

figure 20

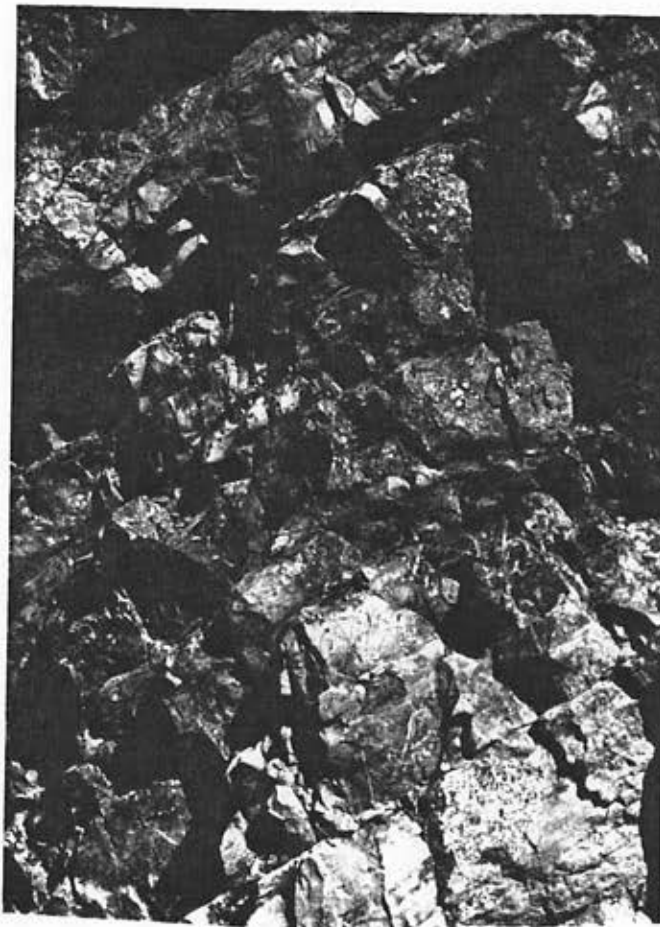


figure 21



Figure 22:

Field photograph of the PAC 6-PAC 7 boundary at Climax (locality 48). Biostromal stromatoporoids abruptly overlie laminated calcarenites (PAC stick is 4 feet long).

Figure 23:

Similar facies relationship is observed at the PAC 6-PAC 7 boundary at New Baltimore (PAC stick is 4 feet long).



figure 22

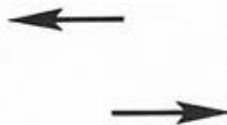


figure 23

Figure 24:

Field photograph of the PAC 6-PAC 7 boundary at Thacher Park (locality 59). Thick-bedded calcarenites with shale interbeds abruptly overlie laminated calcarenites (PAC stick is 4 feet long).

Figure 25:

Field photograph of the PAC 6-PAC 7 boundary at Schoharie. PAC stick (4 feet) rests on the boundary.



figure 24



figure 25

outcrops, from South Catskill to Thacher Park (6 localities in approximately a 25 mile distance), reveals the same lithologic relationship; the cryptalgal stromatolites of PAC 5, often mud-cracked and dolomite rich, are abruptly succeeded by the laminated calcarenites of PAC 6. Although an abrupt facies change is observed at the Kingston localities (figure 26) and at Schoharie (figure 27), it is not the same lithologic relationship encountered at that boundary from South Catskill to Thacher Park (figure 28) and, therefore, cannot be identified as the same boundary by simple lateral tracing of facies. However, analysis of the PAC 5-PAC 6 boundary, from the relative water depth curve at South Catskill, reveals that the first boundary below the most significant datum (PAC 6-PAC 7 boundary) is a relatively minor deepening event and that the ensuing PAC is thin. Comparison of the relative water depth curve to the depositional patterns at the Kingston localities, Schoharie locality and South Catskill through Thacher Park reveals the same genetic style of deposition. Since the depositional pattern can be matched at all localities by tracing lithologies or comparing relative water depth curves, this interval is interpreted to be correlative.

The stratigraphic correlations illustrated among the Hudson Valley localities (figure 29) have been conducted through utilization of the PAC approach to chronologic correlation. These interpretations which incorporate the lateral tracing of individual lithologies between closely

Figure 26:

Field photograph of PAC 4 through PAC 6 at East Kingston (locality 25). Note the abrupt facies change at the PAC 5-PAC 6 boundary (PAC stick is 4 feet long).

Figure 27:

Field photograph of PAC 5-PAC 6 boundary at Schoharie (arrows indicate boundary, lens cap is for scale).



figure 26



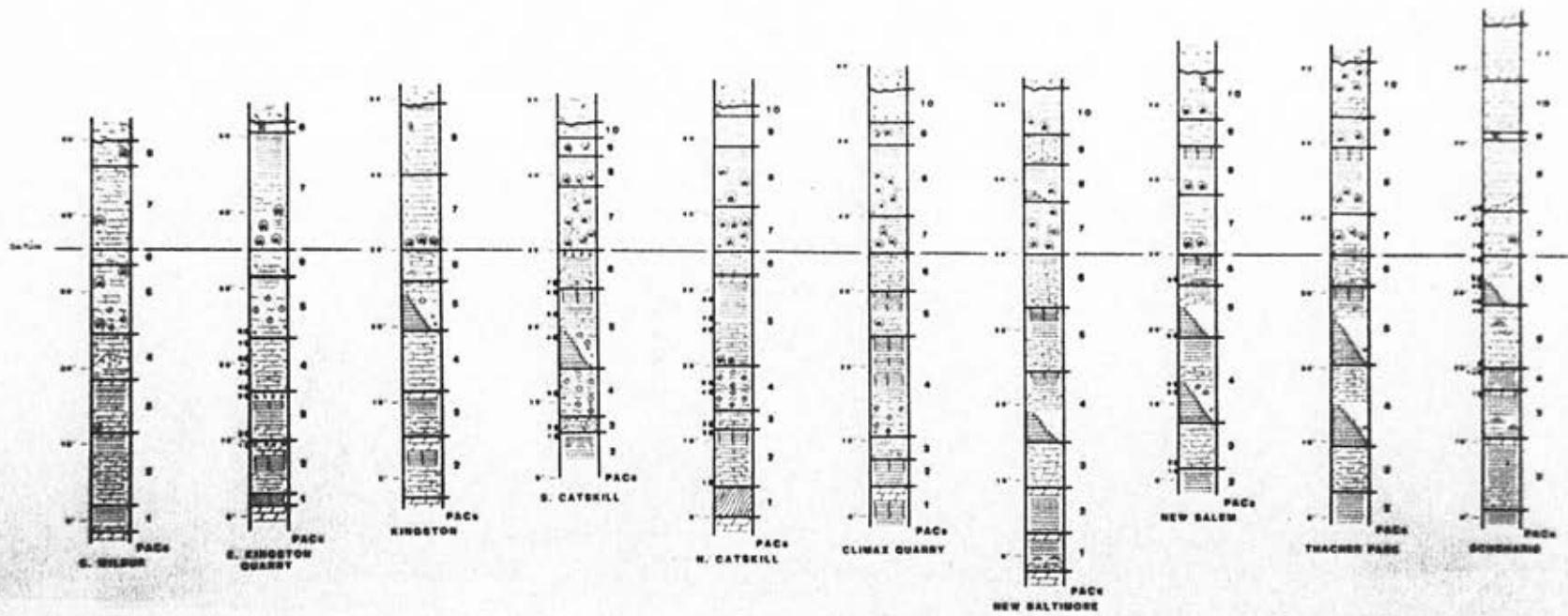
42

figure 27



Figure 28:  
Field photograph of the PAC 5-PAC 6 boundary at South Catskill (locality 43). Comparison of this facies change across the PAC 5-PAC 6 boundary, from South Catskill to Thacher Park, exhibits a pronounced difference in lithologic relationships at East Kingston (figure 26) and Schoharie (figure 27).

Figure 29:  
Correlated columns encompassing the  
entire study area. Columns are hung on  
the major correlation line (PAC 6-PAC 7  
boundary).



spaced sections, and the comparison of relative water depth curves permit detailed paleoenvironmental analysis of individual PACs throughout the study area.

#### PACs, Paleoenvironments and Paleogeography

Beside providing a detailed paleoenvironmental analysis of facies within a PAC, the PAC approach to stratigraphy permits paleotopographic reconstruction of individual PACs based upon the occurrence of facies and, therefore, depositional environments that were in existence prior to each punctuation event. In order to simplify depositional history, facies have been classified into the three sub-environments characteristic of the Manlius Formation (sub-tidal, low intertidal, high intertidal/low supratidal) without regard to minor lateral facies variations.

Data gathered from stratigraphic measurements is utilized to construct PAC "slices". Each PAC slice is constructed utilizing the upper PAC surface as the topographic datum and the lower PAC surface as the lower limit of that specific PAC. The enclosed depositional history is recorded according to actual stratigraphic thicknesses measured at various localities; no corrections have been incorporated to account for differential rates of subsidence.

To demonstrate the lateral variation of facies within a PAC, PAC 5 is traced from Kingston to Schoharie, New York (figure 1). Five localities are chosen as representative columns for the following areas: Kingston; Catskill; New Baltimore; Thacher Park; and Schoharie.

In the Kingston region PAC 5 consists almost entirely of subtidal facies and is interpreted to represent a single-environment PAC. Bioturbated, nodular, shale-rich calcarenites (figure 30) are the dominant facies throughout this region. Occasional stromatoporoid-rich beds or micritic, lime ribbon interbeds are observed as minor variations within the calcarenites.

