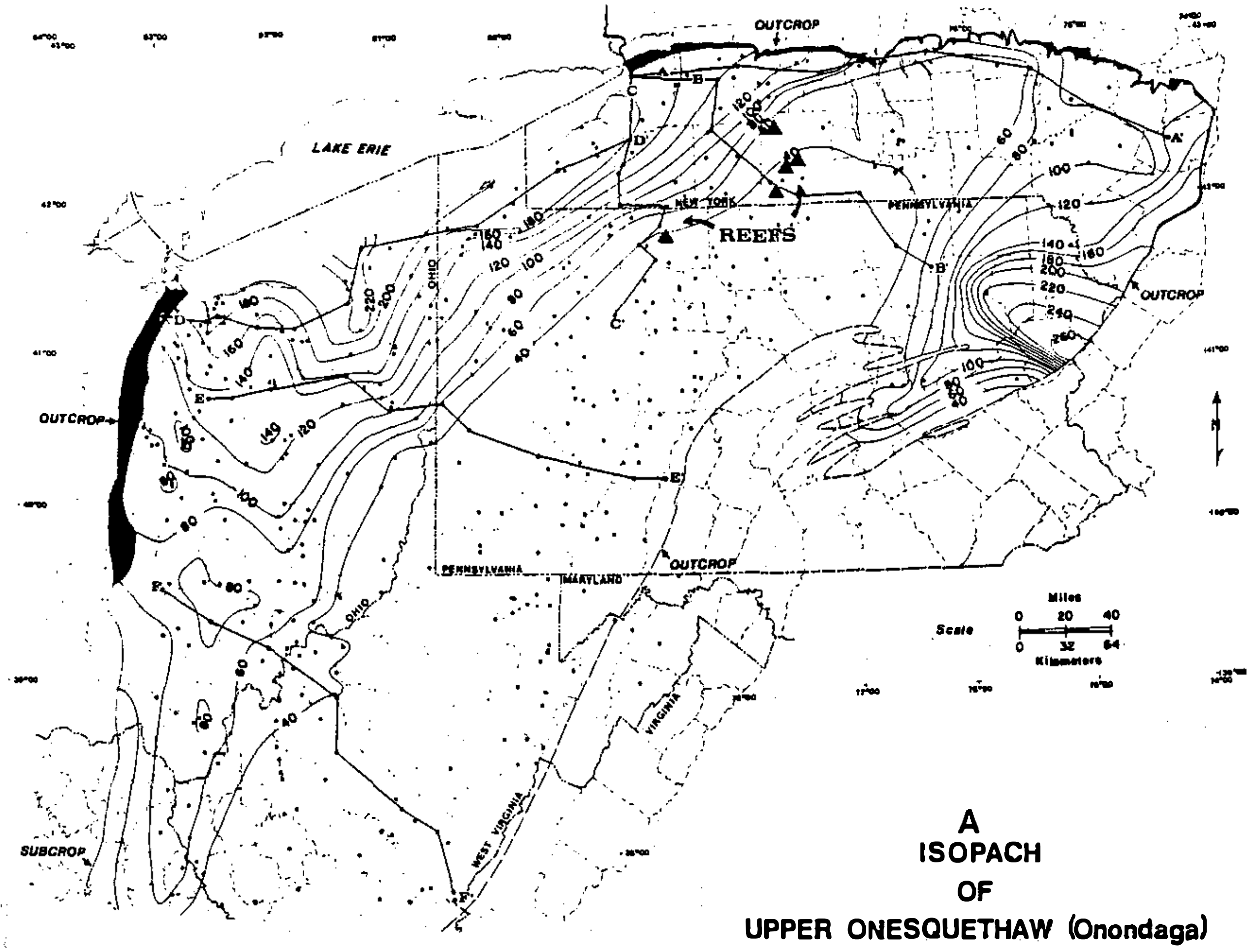
PALEOGEOGRAPHIC SETTING

Buffalo to the Helderbergs

Understanding of Onondaga paleogeography, as studied in east-west outcrop, has not changed substantially since the work of Oliver (1954, 1956), Lindholm (1969) and Laporte (1971). A short-lived late Emsian regression of the sea to a position in eastern New York left the western and central areas of the state subaerially exposed. Early in the Eifelian, assuming that the entire Onondaga is Middle Devonian, a transgression submerged the region initiating Edgecliff deposition in a shallow shelf environment. Shortly thereafter subsidence in central New York, resulting from a northward extension of the Appalachian Basin, brought a deeper water, or offshore, environment to that area. The initial pulses of subsidence are recorded in the Nedrow Member, while continued subsidence is recorded in the Moorehouse and Seneca members of central New York. However, the eastern and western parts of the state remained in shallow shelf conditions throughout Onondaga deposition. Thus, post-Edgecliff paleogeography, as seen in east-west outcrop, consists of a symmetric shelf-basin-shelf pattern. Subsurface studies (Kissling and Moshier, 1981; Cassa and Kissling, 1982) indicate that deposition took place on a carbonate ramp dipping predominantly southward into the Appalachian Basin and that east-west outcrop roughly parallels depositional strike for at least Edgecliff time (Fig. 1).

The Helderbergs to Port Jervis

To understand Onondaga paleogeography in eastern and southeastern New York it is helpful to establish a context in the mid-Silurian and proceed up section. The Middle Silurian Shawangunk Conglomerate thins from approximately 1500 feet in northern New Jersey (Wolfe, 1977) to a pinchout just north of Rosendale, New York. A roughly similar pattern is evident throughout the Upper Silurian and Lower Devonian. As an arbitrary example of what this means in terms of despositional environments and an onshore-offshore orientation, Waines (1976) reports that the Silurian Binnewater Sandstone not only thickens to the south of Kingston, New York, but it also becomes increasingly dolomitic as the unit grades southward from supratidal to intertidal and shallow marine facies. During deposition of the Lower Devonian section the onshore direction



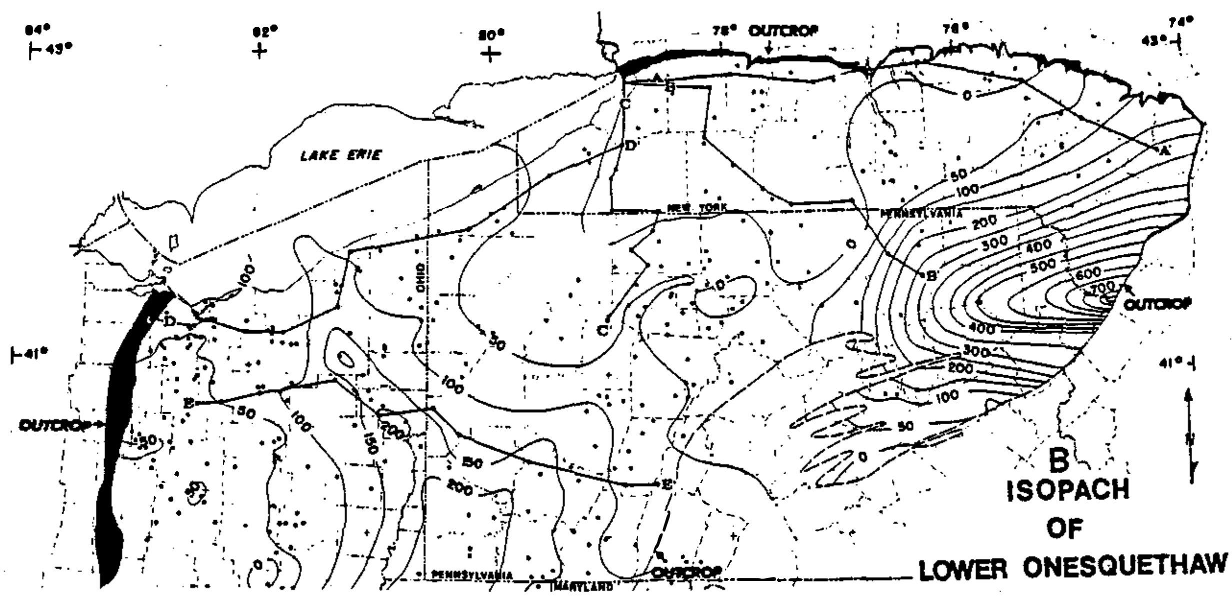


Figure 2. Isopach maps of Upper Onesquethaw (A) and Lower Onesquethaw (B) strata. C.I. = 50 ft. From Mesolella, 1978.

shifted to the northwest (Anderson, 1971), an orientation which lithostratigraphy (Rickard, 1975) and subsurface isopachs (Fig. 2B) (Mesolella, 1978) indicate persisted until the Middle Devonian.

It is generally acknowledged that during Onondaga deposition the axis of the Appalachian Basin migrated into central New York. This shows up clearly in the distribution of Onondaga lithofacies and in subsurface isopachs (Fig. 2A). However, to clarify eastern New York paleogeography it is necessary to discriminate between "topographic" and "structural" basins. Mesolella (1978) defines a topographic basin as the area of deepest water and a structural basin as the area of greatest sediment accumulation, implying greatest crustal subsidence. As previously discussed, the preponderance of Lithofacies V in the upper Onondaga in central New York is the direct result of deposition in proximity to the carbonate starved axis of the Appalachian (topographic) Basin. However, Lithofacies V is absent from eastern New York at least as far south as the Mid-Hudson Valley where it is replaced by the coarser-grained and less argillaceous Lithofacies I and II. Even the most offshore Onondaga facies in eastern New York, the Buttermilk Falls Limestone, is interpreted as a "shallow marine basin" (Wolfe, 1977). And yet the greatest sediment accumulation is centered in, or just south of, the Port Jervis (Tristates) area (Fig. 2A). This was the focus of a subsiding structural basin not directly related to the topographic basin of central New York. This structural basin, which had existed since the Middle Silurian, exerted a pronounced influence on Onondaga deposition in eastern New York by establishing a paleogeographic pattern of a shallow carbonate shelf in the Helderberg-Coxsackie area, a thick accumulation of shelf-margin bryozoan bafflestones between Leeds and Saugerties and an even thicker accumulation of sparse to packed biocalcisiltites deposited on a carbonate slope or ramp dipping into the Port Jervis area. Apparently water depths on this slope were never great, at least within the field trip area, prior to the subsidence event which set the stage for deposition of the Bakoven Shale.

MEGAFOSSILS OF THE ONONDAGA LIMESTONE IN SOUTHEASTERN NEW YORK

Collecting megafossils in the Onondaga Limestone in southeastern New York presents certain problems not inherent in the central part of the state. For example, there in no shaly Nedrow facies from which well-preserved specimens weather out and there are few quarries which allow for extensive collecting on bedding surfaces. Most of the exposures in the Mid-Hudson Valley are vertical and weather slowly. The limestone is quite dense with little shale, consequently megafossils, although observable in cross section, are difficult, if not impossible to remove without damage to the specimen. However, one of the advantages of collecting in the southeastern part of the state is the occurrence of silicified fossils in parts of the Mid-Hudson Valley. During this trip we expect to sample some of these silicified outcrops and blocks may be taken for subsequent etching in hydrochloric (or muriatic) acid. Brachiopods (Table 3; Figs. 3,4) and corals (Table 4) are the most dominant megafossils that we will collect from the Onondaga and therefore will be treated in more detail than other taxa (Table 5).

Brachiopods

Acrospirifer duodenaria - Biconvex shells transversely subelliptical in outline; hinge line long and straight; medial open delthyrium with no preserved deltidial plates; pedicle valve bears narrow, triangular, moderately deep, noncostate sulcus; brachial valve bears corresponding fold; five to six rounded plications on each pedicle flank with U-shaped interspaces; anterior commissure uniplicate.

Ambocoelia sp. - Small, ventribiconvex shells; pedicle valve with weak sulcus; beak incurved; hinge line straight, delthyrium open; brachial valve slightly convex with no ornamentation; anterior commissure rectimarginate to uniplicate to slightly intraplicate.

Athyridacean indet. - Small, ovate shells with laterally directed spiralia; crura united with primary lamellae by pair of S-shaped loops; most closely resemble the Meristellidae.

Athyris sp. A -Shells transversely suboval in outline, and subequally biconvex with pedicle valve slightly deeper than brachial valve; ventral beak suberect terminating in, small round foramen; brachial beak smaller and less noticeable; pedicle valve bears shallow sulcus with corresponding low fold on brachial valve; anterior commissure weakly uniplicate; some forms nonsulcate and rectimarginate; fine, concentric growth lines on both valves.

Athyris sp. B - Differ from Athyris sp. A in its larger size, subparallel dental plates and narrow muscle field.

Atribonium halli - Shells small, nonstrophic, impunctate and subpentagonal in outline; beak short curved, rounded and suberect; commissure uniplicate with high brachial fold and deep pedicle sulcus; costae weak, rounded; small pedicle foramen and triangular delthyrium.

Atrypa "reticularis" - Dorsibiconvex shells with well rounded radial costellae which increase in size and number anteriorly; costellae separated by U-shaped interspaces; concentric growth lamellae cross costellae becoming more distinct and frilly anteriorly; anterior commissure rectimarginate or slightly deflected towards brachial valve.

Atlanticocoelia acutiplicata - Subcircular in outline with length almost equal to width; brachial valve gently convex, pedicle valve slightly more so; weak pedicle sulcus sometimes noticeable on larger specimens; no corresponding dorsal fold; hinge line very short and becomes rounded anteriorly; no interareas present; anterior and lateral commissures crenulate; ten to

Table 3. Brachiopods of the Onondaga Limestone in southeastern New York (from AMNH Loc. 3132 [Thompson's Lake] to AMNH Loc. 3151 [Wawarsing]; See Feldman, 1985, for index map of localities and locality descriptions.)

Taxon	Common	Rare	Very Rare
Acrospirifer duodenaria	X		
Ambocoelia sp.			X
Athyridacean indet.			X
Athyris sp. A		X	
Athyris sp. B			X
Atribonium halli			X
Atrypa "reticularis"	X		
Atlanticocoelia acutiplicata			X
"Chonetes" aff. lineata			X
Coelospira camilla	X		
Cupularostrum? sp. A		X	
Cupularostrum? sp.B			X
Cyrtina hamiltonensis		X	
Cyrtina sp. A			X
Dalejina aff. alsa		X	
Discomyorthis? sp.			X
Elytha fimbriata		X	
Eospiriferid? indet.			X
Gypidula sp.			X
Leptaena aff. "rhomboidalis"	X		
Levenea aff. subcarinata		X	
Megakozlowskiella raricosta	X		
Megastrophia sp.		X	
Meristina cf. nasuta			X
"Mucrospirifer" cf. macra		X	
Nucleospira aff. ventricosa	X		
Orthotetacid indet.			X
Pentagonia unisulcata		X	
Penatmerella arata		X	
Rhipidomella?			X
Rhynchospirina sp.			X
Schizophoria cf. multistriata		X	
"Schuchertella" sp.			X
Strophodonta cf. demissa		X	
Stropheodontid indet.			X

Note: Although this table denotes relative abundance of brachiopod taxa in the central part of the state in terms of common, rare and very rare, it should be noted that some species are more abundant in specific horizons or beds and are relatively rare throughout the remainder of the formation. For example, Levenea occurs abundantly in Wawarsing, New York, but sporadically in the rest of the southeastern exposures of the Onondaga.

Table 4. Corals of the Onondaga Limestone in southeastern New York.

Taxa	Common	Rare
Tabulates		
Aulocystis (=*Ceratopora*)	X	
Aulopora	X	
Favosites	X	
Striatopora	X	
Rugosans		
cf. *Amplexiphyllum*	X	
Acinophyllum	X	
Breviphrentis	X	
Cystimorph?		X
Heliophyllum	X	
"*Heterophrentis*"	X	
cf. *Syringaxon*	X	

Table 5. Other faunal constituents of the Onondaga Limestone in southeastern New York.

Taxa	Common	Rare	Very Rare
Gastropods			
Platyceras dumosum	X		
Platyceras (*Platystoma*)	X		
Platyceras sp.	X		
Pseudophoracean indet.		X	
Ecculiomphalus			X
Loxonema			X
Trilobites			
Phacops cf. *cristata*	X		
Dalmanitid fragments			X
Indet. fragments	X		
Crinoids			
Non-pinnulate inadunate ossicles	X		
Camerate columnals	X		
Bryozoans			
Dyoidophragma			X
Sponges			
Hindia	X		

twelve plications with U-shaped interspaces; concentric growth lines, two or three per shell, common on ephebic forms.

"Chonetes" aff. lineata - Shells small, subsemicircular in outline and concavoconvex in lateral profile; interareas very narrow; no delthyrial structures preserved; greatest width at hinge line or anterior to midlength; valves covered with fine capillae which increase anteriorly by bifurcation.

Coelospira camilla - Small, concavoconvex to planoconvex, subcircular to suboval in outline; small, distinct pedicle foramen on incurved pedicle beak; no interarea evident; maximum width about one-third valve length in adults; pedicle valve bears two medial plications usually at least as large as remaining radial plications on flanks; interspaces U-shaped; brachial valve bears medial plication which generally bifurcates at one-third valve length; median interspace usually flat but sometimes bears small ridge; plications broader on flanks and thinner toward lateral commissure; several well-defined, concentric growth lines evident near anterior commissure in adult forms.

Cupularostrum sp. A - Shells small, equibiconvex, and subtrigonal to to transversely suboval in outline; pedicle beak erect to slightly incurved; delthyrium open, triangular with small foramen located apically; pedicle valev with sulcus and brachial valve with corresponding fold considerably weaker than sulcus; about 15 simple plicae U-shaped in cross section.

Cupularostrum sp. B - Externally identical with Cupularostrum sp. B except for lack of sulcus and fold.

Cyrtina hamiltonensis - Shells small, hemipyramidal in outline with straight hinge line; ventral interarea high, smooth; convex psuedodeltidium covers triangular delthyrium in most specimens; pedicle valve bears triangular, smooth sulcus with two or three rounded plications along flanks; brachial valve bears fold with three to four lateral plications; ornamentation consists of concentric growth lamellae.

Cyrtina sp. A -May be differentiated from Cyrtina hamiltonensis by larger size and more robust appearance.

Dalejina aff. alsa - Shells ventribiconvex, transversely suboval to subcircular in outline; hinge line very short and straight in apical area but becomes rounded as lateral margins approached; maximum width at or just anterior to midlength; pedicle valve bears slight median depression; brachial valve often bears corresponding median ridge; anterior commissure most often recti marginate to slightly sulcate; ventral interarea short, narrow; numerous radial costellae which increase anteriorly both by intercalation and bifurcation; at anterior commissure there are 18 to 20 costellae per 5 mm, near midline; costellae medially grooved, flat, occasionally crossed by concentric

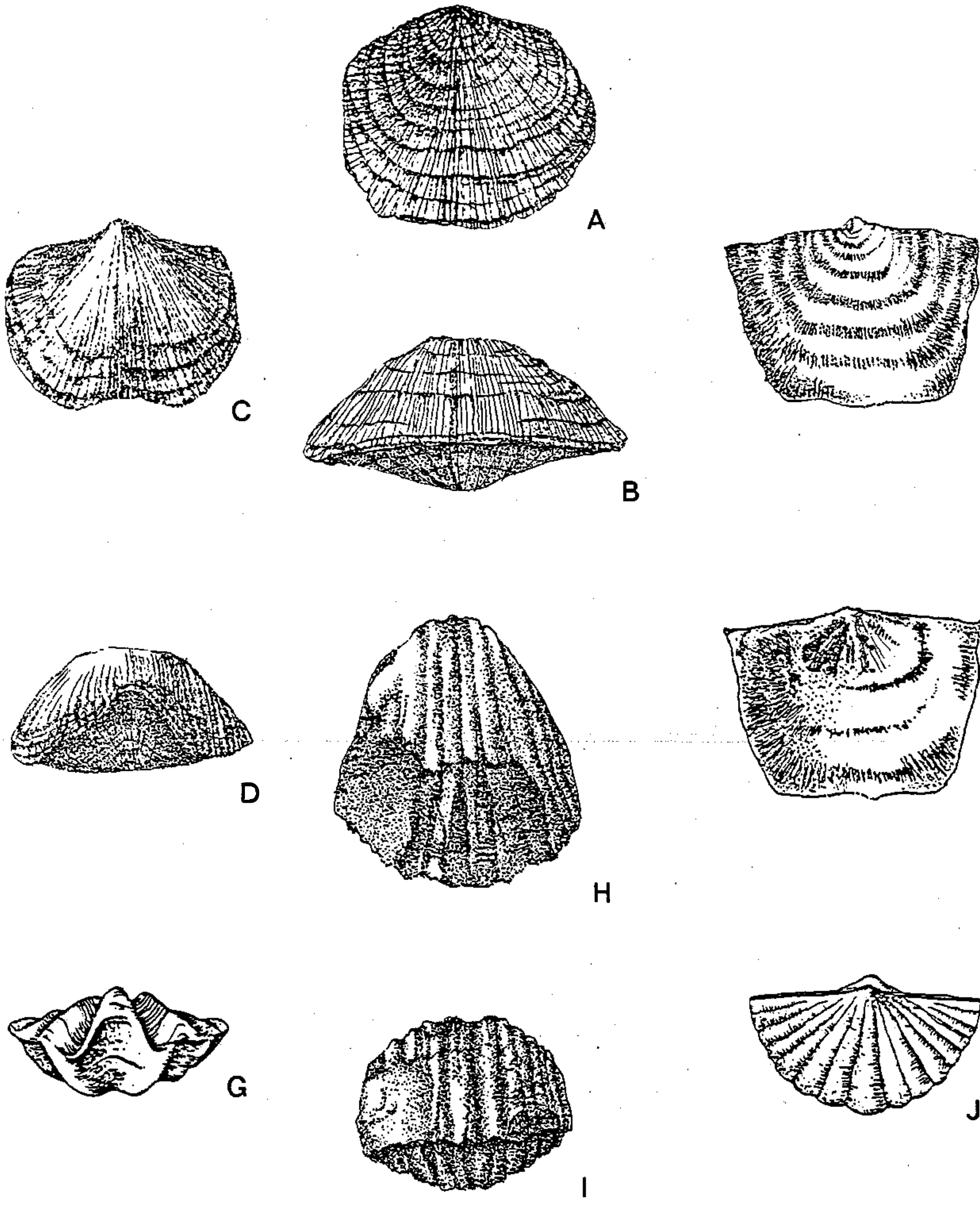


Figure 3. Brachiopods of the Onondaga Limestone in eastern New York. A,B. Rhipidomella sp., ventral and anterior views, X3. C,D. Schizophoria cf. Multistriata, ventral and anterior views, X1.5. E,F. Leptaena aff. "rhomboidalis," ventral exterior and interior, X1.5. G. Megakozlowskiella raricosta, anterior view, X1.25. H,I. Pentamerella arata, ventral and anterior views, X1.75. J. Acrospirifer duodenaria, dorsal view, X3. Modified from Dunn and Rickard (1961).

growth lines near anterior margins.

Discomyorthis? sp. - Similar to Dalejina in general morphology but may be differentiated by more circular outline and larger ventral diductors; pedicle valve bears well-developed pedicle callist and short, triangular hinge teeth; costellae medially grooved.

Elytha fimbriata - The shells are medium-sized, biconvex in lateral profile and transversely oval in outline; beak short and erect; pedicle valve bears shallow, triangular sulcus with corresponding low, rounded fold on brachial valve; faint plications cover lateral slopes; concentric growth lamallae cross plications and terminate in short, attenuated spines; anterior commissure uniplicate.

Eospiriferid indet. - Extremely rare in the formation and represented by only one pedicle valve which is convex, moderately transverse, sulcate, plicate and covered by fine radiating striae; delthyrium triangular with possible deltidial plates.

Gypidula sp. - Elongate oval to subcircular in outline; pedicle valve swollen; costate to multicostate; almost identical to Pentamerella arata (see description below) but can be differentiated by a pedicle fold and brachial sulcus whereas Pentamerella has a pedicle sulcus and brachial fold.

Leptaena aff. "rhomboidalis" - Transversely subquadrate in outline, concavoconvex to slightly biconvex with pedicle valve strongly geniculate at anterior and lateral commissures; brachial valve correspondingly geniculate within pedicle trail; hinge line straight, pedicle interarea flat; ornamentation consists of radial costellae which extend past point of geniculation and continue on trail of valves; concentric rugae cross costellae becoming larger anteriorly.

Levenea aff. subcarinata - Shells small to medium sized, transversely suboval in outline, ventribiconvex in lateral profile; brachial valve bears shallow, rounded sulcus which broadens anteriorly; maximum width at or just anterior to midlength; ventral interarea short, slightly incurved; triangular delthyrium encloses angle of approximately 60 degrees; delthyrium often widens apically into small, circular foramen; ornamentation consists of rounded, radial costellae which increase in number anteriorly by bifurcation.

Megakozlowskiella raricosta - Shells subtransverse in outline, strophic, medium to large, ventribiconvex; hinge line straight; pedicle interarea moderately narrow with striae which parallel hinge line; brachial interarea extremely narrow; distinct slightly flattened fold on brachial valve and corresponding deep, U-shaped sulcus on pedicle valve; commonly three plications on flanks; delthyrium includes angle of approximately 60 degrees; no deltidial plates preserved; anterior commissure uniplicate; strong, concentric growth lamellae with anterior frills; radial ornamentation consists of very fine striae.

Megastrophia sp. - Medium sized to large, subsemicircular to transversely suboval in outline; somewhat alate, concavo-convex in lateral profile; maximum width attained at hinge line; unequally parvicostellate to subuniformly costellate; psuedodeltidium flat, complete, with narrow median ridge; chilidium flat, complete, with median ridge; hinge entirely denticulate.

Meristina cf. nasuta - Convex, elongate and suboval in outline with no noticeable interarea; Unequally biconvex, with pedicle valve much deeper than brachial valve; maximum width commonly anterior to midlength; delthyrium broad, triangular and opens apically into semicircular foramen; faint pedicle sulcus modified by development of low, rounded medial plication that extends anterior commissure in tongue-like projection; concentric growth lamellae evident at anterior portion of valves but remainder of shell smooth.

"Mucrospirifer" cf. macra - Small to large alate shells transversely subtrigonal to subsemicircular in outline; biconvex in lateral profile with brachial valve slightly flatter than pedicle valve; ventral interarea moderately high, long, somewhat curved; ventral beak, posterior to interarea, short and stubby; open, triangular delthyrium present which divides interarea medially; dorsal interarea long, thin, ribbon-like; brachial valve bears high, medial fold flattened at top; pedicle valve bears corresponding U-shaped sulcus; surface of shells covered by sharply defined plications ranging from U-shaped to subangular in cross section; numerous, concentric, frilly growth lines present; no fine radial ornamentation.

Nucleospira aff. ventricosa - Small, transversely suboval in outline, biconvex in lateral profile with pedicle valve slightly deeper than brachial valve; hinge line curved; brachial beak fits into anterior end of delthyrium which is partially covered by concave pseudodeltidium in some specimens; both beaks erect, no interarea evident; shell surface lacks radial ornamentation; no fold or sulcus present; pedicle valve shows faint median depression in some specimens; concentric growth lamellae present, more concentrated towards rectimarginate anterior commissure.

Orthotetacid indet. - Small to medium sized shells, generally poorly preserved as internal impressions; hinge line straight; ornamentation finely costellate.

Pentagonia unisulcata - Medium sized, nonstrophic, pentagonal in outline when viewed posteriorly; beak suberect, dorsibiconvex with greatest width attained between midlength and anterior commissure; brachial valve cariniform due to presence of raised, rounded fold bearing narrow, median groove; in some forms groove

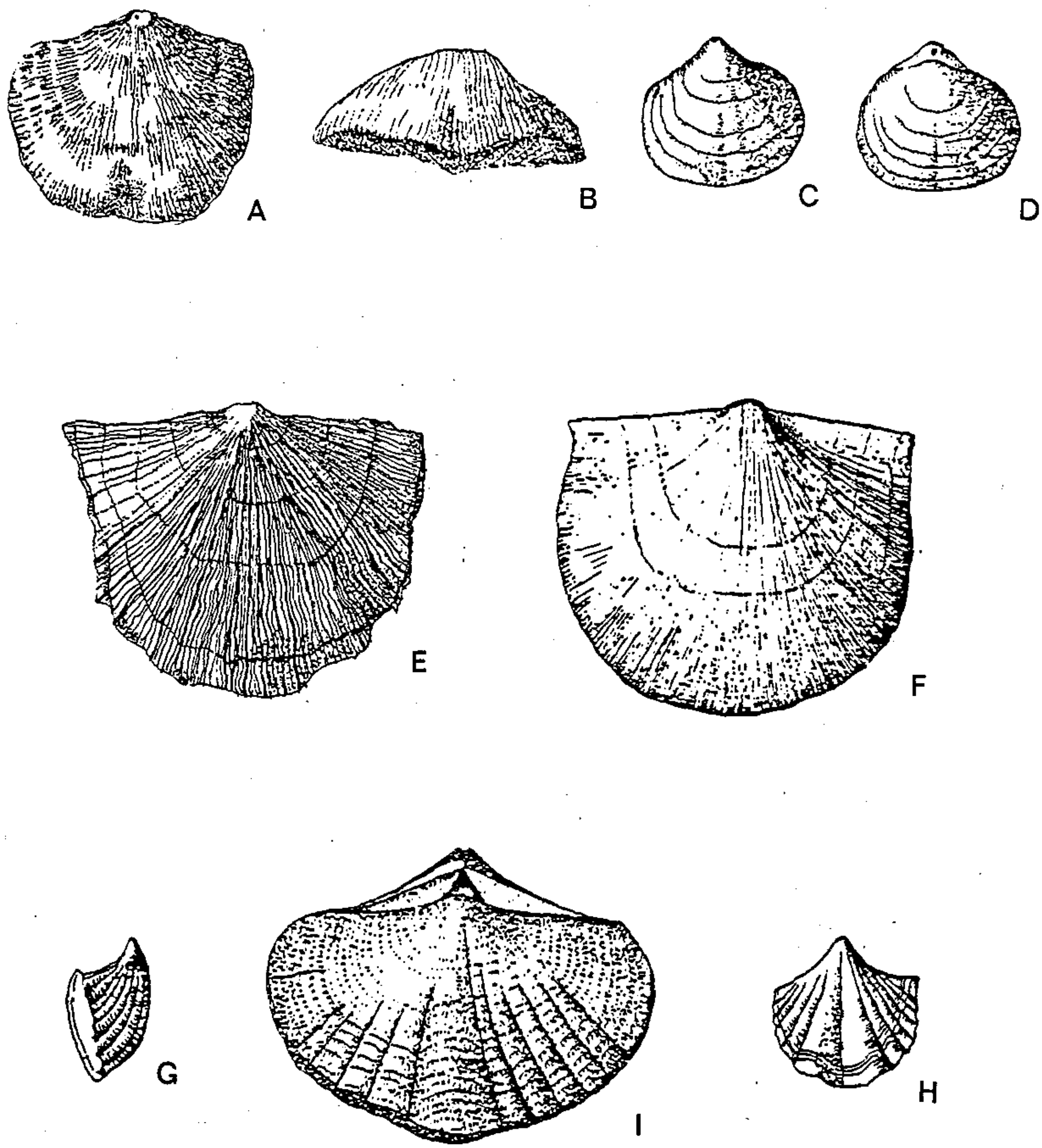


Figure 4. Brachiopods of the Onondaga Limestone in eastern New York. A,B. Schuchertella sp., ventral and anterior views, X1.75. C,D. Athyris sp. A, ventral and dorsal views, X2. E. Megastrophia sp., ventral view, X2. F. Strophodonta demissa, ventral view, X3. G,H. Cyrtina hamiltonensis, lateral and ventral views, X2. I. Elytha fimbriata, dorsal view, X3. Modified from Dunn and Rickard (1961).

widens slightly anteriorly forming two parallel to subparallel ridges extending almost half the valve length; flanks concave, dropping steeply away from sulcate fold; sulcus broad, shallow with two distinct ridges which define sulcus laterally and extend from umbo across posterolateral margins of flanks to uniplicate anterolateral commissure; vague, concentric growth lines on anterior portion of shell.

Pentamerella arata - subglobose and broadly pyriform in outline with strongly convex pedicle valve and weakly convex brachial valve; hinge line short, curved, narrow; no interarea evident; pedicle valve beak short, strong, incurved, not closely pressed against brachial beak; brachial beak small, less erect and less incurved; maximum width attained at or about midlength; weak sulcus present on anterior half of pedicle valve with corresponding fold on brachial valve (note: this morphological feature is the key to differentiating Gypidula from Pentamerella; see Gypidula above); both valves ornamented with numerous, rounded, bifurcating plications which become narrower on lateral slopes than near midline; interspaces between plications U-shaped and wider than plications which tend to become slightly V-shaped in cross section on some specimens; About 5 plications in sulcus and 6 on fold; concentric growth lines more numerous anteriorly.

Rhipidomella - Subcircular in outline, dorsibiconvex, delthyrium open; costellae cylindrical in cross section, not grooved; fold and sulcus weak, if present at all.

Rhynchospirina sp. - Shells small, pyriform in outline and biconvex in lateral profile; pedicle beak erect with small permesothyridid foramen; weak sulcus on pedicle valve but no corresponding fold on brachial valve; anterior commissure slightly uniplicate; normally about eight subangular plications with subangular interspaces.

Schizophoria cf. multistriata - Shells medium sized, suboval to subquadrate in outline, unequally biconvex; brachial valve deeper and more uniformly convex; in juveniles both valves become almost equally biconvex; pedicle valve develops broad, shallow sulcus on adult forms; brachial valve bears indistinct fold; hinge line short, slightly rounded; maximum width attained at or just past midlength; ventral interarea triangular, fairly high in larger shells, relatively narrow in younger ones; dorsal interarea narrower; interareas of both valves equal to about one-half width; ornamentation consists of rounded to subangular radial costellae with broad, flat interspaces; about 11 costellae in a 5 mm space near anterior commissure at midline.

"Schuchertella" sp. - Medium-sized, plano-convex to biconvex, transversely subelliptical in outline but subpyramidal in umbonal region; exterior multicostellate with costellae added by intercalation; interarea flat and broadly triangular; delthyrium covered by convex pseudodeltidium.

Strophodonta cf. demissa - Subcircular to shield shaped shells, concavoconvex in lateral profile; shells wider than long; point of maximum width at hinge line; lateral margins almost straight posteriorly; anterior margins evenly rounded; all margins crenulate; anterior commissure rectimarginate; costellae coarse, bifurcating with angular interspaces in cross section.

Stropheodontid indet. - Small, subcircular in outline, alate; Smooth exterior with irregularly spaced growth lines.

BRACHIOPOD LIFE STRATEGIES

The terminology used in this paper follows Bassett (1984) in which he reviewed the life strategies of Silurian brachiopods. Table 6 summarizes the main strategies under which the brachiopods of the Onondaga Limestone can be categorized but it must be noted that the classification is flexible. It is possible that several taxa may fit into different categories as ontogeny progressed since most brachiopods require an initial post-larval attachment to a hard bottom but may differ in post-larval development, especially in relation to the substrate. Ephebic or mature forms usually fall into a single category while immature forms may pass through more than one catagory during development.

Brachiopod specimens used in this study were collected from a variety of depositional environments and modes of preservation vary from well-silicified, to poorly-silicified to non-silicified forms. In addition, specimens were studied in situ in cases where removal from the field was impossible and successful extraction from the encasing matrix doubtful.

Quasi-infaunal Forms

Rudwick (1970) first used the term quasi-infaunal to describe strophomenid brachiopods that were partially buried or sank into sediment during ontogeny after initial hard-bottom attachment. These forms could become free-lying during burial or remain attached. A concavo-convex morphology is most typical of quasi-infaunal brachiopods found in the Onondaga Limestone. This occurred as a result of an alteration of growth rate later in ontogeny combined with an increased thickening of the convex valve (usually the ventral valve). The effect of this change in growth was to increase stabilization on the sea floor and prevent overturning by current action. In soft sediment, of course, the convex valve would have partially sunk in to a certain degree. During turbulence, sediment falling on the concave valve may have concealed the entire brachiopod except for the crescentic valve edges projecting above the surface of the sediment. If burial was too severe, a quick "snap" of the valves would have lifted it back and up, above the sediment-water interface. There are no known Recent examples of quasi-infaunal brachiopods, however, this mode of life would have been the closest to a truly infaunal habitat known for any of the articulates.

Table 6. Life strategies of ephebic brachiopods from the Onondaga Limestone.

LIFE STRATEGIES	NATURE OF SUBSTRATE
Endofaunal habits	Partial burial in soft
Quasi-infaunal	botttom
Epifaunal habits	
Fixosessile	
Plenipedunculate	Usually hard bottom
Rhizopedunculate	Hard or soft bottom
Epiphytic	Plants or plant-like structures
Liberosessile	
Ambitopic	Hard or soft bottom
cosupportive	Mutual support in dense clusters

Some forms, such as Cymostrophia cf. patersoni and Strophodonta demissa display a strong increase in curvature in adults so that the commissure was raised as burial increased. The most extreme increase in curvature is shown by Leptaena cf. "rhomboidalis" and Strophonella sp. which are both geniculated. It is conceivable that these brachiopods lived almost buried within the sediment with the commissure extended for feeding. A "snapping" action may not have been periodically necessary.

Leptaena depressa from the Silurian of the Anglo-Baltic region displays both both geniculation and folding, with the dorsally deflected anterior shell bearing a median fold. This fold is, in many instances, developed as a long trail able to extend well above the sediment-water interface. Indications of a trail are sometimes evident in Leptaena cf. "rhomboidalis" from the Onondaga. The brachiopod's efficiency in separating inhalant and exhalant water currents would have been increased by the presence of a trail.

Plenipedunculate Forms

The brachiopod pedicle was once thought to be a rather simple, relatively short, fleshy projection with a more or less constant diameter. However, recent workers have shed light on the tremendous variation in pedicle morphology (Bromley and Surlyk, 1973; Curry, 1981; Richardson, 1979, 1981). Variation in thickness and length is considerable, with expansion and contraction often occurring outside the shell so that foramen size is not necessarily a reliable guide to functional diameter or strength (Bassett, 1984). Nevertheless, the presence of an open pedicle foramen throughout life is indicative of a functional pedicle, presumably in all ontogenetic stages. Bassett

(1984) used the term plenipedunculate for brachiopods in which the pedicle is a single, unbranched muscular structure apart from its distal tip (included in which are groups 1 to 4 of Bromley and Surlyk [1973, pp. 350, 351]).

Most Recent brachiopods attach to hard bottoms by mucal adhesion of the distal tip of the pedicle which usually possesses hold-fast papillaeor terminal rootlets that are able to etch and penetrate carbonate substrates for additional attachment strength (Bromley and Surlyk, 1973). Specimens of *Athyris* collected from the Onondaga Limestone near Saugerties, New York, have an open, rounded pedicle foramen throughout ontogeny. The structure of the pedicle opening is very similar to that of Recent terebratulids and rhynchonellids, and therefore suggests a similar pedicle function.

Rhizopedunculate Forms

Bassett (1984) uses the term rhizopedunculate for those brachiopods in which the pedicle is branched into fine filaments throughout much of its length rather than only at the distal tip (eqiuvalent to groups 6 and 7 of Bromley and Surlyk [1973, p. 351]). Bromley and Surlyk (1973) studied the pedicles of Recent brachiopods and found that they etch a very characteristic trace, composed of a number of pits, into hard calcareous substrates. The trace in rhizopedunculate forms consists of a series of widely scattered pits corresponding to the rootlets of the pedicles. The fact that the pedicle is so variable and that it is able to dissolve carbonates implies that many brachiopods are capable of attaching themselves to a wide variety of substrates. This, in effect, means that many brachiopod-substrate relationships in paleoecology must be re-evaluated.

A well-known Recent example of a rhizopedunculate brachiopod is *Chlidonophora*, a terebratulacean, in which the pedicle rootlets have been found to penetrate *Globigerina* tests (Rudwick, 1970) and thereby become rooted into the foraminiferal ooze. The importance of this lies in the fact that the size of the pedicle foramen alone would not indicate the pedicle length (which is rather long in *Chlidonophora chuni*, for example) or the branching, root-like character of the pedicle. It is clear that this type of attachment may have been more common among Devonian articulate brachiopods than assumed by earlier workers. However, it is difficult to confirm that any Devonian forms were in fact rhizopedunculate, or even plenipedunculate, but it is possible to draw certain conclusions based on morphology and substrate.

The Moorehouse Member of the Onondaga Limestone in the Mid-Hudson Valley is though to represent a very soft-bottomed, lime mud substrate. It displays the greatest faunal diversity of all members of the Onondaga Limestone in the area. Many forms may have existed with rhizoid pedicles which were able to attach to local hard bottoms, such as shell fragments. For example, *Atrypa* "*reticularis*", *Athyris* and *Leptaena* "*rhomboidalis*" showed traces of a small pedicle foramen early in ontogeny which may have accomodated pedicles that acted in the capacity of tethers and which may have very well been rhizoid. This type of attachment would have permitted the brachiopods to utilize a wide range of substrates during Onondaga time.

All adult specimens of Mucrospirifer collected from the Onondaga Limestone had an open delthyrium with no evidence of a stegidium or modifying plates. It is therefore assumed that a functional pedicle was probably absent throughout all ontogenetic stages although the dimensions of the pedicle are unknown. Cowen (1968) correlated the decrease in function of the pedicle with an increase in the development of alae which acted to stabilize the shells on the substratum. Mucrospirifer may have possessed an inert pedicle, as described by Richardson (1981), similar to that of the Recent Magadina cumingi from southern Australia, in which the pedicle acted as a pivot around which the shell moved by contraction of the pedicle muscles. The inert pedicle may also have branched into fine filaments. Richardson's (1981) criteria for determining the relationships between pedicle and shell characters are useful for Recent forms but are not yet proven valid for fossil specimens. She noted that a straight beak with a wide, high deltidium is characteristic of species with an inert motile pedicle. This description is compatible with Mucrospirifer in that the deltidium is relatively high but the beak ranges from straight to suberect.

Epiphytic Forms

There have been reports in the literature (Rudwick, 1961, 1970; Foster, 1974) of brachiopods attaching themselves to various structures for support. Rudwick (1961) found shells of Terebratella sanguina dredged from a muddy bottom off the coast of New Zealand attached by their pedicles to the tangled, horny tubes of Phyllochaetopterus socialis, a chaetopterid worm. Hosts such as these would not normally be preserved as fossils but it appears probable that they were used in the past as they are used now. Some workers noted that certain thin-shelled, light weight brachiopods, such as Aegira grayi, could have floated or attached to drifting algae. Bergstrom (1968) believed that Shagamella ludlovensis was epiphytic on benthic algae. Silurian forms from England, such as Dicoelosia biloba, have been described (Wright, 1968) that were attached to a stick-like organic fragment (Bryozoan?).

Thin-shelled forms of Atribomium halli, Coelospira camilla and Ambocoelia found in the Moorehouse Member may have been epiphytic. However, it seems clear that even if they were epiphytic, the majority of forms found in the Middle Devonian Onondaga Limestone were predominantly benthic.

Ambitopic Forms

Ambitopic brachiopods were attached at early growth stages and subsequently became detached and capable of resting on soft bottoms (Jaanussen , 1979). As adults all ambitopic forms were liberosessile, but some liberosessile forms are not adapted to living on soft bottoms. There are some Recent brachiopods that became detached and remained on hard bottoms, although these forms appear to have a reduced life expectancy as noted by Doherty (1979).

Some brachiopods, such as Costistrophonella punctulifera, Schuchertella and indeterminate strophodontids collected from the Nedrow and Moorehouse members of the Onondaga near Kingston, New York, display weak curvatures and are relatively thin-shelled, indicating that they most likely rested on the sediment surface. Thus, there was intergradation between those forms and the more strongly curved types, such as Leptaena, Cymostrophia, Megastrophia and Strophonella that sank into the sediment.

Atrypa "reticularis" from the Moorehouse Member of the Onondaga developed a frilly border thought to function as a snowshoe in preventing adults from sinking into the sediment. Specimens from the underlying Nedrow and Edgecliff members had no frills possibly indicating a less muddy, higher energy environment.

An unnamed species of Cyrtina from the Moorehouse Member near Leeds, New York, appears to have an atrophied pedicle in addition to a broad ventral interarea upon which the animal rested. This, in effect, spread the weight in order to again prevent sinking into the substrate. Alate species of Mucrospirifer from the same member show a more extreme variety of this morphotype.

The concavo-convex Chonetes lineata, found by the thousands in the "Chonetes" Zone ten feet above the Tioga Bentonite in central New York but also recovered from upper Moorehouse strata in the Mid-Hudson Valley, apparently closed its pedicle opening early in ontogeny and rested convex side down witht he spines acting as restraints in preventing sinking. Poor preservation precludes exact determination of spine morphology.

Pentagonia unisulcata from the Moorehouse Member of the Onondaga is a thick-shelled, biconvex brachiopod which probably depended on weight to maintain stability on the seafloor. Pentagonia was posteriorly weighted and possesssed a minute pedicle foramen in some ephebic specimens and none at all in others, indicating pedicle atrophy. Secondary shell material was developed posteriorly in mature individuals further increasing stability. Curry (1981) noted that Neothyris lenticularis, a Recent brachiopod from New Zealand, had a posteriorly weighted shell, minute foramen, and atrophied pedicle and could be considered an ideal adaptation for the high energy subtidal habitats of the species which is frequently disturbed by bottom currents. The morphology and adaptive features of Pentagonia may be indicative of a similar habitat in Moorehouse time.

Cosupportive Forms

Bassett (1984) introduced the term cosupportive to describe those ambitopic brachiopods which maintain an umbo-down posture and are packed tightly together often growing on one another. This type of growth afforded the brachiopods some degree of mutual support from the time of pedicle atrophy. Examples in the Onondaga Limestone are rare, with clusters of *Atrypa* "*reticularis*" possibly showing this type of life strategy. Occasional specimens retrieved from Moorehouse strata near Leeds, New York, display deformation indicative of crowding. *Pentamerella arata* from the Nedrow and Moorehouse members observed *in situ* near Saugerties, New York, also show evidence of deformation indicating a possible cosupportive life strategy.

FIELD TRIP OUTCROP LOCALITIES

Below is a list of outcrop localities, mostly in the Mid-Hudson Valley, which illustrate how Onondaga deposition in the southeastern part of New York varied from a shallow carbonate shelf in the Helderberg-Coxsackie area to shelf-margin bryozoan bafflestones between Leeds and Saugerties, and relatively thick sparse to packed calcisiltites depositied on a shelf-to-basin ramp deepening into the Tristates area. The trip begins in Wawarsing, New York, where we believe that the accumulations are indicative of the deeper part of a second basin, the first, well-known to geologists, located across the state (east-west) with the basinal axis near Syracuse. As we progress northeast up the Mid-Hudson Valley, the outcrops show a progressively shallower water facies, correlative with movement up a ramp towards strandline.

LOCALITY 1: The trip begins in Wawarsing, New York, approximately 0.5 miles northeast of Vernooy Kill, 100 feet north of Route 209, on the property of Steve and Sue Caruso (Be sure to ask permission before entering outcrop area). The Onondaga/Schoharie contact can be observed in an abandoned quarry (AMNH [American Museum of Natural History] Locality 3151B; see Feldman, 1985) where the Edgecliff Member with characteristic large crinoids, trilobites and some *Amplexiphyllum* is accessible. The Edgecliff here is finer grained than in the Mid-Hudson Valley and represents the deepest part of the basin to shelf lithology we will see today. Proceed north on Route 209 for 14 miles (note turnoff to Ulster County Highway 26) and continue for another 3.0 miles.

LOCALITY 2: Pull off on the west side of Route 209 (wide shoulder). On the east side of the road note a transitional, deeper water facies, similar to that found at Locality 1, about 1 meter thick, with 0.5 meter of shallower water, "cleaner" Edgecliff Limestone. The fauna here consists of large crinoids, ?*Amplexiphyllum*, ?fenestrate bryozoans (weathered), and *Syringopora*. Note storm layers and a sharp break between two facies. Continue on Route 209 north for 2.6 miles where the Onondaga outcrops on the west side of the road.

LOCALITY 3: Here we are higher in the Edgecliff (about 4 meters thick). The water was shallower and the brachiopods larger. Chondrites is evident here but not further southeast due to the fact that as the ramp deepened (to the southwest) the sediment became too "soupy" for tubelike or tunnel structures. Continue to Route 199 east and exit at Route 32 south (7.2 miles). [Note that along Route 199 we are passing through the entire Lower Devonian section, from the Thacher at the base, to the Schoharie, which underlies the Onondaga in this part of New York State.] Make a left turn at the stop sign and continue south on Route 32. On the west side of the road note complex thrust slices oblique to the section and, about one-eighth of a mile further south, an angular unconformity between the Wilbur Limestone Member of the Rosendale Formation (Late Silurian) on Normanskill (Austen Glen aspect) strata. After 2.7 miles make a left turn onto Route 9W south (= Frank Koenig Boulevard), continue for 1 mile, and stop at the Delaware Avenue sign.

LOCALITY 4: Note the gradational nature of the Onondaga/Schoharie contact which is placed at the uppermost buff-weathering band. Ranging through the upper Schoharie into the lower Edgecliff are massive cyclostome bryozoans often encrusting (e.g. crinoids). Other faunal constituents here include brachiopods, particularly Atrypa "reticularis," and Fistulipora. The stratigraphy at this locality is complicated by faulting and repetition due to thrusting (note slickensides and slip-fiber sheets), thus making the Edgecliff seem to be thicker than it actually is. According to Marshak (1986) there are two major thrusts which display a relatively large stratigraphic throw along Route 9W. The upper one, now covered by the exit ramp, emplaces Esopus Formation on Onondaga Limestone while the lower one, exposed further to the north along the roadcut, emplaces Onondaga Limestone on Schoharie. The upper fault may be the continuation of the Fly Mountain Thrust. In general, there is an absence of favositids between here and Wawarsing, but north of here, especially in Leeds, they are abundant. Note the light-weathering chert. Exit at Delaware Ave., make a left turn at the light, and re-enter Route 9W north. Proceed to Route 32, turn right (north),and continue for 8.3 miles; pull into McDonald's parking lot for a brief lunch stop.

LUNCH STOP - McDonald's, Route 32.

Upon exiting the lot turn north and continue on Route 32 passing through the town of Saugerties. Cross the New York State Thruway and note Howard Johnson's on the right, 3.4 miles from McDonald's. (If time permits we will pull into the parking lot and observe well-weathered blocks of Onondaga with silicified fossils [bryozoan bafflestone].) Continue north on Route 32 for another 1.6 miles until the turnoff for Old King's Highway (= Old King's Road). Pull off on the right just before the turnoff.

LOCALITY 5: On the east side of Route 32 note a large outcrop of Edgecliff which shows, for the first time on this southwest-northeast transect, typical coarse-grained Edgecliff lithology. This is the southernmost exposure of the crinoidal biosparites which are so characteristic of the Edgecliff Member. Turn onto Old King's Highway (Greene County Route 47) and proceed 5.2 miles to High Falls Road. Make a left turn and pull over to the right just before the sharp bend (.3 miles).

LOCALITY 6: DO NOT COLLECT AT THIS STOP; IT IS ON PRIVATE PROPERTY AND THE OWNERS DO NOT WANT ANY SPECIMENS OR BLOCKS REMOVED! This outcrop, on the Kaaterskill (AMNH Locality 3137; see Feldman, 1985), known as Quatawichna-ach, takes its name from the Indian "place where all the water goes in a hole" referring to the chert seams and massive joints which take the water underground as it passes through the limestone (Chadwick, 1944). A stratigrphic placement of upper Moorehouse is indicated by [1] shale chips in the adjacent woods (probably Bakoven, since it outcrops a short way downstream], [2] dark-weathering chert, and [3] faunal similarity with upper Moorehouse strata from the Leeds area, specifically, Platyceras dumosum and Atrypa "reticularis." The fauna here is moderately to well-silicified probably due to the diagenetic action of percolating groundwater through the numerous joints. At this locality Feldman (1980) recognized a highly diverse Atrypa-Coelospira-Nucleospira Community containing the following morphotypes:

[1] Orthotetacids, Schuchertella (broad, flat)
[2] Nucleospira, Athyris (smooth spiriferids)
[3] Schizophoria (unequally biconvex)
[4] Atrypa (with frills)

There is a great similarity here with Lenz's (1976) Lower Lochkovian Howellella-Protathyris Community from the northern Canadian Cordillera in which he found similar faunal elements in an offshore position. A similarity is also evident to Copper's (1966) biotope of primitive, abundant Atrypidae in which variably sized atrypids occur with spiriferids and schizophorids in fine-grained sandstones, siltstones and shales with thin limestone interfingerings. Proceed back up High Falls Road and turn left onto Old King's Highway. Continue for 2.1 miles to Route 23A. Turn left for .3 miles and just before crossing Kaaterskill Creek pull onto right-hand shoulder.

