A PAC ANALYSIS OF THE MANLIUS-COEYMANS FORMATIONAL BOUNDARY HELDERBERG GROUP OF NEW YORK STATE

A Thesis Submitted
to the Temple University Graduate Board

in Partial Fullfiment
of the Requirement for the Degree

MASTER OF ARTS

by

William M. Goodman

April 1985

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Geology, College of Arts and Sciences, Temple University Philadelphia, Pennsylvania

April, 1985

E. J. Anderson

Dr. Edwin J. Anderson — Date

Peter W. Goodwin

Dr. Peter W. Goodwin — Date

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Finally, I would like to thank Temple University for the financial support that made this project possible.

Dedication

This thesis is dedicated to my family with love. Their support remained unwaivering throughout the extent of this project.

TABLE OF CONTENTS

LIST OF FIGURES

PAGE

PAGE

ABSTRACT

Application of the PAC hypothesis to the Thacher Member of the Manlius Formation has resulted in its division into eleven correlative PACs, shallowing-upward cycles produced by sedimentary aggradation following rapid episodic base-level rises. The eleven Thacher PACs are organized into two sequences. Manlius PACs 1-5 contain predominantly intertidal facies; Manlius PACs 6-11 are comprised mainly of subtidal and supratidal facies. These sequences are discernible at all localities in the Hudson Valley and central New York State.

This study demonstrates that certain distinctive facies found in PACs of the upper Thacher sequence developed laterally persistent horizons, an observation made earlier by Rickard (1962). The PAC 8 algal laminite horizon, which corresponds to the waterlime datum of Rickard (1962, figure 2), provides the primary time and environmental datum for the upper Thacher PAC sequence.

Correlation of upper Thacher PACs demonstrates that the Manlius-Coeymans formational contact is unconformable in eastern New York State. The thickness of section and number of PACs in the upper Thacher decreases progressively from west to east. Erosion responsible for the missing section and PACs is attributed to differential tectonic uplift of the eastern basin margin prior to any Coeymans deposition.

INTRODUCTION

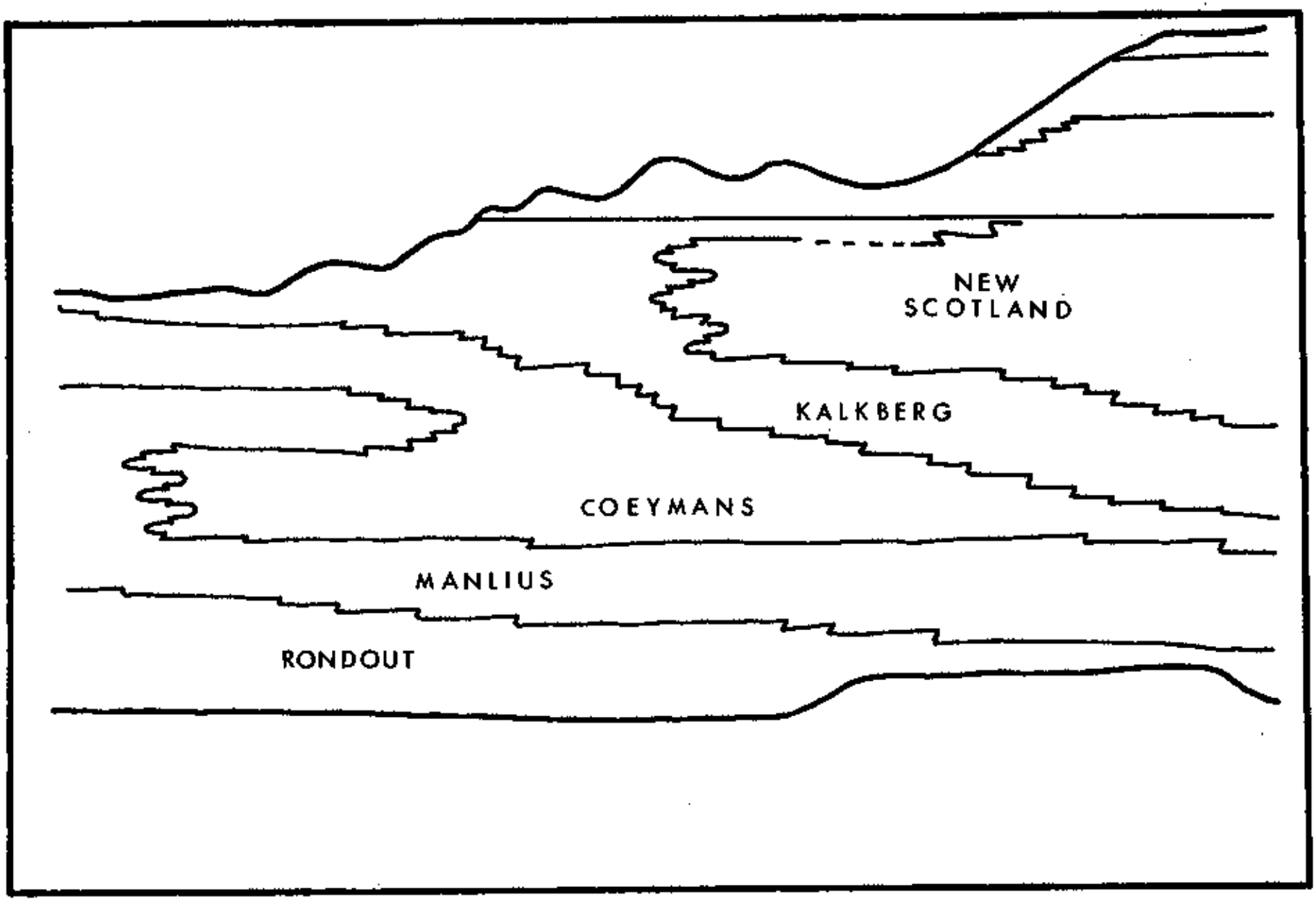
The purpose of this study is to apply the principles and methods of the PAC hypothesis to a detailed analysis of the Manlius-Coeymans boundary. This formational contact has been variously interpreted as a major unconformity, a depositional contact and a ravinement, each interpretation a product of gradualistic stratigraphic assumptions. In this study, the Manlius-Coeymans boundary is analyzed from an episodic perspective.

Previous Interpretations of the Manlius-Coeymans Boundary

Jaanusson (1960, p. 221) recognized discontinuities in limestones as distinct surfaces which "show signs of etching ing, boring activities of organisms, or both". He cited many examples of disconformities from the stratigraphic records of Europe and North America. From Jaanusson's description of the erosional surfaces, the following list of some features indicative of discontinuities can be compiled: 1) solution pits or other karstic features on the boundary surface; 2) bleached zones below below sharp contacts; 3) concentrations of iron or phosphatic compounds on the boundary surface; 4) wedging out of part of a succession in one direction; 5) intraformational conglomerates; 6) encrusting of organisms on the boundary surface.

The presence of many of these features at the Manlius-Coeymans formational boundary in the Helderberg Group of New York State (figure 1) has not been sufficient evidence for universal acceptance of this surface as a disconformable

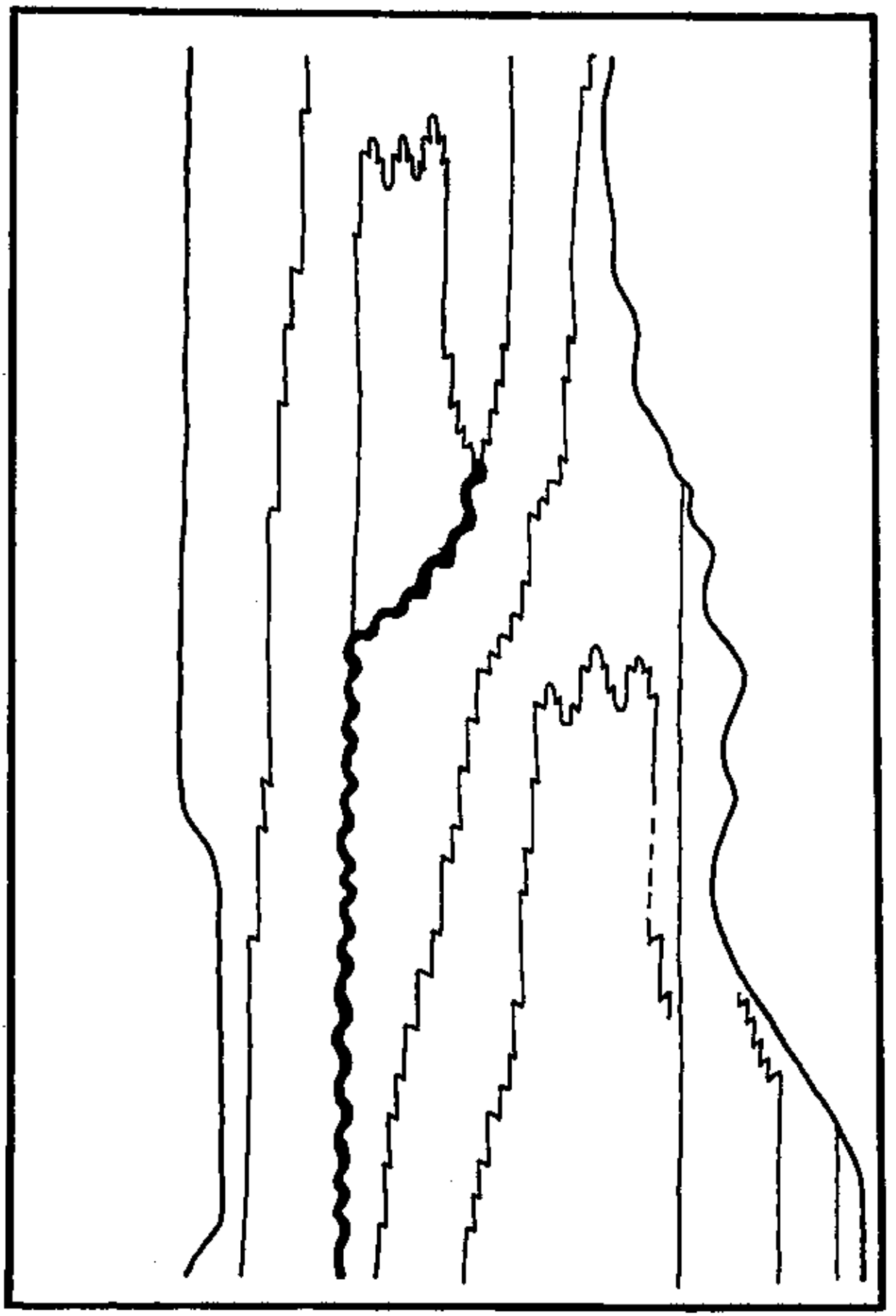
Figure 1:
Stratigraphic framework of the Helderberg Group in eastern New York State. After Rickard (1962).


NEW
SCOTLAND
KALKBERG
COEYMANS
MANLIUS
RONDOUT

contact. Over the past fifty years, opinion regarding the nature of this surface has vacillated coincidentally with changes in the basic assumptions which underlie prevalent stratigraphic theories. Early researchers, working under the premise that each Helderberg formation is contemporaneous throughout its extent (reviewed by Rickard, (1962, p. 104), contended that the Manlius-Coeymans boundary marks a significant unconformity (figure 2). The absence of younger Manlius members in eastern New York and the wavy, irregular nature of the contact in the Hudson Valley were cited as evidence of large-scale erosion. Logie (1933) noticed that several feet of the uppermost Manlius (Thacher Member) were missing at some localities in the Catskill and Saugerties quadrangles. Chadwick (1944, p. 152) reported slabs of Manlius rock up to a yard or more in length "caught up" in the Coeymans two to three feet above the contact at localities north of Catskill.

The "layer cake" approach of early workers was abandoned by later workers, who following the actualism of Walther, envisioned formations to be the products of "facies-areas", or depositional environments, which have migrated over time with gradual changes in sea-level. Consequently, the notion that each Helderberg formation represents an isochronous, basin-wide environment gave way to the idea that these formations are time-transgressive deposits of once laterally contiguous paleoenvironments. This new concept was based primarily upon observation of the juxtaposition of modern sedimentary environments. Accordingly,

Figure 2:
Large-scale unconformity at the Manlius-Coeymans contact as contended by early workers.