Approximately 20 miles north of Kingston, in the Catskill region, PAC 5 occurs as a multiple-environment PAC. Here subtidal facies are dominantly micrite-rich lime ribbons (figure 31). Some lateral variation of contiguous facies is observed at North Catskill (figure 32); a stromatoporoid-rich biostrome grades laterally into lime ribbons. Occurrence of these two facies at the same stratigraphic horizon yields a relative depth relationship between two lithologically distinct facies. This relationship suggests that depositional environments, with respect to relative water depth, for the stromatoporoid-rich beds and the lime ribbons are essentially the same. Aggradation through laminated calcarenites and dolomite rich cryptalgal stromatolites indicates that much of PAC 5 deposition was at or near sea-level.

In the New Baltimore region, approximately 15 miles north of Catskill, PAC 5 is recognized as a multiple-environment PAC. Because of a topographic high that existed from PAC 4 deposition, the ensuing punctuation event that produced the PAC 4-PAC 5 boundary only created low

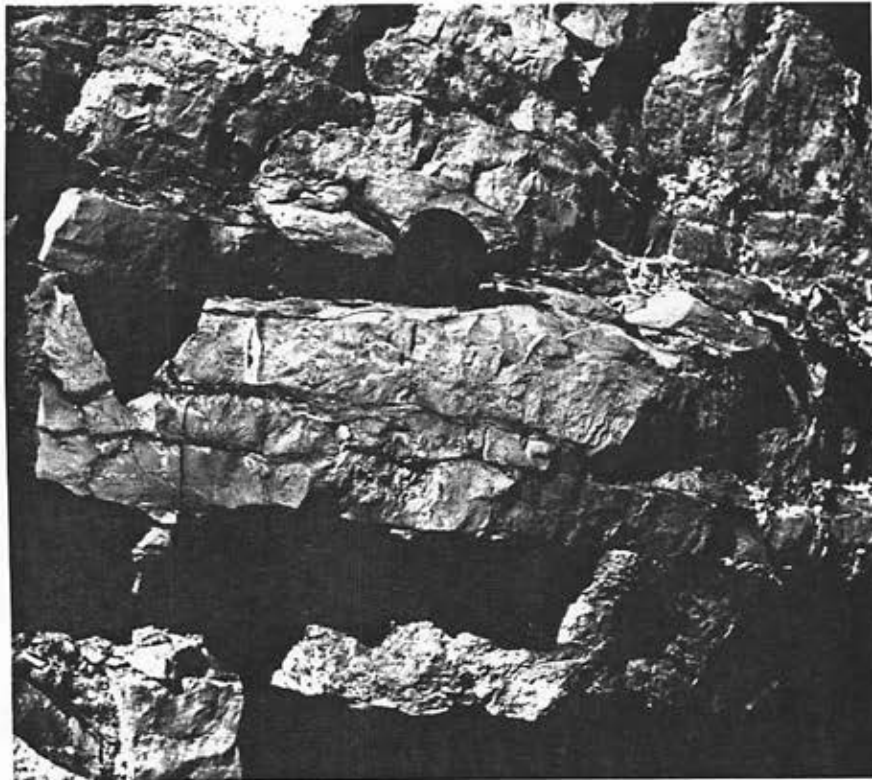


Figure 30:  
Close-up of PAC 5 at East Kingston (locality 25). Nodular, bioturbated, shale-rich calcarenites are the typical lithologic facies that occur in the subtidal of PAC 5 throughout the Kingston region (lens cap is for scale).

Figure 31:

Close-up of PAC 5 at South Catskill (locality 43). Lime ribbons dominate subtidal PAC 5 at South Catskill (PAC stick is 4 feet long).

Figure 32:

Field photograph of PAC 5 at North Catskill (locality 44-B). Note lateral change of facies from biostromal stromatoporoids to lime ribbons in the subtidal of PAC 5 (base of PAC stick).

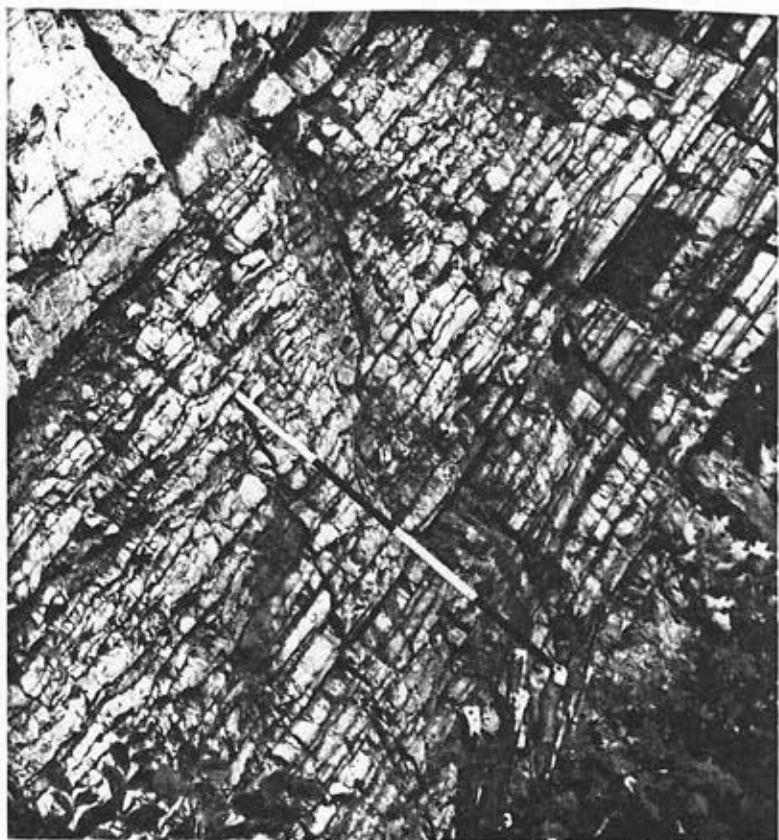


figure 31

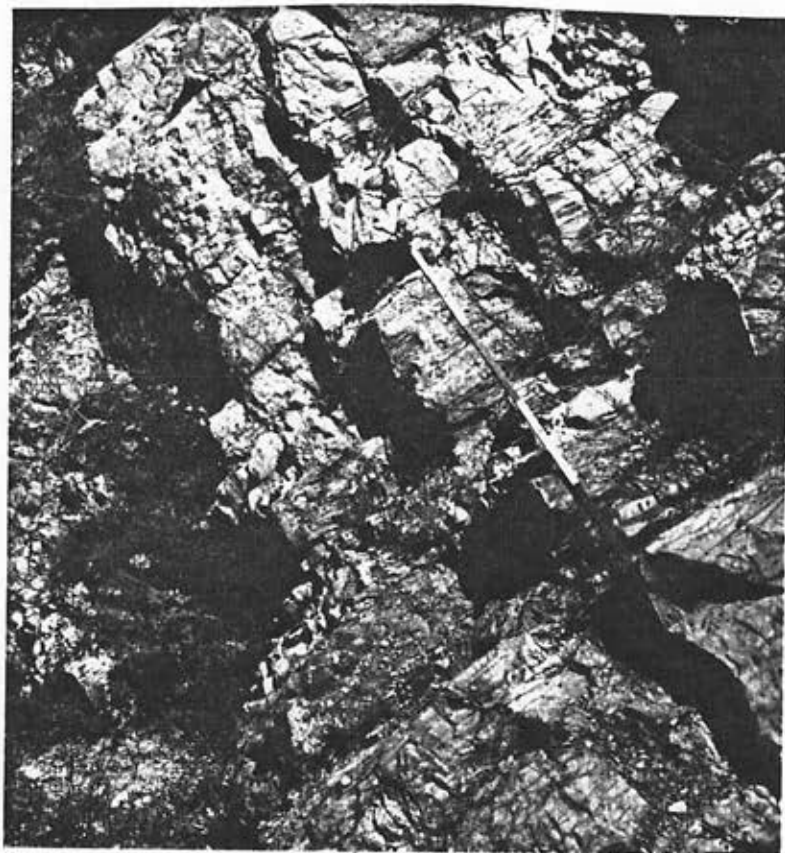


figure 32

intertidal conditions throughout the New Baltimore region. Facies of PAC 5 are laminated calcarenites and mud-cracked, cryptalgal stromatolites suggesting that much of the New Baltimore region attained near sea-level conditions (figure 33).

Much of PAC 5 in the Thacher Park region is dominated by subtidal facies but the addition of intertidal and low supratidal facies makes PAC 5 a multiple-environment PAC (figure 34). Here typical subtidal facies include the micrite-rich, lime ribbons with shale interbeds previously described by Rickard (1962) as thin-bedded Thacher facies (figure 35). Many of the lime ribbon bedding surfaces contain a recurring faunal assemblage that is rich in Howellella brachiopods, Tentaculites, and leperditid ostracods. Comparison of the laminated calcarenites and cryptalgal stromatolites from the Thacher Park region to the same facies in New Baltimore and Catskill reveals a thinning of low intertidal and high intertidal/low supratidal environments toward Thacher Park. Dominance of subtidal facies at Thacher Park suggests that water depth in this region was originally greater than at Catskill and New Baltimore.