LOCALITY 7: Descend steep embankment to Kaaterskill Creek where the only known exposure of the Bakoven/Onondaga exists. Whereas Oliver (1956) considered the Onondaga/Bakoven contact to represent a minor break in deposition we believe that the contact is a disconformity, albeit a minor one in this part of the state, representing a time period during which rapid crustal subsidence, to a shallow or proximal basin depth position below storm wave base, resulted in stratification of the water column and dysaerobic bottom conditions. We found evidence of a more substantial disconformity in central New York, near Syracuse, where the Union Springs Shale (lateral equivalent of the Bakoven) truncates westwardly dipping Seneca strata. At that contact there exists a substantial bone bed with reworked (?) crinoids and brachiopods, and current-sorted fish spines and/or teeth. Proceed up the hill (east) on Route 23 and pick up Route 9W north through Catskill, New York. Pass under the trestle and go 8.1 miles (from Locality 7), turn left (west) onto Route 23. Follow signs to New York State Thruway (exit and make right turn), and head into Leeds (Green County Route 23B). In Leeds turn left on Gilfeather Park Road, drive to the end and park.

LOCALITY 8: Overlooking Catskill Creek, to the east, note the Schoharie/Onondaga contact, to the east of which the Onondaga lies in an (overturned?) thrust-faulted syncline. If time permits we will examine the typical Edgecliff lithology at the waterfalls where trilobites, corals, and brachiopods are evident.

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STRUCTURE AND STRATIGRAPHY OF THE NORMANSKILL GROUP (EARLY MEDIAL ORDOVICIAN) WEST OF THE HUDSON RIVER, TOWN OF LLOYD, ULSTER COUNTY, NEW YORK

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INTRODUCTION

The rocks of the Normanskill Group, formerly included in the Hudson River slates and shales are among the first studied rocks in North America. Notables such as W. W. Mather, Sir William Logan, and James Hall studied the rocks in the mid-Hudson area in the 1830's to 1860's. Because of the complex structure and repetitive stratigraphy of the Normanskill work has progressed slowly, with the most extensive and recent studies being done in the Albany, N.Y. and Quebec areas. In the Mid-Hudson, particularly in Ulster County, the Normanskill rocks have never been adequately mapped, despite extensive exposures along the Hudson River and in area highway and railroad cuts.

Recent fieldwork in the eastern part of the Town of Lloyd has resulted in several discoveries in the Normanskill Group. A relatively diverse shelly fauna has been found in a thick sequence of laminated strata tentatively dating these rocks as post-Austin Glen, but pre-Balmville in age, probably making these the youngest Normanskill rocks yet found. Outcroppings of lower Normanskill aspect (Mt. Merino Formation?), the first seen in this part of Ulster County, have been mapped around Blue Point. Four structural domains have been recognized on the basis of structural and lithologic criteria. Two of the domains apparently cross the Hudson River. Numerous folds and faults have been mapped, some of which show evidences of multiple deformation. Outcrops exposing thick stratigraphic sections have been measured for possible correlation, and excellent sedimentary structures noted in the Austin Glen Formation. Analysis of the data collected during this fieldwork can lead to a more comprehensive understanding of the age relations, sedimentology, stratigraphy, and styles of structural deformation.

TECTONIC SETTING

The Normanskill Group is composed of pelites and turbidites deposited on the basin floor of a trench/foreland basin being transported onto the North American continental margin during early medial Ordovician time. Normanskill sediments apparently were derived from an island arc to the east (Rowley and Kidd, 1981), formed during the attempted subduction of the Laurentian plate beneath the crust of the pre-Atlantic ocean (Iapetus) which lay between Europe and North America. After lithification, the strata were trapped between the two colliding masses causing folding and subsequent shearing into thrust slices. These slices were forced across the foundering coastal platform until they reached their present locations, juxtaposed against autochthonous sedimentary rocks of Martinsburg - Quassaic - Snake Hill aspect. Today they are seen in prominant outcrops dispersed along the Hudson River, and near Lake Champlain.

STRATIGRAPHY

The Normanskill Group is presently comprised of three formations. The lowermost is the Indian River Formation (Keith, 1932), of Porter-field age, which contains graptolites of the *Nemagraptus gracilus* zone (Berry, 1962). It contains red and green shales or slates with interbedded red and green cherts attaining a thickness of about 150 feet (46 m.) at Granville, New York. The Indian River Formation probably does not crop out in the Town of Lloyd.

Succeeding, and /or laterally equivalent to the Indian River is the Mt. Merino Formation (Ruedemann, Cook, and Newland, 1942), which also contains graptolites of the *Nemagraptus gracilus* zone. Most of this formation is a well indurated, green argillite, with interbedded green to brown cherts and siltstones. The upper part of the Mt. Merino Formation is a gray to black shale known to contain numerous graptolites. The upper contact may or may not be conformable with the overlying Austin Glen Formation. The thickness of the type-section at Mt. Merino is about 150 feet (46 m.), but is probably in excess of 300 feet (92 m.)at Blue Point in the Town of Lloyd.

The Austin Glen Formation (Ruedemann, Cook, and Newland, 1942), is of Wilderness age and contains graptolites of the *Climactograptus bicornis* zone (Berry, 1962). Otherwise it is largely barren of fossils in this area. The formation is composed of thin to medium bedded subgraywackes and shales in the lower portion, and thick bedded graywackes with thin shales in the upper part. Zones of medium bedded graywackes and shales contain as much as 50 per cent $CaCO^3$ by weight and occur in the middle of the formation in the Town of Lloyd and across the Hudson River in the Town of Hyde Park. Thick channel deposits of graywacke can be found at almost any level. Approximately 400 feet (122 m.) of section is exposed at Austin Glen, the type-section, but over 2500 feet (765 m.) of Austin Glen has been measured and described in the eastern limb of a syncline exposed along the western approaches to the Mid-Hudson Bridge and Poughkeepsie railroad bridge (Kruzansky, 1983, Manning, 1983, Boeck and Schimmrich, 1987).

A fourth formation may be proposed for about 3000 feet (916 m.)of laminated shales, siltstones, and sandstones exposed along the eastern flank of the Marlboro Mountains. These rocks contain a locally abundant shelly fauna with a distinctive trilobite population. Tentative identification of these trilobites shows some types common to eastern New York State along with some Proetids resembling those reported from Great Britain. Balmville and later forms appear to be absent. This assemblage would appear to date these rocks as post-Austin Glen, but pre-Balmville, filling a gap in the stratigraphic record of New York State.

SEDIMENTATION

Sedimentologically, the Indian River and Mt. Merino Formations are considered basin deposits with interbedded ash from island arc volcanism (Rowley, Kidd, and Delano, 1979), while the Austin Glen is probably a distal fan deposit (facies C of Mutti and Lucchi, 1978). The newly mapped laminated strata are likely more distal (facies D). Sedimentary deposits along the western flank of a region of uplift probably supplied the bulk of the sediment found in the Normanskill Group. Density currents carried these sediments westward or southward into the Normans-kill basin. Turbidite sequences show classic graded beds and various parts of Bouma cycles, although locally, coarse pebble conglomerates are relatively rare in the Austin Glen. Sedimentary structures such as flutes, load casts, convoluted bedding, flame structures, and drag marks are seen commonly.

STRUCTURE

Structurally, rocks of the Normanskill Group in this area are thought to be allochthonous, having been transported westward by thrusting during the Hudson River phase of the Taconian orogeny. Locally, the Esopus fault is thought to separate the autochthonous strata (Quassaic Group) from the allochthonous (Normanskill Group). Slaty cleavage, en echelon, sigmoidal, and massive tension gashes, numerous slickensides, drag folds, normal and reverse faults, and thick shear zones are evidence of tectonism. The residual effects of this are seen in four domains which exhibit differences in lithology and style of deformation.

The first domain encompasses an area beginning about 0.5 miles south of Routes 44 and 55 and bounded by Route 9 east of the Hudson River, Route 9W on the west side, and running south to the Town of Marlborough boundary line (figure 1). This domain contains the Mt. Merino exposures which form four probable thrust slices, two on each side of the Hudson River, bounded by massive graywackes of Austin Glen aspect. To the north of these outcrops are more thinly bedded Austin Glen graywackes and shales displaying relatively small scale folds, sheared drag folds, and calcite slickensides on bedding planes which indicate movement from the southeast.

The second domain, which commences 0.5 miles south of Routes 44 and 55, is bounded on the east by the Hudson River, on the west by a fault near Route 9W, and continues north to near Clearwater Road. This area encloses a substantial synformal structure composed of lower middle, and upper Austin Glen lithology. Roadcuts in the area of the Mid-Hudson Bridge expose over 2500 feet (763 m.) of section (Kruzansky, 1983, Manning, 1983), the most ever measured in the Austin Glen Formation. The structure plunges gently about N 5° E and, in areas, shows characteristics of a downward facing structure indicating later reorientation of the syncline. Also within this domain are small wrench faults and folds with sheared hinge lines containing rounded, elongate graywackes enrolled in shale mattrices. Most folds in this domain are recumbent.

The third domain encompasses an area north from Clearwater Road to the Town of Esopus boundary line, and is bounded on the west by a fault zone trending about N 5° E beginning east of Route 9W. On the east, this domain starts on the west bank of the Hudson River and probably crosses the river south of Crum Elbow

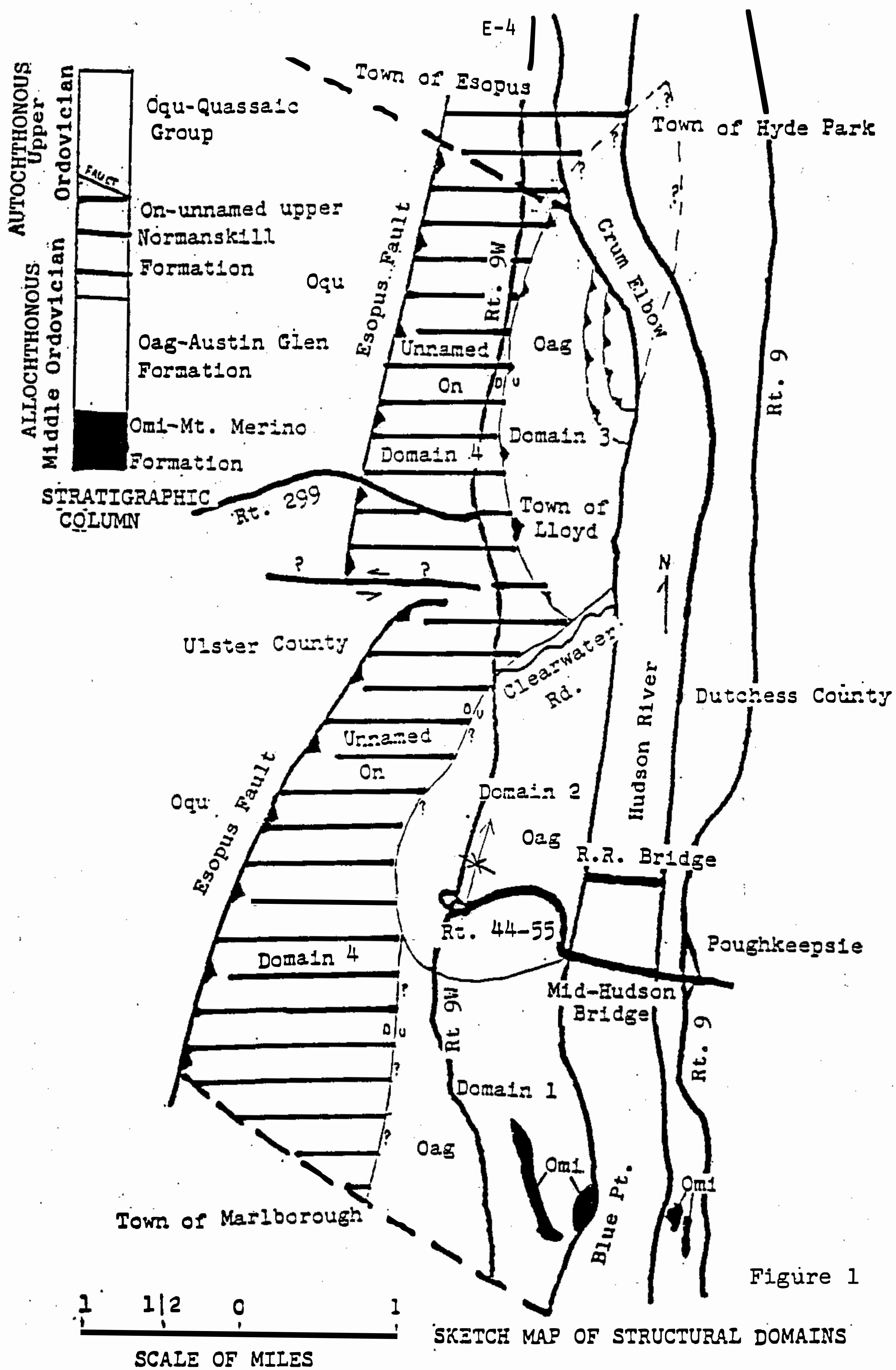

Figure 1

SKETCH MAP OF STRUCTURAL DOMAINS

continuing until it intersects a fault trending obliquely S 45° W through the intersection of the west bank of the Hudson River and the Town of Esopus boundary line, running to the western boundary fault.

This domain is composed largely of upper Austin Glen strata, including several thick graywacke sequences, and medium bedded turbidites containing a large percentage of interstitial $CaCO^3$. Structurally, this area shows numerous imbricated thrust slices which center around Crum Elbow. Strata generally dip southeast, but strikes and dips change rapidly near fault boundaries. Folds near the northern boundary are nearly vertical, plunging steeply northeast.

The fourth domain essentially contains all the area west of a fault zone running approximately parallel to Route 9W, crossing the Hudson River along the north boundary of domain 3. The western boundary is the Esopus Fault running along the lower part of the eastern flank of the Marlboro Mountains except at the north end of Illinois Mountain where the fault apparently has been folded and offset to the east. The southern and northern boundaries of the domain lie outside the Town of Lloyd.

The laminated strata of uppermost Normanskill comprise this domain. These strata are bounded on the west by sandstones of the Quassaic Group (middle to upper Ordovician). Except at the north end of Illinois Mountain these strata largely strike between N-S and N 10° E and are overturned dipping 80° to 87° SE. A few outcrops are upright, dipping 20° to 30° NE. Younging directions are often difficult to determine in these laminated sandstones, siltstones, and shales, and the possibility of isoclinal folding exists, but has not been established in the field. These strata demonstrate more continuity of structure than those in any of the other domains. Possibly this indicates less distance of transport during thrusting. The most impressive structural complication in Domain 4 occurs at the north end of Illinois Mountain where the strike of Quassaic beds turns from the usual N 10° E to E -W indicating a folding of the Esopus fault to the east (Cunningham, 1987). On Illinois Mountain the fault averages about N 15° E in trend, while on the mountain to the north of Route 299 the fault trends about N 5° E. A cross fault trending generally E-W is inferred between the two mountains.

All domains show indications of multiple deformation ranging from the folding and offset of the Esopus Fault, to abrupt changes in orientation of slaty cleavage common throughout the area, to the changes of vergence directions of folds from westward verging recumbent folds to northeast verging, nearly vertical folds in domain 3. Finally, a number of minor faults indicate south to north movement.

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STOP DESCRIPTIONS

Stop 1 Near Mid-Hudson Bridge approach. This road cut exposes rocks of middle to upper Austin Glen lithology, dipping about 45 degrees west. Thick beds of graywacke show massive bedding, and thinner beds expose primary sedimentary structures such as flame structures, convoluted bedding, and cross-lamination. Cleavage dips less steeply than bedding indicating a possible downward facing structure. Looking south into the road cut for the Mid-Hudson Bridge, one can see the most complete section of Austin Glen strata yet measured (Krusansky, 1983, Manning, 1983). This section begins at a fault exposed near the final turn to the bridge, and continues with little interruption to the toll gate. It then continues in a railroad cut until it intersects the center of a N15°W trending syncline. This syncline plunges NE, and covers much of the area in domain 2 (figure 1). Strata from lower to upper Austin Glen is seen in this section.

Stop 2 This outcrop in the vicinity of Johnson Iorio Park contains lower Austin Glen strata. Both the north and south ends are quite deformed with a small reverse fault exposed at the north end, and an intense fault zone at the south end. Numerous graptolites have been found in rock fall near the Park entrance.

Note: The subsequent stops along the railroad are described in order of appearance from south to north. Because access is limited, all outcrops are described, although not all may be visited.

Stop 3 Blue Point. This area consists largely of lower Normanskill strata - probably Mt. Merino Formation. This is the only known exposure of this rock type west of the Hudson River between Kingston and Newburgh. East of the Hudson it is more commonly exposed. This rock is a highly indurated, gray-green argillite with silty or cherty interbeds, and occasional pyrite layers. Gray to black shales are characteristic of the upper part of the formation.It is probably allochthonous with four thrust slices present locally, two on each side of the Hudson (figure 1). These outcrops constrict the river by about 30 per cent (pre-railroad width) accentuating the hardness of this material. The strata generally dip and young northwest except at the north end where it is overturned. It is highly sheared and folded making stratigraphy very difficult. Bedding can be traced by following the cherty or silty layers when the light is 'right'. The southern part of the exposure is green argillite cored by a brown, dolomitic argillite forming an antiformal structure. The middle portion of the outcrop is primarily green argillite while the northern end contains sheared, gray to black shales known from the upper Mt. Merino. Graptolites are commonly found in these shales. To the northwest, the contact with the overlying Austin Glen Formation is probably at the north end of the outcrop where light gray, thin-bedded shales appear. A thin covered zone separates this strata from thick bedded graywackes with thin shales characteristic of the upper Austin Glen. This suggests a major fault trending southwest. The presence of other Mt. Merino outcrops directly across the river at Mine Point raises the question of whether the

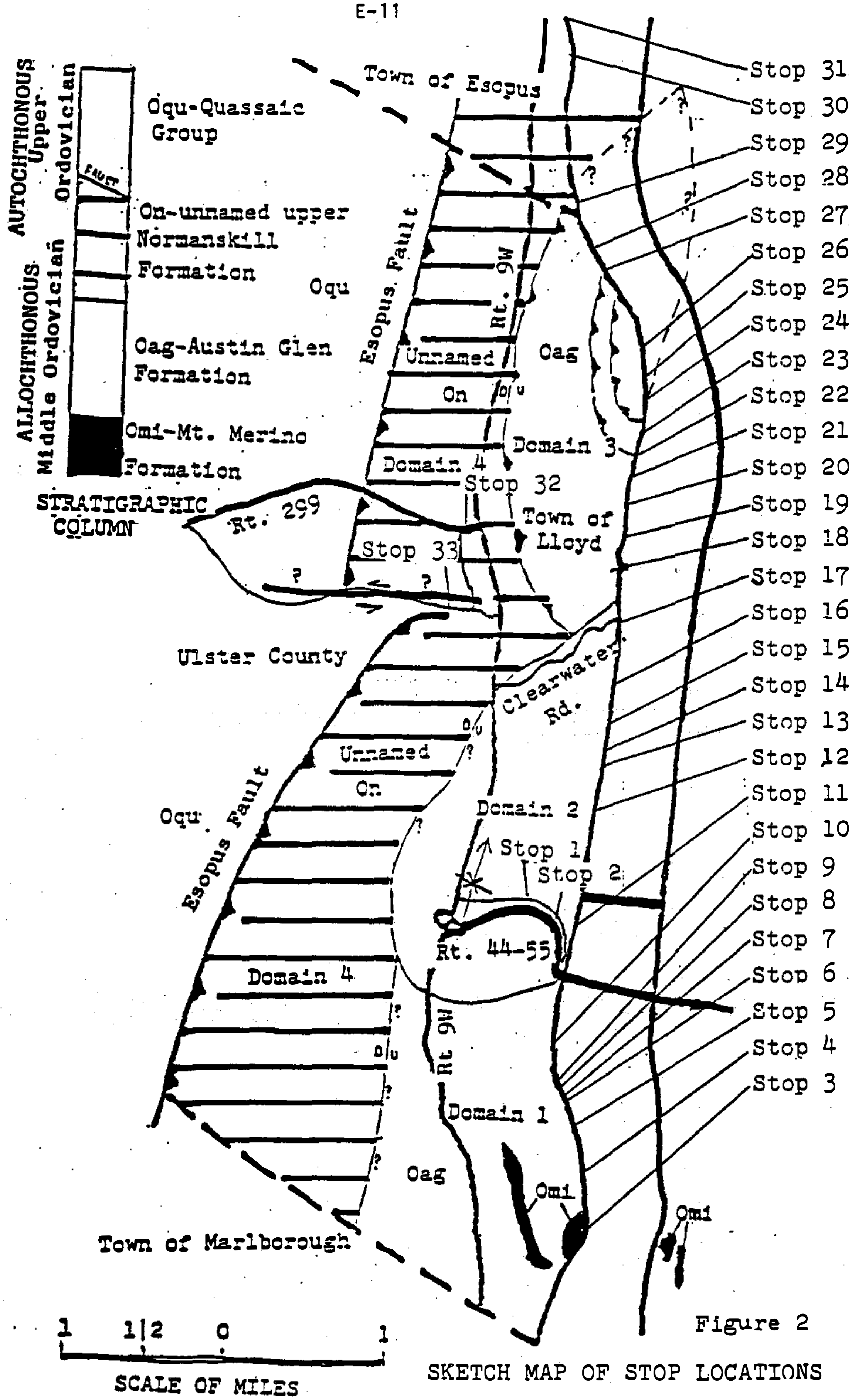

Figure 2

SKETCH MAP OF STOP LOCATIONS

Hudson River is structurally controlled or whether it is a superposed stream. Circumstantial evidence here and to the north at Crum Elbow suggests that this is a superposed stream.

Stop 4 This outcrop contains thick graywacke beds with thin shale interbeds typical of upper Austin Glen lithology. These beds dip northeast and are overturned. Cleavage dips gently southeast. The stream to the south may be a fault trace. If this is so, the fault may have reoriented this strata causing the shallow orientation of the cleavage.

Stop 5 Interbedded gray shales and graywackes averaging 2 to 4 cm. in thickness with occasional calciferous or dolomitic, laminated siltstones comprise this outcrop. The rocks in the upper part of the outcrop dip northwest and may be separated from the lower part by a bedding plane fault. The lower strata dip generally northeast and are more deformed than those above. All strata appear to be overturned.

Stop 6 Here the same lithology is exposed as in Stop 3 except many broken sections of thick graywacke are present in the shales due to tectonic disturbance. These beds are overturned and dip about 25 degrees to the east. Bedding plane slickensides are numerous and are aligned approximately east west.

Stop 7 This section represents strata of middle to upper Austin Glen aspect with thin turbidites at the south end and thick graywackes at the north. These beds are highly deformed with the northern, more massive strata apparently dragged into folds along a fault at the north end. Another fault separates the thick graywackes from thin turbidites at the south end of the outcrop. The overall structure dips northeast with the beds dipping nearly 90 degrees at the south part of the section, decreasing to 40 degrees to the north, and then overturning and dipping 40 degrees southeast at the north end. This outcrop also contains curved tension gashes in the massive graywackes and disarticulated folds of thin graywacke in 'smeared' shales at the south. A thick graywacke surrounded by shales truncates abruptly near the south end. Just north of this outcrop, a tight drag fold of smaller dimensions is exposed.

Stop 8 Medium to thick bedded graywackes are exposed here which are upright, dipping 15 degrees northeast. Higher on the hill, these beds increase in dip and are likely to be separated from those of Stop 6 by a fault in a stream bed.

Stop 9 This outcrop contains black shales with fragmented sandstone layers enrolled in the shales. This outcrop is highly disturbed. Relatively flat-lying beds appears to pin almost vertical graywackes to the hill, while thick shales show pinch and swell structure between graywacke layers. Tension gashes and riedel shears can be seen in this convoluted section.

Stop 10 This exposure of lower Austin Glen contains 1 to 2 cm. thick graywackes and shales. Pyritic graptolites can be found here. Tight folds have formed in this sheared strata with shale enveloped sandstone fragments indicating the degree of deformation. Strata dip northeast at the south end and northwest at the north end, while the cleavage dips east-southeast at a low angle.

Stop 11 This 1500 foot (460 m.) long section consists of lower to middle Austin Glen lithology south of the Poughkeepsie Railroad bridge, and upper Austin Glen north of the bridge (figure 1). This area offers a good stratigraphic section to compare to that in the Mid-Hudson bridge approach (stop 1), and that seen in the railroad cut north of Crum Elbow (stop 27). Beds 1 to 4 cm. thick of alternating graywackes and shales predominate in the southern strata with well developed (ignore the graffiti) reclining, parasitic folds. These give way to thicker graywackes and shales just south of the bridge. Graptolites were found where a cut was made for cables which cross the Hudson River. Thick beds of graywacke dominate north of the bridge abutment. At the south end of the outcrop the beds dip northeast at 40 degrees, increasing to 53 degrees north of the bridge. This is part of the synclinal structure seen at Stop 1.

Stop 12 Highland Landing. This stop consists of middle to upper Austin Glen strata dipping N65E. A small reverse fault cuts this outcrop and a thrust runs along the upper part. Turbidites averaging 10 cm. in thickness dominate the southern half of this outcrop, while thick turbidites with thin shales constitute the northern part. Flute casts are visible on the undersides of some beds.

Stop 13 A shear zone formed in a failed fold hinge occurs at the south end of this stop. Rounded sandstone blocks enrolled in a shale matrix give good evidence of the shear couple at work here. This commonly happens in the hinges of the recumbent folds found in this area when the rock is stretched beyond its yield point dragging fragments of more competant strata into dismembered folds surrounded by shale. The rocks dip steeply northwest at the south end of the outcrop, but flatten considerably to the north. This is apparently middle Austin Glen lithology.

Stop 14 These thick graywackes with thin shale interbeds characteristic of the upper Austin Glen are overturned, dipping 85 degrees northeast. Convoluted beds and rill patterns show the effects of dewatering of the clay layers due to loading. Note the foliated shale clinging to the bottom of some graywacke beds. Sigmoidal tension gashes show orientation of compressive forces, although block rotation cannot be inferred here. A tight fold seen at the north end leads into another shear zone with fragmented graywackes in a shale matrix.

Stop 15 Here, middle to upper Austin Glen with turbidite beds vary from 3 to 7 m. thick with thin turbidites overlying them. Beds are steeply dipping (NW) with a northeast strike. Sedimentary convoluted beds can be seen at the south end.

Stop 16 This is a steeply dipping limb of a synclinal fold which plunges gently north-northwest. Complementary sets of tension gashes indicates direction of maximum compression. Sedimentary structures include rilled surfaces, cross-cutting tool marks, and to the north a 100 foot long by 60 foot (30 m. x 20 m.) high bed under-surface with large flute casts of bidirectional orientation. Shales are altered in color from black to orange, possibly due to incipient metamorphism. It is unfortunate that this as well as many other important geologic features have been painted over in the name of school spirit, young love, or personal identity

North of this outcrop is a tidal pool indicating the pre-railroad (1878) shoreline. Before the railroads were constructed the Hudson River shoreline was considerably more sinuous.

Stop 17 This outcrop contains more sedimentary structures such as convoluted bedding, parallel, horizontal tool marks and, to the north, curved tool marks. Structural indicators are fibrous calcite slickensides, and tension gashes whose sigma one direction appears to be perpendicular to that of the last stop. Here again, orange weathering shales are seen.

Stop 18 House on river, quarry. This quarry supplied graywacke curbstones for New York City. Near the river these middle to upper Austin Glen graywackes and brown weathering gray shales are quite deformed. Overturned shales are pressed against thick upright turbidites which dip 40 to 75 degrees southwest. In the quarry the beds dip 60 to 70 degrees southeast.

Stop 19 This outcrop contains varying lithologies with thick graywackes underlain and overlain by thin turbidites. Similar sequences are seen at several other outcrops. The south end of this section is a shear zone with folded, dolomitic graywackes enrolled in a shale matrix. Toward the north a thick graywacke is encountered, truncated by a reverse fault forcing thin turbidites around it. Immediately beyond, a thick section of 1 to 3 cm. thick graywackes and shales are displaced by faults every few feet.

Stop 20 Thin turbidites form an antiformal structure. Deformation is similar in style to Stop 19. Here, brittle deformation has resulted in at least 4 steeply dipping, cross-cutting faults. These faults separate the strata into zones with different orientations. At the south end the rocks dip 70 degrees to the east. In the next zone they dip about 30 degrees northeast, then 40 degrees northwest. They then change to 5 degrees to the west, and finally at the north end dip 40 degrees southwest and seem to dissect a north plunging anticline. Numerous tension gashes are exposed at the south end of the structure.

Stop 21 This outcrop begins in thin gray shales and laminated siltstones striking slightly west of north and dipping 65 degrees northeast. Small scale folds are well developed as are joint sets. To the north thick graywackes predominate. Here the beds have rotated to N35E, exhibiting tension gashes. North of the outcrop is a broken zone probably representing a fault.

Stop 22 Following a shear zone at the south end, the cut exposes thick graywackes with dolomitic, laminated turbidites. These beds strike S80W, and dip 35 degrees northwest. This is the first of two outcrops with this anomalous orientation. These rocks probably form a thrust slice separate from the surrounding rocks. This is probably an upper Austin Glen lithology.

Stop 23 Here is a continuation of the lithology in Stop 22. Thick, massive graywackes contain many rip-up clasts of foliated shale. At the north end of the outcrop laminated, dolomitic sandstones underlie the thick graywacke beds. These rocks strike S85E and dip 23 degrees NE.

Stop 24 These beds are oriented N60E to N40E dipping 40 to 67 degrees NW. This assemblage of rocks is dominated by thin turbidites with 10 to 15 cm. thick shale interbeds. This cut shows very good cleavage development with refraction of cleavage into the graywackes. Cleavage is oriented at N42E by 85 degrees SE. At the north end these turbidites dive under thick graywackes which lay at N85W, dipping 55 degrees, increasing to 90 degrees at the north end.

Stop 25 This outcrop consists of a 7 m. band of (2 to 30 cm.) turbidites underlain and overlain by graywackes up to 5 m. thick in a section totalling 40 m. (Hayden, 1986). Insoluble residue studies of some of these shales have revealed up to 55 per cent $CaCO^3$ by weight (Miller, 1986). This outcrop is extremely similar in lithology and cleavage orientation to those in an outcrop located across the Hudson River the Roosevelt estate, suggesting a continuation of structure across the river. The strata of the outcrop dip southeast at 15 degrees at the south end, flattens in the middle, then steepen to 25 degrees SE at the north end.

Stop 26 Crum Elbow. Here the lithology contains middle Austin Glen with 2 to 15 cm. thick turbidites and occasional thick graywacke beds. Cleavage in this outcrop is N35E dipping 76 SE. Several small thrust faults cause the bedding to splay in several directions at the center of the outcrop. Toward the north end of the outcrop is a kink fold whose axis trends N35E, plunging 73 degrees SE. North of this are lower Austin Glen strata striking N25E, dipping 35 degrees SE. The open valley and stream to the north probably indicate a fault zone.

Stop 27 This road cut contains the best stratigraphic section of lower Austin Glen north of Highland. A fault zone at the south end of the cut is traceable for a couple miles to the south-southeast, and forms the boundary between domains 3 and 4 (figure 1). The north edge of this fault zone contains small drag folds along the last two faults in the fault zone. North of here the strata are overturned, dipping steeply to the east. Thin (1 to 3 cm).

turbidites dominate the youngest part of the section, thick graywackes are common in the middle, and thin turbidites again dominate the north end with a few thick graywackes interspersed. Where outcrop on the east side of the tracks ends, another fault terminates the stratigraphic section. North of this are more complexly deformed rocks of the same type and age.

Stop 28 This cut begins at Mile Marker 76, continues for about 1000 feet (300 m.) and contains repeating, sometimes overturned sections of lower Austin Glen strata. These rocks strike about N25E dipping 74 degrees SE. These turbidites usually are 2 to 15 cm. thick. At the north end the graywackes and shales are highly disturbed with massive sigmoidal tension gashes, and en echelon phacoidal fragments of sandstone surrounded by a shale matrix. The stream is probably another fault trace.

Stop 29 This section is complexly deformed and folds plunge steeply northeast. Beds are alternately upright and overturned. At the south end the bedding is overturned, and forms an undulating, curved surface. Tension gashes are vertically oriented, with a number of en echelon sets exposed. In the middle of the section the beds are generally upright. Boudined calcite slickensides are exposed about in gray shale 12 feet up from the road. A massive tension gash oriented horizontally is over twenty feet long and may bend around the rock mass which it envelopes. At least three generations of vein filling can be identified including milky quartz, white calcite, and late clear calcite. The beds at the north end of this outcrop are overturned and are composed of gray shale and thick graywacke. Flattened flute casts are oriented in a near vertical position.

Stop 30 Here the uppermost Normanskill strata are seen for the first time. These are laminated siltstones and shales (usually less than one cm.) with occasional thicker graywacke layers. Here the beds are overturned, striking N8W and dipping 57 degrees NE. At the south end thick tension gashes are seen in the graywackes. Further north curvi-planar surfaces cut by joint sets are seen. These rocks seem almost 'reptilian' in appearance (curvi-planar with 'scales'). To the north, a thrust fault trace is exposed plunging moderately north. Massive tension gashes are exposed below, and up the cliff face they form large curving cavities. At the north end of the outcrop on the footwall of the fault the rocks are less deformed, although they still exhibit good jointing.

Stop 31 These rocks at Mile Marker 77 contain the same lithology as those in Stop 30; laminated siltstones and phyllitic shales showing good jointing. These beds are oriented N8E and dip 72 degrees SE. The strata, and most of those to the north and west continue for miles striking a few degrees east or west of north and dipping steeply east for the most part.

Stop 32 Rt. 299. These laminated siltstones, sandstones, and shales belong to the uppermost Normanskill strata. Bedding is variable as this location is near an inferred east-west fault zone. The Esopus fault lies about 3000 feet west of here. Fossil brachiopods are found in the disturbed rock, but the exotic trilobites found further south have not been seen here.

Stop 33 Railroad cut through north end of Illinois Mt. Here the Esopus fault lies to the south with rocks of the upper Ordovician Quassaic Group sitting to the west. These rocks form most of Illinois Mountain, and then bending eastward to form the hill to the northeast. The unnamed rocks of uppermost Normanskill are laminated sandstones, siltstones, and shales. They are seen on the east end of Grand Avenue and along a powerline running along the east side of Illinois Mountain. Numerous small brachiopods are found in these rocks. In the railroad cut rocks of the Slabsides Formation of the Quassaic Group are exposed. These are steeply dipping, medium to thick graywackes with thin shale interbeds. Shale clasts and limestone pebbles are much more common than in the Normanskill strata. Large strophomenid brachiopods are often seen on the bottoms of sandstone beds.

ROAD LOG FOR
STRUCTURE AND STRATIGRAPHY OF THE NORMANSKILL GROUP

This road log covers distances and routes for Stops 1 to 3, 11, 12, and 32, 33. Stops 3 to 31 are along a seven mile reach of the Hudson River accessible only by railraod right-of-way. Driving is prohibited except by permission of Conrail. Stop 3 is at Mile 70 and Stop 31 is at Mile 77. Refer to Figure 2 for locations of these stops. Stops 11 and 12 are on public right-of-way near Highland Landing and are logged here.

Cumulative miles	Miles from last point	Log
0.0		Intersection of Rt. 299 and Exit 18, I-87. Turn right (east) on Rt. 299.
5.2	5.2	Turn right at light onto Rt. 9W south.
7.4	2.2	Turn left at light onto Mile Hill Rd., follow sign toward Johnson Iorio Park. Continue parallel to Mid-Hudson Bridge approach.
8.0	0.6	Stop 1 at outcrop on left with good view of road-cut on right.
8.2	0.2	Continue east to Johnson Iorio Park. Stop 2 encompasses entire ridge on right.
8.4	0.2	Turn around and head west. Turn right on paved road.

8.7	0.2	Turn right on Oakes Rd. by river.
8.9	0.2	Pass under railroad bridge.
9.4	0.5	Pass under Mid-Hudson Bridge.
9.5	0.1	Park and walk to Stop 3 at Blue Point 1.8 miles.
10.1	0.6	From Stop 10 walk to car. Turn around and drive north to vicinity of railroad bridge where long outcrop is Stop 11.
10.3	0.2	Drive north on Oakes Rd. to Highland Landing-Mariners Harbor Restaurant Parking lot. Stop 12 across tracks to west.
10.4	0.1	Drive north and park near tracks to visit stops 13-31. This is a 5 mile hike one way. Railroad can also entered from north by driving north on Rt. 9W 5 miles to West Park and take right on Floyd Ackert Rd. Park near overpass of Rt. 9W.
11.3	0.9	Return to car and travel west on Main St. Turn right on Grand St.
12.1	0.8	Travel on Grand past side streets to intersection with Rt. 9W. Turn right (north).
13.0	0.9	Turn left at light onto Rt. 299 (west).
13.4	0.4	Pull off onto shoulder and park. Stop 32 on right.
13.7	0.3	Resume west on Rt. 299, and turn left onto South Chodikee Lake Rd.
14.5	0.8	Turn right on Old New Paltz Rd.

14.6	0.1	Stop 33 Hiking along power line to south will bring you to outcrops of uppermost Normanskill Fm. and exploration of hillside should lead to contact of Quassaic Gp. (Esopus Fault).
16.9	2.4	Drive west on Old New Paltz Rd. Pass over 2 railroad cuts and Pancake Hollow Rd. and several side roads. Turn left (west) on Rt. 299
19.3	2.4	Return to point of origin, intersection of Rt. 299 and I-87.

GEOLOGY ACROSS THE GREAT VALLEY:
from the Shawangunks to the Hudson Highlands

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Introduction

Orange County is a region of diverse geology, with bedrock ranging in age from Precambrian to Devonian, with structures ranging from klippe and overturned folds to relatively flat-lying strata, with geomorphic features varying from bedrock to glacial, and with fossils varying from the Otisville Eurypterid to the Sugarloaf Mastodon. Despite this diversity the county has not(with the exception of the Hudson Highland area) been the site of a great deal of geologic study.

On this field trip we will begin with the least deformed Silurian Bloomsburg and Shawangunk formations on the west side of the county near Port Jervis and traverse southeastward through succeedingly older and more deformed rocks of Ordovician and Cambrian age to the 1.1 billion year old Precambrian rocks of the Hudson Highlands following routes I-84 and 9W. We will not have time to see some of the interesting rocks and structures farther south along the New Jersey border but these have been discussed by Offield(1967) and Jaffe and Jaffe(1973).

Terminology

The problem of stratigraphic nomenclature, particularly along state boundaries and in complex areas, is frustrating both to beginners in geology and to old-timers. This area is no exception, especially when it comes to the Ordovician shale-graywacke sequence where no fewer than 10 different names may be found in the literature. An abbreviated stratigraphic column is given below showing the names and ages of the rocks we will see on this trip. Although the stratigrapher familiar with the area may cringe at what they regard excessive "lumping" of names(or even omission of some names between the Bloomsburg and Helderberg for example), and the geochronologist may frown at the lack of precision in the ages, I feel justified in leaving the details for other publications(many are listed in the bibliography). However I will try to explain some of the more significant usages I have chosen.

The Bloomsburg Red Beds is the name applied to the formation overlying the Shawangunk in Pennsylvania(Epstein and Epstein, 1972) while the High Falls Shale(or formation) has been applied in New York(Waines et al, 1983, and Fink and Schuberth, 1958). Since the formation as seen above Port Jervis(stop 1) is obviously not a shale and since it seems closely related to the stratigraphically equvalent formation described by the Epsteins, I have chosen to use the name Bloomsburg Red Beds.

The Ordovician shale-graywacke sequence, which I will refer to the Martinsburg formation, began as the Hudson River shales and since then has been variously referred to(in no particular order) as the Normanskill, Snake Hill, Austin Glen, Mount Merino, Bushkill aspect shale, Ramseyburg aspect shale, Pen Argyle aspect shale, and Taconic Affinity Shales(TAS) among others. See Waines et al(1983) as a starting place if you are interested in more detail. Since the Martinsburg is the most widely recognized name I have chosen to use it. As we traverse the county see if you can recognize distinctive, mappable lithologic variations in these rocks.

The Wappinger Group, a series of dolomitic to calcitic rocks, has been subdivided into a number of formations, however since we will not examine these rocks closely on this trip, I have chosen to use the group name.

The igneous/metamorphic rocks of the Hudson Highlands are quite variable. Helenek and Mose(1984) have mapped a number of different gneiss units. For this trip I will refer only to the Storm King Granite Gneiss which we will see at stop 8 and "other" gneisses which we will see at stop 9.

Simplified Stratigraphic Column

Devonian	Hamilton Group(sands, shales, silts)	
	Onondaga Limestone	
	Ulster Group	Esopus Shale(Grits)
		Glenerie Limestone
	Helderberg Group(limestones)	
Silurian	Bloomsburg Red Beds(High Falls)	
	Shawangunk Conglomerate	
Ordovician	Martinsburg Formation	
Camb./Ordov.	Wappinger Group(dolomite/limestone)	
Cambrian	Poughquag Quartzite(Hardyston)	
Precambrian	Storm King Granitic Gneiss and "other" gneisses	

Road Log

This road log will start at the beginning of the entrance ramp for I-84 at Exit 1 in Port Jervis, New York. It then goes eastward along I-84 to Newburgh then southward as far as Highland Falls. Mileages will be related to green interstate mileage markers when possible. Stop 4 will be made first during the field conference to avoid crossing the interstate with a group of people.

Total Miles	Miles from last point	
0	0	Entrance ramp to I-84 eastbound at Port Jervis(near the junction of N.J. 23 and U.S. 6). The cliff behind you is the sands and shales Lower Devonian Esopus formation(sometimes called the Esopus Grits in this area).
0.4	0.4	Enter I-84 at mile marker 1. Between mile markers 1 and 2 the ridge visible to the left(north) side of the interstate is Trilobite Ridge, a famous collecting locality composed of the Lower Devonian Glenerie Limestone.
2.4	2.0	The redbeds on the right are the sands and shales of the Silurian Bloomsburg Red Beds.
2.7	0.3	**STOP 1:** [Approximate mile marker location 3.3] Stop at the parking area. The view northwest from this overlook is across the valley of the Neversink River which flows in a valley composed of Devonian carbonates(the Onondaga Limestone) lying between the Shawangunk Ridge (to the right) composed of middle Silurian clastics and Allegheny Front(across the valley), composed of Devonian clastic strata of the Hamilton Group. The confluence of the Delaware and Neversink Rivers is to the left in Port Jervis. The

Delaware River can be seen to the southwest as it flows along the west side of the Shawangunk Ridge.

The rock cut to the west of this parking area is in the redbeds of the Silurian Bloomsburg Redbeds(or High Falls Formation) which strike approximately N.40°E and dip 25-30° NW at this location. They consist of fine red sands, silts and shales, often with mud cracks and gray reduction spots, interbedded with coarse, gray-green sands showing trough cross-bedding. There are noticeable carbonate grains in the coarse cross-bedded sands. The Bloomsburg, which is conformable with the underlying Shawangunk conglomerate(stop 2), is inferred to be an alluvial deposit with the coarse beds reflecting channel deposits and the finer redbeds being floodplain deposits. It was shed westward from the mountains of the Taconic Orogeny, which existed to the east, into a sea which existed to the west. This formation grades downward into the basal Shawangunk conglomerate which unconformably overlies earlier(pre-Taconic Orogeny) sediments.

Things to look for at this stop include:

1. Good cross-bedding in the coarse gray sands.
2. Carbonate grains in the coarse gray sands(what is their origin?).
3. Gray reduction spots in the redbeds. Some vertical reduction spots may follow burrows.
4. Pebbles of fine red silts/shales in the coarse gray sands.
5. Mud cracks in the finer sediments.
6. Invertebrate tracks. I have seen these at one other locality, but not here.

3.5	0.8	Mile marker 4. Elevation 1272 feet.
3.6	0.1	<u>**STOP 2:**</u> [Approximate mile marker location 4.2]

This location is at the angular unconformity below the middle Silurian Shawangunk formation and the underlying mid-Ordovician Martinsburg formation. At this locality the angular discordance is very slight which is the same as I have seen at other exposures of the unconformity in Orange County.

The basal Shawangunk is a quartz-pebble conglomerate with a sandy matrix which grades upward into a coarse sand with fewer and smaller pebbles. Some feldspar fragments are visible in the upper coarse sand areas. The limonite stain on the Shawangunk results from oxidation of pyrite which may be seen as minute grains in the matrix of the conglomerate. The Shawangunk has been interpreted as a beach deposit(Fink and Schuberth, 1962) and as a braided stream deposit in a complex transitional marine-continental environment(Epstein and Epstein, 1972).

Between the Shawangunk and the Martinsburg is a brown clay layer which may be seen in other exposures of the unconformity in this area. Waines(Waines, Shyer and Rutstein, 1983) has speculated on the origin of this layer and has called it a paleosol, although there are several other plausible origins. The other possibilities will be discussed on the outcrop.

Walking around the outcrop to the right(west) you may note some glacial smoothing of the dip slope and along a trench behind the outcrop you can see an exposure of slickensides on a fault plane which strikes N.60°W and dips about 65°NE. The slickensides plunge about N.40°W at 30°. According to Fink and Schuberth(1962) tear faults like this are more common farther south in New Jersey. There are also several quartz veins on the dip slope and they strike N.70° ± 10°W.

Things to look for at this stop include:

1. The clay layer at the unconformity.
2. Pyrite grains in the Shawangunk.
3. Slickensides on the tear fault.
4. Glacial smoothing and quartz veins on the dip slope.
5. Variation in quartz pebble size and quantity. An interesting question is what is the source of the quartz pebbles since they are not common in the underlying Martinsburg.

5.2 1.6 The swamp in the median and to the right(south) is an example of drainage interruption due to the highway. A beaver lodge is sometimes visible in this swamp.

9.2 4.0 **STOP 3:** [Approximate mile marker location 9.8]

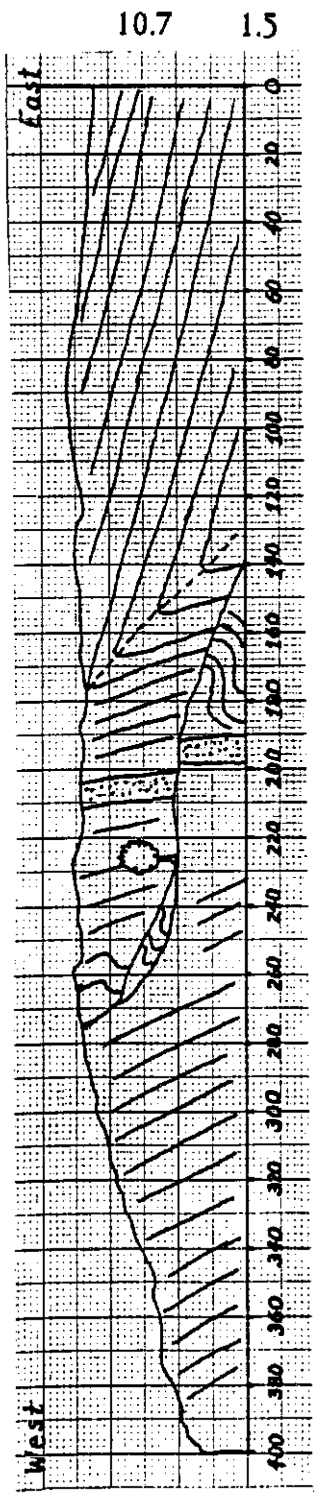
This is the first of four stops in the mid-Ordovician Martinsburg formation which will emphasize different types of structural deformation and sedimentary features.

At this location you can see more or less horizontal beds in the Martinsburg at each side of a section of almost vertical beds. The deformed structure is approximately 225 feet wide and varies from N.25°E., dip 82°SE on the south side of the highway to N15°E. and vertical on the north side. This seemingly isolated segment of almost vertical beds could be several things: an isoclinally folded anticline or syncline, a monocline downthrown to the northwest or to the southeast, a rotated fault block or possibly something else. The graywacke beds in the Martinsburg often show graded bedding so it is possible to determine the original bed tops in the vertical section. It appears the bed tops are all facing the northwest(thus eliminating the isoclinal fold possibility) and they show an obvious upward curvature at the west end of the tilted section. This suggests a monoclinal flexture downthrown to the northwest, but similar indications of folding at the southeast end of the tilted section are not apparent. I suspect the monocline has been cut off by faulting at the southeast end but the evidence is not clear.

A second question is when did the deformation occur. Conventional thought would relate it to the Taconic Orogeny of late Ordovician time, but Epstein and Lyttle(1986), based on work done in 15 areas along the Taconic Unconformity from Pennsylvania to New York, suggested that post-Taconic faulting had cut both the Martinsburg and the overlying Shawangunk. Compare this style of deformation with the other styles of deformation you will see in the Martinsburg at stops 4 and 6 and ask yourself whether this high-angle faulting might represent a different episode of faulting.

Things to look for at this stop include:

1. Grading in the graywacke beds.
2. Slickensides on the bedding planes of the vertical beds. Try to determine sense of motion of the slip.
3. Evidence for folding/faulting at the east end of the deformed section.



Stop 4: [Approximate mile marker location 11.3]

This cut is on the north side of the west-bound land of I-84[Note: During the field conference this will be the first stop so that we will not have to cross the highway].

At this location the Martinsburg shows a typical "suddenness" of intense deformation. Beneath the overpass and to the east of the overpass the beds are relatively flat and seemingly undisturbed, but about 130 feet west of the overpass the bedding is sharply deformed by an overturned anticlinal fold which has been cut by a thrust fault. This thrust fault and associated drag folding extends 140 feet further west where it curves upward to the top of the road cut in a characteristic listric-fault fashion. The fault and associated drag folds strike about N.40°E and dip SE. Be sure to compare this style of deformation, which I consider to be unquestionably Taconic, with the style of deformation you see at Stops 3 and 6 in the Martinsburg.

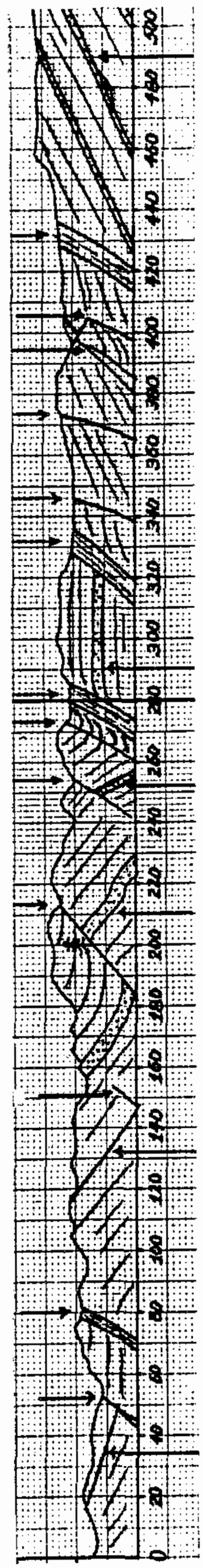
This is a good location to examine slaty cleavage in the shale layers. It strikes N.40-60°E and dips 25° SE, but does not penetrate the graywacke layers. This is a good stop to show students that slaty cleavage is a pressure phenomena unrelated to primary bedding.