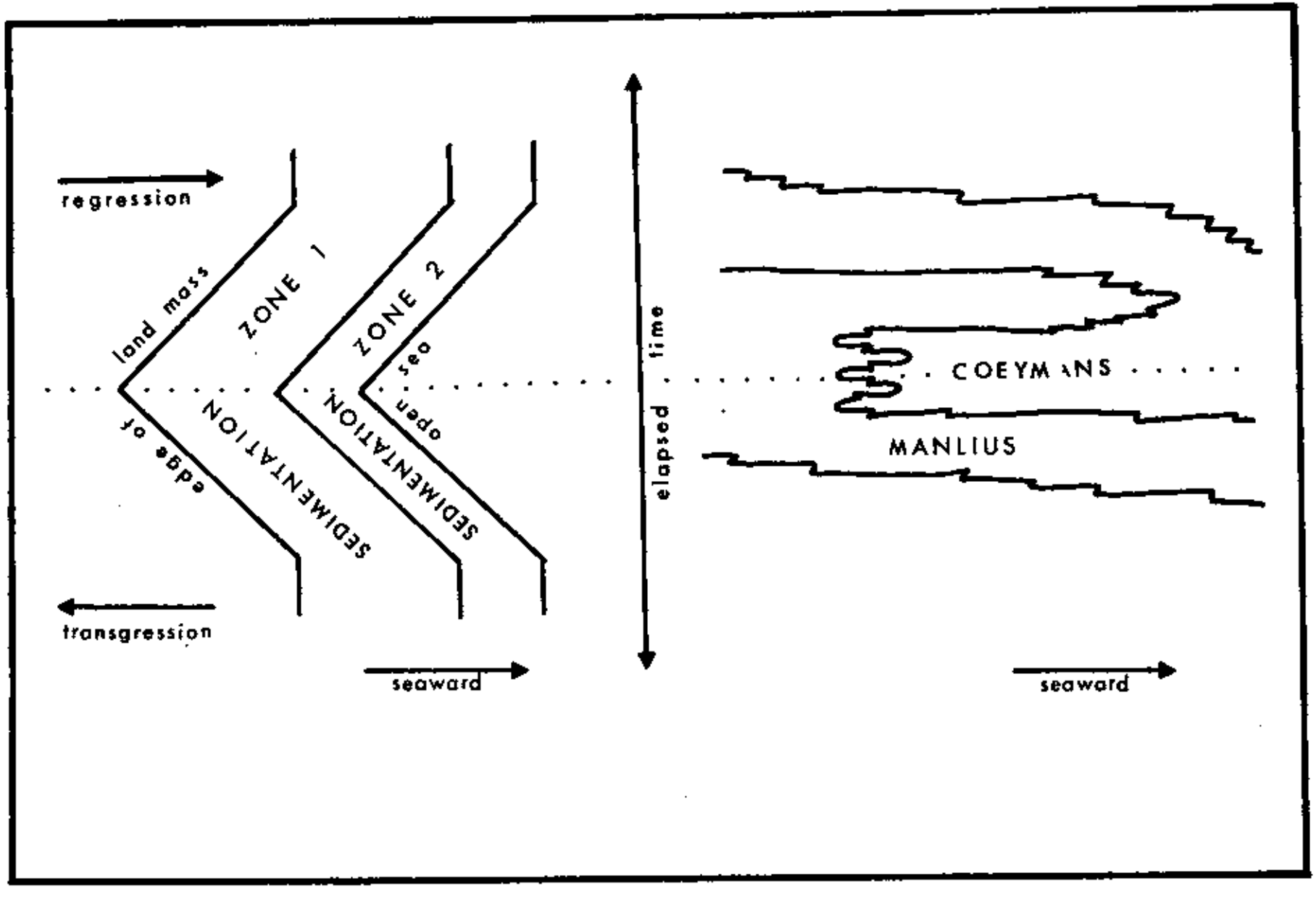
the differences in lithology between formations of the Helderberg Group have been thought to reflect the variation in facies observed in a transect from onshore to offshore in modern carbonate environments.

Consistent with these new assumptions, Davis (1953, p. 27), after a stratigraphic analysis of the Manlius-Coeymans formational boundary in central New York State, concluded that although minor local disconformities attributable to oscillating conditions of deposition may exist at the contact, there was no hiatus between Manlius and Coeymans deposition. Rickard (1962, p. 101), in his definitive reconstruction of Upper Cayugan and Helderbergian stratigraphic relationships for New York State, suggested that in view of the inferred environments in which each facies (formation) was deposited, the possibility that all could have existed contemporaneously in an advancing sea is a strong one. He refuted evidence for the unconformity at the Manlius-Coeymans boundary proposed by early workers by demonstrating that the younger Manlius members grade laterally into the Coeymans and Kalkberg Formations in the Hudson Valley. Rickard's conclusion that the Olney and younger members were never deposited in eastern New York greatly reduces the magnitude of the unconformity required to explain the configuration of Helderberg formations. Consequently, Rickard (1962, p. 49) concluded that any erosion occurring at the formational contact in the Hudson Valley is attributable to "the advance of somewhat deeper, better agitated waters into an

area previously occupied by relatively shallow, quiet waters."

In support of Rickard's interpretations and consistent with the deductive models of Shaw (1964) and Irwin (1965), Laporte (1969) interpreted the Helderberg Group as a transgressive carbonate sequence deposited continuously within a shallow epeiric sea. Laporte (1969, p. 117) concluded that the Manlius, Coeymans, Kalkberg and New Scotland Formations, representing supratidal through below-wave-base subtidal environments, developed contemporaneously in a generally west to east direction across a shallow epicontinental sea. According to Laporte, slow gradual transgression of the Helderberg sea occurring simultaneously with regional subsidence permitted the accumulation and northwest secular migration of facies belts (formations) across central New York producing a vertical stratigraphy which today records the lateral pattern of depositional environments which existed in the Helderberg Basin (figure 3). According to this interpretation, the Manlius-Coeymans formational boundary represents the migration of a near-wave-base shelf environment over a restricted lagoon and tidal flat environment. Arguing against the supposed disconformity at the contact, Laporte (1967, p. 95-96) concluded that "the presence of Manlius-derived intralasts within the Coeymans...indicates that parts of the Manlius were indurated and eroded during early Coeymans deposition", and the time intervals between subaerial exposure and subsequent reworking could have been geologically very short.

Figure 3:
Application of the gradualistic concepts of Shaw (1964) and Irwin (1965) to the Helderberg Group

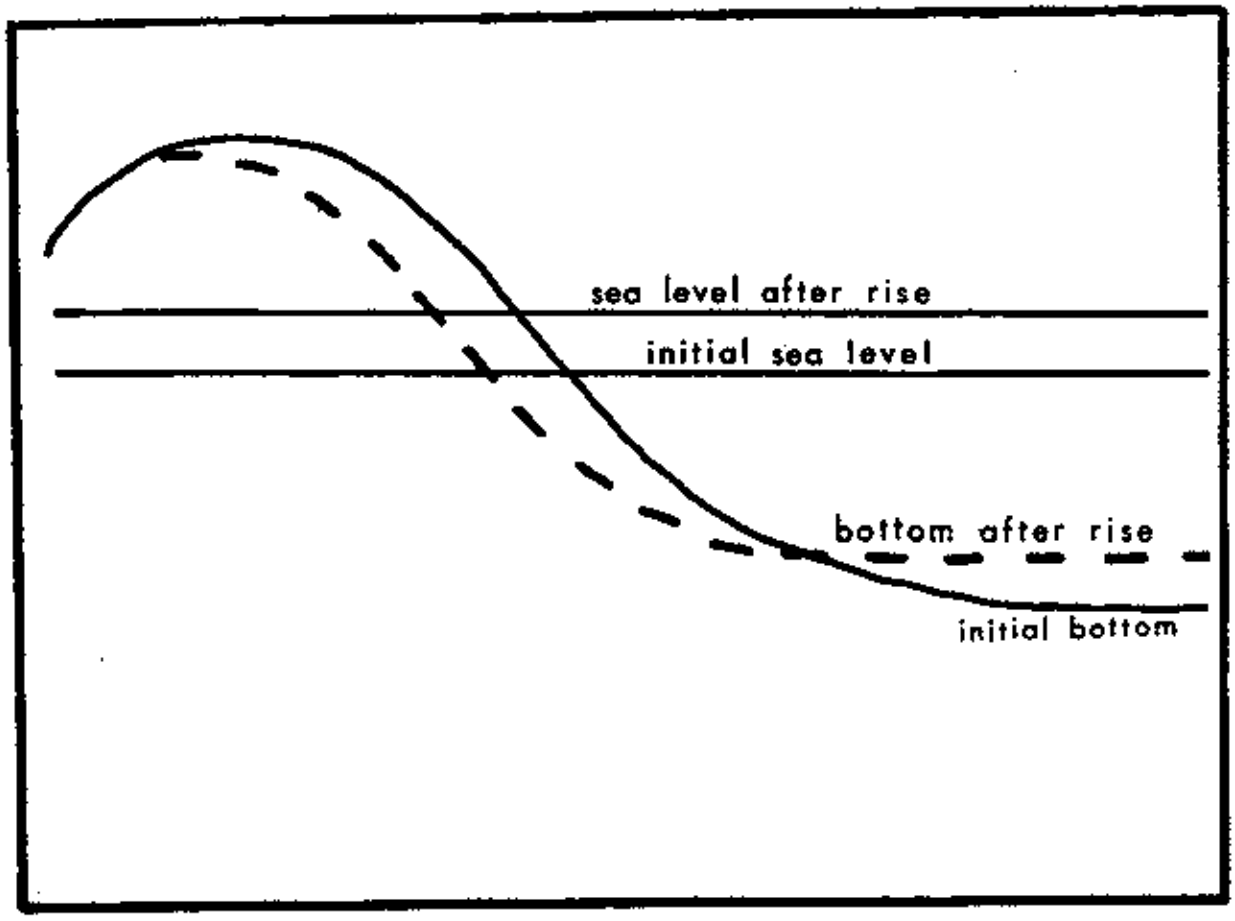

regression
land mass
ZONE 1
ZONE 2
sea
open
edge of
SEDIMENTATION
SEDIMENTATION
transgression
seaward
elapsed time
COEYMANS
MANLIUS
seaward

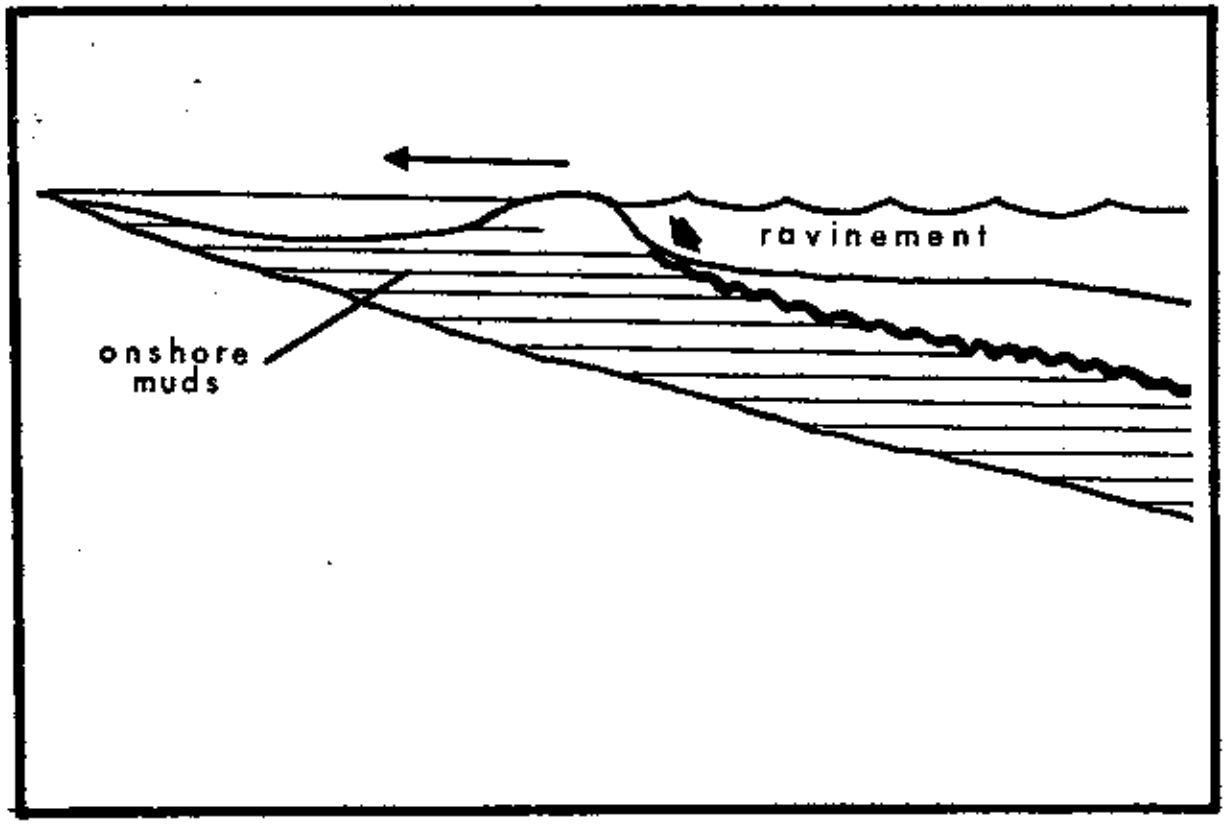
A detailed analysis of the erosional nature of the Manlius-Coeymans contact working under gradualistic assumptions was presented by Anderson (1972). He argued that the contact is a ravinement (figure 4), a discontinuity surface produced by shore-face erosion of a migrating barrier system with a rise in sea-level (Fischer, 1961; Swift, 1968). Explaining erosion at the formational boundary as the result of migration of the high energy Coeymans environment over the low energy Manlius environment, Anderson (1972) proposed a specific mechanism for the erosion evident at the contact in the Hudson Valley in a manner consistent with the basic assumptions underlying the prevalent gradualistic stratigraphic model.

In a recently published article, Anderson, Goodwin and Sobieski (1984) have questioned the validity of the assertion that Helderberg formational boundaries are actual diachronous surfaces separating paleoenvironmental units (p. 12). Detailed field observation indicated that most formation boundaries in the Helderberg sequence mark sharp contacts between markedly different facies. Because these facies are generally not transitional in lithological characteristics, they cannot represent laterally contiguous environments. Therefore, Helderberg formations could not have been deposited in response to lateral migration with gradual base-level rise. The sharp formational contacts are, however, consistent with the tenets of the hypothesis of punctuated aggradational cycles (PACs), a model of episodic accumulation which predicts abrupt facies changes at strati-

Figure 4a:
Schematic representation of the ravinement process. After Fischer (1961).

