PUNCTUATED AGGRADATIONAL CYCLES (SMALL-SCALE, UPWARD SHALLOWING UNITS) OF THE THACHER MEMBER, MANLIUS FORMATION (LOWER DEVONIAN) IN NEW YORK STATE

A Thesis Submitted
to the Temple University Graduate Board

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in Partial Fullfiment
of the Requirement for the Degree

MASTER OF ARTS

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by

Patrick F. Rush

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A Thesis Submitted in Partial Fulfillment of the Requirements
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Temple University

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Approved: Peter W. Goodwin

Dr. Peter W. Goodwin

Date: Nov. 2, 1984

DEDICATION

I am dedicating this thesis to my parents Martin J. Rush and Bridget Ann Rush who instilled in me a will to learn and gave me the opportunity to achieve.

ACKNOWLEDGEMENTS

This study was conducted under the supervision of Doctors Peter W. Goodwin and Edwin J. Anderson. I wish to thank both these men for generously sharing their time, knowledge and experience whenever requested. I wish to thank Pete for his friendship and encouragement throughout this study and during my stay at Temple. I also wish to extend my thanks to the entire faculty of the Geology Department at Temple University.

I also appreciate fellow graduate students Rich Busch, Rick Lee and Mike Edelman for their friendship and constructive discussions concerning classes and field work. I thank Rich Busch who along with Pete and Andy critically read this manuscript. A special appreciation goes to Jan who made everything run smoothly during the final stages of writing this thesis.

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ABSTRACT

The facies mosaic within the Thacher Member of the Manlius Formation in central New York State can be subdivided into a sequence of ten upward-shallowing carbonate units. Each unit or Punctuated Aggradational Cycle (PAC), is bounded by non-depositional transgressive (deepening) surfaces. Between these surfaces, basal subtidal facies grade upward into shallow subtidal, intertidal and/or supratidal facies. These PACs exhibit facies which were deposited in several environments including an open shelf, a subtidal stromatoporoid patch reef, a restricted shelf, a bioclastic sand shoal and sand shoal fringe, and gradational shallow subtidal environments into intertidal and supratidal flat environments.

Each PAC can be correlated between closely spaced outcrops by tracing key beds, facies lithosomes, cycles of similar thickness and internal facies arrangement. Longer distance correlation across the study area can be accomplished by matching shallowing sequences of PACs, matching major vertical facies changes across transgressive surfaces (indicating major deepening events) and by matching laterally persistent facies lithosomes.

Analysis of the facies mosaic within a PAC provides a detailed interpretation of the paleogeographic changes accompanying its deposition. The Thacher Member consists of a sequence of ten paleoenvironmental units consisting of facies which exhibit gradational transitions within and distinct facies changes at their boundaries.

TABLE OF CONTENTS

LIST OF FIGURES

Punctuated Aggradational Cycles (Small-Scale, Upward Shallowing Units) of the Thacher Member, Manlius Formation (Lower Devonian) in New York State.

INTRODUCTION

This research will constitute a limited test of the hypothesis of Punctuated Aggradational Cycles (Anderson & Goodwin, 1980) by applying the concept to a stratigraphic analysis of a portion of the Manlius Formation of New York State. The Punctuated Aggradational Cycle Hypothesis states that most stratigraphic accumulation occurs as thin (1-5 meter thick) shallowing-upward units separated by sharply defined non-depositional surfaces (Figure 1). According to Goodwin & Anderson (1980) these non-depositional surfaces are created by geologically instantaneous basin-wide relative base-level rises. Deposition occurs during the intervening periods of base-level stability. Each Punctuated Aggradational Cycle (PAC) is a lithologically defined time-stratigraphic unit because it is bounded by succesive, isochronous, deepening surfaces. Theoretically each PAC represents continuous aggradation initiated after a non-depositional deepening event. Aggradation was abruptly altered by the next punctuation (deepening) event.

This study applies the PAC model of stratigraphic accumulation to a portion of the Thacher Member of the Manlius Formation. The studied interval is approximately 20 meters thick (Figure 2) and was examined over a lateral distance of approximately 50 miles along the Helderberg

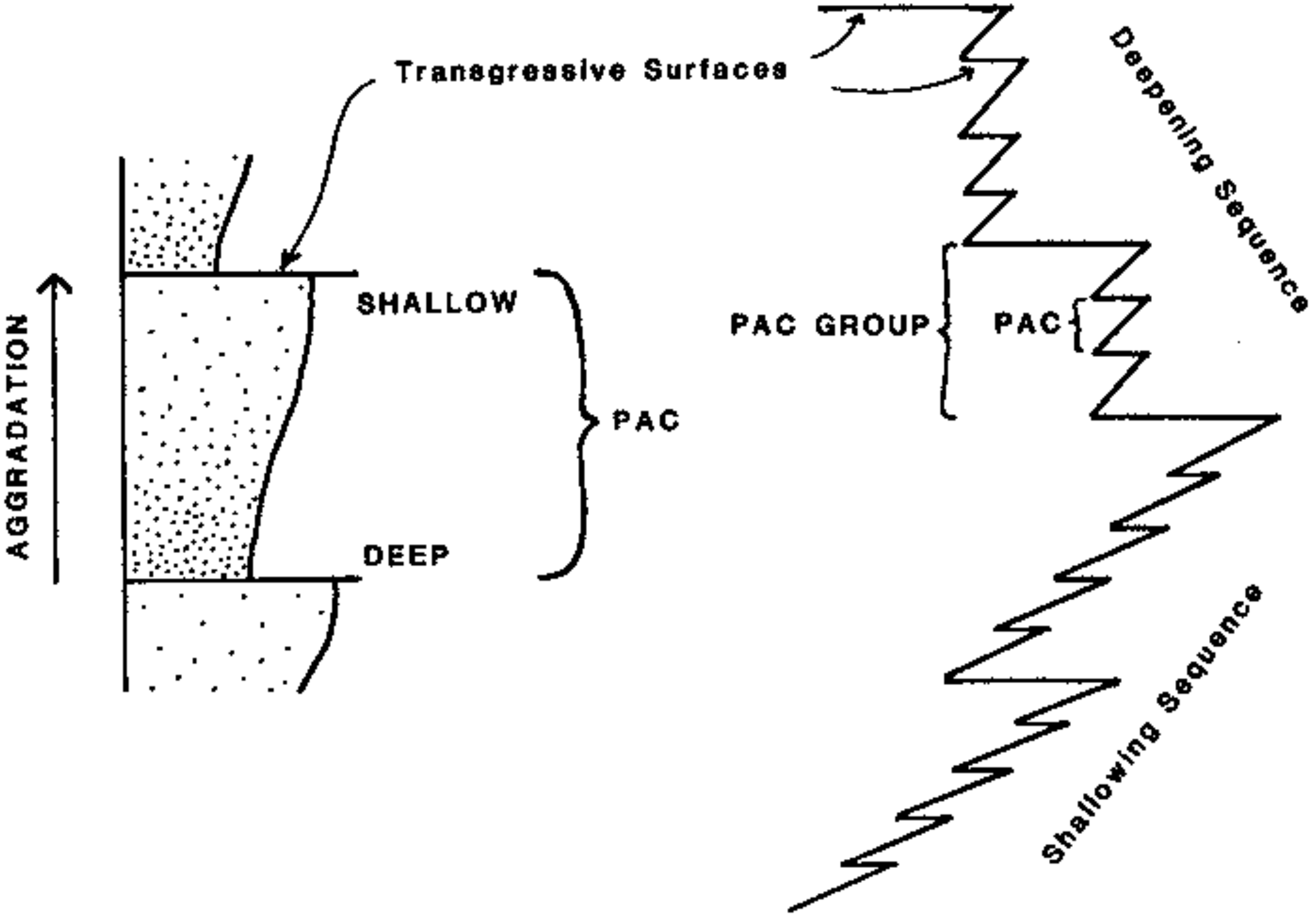


Figure 1: The Punctuated Aggradational Cycles Hypothesis; modified after Anderson and Goodwin, 1980.