The sketch at the left extends west from the overpass to the west end of the cut.

Things to look for at this stop include:

1. Slaty cleavage between the graywackes.
2. Synclines and overturned anticlines produced by drag folding.
3. The listric thrust fault. Try to estimate the amount of offset if you can find a suitable marker.

12.1	1.4	Underpass with wind generator to left(north).
16.2	4.1	Entrance to rest area.
17.6	1.4	**Stop 5:** [Approximate mile marker location 18.2] This is a brief stop to examine recent(1968?) deformation in the Martinsburg. Notice the drill holes on the south side of the highway. They have been offset by slippage in an up-dip direction to the northwest. I was told by Cliff Lloyd, who brought this site to my attention, that most of this deformation took place shortly after completion of the highway and that for a time the highway department had been quite concerned about it. I have stopped here a number of times since 1973 and there has been no noticeable change since that time. You can see that there are several slippage planes, each deformed by a thrusting motion, probably related to stress relief following excavation of the road cut. For a recent article on this phenomena with a list of reference see Bell(1985). He lists references to other such features in the Appalachians. Across the road you can see another thrust fault(Taconic) which strikes N.20°E and dips 35° SE. Things to look for at this stop include: 1. Amount of offset on the recent faults. 2. Drag-folding on the thrust fault.
25.6	8.0	Bridge over the Wallkill River.
27.0	1.4	Gravel flows on the right(south) side of the highway. The gravel, intended to prevent slumping of the underlying material, has itself flowed downslope. These flows have noticeably enlarged over the past few years. Do you think the motion is partly within the gravel, or is it merely slipping over the substrate? Compare this with the cuts at 34.0 and 35.3.
30.9	3.9	**Stop 6:** [Approximate mile marker location 31.5] This long road cut shows a number of interesting features, both structural and sedimentological, in the



Martinsburg formation. The diagram at the left extends along the cut on the south side of the highway westward from the overpass for 500 feet.

Structure: On the south side of the highway there are a number of faults which cut the strata. Examination of the drag folds and the offset of the strata at 200 feet show that these are mainly normal faults. This deformation does not seem to match the thrusting which was evident at stops 4 and 5. While it would be nice to see a normal fault offseting a thrust fault, I nevertheless believe this is a post-Taconic period of faulting. Whether these faults, downthrown to the southeast, are related to the deformation at stop 3(downthrown to the northwest) I can't tell.

North of the highway and east of the overpass are a pair of adjacent anticlines offset by a fault, and plunging in opposite directions. This in an interesting spot to have students test their powers of observation.

Sediments: The Martinsburg is a classic flysch deposit with the graywackes of the Martinsburg being classic turbidites(turbidity current deposits)(McBride, 1962). Turbidites are considered to have an "ideal" sequence of structures which has been called a *Bouma* cycle after the Dutch sedimentologist who described them in 1962. A complete Bouma cycle consists of the five divisions shown in the diagram below. Often some of the divisions are missing but the ones that are present are always in the same order. Proximal deposits(near their origin point) are more likely to have a significant A division whereas more distal deposits may consist only of divisions C, D, and E. Examine the graywacke beds closely and try to identify the various divisions of the Bouma cycle. Are these proximal or distal deposits?

Things to look for at this stop include:

1. Faults. What type? Amount of offset.
2. Drag folds along faults.
3. Oppositely plunging anticlines on north side of the highway.
4. Bouma cycles in the graywackes. Identify each division present. Are the turbidites proximal or distal?

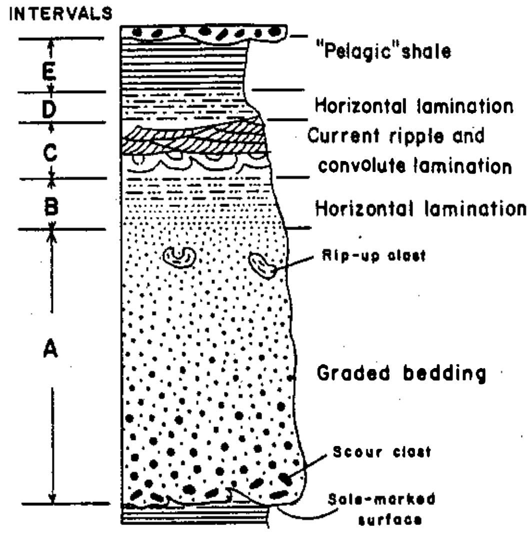


Diagram showing ideal sequence of structures (Bouma cycle) in a graded bed. (After Stanley, 1963, Jour. Sed. Petrology, v. 33, Fig. 2.)

33.1 2.2 Another long outcrop of Martinsburg.

34.0 0.9 Slumping in road cut to right. This cut was given no special engineering protection to prevent mass wasting. Compare this with the cuts at 27.0 and 35.3.

35.3 1.3 Gravel drainage zone around top of road cut to right. Highway engineers apparently decided to intercept the water which would percolate down the slope and cause mass wasting and drain the water off to the side. The lack of slumping or flow compared to cuts at 27.0 and 33.0 suggests it was effective.

36.2 0.9 **Stop 7:** [Approximate mile marker location 36.8]

This is one of perhaps 14 small(?) klippe, or allochthonous blocks of Precambrian Hudson Highlands material which was thrust northwestward during the Taconic Orogeny and then isolated from the parent mass by later erosion(other interpretations have been made but this is the one I like).

Toward the east end of the road cut you can see the Cambrian age Poughquag Quartzite, which at this location is noticeably conglomeratic. The pebbles are mainly quartz and the matrix contains substantial amounts of pyrite. Oxidation of the pyrite has caused the pervasive limonite staining of the rock. Toward the western end of the cut the Poughquag overlies Precambrian granitic gneisses in a classic non-conformity. The gneisses have been severely weathered and are almost unrecognizable at the first casual glance. The attitude of the unconformity shows that the Poughquag extended above the level of the cut on the north side of the highway and has been eroded away so that only gneissic material is exposed. This transgressive Cambrian sand marks the inundation of the continent following rifting of the continent after the Precambrian Grenville Orogeny. It probably represents a beach environment.

The outcrop across the entrance ramp to the northwest(onto I-84 west) is Martinsburg, so the basal fault below this thrust block **must** be located between the two cuts north of the highway, however I have never seen reference to it by anyone who noted it during the building of the highway.

Things to look for at this stop include:

1. The non-conformity at the base of the Poughquag.
2. The granitic gneiss below the unconformity.
3. Variations in pebble content in the Poughquag.
4. Evidence for faulting in the Poughquag.
5. Pyrite in the matrix of the Poughquag.

38.1	1.9	Road cut though Cambro-Ordovician age Wappinger Group Dolomites. These represent a stable shelf environment which existed here following the transgression of the Poughquag. They persisted until the downwarping of the continental margin began during the subduction and closing of Iapetus which preceded the Taconic Orogeny. They are overlain by the flysch deposits of the Martinsburg which are subduction-related (Isachsen, 1980). For additional information on these carbonates see Friedman(1975).
38.3	0.2	Exit right(south) off I-84 at Exit 9 to stoplight. Turn right at stoplight onto 9W south for 1 block.
38.35	0.05	Stoplight. Turn left onto N. Plank Road.

38.8	0.45	Stoplight. Make second right onto Leroy Place(not Liberty). Continue along this road - it will change its name first to Water Street then to River Road as it parallels the Hudson River.
40.2	1.4	Stop sign at Washington Street. Continue straight ahead on River Road.
40.3	0.2	Stop sign at Renwick Street. Continue straight ahead on River Road.
41.1	0.7	Start of oil tank area for Port of Newburgh on the left. Several of the homeowners in the area complained of devaluation of their property as this tank farm expanded. Would you agree?
41.8	0.7	Continue up hill following 9W south signs.
42.2	0.4	Curve left onto access ramp for 9W south.
43.0	0.8	Bridge over Moodna Creek. Continue south on 9W.
46.3	3.3	The hill in front of you marks the beginning of the Hudson Highlands. The road leaves the valley of Martinsburg sediments, crosses the northwest border fault of the Highlands thrust block and starts up the Precambrian gneissic material. The first outcrop is visible on the left shortly after you start up the hill.
47.9	1.6	**Stop 8:** Overlook at Storm King. [Note: During the field conference this will follow stop 9 so that we will be able to park at the overlook.]

This cut is an excellent exposure of the Storm King granite gneiss, at this location a two-feldspar, hornblende granite gneiss. The gneissic structure is shown by lineation of the amphiboles and a similar elongation of the quartz(Lowe, 1958, indicates there is "no clearly preferred space-lattice orientation" of the quartz). There are a number of pegmatitic zones in the granite and these have a similar mineralogy to the surrounding finer-grained areas. The pegmatite zones sometimes follow the strike of the lineation in the gneiss and at times cut across the lineation suggesting they are either late-phase crystallization or later remobilization of the material. The Storm King was first thought to be a late intrusion into the gneisses(Lowe, 1958) but is now suggested to be an early Grenville intrusion(Helenek and Mose, 1984, give a date of 1140 m.y.).

The overlook to the east provides an impressive view over the Hudson River.

Things to look for at this stop include:

1. Large hornblende crystals in the pegmatitic zones.
2. Orientation of the pegmatitic zones relative to the lineation of the gneiss.
3. Nature of the lineation.
4. A cross-cutting, epidote-filled fracture.
5. View from the overlook.

48.7 0.8 The proposed Storm King pumped storage reservoir site is on the right(west) side of the highway.

51.8 3.1 Exit right to Rt. 218 toward Highland Falls.

51.9 0.1 **Stop 9:** This cut exposes some of the "other" gneisses of the Hudson Highlands, and one of the best dikes you could ask for.

The gneisses are quite varied in composition and in several places show coarse-grained remobilized zones. Garnets are abundant locally but they are usually fractured and are difficult to remove from the gneiss. You can see how distinct the Storm King gneiss is from these other gneisses.

The dike, which is visible on both sides of the road cut, strikes across the road cut at N.47°E and dips approximately 70°NW but it curves markedly on the right(east) side of the cut. Close examination of the dike shows it to be mafic(dioritic to gabbroic) with accessory pyrite. There are excellent chilled margins with knife-edge sharp contacts with the country rock(best seen on the east side of the cut). There are also several apophyses(tongues) extending into the country rock. About 2 meters above road level on the east side of the cut, you can see two small light-colored intrusions into the chilled margin of the dike.

These obviously came from the dikes' still molten interior and thus are autointrusions, one of the clearest examples I have ever seen.

Facing the dike on the east side of the cut, you should notice the dark(mafic) band about 7 cm wide which parallels the right contact **inside** the chill margin. This mafic zone does **not** exist along the left contact but there is visible a zone parallel to the contact and inside the chilled margin characterized by coarse blebs of light and dark minerals. Similar zones are visible in the dike on the other side of the cut but they are harder to see because of groundwater which normally drains along the margins on that side. These dissimilar zones present a problem. Why is the dike not symmetrical? I am tempted to believe the mafic zone on the right is an example of crystal settling of the mafics and the blebby zone on the left represents the last stages of crystallization of the dike, but if this is true it would seem to require a significant upward rotation of the dike since its crystallization. I have not seen or read of a similar feature on other dikes in the area(Mack, 1962; Ratcliffe et al, 1983; and others).

Differential weathering is noticable at the top of the dike where the spheroidal weathering of the mafic dike is in sharp contrast to the minimal weathering of the surrounding gneisses.

The engineering techniques used to minimize the hazard of falling rocks are also worth mentioning. On the west side of the cut you can see rock bolts, a ledge and a fence(chicken-wire conglomerate). What you can't see is that they have replaced the guard rail on that side 3 times in the past 15 years and still there are dents visible **on top** of the rail. The fault zone visible above the ledge was the source of a major fall several years ago. A fracture pattern on that side of the cut dips into the cut so it is virtually impossible to totally prevent rock falls here.

Things to look for at this stop include:

1. Intrusive features such as chill margins on the dike, autointrusions in the dike, and apophyses from the dike.
2. Mafic and blebby zones in the dike.
3. Spheroidal weathering at the top of the dike.

4. Remobilized zones and garnets in the gneisses.
5. Evidence of falling rocks and engineering techniques to prevent them.

End of Road Log

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KARST AND STREAM CONSIDERATIONS IN THE ENVIRONMENTAL GEOLOGY OF THE MIDDLE RONDOUT AND ESOPUS VALLEYS, ULSTER COUNTY, NEW YORK

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INTRODUCTION

The geology of the middle Rondout and Esopus Valleys is as rich and varied as is the story of the struggle of the early colonial Dutch, French and English settlers of this region. The area has remained essentially rural in character until recently, but with the relative nearness of the nation's largest metropolis in the time of rapid transportation and hightech employment the region's land is quickly becoming developed.

Soils in these valleys are on bedrock of carbonates topped by thick deposits of till, modern alluvium and post-glacial lake bottom deposits. These valleys are well known for abundant harvests of sweet corn and apple production. Any acid precipitation is apparently neutralized by the carbonate character of the bedrock and the alkalinity of the streams that flow across them since no noticeable effects that occurred in these valleys. But the increase of population is coupled with a greater need for groundwater construction resources such as sand and gravel, and additional land fill sites for waste disposal. Land development has occurred here, as it has in many other areas, with little forethought and planning for environmental consequences. This field trip is a look at some factors that should be considered here and in other areas with a similar projected development of the land.

Figure 1 is a location map for this field trip. The trip can be taken with 11 stops or as either of its parts. The first part, trip G-I (stops 1-6) is a study of the environmental geology and hazards associated with Karst features of the Stone Ridge area; and the second part, trip G-II (stops 7-11) is a study of the environmental geology of the Esopus Creek Valley and some factors that may be at least partially responsible for apparently increased stream flooding and the resulting publicly-voiced concern of local residents.

The middle Rondout and Esopus Valleys are enclosed by clastic rocks of the Shawangunk Mountains to the southeast and the Catskill Mountains to the West. A more complete discussion of the bedrock geology of this "classic" area has been recently described by Lindemann and Waines (1987), and a postulated stratigraphic column of most of the formations of the valley is given in Figure 2. The Onondaga Formation is located stratigraphically 225-420 feet higher in the column than the Glenerie Formation. The basal Onondaga Formation beds are coarse-grained limestones containing abundant corals and large crinoid columnals, while the upper beds are fine-grained limestones containing dark-gray to black chert and bryozoa and brachiopod fauna.

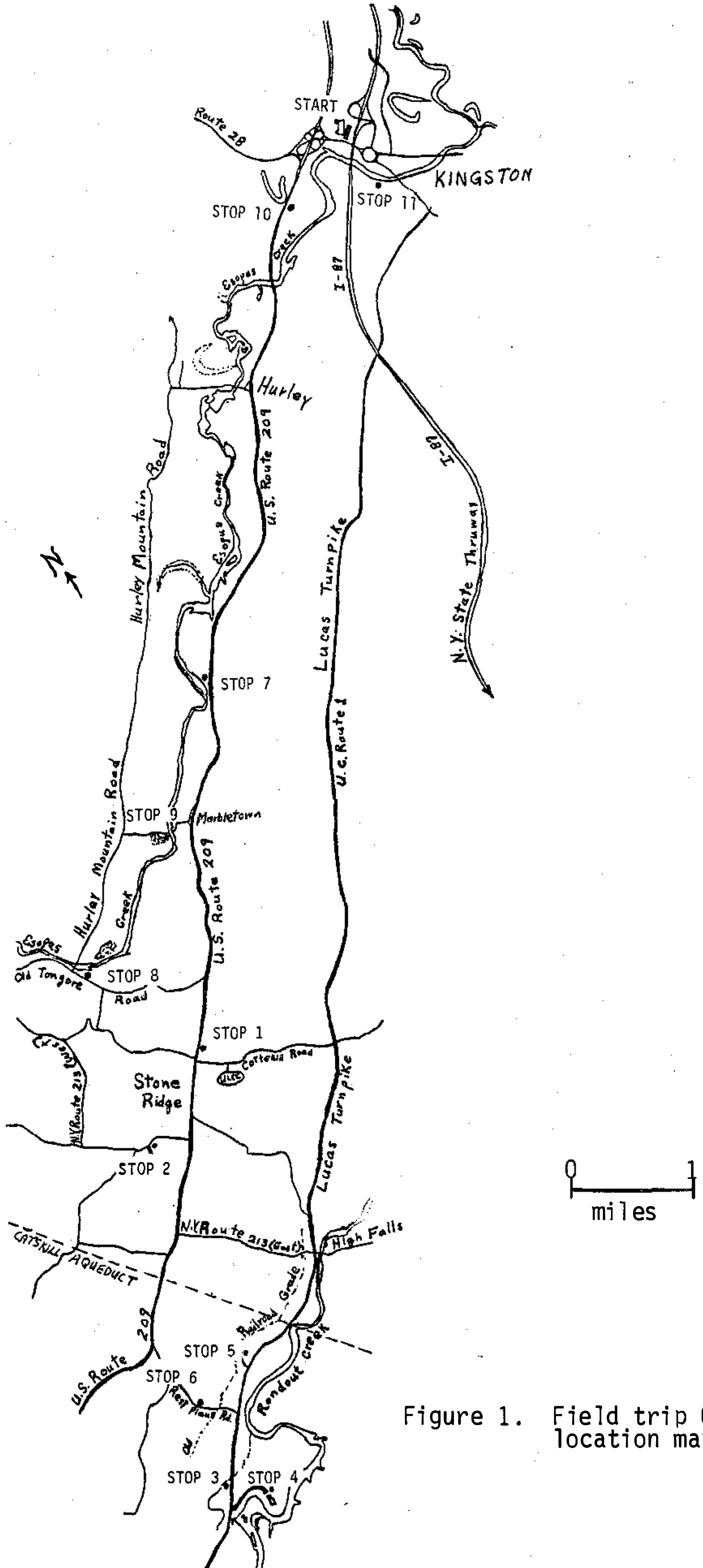


Figure 1. Field trip G field stops location map.

Karst features of the Stone Ridge, N.Y. area involve principally the Onondaga, Becraft and Rondout Formations, all quite pure limestones subject to dissolution. These units have been mined in open pits and shafts for the manufacture of natural and portland cement and for use as construction aggregate. A small solution cavity swallowing an intermittent stream is located in the Onondaga Limestone near the intersection of Route 9W and Route 199 near Kingston, N.Y. and outside of this field trip area.

Pre-Wisconsinan near-surface weathering may have led to the development of solution features along joint planes in the carbonates of these valleys.

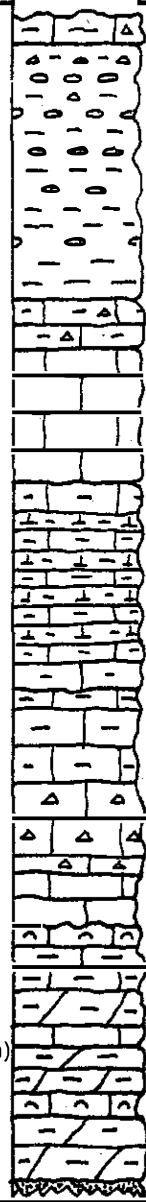
Concurrent with the forced closings of present landfills throughout the region, community leaders are faced with the difficult tasks of locating economically feasible waste disposal sites while also protecting their citizens, present and future. In order to locate and determine sites that are suitable for safe waste disposal, knowledge of site geology must be included. Early input by geologists and hydrogeologists may quickly rule out some areas before costly engineering and construction is performed. Conversely early study by geologists and hydrogeologists may affirm the inherent suitability of a site and allow progress in the difficult task of landfill selection. Important in the study of landfill site selection, in the proper management of sand, gravel and water resources and in stream flood control is an appreciation of the surficial deposits. The surficial deposits of the study area include lodgement till, modern alluvium and kames, (figure 3).

Figure 4 is the location map for a proposed landfill site near Rest Plaus Road in the Town of Marbletown. The geology and hydrology of the site and nearby areas proved to be more complex than could be estimated from published geologic maps and a brief study would indicate. Field trip part G-I examines the evidence that geological and hydrological data should be gathered and analyzed early in landfill site selection.

Field trip part G-II is a study of stream conditions that have become, at least in the eyes of the public, an increasing threat from flooding. The Esopus Creek has, however changed its course several times in the pre-history and perhaps early history of the area. With this fact in mind, present land-use practices may be evaluated less harshly than may immediately be apparent. Nevertheless, certain land-use practices, such as mining or other stream disturbances may upset a balance and increase existing environmental problems. We will examine the possible or probable effects of mining, agriculture, and residential and commercial development in the Esopus Creek floodplain.

ACKNOWLEDGEMENTS

My thanks go to many who have contributed their time and efforts to assist my study of these field trip areas, including



	CUMULATIVE THICKNESS	FORMATION	THICKNESS ± m (ft)	LITHOLOGY - REMARKS
LOWER DEVONIAN		GLENERIE	3 (10)	argil. ls., occl. chert
		PORT EWEN	30 (100)	argil. mudst. w/bands of ls. nodules and chert toward top
	30 (100)	ALSEN	6 (20)	argil. ls., sly. cherty
		BECRAFT	15 (50)	'crinoidal' ls., relatively soluble, possible aquifer
	61 (200)	NEW SCOTLAND	24 (80)	alternate calc. mudsts. and argil. ls., very fossilif.
	91 (300)	KALKBERG	21 (70)	argil. ls. at top grading to cherty ls. at base
		RAVENA	6 (20)	'crinoidal' ls. relatively soluble, possible aquifer
		THACHER	15 (50)	organic ls., argil. ls., argil. dol., occl. thin sh.
UPPER SILURIAN	122 (400)	WHITEPORT (RONDOUT)	5 (15)	argil. dol.
		GLASCO (RONDOUT)	3 (10)	organic ls., relatively soluble possible aquifer
		ROSENDALE (RONDOUT)	8 (25)	argil. dol.

Figure 2. Postulated Stratigraphic Column - Rest Plaus Property, Stops 5 and 6. Data Largely after Waines and Hoar (1967), diagram after Matson and Waines (1985)

several landowners who have allowed geologists and students to cross and examine their property, my college administrators who have supported an active UCCC geology field trip program and numerous students who have had to suffer with wet shoes, cold winds, and instructor lectures while on these field trips. The continuing support of my family in sharing my time has been most important. I especially am pleased to thank Dr. Russell Waines for the privilege of working with him (and thereby hopefully absorbing some portion of his depth of geologic understanding) and typists, Susan Salzmann, and Helen Chase, Assistant to the Dean of Instruction. Errors are assuredly mine. It is also important to me that increasing numbers of people learn and appreciate the important role of geology in protecting our environment. I hope this small study may encourage additional serious study and proper planning, and will be a help to secondary school science and introductory college science course teachers.

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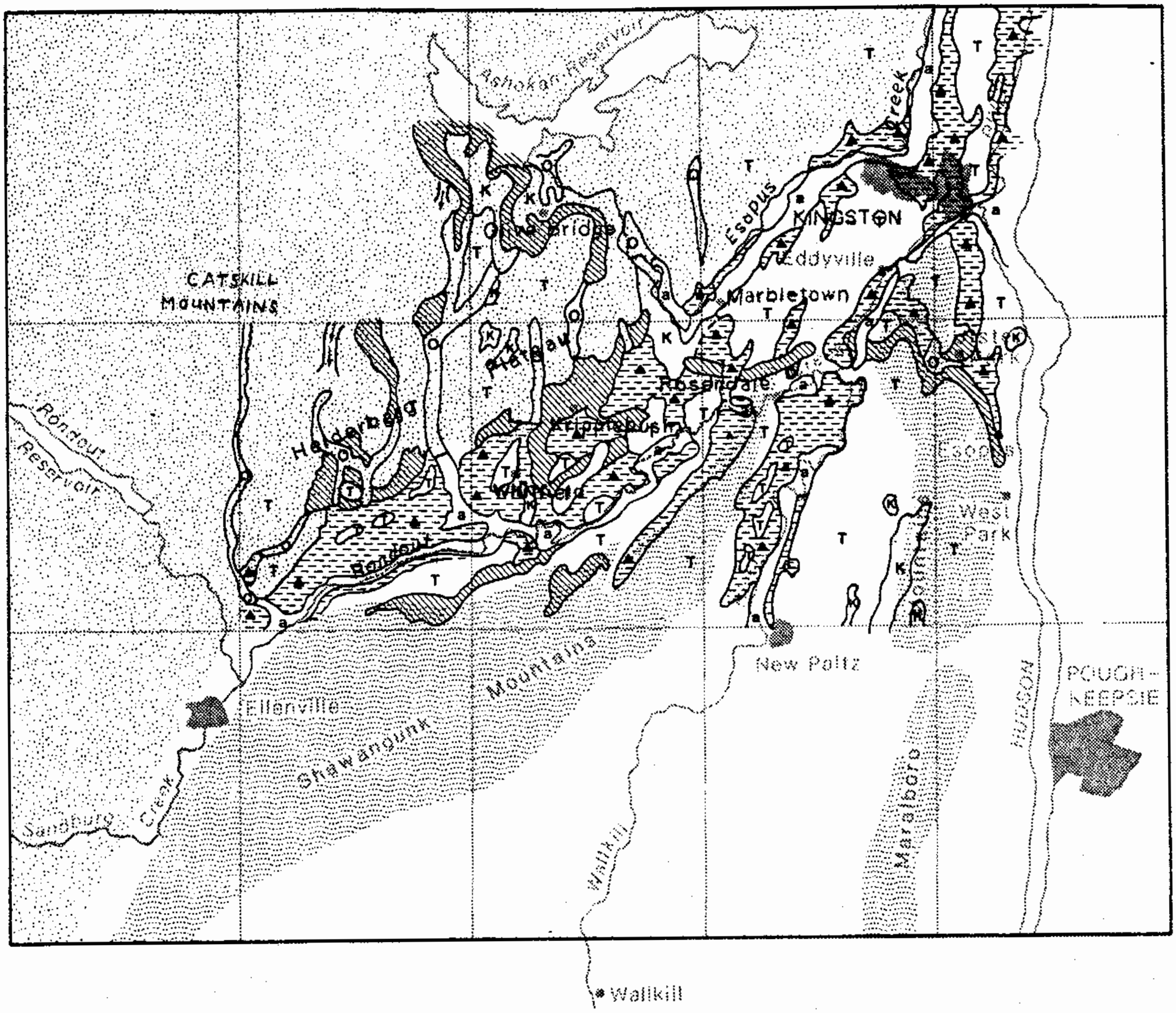
FIGURE 3. SURFICIAL GEOLOGY



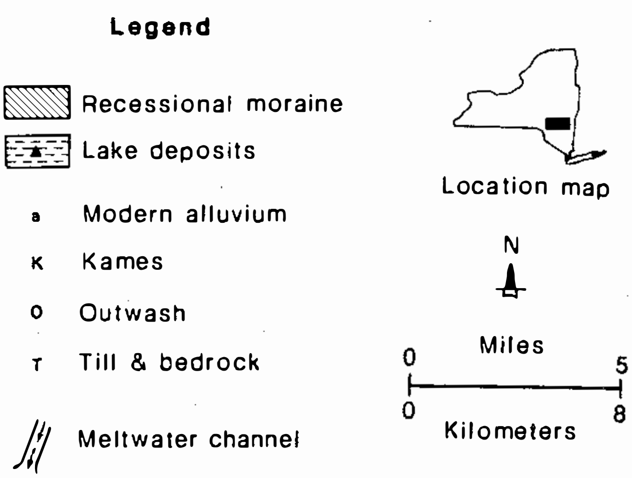


Figure 3. Surficial Geology of Middle Esopus and Rondout Valleys, Ulster County, N.Y. Modified from Dineen and Duskin (1987)

Road Log - Trip G

Cumulative Mileage	Trip G-I
0.0	Road log begins at the parking lot of the Ramada Inn, Route 28 west of Kingston, N.Y. - Kingston West quad.
0.1	At traffic light, turn right onto Route 28.
0.4	Take Route 209 Exit South, Ellenville.
1.2	Oxbow on right (west), and Stop 10.
1.9	Bridge over Esopus Creek.
2.9	Hamlet of Hurley and overpass.
3.4	Roadcut with Onondaga Limestone exposed alongside highway for next 1.5 miles.
5.7	Meander of Esopus Creek on right (west).
8.5	Onondaga Limestone (old quarry?) on right (west); entering hamlet of Stone Ridge.
9.1	Park along east side highway next to fruit and vegetable stand on the corner of Cottekill Road and Route 209.

STOP 1. Enlarging Sinkhole

This sinkhole was first noted in the mid-1970's. At that time, it was approximately 5 feet in diameter and provided a convenient drain for the then-producing grapevines nearby. In ten years, it has enlarged to its present diameter of about 20 feet, with two well-developed channels leading to it. A drain next to the highway leads to a storage basin that overflows with each heavy rain. CAUTION PLEASE: the storage basin cover is a lightweight steel plate and is usually lifted off the basin entrance by the force of the overflowing water; the opening is a danger to anyone walking through the brush along this road.

Another small sink has developed next to the foundation of the rear of the two-century-old house immediately north of this stop. Please respect private property and do not enter without permission. An additional sink is located east of the rear lawn, and some subsidence is in evidence on the front and side lawns.

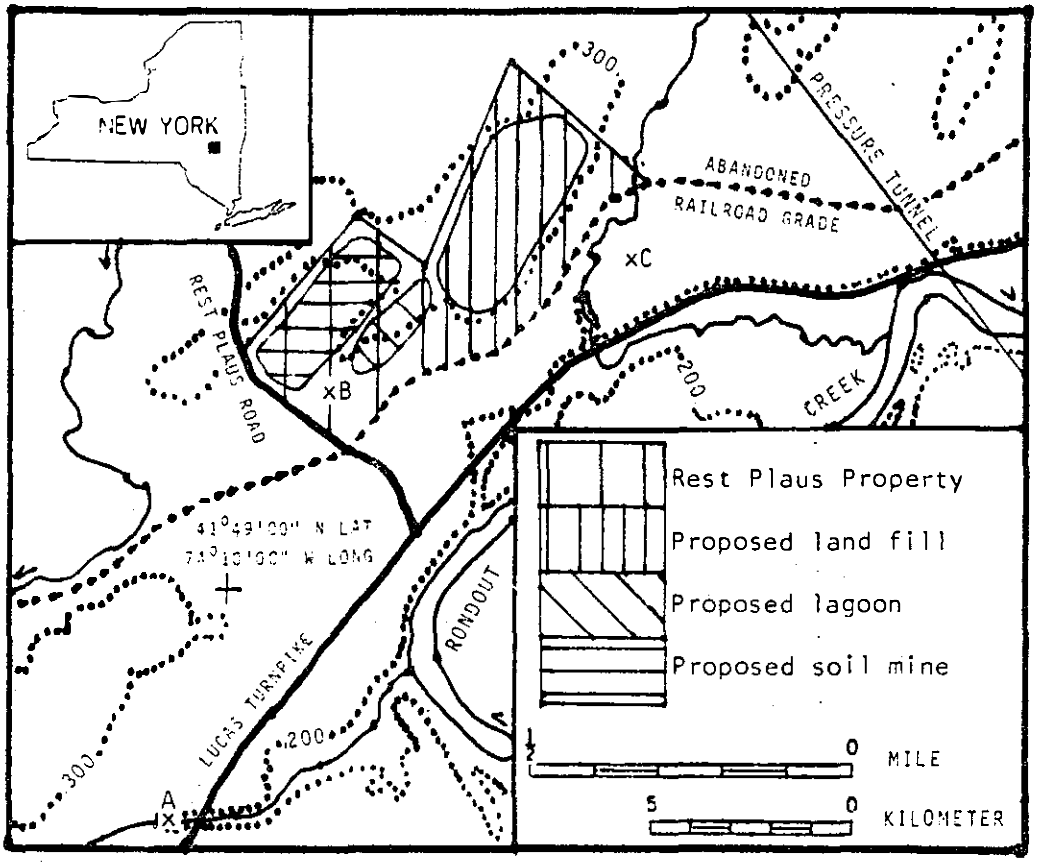


Figure 4. Location Map, adapted from Matson and Waines (1985). A on map is stop 3, C on map is stop 5, B on map is stop 6, location of sinkhole in the Becraft Limestone.

The former owner of the property on the west side of the highway wished to construct a small pond on the property. He excavated soil and lined it with clay as he was instructed by personnel with the State Department of Environmental Conservation, and watched it fill with rain water. He was quite perturbed to see the water go "down the drain." In the center of the dry basin was a hole about one foot in diameter which he sealed with cement. The man-made basin stays dry and the present landowners are evidently trying to fill it with debris.

The cause of the sinkhole development here is evidently the collapse of a cave or cave system within the Onondaga Limestone during a lowering of the local water table. When the water level dropped, the cave roof was unsupported and collapsed. The condition is accelerated by the entrance of surface water that can cause more solution of the carbonate bedrock.

In the mid-1970's, a company located about one mile to the north of this site was using water drawn from several drilled wells. The company reportedly had a need for a dependable and plentiful supply of water and were concerned that the water level in its wells had dropped more than 40 feet in three or four years. The company wanted to know where it should drill for more water. At least one neighbor was concerned that the company's drilling for more water was causing his household well to be contaminated with silt and clays. The company was advised to obtain its water from the west side of the highway from tills and alluvial sediments in the Esopus Valley. This "solution" has evidently ended for the present the company's water supply problems.

The cause for the lowering of the local water table is difficult to determine. The construction of the wider highway may have restricted important recharge locally (Egemier, personal communication). Ulster County Community College with large, impermeable parking lots and increased commercial development locally may all be withdrawing much water and preventing recharge that could result in a lowering of the water table. There has been a significant increase in the number of homes built nearby, and all have drilled wells with cones of depression that may cause a lowered water table. The temperature-precipitation conditions may have changed to decrease the ground water recharge. A stream, local excavation, or road-cut nearby may have intersected a cave or fracture system that is now flowing as a spring. Of course, the lowering may be a natural event producing a sinkhole that should be considered normal in a carbonate bedrock located in a humid region. Well-developed sinkholes that are located at Stop 2 have evidently formed naturally during the past.

Continue driving south on Route 209.

9.8 Intersection of Route 209 and Route 213 West; turn right onto Route 213 West.

10.0 Sinkhole pond(?) on left.

10.25 Turn left at Hendricks Lane and park along the side road (old Route 213).

STOP 2. Hendricks Lane Sinkholes

Positions of at least four sinkholes can be seen in the field to the south. They can be recognized by stands of large trees. Farmers were not able to work the land at sinkholes and trees were allowed to grow there. A sinkhole in the field to the north was covered during the early 1980's. It will be interesting to see how long it will remain covered and tillable.

Return to cars and drive east on Route 213 back to Route 209.

10.7 Intersection with Route 209, turn right (south).

11.0 Town of Marbletown, Town Hall on left.

11.5 Intersection with Route 213 East, turn left (east).

12.7 Limestones in roadcut, former railroad overpass at hamlet of High Falls.

12.8 Light at High Falls intersection with Lucas Turnpike (Ulster County Route 1); turn right (south).

13.1 Rondout Creek meander on left.

13.5 Rondout Creek meander on left.

14.7 Limestone on right, New Scotland and Kalkberg Formations.

15.0 Bridge over dry Kripplebush Creek and parking area on right side of road. Park car and walk to dry creekbed, Stop 3.

STOP 3. Pompey's Cave

A suggested explanation of the initiation of this cave and subsurface drainage follows. Kripplebush Creek has cut through a recessional moraine at the hamlet of Kripplebush and its course meanders considerably as it flows southeasterly across the post-glacial lake bottom deposits and empties into the Rondout Creek nearby. The Rondout Creek flows over a shrinking waterfall ~ 2 miles north at High Falls since the caprock is dipping west. As the waterfall height lowers and as the Rondout Creek above the waterfall continued to erode through the carbonates, the base level of the Kripplebush Creek was lowered and the local water table dropped. Subsequently, the lower reach of the Kripplebush Creek was rejuvenated and has cut into the Rondout carbonates. The water evacuated from the cave beneath the Mg-Carbonate member of the Rondout Formation following the lowering water table, and eventually the surface stream began seeping downward through and, thereby, enlarging joints in the Rondout carbonates. This probably occurred first in joints near the Rondout Creek, then later in joints farther upstream. Now, the stream enters several "swallow holes" upstream and has become an underground stream flowing presumably into the Roundout Creek. Indications are that this process will continue and, in fact, the upstream, meandering portion of the stream seems to be rejuvenated more each year; it is expected that the increased downcutting will result in additional sinks developing in the stream bed as long as the surface water can enter a cave below it.

Note the character of the dry stream bed near the Lucas Turnpike bridge. Joints are apparent, and well-developed mudcracks can be observed. An entrance to the cave is located a few hundred feet "upstream" in the dry stream bed, and a homemade ladder is constructed to assist people who wish to enter the cave. CAUTION: The property owner has not chosen to "post" or restrict valid study of this local phenomenon. If you decide to enter, please realize it is your decision and you have decided to assume any associated risk. Before studying or entering the cave, you may wish to walk upstream farther to see a partial collapse of the stream bed into the cave below, and to observe the stream entrance holes farther upstream. CAUTION: The fields nearby are used for pasture for cattle. Be careful that a bull in not loose nearby or you may need to make a hasty retreat downstream! If you decide to enter the cave, check each ladder rung very carefully to determine if it will hold your weight. Always leave at least one person on the surface to obtain help if the ladder breaks.

Return to the cars and drive south to the driveway for the United Methodist Church Camp.

15.1 Turn left into Camp Epworth and drive to the lodge parking lot and park.

STOP 4. Rondout Creek Meander

This vantage point provides an excellent view of the Rondout Creek at a magnificant sweeping mobile meander. During flood stage, the stream severely undercuts its bank and some slumps and subsidence have occurred. Return to cars and drive out to highway.

15.7 Lucas Turnpike, turn right (north).

17.0 Turn left and drive up a slight incline and park in the lot of Rondout Manufacturing Company (RMC).

STOP 5. Artesian Spring and Pool

A fence protects an unwary visitor from the artesian spring (locally called a sinkhole) located near the western boundary of the RMC parking lot. This is reported to be the third protective fence placed around this feature, following the enlargement of the pool and loss of the fences. This lot was a sand and gravel quarry that was mined until the operators noted the appearance of groundwater surfacing. After mining ceased, the property was developed in the 1970's as the current operation. Water broke through the sand forming an apparent sinkhole. Evidently, sand is flushed out and onto the land surface with occasional increased water flow, causing a pit to form filled with water. The pool within this pit was plumbed to be about 40 feet deep in the early 1980's. I have observed water, and possibly gas bubbles, ejected one or two feet into the air, with the appearance of "rising" and/or "jumping" fish! The aquifer feeding this spring is unknown and somewhat of an enigma, since the elevation of discharge is about 30 feet higher than the nearby unnamed stream. The surrounding surface is generally at a lower elevation and increased discharge does not seem to be immediately correlated with rainstorms. No geochemical tests of the water or continuous studies or monitoring of discharge are known. Could this spring be the outflow of a leak in the nearby Rondout Pressure Tunnel section of the New York City Aqueduct? Clearly, additional study is warranted and could prove interesting. In any event, it does indicate that the hydrology of this area is not well-known.

Drive back to highway.

17.2 Turn right (south) onto Lucas Turnpike.

17.8 Turn right onto small road named Rest Plaus Road.

18.0 Narrow former underpass of former railroad. The rocks used in constructing this underpass/railroad bridge foundation were taken from the old Delaware and Hudson Canal works. Continue up slight grade and park along road with flashers on.

18.1 STOP 6. Rest Plaus Road Proposed Landfill Site

This site was considered as a landfill for the Town of Marbletown in the early 1980's. The landfill would be located within the shielding forest to the northeast with a leachate lagoon located on the southwest. The soils of the land on the western portion of the property would serve as the mine for the daily landfill cover, as well as to provide for some future expansion of the landfill if needed.

Near the southern boundary of the property, a small stand of trees can be seen from the road in the field. Close examination shows that the trees are growing within and around a shallow, filled sinkhole. Blocks of the relatively soluble Becraft Limestone are exposed, and dissolution has occurred between the separated limestone blocks which are at slightly different attitudes. Some surface runoff is passing into this depression. At various depths, Becraft Limestone and other limestones less susceptible to solution and sinkhole development underlie the proposed lagoon and landfill areas, as well as the proposed landfill mine.

Some less obvious solution effects can be observed along joint planes and limestone nodule layers in the Port Ewen mudstones. These appear to occur within 2 m. ($\sim$6 ft.) of the bedrock surface and can be seen after a short walk along the abandoned railroad grade along the east border of the site.

In addition to solution effects calling into question the use of the site as a landfill, there is some evidence that a southeast-northwest thrust in the Port Ewen Formation occurs in the eastern limb of a northeast-trending plunging syncline, projected along the hillside and crossing the abandoned railroad grade. Also, a much smaller, narrower, more tightly folded, northeast-trending and plunging anticline may project into the southern half of the property and may pass through the location of the previously described sinkhole in the Becraft Limestone.

Clearly, additional geology and hydrology investigations are called for before this property should be used as a landfill. The recent search for a town landfill has been abandoned, and there are at present no known plans to determine the suitability of this site.

Return to cars and continue driving west.

18.6 Intersection with Old Kings Highway - continue straight (west).

18.8 East overview of Stop 6, former proposed landfill site.

18.9 Intersection with Route 209.

END OF FIELD TRIP G-I. To return to Ramada Inn, turn right and drive about 13 miles north.

Start of Trip G-II.

18.9 Turn right (north) onto Route 209.

19.9 Intersection with Route 213 East, drive straight on Route 209 North.

20.3 Hamlet of Stone Ridge, N.Y.

24.9 Meander of Esopus Creek along west side of highway.

25.1 Turn left onto short drive to Esopus Creek.

STOP 7. Esopus Creek - "Bathtub"

This area is called locally the Bathtub. Reportedly, sand and gravel mining was conducted here, along the outside of a stream meander. During a flood in the 1960's, the stream cut through the narrow berm separating the quarry from the stream, and the quarry became a portion of the stream. Mining operations have been relocated to several other areas of the Esopus Floodplain; we will visit some of the newer operations.

Environmental problems associated with a breach of quarry operations that could affect the Esopus Creek include the following. (1) The stream slows when entering the wider, deeper area, and exposure to additional light coupled with less shade from protective shoreline trees will warm the waters. The warming waters will be expected to hold less dissolved oxygen and the stream ecology will, thus, change. This renowned fishing stream will probably produce fewer trout in the future. (2) More rapid stream bank erosion may be expected during flood stage causing an increase in stream sediment load. This also is expected to change the stream ecology. (3) Increased erosion here should produce increased stream channel deposition downstream, and more over-bank flooding more often. Communities downstream include the hamlet of Hurley, the City of Kingston, the hamlet of Lake Katrine, the Town of Ulster, and the Village of Saugerties; increasing concern is being expressed in local newspapers by citizens and local government officials (Kwiatoski byline, Kingston Daily Freeman, 10/2/87 and 10/5/87). The usual call is for the Army Corps of Engineers to dredge, channelize, or to otherwise provide increased flood control of the middle Esopus Creek.

25.1 Return to cars and turn right (south) onto Route 209.

27.8 Turn right onto Tongore Road (Old Tongore Road on Mohonk Lake, N.Y. Quad.) and drive west. CAUTION: Make sure you slow down well before this turn and signal a right turn to avoid a rear-end collision, a common occurrence here.

29.0 STOP 8. Town of Marbletown Park, Esopus Creek

A kame can be seen to the south that has been mined since the late 1970's. A kame is valuable for sand and gravel mining, since it is sorted by glacial-fluvial processes and operations can thereby save considerably.

The Esopus Creek enters the valley about one-half mile upstream (west) of this stop and begins a broad meander to flow northeasterly. Mining of sand and gravel deposits was done on the floodplain on the opposite side of the stream, evidently in accordance with (then) existing state and local regulations that required a minimum 10-foot berm to be left untouched. Floods of the late 1970's repeatedly breached the berm; and repeated efforts to reinforce the berm with at first gravels and then a steel wall continually failed. Rapid bank erosion has begun on the south side of the Esopus. In 1977, a row of trees about 20 feet wide existed from the man-made sand beach to the east along the creek. These have been washed away. The channel downstream is evidently filling with gravels, and it appears the stream may be changing its course here because of, or in spite of, the mining disturbance.

Return to cars and continue driving west on Tongore Road.

29.4 Turn right (north) onto Hurley Mountain Road, unnamed on Ashokan and Kingston West Quads.

29.45 Cross bridge over Esopus Creek.

29.8 On the left side, is this a meander scar of an earlier Esopus Creek channel?

30.4 Is this an oxbow of an early Esopus Creek? This was a nearly filled pond until the 1980's, when it was dredged to provide a more attractive pond. It is possible that the stone house was contructed alongside a well-flowing stream two or three centuries ago. Several small streams flowing into the valley seem to flow into meander scars of a once larger stream. Of course, they may have constructed these meanders themselves if they previously had a greater discharge. However, several other undoubtedly Esopus Creek oxbows and meander scars are apparent from a study of the Kingston West Quad.

30.7 Crossroads of Lomontville, turn right (south) onto Fording Place Road.

31.1 Sand and gravel mining on right side; operation has been intermittent during the 1980's.

31.2 STOP 9. Fording Place on Esopus Creek.

Sand and gravel mining can be studied here. Note that an operation in modern alluvium, ground moraine, and lake deposits must include mechanical separation or grading. This increases mining costs to the operators. Occasional glacially carried boulders and cobbles can be found here, recognized by facets and striae. Note also that the operations of the mine are near the stream and the berm is occasionally breached by floods. When water is low, many local residents ford the stream here with their vehicles. The hamlet of Marbletown is located on the other side.

Cautiously turn around (since local residents are not used to finding cars blocking their accustomed stream crossing), and drive back on Fording Place Road.

32.4 Turn right (north) onto Hurley Mountain Road.

33.1 Fallen rock zone; cliff prone to landslides. This valley wall was probably cut by the glacier(s), but the cliff base may have also been undercut by an early meandering Esopus Creek.

33.7 Landslide prone area. Rockslides and slumps occur here about every 7 to 15 years, often covering the roadway. The highway department has each time quickly removed the supporting talus at the base of the cliff, probably encouraging additional future landslides. Note the "blocks" of rock (Hamilton Formation, shales and siltstones) that are ready to break loose along joints.

35.7 Turn right onto Wyncoop Place (no sign and not named on Kingston West Quad.), now occupied by Englishman's Creek, a local name.

35.8 Crossing over a meander scar of early Esopus Creek? At the end of Evergreen Lane, a broad, open oxbow lake, a meander of an early Esopus Creek can be seen (on private property). This oxbow lake is apparent on the Kingston West Quad.

36.2 Lawns of the houses on the left were severely damaged by Esopus Creek floodwaters during the heavy rains of mid-April, 1987. If the rains had occurred with a melting snow, the damage might have been more serious. Large "potholes" or "swirlholes" over 10 feet in diameter, several feet deep, developed in at least one lawn. The damage has since been repaired by residents.

36.3 Bridge over Esopus Creek.

36.4 Stop sign at hamlet of Hurley, N.Y.

36.5 Intersection with Route 209, turn left (north).

37.5 Bridge over Esopus Creek, rip-rap placed along stream bank.

38.2 STOP 10. Oxbow Lake

A large gravel-covered area on the right side of the road provides ample parking space. If you cross the road, use extreme caution since cars are leaving a controlled-access four-lane highway here and are often travelling at a high speed.

Some area residents believe that the stream's channel was changed by man during the construction of this newer section of Route 209, and that the pond along the west side of the highway was where the pre-highway Esopus Creek was flowing. The 1942 Kingston West Quad, however, shows that this existed before the highway was constructed in the early 1960's. It is certain evidence that the Esopus Creek has changed its course in the past, and probably will continue to do so in the future barring complete channelization.

This oxbow is undergoing rapid eutrophication now, since the nearby agricultural fields are heavily fertilized; normal runoff is feeding the vegetation within this oxbow.

Return to cars and drive north.

38.6 Turn right onto Route 28 Exit to Kingston, N.Y.

39.2 Traffic circle; turn onto first exit, Washington Avenue, Kingston.

39.7 Bridge over Esopus Creek.

39.8 Turn left (northeast) at traffic light onto Schwenk Drive.

40.0 Turn left (west) into Kingston Plaza and take first left into drive along the side of the Sear's Department Store. Drive to the right in back of the Plaza and park.

40.3 STOP 11. Plaza Flood Control Project

Flooding during January thaws and spring melts of 1976-1978 caused citizens, commercial interests, and politicians to request the Army Corps of Engineers to provide flood control. The Corps of Engineers at first suggested that flood control might not be wise since it might cause increased flood problems downstream (north), but a compromise was agreed upon to construct flood control on the Plaza side only. High waters are now not a hazard to the stores, but some people have wondered if flooding of the oposite side might become more common now that nearly all the flood waters must flood onto the opposite side.

40.5 Continue driving along the flood control dike. Note that high flow water can be diverted to a confined wetland to allow some groundwater recharge.

41.1 Exit the Kingston Plaza and turn right onto Schwenk Drive.

41.4 Turn right (north) at traffic light onto Washington Avenue.

41.6 Bridge over Esopus Creek.

41.9 Traffic circle.

42.0 Take first right after N.Y. State Thruway (Route I-87) entrance, turn right into the parking lot of the Ramada Inn.

42.3 END OF FIELD TRIP G-II.

GENERAL STRUCTURE AND ORDOVICIAN STRATIGRAPHY FROM THE MARLBORO MOUNTAIN OUTLIER TO THE SHAWANGUNK CUESTA ULSTER COUNTY, NEW YORK

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INTRODUCTION

The Lower Wallkill Valley lies within the western portion of the Appalachian fold belt and is approximately 70 miles (43.5 km) northwest of New York City (fig. 1).

Within the study area the eastern side of the valley is flanked by Ordovician flysch deposits forming the Marlboro Syncline (Waines, 1986). On the western side is the Shawangunk Mountain escarpment capped by the Upper Silurian Shawangunk Conglomerate.

The Middle to Late Ordovician Martinsburg Formation forms the bedrock of most of the Lower Wallkill Valley while the bedrock on the eastern side is underlain by Middle to Late Ordovician Quassaic arenites. Most of this is usually blanketed by Wisconsinan till or alluvial deposits derived from the Wallkill River (Connally and Sirkin, 1967).

Because of structural complexities, infrequent fossils, and lack of stratigraphic markers it is difficult to establish close lithologic correlation within the Martinsburg Formation.