Figure 4b:
Ravinement concept as applied to the Manlius-Coeymans formational boundary. After Anderson (1972).


sea level after rise
initial sea level
bottom after rise
initial bottom


ravinement
onshore
muds

graphic discontinuities.

According to the hypothesis of punctuated aggradational cycles (Goodwin and Anderson, 1980), stratigraphic accumulation occurs as thin (1-5 meter thick) shallowing-upward cycles (PACs) which are bounded by sharply defined non-depositional surfaces (figure 5). These surfaces are produced by geologically instantaneous, basin-wide base-level rises. Deposition between punctuation events occurs during periods of base-level stability. Because PACs are the products of these instantaneous basin-wide events, they are time-stratigraphic units which are laterally traceable through variable lithofacies and across diachronous formational boundaries (figure 6).

PACs occur in asymmetric deepening and shallowing sequences. According to the PAC hypothesis, these sequences are time-stratigraphic units produced by basin-wide synchronous patterns of punctuation events. Because they reflect pervasive vertical facies patterns on a scale larger than individual PACs, PAC sequences are useful as a means to correlate widely-spaced outcrops between which facies may change significantly.

Objectives

This study is an attempt to apply the PAC hypothesis to the Manlius-Coeymans formational boundary. In order to accomplish this purpose, it is necessary to satisfy the following objectives: 1) to demonstrate that the upper portion of the Thacher Member of the Manlius Formation is completely divisible into PACs; 2) to correlate individual up-

Figure 5:
Diagrammatic representation of fundamental tenets of the hypothesis of Punctuated Aggradational Cycles. After Anderson and Goodwin (1980)

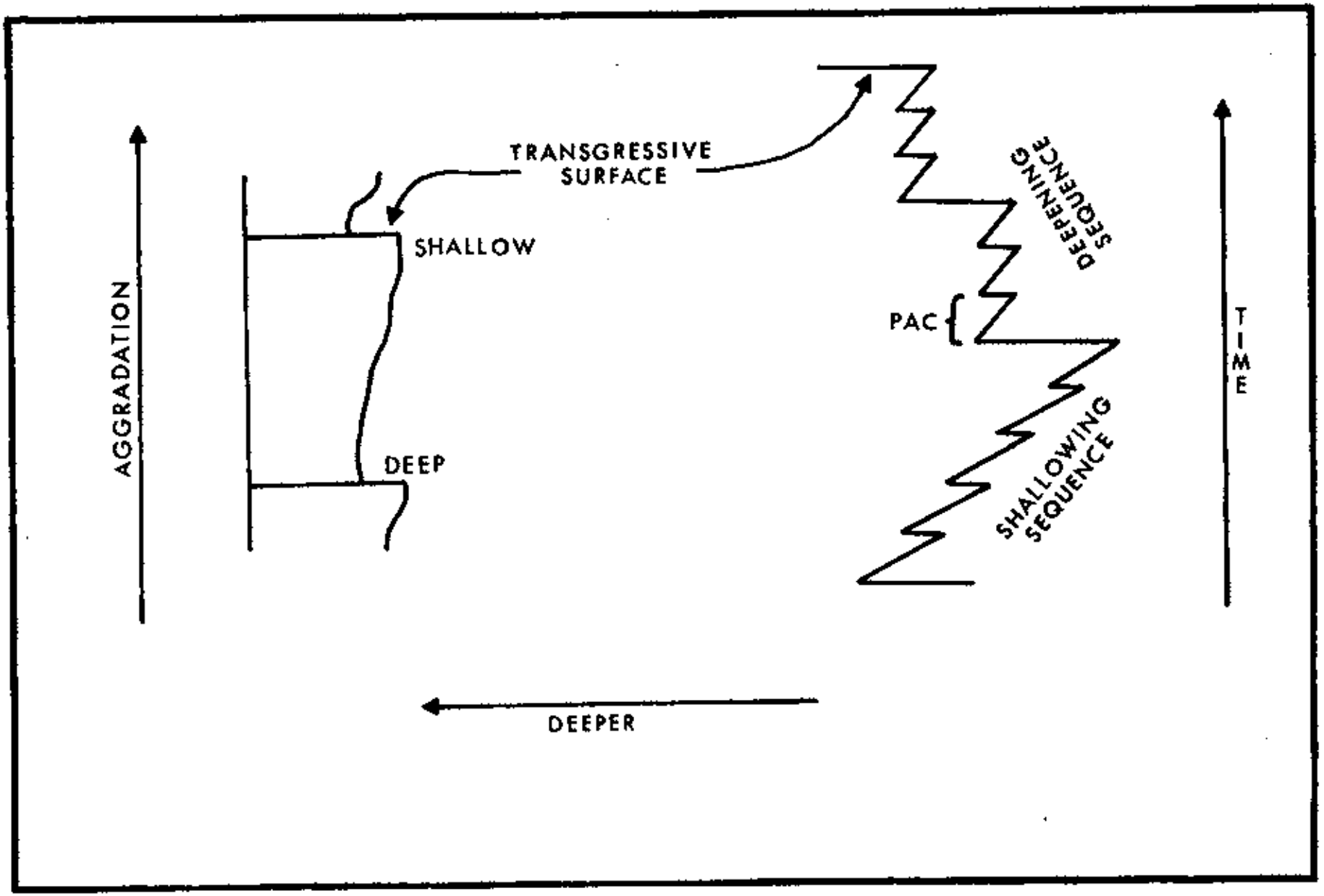
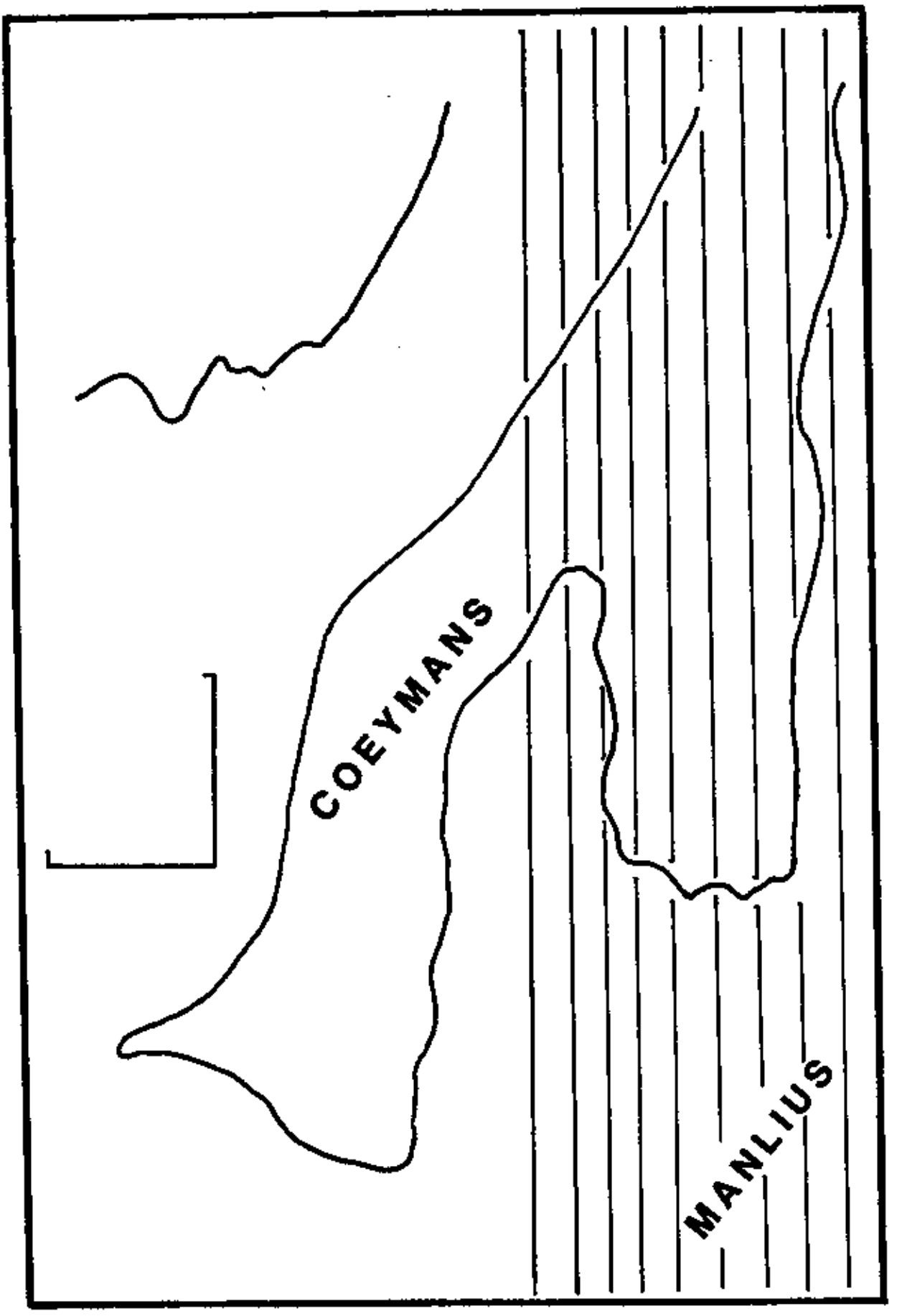

AGGRADATION
TRANSGRESSIVE SURFACE
SHALLOW
DEEP
PAC
DEEPENING SEQUENCE
SHALLOWING SEQUENCE
TIME
DEEPER

Figure 6:
Illustration of the time-stratigraphic nature of PACs as compared to the diachroneity of traditional stratigraphic units. After (Anderson and Goodwin, in press).


COEYMANS
MANLIUS

per Thacher PACs between localities; 3) to determine the lateral persistence and degree of preservation of uppermost Thacher PACs; and 4) to interpret the Manlius-Coeymans formational boundary as the product of one or more episodic base-level rises.

Methods

The PAC hypothesis, as an episodic model of stratigraphic accumulation, offers a new method of outcrop description and stratigraphic analysis (Goodwin et al., 1980). The PAC hypothesis states that deposition occurs in thin packages of facies which display a shallowing-upward motif. Application of this idea to field investigation changes the focus of data collection from rock-stratigraphic units (formations, members) to time-stratigraphic units (PACs, PAC sequences). This change in focus leads to different methods of subdividing and correlating a rock sequence.

At any single outcrop, field analysis involves the construction of a detailed stratigraphic column on graph paper at a scale of one inch to five feet of rock section. Special attention is given to vertical facies successions in the context of shallowing-upward cycles. Non-depositional surfaces between shallow facies below and deeper facies above mark PAC boundaries which are labeled on the constructed column. According to the PAC hypothesis, they are correlative, isochronous surfaces which can be traced basinwide. As such, these surfaces provide the principle means of correlation from outcrop to outcrop.

Fieldwork for this study was accomplished during the

summers of 1982 and 1983. Stratigraphic columns were constructed for each of fourteen localities between Cherry Valley, New York, and South Wilbur, New York, a distance in excess of 100 kilometers along the outcrop belt (figure 7 foldout).

While facies changes in the Manlius Formation are generally discernible in the field, oriented whole-rock samples were collected for microscopic analysis at six key localities to support facies interpretations. Samples were taken directly above and below the Manlius-Coeymans contact, above and below each Manlius PAC boundary, and occasionally within PACs to obtain samples of the representative upper Thacher facies. Sixty thin sections were prepared from slabs cut normal to bedding. Samples were mounted on 75x38x1.00 mm petrographic glass slides with Conap epoxy adhesive and polished with 1000 mesh silicacarbide grit in the final polishing stage.

MANLIUS FACIES AND PALEOENVIRONMENTS

In order to define PACs to be used in a stratigraphic analysis of the Manlius-Coeymans formational boundary, it is necessary to understand upper Thacher facies and to recognize persistent lateral and vertical facies patterns. Rickard, in his definitive reconstruction of Upper Cayugan and Helderbergian stratigraphy of New York State, recognized that, at its proposed type section, the Thacher Member of the Manlius is divisible into two parts: a lower 30 foot sequence consisting of relatively homogeneous facies, and an upper sequence about 20 feet thick containing variable lithologies. In the upper Thacher sequence, Rickard recognized three distinctive horizons: two stromatoporoid biostromes separated by a planar-laminated "waterlime" horizon. Rickard used the waterlime as a correlation datum on which to align stratigraphic columns from central New York and Hudson Valley localities. Although he considered them laterally discontinuous, Rickard also used the biostromes as a secondary means of correlation (1962, figure 2). Laporte (1967) recognized that the Manlius Formation is divisible into subtidal, intertidal and supratidal facies and that each was deposited at or near sea-level. In agreement with Rickard's observations, Laporte (1967) divided the Thacher Member into two parts according to sedimentary patterns. Laporte (p. 97) interpreted the lower sequence to to consist mainly of intertidal facies and the upper sequence to be comprised primarily of supratidal and subtidal facies. As support for the use of the stromatoporoid biostromes for

making tenative correlations, Laporte (p. 85) noted that there are many places where the biostromes seem to be continuous for several miles.