PAC 5 at Schoharie (figure 36) is completely subtidal; calcarenites (some exhibiting cross-bedding) that are rich in bryozoans, gastropods and thrombolitic algae indicate "open" marine conditions. Lack of intertidal and low supratidal facies indicates that the deepening trend of facies north and west of New Baltimore continued into the

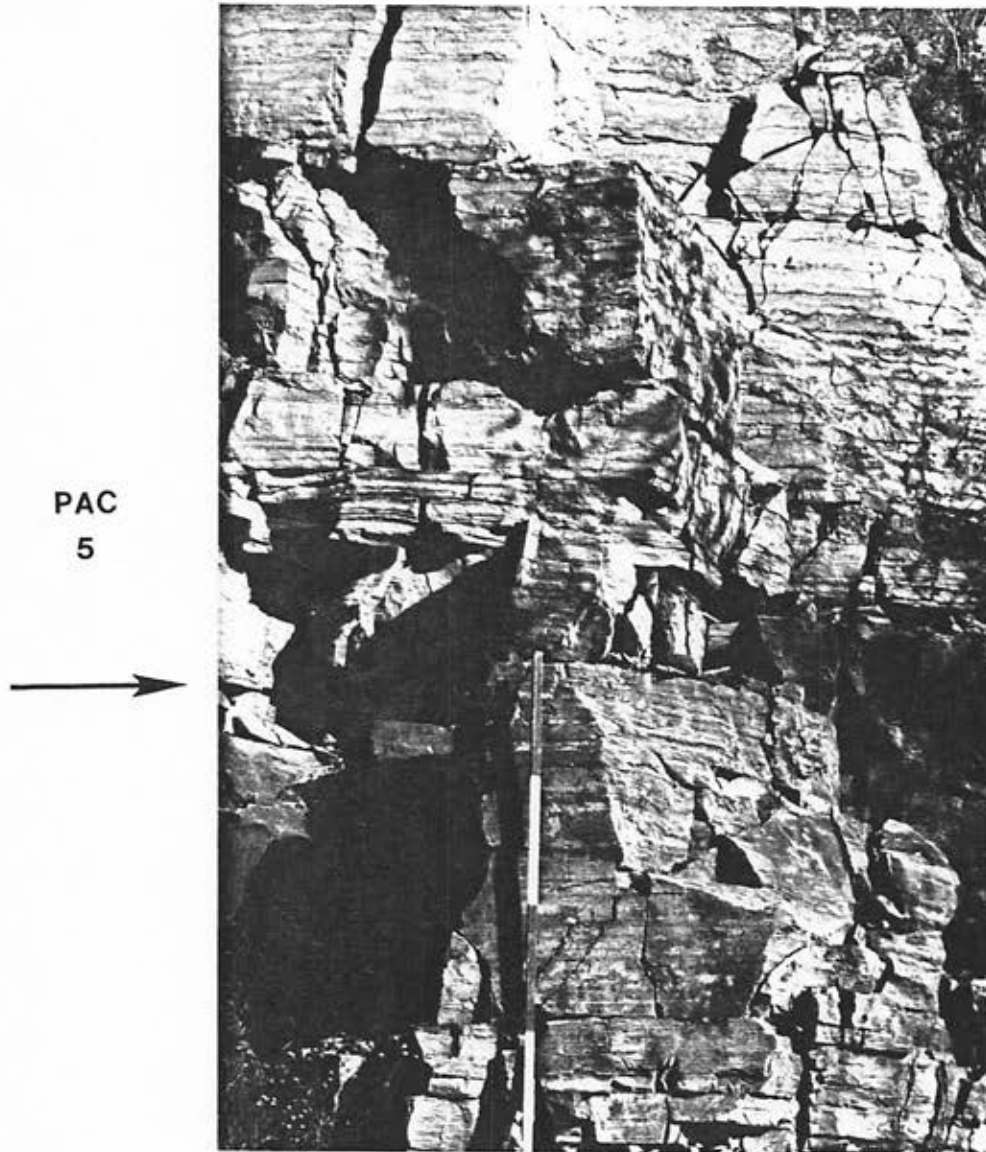


Figure 33:  
Field photograph of PAC 5 at New Baltimore (locality 53). Facies composition of PAC 5 suggests that most of PAC 5 deposition took place near sea-level (PAC stick is 4 feet long).

Figure 34:

Field photograph of PAC 5 at Thacher Park (locality 59). This multiple-environment PAC shows a complete (subtidal through supratidal) shallowing-upward motif (PAC stick is 4 feet long).

Figure 35:

Close-up of subtidal facies of PAC 5 at Thacher Park (PAC stick is 4 feet long).



figure 34

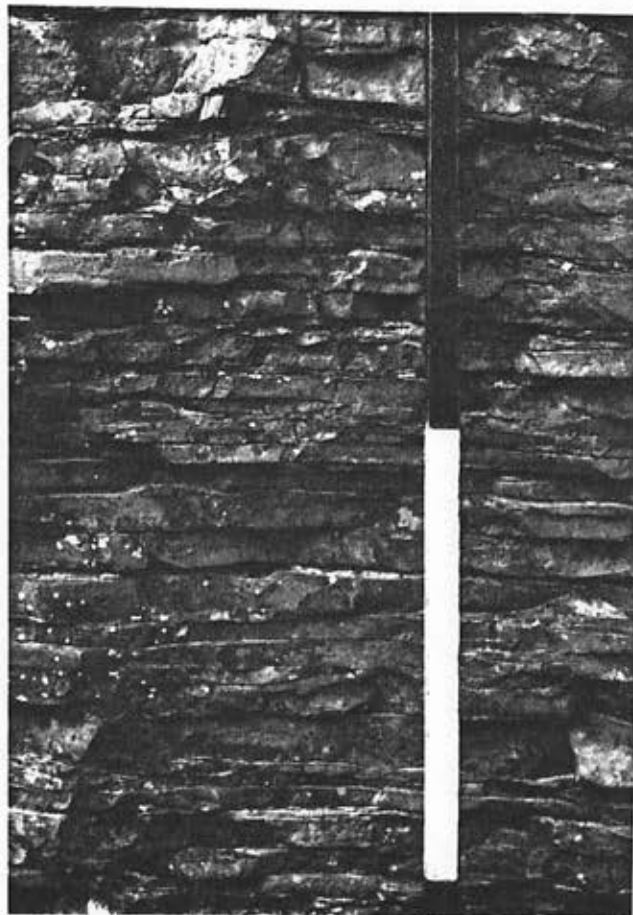


figure 35



Figure 36:  
Close-up of subtidal facies of PAC 5 at  
Schoharie (PAC stick is 4 feet long).

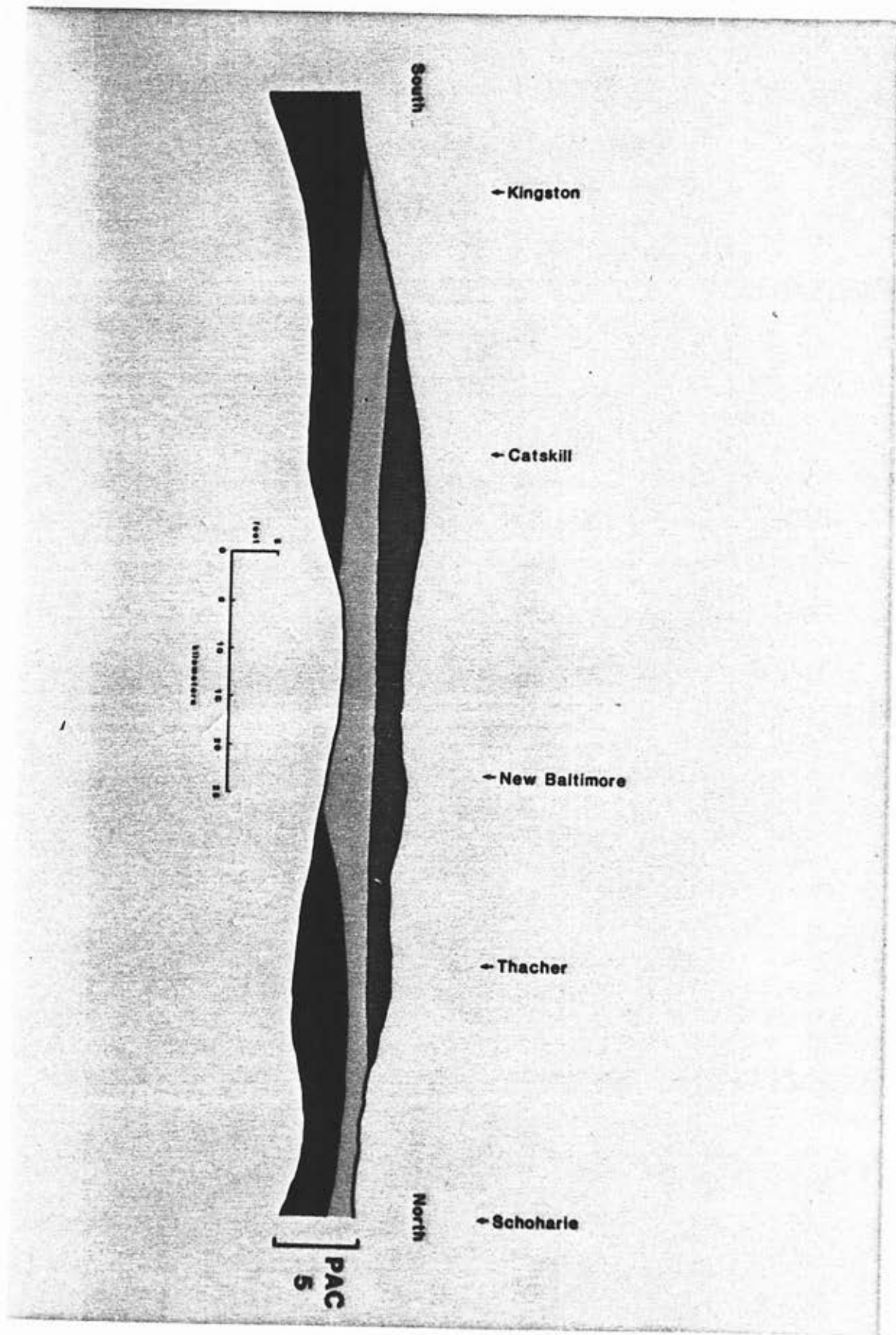


Figure 36:  
Close-up of subtidal facies of PAC 5 at  
Schoharie (PAC stick is 4 feet long).