Previous attempts to determine and depict the structure and stratigraphy of the area by Holzwasser (1926), Rickard(1973), and Waines et al. (1983) have not been entirely successful. An increase in bedrock exposures as a result of recent road construction together with geologic data acquired from the Delaware West Branch Aqueduct (City of New York Board of Water Supply, 1938, 1939), Catskill Aqueduct (Board of Water Supply, 1905-1918), and logs from three wild cat wells (Susi, Modena, Minnewaska) have

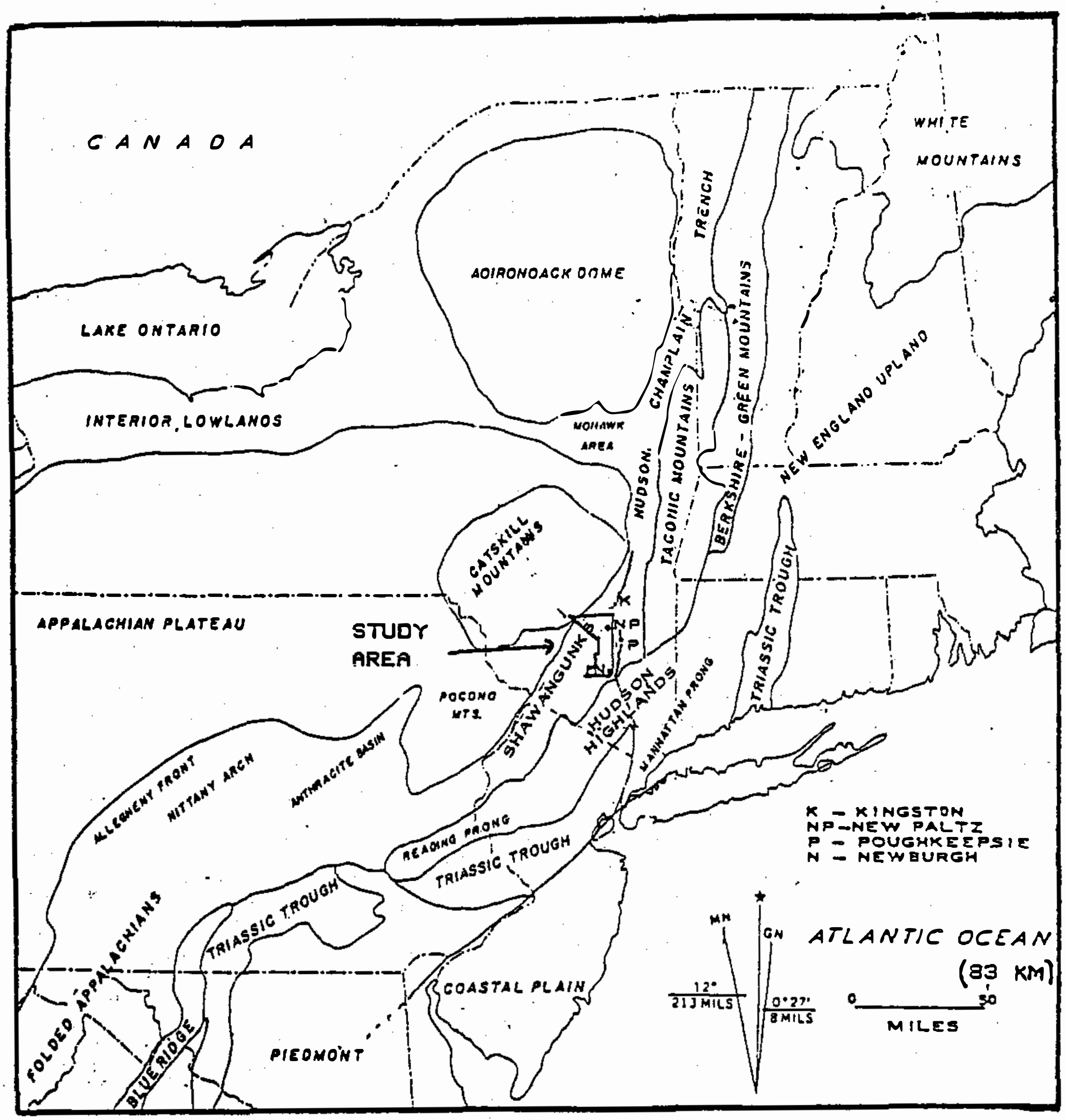


Figure 1

REGIONAL SETTING OF STUDY AREA

(Adapted from H.A. Meyerhoff, 1963, in NYSGA Guide Book 35th Ann. Meeting, p. 17, Fig. 1) enabled the construction of a composite northeast-southwest structure section (Kalaka, 1985, fig. 23). This section extends from the center of the Marlboro Mountains near Lloyd, New York westward through the Martinsburg Formation in the eastern central, central, and western portions of the valley continuing under the Shawangunk Mountains almost to Wawarsing, New York (figs. 2 and 3).

The section reveals three major structural domains (east to west): (1) a monoclinal, southeast-dipping domain in which an arenite facies shales to the west and southwest (west limb of the Marlboro Syncline); (2) a complex domain involving mostly shales (central portion of the Wallkill Valley); (3) an open fold domain involving mostly shales (western portion just east of and under the Shawangunk Cuesta) (Kalaka, 1985, fig. 24), (fig. 2).

STRATIGRAPHY

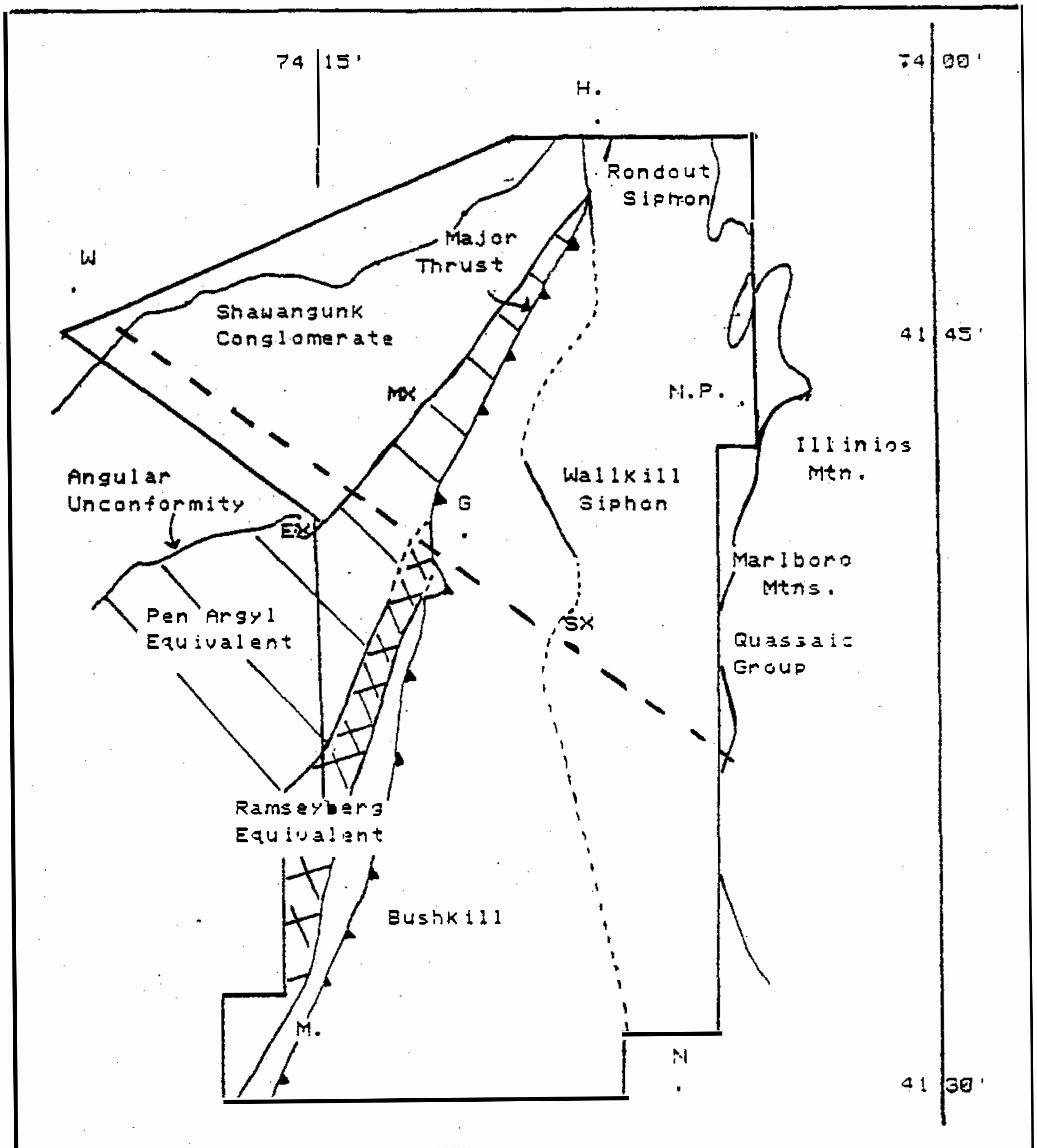
The Lower Wallkill Valley is underlain by three main stratigraphic units (Kalaka, 1985, fig. 14). In the north-south trending Marlboro Syncline the 10,000 foot (3048m) Ordovician Quassaic Group outcrops as medium bedded sub-graywackes and quartz arenites (Waines et al., 1983; Waines, 1986). In the eastern central, central, and western portion of the valley the Bushkill Shale (lower member of the Martinsburg Formation) crops out. In the western portion, possible stratigraphic equivalents of the middle and upper Martinsburg are overlain by the Shawangunk Conglomerate with angular unconformity.

SHAWANGUNK CONGLOMERATE On the western margin of the valley the Shawangunk Mountain Cuesta is capped by a late Silurian, white, vein quartz conglomerate that is in angular unconformity with the upper portion of the Martinsburg Formation. Thickness ranges possibly between 600 and 300 feet (92m) in the study area (Waines and Sanders, 1968).

QUASSAIC GROUP This group is late Medial to medial Late Ordovician in age. It consists of a 10,000 foot (3048m) sequence of arenites which have been subdivided into five formations which, top to bottom, are: Creeklocks (1410 feet, 430m), Rifton (2509 feet, 765m), Shaupeneak (2115 feet. 645m), Slabside (2214 feet, 675m), and Chodikee (1640 feet, 500m) (Waines, 1986). The group occurs as an outlier occupying the Marlboro Syncline with the east limb of overturned arenites determining the trace of the Marlboro Mountains (Waines, 1986). To the west and southwest the lowermost three formations appear to grade rapidly into the Bushkill Member of the Martinsburg Formation.

MARTINSBURG FORMATION AND EQUIVALENTS The eastern central, central and western portions of the valley are underlain by Medial to Late Ordovician Martinsburg Formation. This unit (composed primarily of dark gray shales and siltstones and less frequent arenites) has an estimated maximum thickness of about 12,000 feet (3659m) (Kalaka, 1985). To the east it appears to grade into the lower Quassaic arenites and to the west it appears to represent lateral facies of the middle and upper units of the Martinsburg (Ramseyburg and Pen Argyl).

BUSHKILL SHALE The lower member of the Martinsburg Formation (Drake and Epstein, 1967) consists of laminated to very thin bedded, dark bluish to dark medium gray shale (low grade slate) that weathers medium to very light gray to yellowish brown. The shale contains minute silty laminae weathering yellowish brown. Weathered laminae often contrast with the blue gray of the matrix and



REGIONAL GEOLOGIC MAP

FIGURE 2A

Legend

H - High Falls	M - Montgomery
N.P. - New Paltz	G - Ganagote
N - Newburgh	W - Wawarsing

Scale:
0 4 miles
(6.7 KM)

Catskill Aqueduct ------------
Delaware Aqueduct – – – – – –

WELL LOCATIONS

Minnewaska #1	MX
Village Of Ellenville #1	EX
Susi Well	SX

AFTER KALAKA, 1985, FIGURE 14

are frequently enhanced by weathering. Sedimentary features most commonly encountered are graded bedding in silt and clay couplets, and cross-laminations in the silty laminae. Thicknesses vary from 2,000 feet plus (610m plus) below the Quassaic arenites (Waines et al., 1983) although where the Quassaic grades to shale the thickness may increase by as much as 6,560 feet (2000m) (Waines, 1986).

Generally the Bushkill Shale appears unfossiliferous, but a limited number of fossil locations have been determined.

RAMSEYBURG EQUIVALENT What is thought to be a lateral equivalent of the middle graywacke-bearing Ramseyburg Member of the Martinsburg Formation crops out just west of Montgomery and continues northeastward through the study area where it shales out and/or is terminated by a regional thrust. Although the Ramseyburg equivalent appears to have been traced by Offield (1967) across the Goshen 15 minute Quadrangle as the Austin Glen no authors have traced it directly to the Delaware Water Gap where the type location crops out (Drake and Epstein,1967). Because of its relative position between more shaley units above and below and its 200 foot plus (61m plus) thickness in the Goshen Quadrangle it is thought to be equivalent to the Ramseyburg.

In the study area the Ramseyburg Equivalent occurs as a sequence of alternating beds of dark low grade slates and shales and light gray, light brown to yellowish brown weathering, thin- to thick-bedded silty subgraywacke to quartz arenites. The graywacke occurs in beds that range from less than ¼ foot (0.1m) to 6 feet (1.8m) in thickness(averaging about 3 feet (0.9m)), and appear to comprise less than 15% of the sequence.

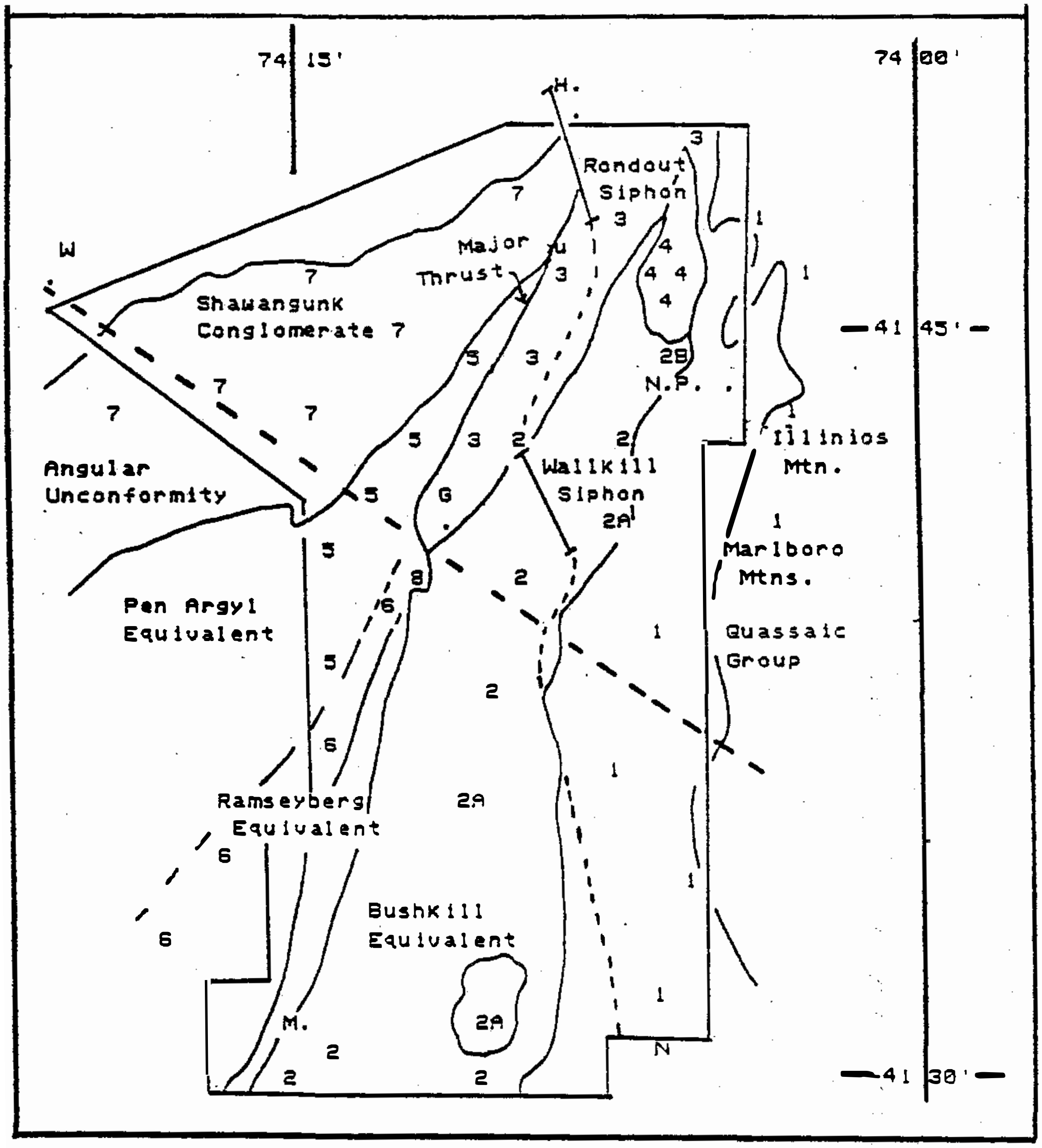
A flow cast-bearing interval can be traced in exposures from just west of Montgomery northeastward into the Shawangunk Kill. If it were not for the identification of this interval which can be projected into the Shawangunk Kill location from the southwest, the laminated shales and siltstones of the Ramseyburg Equivalent would be virtually indistinguishable from those of the Bushkill or Pen Argyl Equivalents. The contact with the overlying Pen Argyl Equivalent is probably gradational with the siltstones and graywacke bands thinning upward. No fossils were observed in the Ramseyburg Equivalent.

The estimated thickness of the Ramseyburg Equivalent in the Ellenville Well is 1600 feet (488m) and 600 feet (183m) in the Minnewaska Well (Kalaka, 1985, Table IV), (fig. 2).

The Shawangunk Kill may expose no more than 100 feet (30m) of graywacke-bearing strata, but the unit appears to thicken to the southwest because Offield (1967) estimated a thickness of about 4000 feet (1219.5m) south of the study area.

PEN ARGYL EQUIVALENT In the western portion of the valley the Martinsburg Formation consists of laminated shales and siltstones and some subgraywackes.

Siltstone layers range from 1/8 inch to 1-2 feet (0.6m), more commonly between 1/8 inch and ½ foot (0.2m). The sands and siltstone typically weather a buff color. A fresh shale surface is medium dark gray with a bluish cast weathering dark gray or black. Because of insufficient exposures



STRUCTURAL DOMAINS OF THE STUDY AREA

AFTER KALAKA, 1985, FIGURE 24

Legend

N.P. - New Paltz   G - Ganagote

N - Newburgh   W - Wawarsing

H - High Falls   M - Montgomery

Catskill Aqueduct ------------

Delaware Aqueduct — — — — — —

Scale:

0 ——— 4 miles

(6.7 KM)

MAJOR STRUCTURAL DOMAINS

Subdomains

(I) 1 Monoclinal SE Dip

(II) 2 Central Complex

2A Open Fold

2B Imbricated

3 SE Dip Imbricated

4 Open Fold East Dip

(III) 5 Open Fold

6 Northwest dip

7 Open Fold Covered

8 Overturned East Dip

FIGURE 2B

it is virtually impossible to develop an acceptable stratigraphic column at present. No fossils were found in the observed outcrops.

An average thickness estimated from the Ellenville and Minnewaska Wells using gamma logs is about 6500 feet (1982m) for this unit (Kalaka, 1985, Table IV). This thickness is comparable to the thickness estimated by Drake and Epstein (1967) for the Pen Argyl member.

STRUCTURE

Except for the studies of Holzwasser (1926) which resulted in four structure sections across or near the Lower Wallkill Valley, few subsequent studies have been attempted, presumably because of the assumed complex structure within the valley (Kalaka, 1985, figs. 5-11).

Recent field data, supplemented with data from the Catskill and Delaware Aqueducts, have lead to the recognition and delineation of structural domains and new structural conclusions in a second approximation of a geologically complex region.

The area, centered on the Wallkill Anticlinorium ('Neelytown' of Rickard, 1973), can be divided into three major structural domains from east to west: (1) Monocline (Southeast Dip), (2) Central Complex, (3) Open Fold (Kalaka, 1985, fig. 24).

Monoclinal (Southeast Dip) Domain The eastern limb of the Wallkill Anticlinorium is represented by east-dipping strata which project into the western limb of the Marlboro Syncline and involve a possible composite 17,000 feet (5183m) (but more likely 12,000 feet (3660m)) of Bushkill and Quassaic sediments.

This domain is generally located between the Marlboro Mountains and Interstate 87 from the Rosendale-Dashville region to the southern tip of the Marlboro Mountains just north of Newburgh (fig. 2A).

Exposures representative of this domain occur along and in the vicinity of Route 299 east of New Paltz.

Central Complex Domain The axis of the Wallkill Anticlinorium which is masked by a complex of imbricate, east-dipping slices is located approximately along the course of the Wallkill River. The imbricate domain occurs along the crest of the anticlinorium and extends from Interstate 87 west to a major northeast-southwest trending thrust (figs. 2A, 2B). Three kinds of subdomains occur within this region: (1) highly complex, (2) east-dipping imbricated, (3) open folded.

Detailed mapping within the complex domain requires a large scale approach because the size of the subdomain inferred within the Wallkill Siphon are estimated to vary from 400 feet to 2800 feet (12m to 853.7m) in width (Kalaka, 1985m fig. 20; Kalaka and Waines, 1985). Detailed surface mapping is inhibited by glacial cover which masks a major portion of the bedrock within the Lower Wallkill Valley. It is unlikely that an entire subdomain is exposed anywhere within the valley (Kalaka, 1985).

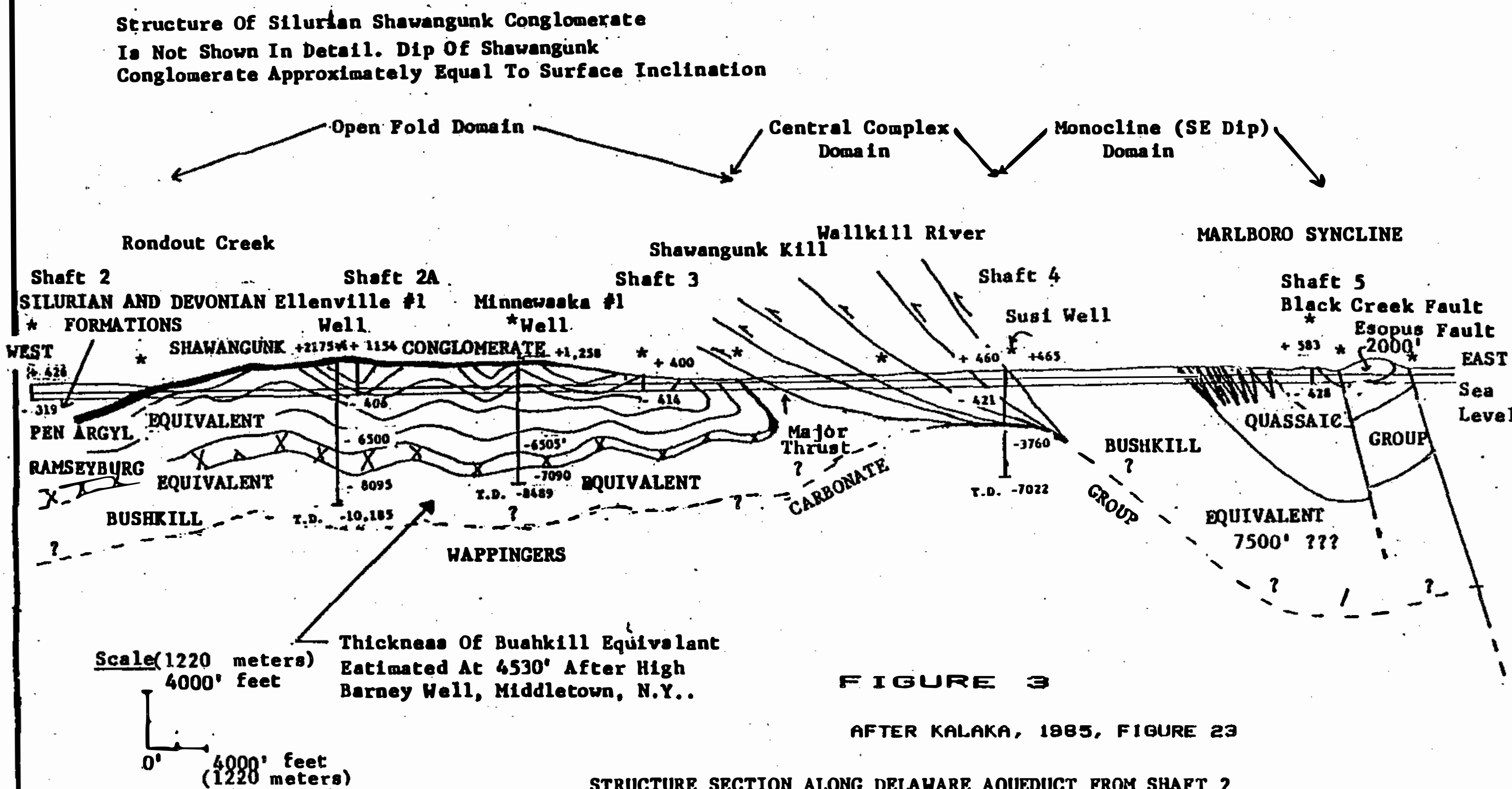
The complex domain is abruptly terminated on its western margin by a major northeast to southwest trending, east-dipping thrust. This thrust may represent a sole fault projecting upward and westward off the surface of the Wappingers Carbonates on the east limb of the Wallkill Anticlinorium (fig. 3). This thrust may have formed during Acadian or later time in response to thrusting of the competent Quassaic arenite mass in the core of the Marlboro Syncline westward into the thick, less competent Bushkill Shales along the crest of the Wallkill Anticlinorium. Further evidence of the major thrust is a 2000 foot (610m) sequence of southeast-dipping, overturned strata in the lower reaches of the Shawangunkill near Tuthilltown. These strata, remarkable in their thickness and attitude, appear to have been overturned in response to overriding along the major thrust. Exposures of upper plate material occur nearby on Route 44-55.

No attempt has been made to determine the extent and nature of offset along the thrust because of lack of stratigraphic markers.

Open Fold Domain West of the major thrust there exists a domain of open folds and relatively minor faults which can be divided into two subdomains: one which is exposed to the east of the Shawangunk Cuesta, and one existing beneath Silurian cover. Structure of the latter was revealed mostly in the Delaware West Branch (City of New York Board of Water Supply, 1938, 1939) and Catskill Aqueduct Tunnels (Board of Water Supply 1905-1918) (Kalaka, 1985, figs. 18,20).

Field observations in the Trapps region (Route 44-55) in addition to the Delaware Aqueduct tunnel data indicate that the fold amplitudes and wave lengths to the east of the cuesta decrease westward beneath Silurian cover (Kalaka, 1985, figs. 10, 21). Although the detailed structure of the Silurian strata was not worked out the general attitudes of the beds appear to be reflected in the general slope of the land surface. Consequently, the Ordovician structure beneath Silurian cover appears to have much greater dimension than the Silurian folds and faults generated in the Acadian or later orogeny. Though variable, wavelengths in the Ordovician folds are about 2000 feet (610m) or smaller in the Rondout Pressure Tunnel and average 1400 feet (427m) to 6000 feet (1829m) or larger in the Delaware West Branch Tunnel (Board of Water Supply, 1905-1918; City of New York Board of Water Supply, 1938m 1939). For these reasons it appears the Ordovician structure is largely Taconian in origin with relatively minor 'Acadian' modification in the open fold domain.

Waines and Sanders, 1968 (figs. 1, 2 and Tables 1, 2) may have anticipated the open fold domain in determining Pre-Silurian Ordovician bedding attitudes in locations 11 through 15 of their paper. Paleodips (16 degrees or less) and dip direction variations (southwest, northwest, northeast, west and east) indicate a region of broad, open, gently plunging folds in the open fold domain. This domain originally may have extended to the east or northeast in Waines and Sanders locations 8, 9A, 9B, and 10 where Ordovician paleodips did not exceed 30 degrees and were inclined to the northwest, southwest, and southeast, indicating somewhat tighter folding. The latter locations lie within the imbricate domain but Pre-Silurian attitudes at the unconformity do not appear to have been affected by imbrication. It may well be that prior to the development of the imbricate domain the Ordovician open fold domain extended further east onto a less complex anticlinorium.



F I G U R E   3

AFTER KALAKA, 1985, FIGURE 23

STRUCTURE SECTION ALONG DELAWARE AQUEDUCT FROM SHAFT 2 (RONDOUT CREEK) TO SHAFT 5 (MARLBORO SYNCLINE)

KEY

* PROJECTED POSITION OF FEATURE ABOVE NOTE ESPECIALLY PROJECTION OF WELL BORINGS, SEE FIGURE 28

Although post-Silurian faulting has been recognized in the open fold domain, especially in the Delaware Aqueduct (Bird, 1943, fig.8), its nature is not well understood and the displacement appears to be relatively minor. Pre-Silurian faults probably occur also, but again appear to have had relatively minor effects.

CONCLUSIONS

On the basis of field observations augmented by data from the Catskill and Delaware Aqueducts and data from four deep wildcat wells (Ellenville #1, High Barney, Minnewaska #1, and Susi #1) a new structural and stratigraphic interpretation of the Middle Ordovician shales and sandstones of the Lower Wallkill Valley has been developed. Rather than a region of general isoclinal folding as envisioned by Holzwasser (1926, Plate 1) and depicted by Sandborn after Berkey (1950), the area appears to be subdivided into three major northeast-southwest trending structural domains which involve the Martinsburg Formation and Quassaic Group.

The easternmost domain is represented by monoclinal southeast-dipping strata (shales and arenites) of the western limb of the Marlboro Syncline. This domain includes Bushkill shales which interfinger with Quassaic arenites (Waines, 1986), (fig. 3).

A central complex domain consisting of imbricated east-dipping thrust slices with highly disturbed to open folded subdomains is located along the Wallkill Anticlinorium axis (Kalaka, 1985, fig. 24; Kalaka and Waines, 1986).

A major thrust appears to border the western margin of the complex domain. The thrust extends southward through the study area transecting the Catskill and Delaware Aqueducts. The motion along the thrust appears to be 'Acadian' because the thrust cuts through the Silurian and Devonian strata located on the northwestern border of the Lower Wallkill Valley.

The domain west of the thrust is characterized by open folds and minor faults. Tunnel and field data within this domain indicate that fold amplitudes generally decrease and wavelengths increase westward beneath Shawangunk Conglomerate cover.

Conclusions would be incomplete without reference to the Wallkill Siphon located within the complexly imbricated domain. Data suggest subdomainal entities which range from 800 feet (244m) to 2700 feet (823m) in width and indicate the size of the subdomains which can be expected within the valley (Kalaka, 1985, fig. 20; Kalaka and Waines, 1985).

If the present structural interpretation of the Wallkill Siphon is correct, mapping of subdomains within the imbricate zone using present geological techniques may be futile because of extensive glacial cover and the complex structure within the subdomains themselves. Were it not for the Catskill and Delaware Aqueduct data and the wildcat well information, the structural and stratigraphic interpretations presented here (fig. 3) would have been much more difficult, if not impossible, to develop.

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ROAD LOG AND STOP DESCRIPTIONS

Cumulative Mileage	Miles Between Points	Remarks
---	0	Enter NY 299 bearing right from NYS Thruway Exit 18 at New Paltz and proceed east.
4.0	4.0	Turn left (north) onto North Riverside Road.
4.15	0.15	Turn right onto Janewood Road and proceed to NY 299. Shale near telephone pole on left side of road is probably allochthonous Normanskill on the east side of the Esopus Thrust.
4.4	0.25	Turn right (west) onto NY 299.
4.5	0.1	Crossing buried Esopus Thrust.
4.7	0.2	Pull off highway and park next to cliff on right.

STOP #1. Here we are in middle third of Chodikee Formation (Stroter, 1983) the uppermost unit of the Quassaic Group. We are located in the east limb of the Marlboro Syncline. The age of these autochthonous strata is Late Ordovician. Beds are vertical to slightly overturned to the west. Continue west on NY 299.

4.8	0.1	Bridge over Black Creek fault where east limb of Marlboro Syncline has thrust westward over west limb of syncline.
5.05	0.25	Park along roadside next to outcrop.

STOP #2. Here is a more shaley version of the Chodikee Formation. Fossils include brachiopods and highly deformed cryptolithids. Strata typically dip east. Continue west on NY 299.

We will be moving down section for the next 2.1 miles and the normally arenitic formations in the Quassaic beneath the Chodikee are shaling out to the southwest.

5.60	0.55	Outcrop of Slabside Formation (?) on right.
6.65	1.05	Shaupeneak or Rifton Formation in road cut. This is the last exposure in the east-dipping domain on NY 299. Continue west.
8.10	1.45	Bridge over NYS Thruway. Entering eastern margin of complex domain.
8.2	0.1	Turn right (north) onto North Putt Corners Road at traffic light.
8.5	0.3	Turn left onto Henry Dubois Drive and proceed west.

9.35	0.85	Stop on the right as near this point as is safe and return on foot.

STOP #3. Here is a typical example of complex domain strata in the road cut on the north side with a good east-west sectional view. The strata are Medial Ordovician Bushkill shales and siltstones. Continue west downhill.

9.7	0.35	Stop; turn left onto NY 32. Proceed to second traffic light.
10.05	0.35	Turn right at light onto Main Street (NY 299) and proceed west.
10.25	0.2	Turn left (south) onto Water Street just before bridge over Wallkill River.
10.35	0.1	After stop, bear right onto Plains Road.
10.5	0.15	Bushkill outcrop on left.
10.6	0.1	Park in area on right and walk back over small bridge to outcrop on east side of road.

STOP #4. Here, beneath the poison ivy, are deformed shales and siltstones with east-dipping cleavage. Again, these appear to be Bushkill and the exposure occurs near the center of the complex domain. Return to cars and drive back to NY 299.

10.95	0.35	Turn left onto NY 299 across bridge over Wallkill River and head west across Wallkill River floodplain.
11.3	0.35	View of Shawangunk Cuesta at 12 o'clock.
11.9	0.6	Bear left onto Libertyville Road and proceed. Roadcuts observed over next 2.6 miles are in the complex domain. Stay on Albany Post Road.
19.25	7.35	Stop and turn left (east) onto Rt. 44-55.
19.8	0.55	Bridge over Wallkill River.
19.9	0.1	Turn hard right onto Farmers' Turnpike and proceed.
20.0	0.1	Park on right next to large blocks of Shawangunk conglomerate.

STOP #5. Extensive outcrop occurs at base of hill along river. Predominantly east-dipping argillites are involved in some folding and faulting. A foundation of an old covered bridge is observable. Here is another aspect of the complex domain. The strata are apparently Bushkill. No fossils have been found. Return to Rt. 44-55.

20.05	0.05	Turn left at stop sign onto Rt. 44-55 and proceed west.
20.7	0.65	Turn left onto Albany Post Road.
20.95	0.25	Bridge over Shawangunk Kill. Park in

open area on left side of road beyond bridge. Walk back over bridge to Tuthilltown Gristmill and assemble outside Gristmill store.

STOP #6. This is a hiking stop and we have been given special permission by the owner of the mill to walk across the property along the north bank of the Shawangunk Kill. Please stay with your leader and do not wander.

The first phase of the hike is about 1100 feet to a concrete dam across the Shawangunk Kill. On the far side of the stream and on the near side, when water is low, one can see an overturned section of east-dipping interlaminated siltstones and argillites which aggregate some 2000 to 2500 stratigraphic feet.

As far as we can tell, there is little faulting other than bedding plane dislocations and the sequence does not appear to belong in the complex domain. The differences between these strata and those at the next stop are noteworthy.

No samples in the dam area, please.

Proceed upstream from the dam along the berm of an abandoned canal. Watch out for woodchuck holes in the berm. They can be treacherous (the holes - not the woodchucks).

Proceed about 1,000 feet upstream from the dam to a point where a large hill on the north side of the stream closes to the stream. Here are numerous arenite layers in the shales, some up to a foot or so in thickness. These arenites are also overturned, dipping east as can be seen by flow structures on the basal bedding planes. This sequence seems to occur at the top of the argillite and silt sequence. The arenites can be traced southwestward into an ever-thickening arenite-shale sequence which seems to approximate the position of the Ramseyburg member in the Martinsburg Formation much further south. The augillite-silt sequence is most likely upper Bushkill if the foregoing is correct. This sequence in the Shawangunk Kill was first noted by Paul Kopsick (1977). Return to vehicle(s). Turn right out of parking area and return on Albany Post Road to Rt. 44-55.

20.3	0.3	Turn left onto Rt. 44-55 and park immediately in available space on right.

STOP #7: Walk uphill (west) along one side of highway and return , walking down other side. This extensive road cut is in the Bushkill shale and strata generally are right side up and dip east, but faulting and some drag folding suggest imbricate thrusting. This exposure is thought to represent a portion of the upper plate thrust over the lower plate exposed at Stop #6. A chance rockfall in this cut yielded an extensive fauna including bivalvia, articulate and inarticulate brachiopods, cryptolithid trilobites, graptolites, gastropods and burrows. Weathering rapidly reduces the shale to fine rubble. Return to vehicle(s). BE EXTREMELY CAREFUL CROSSING THE HIGHWAY!

24.4	4.1	Proceed west on Rt. 44-55. Turn out on right at hairpin curve.

STOP #8: Here Martinsburg strata, which appear to be Bushkill, may actully be Pen Argyl Equivalent though they do not resemble the latter. Here and at STOP #9, a short distance away, the strata occur in the open fold domain and in the immediate vicinity the overlying Shawangunk conglomerate may reflect Acadian or later deformation which was superposed on a predominantly Taconian structure. Proceed 'west' on Rt. 44-55.

24.9	0.5	Turn left VERY CAREFULLY on BLIND CURVE into parking area at Lookout. Park if possible. It may be very crowded with climbers and tourists on good weather days.

STOP #9: Facing northwest we see the relative attitudes of the underlying Martinsburg (Pen Argyl Equivalent?) and the overlying Shawungunk conglomerate. Although the angular unconformity between the two can be projected, the actual contact can be seen just south of Rt. 44-55 at the base of the Shawungunk (Waines and Sanders, 1968). The study of the relative structure of the Shawangunk and Martinsburg in this immediate vicinity was conducted by Persico (1984). He concluded that some Taconic structures were further deformed at a later time.

Next, a view to the southeast and east stretches beyond the immediate Wallkill Valley to the Hudson Highlands and the Hudson River Gap (southeast) and the Housatonic Ridge along the Connecticut border to the east. Closer at hand, to the east, we can retrace our general progress of the day from the irregular ridge of the Marlboro Mountains (overturned east limb of the Marlboro Syncline). Slightly closer we drop in elevation across the east dipping monoclinal domain which cannot be recognized from this viewpoint. We know that the complex domain centers on the lower elevations of the Wallkill Valley, but again the domain cannot be recognized from here. Similarly, the open fold domain and its eastern boundary fault give no indication of their presence. It must be concluded that only extensive exposure data (borings, tunnels) are necessary to augment meager or fortuitous exposures as in Stops 6 and 7.

END OF TRIP.

Return to Kingston Ramada Inn by way of Rt. 44-55, NY 299 and NYS Thruway.

BLOCKSTREAMS AT MILLBROOK MOUNTAIN, TOWN OF GARDINER, ULSTER COUNTY, NEW YORK

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PURPOSE

To raise questions concerning the origin of the features found in the scree below Millbrook Mountain.

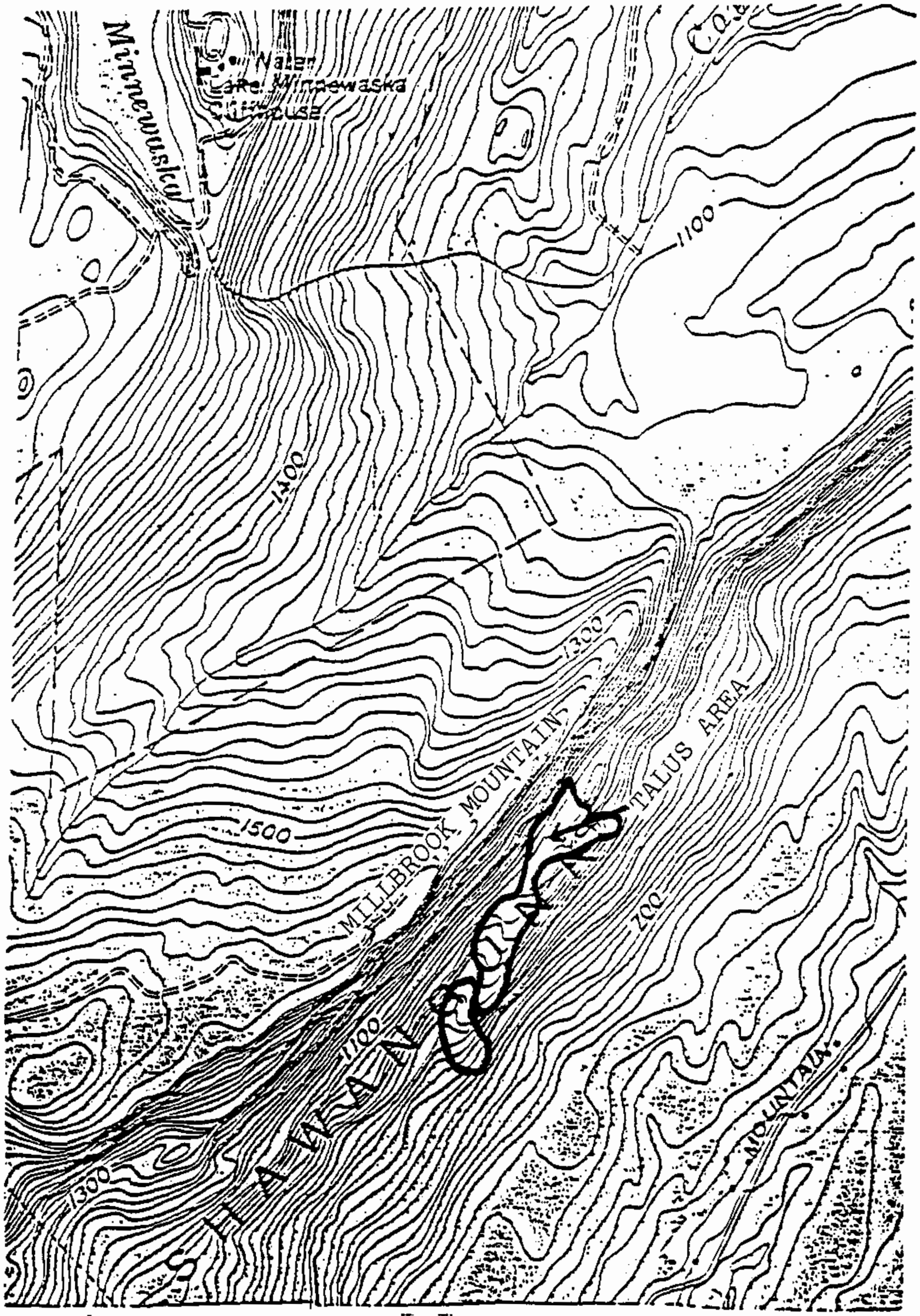
INTRODUCTION AND DESCRIPTION

Millbrook Mountain is a three quarter mile long anticlinal structure forming a topographic high (elevation 1620 feet, 495 m.). It is located about one mile south-southeast of Lake Minnewaska in the Shawangunk Mountains (figure 1). This anticline is truncated on the east side by a 350 foot (107 m.) cliff and is composed entirely of Shawangunk conglomerate dipping up to 55 degrees to the northwest. While the vista from the top offers a commanding view of the Wallkill valley and Shawangunk Mountains, the most unusual and engrossing geomorphic features lie 500 feet below in the talus at the foot of the cliff forming Millbrook Mountains' south-east face. Instead of forming the 25 to 35 degree straight talus common to the Shawangunks, this scree displays a varied mixture of steep slopes, block streams ramps sub-parallel to the cliff face, rampart-like ridges, valleys and closed depressions (figure 2).

These features are composed of blocks of Shawangunk conglomerate averaging five to ten feet cubed (1.5 to 3 $m.^3$, with some blocks forty feet (12 m.) in length (Robson, 1972). These blocks are significantly larger than those in the scree presently being deposited at the base of Millbrook Mountain. Block streams are largely lacking vegetative cover, exposing the bright, white surfaces of conglomerate to view; this is what initially aroused the curiosity of Dr. Russell Waines who encouraged the initial studies of these talus features by Robson and Cunningham in 1972.

The block streams generally slope from one to ten degrees along their long axes, while the adjacent rampart-ridges slope at greater than thirty degrees. The steepest slopes are on the main rampart (figure 2) and attain a maximum angle of repose of 41 degrees (Cunningham and Robson,1973). Mature hemlocks up to three feet (1 m.) in diameter growing in several feet of humus cover the slopes and tops of the ramparts indicating a long period of stability. The block stream ramps, valleys, and depressions are barren rock with occasional small shrubs and sparse pines of small diameter. The newer talus forming at the foot of the cliff, and spreading onto the larger blocks supports mixed deciduous and coniferous trees of moderate size.

The steep, vegetated slopes, topped by the rampart-like



CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

MILES 1 ½ 0

FIGURE 1 A portion of the U.S.G.S. 7.5' Gardiner, N.Y. Quadrangle ridges sit east of relatively unvegetated high valleys (figure 2). Block streams A and B descend up to 0.5 miles (0.8 km.) north and south from valleys 2 and 3 respectively. Block stream C descends from valley 4 extending to the south then to the southeast. These contrasting surface features offer good evidence that this block scree has been redistributed about the base of Millbrook Mountain.

In the northern part of the area the heavily vegetated slopes have apparently remained stable, while the scree behind the main ramp-art has presumably migrated to the north and south leaving shallow valleys (2, 3) separated by a saddle.

Another feature occurs south of block stream C where a mass of scree, set out from the cliff face occurs as a domal structure (figure 2) with blocks dipping outward in all directions. A small vegetated area separates this structure from the unvegetated block stream to the north.

On the steep eastern face of block stream B, is an alignment of several thin, unvegetated crescents of scree trending horizontally and surrounded by vegetated slopes (figure 2).

THEORIES OF FORMATION

Why is there such a pronounced difference is size between the scree forming the new talus, and that found in the block streams, ramparts, and other features formed from a presumably older scree deposit? It seems likely that existing joint sets in the Shawangunk conglomerate were weakened by ice and frost wedging and loading-unloading processes during and after the last glaciation, causing the cliff face to waste into large blocks. It may be that the older, coarser scree was released relatively quickly after glaciation from Millbrook Mountain after a long period of weakening during glaciation. Newer, finer scree seen here and along the Shawangunk ridge is smaller because forces of smaller magnitude are working on the cliff surface today.

If the stable surface of the main rampart represents the remnants of an earlier talus, then that talus must have reached a higher elevation on the cliff face than the presently forming talus sitting west of this rampart. Using an estimate of 33 degrees as an average angle of repose, the talus would have reached an elevation of 1400 feet (427 m.), 120 feet (37 m.) above the elevation of the presently forming talus (figure 3-a). Using the maximum angle of 41 degrees found on the stable vegetated slope would bring the proto-talus elevation to 1500 feet (458 m.), 120 feet (37 m.)below the mountain top (Figure 3-b. A conservative estimate for the amount of material moved if the talus sloped at 33 degrees would be about 2 million cubic yards (1.54 mcm.), which with 25% porosity would weigh about 3.35 million tons. If all this material was derived solely from Millbrook Mountain at its present elevation, it would represent a recession of the cliff face of about 80 feet (Robson and Cunningham, 1972).

THEORIES OF MOVEMENT

How did this material move? Some sort of mass wasting process seems likely. Evidence can be found for both rapid movement, i.e; angular blocks of conglomerate located east of the main mass of talus, or block stream surfaces tilting toward

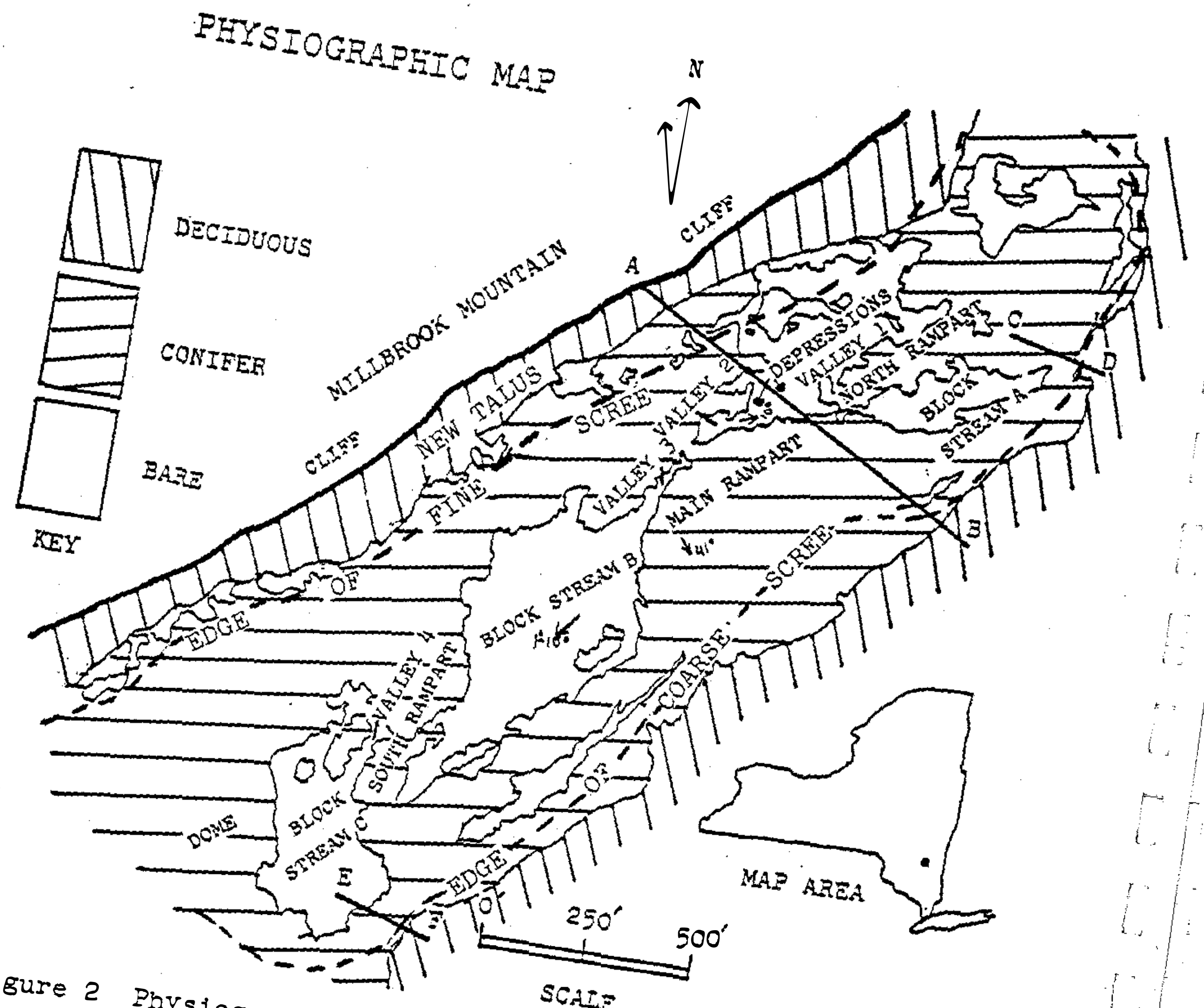


Figure 2 Physiographic Map showing lines of traverse A-B, C-D, E-F, lower limits of coarse and fine scree, block streams, ramparts, valleys, depressions and dome, and areas vegetated by coniferous or deciduous trees, or barren of vegetation

Millbrook Mountain. Alternatively, more evidence can be found suggesting slow, cohesive flow. In places the scree stops on downslopes exceeding 30 degrees where fragments of Martinsburg shale can be found in the subjacent soil. Further evidence may indicate possible pressure ridges and apparent arcuate alignment of elongate blocks in block stream C.

Rapid movement could have been initiated by several mechanisms.

1) Over-steepening by differential post-glacial rebound eventually overcoming the force of friction.
2) A large rock fall from Millbrook Mountain triggering movement of scree which had attained a maximum angle of repose.
3) Failure of shales (probably underlying the scree) due to excessive loading and/or excess groundwater.
4) Activation by an earthquake causing the fluidization of possible underlying glacial deposits or slippage of scree.
5) If the scree contained a great amount of interstitial ice and/or water, one of the aforementioned actions could have set off a rapid flow.

Slow movement could have been the result of several sets of circumstances.

1) The larger blocks could be remnants of debris formed on stagnant glacier ice at the base of Millbrook Mountain. Blocks of Shawangunk conglomerate, weakened by periglacial processes may have dropped onto the glacier and been deposited at their present positions. Some of the debris may have entrapped masses of clean ice. This might relate the depressions in the block streams to relict kettles. The ramparts may be merely a veneer of 'drift' overlying shale ridges (figure 3-b). Such ridges are common on the slopes below the talus.
2) These might be rock glaciers which contained much interstitial ice, either relict from the Pleistocene ice sheet, or formed during one of the colder time intervals since Pleistocene glaciation, i.e; the 'Little Ice Age' of the 17th to 19th centuries.
3) These could be rock streams as in the Hickory Run, Pennsylvania boulder field as described in Bloom, 1978, p.360,361, driven by gelifluction and frost creep, even though these blocks are much larger and more angular.
4) Groundwater might have carried away fine shale fragments, and/or stratified drift possibly underlying the scree a little at a time causing a gradual, but relatively steady settling effect. This is unlikely, because there is no evidence of this material being deposited at the foot of the talus. In addition, this would probably not cause devegetation of the block streams.