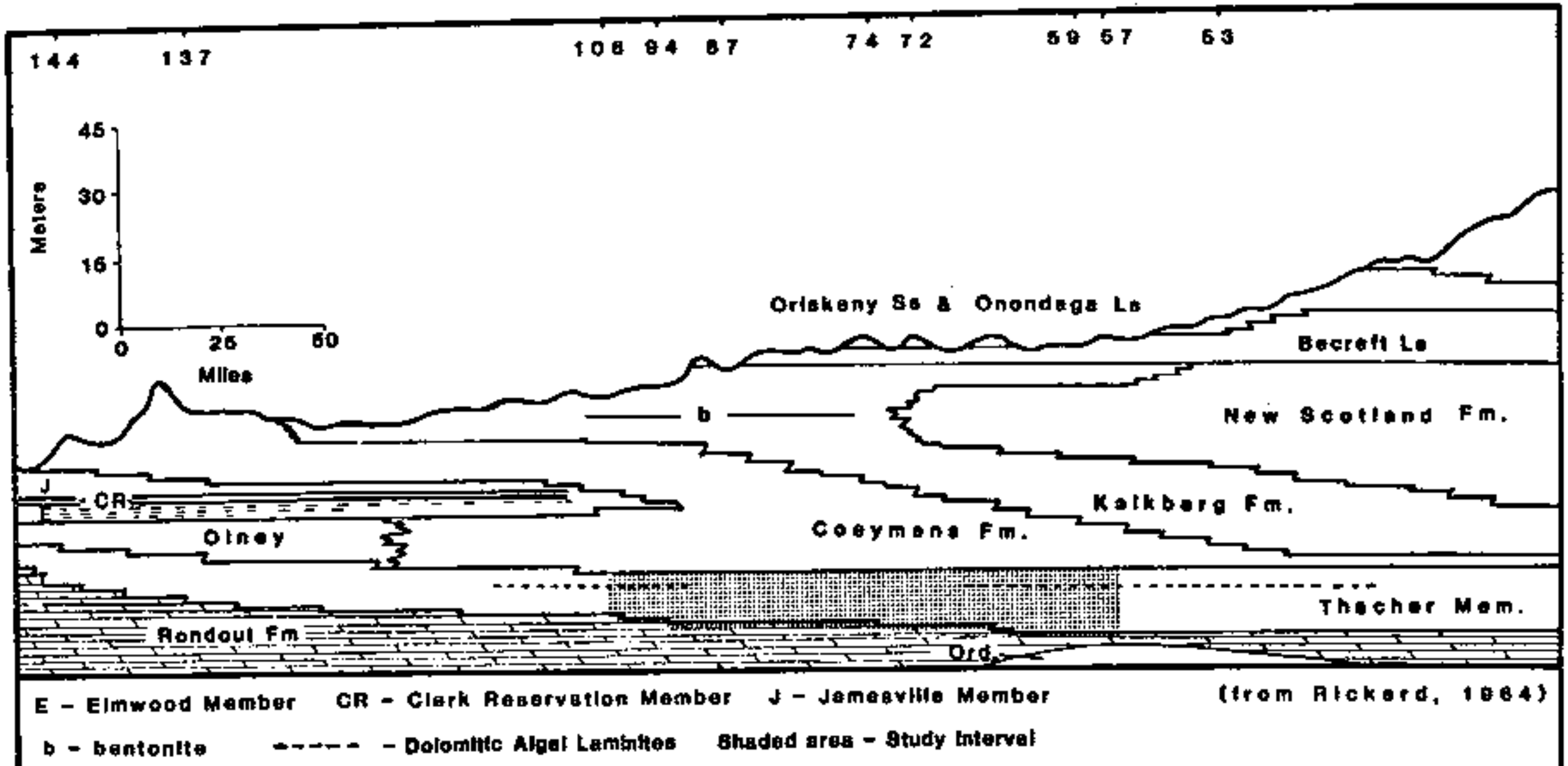
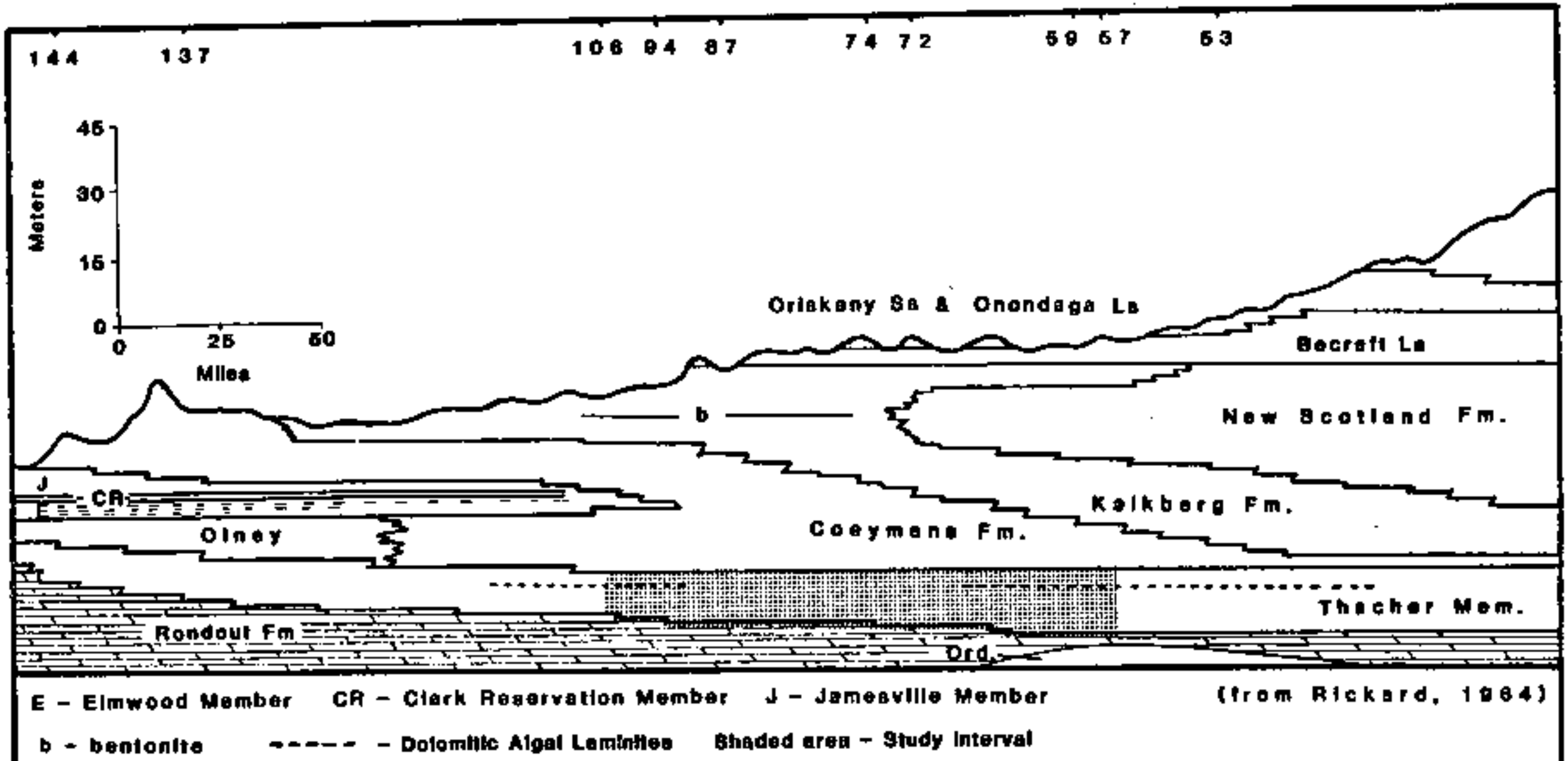


FIGURE 2: The Helderberg Group cross-section showing the lateral and vertical extent of the study interval (shaded portion). The Manlius Formation includes the Thacher, Olney, Elmwood, Clark Reservation and Jamesville Members.



(from Rickard, 1964)

FIGURE 2: The Helderberg Group cross-section showing the lateral and vertical extent of the study interval (shaded portion). The Manlius Formation includes the Thacher, Olney, Elmwood, Clark Reservation and Jamesville Members.

outcrop belt (Figure 3) between New Salem, N.Y. (locality 57) and Van Hornsville, N.Y. (locality 106-b).

The Helderberg Group of New York State is composed of the Manlius, Coeymans, Kalkberg, New Scotland and Becraft Formations (Figure 4). The Manlius Formation has been further sub-divided into the Thacher, Elmwood, Clark Reservation and Jamesville Members (Rickard, 1962). According to Rickard (1962) these members are macrofacies reflecting the generalized paleoenvironments of deposition. For example, Thacher Member calcilutites reflect deposition in quiet water lagoonal (restricted marine) settings (Rickard, 1962). Later Laporte (1967) distinguished a facies mosaic of subtidal, intertidal and supratidal deposits within the Manlius Formation. The crinoidal calcarenites of the Coeymans and Becraft Formations reflect deposition in agitated normal marine conditions (Rickard, 1962; Laporte, 1969), the Kalkberg cherty calcisiltites and New Scotland Formation argilli-calcisiltites represent normal marine neritic conditions below wave base (Rickard, 1962; Laporte, 1969).

Laporte (1969) applied the models for epeiric sea deposition of Shaw (1964) and Irwin (1965) to the Helderberg Group and proposed the Lower Devonian of New York as a model for a transgressive carbonate sequence. This interpretation is based on a strict application of Walthers Principle (Middleton, 1973) to the entire Group.

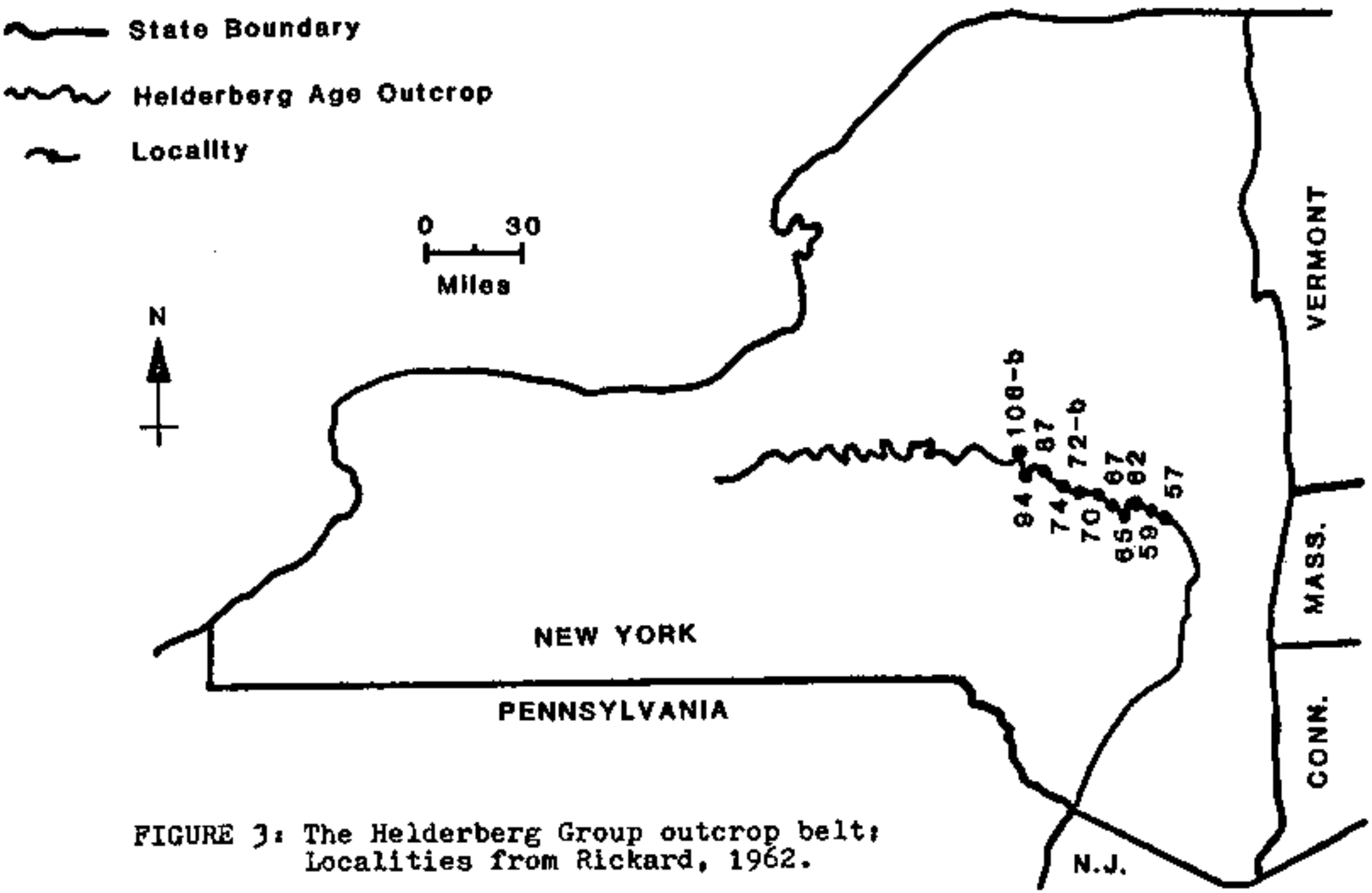


FIGURE 3: The Helderberg Group outcrop belt; Localities from Rickard, 1962.