Schoharie region.

This lateral tracing of PAC 5 represents a restored depositional sequence complete with a topographic profile of the Manlius Sea, from Kingston to Schoharie, New York, at the time of the punctuation event that produced the PAC 5-PAC 6 boundary (figure 37). Within PAC 5 laterally adjacent facies represent contiguous paleoenvironments; coeval facies of the same general environment (e.g. subtidal) often vary in lithologic characteristic due to autogenic processes. Facies response to topographic highs and lows, current restrictions, variable salinities and other processes is most pronounced in the subtidal environment.

Figure 37:  
Slice reconstruction of PAC 5 (dark blue  
is subtidal, light blue is low intertidal,  
and yellow is high intertidal/low supra-  
tidal).



## MANLIUS DEPOSITIONAL HISTORY

Introduction

PAC analysis of the Thacher Member of the Manlius Formation revealed that the Thacher Member consists of 11 PACs. Each PAC is an independent depositional entity that represents the paleoenvironmental conditions that prevailed during a specific time in Thacher depositional history. Therefore, in contrast with traditional gradualistic interpretation (e.g. Laporte, 1967), the PAC interpretation presents Thacher depositional history as a discontinuous series of events producing discrete facies units that accumulated in an ordered response to allogenic processes.

A Stratigraphic Analogue: The Pleistocene and Holocene of Florida

Perhaps the best Recent stratigraphic analogue to be compared with the discontinuous series of facies that comprise the Manlius Formation in the Hudson Valley is the Pleistocene and Holocene of south Florida. Perkins (1977), and Enos and Perkins (1979) have analyzed the sediment and facies deposits of south Florida and concluded that these deposits were directly affected by allogenic (eustatic) events.

Enos and Perkins (1979) reviewed the most recent sediments (Holocene) of Florida Bay that are accumulating as a result of the latest eustatic sea-level rise. This most recent accumulation, which is from 0-5 meters thick, contains the same genetic patterns of deposition that are

present in Thacher PACs: 1) the Holocene-Pleistocene contact is an almost planar surface of the Pleistocene Key Largo Limestone on which Holocene sediments are disconformably accumulating; 2) after an initial rapid rise in sea-level, base-level conditions stabilized and sediments began to accumulate through vertical and lateral accretion; and 3) autogenic mechanisms affect lithofacies distribution and unit thickness throughout Florida Bay. Enos and Perkins (1979) contend that if the present depositional trend continues without significant increase in the rate of sea-level rise, Florida Bay will aggrade to the supratidal environment, thereby completing the asymmetric cycle.

Perkins (1977) analyzed the five eustatically controlled subunits that comprise the Pleistocene Key Largo Limestone, which unconformably underlies the Florida Bay sediments. The stratigraphic analysis of the Pleistocene of south Florida is particularly relevant to this study because of the analogies that may be drawn between the depositional mechanisms that governed Pleistocene deposition in south Florida and the mechanisms that governed Thacher deposition in eastern New York.

In his study of south Florida, Perkins (1977) suggested that previous geologists tended to "group" lithologically similar stratigraphic sequences into single depositional entities. However, Perkins noted that closer observation of the depositional entities revealed possible discontinuity surfaces, which he attributed to eustatic sea-level changes,

could be utilized to subdivide an assumed depositional entity into a series of discrete, correlatable depositional units (Perkins, 1977).

Although the five Pleistocene depositional units of south Florida are lithologically similar, each is bounded by discontinuity surfaces that are produced by sea-level rises and falls and exhibits an internal variation of lithologies. The mechanisms that affect facies distribution and the thickness of depositional units are interpreted to be autogenic. Primary controls on facies distribution and unit thickness includes: 1) organic productivity, often controlled by such variables as temperature fluctuations, turbidity, nutrient depletion, and salinity fluctuations; 2) mechanical redistribution, transport and reworking of sediment; 3) pre-existing topographies which include topographic highs that produce restricting conditions, limiting carbonate production, and topographic depressions that allow more room for sediment accumulation; and 4) contemporary topographies, which are indirectly controlled by pre-existing topographies, often form accentuated topographic highs and lows due to varied rates of carbonate production (Perkins, 1977).

Even though the Pleistocene discontinuities were produced by sea-level rises and falls and Thacher PAC boundaries were produced by a series of sea-level rises, there are many genetic similarities in depositional patterns. Such similarities include: 1) each Thacher lithologic unit

(PAC) is bounded by discontinuity surfaces; 2) each Thacher PAC is lithologically similar (in varying degrees) to other Thacher PACs; and 3) each PAC exhibits variations in facies distribution and unit thicknesses that are interpreted to be a result of environmentally autogenic processes (e.g. organic productivity, mechanical redistribution, etc.).

Perhaps the most striking similarity between studies of the Pleistocene of south Florida and the Thacher of eastern New York is that both studies identify a similar depositional unit that may be utilized for stratigraphic interpretation. Although he does not directly address the issue of the formation as "the" unit of stratigraphic interpretation, Perkins makes an important observation about the sequences that comprise the Pleistocene of south Florida:

Stratigraphic sequences characterized by lithologic similarity should not necessarily be assumed to represent single depositional entities but should be examined closely for the possible presence of discontinuity surfaces (Perkins, p. 187, 1977).

These "special" discontinuity surfaces, which are controlled by eustatic sea-level conditions, often cut across traditional stratigraphic boundaries (Perkins, 1977).

Goodwin, Anderson and their graduate students observed a repeated occurrence of discontinuity surfaces (PAC boundaries) that transect traditional stratigraphic boundaries throughout the Helderberg Group of New York. Furthermore, Anderson, Goodwin and Sobieski (1984) conclude that the occurrence of such "discontinuity-bounded" depositional units (PACs) suggest that the concept of the

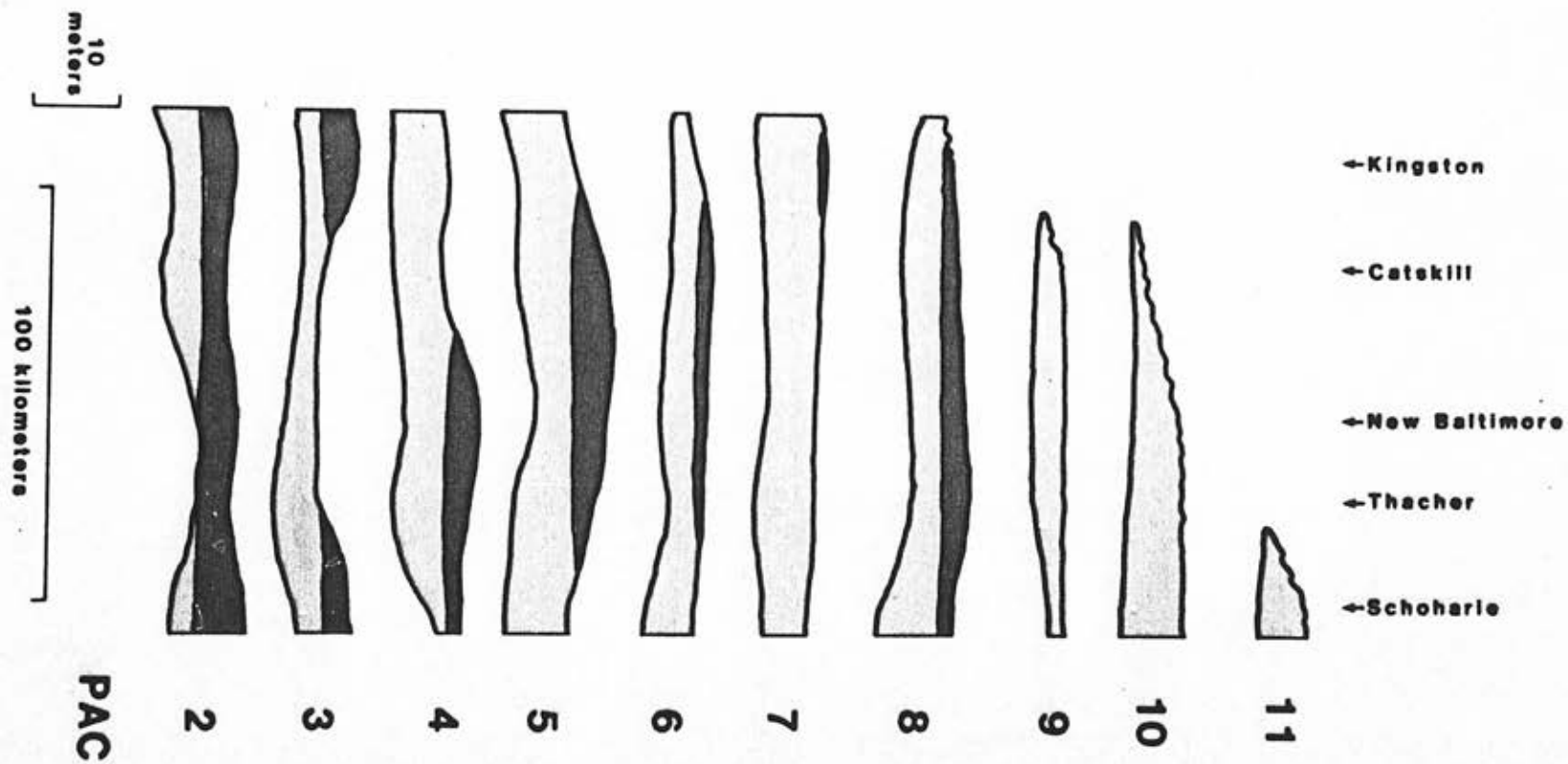
formation as the fundamental unit of stratigraphic interpretation may need to be revised if the stratigraphic record accumulated episodically on a small scale. Certainly the results of this study of the Thacher Member as well as the interpretation of Perkins suggest that thin, time-stratigraphic, discontinuity-bounded units are more genetically fundamental in the interpretation of stratigraphic history than the traditional, thick, diachronous units such as members and formations.