The ultimate truth here might involve a complex of processes including varying rates of flow, and a combination of any of the above circumstances. While pondering these suggestions, it must be kept in mind that except for the lobe of talus directed southeastward at the south end of block stream C, the unvegetated block streams trend near-parallel to the cliff face rather than

CROSS SECTIONS

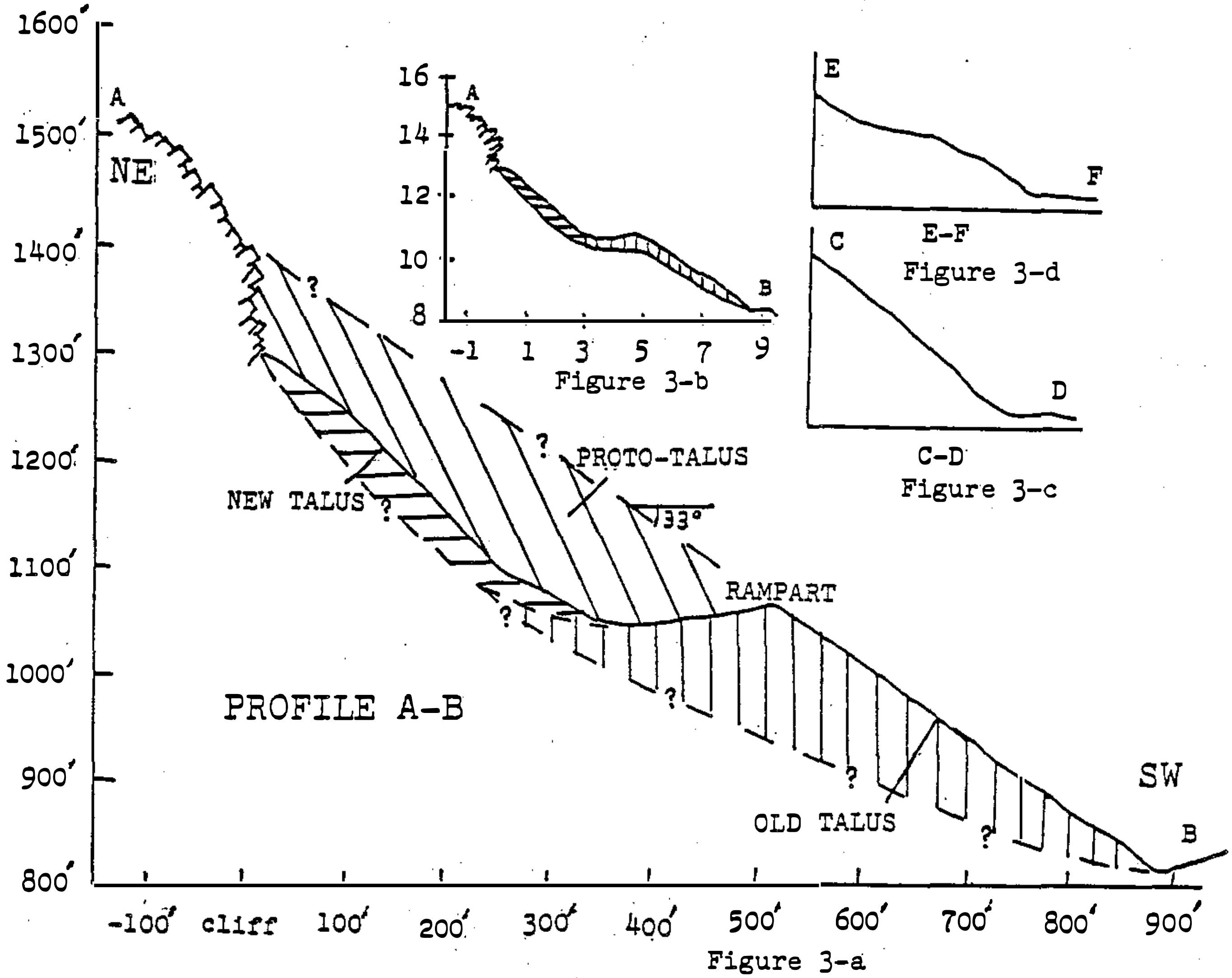


Figure 3-a Profile of Traverse A-B showing approximate contacts of coarse, old talus with new finer talus and probable slope of proto-talus before movement. This is shown over steeply sloping bedrock. 1 inch equals 170 feet

Figure 3-b Same as 3-a except scree shown as veneer over bedrock ridge with proto-talus removed. 1 inch equals 600 feet

Figure 3-c Profile of traverse C-D. Length equals 250 feet.

Figure 3-d Profile of traverse E-F. Length equals 250 feet.

down the steep slopes. Is this a function of unseen, underlying topography or was movement hemmed in on the east by a barrier such as glacial ice? Was it a sudden adjust-ment of much of the scree by block rotation, with only minor lateral or downslope movement? Remobilization might occur during subsidence, a slow process, or during an earthquake, a much more rapid process.

QUESTIONS

Why are the block streams unvegetated? Do they represent an early post-Pleistocene readjustment of the talus where the porosities are too great to allow buildup of humus or sediment? Do they represent recent movement where the organics have been 'shaken through the interstices', and the dead vegetation rotted away? Was this area always vegetated regardless of when the movement occurred, until a forest fire oxidized all the organics in the block streams? Off and on observation and arm waving during fifteen years has produced little of substance and evidence of forest fire has been sought in vain.

What of the thin crescents of unvegetated scree on the steep face of block stream B? Are these due to continuing instability in the scree, or just random barren streaks missed by revegetation? Some features like these may be seen in the talus along other parts of the Shawangunks.

Why is the distribution of the block streams varied with respect to the position of the main rampart? Was the initial scree distributed further to the south by flowing ice? Perhaps it was 'bulldozed' to the south by a late glacier readvance. Perhaps when movement took place, the main rampart at the northern end was relatively 'anchored' by an unseen topographic feature, or by the geometry of the blocks comprising the rampart.

IS IT MOVING?

Is this talus moving today? No definitive study has been done to answer this question, although there are several ways in which it could be carried out. Fifteen years experience in this area gives these authors impression of 'no change', but that is still to be proven. It is possible that the talus houses permanent ice, as temperatures measured in crevices in the talus during mid-July (1973) measured as low as 6°C (43°F), probably below ambient ground temperature in this area. This may suggest the presence of permanent ice in the scree but, it is unlikely that it would be of sufficient volume to allow or promote flow of the blocks. A study which might shed some light on the age of this talus movement would involve dendrochronology to see if there is a gradient in tree ages or gaps in ages. In addition, changes of climate might be inferred by ring thicknesses. Geophysical studies designed to determine the underlying bed rock topography and thickness of possible glacial drift would be invaluble in solving questions concerning this area of scree.

As can be seen, many questions remain to be answered about this unique geomorphic feature at Millbrook Mountain. These talus features could be the result of periglacial, tectonic, or more gradual processes which may be continuing to this day. Occasional trips over the past fifteen years appears to have raised more questions than they have answered, but any excursions have raised

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Robson, P.A., 1972, Features in Rock-Fall Talus, Millbrook Mountain, Northern Shawangunk Mountains, Ulster County, New York, (abs.) in 26th Annual Eastern Colleges Science Conference, Abs. in Prog., p. 55.

MAP

________. 1957, Topographic Map of Gardiner, N.Y. 7.5', U.S.G.S., Scale 1:24,000.

ROAD LOG

When hiking on the talus below Millbrook Mountain good shoes are required! Good physical conditioning and agility are important. Permission of the owner is necessary! He lives just north of the target area up long driveway on the west side of the road.

Approach scree from below (east).

Drive west from Exit 18 of New York State Thruway on Route 299 to New Paltz 1.0 miles.

Continue west on Rt 299 6.4 miles to intersection of Routes 299 and 44-55.

Turn left on Routes 44-55 and travel 1.0 mile then veer right at fork onto North Mountain Road (south).

Travel 1.0 mile and park. Talus features are approximately 0.5 miles west and 600 feet above you. Halcyon Road is 0.1 mile too far.

Approach from over Millbrook Mountain (west) for aerial view only.

Drive west from exit 18 as above to intersection of Routes 299 and 44-55.

Turn right on Routes 44-55. and travel 4.5 miles to entrance to Minnewaska State Park.

Enter park and drive to parking lot near site of old hotel.

Hike about 4 miles along trail to Millbrook Mountain.

Use extreme caution along cliff edge!
Do not attempt to go down!

THE WHITEPORT DOLOSTONE OF THE LATE SILURIAN RONDOUT GROUP, VICINITY OF KINGSTON, ULSTER COUNTY, NEW YORK

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Introduction

The term Whiteport was proposed by Rickard (1962) for a dolostone referred to by Hartnagel (1903) as the 'Rondout' in a rather restricted sense. Rickard suggested "that the name Rondout be applied to the dolomite strata subjacent to the Manlius everywhere in New York" (p. 30). Thus, according to Rickard, in the Rondout Formation the Whiteport is the uppermost of three members (Whiteport, Glasco, Rosendale), with a type section near Whiteport, New York.

Harper (1969) described the Whiteport as a "buff-weathering, light-gray to blue-gray on fresh, argillaceous silty dololutite. It is mudcracked, finely laminated, commonly burrowed, and very rarely fossiliferous" (p. 14). Harper's environmental interpretation is that of a mudflat facies.

Harper acknowledged that lime interbeds do exist within the Whiteport in the vicinity of Kingston:

> "One prominent interbed has been termed the "Twalfskill Bed" (Wanless, 1921; Van Ingen, local unpublished field term). Its thickness averages about one foot, and it is found to occur in the majority of sections in the Rosendale quadrangle... In this blue weathering, dolomitic limestone the fossils are commonly algal-coated, a fact which prompted Wanless to describe it as the "Algal Reef Limestone" (p. 14-15).

An additional limestone was recognized by Harper in the base of the Whiteport; a "two-foot interval of interbedded ostracod-rich calcarenites, calcilutites and calcareous silty dolomites" (p. 119).

Waines and Gomez (1977) divided the Whiteport (from Accord to Kingston) into five recognizable units (from top to bottom): Unit one, an argillaceous shaly dolostone (found south of Kingston); unit two, a massive weathering dolostone (unit one of this paper); unit three which can be subdivided into an upper, laminated portion and a lower, organic "reef" (unit two here); unit four, a massive dolostone (unit three here), and unit five, a somewhat fossiliferous lime unit (unit four here). This unit, which was often placed in the top of the Glasco, is actually a separate unit in the base of the Whiteport.

It is the presence of these limestone units which appear in the vicinity of Kingston that allows additional interpretations of environments and, due to their fossiliferous nature, a determination of age.

Stratigraphy and Environment of Deposition

In the Kingston area, four units of the Whiteport Dolostone have been recognized. See Figure 1 for sections.

Unit One

This unit is a buff-weathering, unfossiliferous laminated dolostone. It is occasionally burrowed, frequently and deeply mudcracked at the top where it is in apparent conformity with strata (limestone and shale) of the overlying Thacher limestone. The contact is drawn at the uppermost mudcrack (if present) or the first limestone or shales of the Thacher. The contact with unit two below is sharp, conformable to disconformable, and frequently limestone intraclasts of unit two can be noted within the lowermost strata of unit one. In East Kingston, where unit two pinches out, unit one rests disconformably upon unit three. Thicknesses of unit one range from over two feet (.61 m) in the Fly Mountain-Wilbur area, to one foot (.30 m) in the Kingston area.

Insoluble residues of unit one range from 25-30 percent. Unit one most probably formed within a shallow intertidal to supratidal environment.

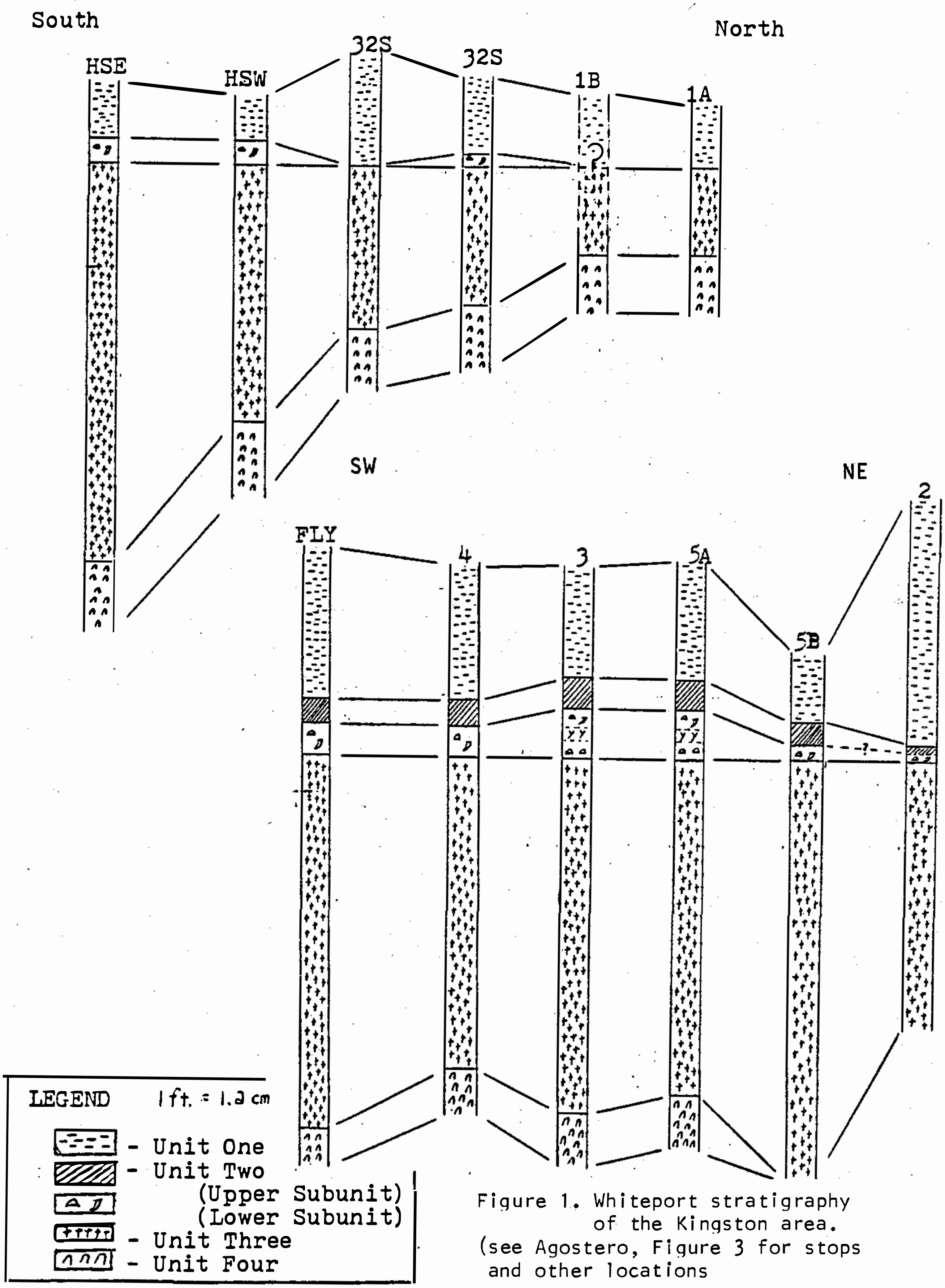

Figure 1. Whiteport stratigraphy of the Kingston area. (see Agostero, Figure 3 for stops and other locations

Unit Two

Unit two is a blue-gray weathering limestone, which may be subdivided into an upper, laminated calcilutite, and a lower organic 'reef' to 'offreef' unit (calcarenite to calcirudite), which contains a varied faunal assemblage.

The upper subunit is distinctly laminated, is not fossiliferous, and is frequently mudcracked with apparent intrusion of dolomitic muds from the unit above. This situation is similar to the mudcracks within unit one above, which are frequently filled with shale. Many of the laminated layers show evidence of being "ripped-up" (brecciation).

The lower subunit contains scattered fossils, which are notably abundant at Wilbur, and are recognizable in three distinct zones: 1) a basal stromatoporoid unit, 2) a solitary rugosa-tabulate-bryozoan unit, 3) and an upper stromatoporoid-solitary rugosa unit. At the western end of Callanan's quarry, at the base of this subunit, there is a quartz silt calcarenite unit, two to three inches (5-7 cm) thick. This thin unit is not fossiliferous and contains angular limestone fragments.

The upper subunit is disconformable on the lower subunit, and the entire unit is distinctly disconformable on unit three. It is possible that much of the lower subunit is missing, either as a result of erosion at the time of deposition, or by solutioning of limestone along the disconformity.

Thicknesses of unit two range from zero to one and a half feet (.46 m) through the Kingston area. In East Kingston, the unit pinches in and out. Where it is present, it averages four inches (10.2 cm) in thickness, and the upper subunit is generally eroded away, leaving a lower subunit with brachiopods, solitary rugose corals, and rare, hemispherical stromatoporoids. At Wilbur, the unit averages one and a half feet (.46 m), with each subunit six to eight inches (15.2 - 20.3 cm). At Fly Mountain the unit thins to one foot (.30 m), with each subunit half a foot (15.2 cm) in thickness. South of Fly Mountain unit two becomes dolomitized (late phase diagenesis?), although each subunit is retained. The lower subunit contains fossil 'ghosts'.

The upper subunit represents a relatively low (6-8 percent) insoluble residue, compared to the lower subunit (10-15 percent) or to unit one above. Although this subunit is limestone, it is in lack of fossils and has similar sedimentary structures to units one and three. It is likely that this calcilutite is intertidal to supratidal, representing similar conditions to the dolostone units, but lacking the requisite insolubles to enhance and early stage of diagenesis.

The lower subunit represents a return to subtidal conditions, and 'reef' to 'offreef' conditions. 'Offreef' conditions exist north and south of Wilbur, where fossils are less abundant and there are greater percentages of brachiopods. 'Reef' waters were well-circulated, relatively shallow and allowed a varied faunal assemblage.

Upper Stromatoporoid - Solitary Rugosa Zone

The hemispherical stromatoporoids are common in this zone, as are solitary rugose corals, while laminar stromatoporoids are not present. This suggests conditions involving relatively high water turbulence with moderate accumulation of fossil material.

Solitary Rugosa - Branching Tabulate Coral - Bryozoan Thickets

This most fossiliferous portion developed on a solid substrate and gentle water currents allowed the more delicate, branching forms of tabulates and bryozoans to develop. Laminar stromatoporoids are present in this zone in greater numbers than below, and there is a decrease in the percentage of hemispherical forms.

Basal Stromatoporoid Zone

This zone contains abundant hemispherical stromatoporoids (many in apparent growth position), rare (poorly developed) laminar stromatoporoids, and occasional solitary rugose corals. Turbulence was moderate, as was the accumulation of fossils.

Unit Three

This unit is a buff, massive-weathering dolostone (dolisiltite), occasionally laminated, occasionally burrowed, and rarely mudcracked. The contact with unit four is gradational, and is drawn at the initial fossils within the underlying unit. A major parting occuring toward the center of the unit is present throughout the Kingston area.

The thickness, ranging from four to seven feet (1.2 - 2.1 m), tends to decrease toward the north, and thicken to the south and east.

Mudcracks, burrowing, leaching, and the disconformity at the top of the unit suggest subaerial exposure indicative of the intertidal to supratidal zone. Unit three is similar in most aspects to unit one. Compared to unit two, unit three represents an increase in insolubles (25-30 percent in this unit).

Unit Four

At the base of the Whiteport, first appearing at Bloomington and extending northeast through Kingston is a dolomitic-calcarenitic limestone that exhibits cross-stratification, occasional ripple marks, intraclasts, and is variably fossiliferous sometimes containing lag deposits with ostracods, solitary rugose corals, and brachiopods. The contact with the underlying Glasco limestone is distinctly disconformable (the top of the Glasco is marked by a thin, black shale).

The thickness of unit four ranges from half a foot (15.2 cm) in the Bloomington-Fly Mountain area, to over a foot (30.5 cm) in the East Kingston area. At Wilbur, the unit becomes dolomitic, with limestone lenses. At the east end of Callanan's quarry the unit becomes entirely dolomitic, unfossiliferous, and is unrecognizable in the base of the Whiteport.

This unit exhibits features attributable to the shallow intertidal to supratidal zone. Ripple marks, cross-stratification, intraformational conglomerates as well as a high percentage of worn and fragmented shells suggest a relatively moderate energy environment. The ostracod shells are disarticulated, and concave down, indicative of the intertidal environment. Many of the brachiopod valves are concentrated in distinct horizons, suggesting storm activity.

The unit becomes very dolomitic around Wilbur, and the faunal assemblage becomes more diversified (now includes solitary rugose corals and hemispherical stromatoporoids). It is at these localities that cross-stratification and intraclasts can be noted. The percent of insoluble residues increases from 15-20 near Bloomington to around 25 near Wilbur.

Paleontology

The Whiteport has generally been considered unfossiliferous, and therefore, few paleontologic studies have been conducted on the formation. Wanless (1921, p. 258) noted 'stromatoporoid corals' and one species of brachiopod (Shuchertella woolworthana) within unit two. Grosvenor (1965) and Hoar and Bowen (1967) studied the brachiopoda of the Rondout Group, giving the most complete faunal listing to date. Within the Whiteport, Hoar noted "cup corals" and ostracods (presumably referring to unit four).

The limestone interbeds in the vicinity of Kingston, however, show a varied faunal assemblage. In unit four, are brachiopods, solitary rugosa, rare, small 'spheroidal' stromatoporoids, and numerous disarticulated ostracod shells which Harper (1969) reported as 'algal-coated'. Thin sections have revealed trilobite, tabulate, bryozoan, and pelmatozoan fragments. These fragments suggest a high degree of transport and/or reworking.

The lower portion of unit two contains hemispherical stromatoporoids (common), laminar stromatoporoids (rare), solitary rugosa, favositid and halysitid corals (rare), tabulate corals/bryozoans, brachiopods, pelmatozoan fragments, and trilobite debris. In the field many of the fossils appear algal-coated, which led Wanless to call this unit the "algal-reef" unit.

Four species of stromatoporoids representing three genera have been identified from unit two. These include Stictostroma pseudoconvictum (Stock), Parallelostroma constellatum (Hall), P. kaugatomicum (Riabinin), and Densastroma pexisum (Yavorsky). These species have been reported by Stock (1979) from the Glasco Limestone Member of the Rondout Formation and the Cobleskill Limestone in upstate New York. Only P. kaugatomicum and D. pexisum have been reported from the Upper Keyser (early Devonian) (Stock and Holmes, 1986).

Many of the stromatoporoid coenostea of unit two are in growth position, but some have been tumbled on their sides, and some are upside down.

The presence of halysitid corals has been reported by Adumkin (1976), Waines and Gomez (1977), Fetterhoff (1986), and Fetterhoff and Waines (1987).

Age

The Siluro-Devonian boundary in southeastern New York has been placed within the Rondout Formation (Fisher, 1960) and, more specifically, at the top of the Glasco Limestone Member (Rickard, 1962). This location is due to the presence of the 'chain' coral Cystihalysites, which is not thought to occur in the Devonian. According to Berry and Boucot (1971, p. 215) "the thin Glasco limestone in its median part contains Halysites. On this basis, the lower half ofthe Rondout Formation is assigned to the Late Pridoli and the upper, post-Halysites beds to the Devonian".

Recently, the placement of this boundary had come into question with discovery of halysitids within the Whiteport Dolostone. A halysitid 'ghost' was first noted by Adumkin (1976), and reported in unit two of Waines and Gomez (1977). Fetterhoff (1986) and Fetterhoff and Waines (1987) reported an unaltered halysitid from unit two.

Three genera representing four species of stromatoporoids have been identified from unit two. Each of these species has been reported from the Glasco limestone (Stock, 1979), and two of these as well from the Early Devonian Upper Keyser (Stock and Holmes 1986). However, Parallelostroma baretti (Girty), an upper Keyser form also occuring in early Devonian Thacher limestone, has not been recognized in unit two of the Whiteport.

It is believed that the foregoing evidence strongly supports a late Silurian age for the bottom three-fourths and, by lithologic association, the upper one-fourth of the Whiteport Dolostone.

Summary

The Rondout Group may well represent a series of near-shore environments which are mirrored in the Whiteport Dolostone with its tripart (dolostone, limestone, dolostone) sequence. Tidal flat deposits and shallow marine trough deposits with varied faunas protected from tidal destruction are well represented. Fossil evidence supports a Late Silurian (Pridoli) age for the Whiteport Dolostone.

LITHOLOGIC AND PALEOENVIRONMENTAL ANALYSIS OF THE LATE SILURIAN (PRIDOLI) GLASCO LIMESTONE IN THE MID-HUDSON VALLEY, VICINITY OF KINGSTON, NEW YORK.

by
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INTRODUCTION

In recent years the Glasco limestone has been studied in a broad to restrictive regional context by authors such as Rickard (1965), Grosvenor (1965), Grosvenor-Hoar and Bowen (1967), Waines and Hoar (1967), Harper (1969), and Rickard (1975). In this investigation the study area is limited to the vicinity of Kingston, New York and attempts to elucidate the intricate lithologic and paleontologic changes occurring within the Glasco sequence. The Glasco limestone within the Mid-Hudson Valley is Late Silurian (Pridolian) age according to Rickard (1975). It is disconformably overlain and underlain by the Whiteport and Rosendale Dolostones. The Glasco consists of a variety of carbonates including highly fossiliferous stromatoporoid and halysitid bearing limestones, dolomitic mudstones, and calcareous to dolomitic mudstones and floatstones. Thickness varies from 0.7 to 15.4 feet (0.2 to 4.7 meters). In the Kingston area the formation has been subdivided into three mappable stratigraphic units (here referred to in ascending order as units A, B, and C) (Figure 1).

Aside from the early work of Hartnagel (1903) the paleontology of this sequence has been most recently studied by Grosvenor (1965), Grosvenor-Hoar and Bowen (1967) who studied the brachiopods; and Stock (1979) who concentrated on the stromatoporoids.

CARBONATE ROCK CLASSIFICATION

For purposes of field description a classification was developed largely based on Cuffey's (1985) reef-rock scheme. He purposed that fossil and/or fossil fragments longer than 2mm (greatest dimension) where the most common elements of reef related carbonates. "When such textural elements constitute 10% or more of the rock's volume - versus fewer or none - they provide the most common logical means for initially subdividing these reef rocks" (Cuffey, 1985, p.307).

The field classification used in this study takes into account percent matrix, packing of fossils and/or fossil fragments, and growth types. Matrix in this sense includes sediment particles less than 2mm in size. The tripartite scheme used here is as follows: matrix greater than 75 percent, matrix 75-25 percent, and less than 25 percent. Floatstones, boundstones, and coverstones follow past usage, while lamstones, cupstones, stickstones, hemstones and chainstones reflect dominant fossil growth forms (Figure 2).

STRATIGRAPHY, LITHOLOGIES, AND PALEONTOLOGY

Three domains were used for mapping and correlation purposes (Figure 3). A northern domain includes the quarries and outcrops in the East Kingston area. The middle domain incorporates the outcrops and mines of the Vlightberg area. The southern domain includes the quarries, mines and outcrops of the Wilbur, New Salem, Fly Mountain and Bloomington areas.

Northern Domain

Here the thickness of the Glasco Formation is 9.5 feet (2.9 meters). The lower most sequence, unit A, averages 3.7 feet (1.1 meters) in thickness. Most sections consist of a basal hemstone or floatstone or lamstone, overlain in succession by a chert-rich coverstone, a calcareous to dolomitic floatstone or lamstone or hemstone, and an upper low matrix chainstone with abundant laminar stromatoporoids (Figure 4). Overall the unit is characterized by matrix poor lithologies (Figure 5). An insoluble residue of 4.2 percent was obtained from the chainstone. The fauna in decreasing order of abundance includes fragmented halysitids, laminar stromatoporoids, solitary rugosa, stick-like tabulates and/or bryozoa, hemispherical stromatoporoids, other tabulates (chiefly cladoporid-like forms), pelmatozoan oscicles, and entire halysitid coralla (Figures 6 and 7). Within the basal portions of the unit the dominant stromatoporoid form is hemispherical, while in the overlying coverstones and chainstones it is almost exclusively laminar.

Unit B is 4.8 feet (1.5 meters) on average and can be identified by several cyclic packages (floatstone or hemstone or lamstone overlain by cupstone or stickstone). This unit starts with a floatstone and ends with a stickstone or shale. The dominant lithology is floatstone, especially in the lower part (subunit 1, Figure 4) which exhibits a dramatic increase in matrix relative to unit (A)(Figures 4 & 5). Insoluble residues formed 4.3 percent of the upper stickstone lithologies (subunit 2, Figure 4) in this unit. The three dominant macro-invertebrates in the unit are solitary rugosa, cladoporid-like tabulates and stick-like tabulates and/or bryozoa (Figures 6 and 7).

Unit C averages 1.0 feet (0.3 meters) in thickness and is comprised of a clean lime calcarenite (subunit 1A) or a

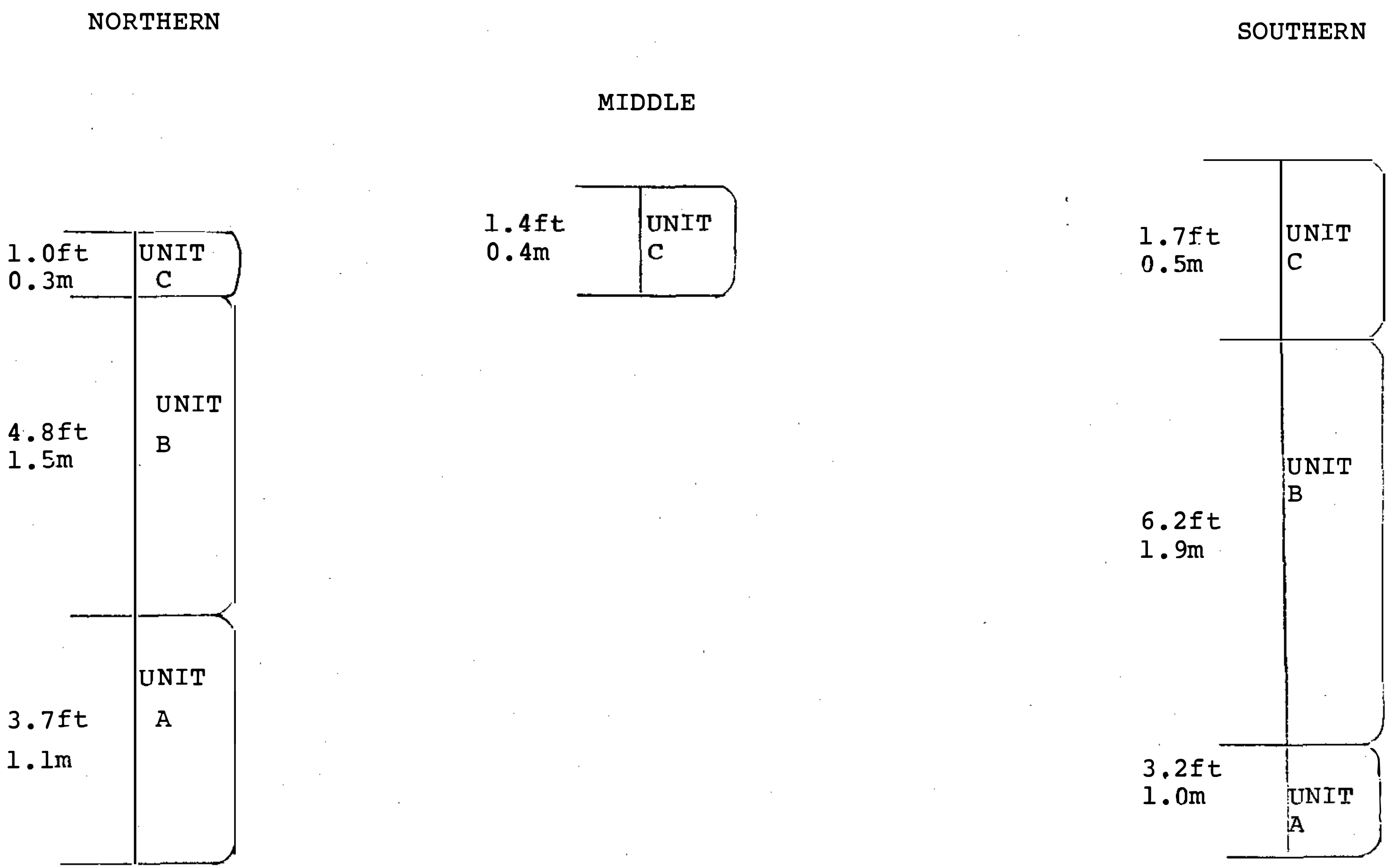


Figure 1 : General thickness relationships of three units in the northern, middle, and southern domains.

lamstone/coverstone (subunit 1B, Figure 4) overlain in one place by a mix of matrix-rich lithologies. Where present (Figure 4) the calcarenites occur above a bedding surface parting at the top of unit B. These calcarenites contain 2.5 percent insoluble residues and appear to be a facies of the lamstone/coverstone lithologies (Figure 4). The upper subunit (2), where it exists, contains floatstones, mudstones, rudstones and shales. Within the lamstone/coverstone package laminar and hemispherical stromatoporoids are equally abundant while solitary rugosa are rare. Although most of the material is fragmental, the calcarenites are characterized by equal proportions of solitary rugosa and cladoporid-like tabulates when identifiable.

Middle Domain

The Glasco in this domain as studied in two localities averages 1.4 feet (0.4 meters) in thickness. Only unit C occurs in this domain. The unit is characterized by dolomitic mudstone, floatstone, and quartz-rich rudstone (subunit 2). These lithologies contain stringers of fossil hash and are indistinctly laminated. Rare stromatoporoids were the only fossils identified.

Southern Domain

In the southern domain the Glasco limestone averages 11.1 feet (3.4 meters). Unit A is 1.7 feet (0.5 meters) thick on average. The basal lithologies are chert-rich boundstones with rare hemstones to the west (subunit 2, Figure 4)) and floatstones and mudstones to the east (subunit 1, Figure 4). Dolomitic to calcareous floatstones or lamstones or hemstones (subunit 3, Figure 4) that overly the boundstones contain 9.8 percent insoluble residues. The upper subunit (4) (Figure 4) is a dolomitic chainstone containing more matrix (50-75 percent) than that in the northern domain. Only fragmented halysitids, laminar and hemispherical stromatoporoids, and solitary rugosa occur in abundances greater than one percent (Figure 7).

Unit B is 6.2 feet (1.9 meters) thick on average. Two distinct subunits can be recognized (subunits 4-5, Figure 4). Dolomitic floatstone and/or lamstone, eastern facies, or a dolomitic floatstone and/or stickstone, western facies, (Figure 4)). The eastern facies may also contain hemstones and coverstones intercalated with matrix-rich (90 percent) floatstones. Some basal floatstones contain burrowed horizons that may be related to hardgrounds. The upper subunit (2, Figure 4)) is a dolomitic mudstone and/or floatstone. Two macro-invertebrates dominate this unit: cladoporid-like tabulates and fragmented halysitids. Solitary rugosa, laminar and irregular stromatoporoids are less abundant (Figures 6 and 7).

Unit C ranges from 1.2 to 9.0 feet (0.4 to 2.7 meters), averaging 3.2 feet (1.0 meters). Two subunits were identified:

CARBONATE CLASSIFICATION

MATRIX 90-75%	MATRIX 75-25%	MATRIX 25-0%
Floatstone -generally heterogeneous	Lamstone -laminar growth (i.e. stromatoporoids, favositids, Cupstone -cup shape growth (i.e. solitary rugosa) Stickstone -stick or branch growth (i.e. tabulates, bryozoans) Hemstone -hemispherical growth (i.e. stromatoporoids, favositlds Chainstone -chain or anastomozlng growth (i.e. halysltid corals)	Boundstone (less than 5% matrix) -always encrusting Coverstone -laminar growth, often encrusting Dense Cupstone Dense Stlckstone Dense Hemstone Dense Chainstone

Figure 2: Carbonate field classification (partly adapted from Cuffey, 1985)

lamstone/coverstone (1B) and floatstone, mudstone, and rudstone (subunit 2). In the west a thin shale overlies the lamstone/coverstone, while in the central portion of this domain deposition of floatstone and mudstone commences. Finally, to the east the lamstone/coverstone sequence is nonexistent while a floatstone/mudstone package becomes dominant. Rudstones and dolomitic mudstones near the top of this unit average 25 percent insoluble residues. The matrix-rich lithologies contain disarticulated ostracod valves, vertical burrows, rare solitary rugosa and brachiopods.

Summary

In terms of thicknesses unit A is thickest in the northern domain because subunit 1 (Figure 4) was probably eroded or not deposited in the southern domain prior to deposition of subunit 2. Unit B is thickest in the southern domain because there is an additional thickness of dolomitic mudstone/floatstone (subunit 2). The thinning of unit C in the northern domain is due to two possible causes. First, the lamstone/coverstone lithologies are much reduced. Second, the overlying matrix-rich package is rare or non-existent in the northern domain.

Faunally, the most significant trend was noted in the middle unit (B). Here solitary rugosa decrease in abundance from 38 percent in the north to 11 percent in the south. Laminar and irregular stromatoporoids increase in abundance from north to south.

Generally, insoluble residue percentage contrasted sharply in two domains: high insolubles in the southern domain versus low insolubles in the north.

DEPOSITIONAL ENVIRONMENTS

A number of relatively shallow water carbonate environments are recognized for the Glasco sequence. These include patch reef and backreef complexes, stromatoporoid knobs and low subtidal to intertidal flats.

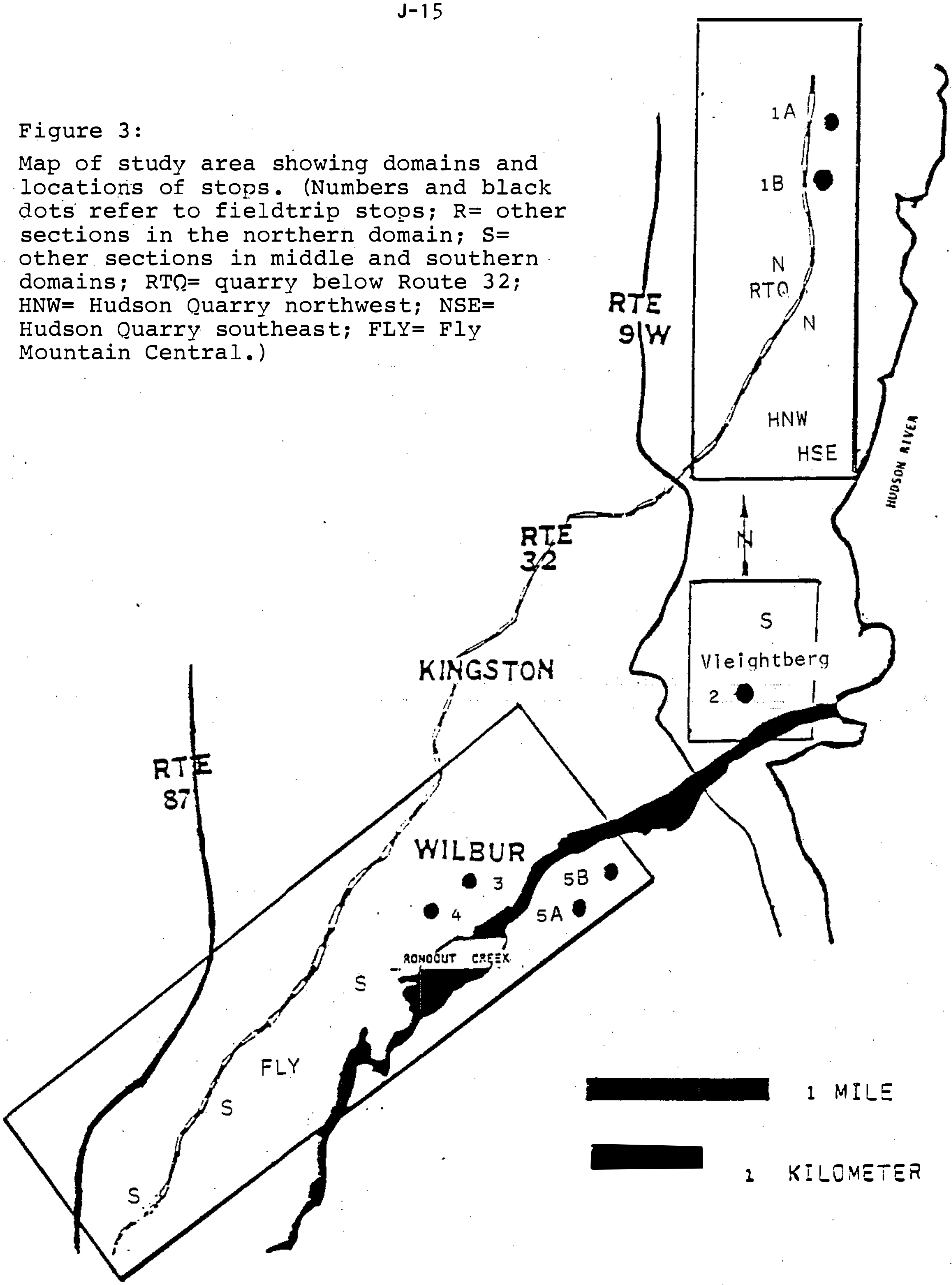
Unit A

Late Rosendale sedimentation probably occurred in a tidal flat environment (Harper, 1969). These flats may have been periodically exposed. Incursion of the sea during early Glasco time saw the development of a patch reef complex and associated halysitid coral thickets. Since the Rosendale substrate was probably well lithified, both stabilization and colonization stages in reef growth were omitted and a rather geologically 'quick' diversification stage progressed in the patch reef.

Hemispherical and laminar stromatoporoids, solitary rugosa,

Figure 3:

Map of study area showing domains and locations of stops. (Numbers and black dots refer to fieldtrip stops; R= other sections in the northern domain; S= other sections in middle and southern domains; RTQ= quarry below Route 32; HNW= Hudson Quarry northwest; NSE= Hudson Quarry southeast; FLY= Fly Mountain Central.)



stick-like tabulates and/or bryozoa, cladoporid-like tabulates, complete and fragmented halysitid corals, favositid corals and pelmatozoans debris have been recognized. The greatest species diversity among stromatoporoid was encountered in the patch reef and overlying reef flat environments. In thirty-seven coenostea sampled, three genera and five species were identified: Parallelostroma constellatum, P. kaugatomicum, P. rondoutense, Stromatopora clarkei, and Densastroma pexisum(Agostaro, 1987).

Sedimentation rates must have been relatively high since the dominant growth form is hemispherical to globular rather than laminar. The implication is that hemispherical stromatoporoids were able to keep pace with sedimentation while laminar forms were engulfed by the sediment. The patch reefs were likely destroyed catastrophically by an influx of fine-grained sediment and/or storm generated debris as indicated by the deposition of floatstones and mudstones in the upper portion of subunit 1.

A shallowing event(s) produced a significantly contrasting environment: high energy stromatoporoid flats probably similar to reef flats. With decreased sedimentation and increased turbulence, laminar encrusting stromatoporoids apparently thrived. One species, Stromatopora clarkei, dominated this assemblage. A domination stage in reef growth is postulated. Laminar stromatoporoids attained their greatest dimensions in this environment. These averaged 4.7 inches (11.9 cm) in breadth although some reached 23.6 inches (60 cm). The lack of matrix adds credence to the high energy, shallow water flat hypothesis.

Halysitid coral thickets developed on top of the stromatoporoid flats. The halysitid coralla may have been stabilized in the following manner. With an upright and open structure the halysitids could have baffled currents and trapped sediment in between corallites thus anchoring the bases of the coralla. During storm events most halysitids appear to have been dislodged, toppled, crushed and transported to form accumulations of flattened assemblages (chainstones). In the northern domain, large laminar stromatoporoids are sandwiched between such debris, either of which may been a favorable settling ground for stromatoporoid larvae as compared to calcareous muds. Stromatoporoids were eventually killed by an influx of fragmented halysitids washing on top of the coenostea. Complete halysitid coralla are exceedingly rare in a chainstone lithology.

In the south the chainstone is dolomitic, thins, and contains much more matrix while laminar stromatoporoids are rare. The coverstone is similarly dolomitic and, where it exists, thins. The environment was apparently less turbulent and possibly deeper than that to the north.

Unit B

Relative deepening of the sea during medial Glasco time

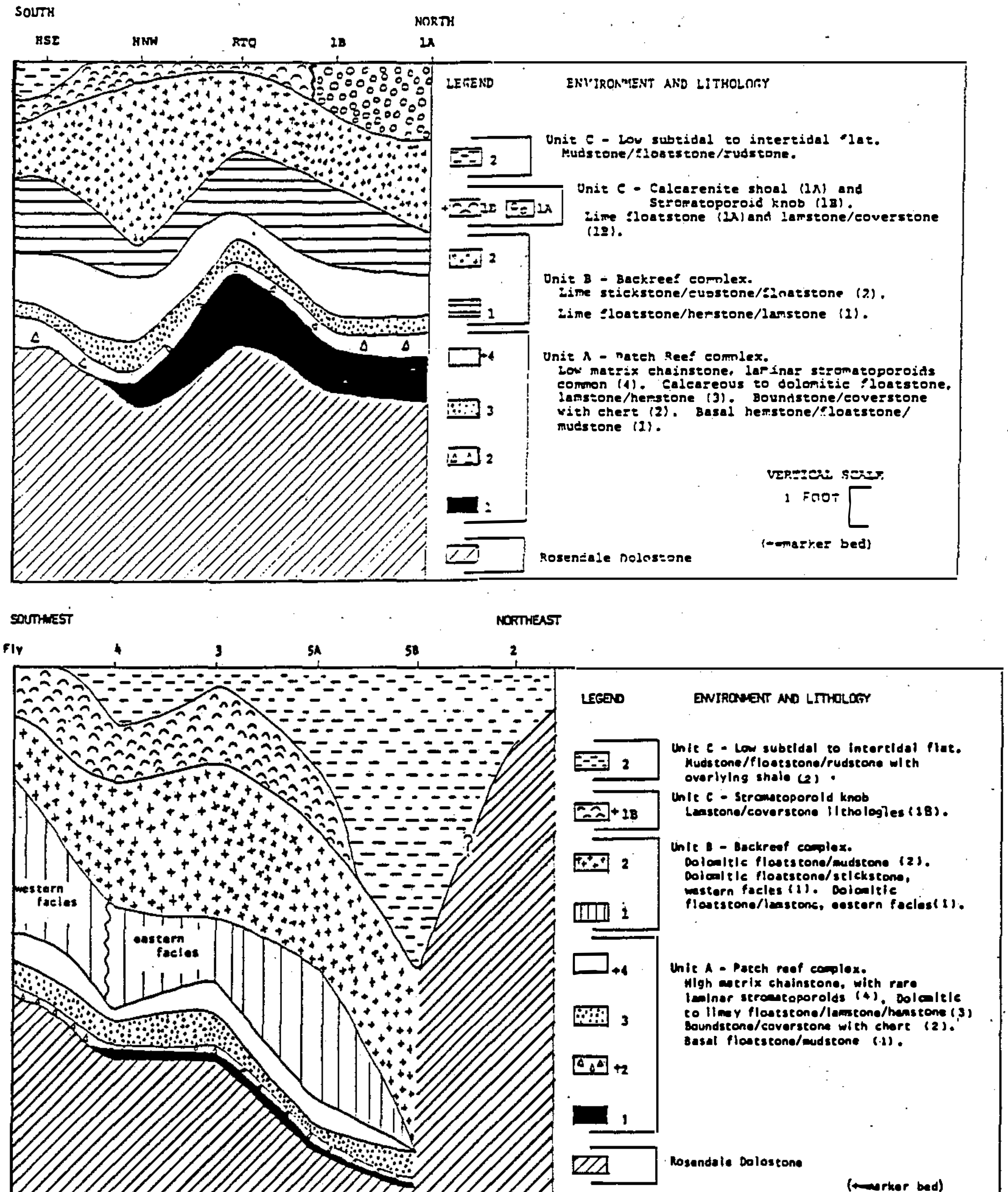
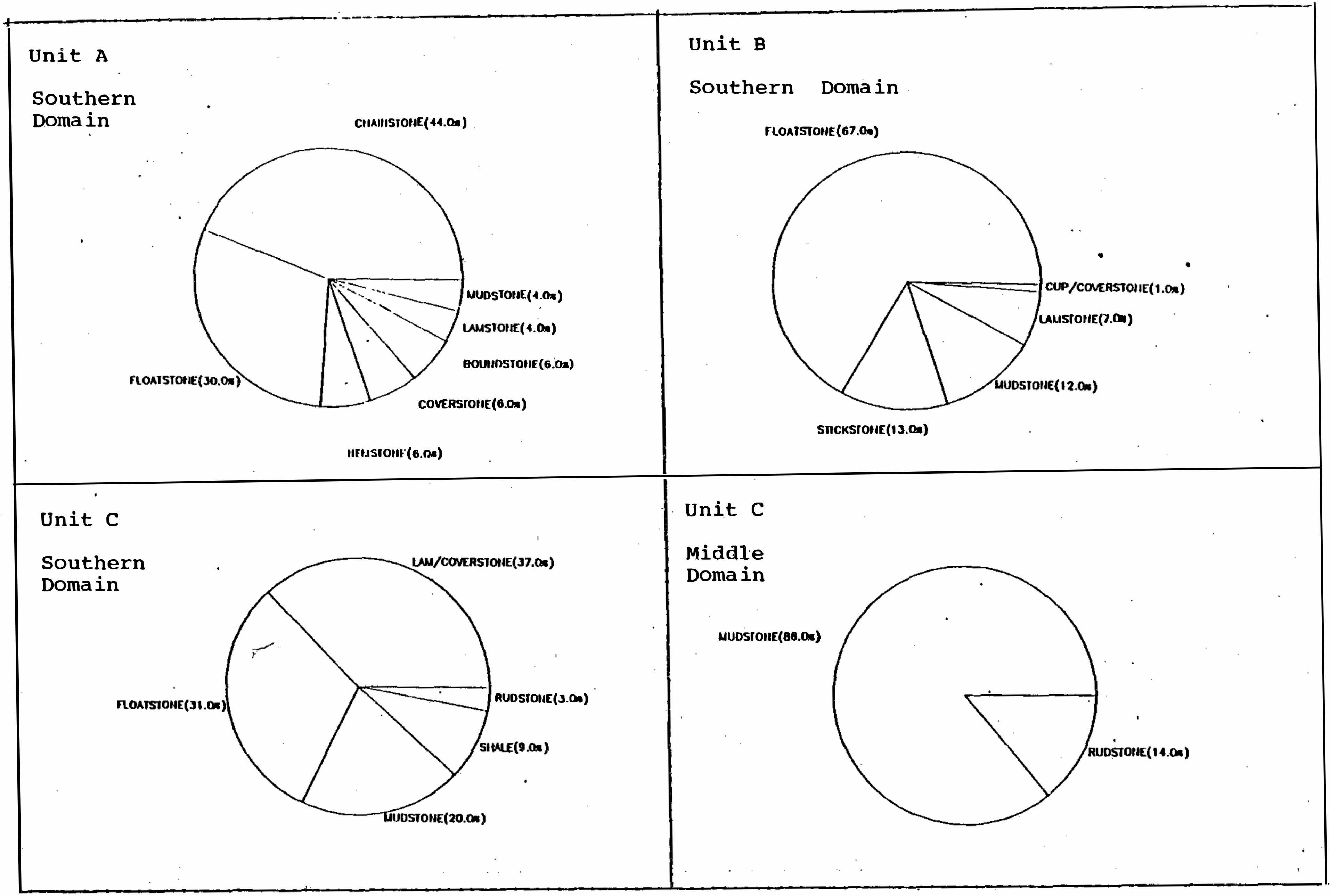


Figure 4: Stratigraphic correlation of sections along with associated environments and lithologies (refer to figure 1 for location of sections).