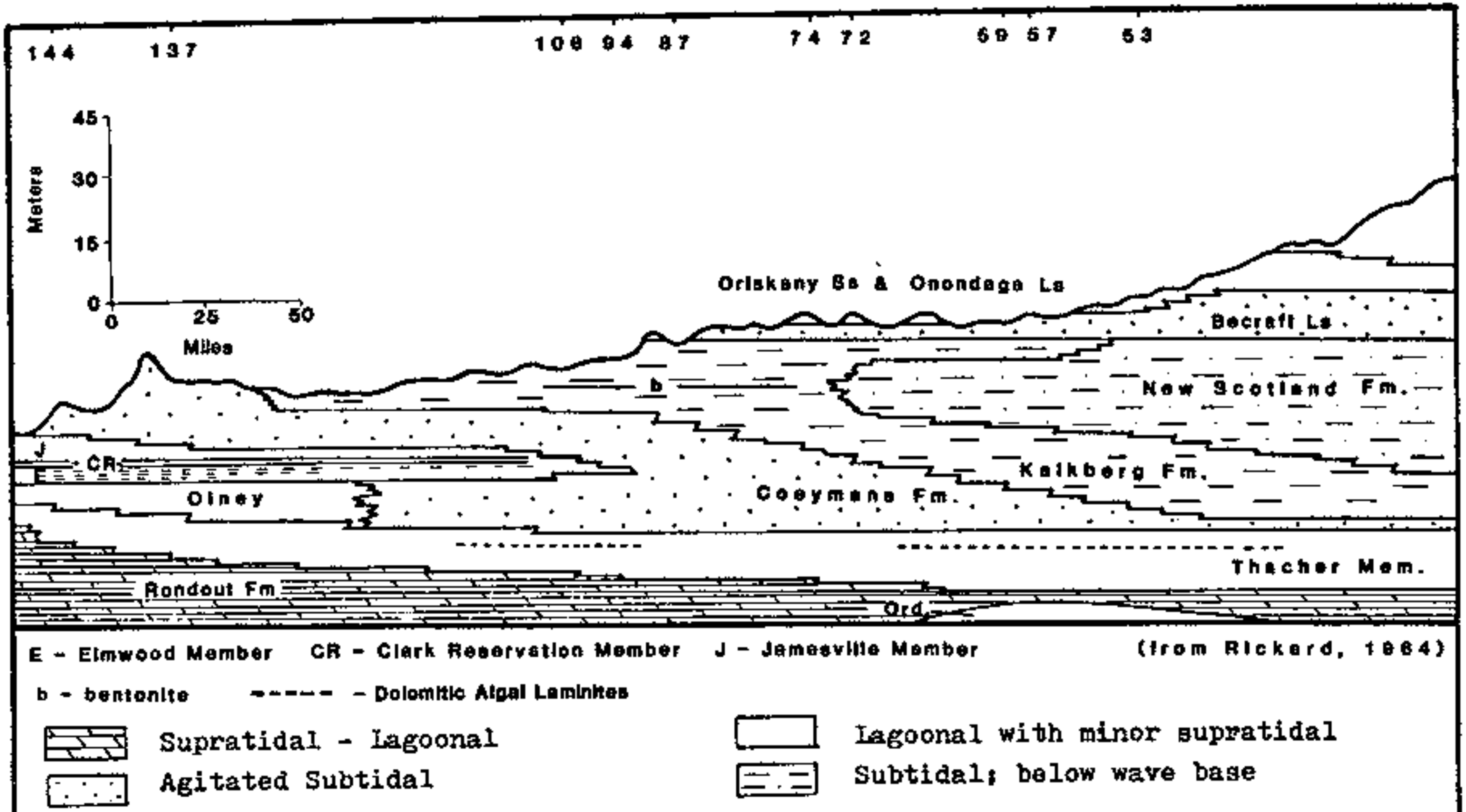


FIGURE 4: The generalized facies and environmental interpretation of the Helderberg Group (after Rickard, 1962 and Laporte, 1969)

The transgressive pattern is best exemplified in the eastern portion of the Helderberg cross-section where superposition of the progressively deeper facies of the Coeymans, Kalkberg and New Scotland Formations overlie the more shallow Manlius Formation facies.

The western occurrence of Lower Devonian Rocks in New York State (Figure 5) may be characterized as a symmetrical transgressive - regressive - transgressive sequence. The scale of this cycle is on the order of 150 to 200 feet (50 m) and corresponds to a fourth order cycle of Kendall and Schlager (1981). The lower transgressive phase is characterized by the deepening from Manlius Formation restricted facies to unrestricted, well agitated shelf deposits in the Coeymans Formation. The regressive portion of the cycle is characterized by the progressive shallowing from Coeymans Formation facies to the Elmwood Member (Manlius Formation) tidal flat facies. The later transgressive phase is represented by the deepening from the tidal flat facies to the less restricted, quiet water facies of the Jamesville Member.

In contrast to the above interpretations the Punctuated Aggradational Cycles described within the Helderberg rocks by Anderson (1978); Goodwin & Anderson (1980) and Cameron & Newman (1980) mandate a reanalysis of this rock unit. The PACs are much thinner, on the order of 1 to 3 meters, and correspond to fifth order cycles

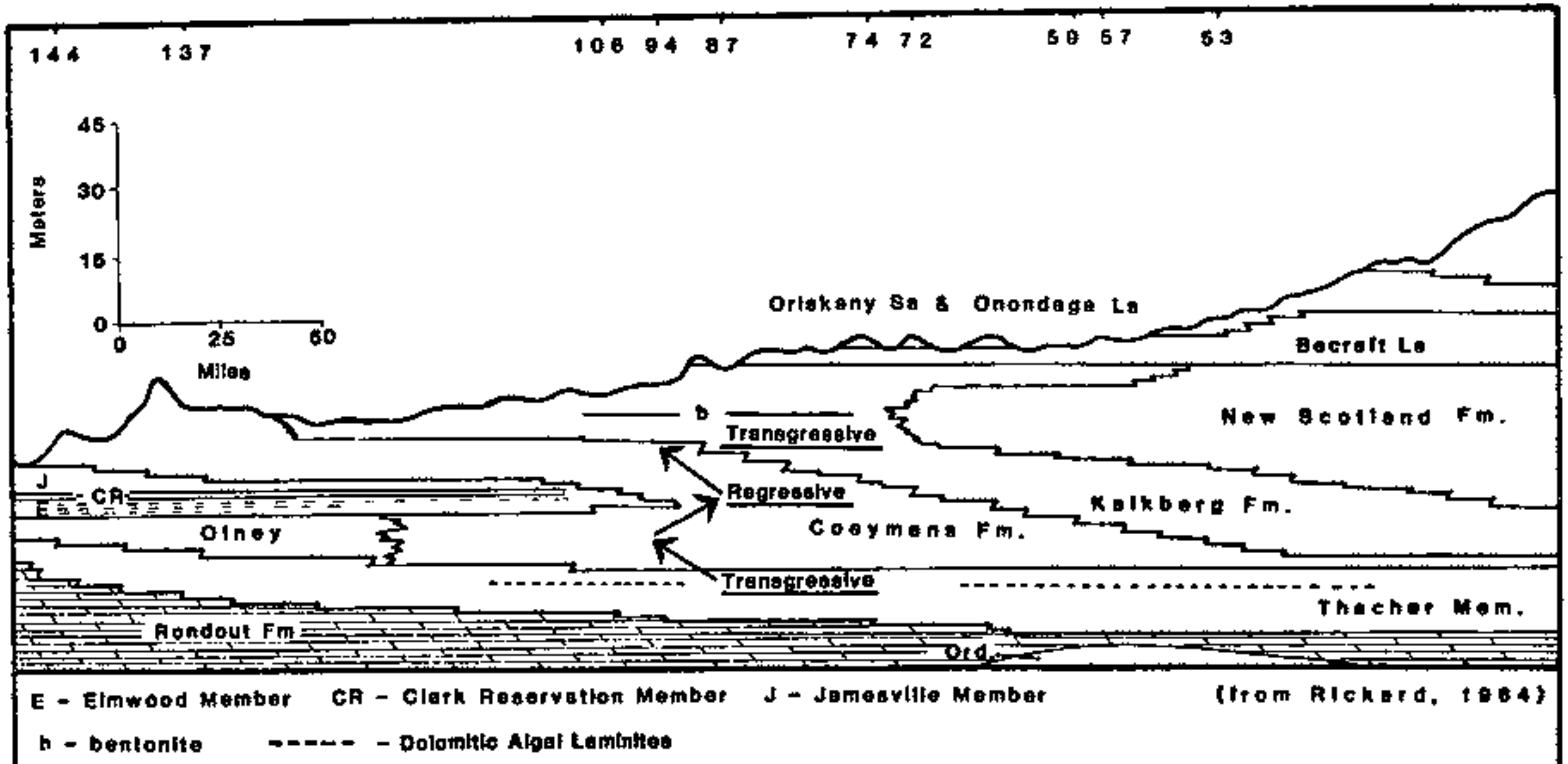


FIGURE 5: The large scale cyclicity (4th order) exhibited in the Helderberg Group.

after Kendall & Schlager (1981). The PACs record repetitive asymmetric sea leval fluctuations as opposed to the symmetric sea level patterns inferred from the larger scale cyclicity. The larger scale cyclicity is caused by deepening and shallowing trends of sequences of PACs (Goodwin and Anderson, 1980). Most significantly the concept of superposition of facies only applies within PACs and not across the deepening boundaries between PACs. Shallow environments are superimposed over deeper deposits, in response to aggradation of carbonate sediments, until a deepening (punctuation) event occurs. Following that event the overlying environment and resulting facies may be in no way related to the underlying facies as is evidenced by the deepening over the top of the Elmwood Member into the Clark Reservation Member (Lee, 1981; Busch, 1981).