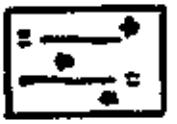
Field observations of repetitive vertical sequences of subtidal, intertidal and supratidal facies are used to subdivide the Thacher Member into eleven correlative PACs, each displaying a shallowing-upward motif. Each PAC contains facies which represent paleoenvironments present at a particular instant in Manlius time. Lateral facies variation within any stratigraphically equivalent PAC represents variation in coeval Manlius paleoenvironments (Saraka and Goodwin, 1984). Lateral facies changes are to be expected since modern analogues to the Manlius depositional environment often contain considerable variation in sedimentation and water depth from shoreline progressively offshore (Shinn et al., 1969) as well as parallel to the shoreline. The environments represented within any one PAC are newly created and separate from environments contained in preceding PACs. This does not imply, however, that there is no influence on facies in one PAC from accumulation in the preceding PAC. As noted by Saraka (1984), topographic relief on the top of a preceding cycle partially limits the facies which may develop in the PAC then aggrading (see PACs 6 and 9).

In this section, facies which occur in the upper Thacher (figure 8) are described, illustrating their characteristic sedimentary structures and faunal assemblages.

Figure 8:
Legend for stratigraphic columns
presented in figure 7.

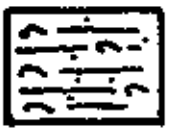
MANLIUS FACIES

Shallowest



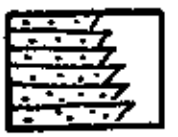
Birdseye Mud

Cryptalgal Laminite



Ostracode Calcarenite

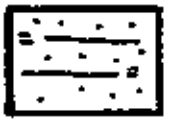
Ribbon Bed



Thin-bedded Calcarenite

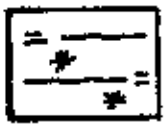
Massive Calcarenite

Biostrome



Medium-bedded Calcarenite

Deepest



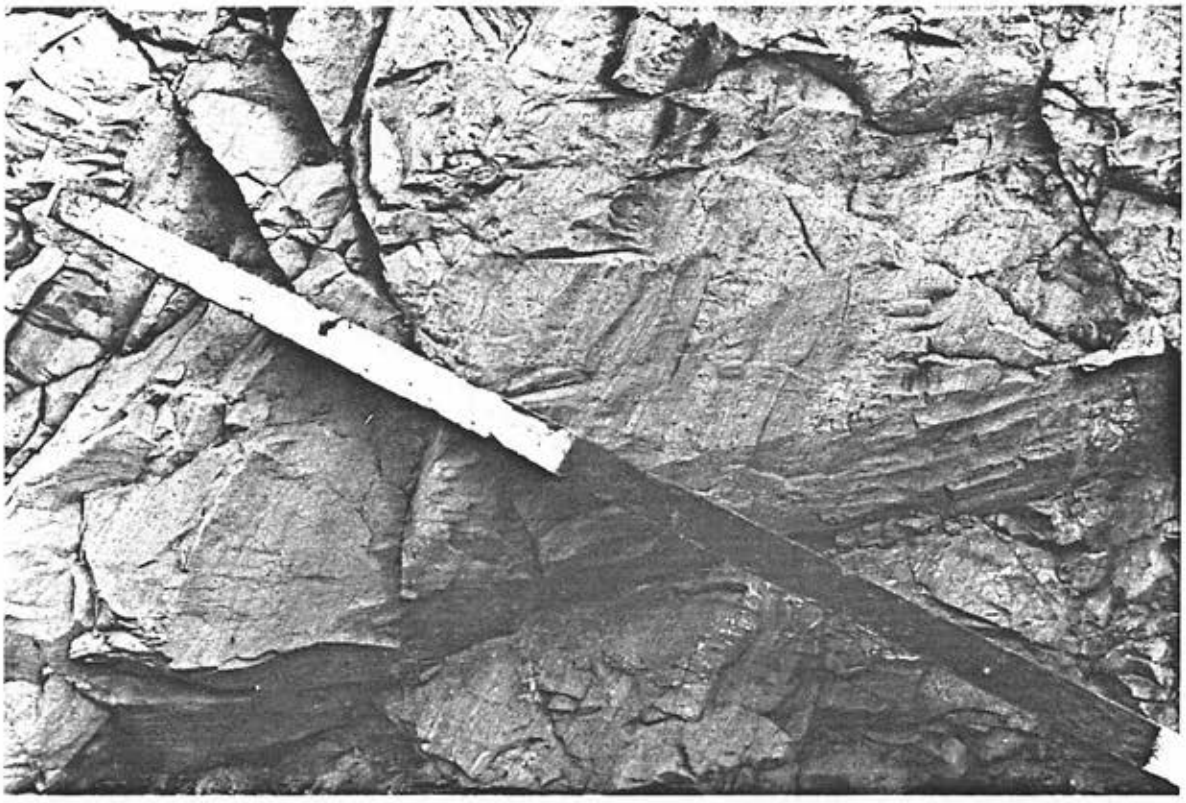
The birdseye mud facies occurs both as sets of thin, light to medium gray beds separated by buff-colored laminated shales and as light to medium gray massive crinkle-textured beds (figure 9). Clasts, similar to those which have been compared to modern soil peds by Fischer (1975) are common in this facies. Fossils are rare except for an occasional disarticulated ostracode valve or thin lens of shell hash. This facies is well-developed in PAC 6 at Catskill localities and in PAC 7 at Kingston.

The birdseye mud facies is interpreted as a supratidal deposit. Birdseye fenestra have been interpreted as shrinkage pores which form during subaerial exposure (Laporte, 1967). Modern birdseye muds have been reported forming on tidal flats of the Bahahmas (Shinn et al., 1969) and south Florida (Ginsburg, 1964) where the laminated facies develops on beach ridges and the unlaminated muds accumulate in tidal ponds. Analogous ancient facies have been described by Fischer (1964) from the Triassic of the Northern Alps and by Read and Grover (1977) from the Ordovician of Virginia.

The cryptalgal laminite facies forms buff-colored blocky units (figure 10), the massive appearance of which often being disrupted by columnar dessication joints. This facies consists of alternating mm-scale beds of lime mud and microcrystalline dolomite. The micritic laminae commonly contain birdseye structures, and as with the birdseye mud facies, fossils are rare except for comminuted skeletal debris. This facies forms a laterally extensive horizon at the

Figure 9a:
Supratidal birdseye mud facies, PAC 7 at Kingston. White portion of stick is one foot in length.

Figure 9b:
Thin-section photonegative of supratidal birdseye mud facies, PAC 6 at North Catskill. Scale in millimeters.



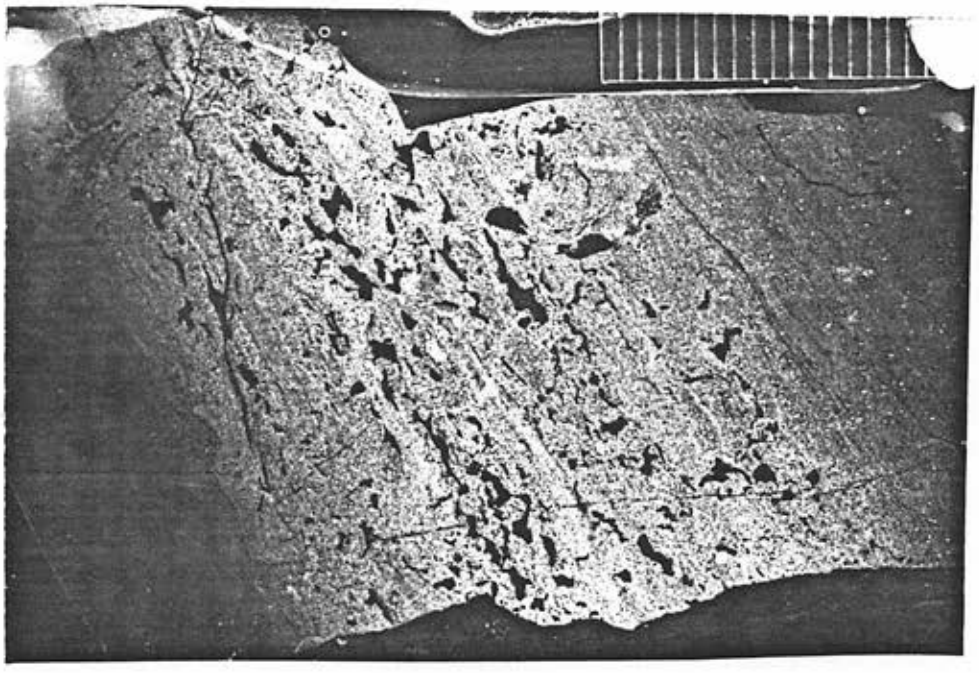
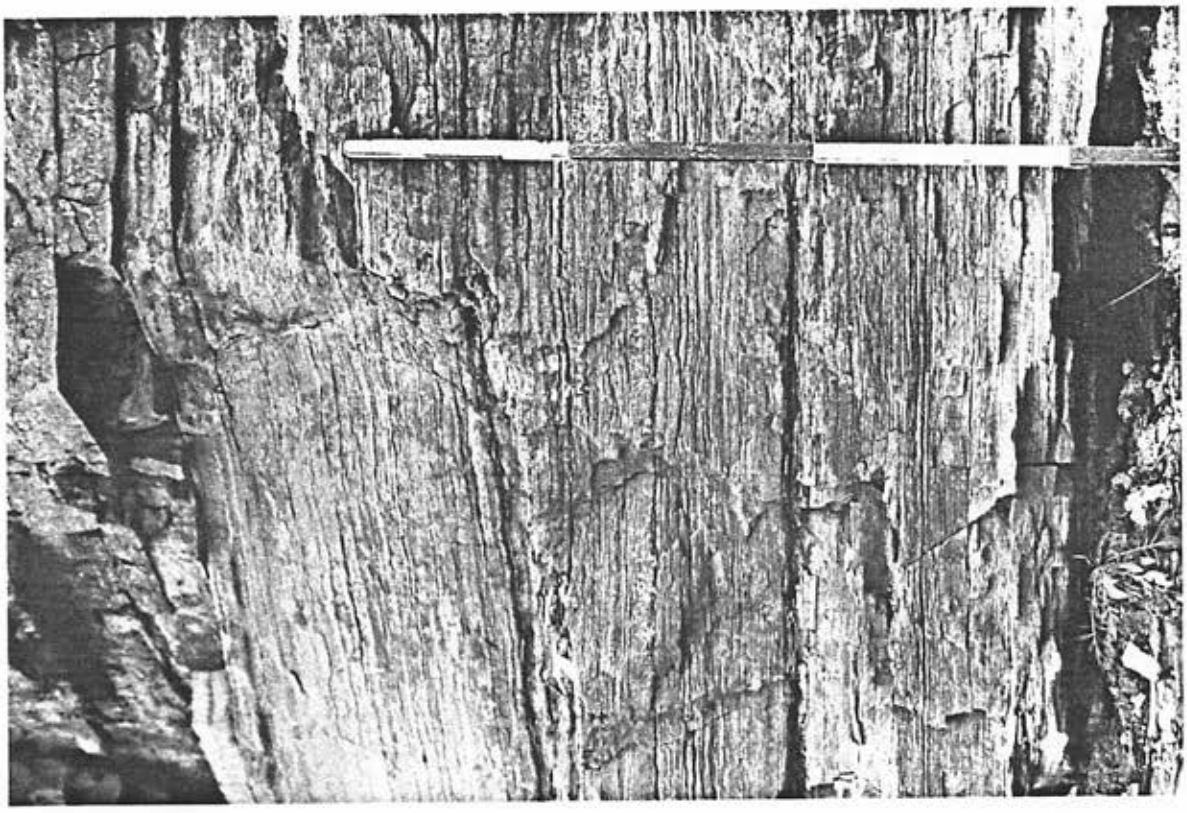
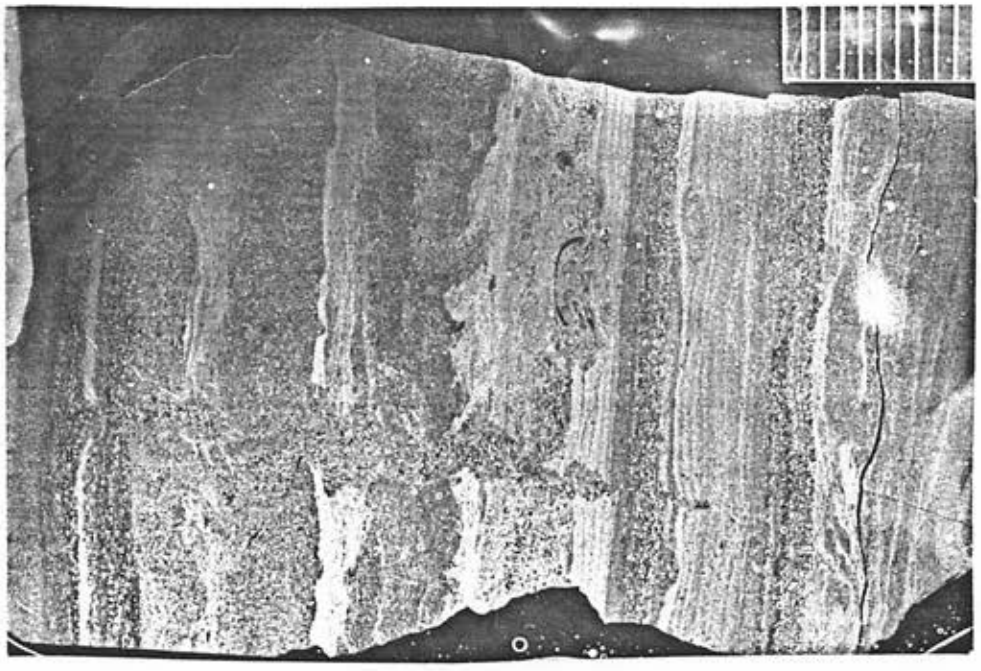


Figure 10a:
Cryptalgal laminite facies, PAC 8 at Cherry Valley. Stick colored in one foot increments.