Unit A
Southern Domain
CHAINSTONE(44.0%)
MUDSTONE(4.0%)
LAMSTONE(4.0%)
BOUNDSTONE(6.0%)
COVERSTONE(6.0%)
HEMSTONE(6.0%)
FLOATSTONE(30.0%)
Unit B
Southern Domain
FLOATSTONE(67.0%)
CUP/COVERSTONE(1.0%)
LAMSTONE(7.0%)
MUDSTONE(12.0%)
STICKSTONE(13.0%)
Unit C
Southern Domain
LAM/COVERSTONE(37.0%)
RUDSTONE(3.0%)
SHALE(9.0%)
MUDSTONE(20.0%)
FLOATSTONE(31.0%)
Unit C
Middle Domain
MUDSTONE(86.0%)
RUDSTONE(14.0%)

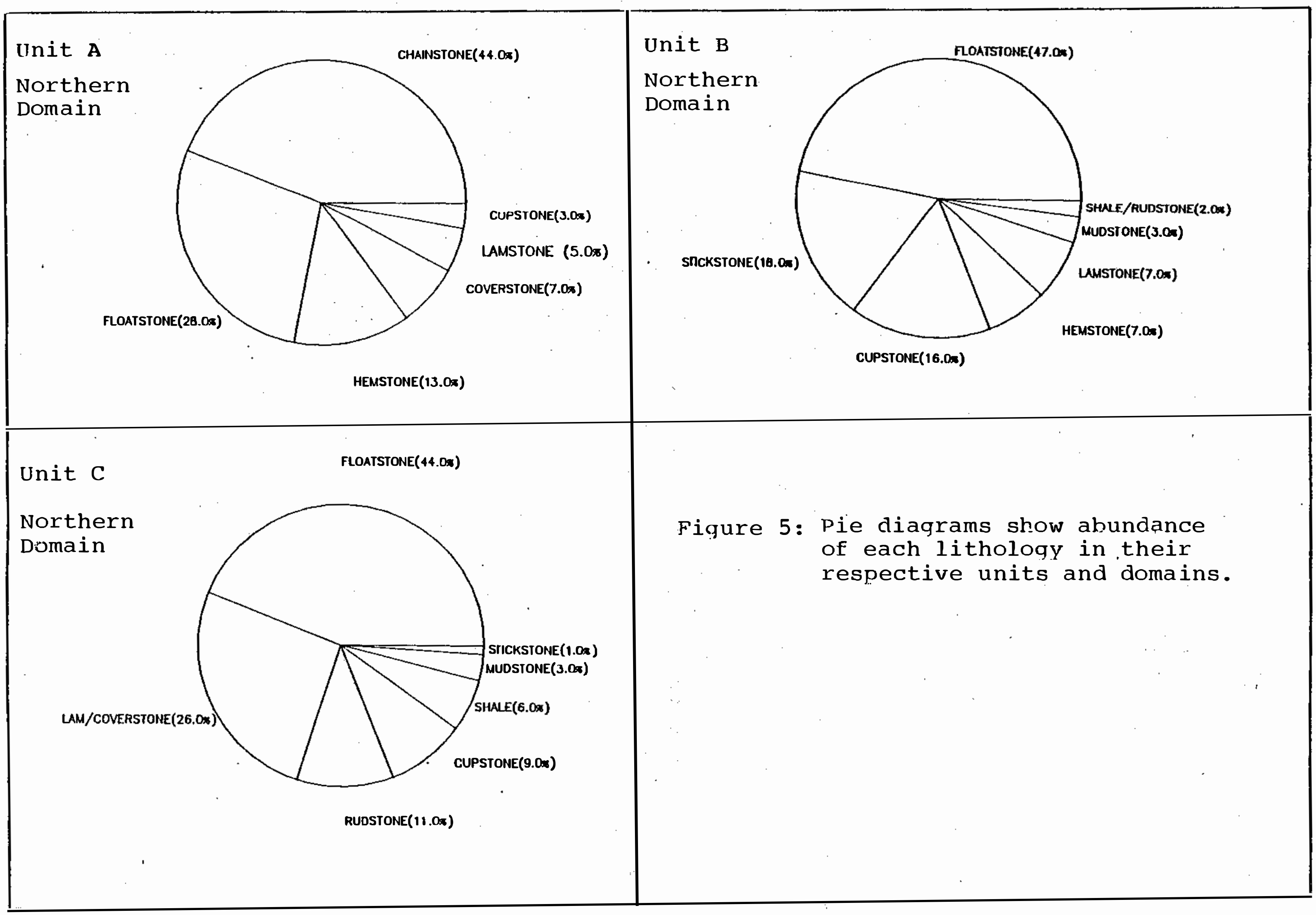


Figure 5: Pie diagrams show abundance of each lithology in their respective units and domains.

brought about a net decrease in water turbulence. Although the unit A patch reefs stood only a few feet above the seafloor (4-5 feet)(1.2 - 1.5 meters), they may have produced sufficient barriers to dissipate energy on a landward side. Matrix-rich packages accumulated in backreef complexes. A backreef complex probably consisted of the backreef environment and a shallower near-shore, subtidal environment.

Cyclic deposition of floatstones with stickstones, lamstones, hemstones or cupstones characterize Glasco backreef deposition. Cyclicity is a common component of European Devonian back-reef deposits (Burchette, 1981). Such cyclicity may suggest periodic attempts to re-establish reef growth; i.e. stabilization and colonization stages. Other evidence for back-reef deposition includes:

(1)abundant skeletal debris
(2)stickstone/cupstone/floatstone/mudstone/ with fine-grained matrix
(3)branching and small laminar growth forms

The delicate branching forms (cladoporid-like tabulates and stick-like tabulates and/or bryozoa) indicate high sedimentation and low energy rates. The water was probably more turbid than that in the patch reefs and thus precluded a more diverse fauna of filter and suspension feeders to develop. The macro-invertebrates most likely grew in thickets and served to baffle currents and allow matrix to accumulate. With the addition of abundant bryozoan, tabulate, and solitary rugosan skeletons the substrate became a muddy gravel. This substrate was colonized by small laminar stromatoporoids (averaging 2.9 inches or 7.3 centimeters in breadth) and fewer hemispherical or dendroid forms, until they were blanketed and killed off by fine-grained sediment. This cycle was repeated numerous times in some localities.

In the northeast the cycles are lime-rich and contain equal percentages of solitary rugosa, stick-like tabulates and/or bryozoa, and cladoporid-like tabulates. The situation suggests better circulation than that to the south. In the southwest the lithologies are dolomitic, more matrix rich and solitary rugosa are fewer relative to bryozoans and tabulates. Circulation was more restricted and the percentage of insolubles were higher.

In the southeast there is evidence for a shallow, quiet water, near shore, subtidal environment. Cyclicity decreases and is ultimately nonexistent. The dolomitic floatstone and mudstones are nearly devoid of epifauna with the exception of stringers of brachiopod and ostrocad valves. To the west the sequence becomes highly fossiliferous and cyclic. An infauna must have tolerated this environment since deep, wide, vertical burrows are common at the base of this unit. If this is a hardground it could imply a temporary stoppage in sedimentation

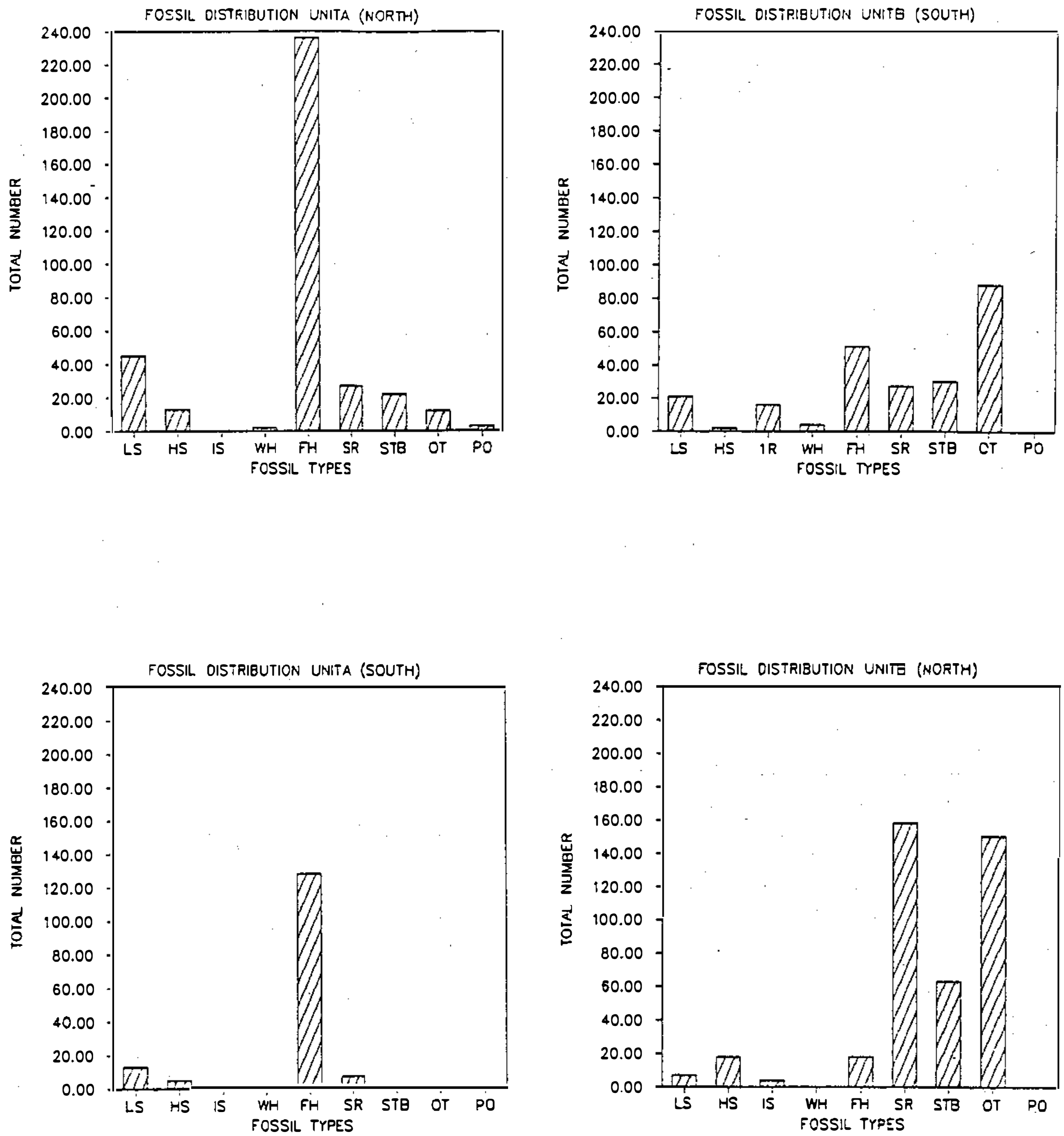


Figure 6: Distribution of macro-invertebrates for units A and B in the northern and southern domains. Histograms show total number of individuals. Strictly outcrop observations. (LS=laminar stromatoporoids; HS=hemispherical stromatoporoids; IS=irregular and dendroid stromatoporoids; WH= entire halysitids; FH=fragment halysitids; SR=solitary rugosa; STB=stick-like tabulate and/or bryozoa; OT=other tabulates ,chiefly cladoporid-like forms; and PO=pelmatozoan oscicles).

(Bathhurst,1975). High salinity might have restricted the epifauna. It is notable that in one locality virtually the entire package of lithologies are dolomitized, indicative of high insolubles, possibly implying a terrigenous source for some of the sediment.

Unit C

Three distinct environments are recognized: stromatoporoid knobs, high energy calcarenite shoals, and low subtidal to intertidal(?) flats. A modern analog of the stromatoporoid knobs would be the coral knobs associated with patch reefs of Bermuda, which may be upto 5 meters (16.4 feet) across and rise 1 to 3 meters (3.3 to 9.9 feet) above the seafloor (James, 1983). The stromatoporoid knobs extend from the southern into the northern domain. When the knobs are exposed on bedding planes they are up to 15 feet across (4.6 meters) and rise 1-3 feet (0.3 - 0.9 meters) above the surrounding shales, calcareous shales, or dolomitic mudstones.

Although evidence for high energy scour is generally absent, rare small scale channeling has been observed at the base of this unit. Laminar stromatoporoids (Parallelostroma constellatum) have been seen to encrust a vertical channel wall and subsequent infillings (Agostaro and Waines, 1987). The implication here is that shallowing possibly occurred.

It is intriguing that laminar and hemispherical growth forms seem to co-exist at similar horizons within the stromatoporoid knobs. In a study of a Silurian biostrome of Gotland, Kershaw (1981,p.1288) noted that laminar and high domical stromatoporoids were found "adjacent to one another and therefore neighbors in the same environment". The author also suggested that intense competition under favorable conditions could lend to low diversity among reef organisms in modern reefs (p.1293). He presented a scenario that may be mirrored in the stromatoporoid knobs of the Glasco. "Laminar to low domical forms were possibly spreading sideways to rapidly increase their surface area for food collection, exclusion of other organisms and to offer a low profile to currents, thereby reducing stresses on the coenostea. High to extended forms developed the alternate solution of upward growth, possibly to take advantage of nutrient-rich currents or perhaps to produce a microenvironment of extra turbulence resulting in a constant supply of clean water" (Kershaw, 1981, p.1293).

Of twenty coenostea sampled from this horizon four species in one genus were identified (Parallelostroma) and two species (P.constellatum and P.kaugatomicum) constituted 80 percent of the population, indicating low species diversity. This has been interpreted as a colonization stage in reef growth (Agostaro, 1987). In general, growth forms were not unique to any particular species.

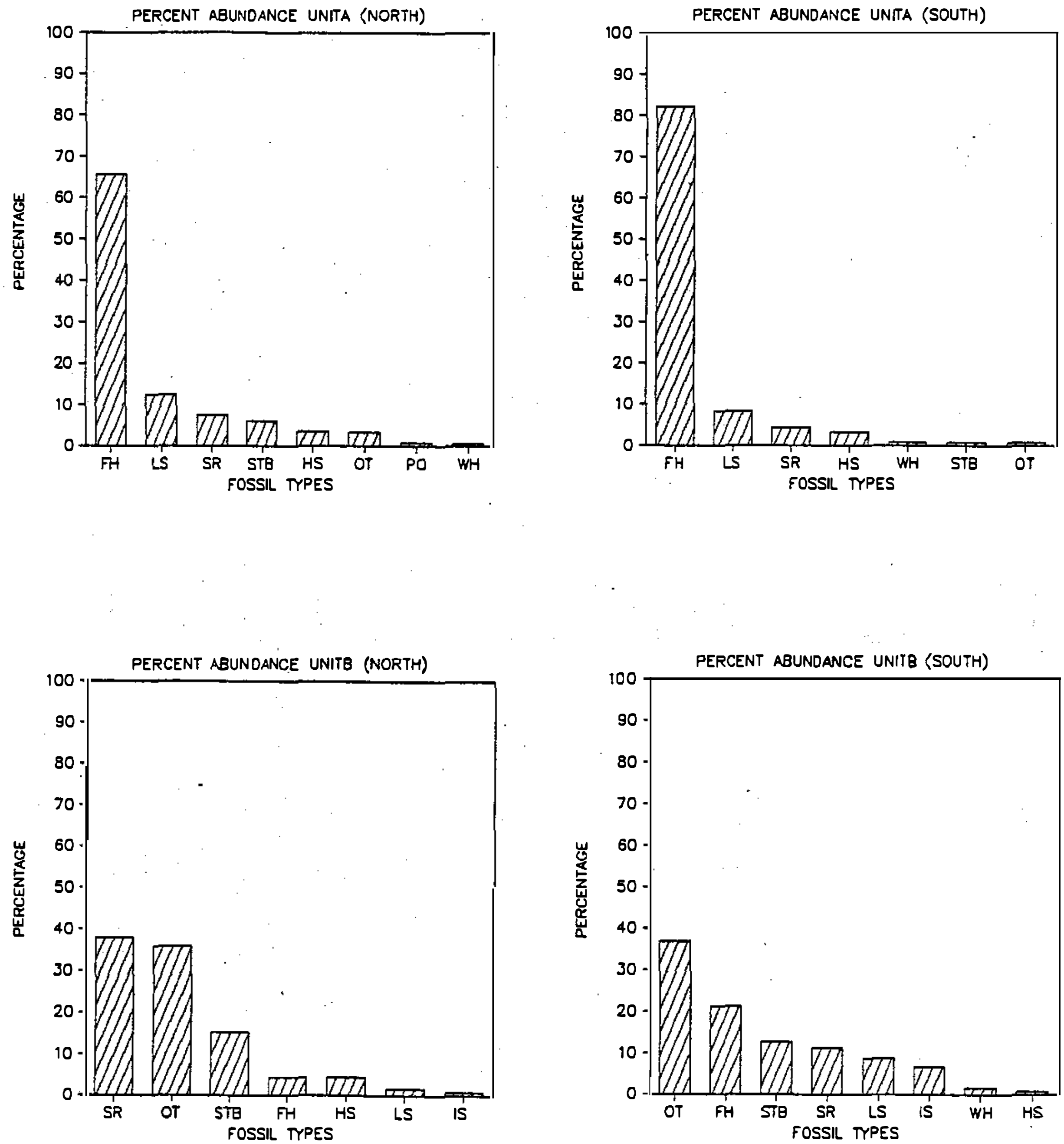


Figure 7: Percentage of fauna within units A and B in the northern and southern domains (see figure 6 key to symbols).

Although dolomitic mudstone and shales are a major component of this knob environment close examination suggests that hydrodynamic energy was sufficient to allow reef-like deposits to develop i.e.: (1) many stromatoporoids exhibit encrusting forms and (2) fragmented, repaired or healed coenostea. As the stromatoporoid knobs built upwards they produced topographic highs scattered over the sea bottom. Fine-grained sediment (shales and dolomitic mudstones) accumulated in the interareas.

With the exception of the unit A stromatoporoid flats, these knobs may represent the shallowest environment in which stromatoporoid activity could thrive. If the knobs were periodically exposed subaerially, this would account for the fragmented but healed coenostea. To the north and northeast the knobs disappear and high energy calcarenite shoals occur.

The high energy associated with the shoals transported the fine grain sediments out of this area. A significant color change occurs between the underlying dark gray to black back reef stickstone and cupstone deposits of unit B and the light gray to blue low insoluble residue lithologies of the shoal deposits. The latter contains the following macro-invertebrates, when identifiable (since most are fragmented): tabulates, bryozoans, solitary rugosa, and rare hemispherical stromatoporoids. The source for the fragments may well have been the backreef thickets of unit B. The shoals appear to represent a facies change from the stromatoporoid knobs since overall thicknesses are similar and both overly similar strata (in the northern domain)(Figure 4).

The most perplexing environment appears to be a low subtidal to intertidal flat environment which is represented in the central portion of the southern domain by dolomitic to calcareous laminated, sometimes rippled, floatstones and mudstones (subunit 2). Hemispherical and globular stromatoporoids are rare. Eastward this subunit thickens and rudstones begin to occur. At the eastern extreme of the southern domain the stromatoporoid knobs disappear and unit C is entirely a mixture of dolomitic mudstones, floatstones, and rudstones. Thin-sections reveal that the rudstones are rich in rounded, fine to medium size, quartz grains that often exhibit graded bedding. These are commonly associated with ostracod valves and 'pellets'. In addition the pellet-like structures have been observed in laminated, often bioturbated, lithologies.

The middle domain is represented by a low subtidal to intertidal flat environment. Unit C appears to be the only one present and it has thinned dramatically (Figure 4). The implication seems to be that this area is closer to the shoreline and salinities were sufficient to allow only ostrocads, rare brachiopods, and some infauna to exist on the tidal flat. Quartz grains from rudstones and fossil-hash floatstones/mudstones suggest a terrigenous influx. The anomalously thin section (less than one foot) of Glasco in the middle domain may be explained by a topographic high (Rosendale Dolostone) on which only latest Glasco sediments accumulated.

Summary

Lithologic, paleontologic, and observational analysis of a marine carbonate sequence, the Late Silurian Glasco Formation in the vicinity of Kingston, New York, define the paleoenvironments within this stratigraphic sequence. The four environments recognized are patch reef complex, back reef complex, stromatoporoid knob and low subtidal to intertidal flat. Relative nearness to shore, water turbulence and turbidity, along with storm activity seem to be major parameters greatly affecting the nature and stability of environments.

Stromatoporoid growth within the patch reef complex appears influenced by depth and turbulence of water. Hemispherical forms occurred in moderately low turbulent waters of the patch reef. Laminar encrusting forms are dominant in shallower, more turbulent, stromatoporoid flats. Lack of good circulaton allowed matrix-rich sediments to accumulate in some of the back reef complexes of unit B. Hemispherical and laminar stromatoporoids were seemingly able to co-exist in the stromatoporoid knobs. High turbulence apparently removed fine-grained sediment and allowed calcarenite shoals to develop contemporaneously to the north. In the southeast, terrigenous input and possible high salinities eliminated nearly all biologic activity toward the end of Glasco time.

LATE SILURIAN (PRIDOLI) ROSENDALE DOLOSTONE AND WILBUR LIMESTONE, VICINITY OF KINGSTON, ULSTER COUNTY, NEW YORK

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INTRODUCTION

The Rondout Group, of which the Rosendale Dolostone is part, has played an important part in Ulster County's past economic development. The Dolostone is comprised of Hydraulic limestone, which was crushed, reduced in kilns and used as a natural cement.

The term Rosendale was proposed by Hall (1893, p. 156) who gave as a location the southern exposure of a high escarpment at Rosendale where this dolostone was mined and manufactured into hydraulic cement. Some of the more recent investigations of the Rosendale in this century are those of Rickard, (1962), Hoar and Bowen, (1967), Harper, (1969) and Warren and Waines, (1986).

Based on field observations from nine different locations from just north of Kingston south to Maple Hill (just north of Rosendale), a four-fold subdivision is proposed for the Rosendale Dolostone. From top to bottom the Rosendale is comprised of Unit One: Limestone, Unit Two: Dolostone, Unit Three: Wilbur Limestone and Unit Four: Dolostone. Although not all subdivisions are present at all locations these units can be correlated laterally.

The term Wilbur Limestone was designated by Hartnagel (1903) based on a stratigraphic sequence of Mather (1843, p. 331). The outcrop referred to by Mather was located on the "right" (southeast) side of Rondout Creek opposite Wilbur. Hartnagel selected Mather's unit # 10 (limestone, dark colored impure and fossiliferous) and placed the Wilbur Limestone at the base of the Rosendale Dolostone. Most authors such as Van Ingen, (1903), Wanless, (1921), Rickard, (1962) and Harper, (1969) have followed this practice.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT

It is suggested a four-fold subdivision of the Rosendale-Wilbur sequence is the best way to present the vertical and lateral variations observed in the Kingston area.

<u>UNIT ONE:</u>
This occurs as a mottled and some what dolomitized limestone that is slightly fossiliferous, and weathers light blue-gray.

At Wilbur Quarry the thickness is two feet (0.6m). In the vicinity of Wilbur the unit is disconformable with the overlying Glasco Limestone with a thin dark shale at the contact. The base of the unit grades into the unit below. To the south (Fly Mountain) the unit appears dolomitized (late phase diagenesis ?) and cannot be distinguish from the underlying dolostone. The unit does not appear to occur north of the southern Vlightberg and may have been removed by erosion prior to the deposition of the Glasco.

Unit one seems to represent a relatively near shore, high saline, 'deep water' trough deposit located between the tide flat and the shoreline. Fossils are not numerous and partial dolomitization may indicate proximity to tide flats deposition. This may account for the mottling of the limestone of the Wilbur area which appears to be in an early stage of diagenesis.

UNIT TWO:

This is a massive to laminated unfossiliferous dolostone which weathers orange-buff. In Wilbur Quarry this unit is 8.3 feet (2.5m) thick. The unit appears to equate with the bulk of Mather's (1843) unit # 9 (gray to black cement rock) and the 'dark cement rock' of many early 20th century authors. At Fly Mountain unit two grades downward into the dolostone below, but from the Vlightberg north the lower part of unit two appears to become interbedded with numerous to sparse slightly fossiliferous limestone stringers forming a subunit.

Unit two probably represents a hypersaline intertidal to tide flat environment. The limestone stringers found north from the Vlightberg and in the east side of Callanan's Quarry may have been derived from lime secreting organisms in a marine trough environment as in unit three and may represent organic debris outwash across tide flats.

UNIT THREE:

In the Wilbur area this unit occurs as a sparsly fossiliferous massive limestone that is somewhat mottled and slightly dolomitized. The unit weathers a light blue-gray. At Wilbur Quarry the limestone has a thickness of four feet (1.2m) and the upper and lower contacts are rapidly gradational to dolostone. This unit is the Wilbur Limestone of many authors and can be readily recognized as a stratigraphic unit below the Rosendale Dolostone from the Vlightberg north as far as West Camp, New York. However in the vicinity of Wilbur and south in Fly Mountain the Wilbur Limestone is an internal stratigraphic component of the Rosendale Dolostone. At the south end of Fly Mountain the Wilbur is a cherty and silicified fossil-bearing dolostone with occasional angular pebble-like structures of undolomitized limestone. The Wilbur can be traced as a thin insoluble resdue and a high Ca/Mg zone many miles to the southwest (Warren and Waines. 1986). Other limestones near or at the base

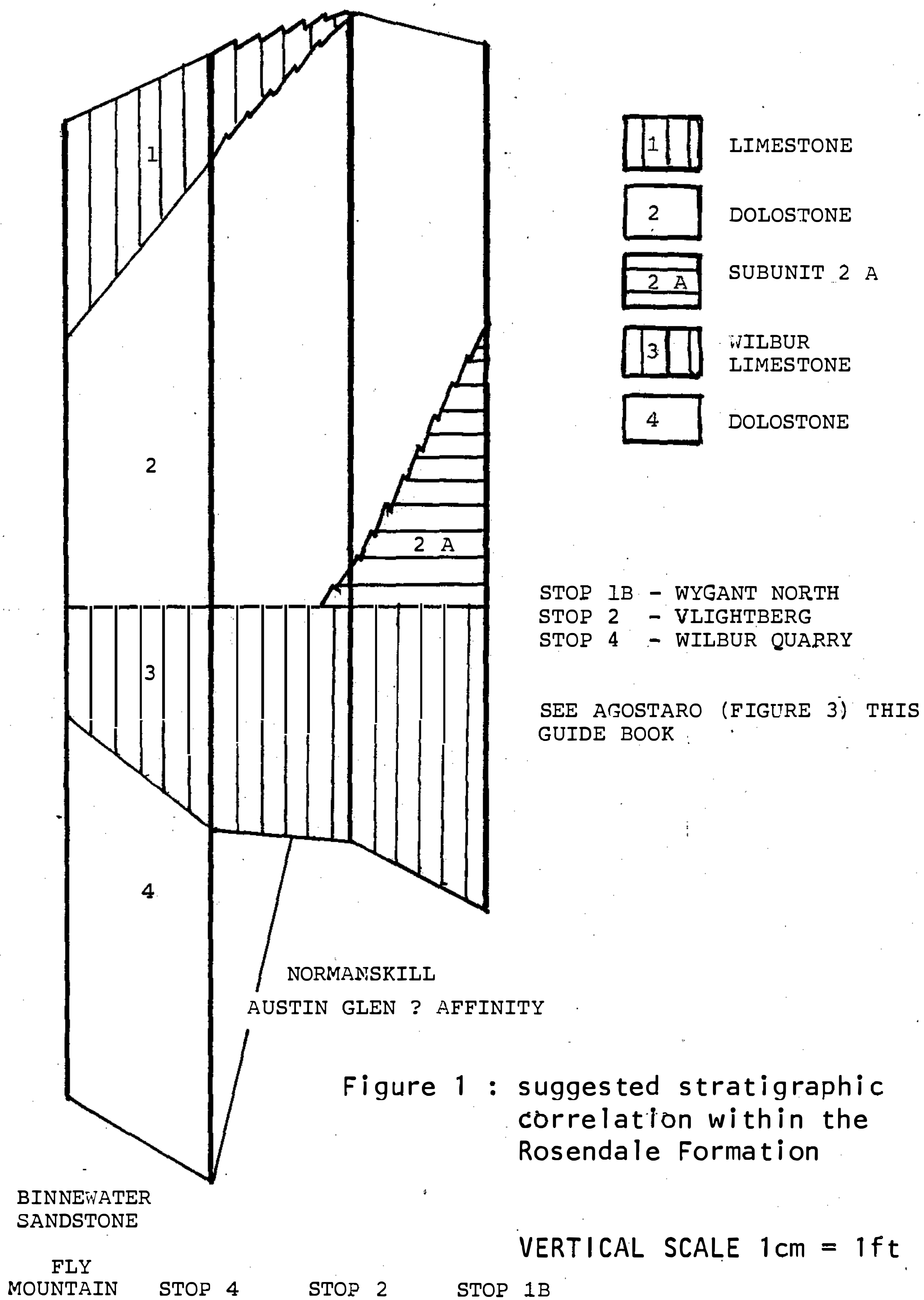

Figure 1 : suggested stratigraphic correlation within the Rosendale Formation

VERTICAL SCALE 1cm = 1ft

of the Rosendale Dolostone, such as those reported at High Falls, do not appear to be correlatable with Wilbur Limestone of the Wilbur area. Fossil content increases from the Vlightberg north and the base of this unit oversteps the underlying Ordovician sandstones and shales with angular unconformity.

The Wilbur exhibits a diverse fauna of brachiopods, bryozoa, tabulate (favositid and halysitid) and rugose corals, trilobites, ostracods, gastropods and pelmatozoan fragements (Hartnagel, 1903). Most recently, stromatoporoids identified by Stock (1979) include Stromatopora bekkeri, Parallelostroma constellatum, Parallelostroma kaugatomicum all from Wilbur strata just north of Kingston. Stromatopora bekkeri located at Accord, New York in the 'Wilbur member' comes from basal Rosendale strata which predate any of the Rosendale in the vicinity of Kingston.

Unit three represents a very fossiliferous limestone formed in a off shore trough-like environoment. Here a variety of fauna can be found ranging from brachiopods to stromatoporoids. The fossils found south at Fly Mountain may represent organic debris outwash across tide flats. Here again as in unit one the mottled limestone of the Wilbur vicinity appears to be in a early stage of diagenesis.

UNIT FOUR:
This unit is a massive dolostone which weathers orange-buff. At Wilbur Quarry the unit is 6.6 feet (2.0m) thick. In the vicinity of Wilbur the unit disconformably overlies the Binnewater Sandstone, and does not appear to extend northeast over Ordovician sediments. To the south at Fly Mountain this dolostone develops sparse chert nodules and occasional fossil ghosts. The unit is absent at the Vlightberg north. It is also absent at the east side of Callanan's Quarry.

Unit four probably represents a intertidal to tide flat environment. These flats most likely had a low energy environment, and perhaps were hypersaline.

CONCLUSION

The proposal of the Four-fold subdivision of the Rosendale Dolostone can be easly recognized in the field. All four units are distict enough to be readly recognized. At most locations all units are present except where removed by erosion, or have under gone facies change or were never deposited.

From the foregoing, it seems that the Wilbur Limestone would be best recognized as a facies and subunit of the Rosendale Dolostone.

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ROADLOG FOR FIELDTRIP J:
STRATIGRAPHY OF THE LATE SILURIAN RONDOUT GROUP
IN THE VICINITY OF KINGSTON, NEW YORK.

CO-LEADERS: AGOSTARO, R; FETTERHOFF, B.V.; WARREN, L.

Fieldtrip starts at the Ramada Inn parking lot.

MILES FROM LAST POINT

0 Turn right out of parking lot onto NY28 heading northwest.

0.1 Traffic light just past light bear right toward US209 bypass and Kingston-Rhinecliff Bridge.

0.2 North on US209. For the next 2.1 miles are extensive roadcuts in gently dipping siltstones and shales of Mt. Marion Formation (Middle Devonian).

2.0 Pass over Sawkill Road.

0.3 Pass over NYS Thruway.

0.3 Bridge over Esopus Creek.

0.7 End US209 bypass. Beginning of NY199. Continue east.

0.1 Pass over US 9W.

0.2 Roadcut shows Lower Devonian strata.

0.8 Exit at NY32. Bear right.

0.3 At stop sign turn left (south) onto NY32. Proceed south 0.5 miles and pull off to right.

STOP 1A: WYGANT NORTH. ROADCUT EXPOSING THACHER, WHITEPORT, GLASCO, AND ROSENDALE. (PLEASE DO NOT CROSS HIGHWAY. BEWARE OF FALLING ROCK - WEAR HARD HATS.)

Whiteport

Thickness of Whiteport is five feet. Unit two is not present in this section, and unit one rests disconformably upon unit three.

Glasco

Note lower disconformable contact with massive dolomitic mudstones of the Rosendale. Coverstone lithology of unit A (subunit 2) characterized by laminar stromatoporoids, chiefly Stromatopora clarkei, intercalated with stick-like tabulates and/or bryozoa, and chert. Take note of the position of this unit in the stratigraphic sequence.

Distinct color change between unit B and C (dark blue vs. light gray). Bedding plane parting marks upper contact of unit C with overlying basal ostracod floatstones of the Whiteport. This unit in the lower Whiteport occurs in virtually all localities studied and serves as an excellent marker bed.

0.8 Pull off on right side of road.

STOP 1B: WYGANT SOUTH. PLEASE DO NOT CROSS HIGHWAY.

Whiteport

Unit four is well exposed at this stop. Note abundance of ostracods, and fragments of limestone (intraformational conglomerate) within this unit. Gradational contact with unit three. Unit one and two are not exposed at this stop.

Glasco

Hemispherical stromatoporoids and halysitids found in the basal hemstones are typical of the northern domain. Compare intact halysitid coralla with fragmented types in chainstone. Note laminar stromatoporoids in coverstone and chainstone lithologies of unit A. Pay particular attention to stromatoporoid/halysitid association in low matrix chainstone.

Dominant macro-invertebrates in unit B are solitary rugosa, cladoporid-like tabulates, and stick-like tabulates and/or bryozoa (especially in subunit 2). Unit C is characterized by fossil fragments. Note irregular disconformable upper contact and associated rip-up clasts.

Rosendale

At this location unit one is missing, probably due to erosion. Unit two is massive dolostone. Unit two subunit is a massive dolostone with discontinuous to continuous limestone stringers. Unit three, Wilbur is mottled and contains a fossil marker bed. The bottom portion of this unit is a sandy limestone which rests on Ordovician sediments with angular unconformity. Most likely, unit four was never deposited.

1.7 Return to transportation and proceed south on NY32. There are intermittent outcrops and road cuts in a more or less regularly ascending stratigraphic order from Austin Glen (?) through Onondoga Formations. The overall structural picture is somewhat complicated. Turn left onto 9W south.

1.6 Stay in left lane at light make left turn into housing development. Cross under railrad bridge.

0.1 Turn right and proceed to dead end circle. Park here.

STOP 2: VLIGHTBERG HILL. (FOLLOW FIELDTRIP LEADERS UP HILL). PLEASE FOLLOW PINK RIBBON TRAIL AND DO NOT WANDER -ESPECIALLY DANGEROUS CLIFFS.

2A: VAN INGEN'S WILBUR

Rosendale

Unit three, Wilbur is massive but still has that mottled look. Here the limestone is in angular unconformity with underlying Middle Ordovician Normanskill (Austen Glen aspect) graywackes.

2B: SOUTH END OF THE VLIGHTBERG

Whiteport

Unit four is not present at this stop. Unit two is dolomitized, and the subunits are barely distinguishable.

Glasco

The Glasco is represented by unit C (subunit 2) which consists of dolomitic mudstones, indistinctly laminated dolomitic mudstone, and stringers of fossil hash with quartz grains. Similar horizons occur at stops 3, 5A and 5B.

Rosendale

A small mottled portion of unit one is present.

0.1 Turn around make left and go back under railroad bridge. At traffic light go straight and cross US9W.

0.15 At next traffic light make a left turn onto Hasbrouck Ave.

0.1 Turn left on Abeel Street (two blocks down).

0.5 Proceed down Abeel Street and go past flashing red light.

0.75 Pass under NY Central Railroad.

0.05 Turn right at stop sign (Wilbur Ave).

0.05 Turn left on RT213 at flashing red light proceed back toward NY Central Railroad underpass (East).

0.15 Pull of road parallel to Rondout Creek just past stonehouse on right. Outcrop next to picket fence.

STOP 3: SWEENEY'S STONEYARD. (FOLLOW FIELD TRIP LEADERS) NO SAMPLING AT THIS OUTCROP - WHEN WE CROSS THE ROAD STAY ON SIDEWALK. DO NOT WALK ON THE FLOWER GARDEN.) OUTCROP DESCRIPTIONS WILL BE PRESENTED BY FIELDTRIP LEADERS ON OPPOSITE SIDE OF OUTCROP.

Whiteport

Best exposure for the Whiteport Dolostone in the Kingston area. Unit four is dolomitized at this stop. Unit two can be seen in its two subdivisions, the upper laminated subunit and lower 'reef' subunit. The three subzones within the lower subunit are best exposed here. Note disconformity at the base of units four, two, and at the top of unit two. At the top of of unit one, mudcracks mark the contact with the Thacher limestone.

Glasco

Cherty boundstone is found near the base of unit A (very thin subunit 1). Unit B contains a lower dolomitic floatstone/lamstone (subunit 1). The upper dolomitic mudstone may be indicative of quiet water in the back reef environment. Note the highs and lows within the stromatoporoid knobs along with laminar and hemispherical stromatoporoids located at similar horizons. Take a close look at the overlying subunit 2.

Rosendale

At this stop all four units in the four-fold proposal are present. The upper limestone of unit one can be seen with its mottled look and a minor parting at the base. Unit two is massive dolostone which has several partings present. Unit three and unit four are present but are hidden behind the fence. Once again do not step on the garden and no samples please.

0.1 Proceed east on Abeel Street. After underpass NY Central Railroad turn left on Devitt to turn around and get back on Abeel Street going west.

0.3 Pass under NY Central Railroad.

0.2 Pass outcrop just examined.

0.05 Continuing down Abeel Street which also becomes NY213.

0.65 Traveling southwest parallel to Rondout Creek. Prepare to pull off road to right suddenly in 0.65 miles. Park in entrance to gravel pit road. If road is open do not block entrance.

STOP 4: CITY OF KINGSTON GRAVEL PIT (FOLLOW FIELDTRIP LEADERS). THE CLIFF TO THE NORTHWEST IS FORMED OF AN EXTENSIVE SEQUENCE OF UPPER SILURIAN AND LOWER DEVONIAN STRATA (MOSTLY CARBONATES) PARTLY REPEATED BY FAULTING.

Whiteport

Unit four is dolomitized at this outcrop. Fossiliferous horizons can be noted, with concave-down ostracod valves, brachiopods, and solitary rugose corals. Hemispherical stromatoporoids also present. Unit three is covered by talus; unit two can be seen in both subunits. Contact between unit one and overlying Thacher limestone is last mudcrack in unit one.

Glasco

The cherty coverstone marker bed essentially sits at the base of unit A. The chainstone lithology has thinned relative to the north, contains more matrix and few, if any, laminar stromatoporoids. The cyclic nature of floatstone and lamstone within unit B is best demonstrated at this locality. The base of unit C shows an unusual stromatoporoid growth form. A vertical channel wall and subsequent infillings are encrusted by stromatoporoid coenostea (Parallelostroma constellatum). Once again take note of of the laminar and hemispherical stormatoporoids that seem to co-exist at similar horizons.

Rosendale

This stop represents the standard reference for the Rondout Formation and the type section of the Wilbur member. Here all four units of the Rosendale dolostone can be seen. The cliff to the northeast shows an extensive sequence of all four units. Unit one can clearly be identified below the base of the Glasco. The massive limestone is mottled and the upper portion is darker than the bottom. The Wilbur, unit three, is sandwiched between the dolostone of unit two and unit four. Unit four lies with disconformity on the underlying Binnewater Sandstone.

0.9	Continue southwest on NY213. Cross over Rondout Creek Bridge.
0.1	After bridge turn left onto New Salem Road.
1.0	Proceed to Callanan's Quarry. Turn left into far entrance. Park in lot, keep roadway into pit open.

STOP 5: CALLANAN'S QUARRY. WAIVER FORMS MUST BE SIGNED RELEASING QUARRY AND ITS EMPLOYEES OF ANY LIABILITY, BEFORE ENTERING PREMISES. IT IS MANDATORY THAT HARD HATS AND FIELD BOOTS BE WORN - NO ONE ADMITTED WITHOUT SUCH SAFETY EQUIPMENT. FOLLOW FIELDTRIP LEADERS TO DESIGNATED LOCALITIES. DO NOT WANDER - EXTREMELY DANGEROUS OVERHANGS AND CLIFFS.

5A: CALLANAN'S WEST: FIELD ASSISTANTS WILL BE ON HAND TO ASSIST (ESPECIALLY KEEPING FIELDTRIP PARTICIPANTS AWARE OF DANGEROUS CLIFFS AND OVERHANGS). NO CLIMBING OF ANY SORT.

Whiteport

'Reef' subunit of unit two is present in this section. Undeformed halysitid coral found at this location. Unit four is almost completely dolomitized.

Glasco

Cherty boundstone marker bed is once again located near the base of unit A. Take a close look at the burrowed horizon and high matrix chainstone (rare entire halysitid coralla). Unit B is rather thick at this locality. Take some time to examine the stromatoporoid knobs and the overlying dolomitic mudstone and floatstone with occasional laminates, fossil debris and scattered hemispherical stromatoporoids. The latter was interpreted as a low subtidal to intertidal (?) flat environment.

Rosendale

At this outcrop all four units are present but due to faulting the beds are repeated several times. Unit one can be found sitting under the shale parting at the base of the Glasco. This mottled limestone has a parting at its base. Unit two massive dolostone has several partings. Unit three, Wilbur is mottled and also has several partings. The lower dolostone of unit four is massive with areas that are more calcareous. This dolostone lies disconformably on the underlying Binnewater Sandstone.

5B: CALLANAN'S EAST: ONCE AGAIN FOLLOW FIELDTRIP LEADERS. STAY AWAY FROM EDGE OF BENCH. DO NOT WANDER OR CLIMB!! FIELD ASSISTANTS ARE INSTRUCTED TO KEEP FIELD TRIP PARTICIPANTS AWAY FROM CLIFF. STAY AWAY FROM ROPED OFF AREA.

Whiteport

Unit four is no longer present; unit three is over seven feet in thickness. Unit two is much thinner in than the western side of the quarry, and, due to the less abundant fossils within the lower subunit, is now 'offreef'.

Glasco

This locality has been the most problematic to decipher due to its seemingly "unusual" character. With the help of marker beds in the Whiteport and Rosendale the intricate nature of this exposure appears to have been clarified. Unit A as usual contains a lower coverstone/boundstone but only fragments of the chainstone remain. Unit B does not contain subunit 1 but is represented by a thick subunit 2 (5.4 feet) consisting chiefly of dolomitic mudstones with fewer floatstones (somewhat cyclic). Some beds are laminated and burrowed. The base of the unit contains wide, deep, vertical burrows that appear related to a horizon on the west side. Unit C is represented by subunit 2 and its associated mixture of dolomitic mudstones and floatstones, rudstones, and black shale at the top. These lithologies contain more fossil debris and quartz grains. Only unit C, at other localities demonstrates these associations.

Rosendale

Unit one, the mottled limestone, is represented in the the cliffs (very dangerous do not climb up talus). Unit two and its subunit along with the Wilbur can be seen on several boulders lying near by. Unit two is massive dolostone which is somewhat calcareous. Again unit two subunit is present, a dolostone with continuous to discontinuous limestone stringers. Unit three, the Wilbur, is mottled, and fossiliferous along with clasts of sandstone present near the base. The Wilbur sits on top of Ordovician sediments at an angular unconformity . Most likely unit four was never deposited here.

END OF TRIP. HAVE A PLEASANT DRIVE HOME!

TIDAL CURRENTS, BIOGENIC ACTIVITY AND PYCNOCLINAL FLUCTUATION ON A LOWER DEVONIAN RAMP: BECRAFT, ALSEN, AND PORT EWEN FORMATIONS, CENTRAL HUDSON VALLEY

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INTRODUCTION

The Helderberg Group (Lower Devonian) of New York State includes eight thin, but extensive formations that comprise two transgressive cycles separated by a minor regression (Rickard, 1962; Head, 1969; Laporte, 1969; Ebert, 1982, 1983). The lower cycle exhibits the classic deepening upward sequence of formations: Rondout, Manlius, Coeymans, Kalkberg, New Scotland (Table 1; Rickard, 1962; Laporte, 1967, 1969) that has been widely cited as an example of epeiric sea (ramp) sedimentation. The regression is recorded by an upper tongue of the Kalkberg Formation and the lower portion of the Becraft Formation (Head, 1969; Arif, 1973; Ebert, 1982, 1983). The upper transgressive cycle is comprised of the Becraft, Alsen and Port Ewen formations and has been assumed to represent a repetition of Coeymans, Kalkberg and New Scotland lithologies and environments (Rickard, 1962; Laporte, 1967). Gross similarity in outcrop appearance had been the only basis for this assumption. Recent descriptions of the upper cycle (Ebert, 1982, 1983, 1985, 1986; Mazzo, 1981, Mazzo and LaFleur, 1984) have indicated significant departures from the characteristics of the lower formations. Comparison of upper and lower cycles (Ebert, 1982, 1983, 1985) has resulted in improved understanding of the processes that operated on the Helderberg ramp.

Tidal sand waves are recognized in the Becraft Formation. This formation and other skeletal grainstone units have previously been interpreted as shoal deposits that accumulated above wave base. The predominance of wave action has always been assumed in these interpretations; however, analysis of sedimentary structures clearly indicates the dominance of tidal currents.

Tidal sand waves occur in a variety of modern environments, from estuarine channels to the open shelf. The simplistic, and possibly erroneous, interpretation of wave dominance in many coarse carbonates probably has led to inaccurate reconstructions

SYSTEM	SERIES	STAGE	GROUP	FORMATION	MEMBER
LOWER DEVONIAN	ULSTERIAN	SAWKILL	TRISTATES	BOIS BLANC/SCHOHARIE	
				CARLISLE CENTER	
				ESOPUS	
		DEERPARK		ORISKANY/CONNELLY/ GLENERIE	
				PORT JERVIS	
		HELDERBERGIAN	HELDERBERG	PORT EWEN	
				ALSEN	
				BECRAFT	
				KALKBERG/NEW SCOTLAND	
				KALKBERG	
				COEYMANS	DEANSBORO
					DAYVILLE/RAVENA
				MANLIUS	JAMESVILLE
					CLARK RESERVATION
					ELMWOOD
					OLNEY
					THACHER
				RONDOUT	CHRYSLER/WHITEPORT
U.SIL.		CAYUGAN	SALINA		CHRYSLER
					AKRON/COBLESKILL
				BERTIE, CAMILLUS, SYRACUSE and VERNON	

TABLE 1

Lower Devonian Stratigraphy of New York state. After Rickard (1975).

of environments and paleogeography, especially when adjacent facies are poorly exposed.

The occurrence of tidal sand waves in a sequence that has been interpreted as representing sedimentation in an epeiric sea (Laporte, 1969) raises important questions about the processes that operate in such seas. Traditional epeiric sea models (Shaw, 1964; Irwin, 1965; Ahr, 1973) have treated these seas as being tideless (Hallam, 1981). These models regard the position of wave base as the primary factor governing the distribution of facies. Tides are considered to be absent or of negligible effect.

Significant tidal exchange in epeiric seas has been disregarded because of the supposed frictional difficulty of moving the tidal prism across such wide, shallow shelves (Shaw, 1964; Irwin, 1965; Mazzullo and Friedman, 1975; Hallam, 1981). Despite this bias, a tidal origin has been demonstrated for many quartz arenites from epeiric sea settings (e.g. Klein, 1970, 1971, 1975, 1977; Thompson, 1975; Johnson, 1975; Swett, Klein and Smit, 1971; Chafetz, 1977; Barwis and Makurath, 1978; Recently, Slingerland (1986) has developed a numerical model that supports the hypothesis (Klein, 1977; Klein and Ryer, 1978) that some epeiric seas could have been tide-dominated. This model for the Upper Devonian Catskill epeiric sea includes the geographic area of the present study. Tidal sand waves of the Becraft Formation and the model of Slingerland suggest that, at least, the shallow portions of the northern Appalachian Basin may have been tidally dominated throughout the Devonian. It should be pointed out, however, that deeper portions of the basin, especially during the Middle Devonian, were storm-dominated (for examples, see Brett, 1986).

Biogenic processes played an important role in the Helderberg sea, as well. The Alsen Formation displays a predominance of biogenically-disrupted fabrics, although remnants of physical structures are also preserved. The overlying Port Ewen Formation also shows evidence of the importance of biogenic activity. A variety of ichnofossils are present in this unit. These traces provide a detailed record of subtle changes in water oxygenation on the deeper portions of the Helderberg ramp. Of particular interest are the cyclic variations in the distribution of <u>Zoophycos</u>, <u>Chondrites</u> and <u>Helminthoida</u> and associated lithologies. These cycles record fluctuations in the position of the pycnocline and its intersection with the sediment-water interface. These fluctuations occurred in response to regional transgression and record the shoreward shift in the location of the pycnoclinal intersection. Both symmetric and asymmetric cycles are recorded. Although PAC-like in scale, these cycles do not seem to fit the PAC motif of shallowing upward. Deepening upward and shallowing followed by deepening seem to be the more typical pattern for these cycles.

PREVIOUS WORK

New York's Helderberg carbonates have been studied since the 1840's; however, few of these works have been sedimentologic in nature. The vast majority of early research was concerned with paleontology and biostratigraphy. Research prior to 1962 has been succinctly summarized by Rickard (1962).

The detailed stratigraphic analysis of Rickard (1962) has provided an excellent standard for evaluation of earlier paleontologic and biostratigraphic efforts. It has also served as the framework upon which all subsequent work is based. Outcrop designations in this report follow Rickard (Fig. 1; e.g. R-44 = Rickard's section 44). Most subsequent study of the Helderberg Group has concentrated upon the lower formations. Significant contributions include Laporte (1967, 1969); Anderson (1967, 1971, 1972, 1974), Head, Harper, Laporte and Andersen (1969), Belak (1978, 1980) and Epstein (1968, 1969, 1971). Numerous detailed stratigraphic studies have also been undertaken by E. J. Anderson and P. W. Goodwin and their students in the development and testing of the hypothesis of Punctuated Aggradational Cycles (PACs).

Paleogeographic reconstructions of the northern Appalachian Basin during Helderberg time (Laporte, 1967; Head, 1969, 1974) show the bathymetric axis of the basin trending northeast-southwest and intersecting the New York outcrop belt in the vicinity of Kingston (Rickard's section 24 and STOP 3 of this trip). These maps also demonstrate the near coincidence of Lower Devonian depositional strike and the trend of the modern outcrop belt through most of New York State.

Upper Helderberg units have received considerably less attention. A cursory account of the Becraft Formation is included in Anderson (1972). Arif (1973) studied Becraft petrology. Mazzo (1981) and Mazzo and LaFleur (1984) described lithologies and cyclicity in the Port Ewen Formation. Ebert (1983) is the only comprehensive treatment of the upper units.