#### Stratigraphic History

Utilization of the PAC as the fundamental unit of stratigraphic interpretation indicates that Thacher depositional history is not represented as a single, continuous depositional entity. Instead, it suggests that deposition during Thacher time was discontinuous, as indicated by the 11 PACs that comprise the Thacher Member. Analysis of each individual PAC reconstruction (figure 38) yields a detailed, small-scale representation of the paleo-environmental conditions that prevailed during specific times in Thacher history (note: Due to lack of complete exposure at all localities, it is not possible to present a complete reconstruction of PAC 1).

The stratigraphic history of the Thacher Member may be subdivided into two general depositional patterns; the large scale change in depositional patterns is interpreted to occur at the PAC 6-PAC 7 boundary. The lower portion of the Thacher Member consists of PACs that primarily contain low

Figure 38:  
Multiple-slice reconstruction of entire  
Thacher Member (light blue is subtidal/low  
intertidal and yellow is high inter-  
tidal/low supratidal).



intertidal and high intertidal/low supratidal facies whereas the upper portion of the Thacher Member consists of PACs that primarily contain subtidal facies.

Paleoenvironmental analysis of sediment accumulation in PAC 2 through PAC 6 indicates that in each instance much of the sedimentation was occurring at near sea-level conditions. Closer analysis of early Thacher deposition (PAC 2 through PAC 6) reveals that the most restricted facies deposition occurred in the Catskill and New Baltimore regions; paleotopographic analysis of the Catskill-New Baltimore region (with the exception of PAC 3) indicates an emerging topographic high (island). Although not as laterally extensive as the emerging island in the Catskill-New Baltimore regions, two other topographic highs existed during early Thacher deposition, an island in the Kingston region (PAC 2 and PAC 3) and an island in the Schoharie region (PAC 2 through PAC 4).

The large scale paleoenvironmental pattern of intertidal and low supratidal PAC deposition that existed through PAC 6 deposition was altered by the punctuation event that produced the PAC 6-PAC 7 boundary. This punctuation event was significant enough to alter the paleoenvironmental pattern of PAC deposition to almost exclusively subtidal deposition during late Thacher time (PAC 7 through PAC 11).

Analysis of upper Thacher deposition (PAC 7 through PAC 11) indicates an emergence of a new paleoenvironmental pattern throughout the Hudson Valley region. All remaining Thacher PACs, with the exception of PAC 8 and a limited

extent of PAC 7, are composed entirely of subtidal and low intertidal facies (figure 38); facies analysis of upper Thacher PACs indicates that marine conditions were more "open" than the previous "restricted" PACs that dominated lower Thacher deposition.

Further analysis of PAC 8 deposition reveals the occurrence of near sea-level, restricted facies from the Kingston region through the Schoharie region. This sea-level surface, which is pervasive throughout the Hudson Valley region, serves as a stratigraphic datum for a study conducted by Goodman (Goodman and Anderson, 1984) on the Manlius-Coeymans Formational contact and also supports stratigraphic correlations established in this study. This lithologically distinct unit is one of the horizons utilized by Rickard (1962) to conduct the stratigraphic correlations of the Helderberg Group.

Analysis of the upper boundaries of PAC 8 through PAC 11 indicates continued removal of the original paleo-topographic surfaces (figure 38). A trend of erosion is observed by the progressive removal of sediment from the southeast toward the northwest in each ensuing PAC. The least affected PAC is PAC 8 in which the erosion surface is only observed at localities southeast of the Kingston region. Effects of erosion become more pronounced as lesser amounts of younger PACs are preserved; this is indicated by the limited aerial extent of PAC 11 (Schoharie region). This erosion surface is interpreted by Goodman (Goodman

and Anderson, 1984) to represent a discontinuity surface in the Hudson Valley region between the Manlius and Coeymans Formational contact. The extension of the erosion surface from Kingston to Schoharie, which persists through the upper Thacher PACs (PAC 8 through PAC 11), was interpreted to be a result of differential uplift to the southeast during the hiatus between Manlius and Coeymans deposition (Goodman and Anderson, 1984).

## SUMMARY

This study, like Laporte's study of the Manlius Formation (1967), concludes that the Manlius Formation is composed of a variety of lithofacies that represent three primary subenvironments: supratidal; intertidal; and subtidal. However, the paleoenvironmental framework constructed from data collected in this study differs significantly from Laporte's paleoenvironmental reconstruction. A comparison of the techniques and objectives utilized in each study may explain the differences in interpretation.

The purpose of Laporte's (1967) investigation of the Manlius Formation was principally paleoecologic not stratigraphic. For his study, Laporte collected and analyzed over two hundred rock samples taken from a variety of localities; etched slabs and thin-sections were analyzed for lithologic and paleontologic content. The information collected from the samples was assigned a facies name, compared with present-day, shallow-water, carbonates and then, by analogy with Recent sedimentary environments, categorized into its appropriate subenvironment.

In constructing the stratigraphic relationships of the Manlius facies, Laporte did not attempt correlations among localities. Instead, his observation of a repetition of the three subenvironments in vertical succession at individual localities led Laporte to conclude that there were multiple lateral shifts of facies due to the continuous fluctuation of Manlius environmental conditions. The result of these

multiple lateral facies shifts is the complex facies mosaic that comprises the Manlius Formation (Laporte, 1967).

In contrast to Laporte, this study incorporates a stratigraphic approach to interpret facies distribution within the Manlius Formation. This approach consisted of applying the principles and methods of the PAC Hypothesis as well as some of the conclusions of Perkins (1977) in an attempt to determine if Thacher facies accumulated as an ordered response to allogenic processes.

Utilization of the PAC approach to the stratigraphic analysis of the Thacher Member required that data be collected by: 1) making measured sections at various localities in an attempt to illustrate that at any locality the Thacher Member is completely divisible into PACs; 2) sampling each locality for lithologic and paleontologic analysis and as a control for interpreted PAC boundaries; and 3) conducting detailed stratigraphic correlations of individual PACs by comparing major punctuation events, tracing PACs laterally between closely spaced localities (noting lithologic and paleontologic variations) and comparing relative water depth curves among localities. After establishing detailed correlations of individual PACs throughout the study area, it was possible to utilize the data to conduct a paleoenvironmental reconstruction of the Thacher Member.

In considering the three dimensional extent of a paleoenvironmental reconstruction, vertical and lateral facies change at a locality and the subsequent spatial

relationships of these facies among localities, it follows that a precise, small-scale stratigraphic framework must be established before a legitimate paleoenvironmental reconstruction may be undertaken. Application of the PAC Hypothesis provided the appropriate framework required to conduct such an analysis. Conclusions based on this study indicate that facies of the Thatcher Member accumulated episodically as an ordered response to allogenic events (rapid base-level rises) followed by sedimentary aggradation resulting in a series of correlative PACs that contain predictable facies patterns.

## CONCLUSIONS

Application of the PAC Hypothesis to the Thacher Member of the Manlius Formation in the Hudson Valley region yields the following conclusions:

- 1) The Thacher Member of the Manlius Formation consists of 11 Punctuated Aggradational Cycles containing shallow subtidal, intertidal and supratidal facies.
- 2) All PACs, although internally variable, are correlative throughout the Hudson Valley region.
- 3) Each PAC represents a distinct paleoenvironmental and paleogeographic setting initiated and terminated by rapid base-level rises. Vertically, within each PAC, facies represent aggradational shallowing; laterally adjacent facies in each PAC represent contiguous paleoenvironments.
- 4) Thacher depositional patterns were controlled primarily by allogenic events (small-scale, rapid base-level rises) not by autogenic processes (lateral migration of environmental elements).
- 5) Thacher depositional history was episodic and discontinuous not gradual and continuous.

## APPENDIX I: FIELD GUIDE TO LOCALITIES

South Wilbur (Locality 22)

An abandoned quarry/gravel pit one half mile south of Wilbur, west of Route 213.

East Kingston (Locality 25)

North wall of the abandoned quarry located approximately two miles south of the Route 199/Route 32 intersection, east of Route 32.

Kingston (Locality 28)

A roadcut three tenths of a mile south of the Route 199/Route 32 intersection, east of Route 32. Also included with this locality is another roadcut located along Route 199 approximately five tenths of a mile west of the entrance to the Kingston-Rhinecliff bridge.

South Catskill (Locality 43)

A roadcut located on Route 23A approximately two and one half miles southwest of the town of Catskill.