Stratigraphic accumulations of upward-shallowing cycles have been described from many geographic areas and in rocks from all ages. Examples of repetitive accumulations of carbonate upward-shallowing cycles include Aitken (1966), Rose (1972), Read (1973), Fischer (1964), Colacicchi et.al. (1975), Lindsay & Kendall (1980), Cameron (1978) and Demicco (1983). Several have been summarized by Ginsburg (1975) and James (1979) along with many examples of the easily recognizable carbonate to evaporite cycles. A common characteristic of all of these studies is that each identifies typical upward-shallowing cycles in their respective rock units but very little data are presented as to the lateral traceability of these cycles. In studies where cycles have been traced across their basin of deposition by Van Siclin (1969), Meissner (1972), Mesollella (1974), Playford (1980) (see Wilson, 1975 for more examples) the scale of cyclicity is one order of magnitude greater (4th order) than the smaller cycles (5th order) typical of carbonate stratigraphic accumulations and described as PACs. Also the larger scale cycles have been interpreted to exhibit reciprocal patterns of sea level high stand to sea level low stand. In contrast to these studies Wilson (1967) documented small-scale, upward-shallowing, carbonate to evaporite cycles within the Williston Basin and was able to trace them laterally over the entire extent of the basin although he interpreted reciprocal sea level fluctuations for their origin rather than asymmetric sea level rises followed by base level stability as the PAC model indicates.

The aims of this study are to reanalyze the facies mosaic of a portion of the Manlius Formation and expand upon preliminary work of Anderson (1978) and Anderson & Goodwin (1980) by identifying the upward-shallowing cycles (PACs) at each outcrop locality within the study interval. A second objective is to construct a correlation chart of these cycles using data derived from outcrop analysis, and reconstruct paleoenvironments and paleogeographic patterns for each PAC based on a facies analysis using petrographic information, outcrop descriptions, and the correlation of the PACs defined in this study.

METHODS

Field work for this project began in the autumn of 1979 and was completed during the summer of 1981, with the bulk of the field work accomplished during the summer of 1980. Laboratory work began in the summer of 1980. The field work consisted of making detailed descriptions and measurements to define PACs at each locality via the PAC approach to outcrop analysis (Goodwin et.al., 1980). These PACs were then documented in greater detail by laboratory analysis of polished slabs and thin sections. Paleoenvironmentally significant properties of the rocks were used as the basis for the interpretation of upward-shallowing cycles at each locality. The properties found to be most useful in the Thacher Member include lithologic type (after Folk, 1959 and Dunham, 1960), grain size, presence of early diagenetic dolomite, biogenic structures, sedimentary structures, macrofauna and types of contacts between beds and different lithologies.

Sampling was conducted for two purposes: to document the upward-shallowing characteristics of PACs defined in the field and to obtain more information pertinent to paleoenvironmental interpretation of Thacher Member lithofacies. Five lithofacies have been defined primarily on the basis of field characteristics, especially lithologic type, bedding thickness and macrofauna. Field descriptions were supplemented by petrographic data from 250 thin sections.

Besides the basic petrographic examination from samples of Thacher Member lithofacies, appropriate samples were stained with an alizerin red and hydrochloric acid solution to aid in identifying dolomite (Freidman, 1959). X-ray powder diffraction was employed to identify, and on occasion to estimate percentages of, mineral species. X-ray powder diffraction was run using a method developed by Butler (unpublished Univ. of Houston study). This method uses unoriented powder slides of the two phase system of well ordered stoichiometric dolomite and low magnesium calcite and compares the intensities of the highest peaks. the ratio of these peaks is then compared to empirically derived curves from known percentages of dolomite/calcite mixtures.

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FACIES ANALYSIS

FACIES 1 - The Dolomitic Cryptalgal Laminated Facies

Description

The Dolomitic Cryptalgal Facies is characterized by non-fossiliferous, planar and finely laminated, dolomicrite. This facies commonly exhibits desiccation polygons which range in diameter from 2 cm to 30 cm. Beds containing this facies are commonly 0.5 m to 1 m in thickness although this facies occasionally occurs in beds as thin as 10 cm. In outcrop this facies is light gray when fresh and weathers to a light tan color. Freshly quarried blocks of this facies are massive and well indurated while weathered occurrences break along platy partings. The cryptalgal laminations are generally less than 1 mm in thickness but thicker laminations on the order of 0.5 cm to 3 cm may occur frequently, especially in the lower portion of beds. These thicker laminations commonly have skeletal hash at their bases and grade up into micrite-sized dolomite. This facies is the only facies to contain appreciable amounts of dolomite within the study interval of the Manlius Formation.

Petrographically the laminations which occur in this facies are normally graded and are as thin as 0.1 mm (Figure 6). The coarser portions contain dolomitized peloids and fragmented skeletal debris. The coarse

Figure 6: Dolomitic Algal Laminites. Finely laminated dolomicrite with a 2.5 mm ripple cross-stratified storm layer (x 15, Sample 94-9).

Figure 7: Fine-grained (0.01 to 0.035 mm) rhombic dolomite within the algal laminites (x 166, Sample 94-9).

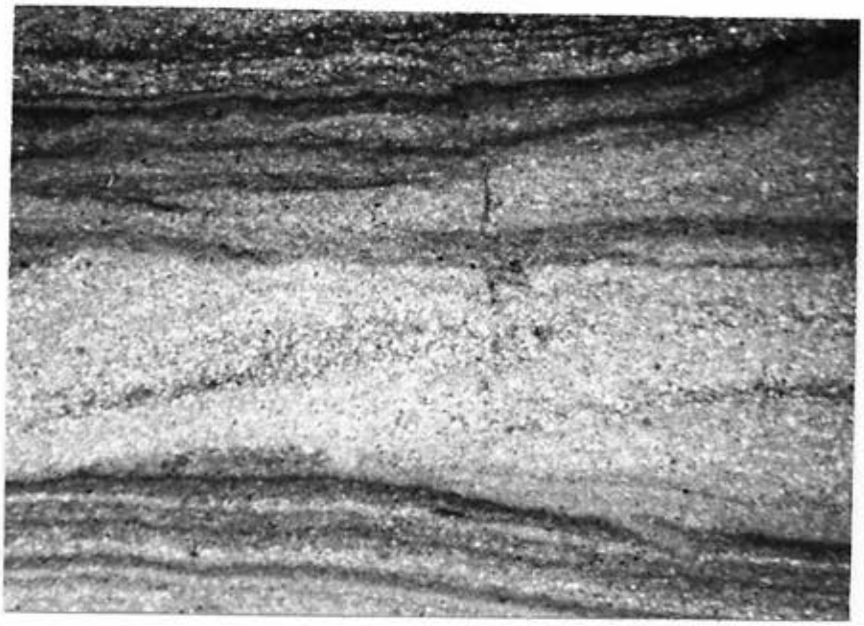


Figure 6.

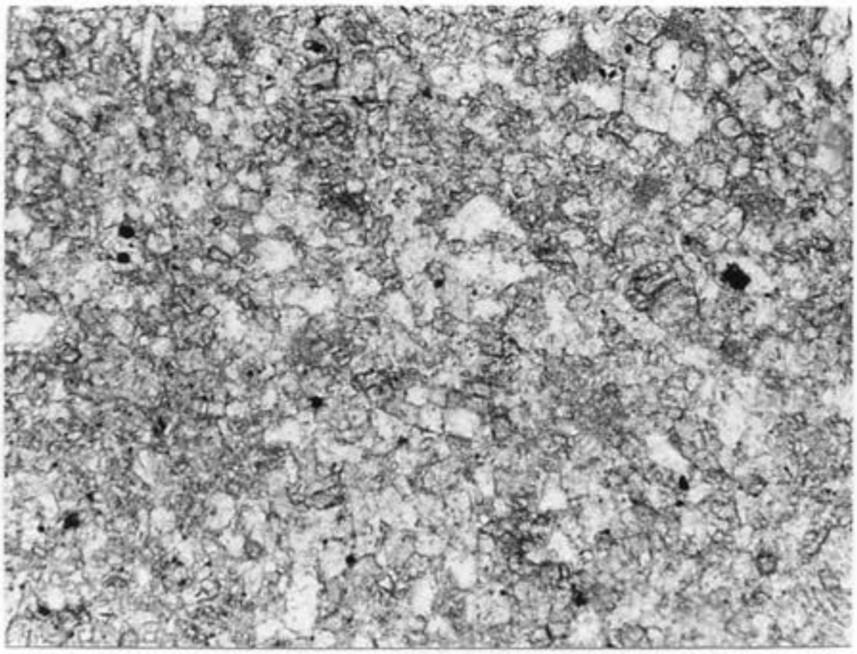


Figure 7.

portion of each lamination grades up into dolomicrite which is stained by dark material assumed to be organics. The dolomite occurs as fine (< 0.1mm) rhombohedra (Figure 7) and appears to have replaced original micritic calcium carbonate. These rocks are cemented with sparry calcite. Quartz grains (<10%) occur as silt to fine sand-sized constituents in this facies. No evaporite minerals are associated with this facies when it is encountered in most Manlius Formation localities. Although authigenic quartz, apparently a pseudomorph after evaporite minerals, does occur near the base of the Thacher Member at Localities 144, 137 and 59, but it is volumetrically insignificant.

The samples analyzed from this facies indicate that from 15 to 60 percent of this facies is composed of dolomite as opposed to calcite. Based on X-ray diffraction analysis the amount of dolomite increases upward from trace amounts in the underlying dense limestone to approximately 60% in the cryptalgal laminated carbonate. The calcite occurs as pore filling spar cement and skeletal material while the dolomite apparently replaced micrite.