Description of the sedimentology of the upper units with a revised model for epeiric sea sedimentation and a slightly revised stratigraphy are included in Ebert (1983). Significant aspects of the revised stratigraphy include: 1) recognition of the upper tongue of the Kalkberg Formation between the New Scotland and Becraft Formations in the Hudson Valley, 2) demonstration of partial temporal equivalence of the Kalkberg and lower Becraft Formation in the east-west portion of the outcrop belt, 3) demonstration of stratigraphic convergence of the Becraft Formation with lower units toward the western end of the Becraft outcrop belt, 4) recognition of four distinctive subfacies within the Becraft Formation, 5) amplification upon earlier correlations of the Minisink Formation of eastern Pennsylvania, and 6) description of a clear exposure of the Port Ewen-Glenerie contact at Bloomington, New York. This work is summarized in Ebert (1982, 1985) and details of Becraft sedi-

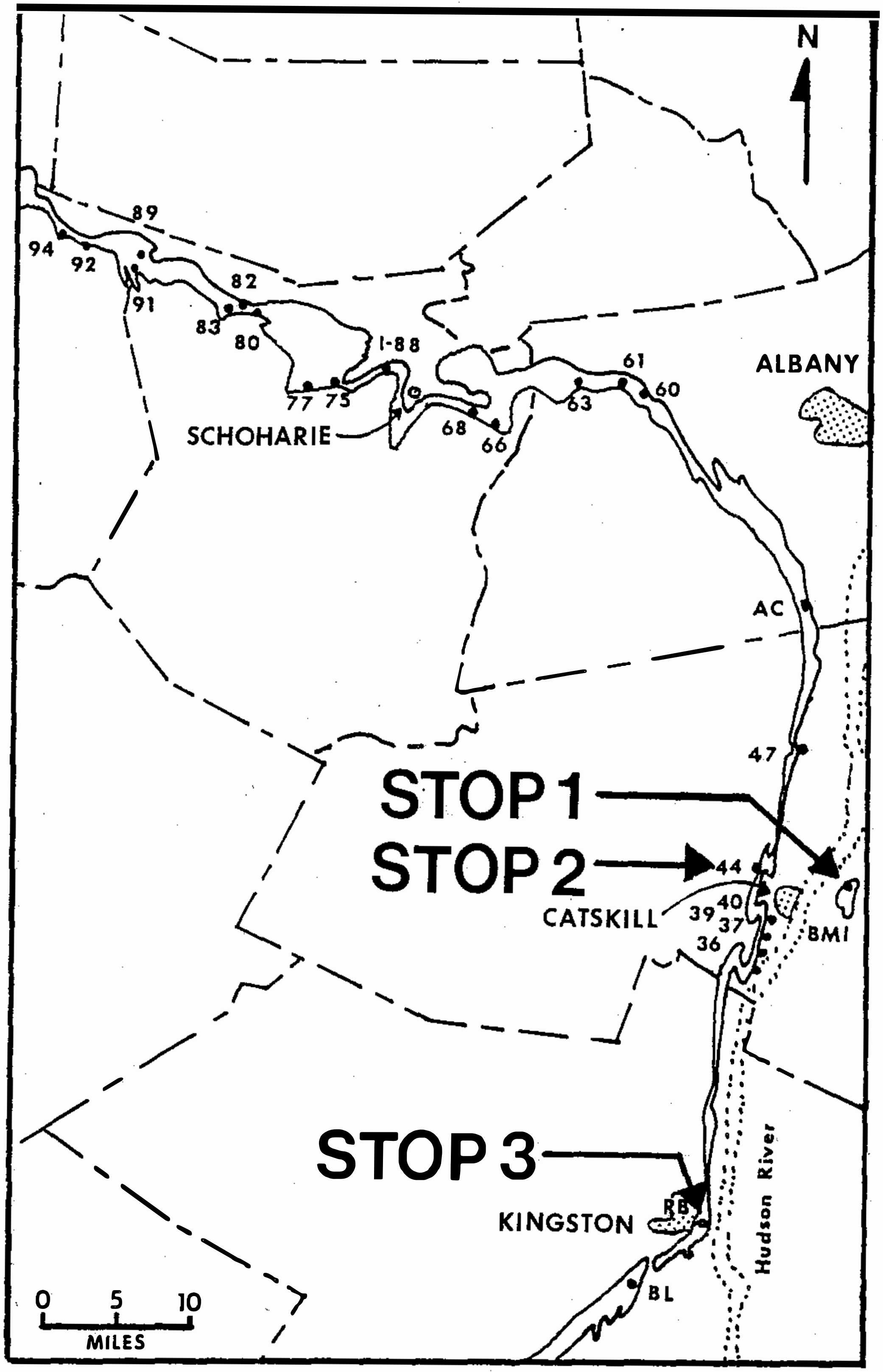

FIGURE 1. - Portion of Helderberg outcrop belt in eastern New York and location of stops. Upper Helderberg formations occur from R-92(?) through Section BL (Bloomington). I-88 = roadcut on interstate, AC = Atlantic Cement quarry at Ravena, BMI = Becraft Mountain Independent Cement quarry, RB = Rhinecliff Bridge, Rt. 199 roadcut. Modified from Rickard (1962).

mentology are presented in Ebert (1986). This paper illustrates some of the major aspects of the sedimentology of the upper Helderberg Formations.

BECRAFT FORMATION

Sand waves are common bedforms in modern, siliciclastic, estuarine and shelf-sea environments. In recent years, sand waves have been widely documented in ancient siliciclastic rocks (e.g. Allen and Narayan, 1964; DeRaaf and Boersma, 1971; Narayan, 1971; Pryor and Amarel, 1971; Johnson, 1975; Anderton, 1976; Nio, 1976; Button and Vos, 1977; Hobday and Tankard, 1978; Lovell, 1980; Visser, 1980; Allen, 1981a, b, 1982; Homewood and Allen, 1981; Allen and Homewood, 1984; Kreisa and Moiola, 1986). These sandstone examples commonly display meter-scale or larger cross-bedding that is arranged in sigmoidal tidal bundles (Boersma and Terwindt, 1981) as defined by silt or mud drapes. Erosional reactivation surfaces and ripples or small scale (<0.04m) cross-stratification produced by the subordinate flow are also common features. Paleocurrents tend to be nearly unidirectional, which Allen (1980) attributes to strong tidal asymmetry.

Tidal sand waves are also common bedforms in modern carbonate environments, especially in oolitic facies and one would suspect that they should be common in ancient carbonates, as well. Tidal sand waves have only recently been reported from ancient carbonate rocks (Ebert, 1983, 1986; DeMicco, 1986). This field trip will examine features of tidal sand waves from a skeletal limestone, the Becraft Formation. The interpretation of this unit as a complex of sand waves is based upon an assemblage of sedimentary structures that is similar to those reported from modern oolitic sand waves (Hine, 1977) and similar to the theoretical suite of structures modelled by Allen (1980). Many structures reported from siliciclastic rocks are present as well. The suite of structures described implies a greater degree of tidal symmetry for these carbonate sand waves than is typically indicated in the siliciclastic examples cited above.

Internal stratigraphy of the Becraft Formation

Four distinct subfacies are recognized within the skeletal grainstones of the Becraft Formation (Fig. 2; Ebert, 1983). Subfacies 1 and 2 comprise the tidal sand waves that will be examined on this trip. Subfacies 1 makes up the lower half of the formation in the central Hudson Valley and is absent west of Ravena, N.Y. as a result of thinning and facies change. Thickness ranges from 0 to 7.5 meters (24.6 feet). This unit was originally recognized by Rickard (1962) and used by Arif (1973).

Subfacies 2 is present throughout the outcrop belt of the Becraft. This subfacies thins from 9.2 meters (30.2 feet) in the Hudson Valley (sections R-44, R-47) to disappearance just east of Cherry Valley (R-94) via truncation along the pre-Oriskany disconformity. Rickard and Arif also noted the occurrence of this unit. Subfacies 1 and 2 will be examined at several stops on this field trip.

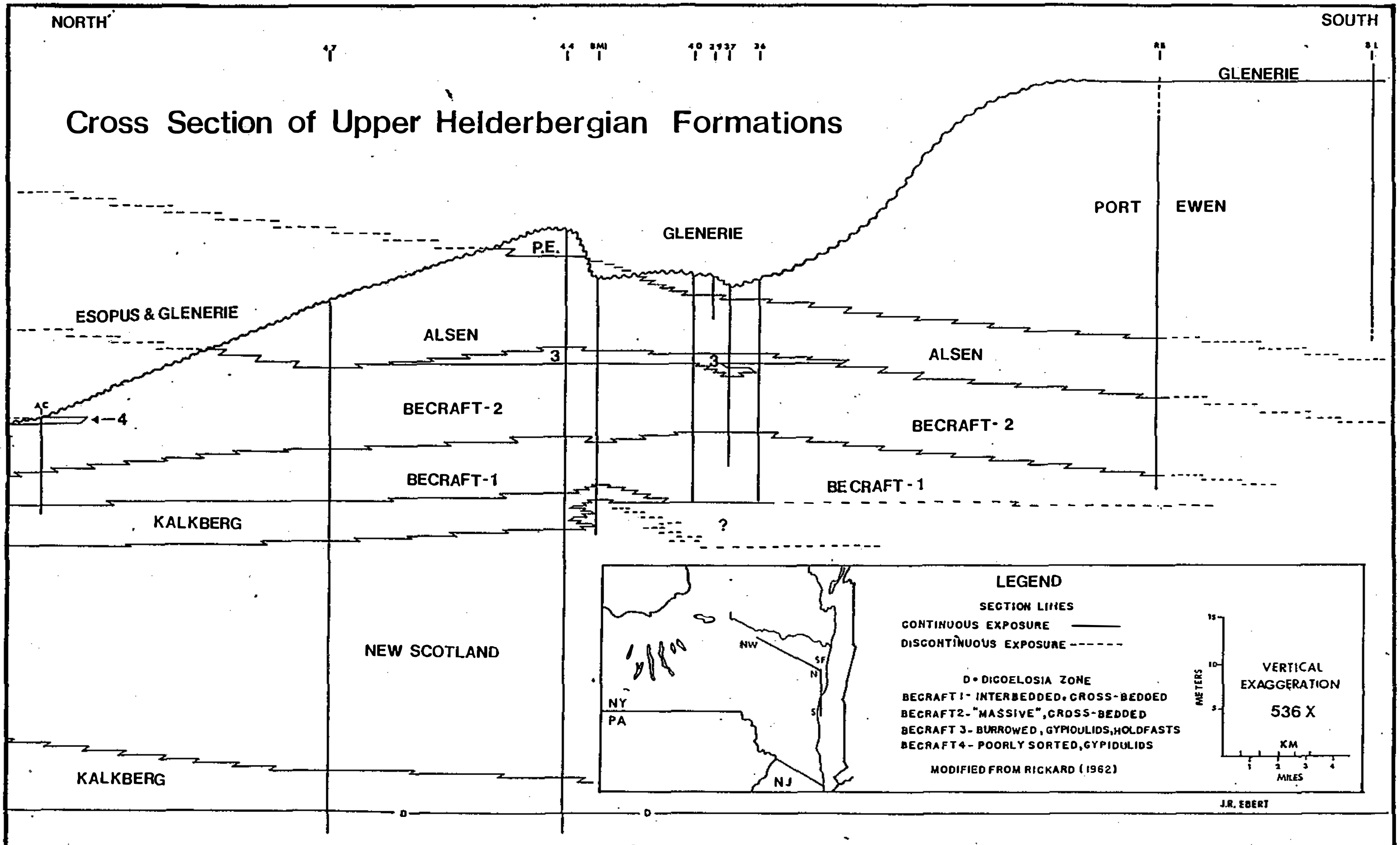

FIGURE 2. - Cross section of upper Helderberg formations and subfacies in the central Hudson Valley. Modified from Rickard (1962) and Ebert (1983).

Subfacies 3 and 4 are thin (<1.6m, 5.2 ft.) and more limited in distribution than subfacies 1 and 2. Subfacies 3 occurs at the top of the formation in the central Hudson Valley only between Catskill Creek and Cementon (Fig. 2) and will be seen at stops 1 and 2. It is comprised of well-sorted, subrounded, medium-to-coarse skeletal grainstone (crinoidal debris - 34%, brachiopod values - 23%, bryozoans - 16%, micritized grains - 16%). This unit is readily recognized by an abundance of disarticulated valves of the pentamerid brachiopod Gypidula pseudogaleata and root-like holdfasts of the crinoid Clonocrinus(?). Planar erosional surfaces separate beds that show few physical sedimentary structures. Asymmetrical ripples and herringbone cross-lamination are present, but are not common. Bioturbate fabrics predominate. Subfacies 3 represents inactive sand waves that were transitional between the active sand waves of subfacies 1 and 2 and the open shelf (Alsen Formation).

Subfacies 4 overlies and interfingers with subfacies 2 at sections I-88, R-66 and AC and is not present in the field trip area. Subfacies 4 of the Becraft has been regarded in the past as Port Ewen (see references in Rickard, 1962, p. 91) and outliers of the Alsen Formation (Rickard, 1962, 1975). Textural and faunal criteria indicate strong similarity to the Becraft and marked differences from the Alsen and should, therefore, be regarded as a subdivision of the Becraft (Ebert, 1983). This unit consists of very poorly-sorted, cross-bedded crinoidal grainstones interbedded with bioturbated skeletal packstones. Gypidula is again abundant. Peloids are common and rare ooids are present. Subfacies 4 occupies a more shoreward position and is interpreted as lagoonal sediments (packstones) interbedded with washovers (grainstones) derived from the sand waves of subfacies 2.

SEDIMENTOLOGY OF BECRAFT SAND WAVES

SUBFACIES 1 AND 2

Becraft sand waves are recorded by two distinctive subfacies (1 and 2) of skeletal grainstone. Both subfacies record nearly symmetrical tidal regimes; however, slight variations in tidal dominance and symmetry occur between subfacies. Most exposures of these subfacies are essentially two-dimentional; so detailed study of paleocurrents was not possible. Estimations of tidal directions, dominance and symmetry are based upon apparent dip data from these two-dimensional exposures and are regarded as representing general trends.

Both subfacies are subtidal in origin as suggested by the presence of a normal marine fauna (e.g. echinoderms, brachiopods, bryozoans and rare corals) and paired silt drapes, a sedimentologic criteria of subtidal deposition (Visser, 1980). Depositional and diagenetic features of intertidal or supratidal origin are absent from both subfacies.

Subfacies 1

The lower subfacies (1) is a heterolithic sequence comprising the following lithologies: a) very coarse, crinoid and brachiopod grainstones to rudstones, b) medium quartz siltstones to very fine sandstones, and c) fine peloidal grainstones. Crinoidal debris (35%), disarticulated brachiopod valves (25%), and bryozoan fragments (24%) are the major particles in grainstones and rudstones. The distinctive holdfast of Aspidocrinus scuteliformis is abundant and diagnostic of this unit at most locations. All grains are sub-angular and poorly to moderately sorted. Finer-grained lithologies display a complete range of compositions from nearly pure quartzose siltstones and very fine sandstones to nearly pure peloidal grainstones. Quartz grains are angular to sub-angular. Peloids are typically sub-spherical to slightly ovoid and average 0.001 m in diameter (very fine sand). These finer grains are typically moderately- to well-sorted.

Skeletal grainstones and rudstones occur as tabular beds, 0.05-0.35 m in thickness or as lenses defined by the finer-grained lithologies. Siltstones and peloidal grainstones occur as thin (0.005-0.05 m) interbeds that separate beds of skeletal grainstone or as sigmoidal drapes (Kreisa and Moiola, 1986) that define the forms of dunes in skeletal grainstones (Fig. 3). Preserved duneforms in this subfacies are typically 0.2-0.3 m in amplitude, with wavelengths of 1.3-3.0 m. Drapes commonly split into pairs along dune foresets. The lateral spacing of drapes in the downcurrent direction may define neap-spring tidal bundles (Fig. 3), however this is difficult to determine because of the limited width of most exposures.

Skeletal grainstones exhibit herringbone and unidirectional cross-bedding in decimenter scale cosets. A slight majority of the sets are generally oriented toward the southwest. Individual sets overlie planar or undulose erosional surfaces or thin interbeds of the finer-grained lithologies. Within cross-sets, single and paired drapes of the finer lithologies are common. These drapes define the duneforms described above.

Interbeds of siltstone and peloidal grainstone are commonly cross-laminated. Asymmetrical ripples are less commonly preserved. Ripples and/or cross-lamination that ascend foresets in grainstones have been noted; however, these structures are rare. These structures indicate apparent paleoflow that was opposite to that recorded by cross-bedding in underlying and overlying grainstones. Cross-laminations without reversal of paleoflow have also been observed. Some interbeds appear to be structureless or vaguely laminated.

Subfacies 1 represents slightly asymmetrical, subtidal sand waves. The tidal regime was slightly ebb-dominant, toward the southwest. Heterolithic bedding records unsteady flow and deposition from both bedload and suspension. Drapes were

FIGURE 3. - Sketch of duneform and silty/peloidal drapes and interbeds in Becraft subfacies 1 from field photograph, taken at R-44 (STOP 2). Paired drapes occur at A and B. Drapes are separated by thin lenses of skeletal grainstone that may represent ripples. Lateral spacing from A to B may define a neap-spring-neap tidal bundle. Note also ripples at the crest of the dune that indicate paleocurrent reversal. Scale bar = 0.1 meters.

deposited from suspension during slack water periods. Paired drapes record two slack water periods which can only occur in a completely subtidal setting (Visser, 1980). Ripples and cross-lamination in fine-grained lithologies indicate current reversal and reworking by the subordinate tide.

Subfacies 2

Very coarse skeletal grainstones and rudstones make up subfacies 2. The distinctive fine-grained drapes and interbeds of the subfacies 1 are absent from this unit. However, some fine quartz and peloids are present as geopetal sediment in shelter pores. Crinoidal debris (40%)and brachiopods valves (30%) are the dominant particles. Both are slightly more abundant than in subfacies 1. Bryozoan fragments are common (14%), but less abundant than in the lower unit. Skeletal grains are sub-angular to sub-rounded. Sorting is moderate to poor. Grainstones of subfacies 2 exhibit improved sorting and roundness relative to subfacies 1.

Grainstone beds of subfacies 2 range from 0.05 to 1.0 m in thickness, but are typically 0.2-0.4 m. These beds are generally tabular or broadly lenticular. Duneforms have been observed and one locality (I-88) displays a train of three slightly climbing forms (Fig. 4). At this location, lenticularity of bedding can be attributed to the geometry of whole or partly preserved duneforms.

Planar and trough cross sets are the dominant type of internal stratification in subfacies 2. Herringbone and unidirectional cosets are present, with herringbone cosets being slightly more common (Fig. 4). Slightly more than half of these sets are oriented toward the northeast. Sets are erosively based by generally planar to very broadly undulose surfaces. Within sets, numerous low-angle, erosional reactivation surfaces are apparent (Fig. 4).

Horizontal or very gently inclined (<5 degrees) planar stratification is common throughout subfacies 2, but is most common in the upper third of the unit. Sets of planar stratification are typically underlain and overlain by nearly flat erosional surfaces. These beds occur in stacks up to 0.1 m thick or as composite sets with cross-stratified cosets. Most planar-stratified beds show uniform distribution of grain sizes, but normal and inverse grading have also been observed. Interbedding of relatively finer grainstones and coarser rudstones is one of the most conspicuous features of this type of stratification. Finer grainstones may display vague cross-lamination(?) in these interbedded associations; however, structures are difficult to recognize owing to the coarseness of the skeletal grains.

Asymmetric ripples and obvious ripple cross-lamination are relatively rare in subfacies 2. Ripples occur as distinctive caps on the crests of duneforms at the roadcut on I-88 near

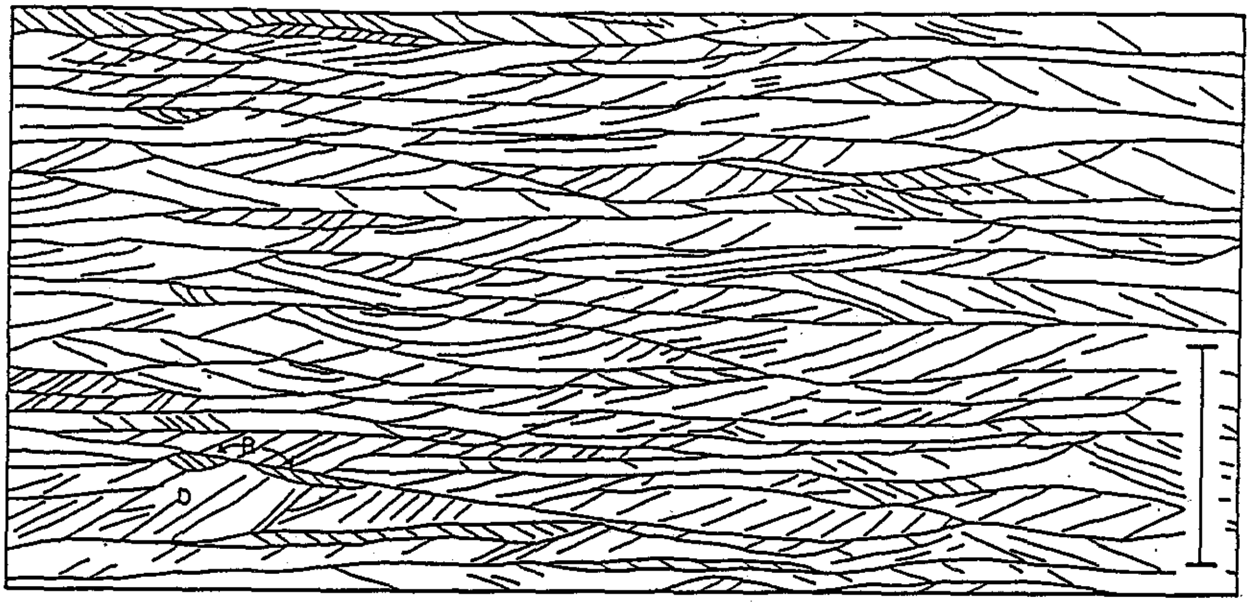

FIGURE 4. - Sketch of cross-stratification and bedforms in Becraft subfacies 2 from field photograph of weathered joint surface taken at the roadcut on I-88. Herringbone and unidirectional cosets are apparent, as are end-on views of troughs. Three, slightly climbing duneforms extend from D to the lower end of the scale bar. One duneform (D) exhibits several reactivation surfaces within its cross-stratification and a distinctive ripple cap (R). These features record a slightly subordinate, reversed tidal flow. A strikingly similar array of structures was modelled by Allen (1980) for nearly symmetrical and symmetrical sand waves. Scale bar = 0.5 meters.

Central Bridge (Fig. 4). Ripple caps exhibit opposed orientations to the paleoflow indicated by the underlying cross-stratification.

Biogenic structures are rare in subfacies 2. Minor biogenic disruption of fabric occurs near the top of the unit near the contact with subfacies 3 or the Alsen Formation.

Subfacies 2 records subtidal sand waves that were slightly flood-dominant toward the northeast and more symmetrical than the sand waves of subfacies 1. Herringbone cross-stratification indicates the near equality of flood and ebb tidal currents in this subfacies. Erosional reactivation surfaces and ripple caps record the reshaping of bedforms by opposed currents. Erosional reworking, rather than deposition of drapes, indicates the presence of a stronger subordinate tide and, therefore, increased tidal symmetry.

A strong subordinate flow is also indicated by the absence of the fine-grained drapes that were present in subfacies 1. The occurrence of fine internal sediment in shelter pores suggests that material capable of forming drapes was available during deposition of this subfacies. Fine sediment remained in suspension or was deposited and resuspended by the subordinate flow and was perhaps transported into adjacent deeper environments (e.g. Alsen Formation).

Coarse, planar-stratified grainstones and rudstones represent upper stage plane beds that formed during maximum velocity of the tidal flow. Interbedded finer grainstones may record flow reversal and/or accelerating and waning flow, especially if they are indeed cross-laminated. These planar- and cross-laminated(?) cosets are interpreted as vertically accreted tidal bundles (Kreisa and Moiola, 1986). Alternation of dominantly vertically accreted intervals with dominantly laterally accreted intervals may record neap-spring variations in tidal regime or variations in the rate of production of skeletal sediment relative to rates of reworking of this sediment by tidal currents.

ALSEN FORMATION

The Becraft Formation is overlain by the Alsen Formation (0-9.5m) in the central Hudson Valley. The Alsen thins to the north as a consequence of pre-Tristates beveling and is absent from Ravena westward. Skeletal grainstones and skeletal, peloidal grainstones are the dominant lithologies. Skeletal packstones with abundant peloids (average 11%) are locally common, especially at section RB (STOP 3). These packstones are typically more argillaceous than other lithologies. Particles are medium to coarse grained and moderately to poorly sorted. Skeletal grains are disarticulated, fragmented and highly micritized, but not rounded. Micritized grains constitute 22% of particles as a formational average. Peloidal lithologies are very fine to fine sands and include much coarser skeletal components.

Bedding in the Alsen is thin, discontinuous and irregular, commonly giving the appearance of a network of fitted nodules. These nodules probably originated through non-sutured seam pressure solution (Wanless, 1979) operating upon thin, vaguely rippled and bioturbated beds (Ebert, 1983). Physical sedimentary structures are rare in this unit owing to extensive bioturbation. Most fabrics consist of swirled or randomly oriented skeletal grains. Discrete burrows(0.5 to 2.0 mm diameter) are quite common and are usually filled with fine peloidal sediment, showing concentric, back-fill structures. Remnant physical structures include small-scale herringbone cross-lamination, asymmetric and symmetric ripples. Physical structures are more common in the base of the formation in close proximity to the Becraft Formation. These remnant structures and grainstone textures suggest the action of weak tidal currents (Ebert, 1983, 1985).

The fauna of the Alsen Formation is a diverse array of epifaunal suspension feeders and infaunal deposit feeders. Encrusting, ramose and fenestrate bryozoans are the dominant constituents. Brachiopods (11%) and crinoidal debris (19%) are also common. This fauna indicates ample oxygenation and relative stability of the substrate.

Textural, faunal, ichnofaunal and structural evidence suggest that Alsen deposition took place on an open shelf where water circulation was sufficient to maintain oxygenation and occasionally stir the substrate. Currents were sufficient to winnow the sediment periodically to produce grainstone textures and physical structures. However, the substrate was probably relatively stable and burrowing organisms were able to destroy most of the physical structures. The high percentage of micritized grains and the limited abrasion of these particles is additional evidence of substrate stability.

PORT EWEN FORMATION

The Port Ewen Formation overlies the Alsen Formation from Catskill Creek (R-44, STOP 2) south through the Hudson Valley. From Catskill Creek to Cementon (R-36) the Port Ewen is less than 2 meters thick as a result of pre-Tristates erosion. From Cementon to Kingston, the Port Ewen thickens rapidly, attaining a maximum thickness of roughly 24 meters (Fig. 2). The disconformable upper contact is clearly marked by phosphatic nodules at Catskill Creek (STOP 2). Elsewhere, the contact is poorly exposed or covered. However, at Bloomington, New York (section BL), the contact is reasonably well-exposed and appears to be conformable (see Ebert, 1983).

Five lithologies make up the Port Ewen Formation: 1) silty, argillaceous, skeletal packstone to wackestone, 2) silty, argillaceous, peloidal packstone to wackestone, 3) nodular to irregularly bedded peloidal grainstone, 4) dark grey to black shale, and 5) nodular to irregularly bedded chert.

Lithologies 1 and 2 comprise most of the formation. Bryozoans (12%), brachiopods (9%), ostracodes (6%), trilobites (5%), sponge spicules (2%) and crinoid fragments (2%) are present. Most skeletal grains are highly micritized and compacted, making them nearly unidentifiable (average 18% of grains). Skeletal particles are typically in the fine to medium sand range. Peloids are slightly ovoid in shape and average 0.1 mm in diameter. Quartz is present as medium to coarse silt.

Compactional and pressure solution fabrics are common in lithologies 1 and 2. Depositional textures and fabrics are difficult to assess and are further obscured by local development of structural cleavage. Primary structures are rare and poorly preserved. Fine lamination, rare, thin beds of graded packstone and burrows interpreted as Helminthoida are the only structures found in these lithologies.

Nodular and irregular beds of light grey, purer carbonate are one of the most striking features of the Port Ewen Formation. Nodules range from 0.02 m to 0.25 m in thickness and from 0.4 m to nearly 1.0 m in length. All nodules and irregular beds are comprised of peloidal grainstone with variable, minor quantities of skeletal debris. Microspar peloids, averaging 0.1 mm in diameter, show indistinct boundaries with the enclosing sparry cement. The skeletal elements within the nodules are slightly coarser than the fauna in surrounding lithologies, but are not different taxonomically.

Nodules are thoroughly burrow-mottled, except where recognizable ichnogenera are present, typically Chondrites and Zoophycos. Bioturbation is more intense within nodules than in the surrounding lithologies (1 and 2). Most nodules have sharp boundaries. However, some nodules have been observed that exhibit a gradual decrease in the degree of bioturbation into the surrounding lithologies.

The formation, geometry and distribution of nodules are the result of early cementation controlled by bioturbation and pelletization of sediment. Organisms responsible for Chondrites and Zoophycos pelleted the sediment in localized areas and thereby generated a more open fabric and greater permeability. These areas were cemented early, perhaps on the sea floor and thus preserved from subsequent compaction. Additional evidence for early cementation is provided by synsedimentary fractures in some nodules that are partially cement-filled, with sediment overlying cement.

Comparable relationships involving bioturbation, early cementation and differential compaction have been reported from chalks by Milliman (1966), Furisch (1972), Noble and Howells (1974), Hattin (1971, 1975, 1981), Bathurst (1975), and Garrison and Kennedy (1977). Nodules in some Cretaceous chalks, although smaller and less well-defined than Port Ewen nodules, display Chondrites, Planolites, and Zoophycos (Garrison and Kennedy, 1977).

Mazzo (1981) and Mazzo and LaFleur (1984) have suggested that nodules in the Port Ewen Formation are the result of soft-sediment deformation of allochthonous flows of carbonate sediment into the deeper portions of the basin. These workers have not noted any biogenic structures within nodules. Indeed, they suggest that burrowing infauna avoided these carbonate-rich horizons (Mazzo, 1981, p. 51). The geometry of nodules and the intimate association with clearly in situ ichnofossils argue against this interpretation. The present attitude of some nodules might possibly suggest transport or reorientation, but this is more likely the result of shearing and/or rotation during Acadian tectonism than synsedimentary processes.

Periodic exhumation of some nodular horizons and the development of patchy hardgrounds may have taken place, although the evidence is not conclusive. At several horizons, the upper surfaces of nodules are encrusted or replaced by fine pyrite. These pyritic zones contain sharp-sided biogenic structures that may be borings. Associated with these zones are pebbly, phosphatic and/or pyritic clasts that contain similar biogenic structures. Pyritic zones are most commonly overlain by dark, barren shales. This association of lithologies and structures collectively indicate low rates of sediment accumulation and quite probably non-depositional hiatuses.

Chert in the Port Ewen is present as rinds that centripetally replace nodules of peloidal grainstone and as continuous beds that were originally peloidal. These features tend to be more common in the upper five to eight meters of the formation. This distribution may reflect greater availability of silica in proximity to the quartz-rich lithologies of the Glenerie and Connelly formations.

Biogenic structures, in addition to those mentioned above, include Planolites and three rarer forms that are questionably identified as Paleodictyon, Teichichnus and Terebellina. The Port Ewen ichnofauna is assignable to the Nereites and Zoophycos associations (Seilacher, 1967, 1978) that define deep-water assemblages. These traces, coupled with the sparse shelly fauna, indicate dysaerobic conditions at or near the pycnocline in a stratified basin.

Cyclic distribution of lithologies and ichnofossils

Mazzo (1981) and Mazzo and LaFleur (1984) noted the presence of cyclic variation of lithologies in the Port Ewen Formation. They describe asymmetric cycles that are lighter colored and more nodular at the base and become progressively darker and shalier upward. Burrows (probably Helminthoida) are noted only in the top, shaly parts of cycles. Cycles are interpreted as recording fluctuations in the supply of allochthonous carbonate during regional transgression. Carbonate input is interpreted to have increased when the aerobic-dysaerobic pycnocline shifted basinward and decreased during shoreward shifts which would decrease upslope production of carbonate.

In addition to variations in lithologies and color, distribution of ichnofauna must be taken into consideration in any interpretation of Port Ewen cycles. Within cycles, ichnofossils vary in a regular fashion with lithology (Fig. 5). A typical asymmetric cycle consists of: 1) a sharp, but generally non-erosive basal surface overlain by thin (a few centimeters) dark shale. These horizons are commonly zones of bedding plane slip during deformation. 2) Thick, light grey, continuous beds or nodules of peloidal grainstone with abundant Zoophycos and/or Chondrites. 3) Smaller and sparser nodules of peloidal grainstone with greater amounts of skeletal wackestone or packstone between nodules. Chondrites and Zoophycos are less common than below and a few Helminthoida tubes are present. 4) Dark, laminated, highly argillaceous, skeletal wackestone and packstone. Helminthoida is the dominant trace. Planolites may be common and Chondrites are rare.

Symmetrical cycles also occur in the Port Ewen Formation (Fig. 5). In such cycles, the sequence described above is inverted in the lower half of the cycle and unit 2, the thick beds or nodules, occur in the center of the cycle.

In general, cycles tend to contain shallower water ichnofossils of the Zoophycos association at the base which are gradually replaced upward by deeper water forms of the Nereites association (Fig. 5). This progression is interpreted to represent abrupt shallowing (base of cycle) followed by gradual deepening in response to regional transgression. These variations occur as a response to shoreward shifts of the pycnocline during transgression. Variations in oxygenation at the sediment-water interface are recorded in a very detailed manner by the assemblages of trace fossils. During these shoreward shifts of the pycnocline, reduction in water oxygenation is responsible for reduced biogenic activity and hence there is little subsequent cementation and nodule formation. Although still a function of pycnoclinal shifts, this explanation of cyclicity differs significantly from that of Mazzo (1981) and Mazzo and LaFleur (1984).

It is interesting to note that Port Ewen cycles are of the same order of magnitude as PACs, yet they record deepening-upward rather than the universal shallowing predicted by the PAC hypothesis (Goodwin and Anderson, 1985). In the case of symmetrical cycles, gradual shallowing followed by gradual deepening are recorded. This symmetry and gradual variation are also at odds with the tenets of the PAC hypothesis.

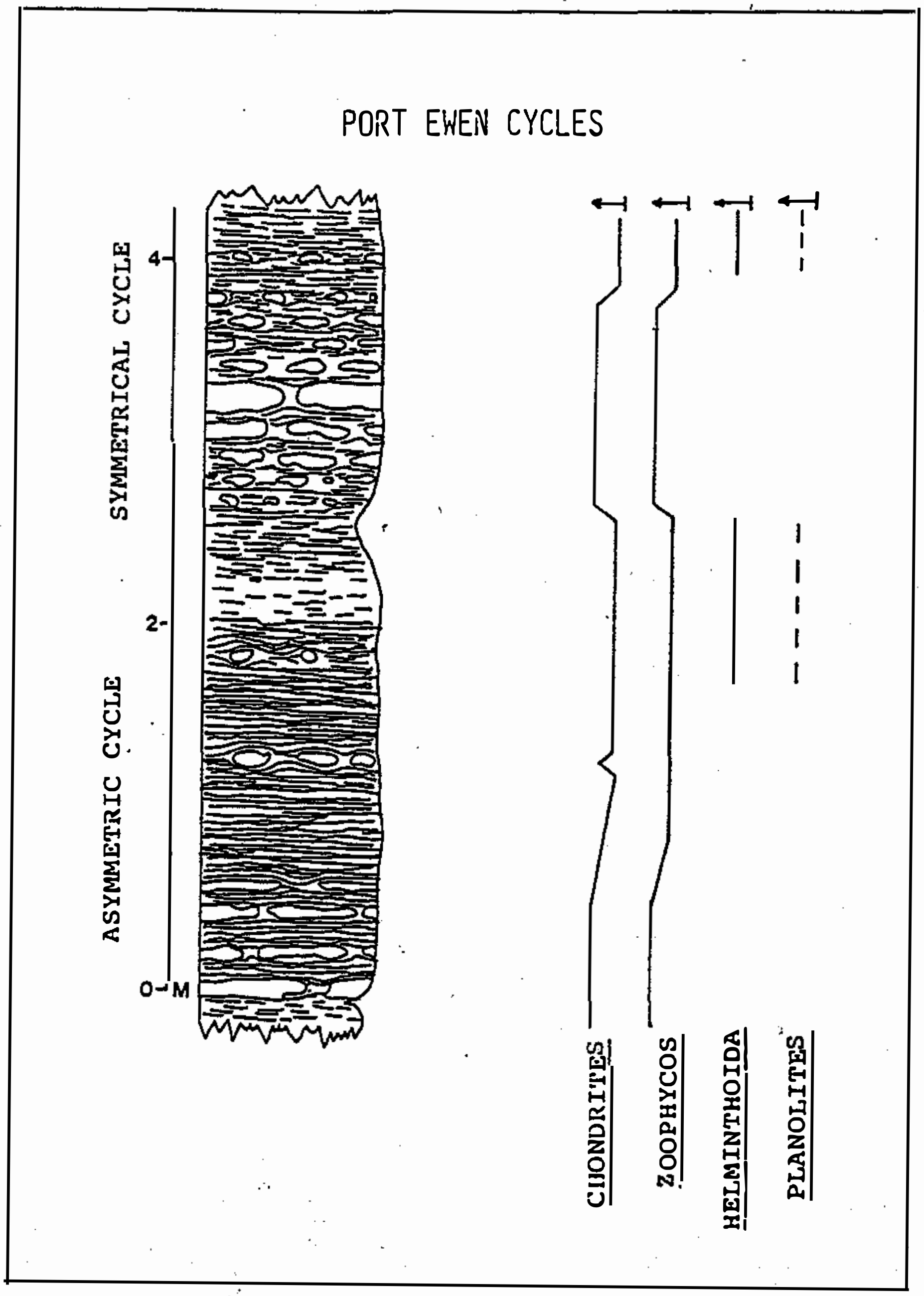

FIGURE 5. - Schematic representation of asymmetrical and symmetrical cycles in the Port Ewen Formation. Cyclicity is most apparent in the distribution of peloidal grainstone nodules. Detailed descriptions of lithologies are in text. Vertical lines show distribution and abundance of the four common ichnofossils of the Port Ewen. Arrows at the top of each column indicate relative abundance increasing to the left.

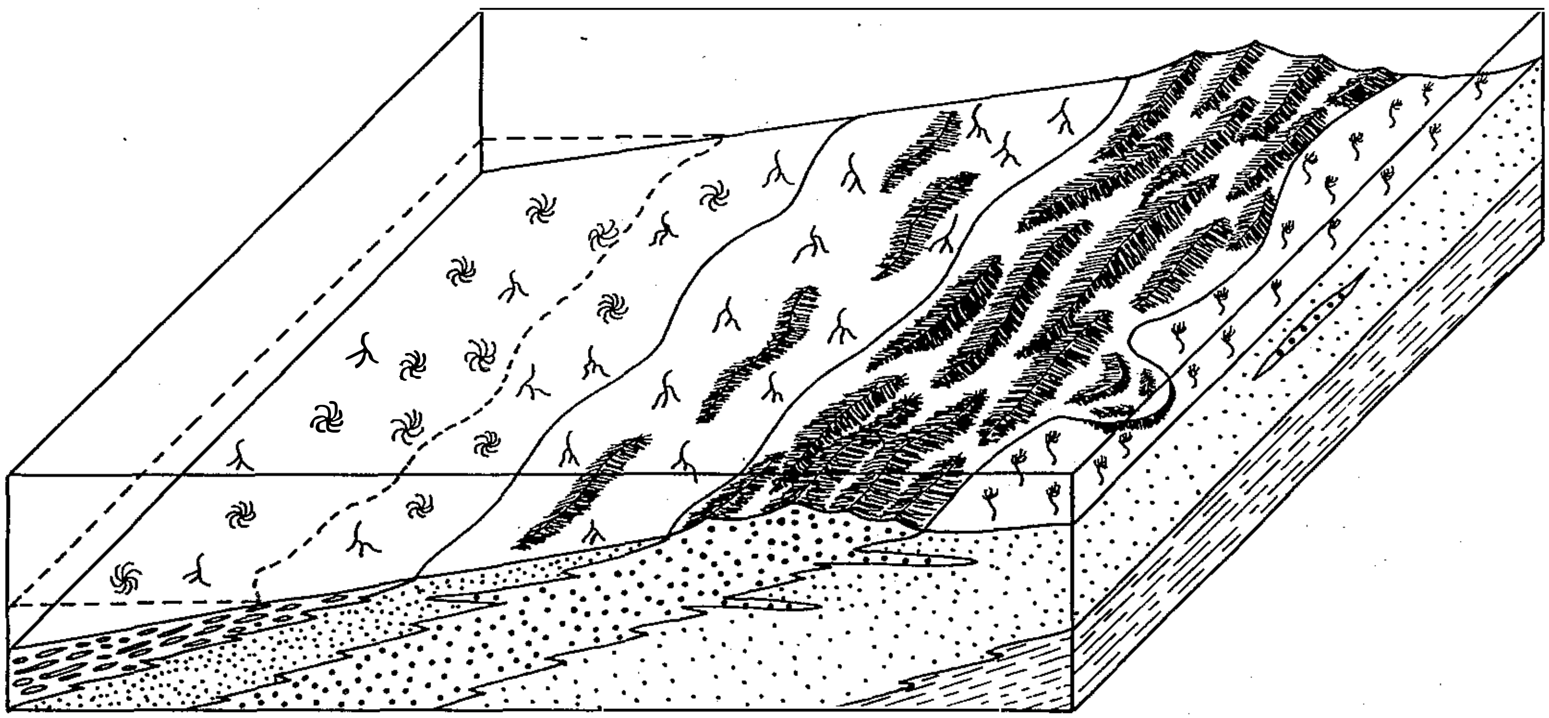

FIGURE 6. - Cartoon representation of upper Helderberg environments during the upper cycle transgression. From left to right environments are: deep, dysaerobic shelf (Port Ewen), open shelf (Alsen and Becraft-3), subtidal sand waves (Becraft-2), shelf lagoon (Becraft-4) and hypothetical tidal flat (lined pattern). Dashed line on left represents the pycnocline. Spirals = Zoophycos, branching symbol = general bioturbation, ovals in cross-section = burrow-generated nodules, brush-like symbol = crinoids. Nearshore environments (presumably similar to the Manlius Formation) have been removed by subsequent erosion.

ENVIRONMENTAL MODEL OF THE UPPER HELDERBERG RAMP

Figure 6 summarizes the distribution of environments on the upper Helderberg ramp. This ramp was characterized by an extremely low slope as in the traditional epeiric-sea models of Shaw (1964) and Irwin (1965). However, wave base was not the primary factor that governed the distribution of facies on the ramp. The depths at which tidal currents began to affect the bottom and the position of the aerobic - dysaerobic pynocline were the primary factors that controlled the nature and distribution of facies.

Subtidal sand waves were molded from loose skeletal debris in the shallow depths that were affected by tidal flow. Only robust brachiopods, crinoids, and a few bryozoans could tolerate this turbulent sand-wave environment. These organisms provided additional coarse sediment for the maintenance of the sand waves.

The sand-wave shoals dissipated much of the tidal flow and, therefore, reduced turbulence on their landward side. This facilitated the deposition of finer sediment in the more shoreward areas. Tidal flats similar to those of the Manlius Formation may have existed along the shoreline. Between the sand-wave shoals and the shore, a shallow shelf lagoon existed that supported a diverse assemblage of suspension feeders. Washovers or spillover lobes from the shoals periodically advanced over the finer sediments of the shelf lagoon.

A well-oxygenated, open shelf lay seaward of the sand-wave complexes. This open shelf supported an abundant and diverse assemblage of bryozoans, brachiopods, crinoids and abundant ichnofauna. Weak tidal currents aerated the shelf and occasionally winnowed the finer sediment or produced minor bedforms and perhaps low-amplitude sand waves. Substrate mobility was relatively infrequent and burrowers were able to destroy most physical sedimentary structures.

Deeper portions of the shelf were below the influence of tidal currents and waves. Micrite, clay and fine shelly debris were deposited on the deep shelf by dilute turbidity flows and by the settling of fine material that was winnowed from the sand waves and open shelf.

Bottom waters were poorly oxygenated and restricted the biota to a moderately diverse ichnofauna and sparse shelly fauna. Burrowers responded to subtle changes in water oxygenation on the deeper portions of the ramp and were thus influenced by the position of the aerobic - dysaerobic pycnocline.

The burrowing activity of organisms increased the porosity and permeability of the sediment in local areas. These areas experienced early cementation and became nodules of peloidal grainstone. The spatial and temporal distribution of organisms directly controlled the subsequent distribution of nodules.

Periodic exhumation of some nodular horizons by submarine erosion may have resulted in the existence of patchy hardgrounds on the sea floor.

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ROAD LOG FOR TIDAL CURRENTS, BIOGENIC ACTIVITY AND PYCNOCLINAL FLUCTUATION ON A LOWER DEVONIAN RAMP

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Exit 21 toll plaza on I-87
0.1	0.1	Turn left on Old State Rt. 23
0.7	0.6	Turn east (left) on Rt. 23, outcrop on left displays Taconic unconformity
1.5	0.8	Jct. Rt. 9W south
1.8	0.3	Jct. Rt. 9W north
1.9	0.1	Steel deck bridge over tributary to Hans Vosen Kill
2.2	0.3	Jct. Rt. 385
2.5	0.3	Rip Van Winkle Bridge toll plaza, outcrops on both sides of road show chevron folds in the Austin Glen Formation, cross Hudson River $0.50 toll for passenger vehicles
3.6	1.1	Jct. Rt. 9G, Rts. 23 and 9G run concurrently, continue east on 23
4.1	0.5	Jct. Rt. 23B, continue east on 23
4.4	0.3	Entrance to Columbia - Greene Community College
6.25	1.85	Jct. Rt. 9, turn north (left) on Rt. 9, outcrop on corner is in Manlius Formation
6.5	0.25	Small outcrop of Normanskill Formation, the hill to the right of the road is Becraft Mountain, an outlier of the Helderberg Group
7.9	1.4	Entrance to inactive Independent Cement Corporation plant
8.0	0.1	Conveyor over road
8.1	0.1	Entrance to quarry, STOP 1, bus will park on opposite side of road.

STOP 1. BECRAFT MOUNTAIN

Location: Inactive quarry of the Independent Cement Corporation on Becraft Mountain outlier ("Becraft Hills"), located in northeast quarter of the Hudson South, New York 7.5 minute quadrangle, just east of Rt. 9, approximately 1 mile south of Hudson.

References: Grabau, 1903; Rickard, 1962

Description: A small pit in the Manlius and Coeymans formations can be seen to the left of the access road to the main quarry. Before entering the main quarry, exposures in the New Scotland Formation are visible along the access road. The main quarry is quite extensive; however, we will concentrate on the northern end. The lower Helderberg formations are largely submerged, but excellent exposures of the upper formations may be studied throughout the quarry.

The upper contact of the New Scotland Formation is clearly exposed in the northern wall of the quarry. Above the New Scotland is a thin (1.8 m) unit that I interpret as the easternmost extension of Rickard's (1962) upper tongue of the Kalkberg Formation. Slightly less than four meters of Becraft subfacies 1 overlie this unit. Subfacies 2 (8.5 m) and subfacies 3 (1.8 m) occur above subfacies 1. The Alsen Formation 2.5 m) is the highest unit present in the quarry.

The eastern position of the Becraft Mountain outlier places this exposure in a more shoreward position relative to localities in the main outcrop belt of the Helderberg Group. This is clearly reflected in the character of the upper formations. Subfacies 1, for example, exhibits fewer and thinner silty interbeds and drapes than at other localities in the central Hudson Valley, an indication of stronger current action in shallower water. Holdfasts of Aspidocrinus scutelliformis are usually sparse in this unit. Elsewhere, this holdfast is abundant in subfacies 1. These two factors combine to give subfacies 1 an overall appearance that is similar to that of subfacies 2 at other locations west of the Hudson. Erosional surfaces and silt drapes within sets of cross stratification are the major features to be observed in subfacies 1 at this stop.

Subfacies 2 is clearly exposed in the quarry, but access for large groups is difficult and potentially dangerous. For this reason, this unit will not be observed here. The general character of subfacies 2 can be seen from a distance, however. Thicker bedding, coarser textures and an abundance of A. scutelliformis and Gypidula pseudogaleata differentiate this unit from subfacies 1. The relative freshness of the exposure and the coarseness of subfacies 2 make observation of sedimentary structures difficult. Interbedding of rudstone and grainstone is the dominant structure. This interbedding is interpreted as vertically accreted tidal bundles. Unimodal cross stratification is common in the center of the unit, but may also be present elsewhere.

Subfacies 3 occurs just below the Alsen Formation. This unit is superficially similar to subfacies 2, but may be differentiated by the presence of bioturbate fabrics and the rootlike holdfast Clonocrinus(?). This unit is readily observable in the quarry, but is better studied at STOP 2, owing to the weathered character of that exposure.

By virtue of its position near the pre-quarry ground surface, the Alsen Formation is better weathered than other units in the quarry. Sedimentary structures and textures are highlighted by this weathering. Nodular chert also helps to differentiate this formation. Herringbone cross stratification, argillaceous interbeds, vague grading and bioturbate fabrics are the important features to note. Faunal differences from the underlying Becraft are evident in the decrease in crinoidal debris and brachiopods and the obvious increase in abundance and diversity of bryozoans. The Alsen Formation at this stop displays significantly more physical sedimentary structures than at other exposures. This is further evidence of a shallower position on the ramp for this location.

8.1	0.0	Return south on Rt. 9
9.85	1.75	Turn west (right) on Rt. 23
11.9	2.05	Jct. with Rts. 23B and 9B, view of Catskill Front across the Hudson
12.6	0.7	Rip Van Winkle Bridge, no toll in this direction
13.85	1.25	Jct. Rt. 385
14.2	0.35	Jct. Rt. 9W north
15.3	1.1	Jct. Rt. 23B, connector to I-87, excellent exposure of the Taconic unconformity on offramp
15.6	0.3	Large outcrop in Helderberg Group, these exposures continue for next half mile, units show complex deformation (see Marshak, 1986)
16.2	0.6	Bridge over Catskill Creek, STOP 2, bus will park on north side of road. CAUTION: TRAFFIC IS OFTEN HEAVY AND FAST-MOVING. CROSS TO SOUTH SIDE WITH EXTREME CARE.

STOP 2. CATSKILL CREEK IN AUSTIN GLEN.

Location: Waterfall and rapids on Catskill Creek, below and just south of the Rt. 23 bridge over the creek, approximately 0.35 miles northwest of the Rt. 23 bridge over I-87. The deep, narrow valley of Catskill Creek is known as Austin Glen or Leeds Gorge in this area. Northeast corner of Cementon, New York 7.5 minute quadrangle, 1980 photo revised.

References: Section 44 of Rickard (1962), Structural geology is described by Marshak (1986), STOP 2B, see also STOPS 1 and 2.

Description: The near vertical bedding at this location has created a natural dam across Catskill Creek. Resistant beds of the Glenerie Formation and the Upper Helderberg Becraft, Alsen and Port Ewen Formations form the dam and subsequent waterfall. Upstream from this dam, the creek has scoured out the less resistant Esopus Formation as it flows parallel to strike. In addition to these units, the top of the New Scotland Formation and the upper tongue of the Kalkberg Formation are also exposed just below the falls on the east bank of the creek.

The upper tongue of the Kalkberg Formation (4 m) and Becraft subfacies 1 (4.9 m) are strikingly similar at this location. The two are differentiated by the abundance of *Aspidocrinus* holdfasts in subfacies 1. This designation follows Rickard (1962). Duneforms, silty and peloidal interbeds and drapes are the essential features to note in this part of the section. Herringbone and unidirectional cross stratification are common, with end-on views of troughs less common. Ripples and cross lamination occur in some of the finer interbeds. The increased abundance and thickness of finer lithologies, relative to STOP 1, suggest that this location occupied a slightly more offshore or down ramp position.