Figure 10b:
Thin-section photonegative of cryptalgal laminite facies, PAC 8 at South Catskill. Scale in millimeters.





top of PAC 8 which provides the major time and environmental datum in the upper Thacher. This datum corresponds to the waterlime datum of Rickard (1962, figure 2). The eastern and western parts of Rickard's datum are linked in the Schoharie Valley by correlation of the algal and current laminites of other localities with a highly stylotized 2-3 inch, buff-colored laminated lime mud at Schoharie.

The cryptalgal laminite facies is interpreted as representing high intertidal conditions analogous to the flat and polygonal zone facies of modern Persian Gulf tidal flats (Kendall and Skipwith, 1968). Similar ancient facies have been described by Aitken (1967) from the Cambro-Ordovician of the southern Canadian Rockies and by Read (1973) from the Devonian of Western Australia.

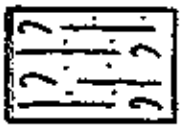
Gebelein and Hoffman (1973) have proposed that the presence of algae in the primary sedimentary environment plays an important role in the formation of secondary microcrystalline dolomite. They suggested that during deposition on algal-dominated tidal flats, Mg^{2+} is organically complexed in algal mats. Only after complete decomposition, which may not occur until burial and lithification, does the mat material release the magnesium required for dolomitization. Thus, in ancient cryptalgal laminite facies, algal mats are preserved as microcrystalline dolomitic laminae.

Research on the electrochemical interaction between clays and algae by Avnimelech and Troeger (1982) adds credibility to this hypothesis. In the presence of sufficient concentrations of $CaCl_2$ or NaCl, algal-clay aggregates have

been experimentally flocculated and removed from suspension, effectively clarifying the water column. Avnimelech and Troeger (p. 63) suggest that

> these interactions may profoundly affect the ecological structure of bodies of water in terms of the temporal and spatial distribution of organisms, the concentration of suspended inorganic particles and nutrients, nutrient recycling, substrate utilization by filter feeding organisms, and other processes.

It is worthy of note that Manlius dolomite beds are generally more argillaceous than Manlius lime units (Laporte, 1967), and that within the same PAC, the algal-dominated intertidal facies is sometimes dolomitized while the capping supratidal birdseye mud facies is not as in PAC 8 at North Catskill. Thus, the entrapment of clay-size particles by mucilaginous algal mats and the flocculation of algal-clay aggregates may have been primary processes which have led to the formation of secondary microcrystalline dolomite in the Manlius tidal flat facies.

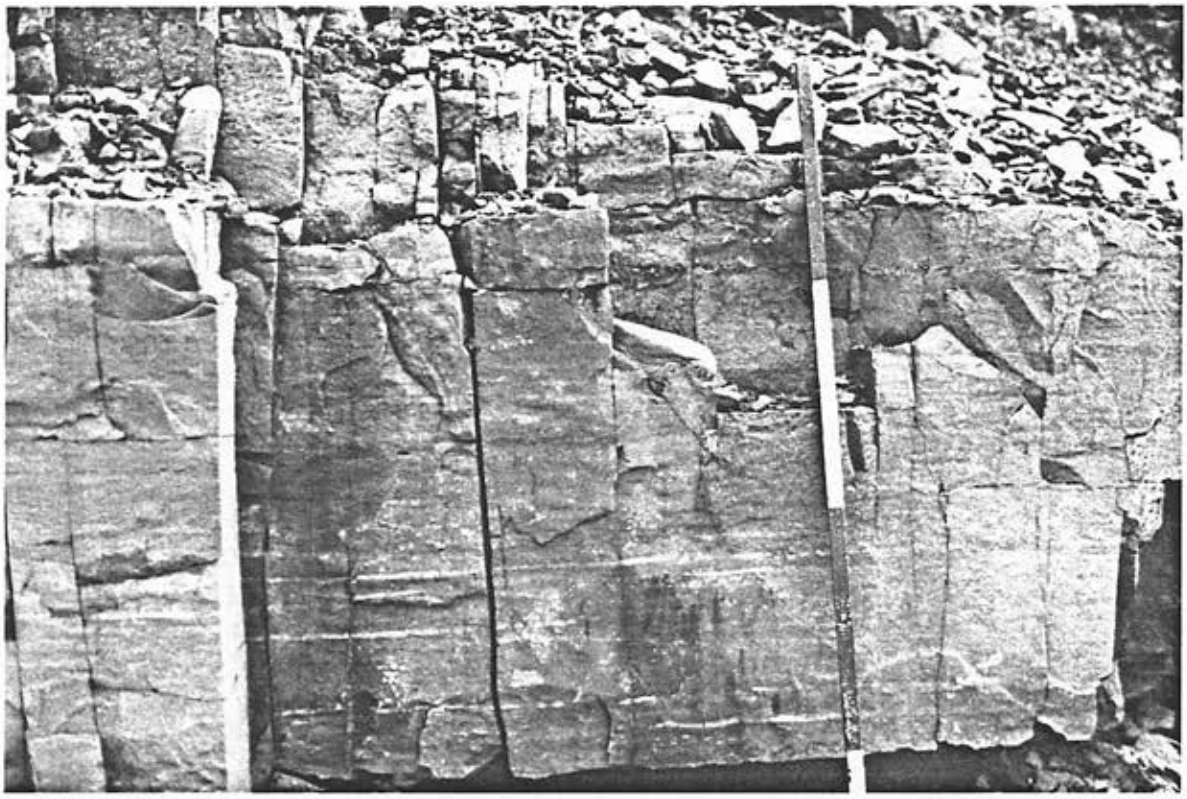


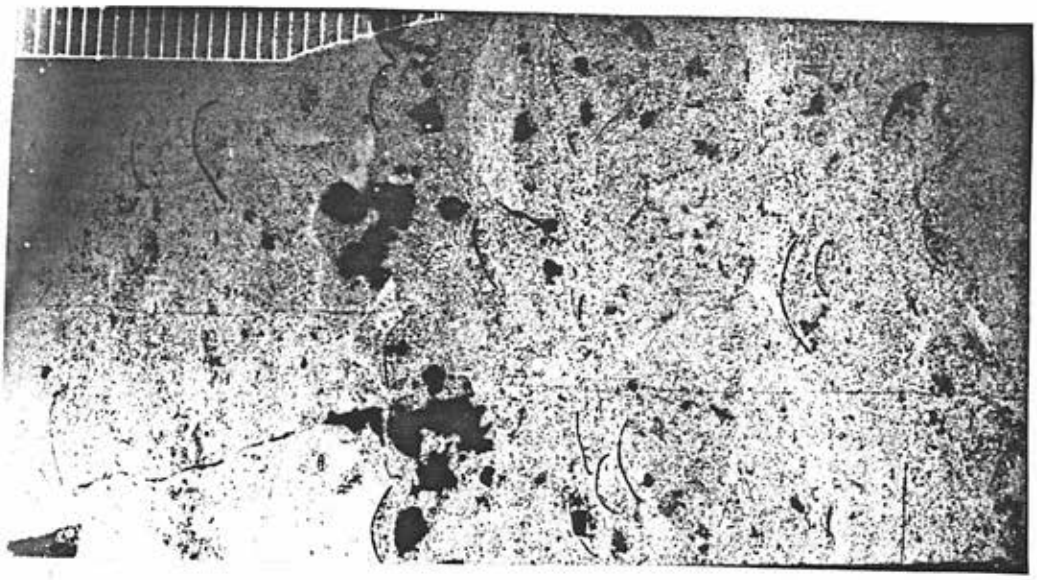
The ostracode calcarenite facies occurs as buff-colored blocky beds (figure 11). This facies consists of planar-laminated or low-angle cross-bedded pelletal sand with disarticulated leperditid ostracode valves most commonly oriented convex-upward. Laminae often have a crinkled texture suggestive of some algal influence on bedform.

The ostracode calcarenite facies is interpreted as representing a low intertidal carbonate bank environment. This facies shows no evidence of subaerial exposure; the fine lam-

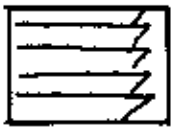
Figure 11a:
Ostracode calcarenite facies, PAC 5 at Schoharie. Stick colored in one foot increments.

Figure 11b:
Thin-section photonegative of ostracode calcarenite facies, PAC 9 at Cherry Valley. Scale in millimeters.





ination and low angle cross-bedding are suggestive of low energy swash of small mud clasts, fecal pellets and delicate bioclasts which comprise this facies. The remarkable lateral persistence of this facies as evident in PAC 6 suggests that Manlius carbonate banks were probably as large as Holocene mudbanks in the Florida reef tract described by Turmel and Swanson (1976).

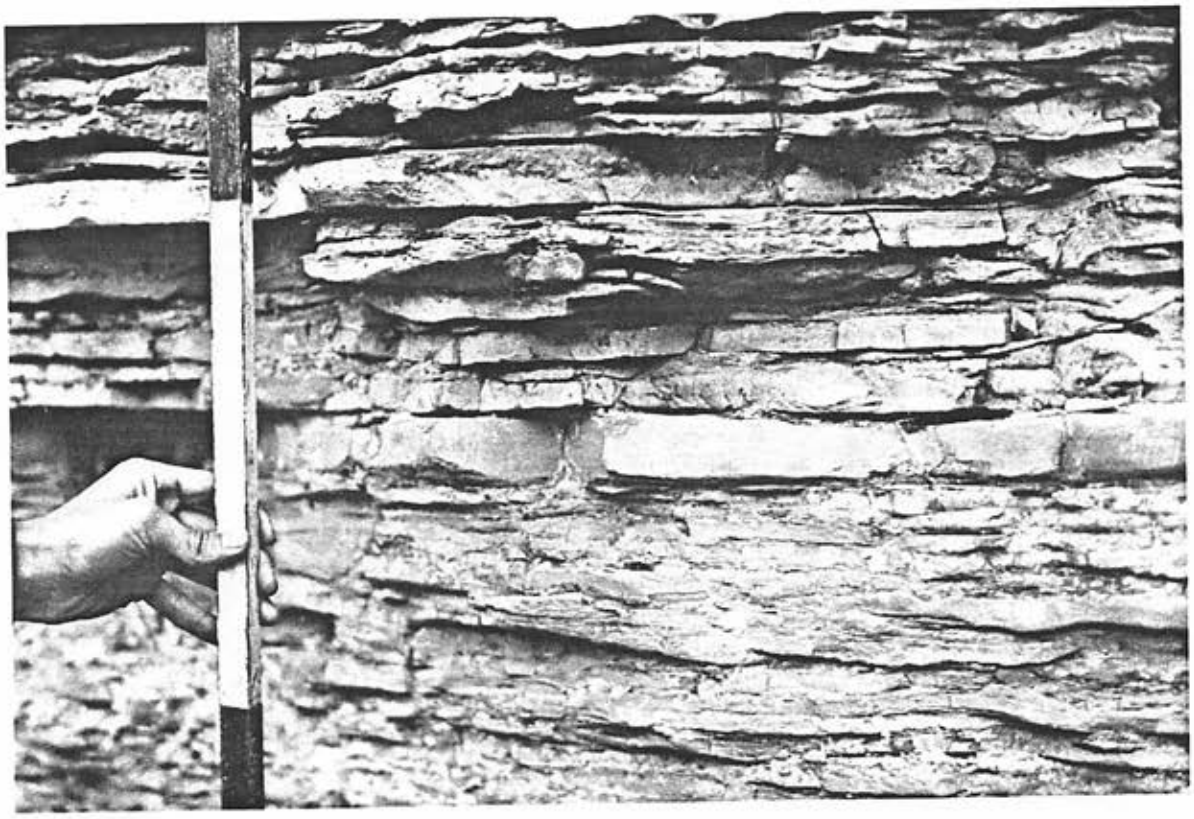


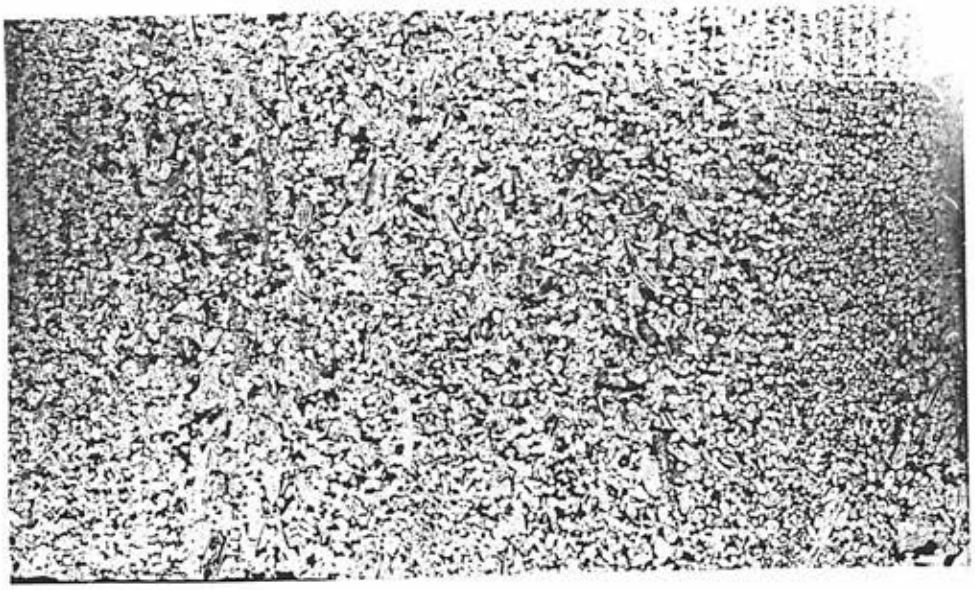
The ribbon bed facies occurs as light gray, one to two inch beds separated by thin buff-colored argillaceous shale (figure 12). Beds consist of pelloids and are most commonly graded or contain wispy cross-beds. The bases of individual ribbons may display erosional relief; the tops of ribbons are generally planar or gently rippled. Most often, beds are internally barren of body fossils, but a lag of shell hash may occur at the base of some beds. In contrast to the internal paucity of fossils, a fauna rich in numbers but low in diversity litters the bedding planes. The bedding plane assemblage includes leperditid ostracodes (Hermannina alta), spiriferid brachiopods (Howellella vanuxemi), tentaculites (Tentaculites gyracanthus), unidentified trepostome bryozoans and an occasional clam (Laporte, 1967). Algal thrombolites also occasionally occur in the ribbon bed facies. Although they weather the same color as the ribbons, they are discernible by their clotted fabric and the disruption of bedding.