North Catskill (Locality 44-B)

A roadcut on the Catskill/Leeds exit ramp of Route 23, approximately one quarter mile east of the New York State Thruway.

Climax Quarry (Locality 48)

An abandoned quarry off of Route 81 behind the Quarry Steakhouse in Climax.

New Baltimore (Locality 53)

An active quarry operated by the Callanan Company west of the intersection of Route 396 and South Road in South Bethlehem.

New Salem (Locality 57)

A roadcut and abandoned quarry located approximately five tenths of a mile past the intersection of Rock Hill and North Roads, on Rock Hill Road, two miles southeast of New Salem.

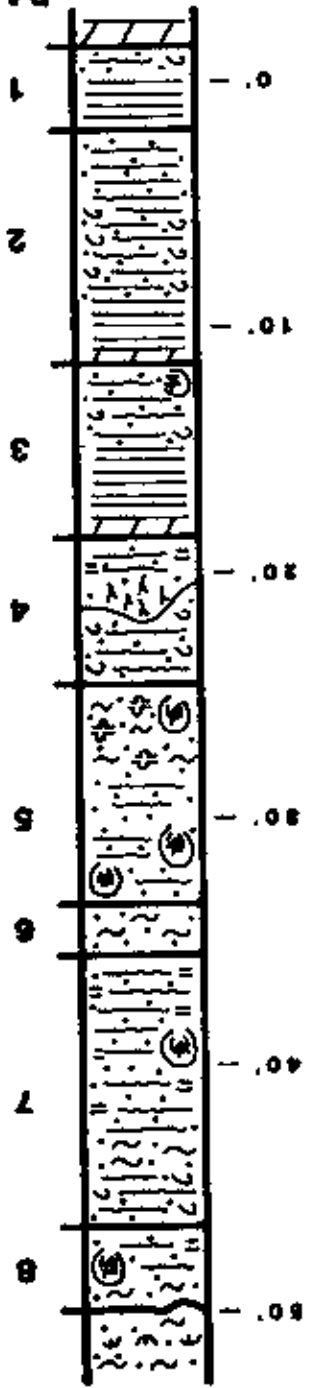
Thacher Park (Locality 59)

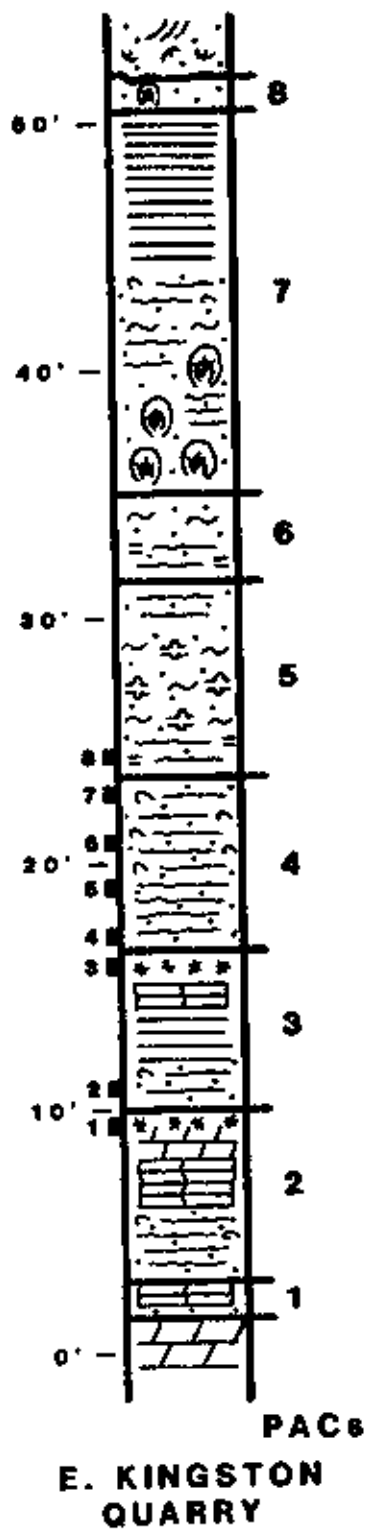
Located off of Route 157 approximately two miles east of Thompson Lake between the two wooden staircases of the Indian Ladder Trail in John Boyd Thacher Park.

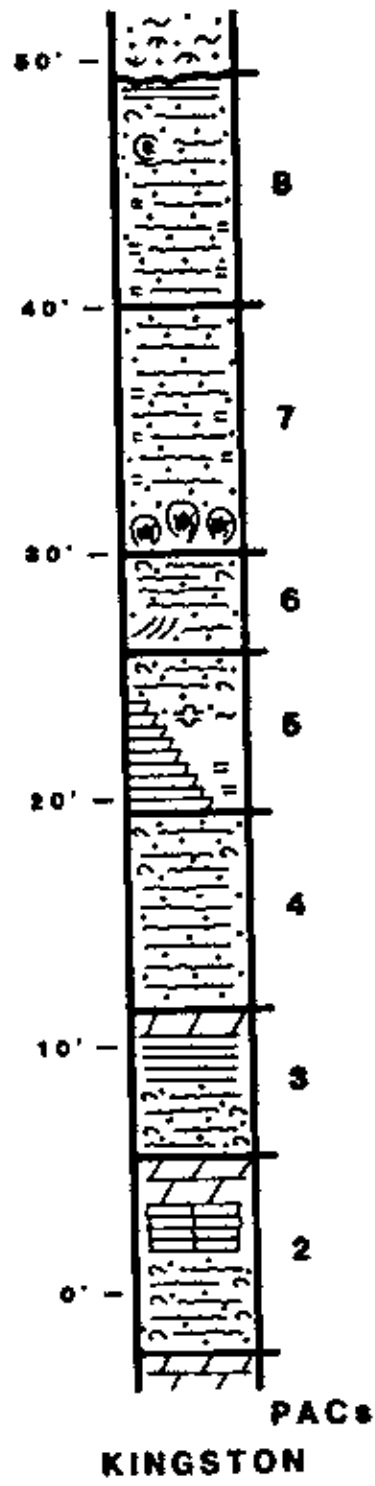
Schoharie

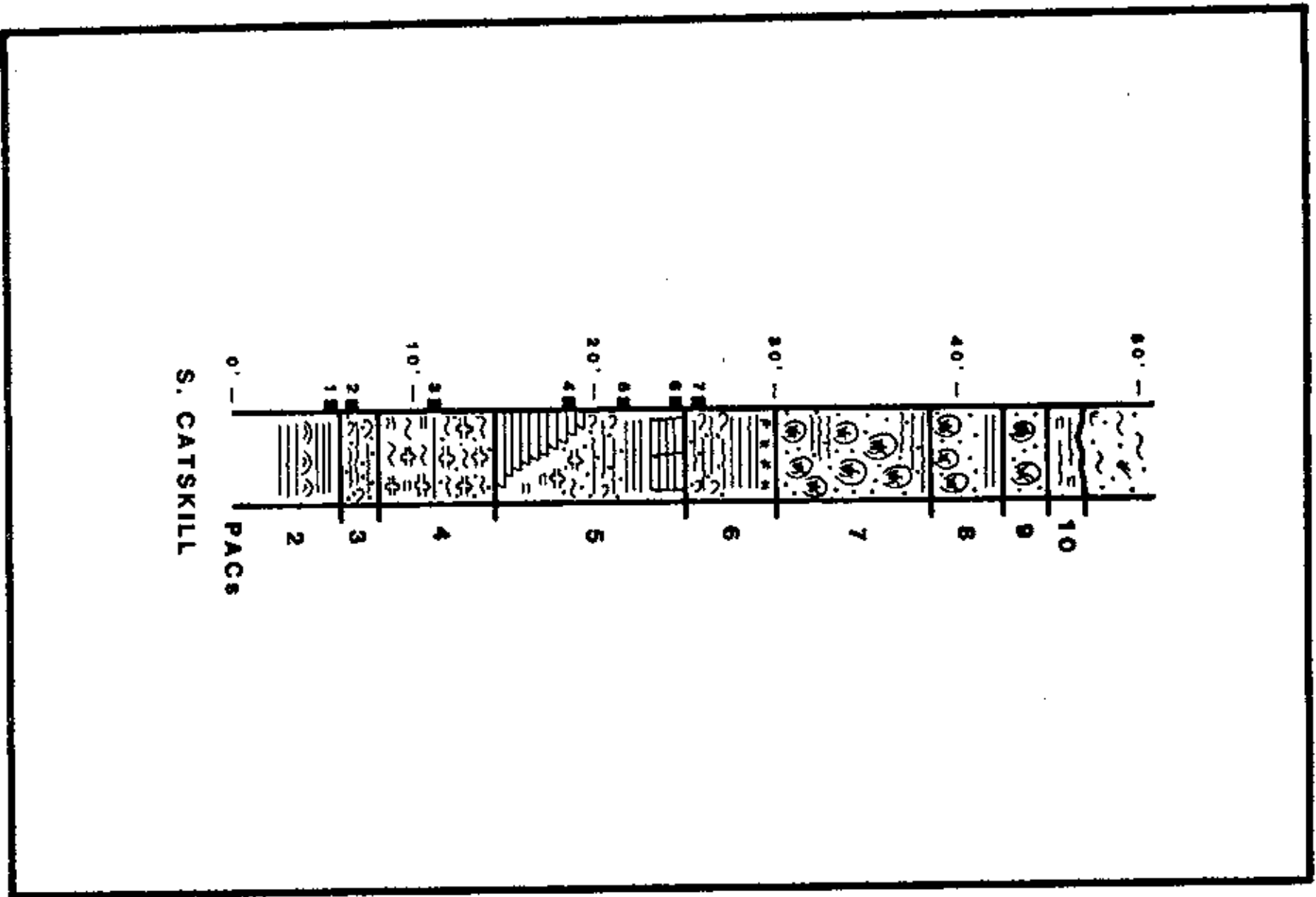
A roadcut located along the west-bound lane of Interstate 88 approximately two miles west of the intersection of Route 30A and Interstate 88, northwest of the town of Schoharie.