Becraft subfacies 2 (approx. 9.5 m) is exposed in the falls and on the west bank of the creek. Thick to massive-appearing bedding and a nearly white weathered color set this unit apart from underlying and overlying units. As at STOP 1, the coarse texture of this unit makes observation of sedimentary structures difficult. Crude bedding is apparent in some crinoidal, *Gypidula* - *Concinnispirifer* rudstones. Planar stratification, grainstone - rudstone interbedding, normal and inverse grading are present. These features are interpreted as upper stage plane bedding and vertically accreted tidal bundles. Cross stratification is present, but is difficult to observe.

Subfacies 3 (1.6 m) is only subtly different from subfacies 2 in overall appearance. This unit is recognized by the abundance of *Gypidula* and *Concinnispirifer* and by the pink, root-like holdfasts of *Clonocrinus*(?). Finer textures and *in situ* holdfasts indicate reduced turbulence and increased stability of substrate relative to the underlying subfacies.

The Alsen Formation (approx. 11 m) is noticeably darker, finer-grained and chertier than the underlying Becraft Formation. The fauna is enriched in bryozoans relative to subfacies of the Becraft Formation. Crinoidal constituents are less abundant and finer and brachiopods tend to be thinner-shelled than in the Becraft.

Sedimentary structures have been largely destroyed by bioturbation. The increase in biogenically-disrupted fabrics and the paucity of physical structures, as compared to the Becraft Mountain exposure, also suggest a slightly more down ramp position for this exposure.

Approximately two meters of the Port Ewen Formation are exposed near the top of the section, just below the Glenerie Formation. The Port Ewen is a moderately fossiliferous, bioturbate wackestone to packstone at this section. Bryozoans dominate the fauna. Trilobites and ostracodes are also common. The Port Ewen is greatly thinned here by pre-Glenerie erosion. Large phosphatic and/or slightly pyritic cobbles in the base of the sandy Glenerie mark this disconformity. These features may be observed in the beds that make up the upstream portion of the "dam".

16.8	0.6	Jct. Cauterskill Rd. (Greene County Rt. 47), Sunoco station on right, Dairy Queen on left. Bus will turn here to return east on Rt. 23
17.3	0.5	Catskill Creek
18.0	0.7	Exit from Rt. 23 for Leeds and Jefferson Heights
18.2	0.2	Proceed left at bottom of ramp onto Old State Rt. 23
18.7	0.5	Turn right for entrance to Thruway, I-87
18.8	0.1	Toll plaza for interchange 21, starting point of road log. Take I-87 south. Note Helderberg outcrops on ramp. Outcrops of the Helderberg Group, Tristates Group, Onondaga Limestone and Hamilton Group may be seen along I-87 over the next 21.4 miles.
36.3	17.5	Ulster Service Area

40.9	4.6	Exit 19, Kingston, exit Thruway
41.5	0.6	Toll plaza
41.6	0.1	Traffic circle, follow Rt. 209 north (Pine Hill) for Rhinecliff Bridge
41.85	0.25	Traffic light on Rt. 28, proceed straight
41.95	0.1	Right turn onto ramp for Rt. 209, north
44.6	2.65	Bridge over Esopus Creek
45.3	0.7	Jct. Rt. 9W south, begin Rt. 199, continue east following Rt. 199
45.6	0.3	Outcrop in Tristates Group and Onondaga Limestone
46.0	0.4	STOP 3. Roadcut through anticline. Bus will continue east and turn around to park on north side of Rt. 199.
46.25	0.25	Outcrops in lower Helderberg Group
46.4	0.15	Exit for Rt. 32, Kingston and Saugerties
46.7	0.3	End of ramp, turn north (right) onto Rt. 32, under bridge
46.8	0.1	Turn right onto ramp leading to Rt. 199
46.9	0.1	Outcrops of Austin Glen Formation on ramp
47.3	0.4	Return to STOP 3.

STOP 3. ROADCUT ON ROUTE 199.

<u>Location</u>: Roadcut through anticline in the upper Helderberg Group on Rt. 199, the approach to the Kingston-Rhinecliff Bridge over the Hudson River. Exposure is 0.7 miles east of the junction of 199 with Rt. 9W and 0.35 miles west of the Rt. 32 overpass. Northwest quarter of Kingston East, New York 7.5 minute quadrangle.

References: STOP 1b of Waines and Hoar (1967); STOP 3 of Heyl and Salkind (1967); STOP 3 of Toots (1976); STOP 9b of Pederson, Sichko and Wolff (1976); STOP 7 of Marshak (1986).

Description: This exposure has been visited on several previous NYSGA field trips for the purposes of illustrating structural features or stratigraphic succession. This trip will examine the sedimentology of the Upper Helderberg Formations exposed in this popular roadcut.

The Becraft Formation (9.5 m) occupies the core of this anticlinal exposure. Slightly less than two meters of subfacies 1 are exposed at the base of the section. Subfacies 2 comprises the remaining 7.6 meters of the formation. Subfacies 3 is absent, although the uppermost parts of subfacies 2 are somewhat similar to subfacies 3. Minor silty interbeds may be found in places in the lower parts of subfacies 2. These interbeds are commonly cross laminated and some show paleocurrent reversals relative to adjacent cross-bedded grainstones. Structures in the grainstones are difficult to observe on this relatively fresh face.

The Alsen Formation (6.3 m) sharply overlies subfacies 2 of the Becraft Formation, although several beds of Becraft-like grainstones are interbedded throughout the lower few meters of the Alsen. Bioturbate fabrics predominate in the grainstones and packstones of this unit. The contact with the overlying Port Ewen Formation is readily recognized, but appears to be gradational.

All five lithologies that make up the Port Ewen Formation (24 m) are present in this exposure. Cyclicity is most noticeable in the distribution of the nodules and beds of peloidal grainstone. Asymmetrical and symmetrical cycles are present.

Nodules are thoroughly burrow-mottled, except where recognizable ichnogenera are present, typically Chondrites and Zoophycos. Bioturbation is more intense within nodules than in the surrounding lithologies. Most nodules have sharp boundaries. However, some nodules exhibit a gradual decrease in the degree of bioturbation into the surrounding lithologies. Differential compaction between nodular and non-nodular lithologies is readily apparent. Note the absence of evidence for soft-sediment deformation which Mazzo (1981) and Mazzo and LaFleur (1984) suggest should be ubiquitous.

The distribution of ichnofauna within cycles is such that Zoophycos and Chondrites are most abundant in the centers of symmetrical cycles. Deeper water forms are present in the upper and lower portions of these cycles. Several nodular beds exhibit pyrite impregnation of the upper surfaces. Borings (?) are associated with these surfaces, as are pebbly, phosphatic and/or pyritic clasts that contain similar biogenic structures.

Periodic exhumation of some nodular horizons and the development of patchy hardgrounds are suggested by these features. Additional evidence for early cementation is provided by synsedimentary fractures in some nodules that are partially cement-filled, with sediment overlying cement.

Chert is present as rinds that centripetally replace nodules of peloidal grainstone and as continuous beds that were originally peloidal. These features tend to be more common within five to eight meters of the contact with the Glenerie Formation.

Sandy, brachiopod-rich beds of the Glenerie Formation are present on the west limb of the fold. A covered interval of approximately 5 meters separates this formation from the Port Ewen below.

END OF ROAD LOG. CONTINUE ON RT. 199 WEST TO RT. 9W AND RETURN SOUTH TO KINGSTON.

THE CATSKILLS REVISITED

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On this trip we hope to present an overview of sediments that accumulated to form the Catskill Clastic Wedge. Rather than develop a paper and field trip guide that deal entirely with new research, we plan to visit some outcrop locations that have already been reported in the literature, add one or two new locations, including a fossil collecting stop in the Mt. Marion formation, and travel to the Blenheim-Gilboa Hydroelectric Power Station north of Grand Gorge.

The study first begins in the post-Onondaga Bakoven shales at an outcrop in the Kingston area. These dark shales, deposited in a deep, euxinic marine environment, are successively overlain at other locations by mudstones, shales, and sandstones that comprise the first gray, and then red beds to be seen as we travel stratigraphically higher into the Catskill Front. The Stony Hollow formation, which we may see en route, was deposited on a distal prodelta slope. The first four stops are clustered a few miles within the trip's point of origin at locations where the Bakoven, then Mt. Marion mudstones, fossiliferous Mt. Marion iron-stained mudstones exposed in a somewhat remote quarry, and the Plattekill sandstones are exposed. the Ashokan formation, which underlies the Plattekill, was deposited on an intertidal shelf, while the Plattekill best represents a piedmont floodplain deposit.

From here, we will travel in a northwest direction through Shandaken, onto NY 23, then along NY 30 N past Grand Gorge to the Blenheim-Gilboa Power Station. On the trip towards Grand Gorge, we will be traveling on terrain mostly underlain by the Oneonta formation and have opportunities to view on our left, the valley of Schoharie Creek. The Schoharie is normally an underfit stream, although heavy rains during April, 1987 caused considerable flooding and erosion. The Blenheim-Gilboa Power Station, completed after World War II, employs waters of the Schoharie Creek, held in a main (channel-level) reservoir and an upper reservoir located on a plateau west of the Schoharie, to generate electricity for the Power Authority of the State of New York. A cluster of four stops in this area, which is essentially underlain by beds that are upper Hamilton and Tully equivalents, will include a visit to a sharply undercut slope in the Schoharie channel produced during the April floods, and a revisit to the Gilboa bridge, north of the Schoharie Reservoir. Near the bridge stand some of the stumps of the famous Gilboa Forest flora.

The return south through Grand Gorge and then eastward, will carry us to a unique exposure of the Oneonta formation, where we can be afforded the chance to examine a small, yet detail-packed outcrop, and discuss various ideas on the environment of deposition of these sediments. It is not a new outcrop, but apparently it is visited by geologists quite often, according to people living nearby, and this would seem to justify our return to it.

As we travel through Haines Falls to Tannersville, in a direction roughly perpendicular to the depositional strike (mean cross-bedding in this area near the Catskill Front has a vector of 297° according to Fletcher's 1967 paper), we will not be traveling "down-section" to any great degree. At Tannersville, we will turn towards North and South Lakes and stop at the edge of the Catskill Escarpment, nearly 2000 feet or about 700 meters above the Hudson Valley floor. Hopefully, we can reach this location before late afternoon. The view eastward, across the Hudson Valley to the Housatonic Mountains in the distance, is a grand vista. It should make any of us speculate on, and perhaps better understand the Acadian Mountains that were the high source terrain for the sediments that we revisited.

We hope that you will enjoy this trip, and rest secure in the comforting thought that there will be no examination at the end of the trip!

Field Trip Road Log and Stop Descriptions

Cumulative Mileage	Distance between Stops	Remarks
---	0.0	Ramada Inn. begin at entrance. Drive to traffic light on NY 28.
0.1	0.1	Turn right onto NY 28 (west).
0.7	0.6	Turn right onto Forest Hill Road then right onto City View Terrace and stop on right.
STOP 1		Bakoven Shale. The black shale and overlying siltstone section in the high road cut across the road area well described by Pedersen et al. (1976, Stop 7) and appear to represent the upper part of the Bakoven formation. This unit may represent initial deposition of a delta toe in a deep distal basin. Return to NY 28.
0.8	0.1	Turn right (west) onto NY 28 and get into left traffic lane.
1.2	0.4	Turn left onto Mountain Road (Ulster 5) and proceed along base of Mountain Marion escarpment (on right) with Esopus floodplain (bottom of glacial lake) on left.
5.4	4.2	Park on right.
STOP 2		Base of Mount Marion Escarpment. Observe the variation in lithology, sedimentary structures, and fossils or lack of them. Can you find any reason for postulating the adavance of a delta into the Bakoven basin such that these sediments represent deposition on a distal to proximal prodelta slope? Many blocks of Mount Marion, some quite large, have rotated with slow gravitational descent to give erroneous impressions of bedding plane attitudes along the escarpment. Continue south on Mountain Road.
6.1	0.7	Turn right (west) onto Johnson Road.
7.6	1.5	Keep straight onto Lapla Road.
7.9	0.3	We have been ascending up section and for the next 0.9 miles will note increasing sandstone bed frequency and thickness in the road cuts and nearby outcrops as we pass from Mount Marion to Ashokan beds.
8.8	0.9	Turn right onto Quarry Hill Road.
9.4	0.6	'Slow Children' and Feral Dogs. Close your windows and drive very slowly.
9.7	0.3	Drive to far end of quarry and park to right on glaciated pavement.

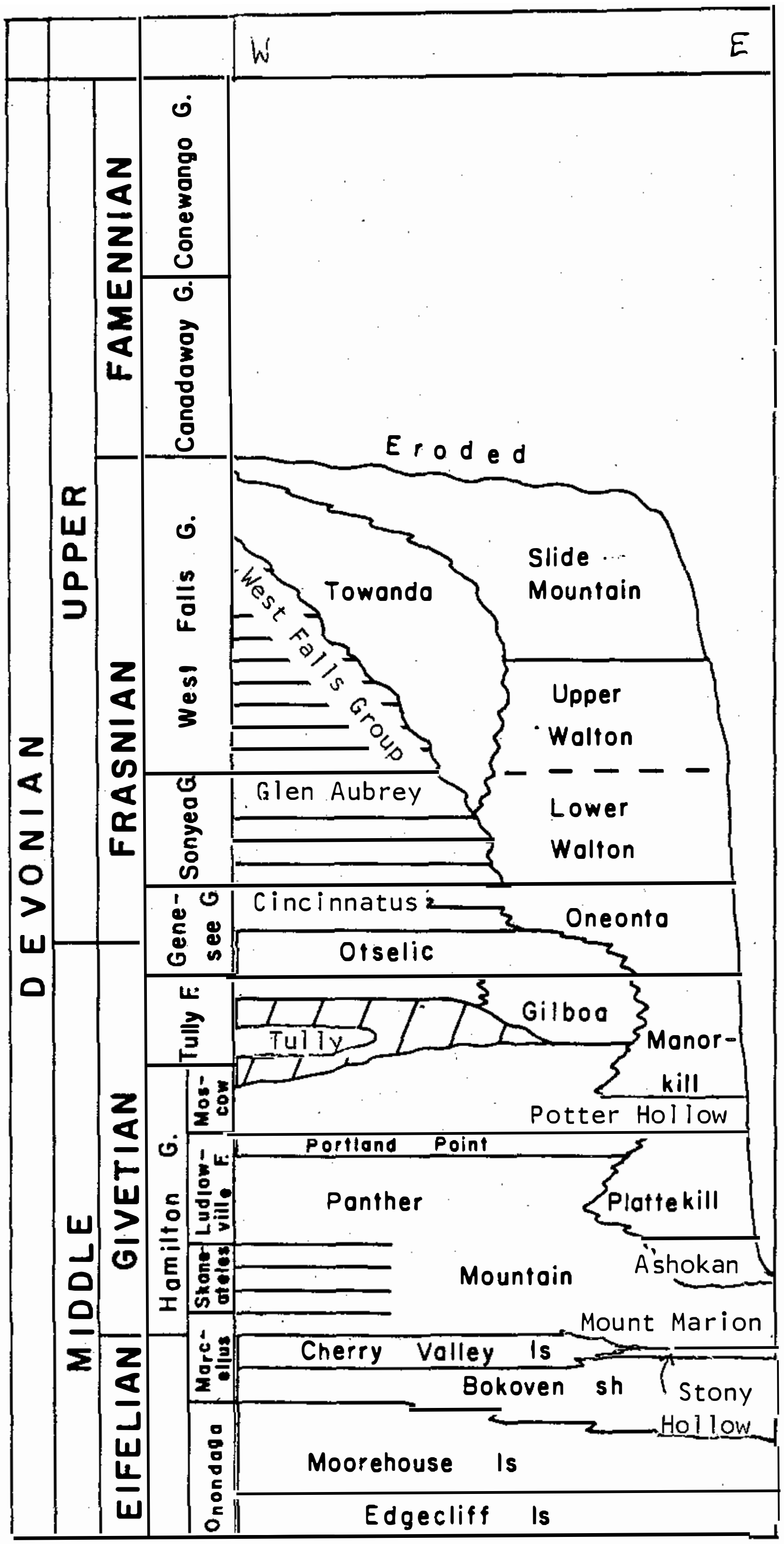

Fig. 1. Stratigraphic Diagram for the Middle and Upper Devonian in study area (modified after Rickard, 1975).

STOP 3:		Quarry in Mt. Marion. This quarry is probably in upper Mount Marion shales and siltstones. Fossils are exceedingly abundant in one horizon with articulate brachiopods and bivalvia most abundant but many other types of fossils also occur. Some of these are very small and some are exceptionally large - especially two inarticulate brachiopods, Roemerella grandis and Lindstroemella aspidium. Sheets of illustrated fossils will be passed out to help you identify your discoveries. A mug-shot of the fractal-like trace fossil Aristophycous will also be distributed. This specimen, obtained from this quarry, appears to be the only Devonian find recognized and is curerntly in private hands. Please help us find the other half of this specimen or another equally well-preserved. The specimen appears to have come from within six inches of the glaciated pavement at the north end of the quarry. Sandstones, possibly representative of the Ashoken formation, can be seen across the road to the west. The strata in the quarry may represent sediments deposited on the shallow, marine shelf of an advancing delta marine platform. The Ashoken sands may represent further shelf advance as intertidal shelf deposits. Return to NY 28 by retracing route.
18.2	8.5	Turn left (west) onto NY 28.
22.9	4.7	Traffic light. Proceed on NY 28.
23.2	0.3	At some point in the next 1.6 miles we will pull off highway and park on right.
STOP 4:		Plattekill Formation. In the 1.6 miles there are many good road cuts where the red and green sandstones and shales of the Plattekill formation can be seen. Look for lithologic changes and sedimentary structures which might indicate a piedmont floodplain environment.
24.8	1.6	Continue west on NY 28.
44.8	20.0	Turn right (north) onto NY 42 at Shandaken.
56.1	11.3	Turn left onto 13A.
56.4	0.3	Turn left onto NY 23A.
62.2	5.8	Continue straight onto NY 23.
68.3	6.1	TURN RIGHT ONTO NY 30N IN GRAND GORGE
75.9	7.6	TURN RIGHT INTO LANSING MANOR AND BLENHEIM-GILBOA POWER STATION.
76.1	0.2	Drive to visitor parking lot.

STOP 5: Blenheim-Gilboa Power Station. Hidden in the Schoharie Valley at this location, and designed to blend in with the natural landscape is one of six power stations operated by the New York Power Authority. The facility is located on the Lansing Manor Estate property, and the Lansing Manor Museum, housed in the 19th Century Manor House is nearby. A dam has been built to block the north flowing Schoharie Creek (compare Figure 2 with Figure 3). Water is recycled between the lower reservoir and an upper one located on Brown Mountain to the east. The substation on the east side of the lower reservoir is not easily recognized from the visitors' center here, and the upper reservoir can not be seen at all. During times of high power demand, water is released from the upper reservoir to drive four turbine generators. Flow of Creek water northward beyond the dam is measured to match water intake into the lower reservoir whenever possible. The Creek here is underlain most likely by the Potter Hollow formation. The visitors' center contains a small museum that includes rock samples and one or two tree stumps. LUNCH STOP HERE.

76.3	0.2	RETURN TO NY 30 AND TURN LEFT ONTO NY 30S.
78.2	1.9	TURN LEFT INTO MINE KILL FALLS OVERLOOK.

STOP 6: Mine Kill Falls Overlook. This is in part of a recreational site located just south of Lansing Manor. We will stop briefly here. At the north end of the parking lot we can view waterfalls of the Mine Kill as it flows eastward into the Schoharie Valley. The Manorkill formation overlies Potter Hollow gray and red beds, but the contact cannot bee seen from the observation platforms.

78.3	0.1	TURN LEFT ON TO NY 30 S
78.6	0.3	TURN LEFT ONTO UNNAMED ROAD
79.9	1.3	STOP ON LEFT SIDE OF ROAD NEAR CREEK

STOP 7: Erosion in Bend of Schoharie Creek. This location is at a sharp bend in the Schoharie at the base of Bornt Hill, in marine facies of the Manorkill formation. Heavy rains during April, 1987 resulted in severe flooding of the Schoharie that caused much erosion in several places, sometimes undercutting nearby roads. This is what we see here on the west side

		(undercut slope) of the bend. Moderate gullying also developed on the opposite (far) side of the road in this area, but road crews have repaired most of the damage. Please watch your step, and do not walk too close to the edge of the rock ledges.
81.2	1.3	T-junction. Cross road to small park.

<u>STOP 8</u>: <u>Tree Fern Trunk Display</u>. A well known display, about a half dozen stumps that are identified by Banks et al. (1985) as progymnosperms which represent typical remains of the Gilboa Forest, uncovered during quarrying operations near here. The trees probably grew to a height of about 60 feet (18 meters), and the specimens we see are mostly <u>Eospermatopteris</u>. The stumps were found in the lower Manorkill beds (and upper Potter Hollow?), which are assigned to the upper Hamilton Group. Although we will not make the attempt, a trek across the bridge and then southward along the Schoharie Channel leads to the east side of the Schoharie Reservoir (see Figure 3), where, during times of lower water levels, cross-bedding and occasional molds of small stumps may be seen in the light gray sandstone near the water's edge. TURN RIGHT FROM T-JUNCTION OR LEFT FROM DISPLAY OF STUMPS.

82.4	1.2	TURN LEFT ONTO NY 30 S
85.4	3.0	TURN LEFT ONTO NY 23 (east) in GRAND GORGE
91.5	6.1	Continue Straight onto NY 23A
95.6	4.1	TURN LEFT ONTO NY 296
95.7	0.1	TURN LEFT INTO LANE AND STOP

<u>STOP 9</u>: <u>Fluvial Facies (?) Red Beds</u>. NO ROCK HAMMERS, PLEASE! This small outcrop is unique in terms of what it has to offer in one package. It consists primarily of three lithologic divisions in a coarsening-upwards sequence with distinct cross-bedding in the uppermost unit, and a small channel cutout on the left (west) side of the outcrop. The top surface of this rock exposure shows a top view of the cross-bedding structures, and a glacially smoothed and striated surface. Buttner (1977) referred to this outcrop as possibly representing a transitional facies (we assume transitional between meandering and braided fluvial systems). What interpretation can you obtain from this outcrop? (Oneonta formation here.)

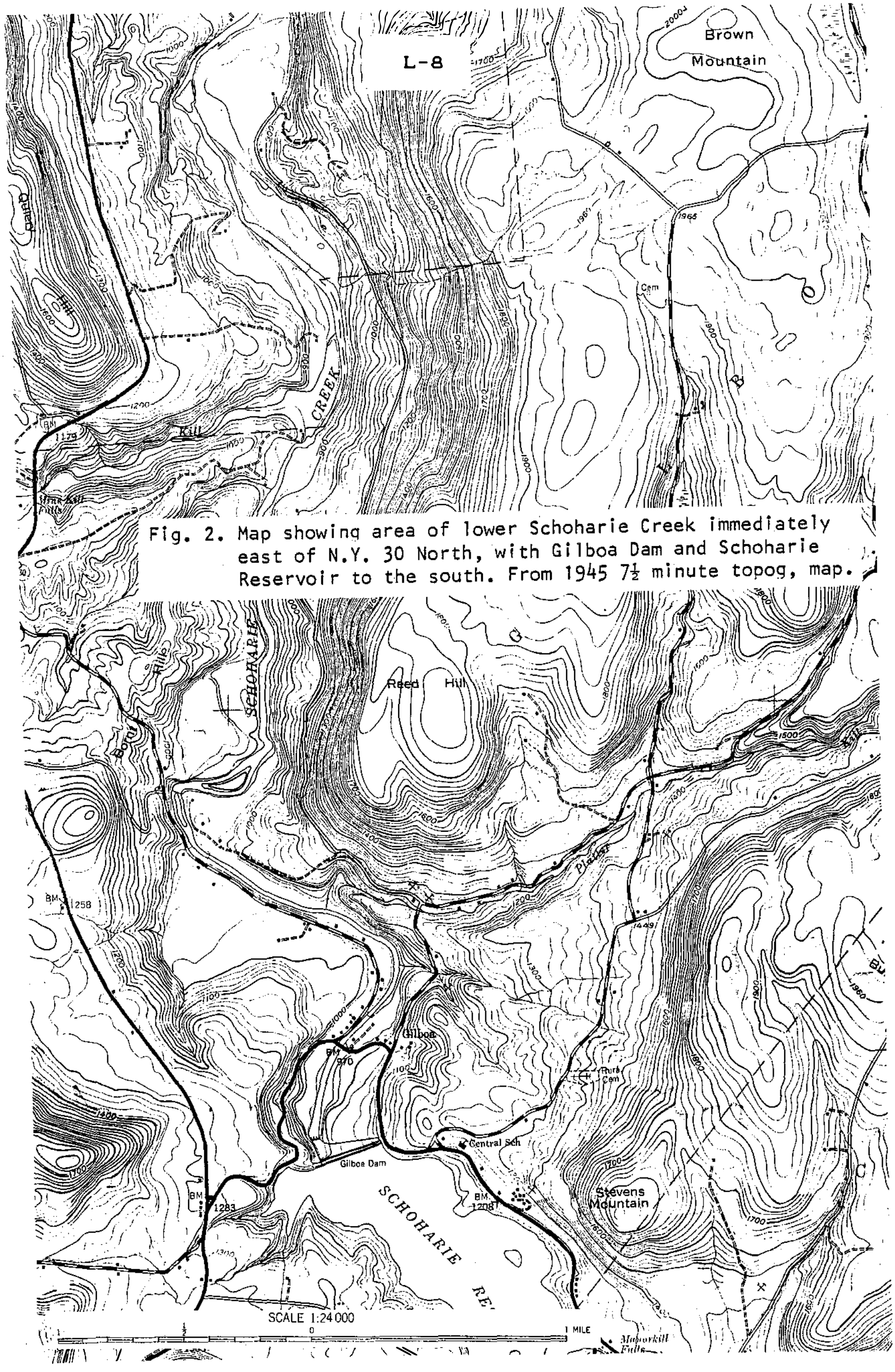

Fig. 2. Map showing area of lower Schoharie Creek immediately east of N.Y. 30 North, with Gilboa Dam and Schoharie Reservoir to the south. From 1945 7½ minute topog, map.

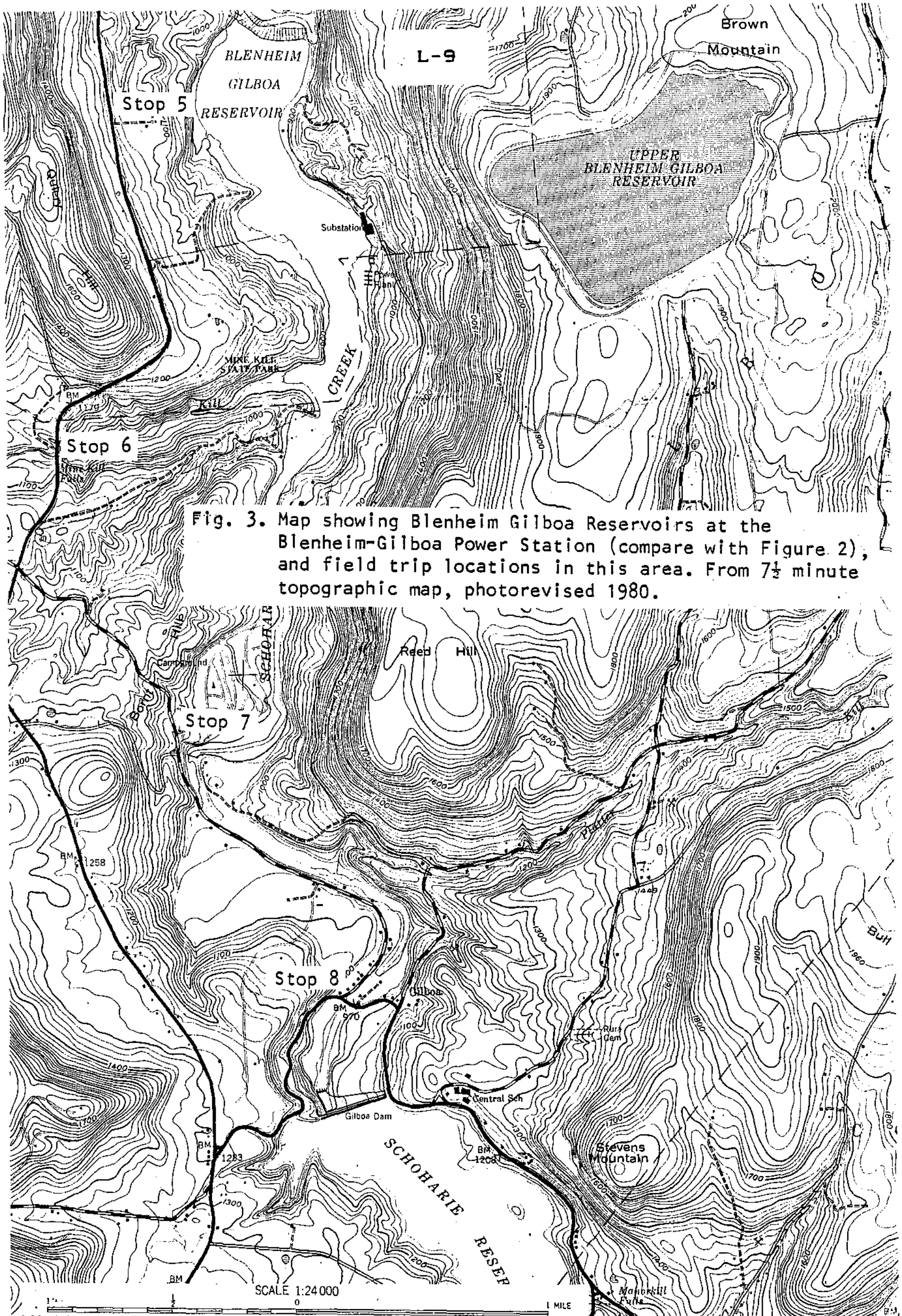

Fig. 3. Map showing Blenheim Gilboa Reservoirs at the Blenheim-Gilboa Power Station (compare with Figure 2), and field trip locations in this area. From 7½ minute topographic map, photorevised 1980.

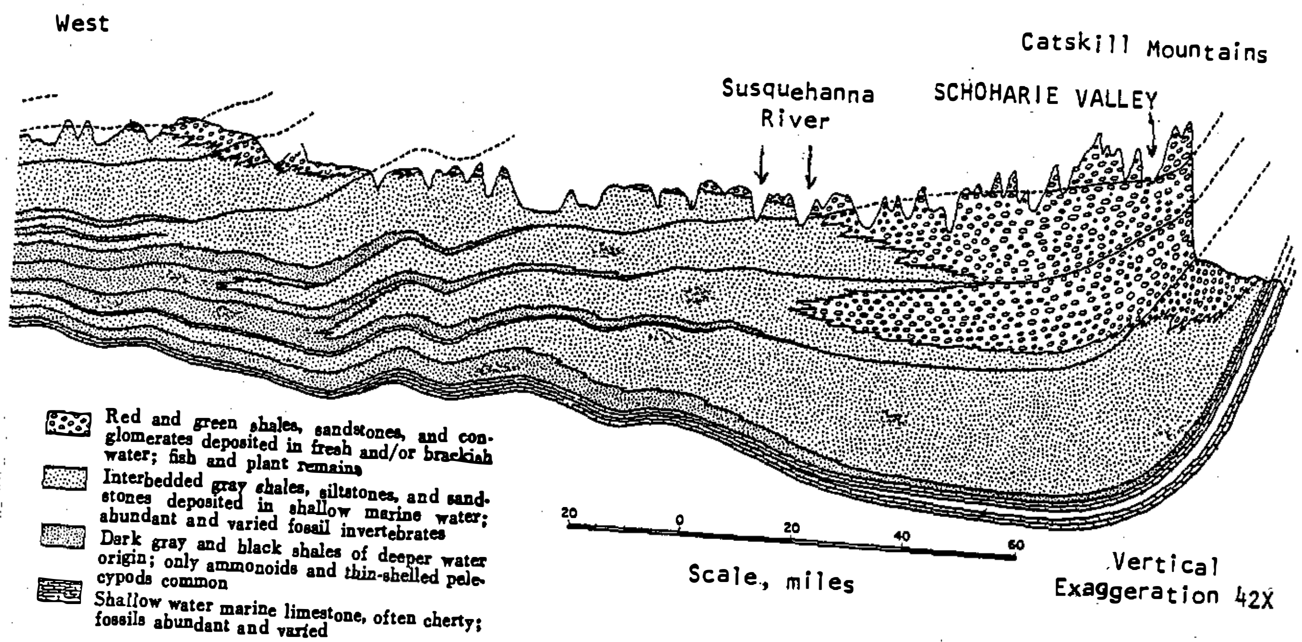

Fig. 4. Cross section of Devonian System along New York - Pennsylvania border (modified after Fig. 17, Broughton et al., 1962).

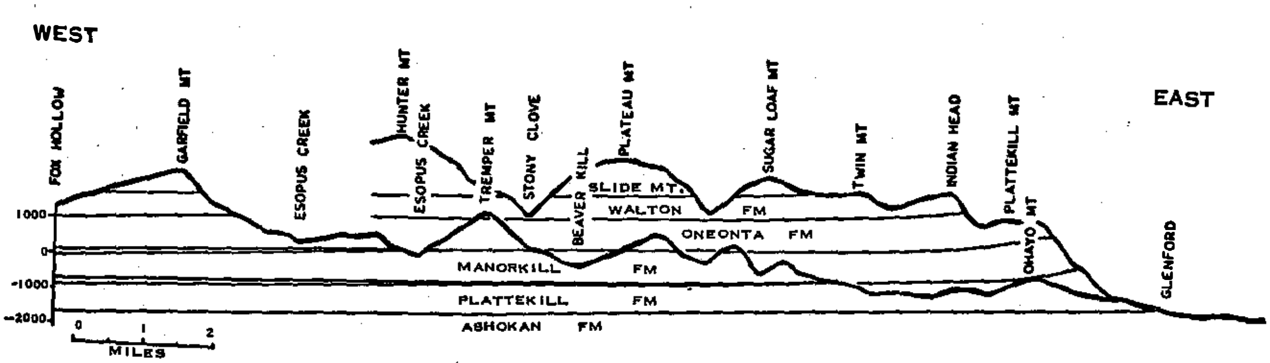

Fig. 5. Geologic cross section of the Catskill Front (after Fletcher, 1967).

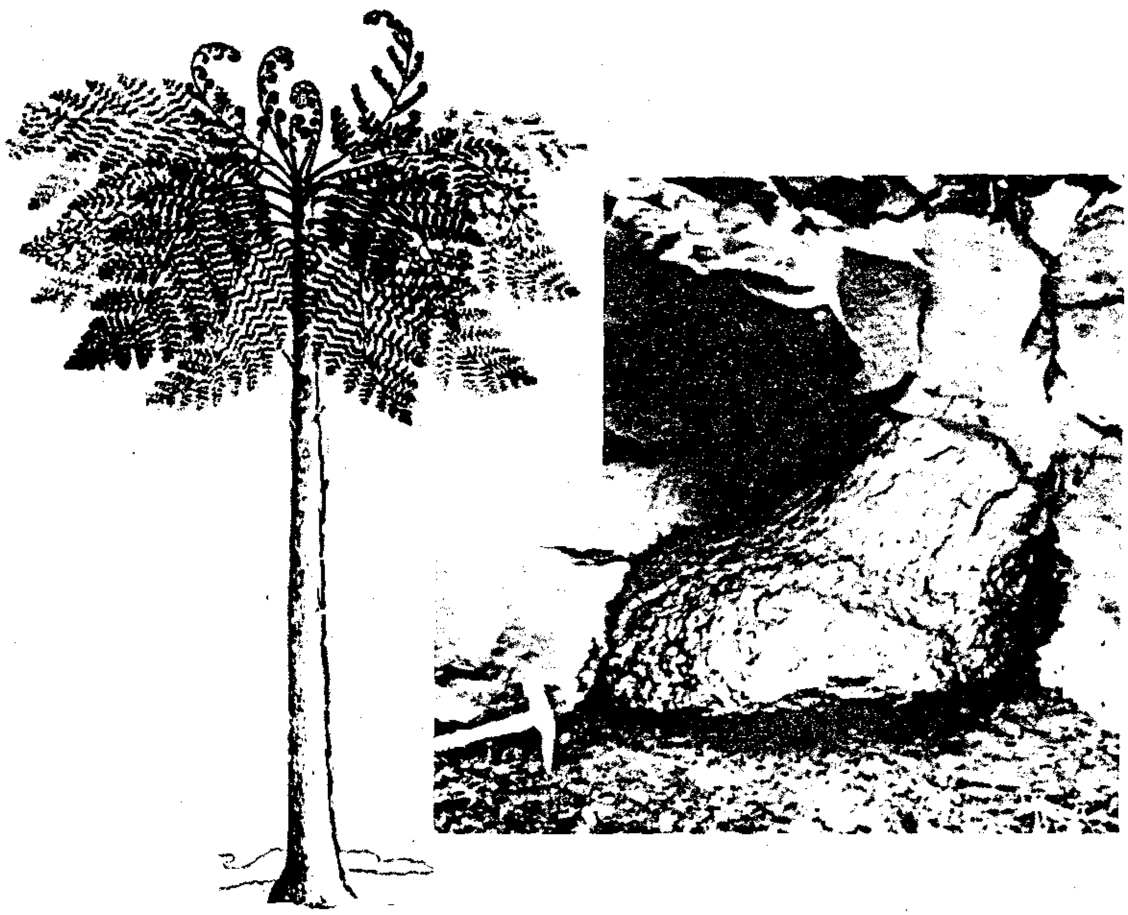

Fig. 6. Goldring's reconstruction of the progymnosperm Eospermatopteris (left) possibly as much as 90 dm tall, and a stump of the same about 5 dm in height (right) (after fig. 2b and 2c in Banks et al., 1985).

95.8	0.1	TURN LEFT ONTO NY 23A (east)
103.2	7.4	TURN LEFT ONTO GREEN COUNTY 18 TO NORTH LAKE
105.5	2.3	PARK REGISTRATION BOOTH
107.0	1.5	Drive to farthest parking lot at east end of North Lake. Take trail for 1/3 mile to site 2, Catskill Mountain House.

STOP 10: <u>Catskill Escarpment</u>. NO ROCK HAMMERS, PLEASE! Site of Catskill Mountain House. Although Figures 4 and 5 show details of topography and stratigraphy of the Catskill Clastic Wedge and the Catskill Front respectively, we feel that Figure 71B on page 139 of Dunbar and Rodgers (1957) is unexcelled in depicting lithologic boundaries, and the Catskill facies crossing time lines, in a simple yet effective way. We are on the very edge of the escarpment, and Palenville is about 1700 feet (520 meters) below us, while the Hudson River farther to the east is at a level that is about another 165 meters lower. We can easily see (hope for a clear day) the Rowena Memorial School Building, built in 1899 in Palenville, and made of Becraft limestone (Helderberg Group). The Catskill Mountain House was a resort hotel first built here in the early 1800's, and enlarged over the decades to become one of the most notable vacation sites in the East. After the turn of the century, its popularity began to decline somewhat, and reportedly, the steel rails used for conveying passengers by a train system up to the level of the escarpment were torn up and scrapped for the war effort in World War I. Although there were changes of ownership, the hotel continued to serve tourists until the late 1940's. By the late 1950's the building was judged to be beyond repair, and on a pre-dawn winter morning in the early 1960's, it was set afire by State authorities. Whatever part of the wreckage that could not be removed was pushed over the escarpment to the slopes below. Today, the view to the east is as spectacular as it was for hotel guests who sat on the front porch which was located very near the edge of the escarpment. At this location during late Devonian time, there was perhaps another mile of sediments above us. Projecting, in our minds, the trend of these sediments upward to the east as we view the present

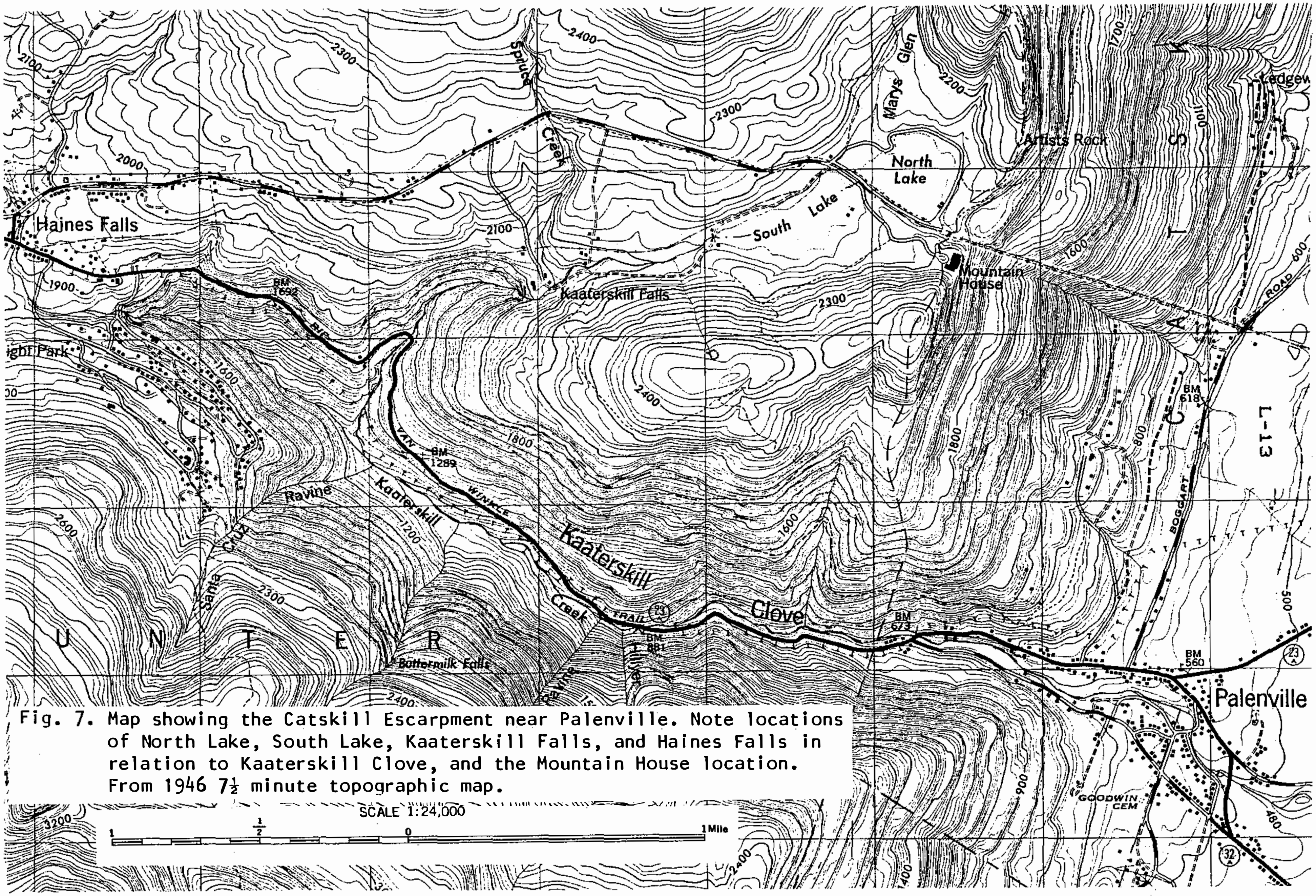

Fig. 7. Map showing the Catskill Escarpment near Palenville. Note locations of North Lake, South Lake, Kaaterskill Falls, and Haines Falls in relation to Kaaterskill Clove, and the Mountain House location. From 1946 7½ minute topographic map.

		Housatonic Mountains beyond the Hudson River, we can begin to comprehend the elevation of the Acadian Mountains source terrain. Red bed sandstones and conglomerates with much cross-bedding evident, can be seen along the escarpment here. Return to NY 23A
110.8	3.8	TURN LEFT ONTO NY 23A (east)
115.8	5.0	Veer right onto NY 32A. Rowena Memorial School - 1899, made of Becraft Ls. at junction of 23A and 32A.
117.7	1.9	Junction with NY 32S
123.5	5.8	TURN LEFT INTO TOLL BOOTH EXIT 20 NY STATE THRUWAY AND GO SOUTH TO KINGSTON, EXIT 19 AND RAMADA INN

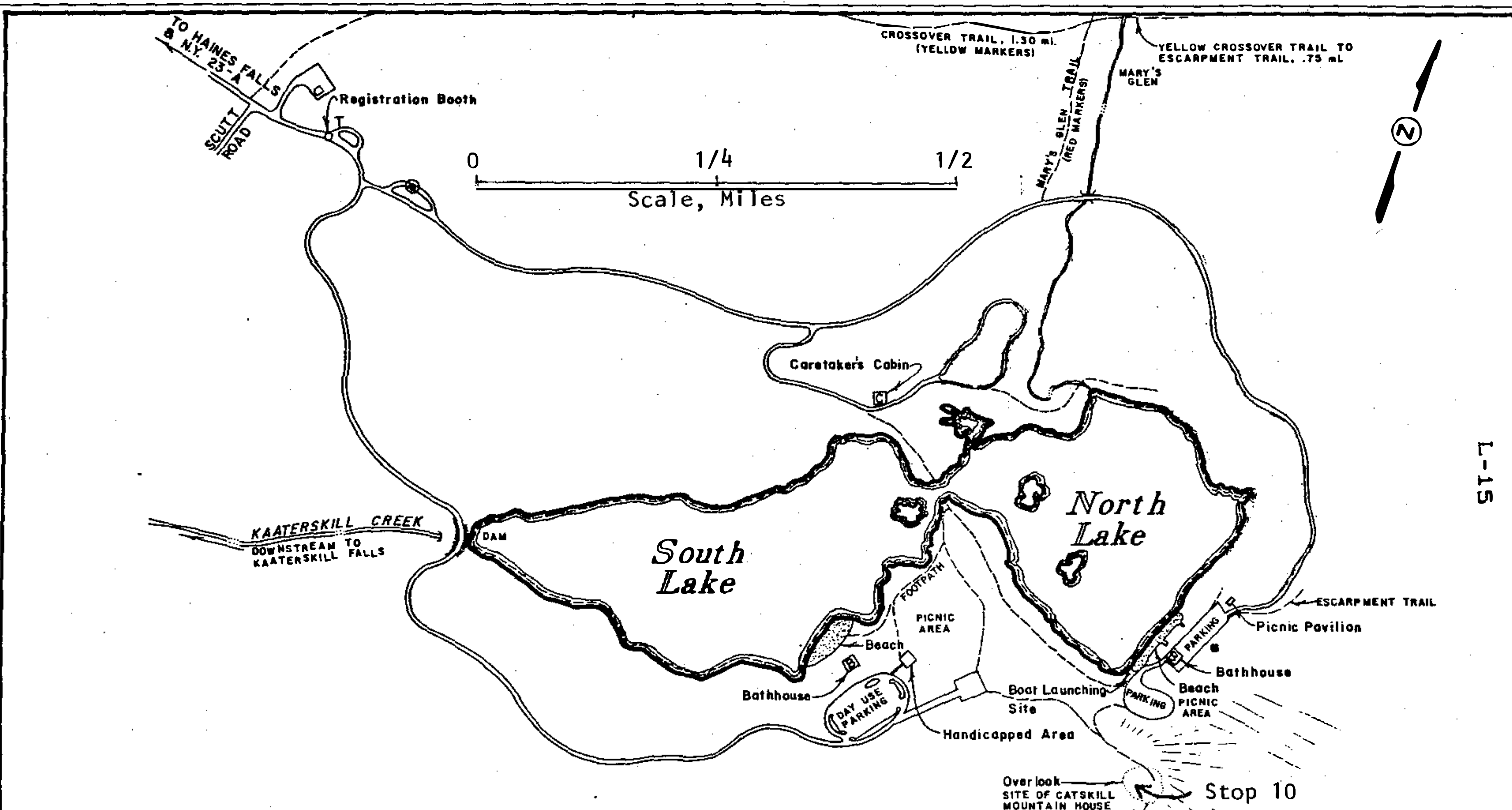

Fig. 8. Map of North and South Lakes. Dam at South Lake has outlet to Kaaterskill Falls. Escarpment overlook at site of Catskill Mountain House is marked as Stop 10 (modified from map by D. Berry, 1984).

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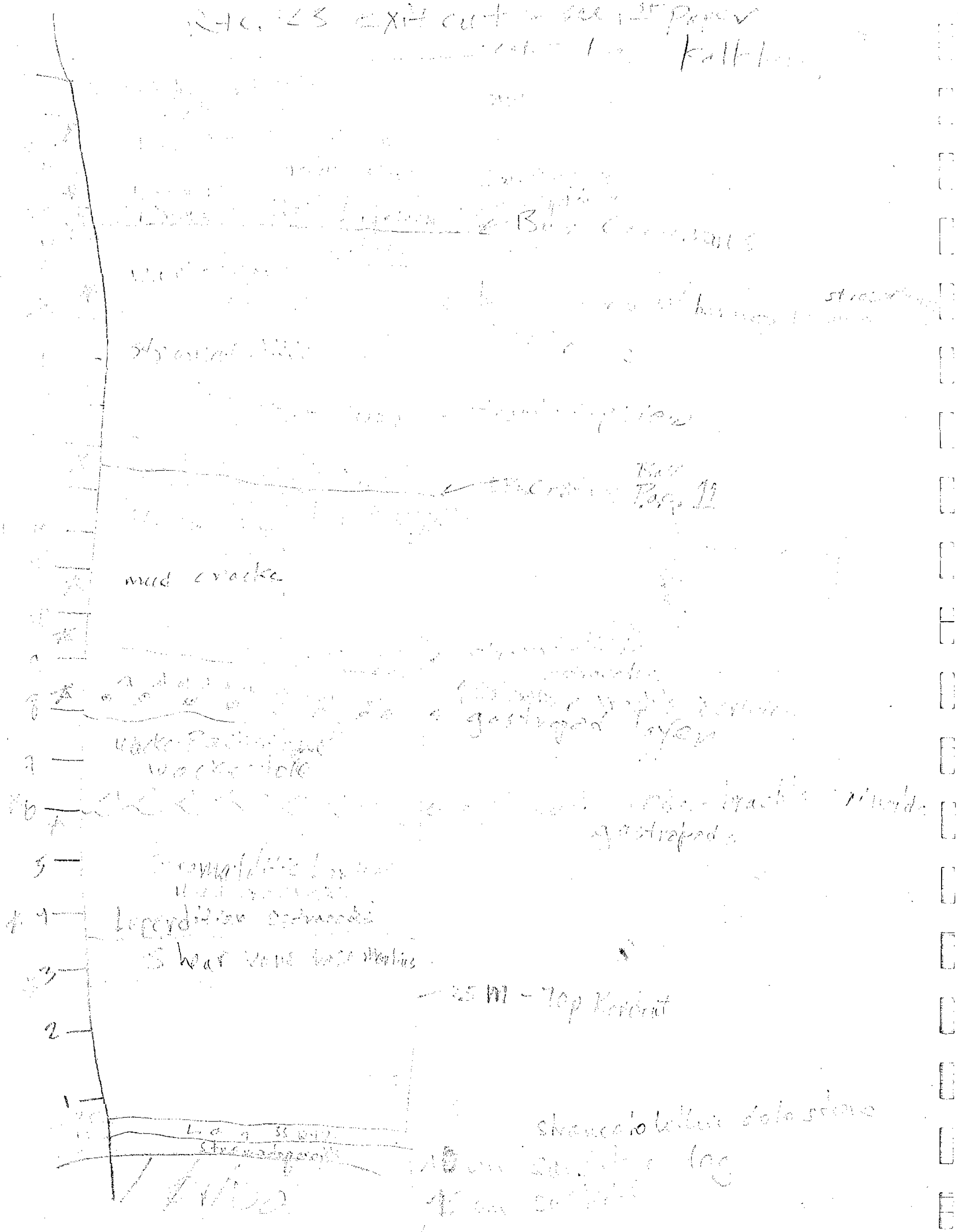

mud cracks
gastropod layer
gastropods
5
2
1