The Manlius ribbon facies is interpreted as representing a shallow subtidal lagoonal environment. Ribbons may be

Figure 12a:
Ribbon bed facies, PAC 5 at Thacher Park. White portion of stick is one foot in length.

Figure 12b:
Thin-section photonegative of ribbon bed facies, PAC 8 at Schoharie. Scale in millimeters.





storm-generated beds which introduced carbonate sediment into an otherwise low energy, sediment starved environment. The prolific population of brachiopods and other body fossils that this facies supports that Manlius ribbons are predominantly subtidal as opposed to the intertidal interpretation presented by Laporte (1967). Manlius ribbons generally do not display any evidence of subaerial exposure (i.e. dessication cracks). However, as aggradation continues beyond the subtidal phase, ribbons grade vertically into intertidal facies exhibiting decreasing bedding thickness and faunas, and increased evidence of scour and fill.

Although slightly different in composition, the ribbon facies described by Demicco (1983) and Read (1983) from the Cambrian Conococheague Formation of Virginia is considered analogous to the Manlius ribbon facies. The presence of dolomite interbeds, instead of argillaceous shale partings may reflect a greater algal influence in the Cambrian setting. Read (1983, p. 4) has noted algal thrombolites and digitate structures in the ribbon facies which supports this hypothesis. Gebelein and Hoffman (1973) have proposed that algae play a major role in the development of microcrystalline dolomite beds, and Avnimelech and Troeger (1982) have discussed the electrochemical flocculation of algae and clay. Therefore, the presence of dolomite in the Cambrian ribbon facies may not reflect a significantly different depositional environment.

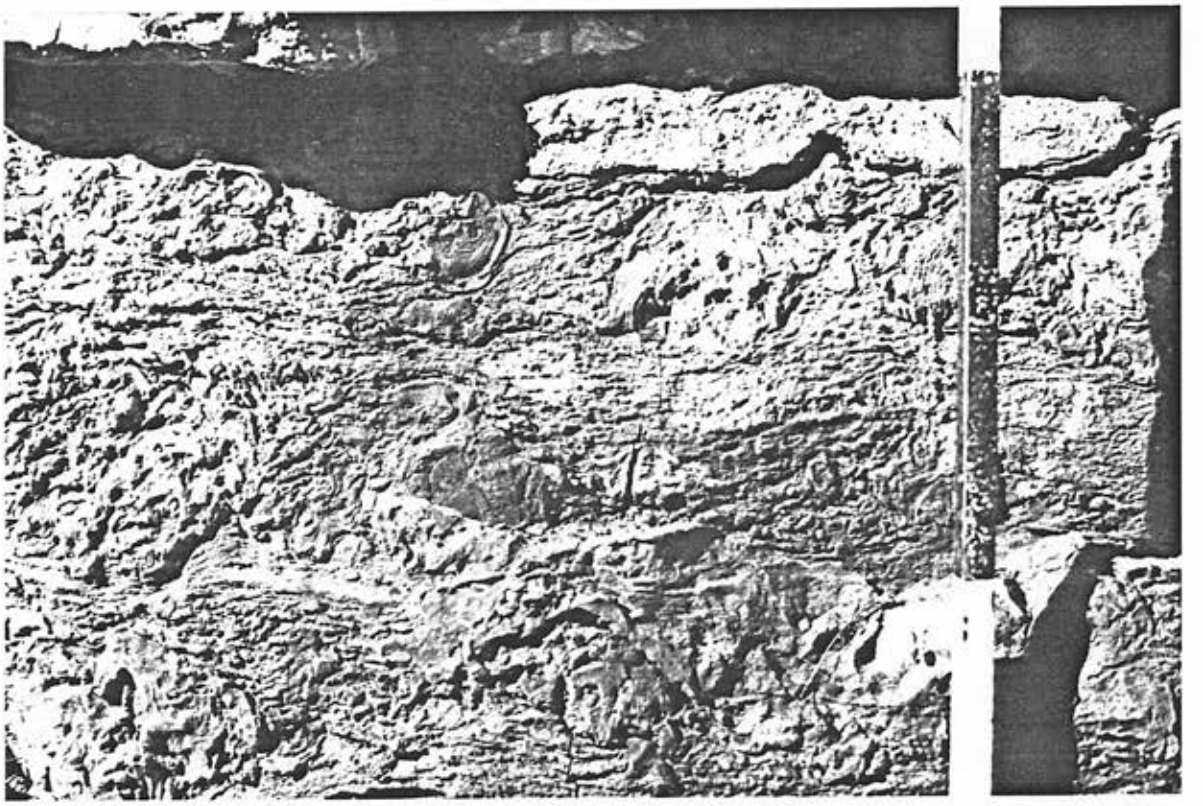
The Manlius biostrome facies occurs as dark gray massive beds ranging from one foot to nearly six feet in thickness (figure 13). The biostromes are comprised of a single species of stromatoporoid, Syringostroma baretti, which forms spherical heads usually less than one foot in diameter. Interstitial pockets in the biostrome contain lime mud and codiacean algae (Laporte, 1963 and 1967) and support a relatively diverse fauna including several genera of ostracodes, loxonematid gastropods, solitary rugosan corals (Spongophylloides sp.) and strophomenid brachiopods (Mesodouvillina varistriata).

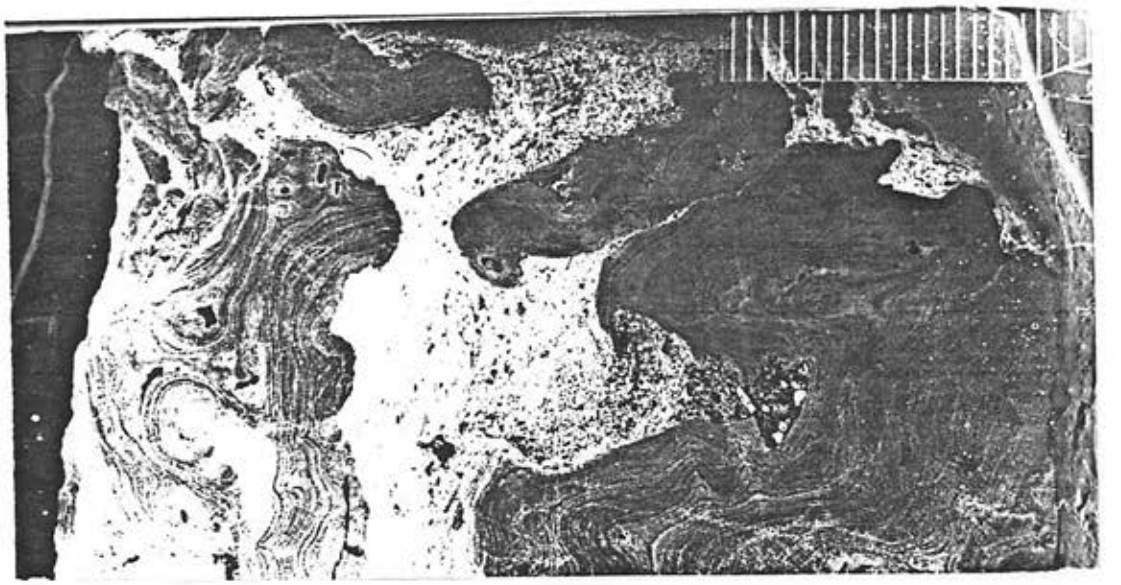
The stromatoporoid biostrome is a key facies in the upper Thacher forming two horizons which provide valuable markers for correlation. The stromatoporoids develop two laterally persistent biostromes, one in PAC 7 extending from Thacher Park to Kingston, a distance of approximately fifty-five miles, and one in PAC 8 extending from Thacher Park to Catskill, a distance of nearly thirty miles. The lateral and vertical gradation of these extensive biostromes into adjacent facies suggests that the buildups were significant contributors of sediment to other Manlius environments.

Manlius biostromes are different from other Devonian stromatoporoid buildups such as the Judy Creek Reef Complex of central Alberta (Wendte and Stoakes, 19) and those of the Pillara Formation of Western Australia (Read, 1973) in that they consist of only one species of stromatoporoid. Laporte (1967, p. 88) suggested that, unlike other species,

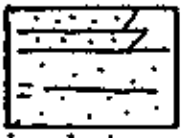
Figure 13a:
Stromatoporoid biostrome facies, PAC 10 at New Salem. Red portion of stick is one foot in length.

Figure 13b:
Thin-section photonegative of stromatoporoid biostrome facies, PAC 7 at New Salem.





Syringostroma barretti may have been tolerant of mud which probably clouded Manlius waters during periods of substrate disturbance.



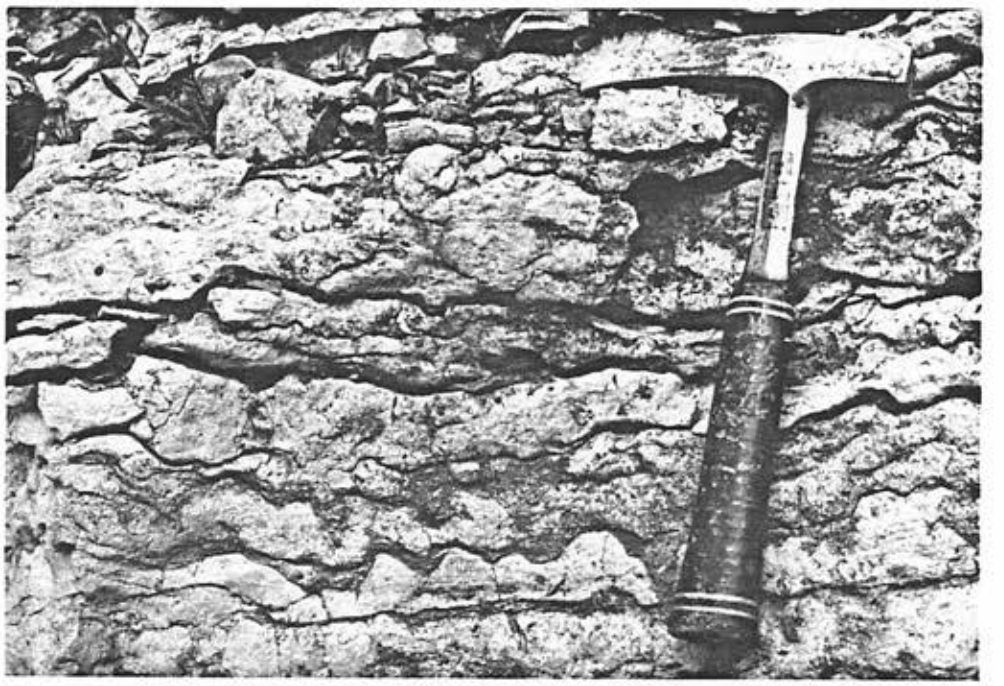
Two types of calcarenite defined by faunas and bedding thickness dominate different stratigraphic intervals in the upper Thacher sequence. Where subtidal portions of PACs are not comprised exclusively of stromatoporoids, Manlius PACs 6-9 are dominated by thin-bedded calcarenite and a bioturbated equivalent. In Manlius PACs 10-11, which contain facies representing the deepest subtidal Thacher environments, medium-bedded calcarenite and its bioturbated equivalent occur in the absence of stromatoporoid biostromes. Although differences in the composition of these calcarenites appear slight, bedding thickness and the lateral and vertical gradation of the calcarenites into other facies provide information leading to the interpreted depth relationships.