Interpretation

In earlier studies, Laporte (1967), Laporte & Walker (1970) and Fisher (1979) interpreted this lithofacies as having been deposited in a supratidal setting. The fine laminations have been attributed to a trapping and binding process which is a result of the growth of filamentous blue-green algae on supratidal flats. The thicker laminations are attributed to deposition during abnormal high tide or storms (Perkins & Enos, 1968). The presence of desiccation polygons suggests periodic wetting and drying. The supratidal environmental setting for planar cryptalgal laminated sediment has been well documented by Shinn, et al. (1969), Logan & Rezak (1964) and Logan, et al. (1970). The environmental significance of fine-grained stratal dolomite has been used extensively to interpret supratidal paleoenvironments by many researchers including Laporte (1967), Fischer (1964), Rose (1972), Read (1974), Fisher (1979) and Busch (1981).

The fine-grained dolomite which occurs in this facies is typical of the occurrence of dolomite forming on modern sabkhas in the Coorang Lagoon. Also well developed fine-grained rhombic dolomite appears to be a common texture in carbonates of tidal flat origin (Morrow, 1982). Shinn, et. al. (1965) describes dolomitic crusts, similar to the dolomite occurrence in the Thacher Member, forming in the humid Bahamian supratidal environment of Andros island. The origin of the Bahamian dolomite is attributed to a high Mg/Ca ratio in the pore water (Folk, 1974) which is due to the evaporation of normal marine water during low tide or between storm and spring tides and the penecontemporaneous replacement of micritic carbonate (Illing, et al., 1965; Shin, et al., 1965).

In summary, the presence of desiccation features, fine cryptalgal and current laminations, early replacement dolomite and the absence of any indigenous macrofauna and evaporite minerals all tend to indicate that these rocks were deposited in a humid supratidal environment.

FACIES 2 - The Stromatoporoid Facies

Description

The Stromatoporoid Facies of the Thacher Member is characterized by dense biohermal and biostromal accumulations (Rickard, 1962) of hemispherical stromatoporoids (*Syringostroma barretti*). Associated with the stromatoporoid accumulations are medium-bedded fossiliferous limestones that commonly pinch-out against the stromatoporoids (Figure 8). The lithologies within the stromatoporoid accumulations are generally biopelmicrite with minor amounts of biopelsparite (Figure 9). The bedding thickness for rocks of this facies ranges from approximately 0.3 m to 1.5 m. In many instances within biostromes it can be seen that the stromatoporoid accumulations have diameters of less than 1 meter and they exhibit relief of 10 to 50 cm relative to contiguous rocks. This quality of facies 2 is evident in the biohermal buildups as well as within the biostromal deposits where the relief of the stromatoporoid accumulations is usually 0.5 to 1 meter and they have diameters of tens of meters. The rocks of Facies 2, taken as a whole, may be described as stromatoporoid/coral boundstones and rudstones.

Figure 8: Photograph of the supratidal Facies 1 (lower portion of photo), the subtidal Facies 2 (upper portion of photo) and the transgressive surface separating PACs 5 and 6 (Locality 59).

Figure 9: Photomicrographs of Facies 2 (x 15).

A. Vertical section of _Syringostoma barreti_ (Sample 62-5).

B. Pelmicrite containing rugose coral, serpulid worm tubes, and fragmented ostracodes (Sample 62-7).

C. Wackestone containing ostracode, serpulid and coral debris (Sample 60-b).

D. Pelsparite containing rugose coral, gastropods and ostracodes (Sample 62-8).

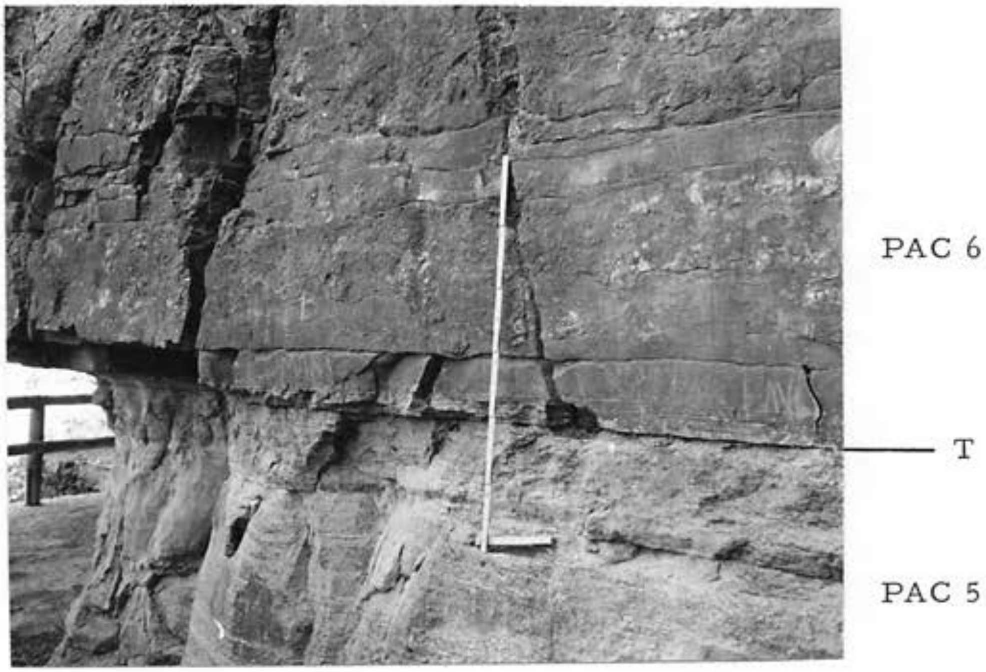
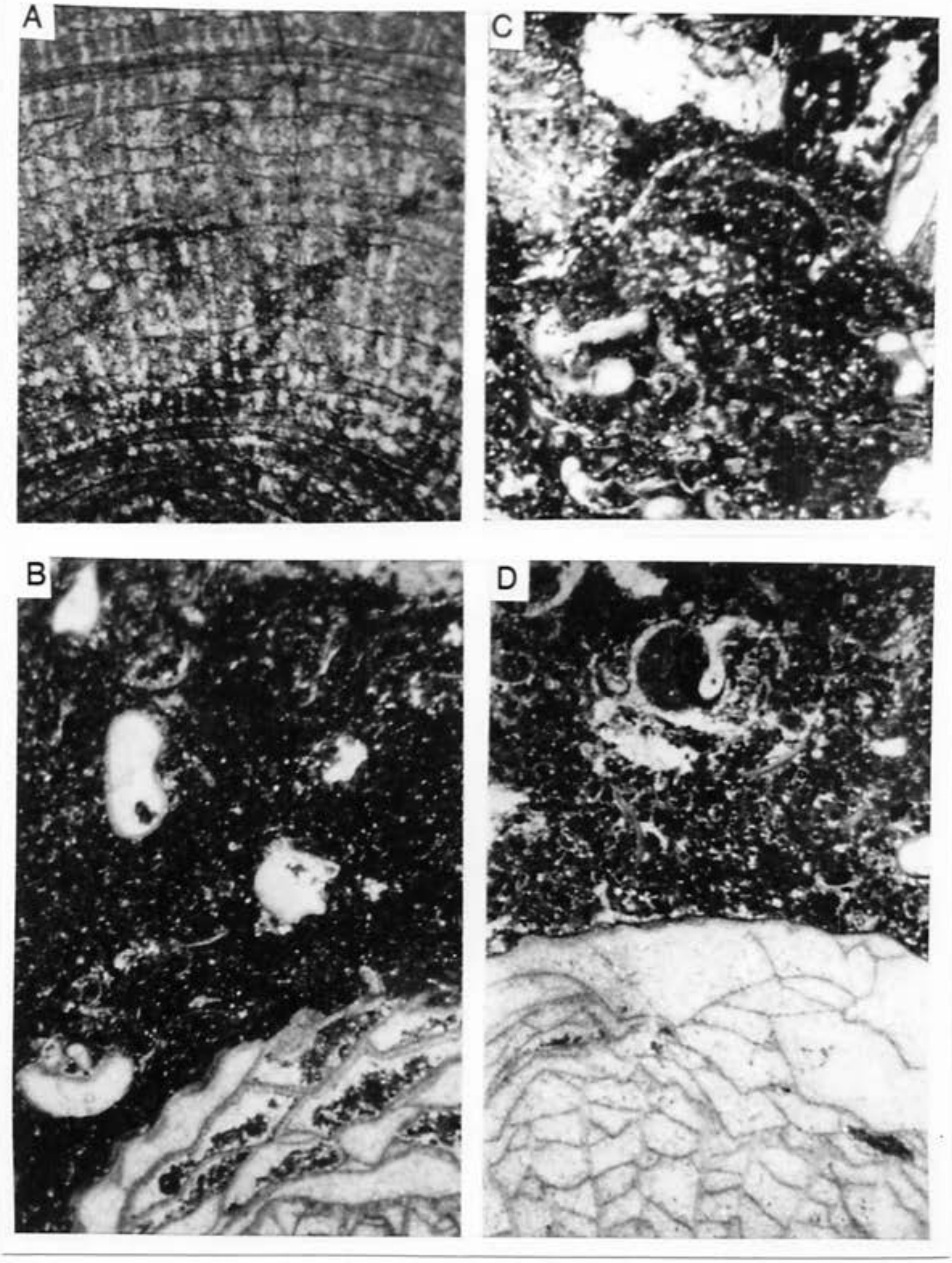


Figure 8.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In many cases the Stromatoporoid Facies underlies, and grades upward through, a thin (10-20 cm) calcarenite bed into the Dolomitic Cryptalgal Facies. Where Facies 2 overlies Facies 1 these two rock types are separated by sharp bedding contacts (Figure 8) which have been interpreted as deepening surfaces. The Stromatoporoid Facies occurs very frequently in the eastern portion of the Thacher Member, south of Albany, in the area where the Mohawk and Hudson River valleys intersect.

The Stromatoporoid Facies contains abundant macrofauna including stromatoporoids, solitary corals, ostracodes, trilobites, bryozoa, encrusting spirorbid worm tubes, codeacian algae, gastropods and brachiopods. The fauna of this facies is highly diverse in comparison to that of most of the Thacher Member. The biopelmicrite associated with this facies is usually thoroughly bioturbated. Where Facies 2 grades into Facies 1 the calcarenite contains a less diverse faunal assemblage. This assemblage includes abundant skeletal debris, ostracodes, spirorbid worm tubes and commonly digitate stromatoporoids. The tops of the calcarenite beds occasionally contain vertical, funnel-shaped burrows (Locality 57).