S. WILBUR  
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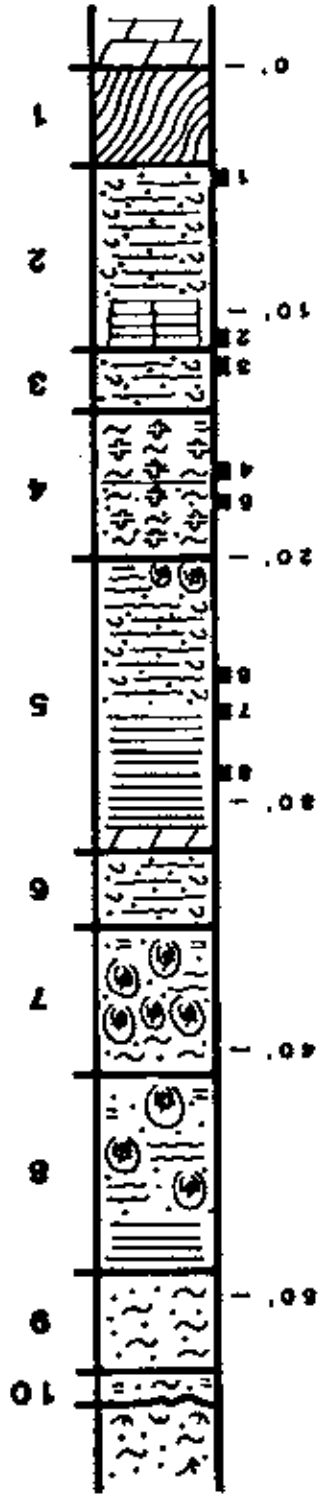


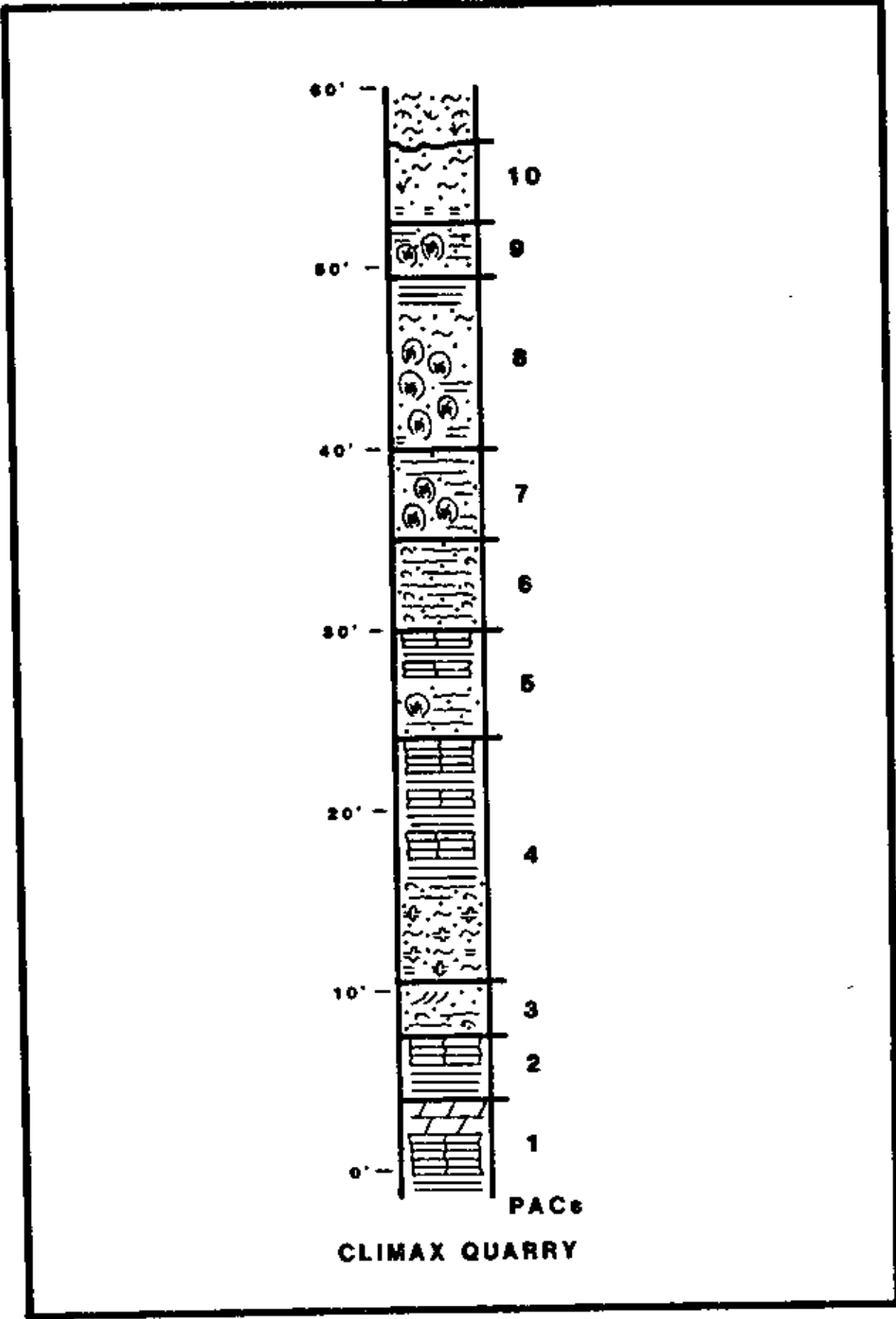




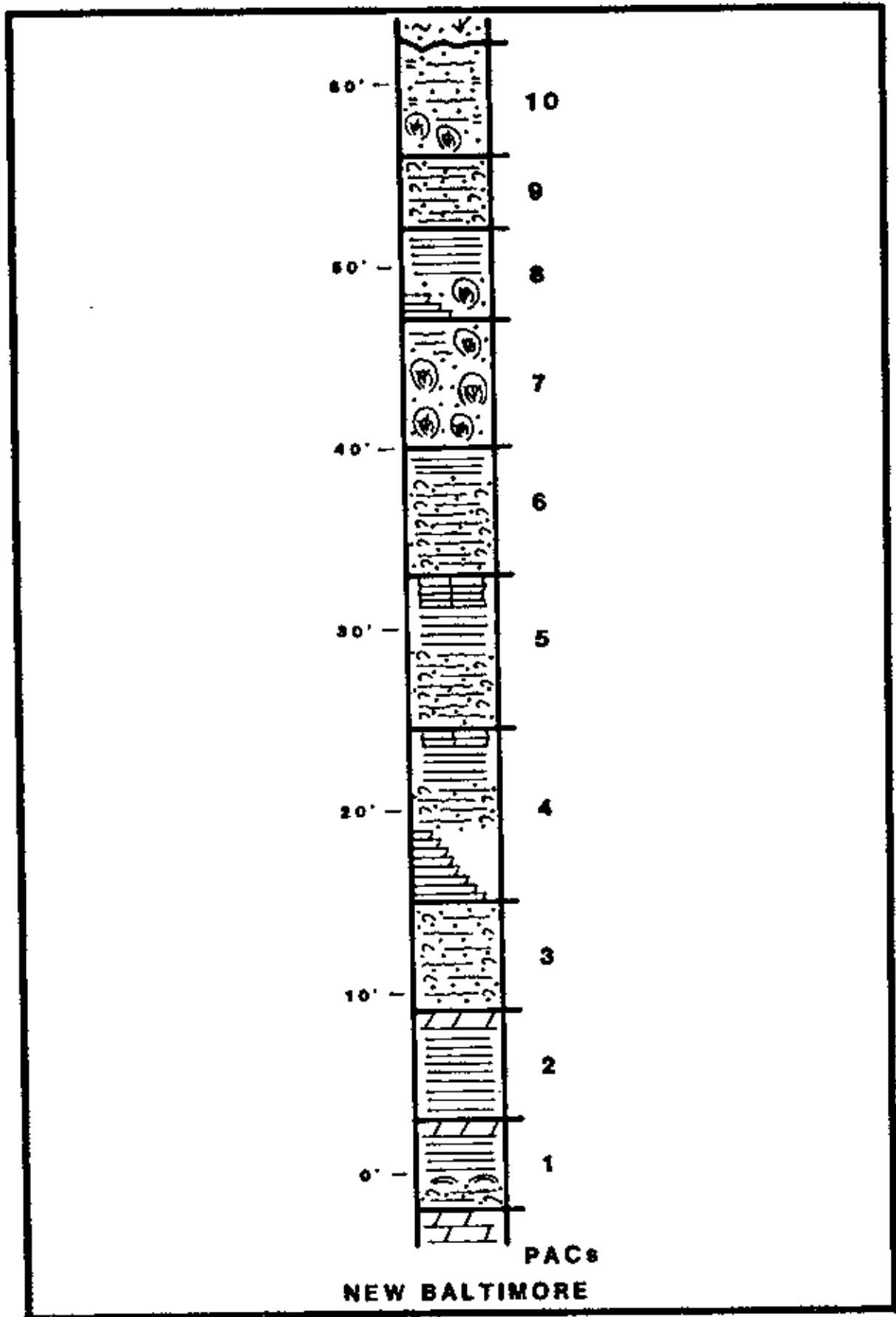


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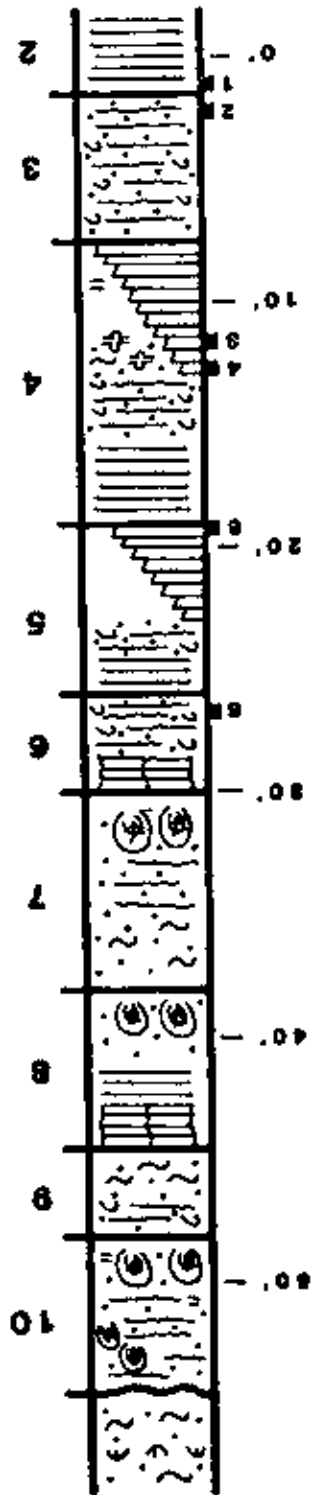