Shallow-water calcarenites occur in Manlius PACs 6-9. Thin-bedded and massive bioturbated calcarenite contain ostracodes, gastropods, spiriferid brachiopods (Howellella vanuxemi), and stromatoporoid fragments. The thin-bedded calcarenite occurs as two inch to four inch beds separated by thin, buff-colored shales (figure 14). The bedding thickness and the color of the shale interbeds reflect the laterally gradational relationship between this facies and the ribbon bed facies as seen in Manlius PACs 6 and 8.

Although no significant difference in water depth is

Figure 14a:
Thin-bedded calcarenite facies, top of PAC 7 at North Catskill.

Figure 14b:
Thin-section photonegative of thin-bedded calcarenite facies, PAC 7 at East Kingston Quarry. Scale in millimeters.



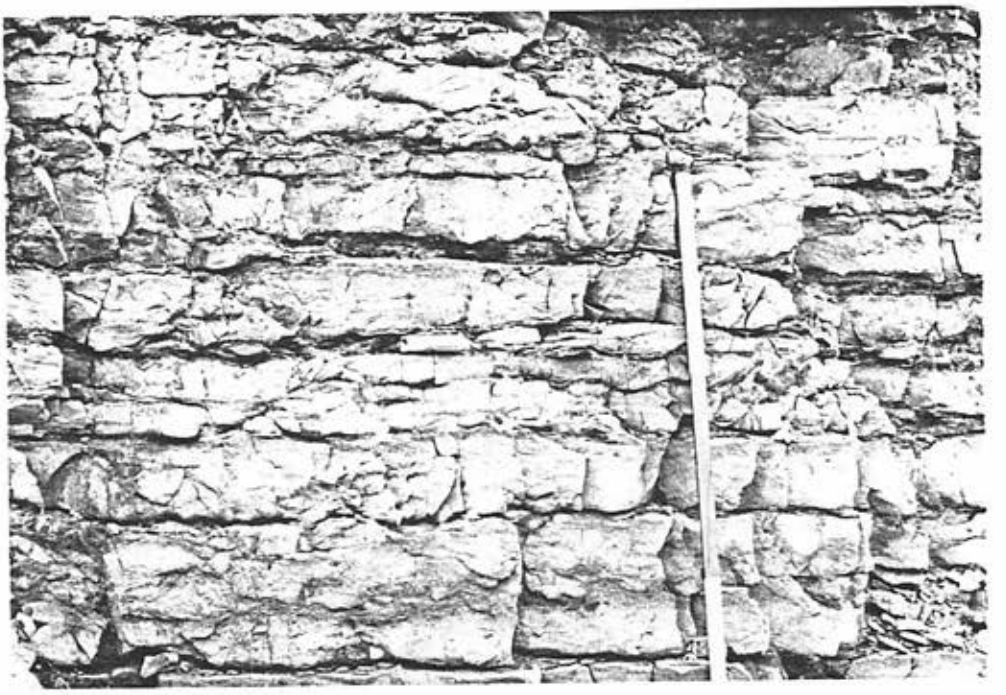
inferred, the lateral facies distribution in Manlius PACs 6 and 8 also suggests some environmental significance to the presence of bioturbation in the shallow calcarenite facies. The bioturbated calcarenite seems to occur atop areas of low relief within the biostrome, whereas the thin-bedded facies is more well-developed at the biostrome margins. Thus, there exists a gradation in the bedding thickness, grain size, and degree of bioturbation from massive bioturbated bedding in the Manlius biostrome environment decreasing progressively through the biostrome margin and into the Manlius lagoonal environment.

One striking difference between the shallower calcarenite facies and the deeper facies is the color and content of shale. The medium-bedded calcarenite, interpreted as the deepest Manlius facies, occurs as five inch to eight inch beds often separated by unfossiliferous black shales up to two inches in thickness (figure 15). At localities where well-developed sequences of this facies are preserved (i.e. Schoharie) the medium-bedded calcarenite displays internal sedimentological changes that reflect shallowing-upward conditions. The basal portion of the sequences contain the thickest shales which decrease in thickness upward as carbonate beds amalgomate. These sequences are capped by massive bioturbated beds up to eighteen inches thick.

The most significant difference in composition between this facies and the shallower calcarenites is the addition of the strophomenid brachiopod, Mesodouvillina varistriata, along with the occurrence of small crinoid ossicles (figure

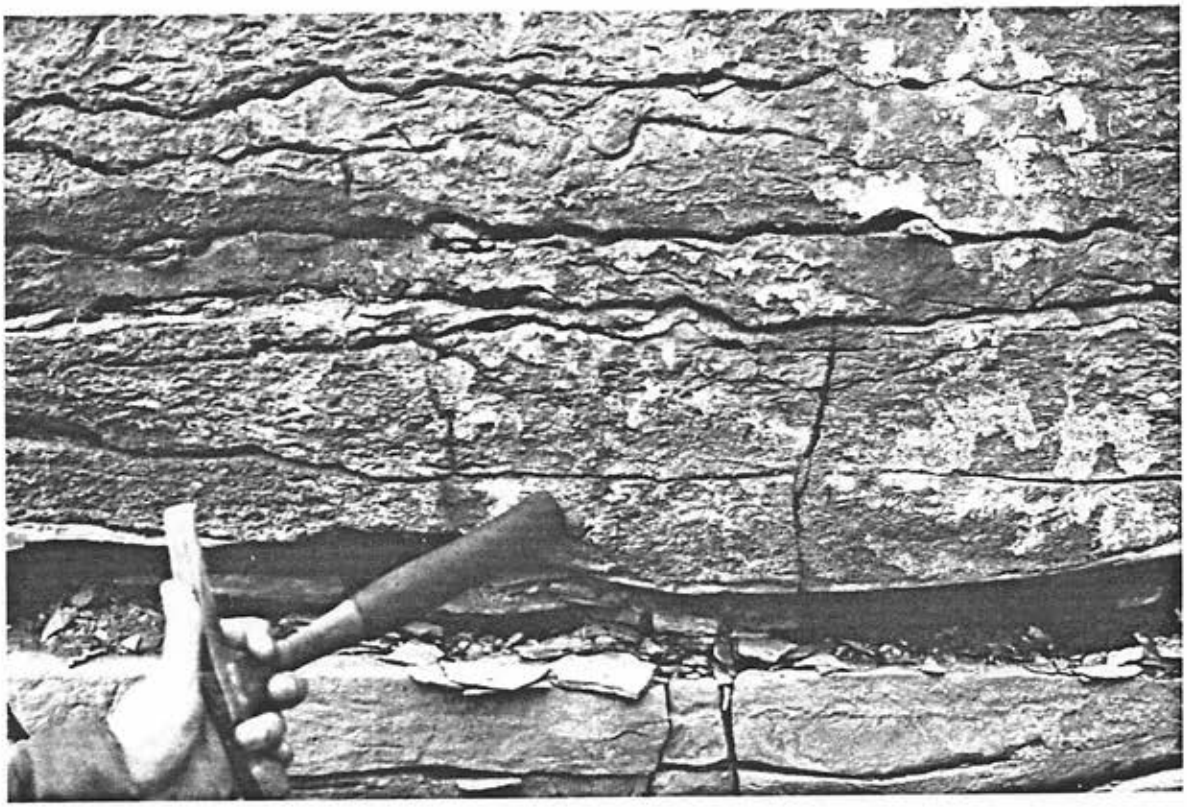
Figure 15a:
Medium-bedded calcarenite facies, PAC 10 at Callanan Quarry. Stick is divided into one foot increments.

Figure 15b:
Thin-section photonegative of medium-bedded calcarenite facies, PAC 11 at Cherry Valley. Scale in millimeters.



16). This is of significance, because Mesodouvillina is found at the top of the Thacher as far south as Catskill and is evidence that the medium-bedded facies extends farther south than earlier workers (i.e. Davis, 1953; Rickard, 1962) have contended. This suggests that the medium-bedded calcarenite facies was not a laterally transitional facies to the Coeymans Formation, but that it may have extended over much of the study area during late Thacher time only to be removed by subsequent pre-Coeymans erosion.

Figure 16:
Strophomenid-bearing medium-bedded calcarenite facies, top of PAC 11 at Schoharie.



MANLIUS PACs

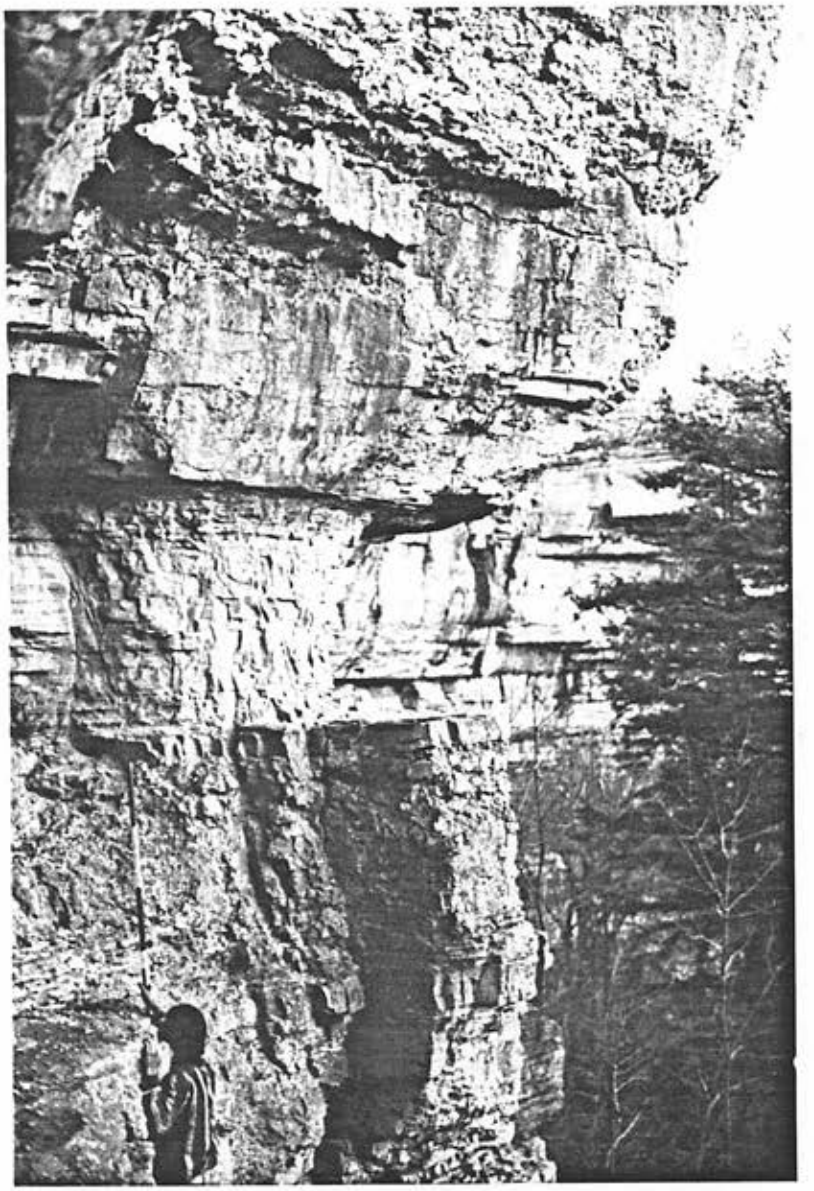
Laporte (1967), recognizing that the Manlius Formation is divisible into subtidal, intertidal and supratidal facies, interpreted the repetitive vertical succession of these facies as a complex mosaic resulting from the irregular migration of Manlius subenvironments. In contrast, this study suggests that the vertical repetition of facies patterns in PACs is an ordered response of Manlius subenvironments to allogenic processes, repeated small-scale base-level rises.

At each of 14 localities in central New York and the Hudson Valley, the Thacher Member of the Manlius Formation is completely divisible into PACs (figure 7). Each Manlius PAC has been assigned a number according to its fixed position within the vertical succession of cycles, so that at every locality where it is preserved, a correlative PAC retains the same number. The focus of this study is on PACs in the upper half of the Thacher Member (Manlius PACs 6-11). For discussion of PACs in the lower Thacher sequence, refer to Saraka (1984).

General Characteristics of Upper Thacher PACs

Two types of PACs occur in the upper Thacher sequence. Manlius PACs 6-9 are of the first type which consists of shallow subtidal through supratidal facies. A typical subtidal-to-supratidal PAC is PAC 8 at John Boyd Thacher Park (figure 17). At this locality, PAC 8 is 9 feet thick. At

Figure 17:
Subtidal-to-supratidal PAC: PAC 8
at John Boyd Thacher State Park.