Interpretation

The presence of a relatively abundant and diverse in situ fauna strongly suggests a subtidal environment of deposition for these rocks. Laporte (1961) maintained that the association of the codiacean algae (Garwoodia gregaria) and stromatoporoids (Syringostroma barretti) indicates deposition in a continuously submerged shallow lagoon or carbonate bank. Rickard (1962) considered the stomatoporoid facies as indicative of deposition in a transition from the normal marine facies of the Coeymans Formation (pelmatazoan/brachiopod calcarenite) to the more faunally restricted (and shallower) facies of the Manlius Formation (Facies 1 & 3). Read (1973) interpreted a stromatoporoid occurrence similar to Facies 2 rocks of the Thacher Member (in the Pillara Formation of Western Australia) as being shallow subtidal. The gradational upward trend of the Stromatoporoid Facies into Facies 1 rocks indicates that the Stromatoporoid Facies was deposited close to sea level and often aggraded to sea level.

The Stromatoporid Facies was deposited as biohermal and biostromal accumulations. The biohermal deposits are meters to tens of meters in diameter and exhibit up to 1 meter of relief. The biostromal deposits contain small biohermal accumulations with diameters of less than 1 meter and relief of 10 to 50 cm over the adjacent thin-bedded facies. The stromatoporoid accumulations in the Thacher Member are interpreted to be analogous to patch reefs which are common on many modern carbonate banks.

FACIES 3 - The Thin-bedded Ribbon Limestone Facies

Description

The Thin-bedded Ribbon Limestone Facies of the Thacher Member occurs as continuous (on an outcrop scale) thin beds, 3 to 10 cm thick, of dense, dark grey to black, fossiliferous limestone. These rocks will often ring when struck with a hammer and possess a fetid odor when freshly broken. The top bedding surface is slightly undulose which may indicate compacted ripples and it is irregularly strewn with fossils, most notably Tentaculities gyracanthus. Thin argillaceous partings are common between beds, especially in lower portions of Facies 3 occurrences. Mudcracks have been previously reported from these rocks (Laporte, 1967) but no desiccation features except birdseye structures were observed within this facies during the course of this study. Each thin bed consists of a composite of normally graded units (Figure 10) which are usually not as continuous as the beds in which they occur. Graded units (1.5 to 4 cm) laterally truncate others, indicating scour. These units grade from bioclastic and/or intraclastic calcarenites to pelletal packstone, wackestone and mudstone. Small-scale ripple trough cross-statification was also observed in the bioclastic (coarser) portions of these graded units. The muddy, pelletal portions of the units are often burrowed

(Figure 10) and rarely the entire graded unit has been homogenized by bioturbation.

The graded units are readily recognizable in thin section (Figure 10). They alternate from sand to cobble sized biointrasparite to sand sized pelletal packstone (packed pelsparite) and biopelmicrite. The slightly abraded bioclastic material is composed predominantly of tentaculitid shells, ostracodes and brachiopods as previously noted by Rickard (1962) and Laporte (1967).

The fauna of this facies is characterized by an extremely abundant number of individuals of a relatively non-diverse fossil assemblage. The taxa include *Tentaculites gyracanthus*, the spiriferid brachiopod *Howellella vanuxemi*, the strophomenid brachiopod *Mesodouvillina varistriata*, the leperdited ostracode *Herrmannina alta*, an unidentified bivalve (pelecypod mold) and treptosome bryozoan. Notably absent are normal marine taxa such as trilobites and echinoderms.

Stratigraphically this facies often underlies the dolomitic cryptalgal laminites of Facies 1. Where Facies 3 immediately underlies Facies 1 it commonly contains "birds-eye" structures, is thicker-bedded (2.5 to 5 cm) and contains fewer argillaceous partings. Also, as first noted by Rickard (1962), the ribbon limestones occasionally occur lateral to the stromatoporoid-bearing rocks of Facies 2 (Locality 53-b). Facies 1, 2 and 3 are

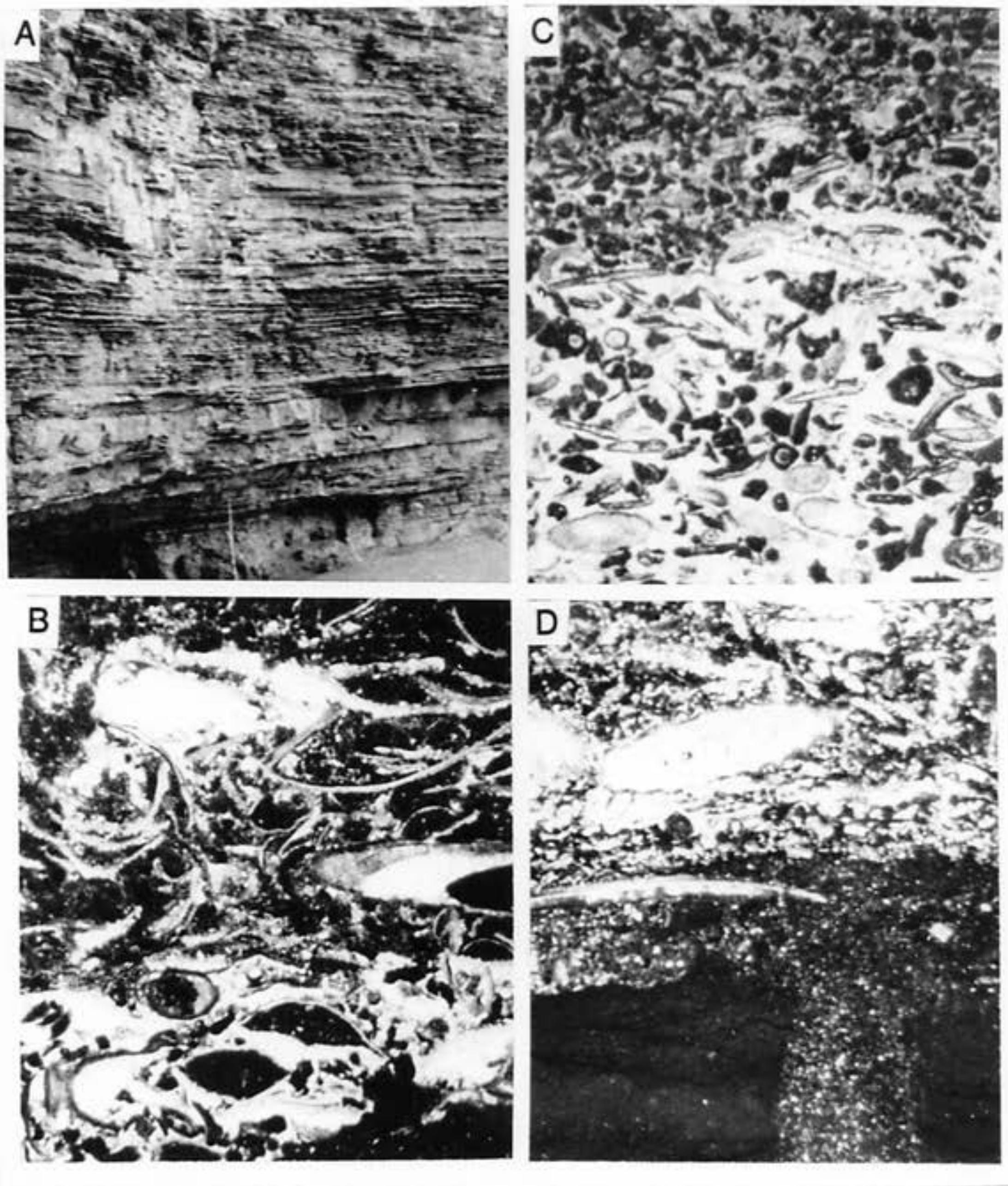
Figure 10: Photographs of Facies 3.

A. Photograph of ribbon limestones near the base of the Thacher Member at Locality 59 (six foot ruler for scale). Note that the beds thicken (toward upper center of photo) which reflects higher energy conditions of deposition. PAC 4 begins over the lower massive bed and continues to the top of thicker bedded ribbon limestones.

B. Graded unit within a ribbon limestone bed (x 15, Sample 60-6).

C. Upper portion of a graded unit (x 15, Sample 60-10).

D. Contact between burrowed micrite and the lower portion of a graded unit (x15, Sample 60-6).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the most frequently occurring facies in the eastern portion of the research interval (localities 67 to 57). Facies 3 is volumetrically very limited west of locality 67. Geographically the thin-bedded ribbon limestones occur most frequently in the area just southwest of Albany and southward in the Hudson Valley (localities 67 to 57).

Interpretation

As noted by Rickard (1962) and Laporte (1967) the presence of large numbers of individuals in a relatively non-diverse faunal assemblege indicates "abnormal" environmental conditions. The factors controlling such conditions are likely to be salinity, salinity variations, temperature, temperature variations, shallowness and accompanying periodic exposure (Rickard, 1962; Laporte, 1967). Periodic fluctuations in energy conditions are suggested by the presence of the internally graded units. Laporte (1967) interpreted this combination of features as an indication that the ribbon limestones were deposited in an intertidal setting. An alternate hypothesis for the deposition of these rocks is that they formed in a restricted subtidal environment (relative to Facies 2, 4 & 5) that was influenced by periodic wind-induced storm currents. These currents are a possible source for the higher flow regime required to deposit the coarse-grained portions of the graded units.

Laporte (1967) defined "intertidal" as "... a sedimentary regime that is regularly and periodically flooded by marine water for an unspecified duration." and when compared to the supratidal environment "...the intertidal environment was more frequently submerged by water generally having greater velocity..." (Laporte, 1967 p.85). The definition for an intertidal facies used in this report is that facies which regularly underlies the supratidal facies (Facies 1), show evidence of fluctuating energy conditions and grade into subtidal facies. This definition implies that the upper boundary for tidal range is known to occur at the contact with Facies 1. The lower boundary of the intertidal facies is not definitively known since it grades into subtidal facies. The problem of identifying an intertidal facies which precisely coincides with the definition from modern environments was addressed by Laporte (1967) and recently by Demicco (1983) who concluded that an ancient facies may be classified as intertidal but that it cannot be absolutely stated that the facies did not also contain shallow subtidal deposits.