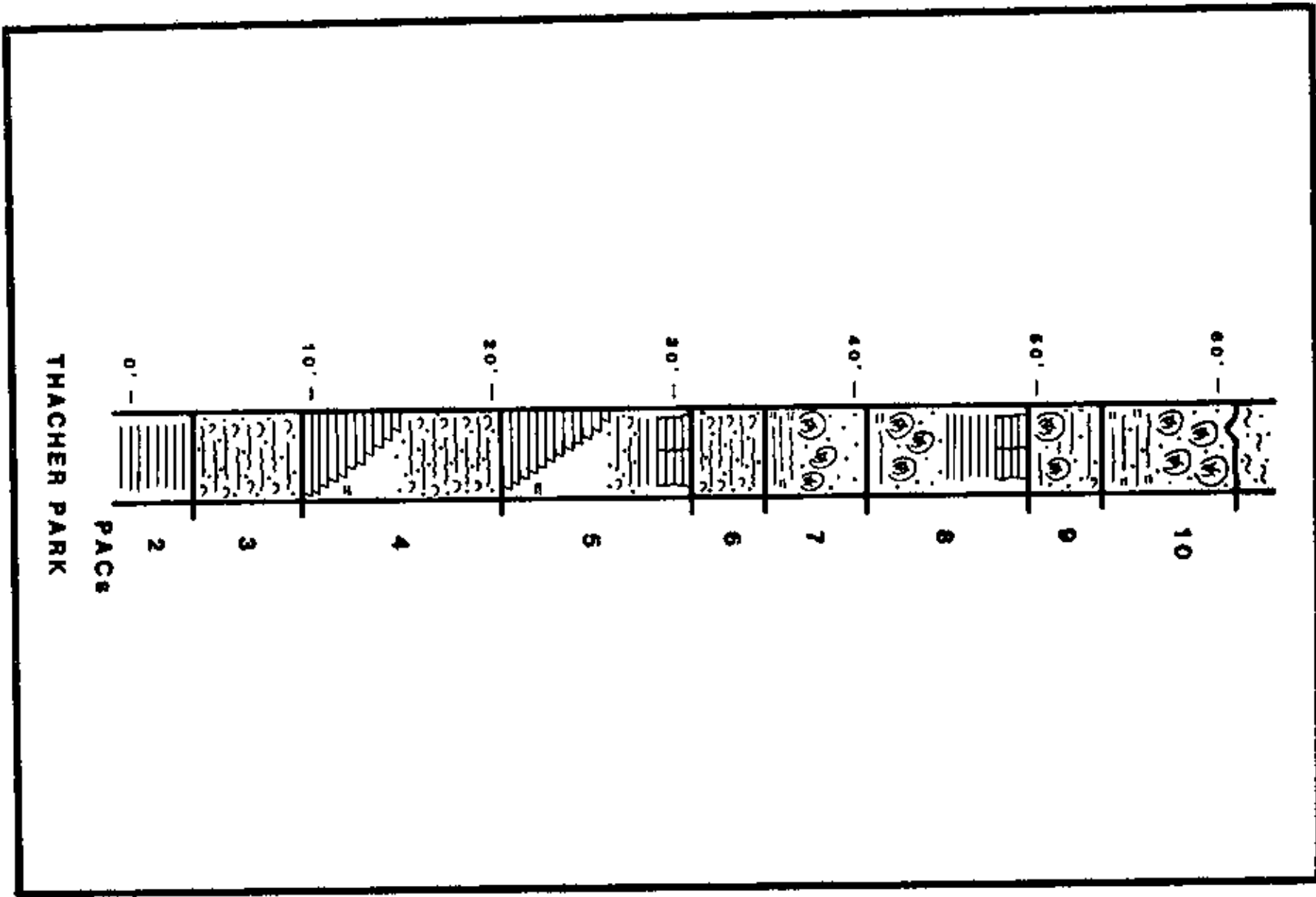
CLIMAX QUARRY

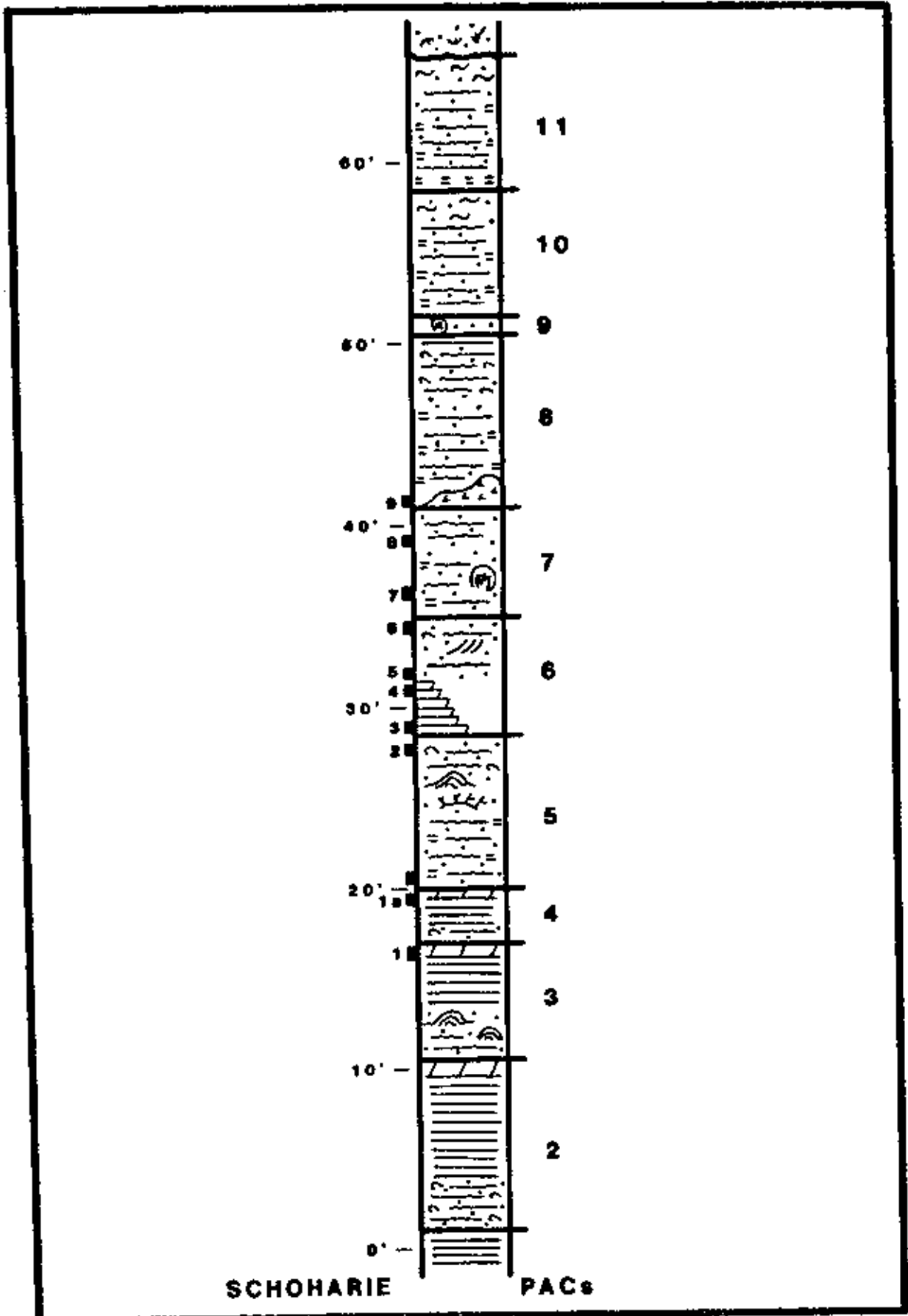


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NEW SALEM  
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