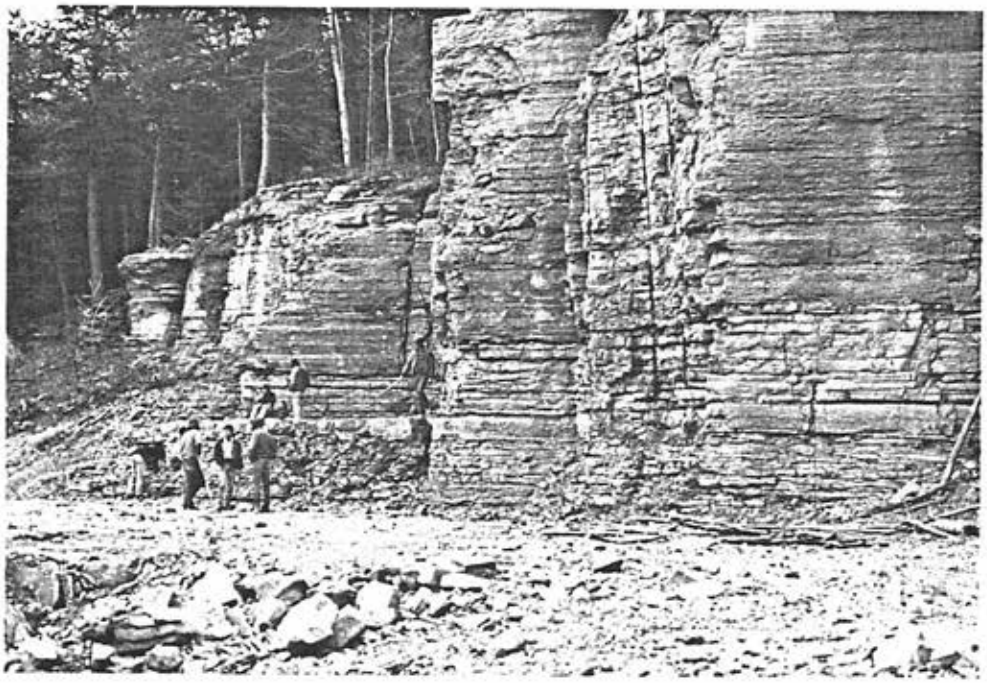
its base, PAC 8 contains 1 foot of thin-bedded calcarenite containing abundant gastropods and ostracodes. This calcarenite is overlain by a well-developed 4 feet thick stromatoporoid biostrome. The biostrome is capped by a 6 inch lime mud bed which marks the transition from subtidal to intertidal facies. Directly overlying the lime mud bed is 6 inches of fine-grained, laminated ostracode calcarenite which records aggradation of sediment into the lower intertidal zone. Above the ostracode calcarenite there are 4 feet of planar algal laminites, the top 6 inches of which are polygonally mudcracked. The mudcracked laminites represent high intertidal to supratidal conditions and completes the series of facies from subtidal through supratidal typical of this kind of PAC.

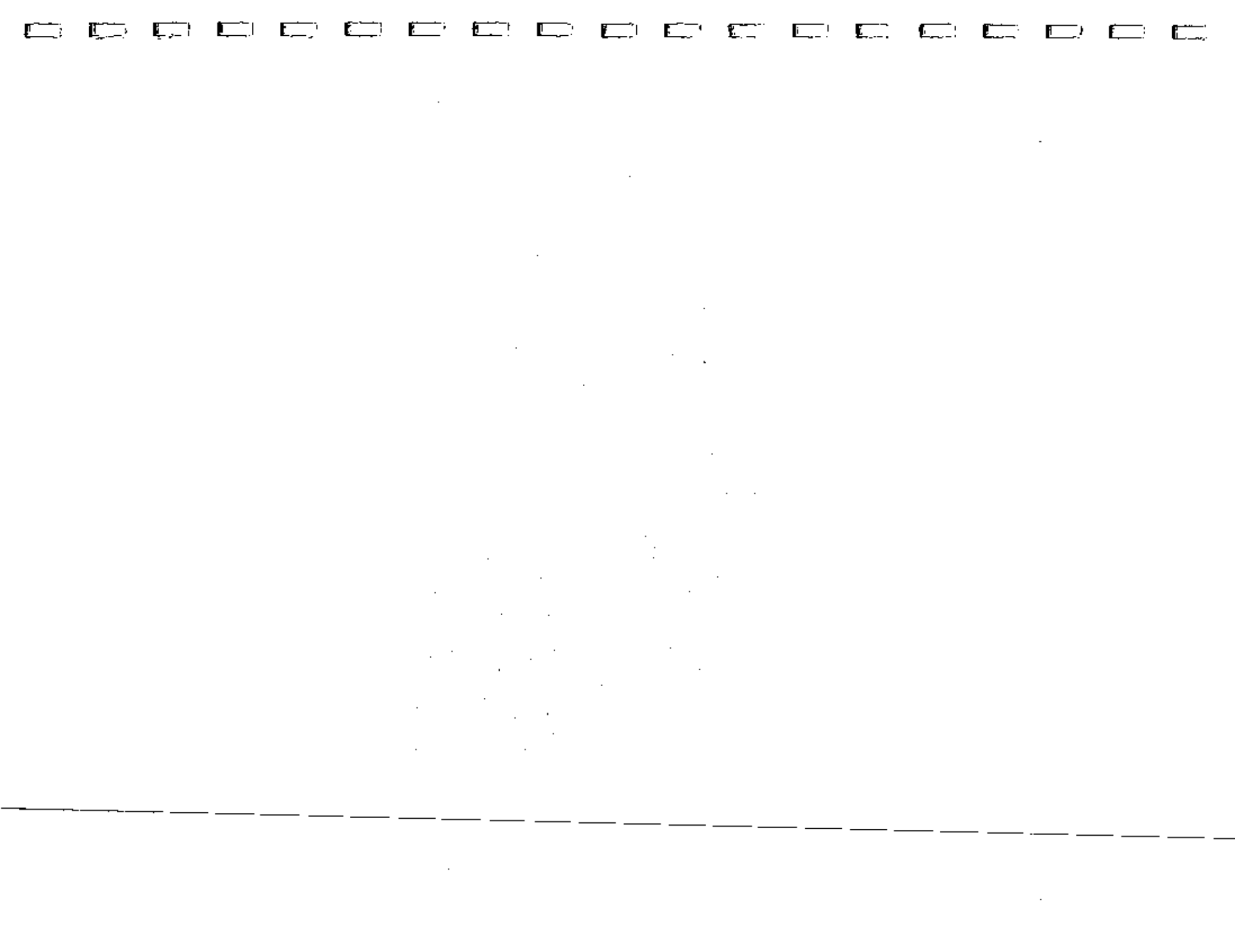
In contrast to PACs 6-9, PACs 10 and 11 consist entirely of subtidal facies. PAC 10 at the Schoharie locality is a typical subtidal PAC (figure 18). At Schoharie, PAC 10 is 6.5 feet thick and is made up of 5 feet of medium-bedded calcarenite containing strophomenid brachiopods overlain by 1.5 feet of massive bioturbated calcarenite containing stromatoporoid fragments. This facies sequence indicates aggradation from relatively deep subtidal conditions to shallow subtidal conditions.

PACs in Columnar Section

At its type section, John Boyd Thacher State Park, the Thacher Member of the Manlius Formation is divisible into 11 PACs. These PACs are organized into two sequences. PACs 1-5

Figure 18:
Fully subtidal PAC: PAC 10 at Schoharie





comprise the lower sequence which is dominated by intertidal facies (Saraka, 1984). The upper sequence, PACs 6-11, is dominated by subtidal stromatoporoid-rich facies and is the focus of this study.

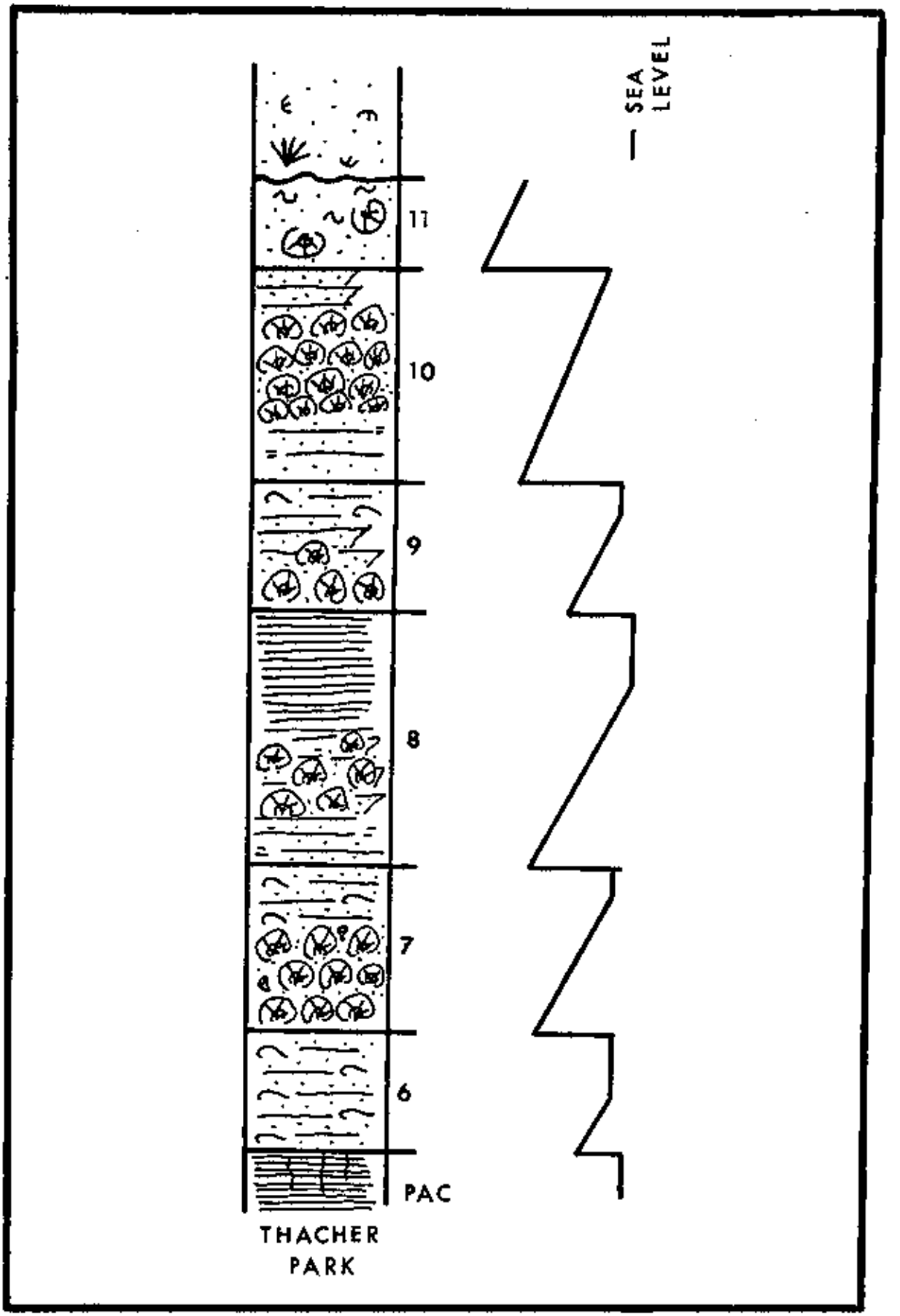
Deposition of the upper Thacher sequence was affected by both allogenic and autogenic processes which can be graphically represented by a relative water depth curve (figure 19). Rapid base-level rises which produce PAC boundaries are allogenic events and are represented by horizontal deflections of the curve. The magnitude of the change in sea-level is proportional to the size of the deflection. Gradual vertical aggradation of facies, an autogenic process, is indicated by diagonal lines. Vertical lines indicate the amount of stratigraphic accumulation attributable to gradual subsidence.

PAC 6, the basal cycle of the upper sequence, is a single-environment PAC (Saraka, 1984, p. 18) which consists entirely of current-laminated ostracode calcarenite. Shallowing in PAC 6 is indicated by progressive thinning and increased planar nature of individual laminae.

PAC 7 is 5.5 feet thick and contains one of four stromatoporoid horizons which occur in the Manlius at Thacher Park. Interbedded stromatoporoids and fossilifierous thin-bedded calcarenite form a sequence about four feet thick. This stromatoporoid facies is capped by 1.5 feet of current-laminated ostracode calcarenite.

PAC 8 (illustrated earlier) is 9 feet thick and displays aggradation of sediment from subtidal through supratidal con-

Figure 19:
Stratigraphic column and interpreted relative water depth curve for upper Thacher sequence at the type section, John Boyd Thacher State Park.


SEA LEVEL
11
10
9
8
7
6
PAC
THACHER PARK

ditions. The subtidal portion of this cycle, like that of PAC 7, is dominated by stromatoporoid facies. The PAC 8 biostrome, which is approximately 3 feet thick, is capped by a 4 foot thick sequence of algal laminites. This laminite horizon is the waterlime datum of Rickard (1962, figure 2) at the Thacher type section.

PAC 9 is 4 feet thick and contains the third stromatoporoid horizon present at Thacher Park. PAC 9 stromatoporoids occur interbedded with medium- to thin-bedded calcarenites which represent subtidal conditions in PAC 9. Two feet of ostracode calcarenite accumulated over this third stromatoporoid horizon indicating shallowing upward to the intertidal zone.

PAC 10 is 7.5 feet thick and contains the fourth stromatoporoid horizon. At its base, PAC 10 contains 3 feet of medium-bedded calcarenite with shale interbeds. The PAC 10 biostrome, which is 4 feet thick, occurs at the top of the PAC. Thus, PAC 10 deposition was terminated under subtidal conditions.

PAC 11, which is 3.5 feet thick, is another single-environment PAC. PAC 11 consists of massive, bioturbated, crinoidal and strophomenid-bearing calcarenite. This lithosome was considered to be a Coeymans facies by Rickard (1962, p. 122). It is included in the Manlius by this author because of the presence of strophomenids and the absence of Gypidula coeymanensis. The PAC 11 strophomenid coquina-like facies is directly overlain by the coarse crinoidal and