The coarse-grained, ripple-scale, trough cross-stratified portions of the graded units within the Thin-Bedded Ribbon Limestones represent periods of higher energy. These periods of higher velocity currents may occur either by the oscillation of tidal and wind-induced currents associated with flood and ebb tide (intertidal setting) or storm events (intertidal and subtidal settings). Given the marine character to the facies, as is evidenced by the continuous bedding planes and faunal content, the most likely process responsible for deposition of the internal graded units is wind-induced currents. The fact that these coarse portions grade upwards into burrowed, peloidal micrite indicates a cessation of flow followed by a period of low energy which allows the preservation of burrowing. Although these features are often attributed to sedimentary processes in an intertidal setting similar features have been observed in a modern littoral sand platform off the southeast coast of Florida (Wanless, 1981). There, local blowouts occur during storms on the Thalassia-covered subtidal platform and form fining-upwards 0.3 m to 2m in thickness. The scale of the Lower Devonian graded storm features is smaller, possibly because of the decreased effects of storms in the Lower Devonian epeiric sea.

The characteristic, restricted faunal association common to this lithofacies is attributed to the development of seaward physical barriers (by the aggradation of stromatoporoid bioherms which occur in association with and in close proximity to Facies 3 rocks in the northeastern portion of the outcrop belt). This restriction by barriers may have lead to salinity fluctuations within this area. Also the Devonian headlands, composed of Ordovician rocks, may also have added to the restriction due to irregularities of the coastline. The cross-section of Helderbergian rocks of New York State (Rickard 1962) shows that the Ordovician unconformity has relief and rises to the east occurring just below the Manlius Formation in many places along the Hudson Valley outcrop belt. The shape of the Ordovician land mass may have given rise to an embayed coastline.

The lithologies of this facies compare with Standard Micro Facies (SMF) 9 and 16 (Wilson, 1975 & Flugel, 1982). SMF 9 includes bioclastic wackestones and bioclastic micrite. This Standard Microfacies occurs within the coarser grained portions of the graded beds in the ribbon limestones and generally indicates deposition in a subtidal environment. SMF 16 includes pelloidal grainstones (pelsparite) and occurs in the finer-grained portions of the graded beds. This facies is thought to indicate deposition in a restricted bank setting (Wilson, 1975).

In summary, the Thin-Bedded Ribbon Limestone Facies of the Thacher Member is interpreted to represent an intertidal as well as a relatively restricted subtidal setting (such as a restricted bay or pond) which occurs in close proximity to the stromatoporoid bearing rocks. These restricted environments are thought to be analogous to the "lakes" in Florida Bay which are restricted by Pleistocene topographic highs and modern mud mound (island) accumulations (Enos and Perkins, 1979). Facies 3 has been observed as a lateral equivalent to the subtidal deposits of Facies 2. In similar fashion to the stromatoporoid bearing rocks, this facies often underlies the supratidal dolomitic algal laminites indicating that it formed in an intertidal to a shallow subtidal setting.

FACIES -4 The Massive-Bedded Calcarenite Facies

Description

The Massive-Bedded Calcarenite Facies of the Thacher Member is easily recognized in the field by the fact that it weathers into massive beds, 2 to 10 feet thick, and is composed of fine-to coarse-grained calcarenites with minor amounts of biomicrite. This facies commonly exhibits current laminations including planar and ripple cross-stratification. The calcarenites are of two types, coarse-grained skeletal and fine-grained pelletal calcarenites.

The coase-grained, skeletal calcarenites commonly grade upward from fossiliferous wackestone (biomicrite) into interstratified wackestones and cross-stratified grainstones to bioclastic and intraclastic calcarenite grainstones (Figure 11). The lower endmember portion of this subfacies is bioturbated biomicrite which grades upward into interstratified wackestone and grainstone (with the grainstones exhibiting ripple cross stratification and planar current-laminations). The upper endmember of the coarse-grained calcarenite is moderately to well sorted and either biosparite (bioclastic grainstone) or biointrasparite. The grain size of the allochems ranges from coarse sand to granule sizes and they are generally well rounded. The biosparite

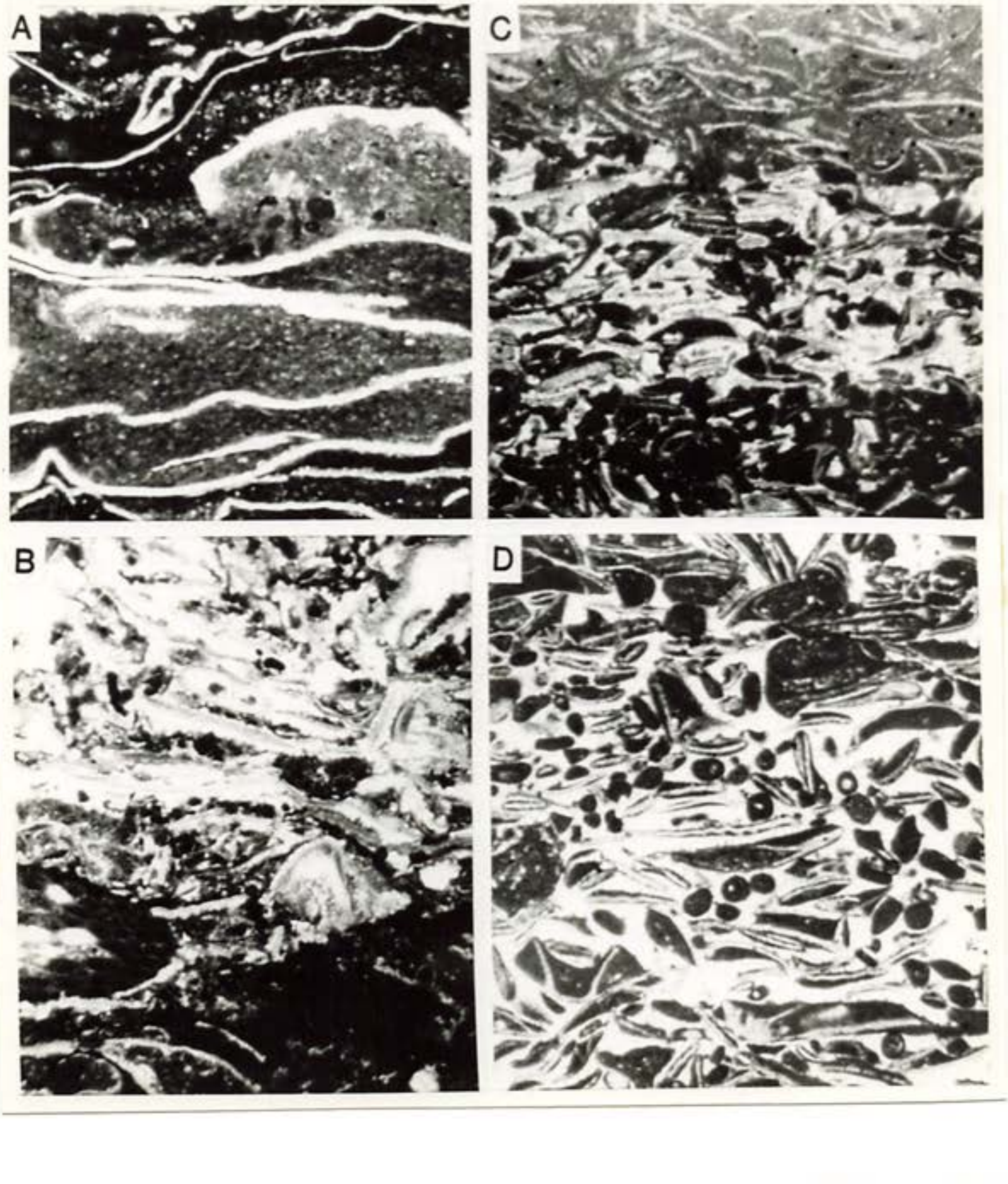
Figure 11: Photomicrographs of the coarse-grained calcarenite of Facies 4 (x15).

A. Brachiopod, ostracode biomicrite (subtidal environment) Sample 94-13.

B. Alternating biomicrite and biosparite (shallow subtidal environment) Sample 94-15.

C. Alternating bioclastic biomicrite & biosparite exhibiting a high degree of abrasion and fragmentation (shallow subtidal to intertidal environment) Sample 94-3.

D. Biointrasparite (generally intertidal) Sample 94-10-a.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commonly occurs in association with unlaminated, clotted, micritic heads which are analogous to thrombolites (Aitken, 1966; Ahr, 1971). The biointrasparite was observed to occur in association with digitate stromatolites, oncolites and superficially coated, radial ooids. Both types of grainstones, biosparite and biointrasparite, commonly exhibit bimodal, ripple cross-stratification and occasionally mixed bedding in the form of flaser bedding (Reineck & Singh, 1972). These coarse-grained calcarenites are analogous to SMF 10 and 11 (Flugel, 1982).

The biointraclastic subfacies of Facies 4 has been called the Thick-Bedded Thacher by Rickard (1962). The Thick-Bedded Thacher occurs predominantly in the western portion of the Thacher Member between Oriskany Falls (locality 130) and Jamesville (locality 151), but rocks of similar character occur throughout the Thacher Member in association with the rock types and sedimentary structures described here.

The second type of calcarenite is a fine-grained, peloidal limestone which grades upward from bioturbated fine-grained pelletal wackestones and packstones to well sorted, finely current-laminated pelletal grainstones (Figure 12). The peloidal grainstone ranges in grain size from fine to coarse sand. The peloidal calcarenites are analogous to Standard Micro Facies 16 (Wilson 1975). The commonly occurs in association with unlaminated, clotted, micritic heads which are analogous to thrombolites (Aitken, 1966; Ahr, 1971). The biointrasparite was observed to occur in association with digitate stromatolites, oncolites and superficially coated, radial ooids. Both types of grainstones, biosparite and biointrasparite, commonly exhibit bimodal, ripple cross-stratification and occasionally mixed bedding in the form of flaser bedding (Reineck & Singh, 1972). These coarse-grained calcarenites are analogous to SMF 10 and 11 (Flugel, 1982).

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Petrographically the coarse-grained calcarenites range from biomicrite through poorly-washed biosparite, biosparite, biointrasparite, and intrasparite (Figure 11). The intraclasts are either mud clasts, bioclasts (commonly containing mud-filled fossil fragments) or aggregate grains. The bioclasts appear to have been derived from the biomicrite (wackestone) portions of this facies and often occur in association with digitate stromatolites and clotted algal fabrics. The fine-grained calcarenites range from packed, bioturbated biopelsparite to finely planar, current-laminated often ripple cross-stratified pelsparite (Figures 12 A & B). The presence of aggregate grains (grapestone) implies partial submarine lithification (Bathurst, 1975).

The fauna of the coarse-grained calcarenite is highly diverse and contains spiriferid and strophomenid brachiopods, gastropods, bryozoa, rugose corals, tentaculities, pelmatozoans, ostracodes and codiacian algae. The skeletal remains show little or no abrasion in the micritic endmember of this facies while in the higher portions of Facies 4 they exhibit fragmentation and rounding. Also common of this facies are oncolites and digitate stromatolites as well as clotted algal fabrics

Figure 12: Photomicrographs of lithologies within the fine-grained calcarenite of Facies 4 (x 15).

A. Bioturbated ostracode biopelmicrite (restricted subtidal environment) Sample 116-1b.

B. Planar laminated pelsparite (intertidal environment). Sample 116-2.

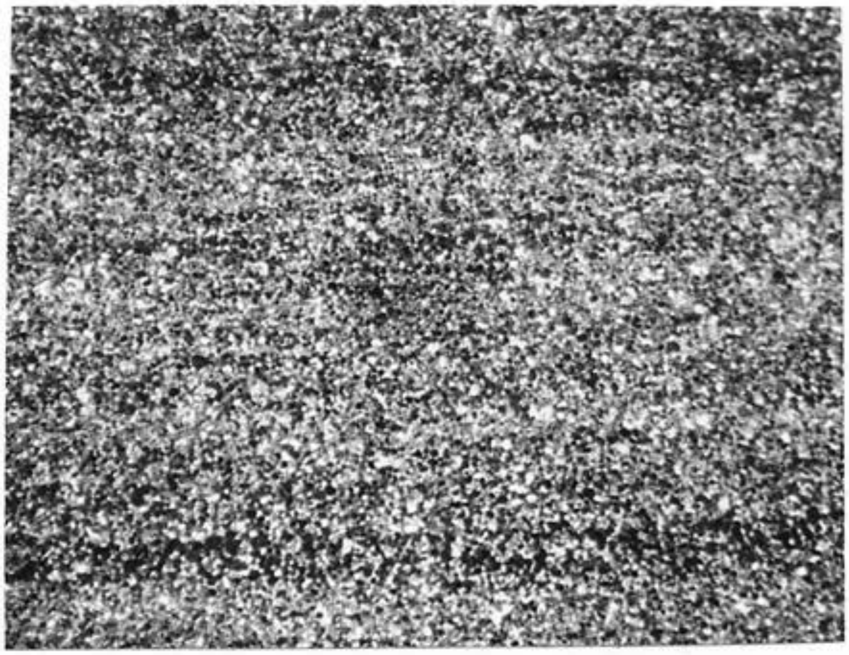


Figure 12 A.

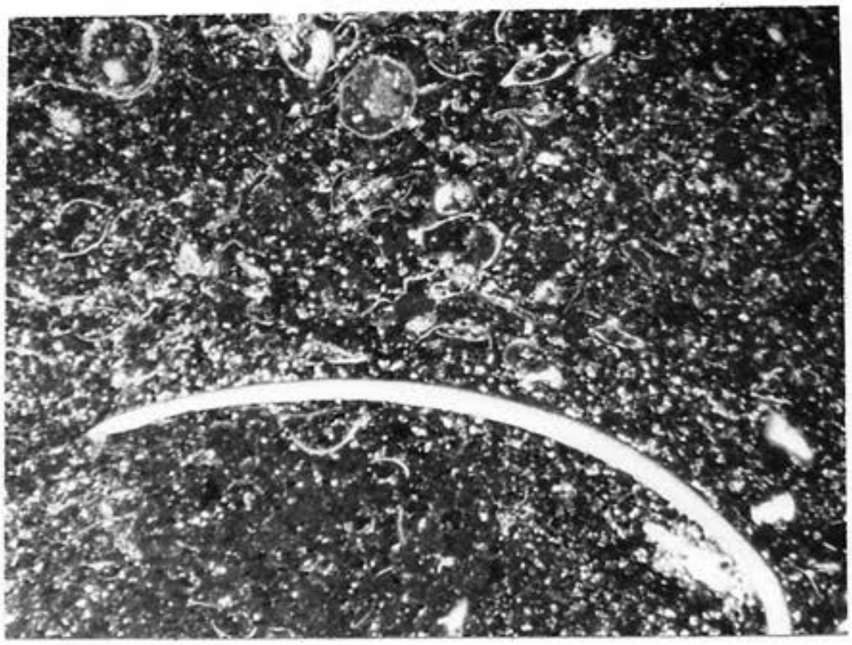


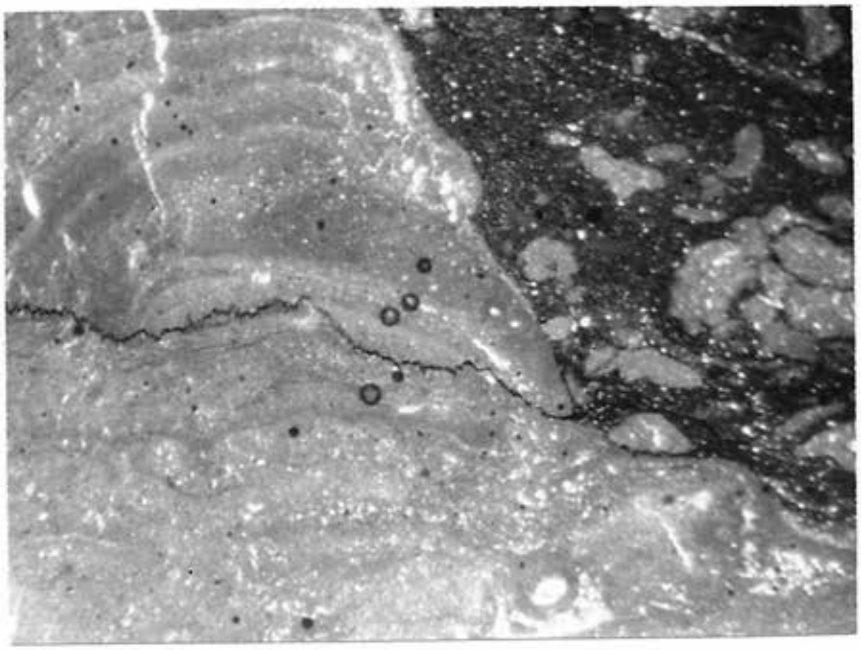
Figure 12 B.

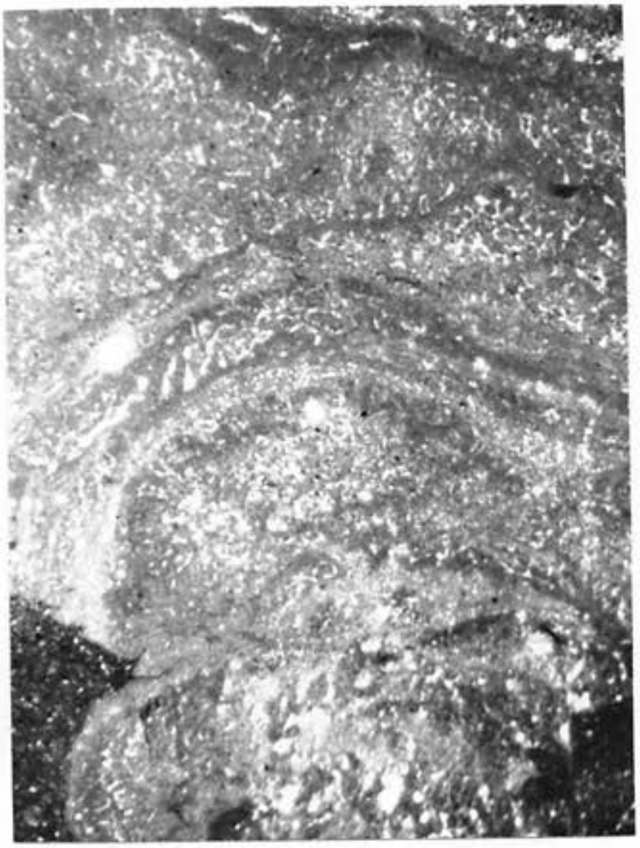
described as thrombolites by Ahr (1971) and Loucks & Anderson (1980). Although macrosocpically the clotted algal fabrics exhibit no fine laminations, in thin section (Figure 13) they are well laminated and are virtually identical to digitate stromatolites.

The fine-grained calcarenite contains a sparse and less diverse fauna in comparison to the coarse-grained calcarenite. It contains a high spired gastropod (Loxonema sp.) and two different ostracodes, one of which is Herrmannina alta.

Stratigraphically the coarse-grained calcarenite facies occurs above the more diverse Facies 5 and underlies Facies 1. The coarse-grained, bioclastic and intraclastic grainstone portion of this facies is the most commonly encountered sub-facies of Facies 4. The complete transition from wackestone to grainstone does not occur ubiquitously, although a complete section showing this gradational transition occurs at locality 94 (Cherry Valley) within PAC 5, 22 feet below the top of the dolomitic cryptalgal laminites to 12 feet below this marker (see Outcrop Analysis). A portion of this transition is repeated in the overlying PAC from 10 feet below the top of the Facies 1 to the base of that unit. This facies appears to occur adjacent to the subtidally deposited rocks of Facies 2 and 5. The fine-grained calcarenites occur over Facies 1 rocks and adjacent to

Figure 13: Photomicrographs from clotted algal head (x 15, Samples 94-10 top & 94-10 base). Note the finely laminated texture to the algal buildups.





Facies 2 rocks. A complete gradational transition for the subfacies of the fine-grained calcarenite can also be seen at locality 94 from just over the dolomitic cryptalgal laminites to 4 feet above them. This is repeated again from 4 feet to 9 feet above the dolomitic cryptalgal laminated marker bed.

Interpretation

The existence of a diverse assemblage of biologic constituents in association with a micritic lithology (e.g. the biomicrite endmember) indicates that the lower endmember of the coarse-grained calcarenite facies was deposited in a quiet water subtidal environment (Purdy, 1961). The interbedded biomicrite and grainstone indicates fluctuating energy conditions within a shallow subtidal to intertidal environment. The presence of thrombolites within these rocks generally indicates a shallow subtidal environment (Aitken, 1966; Ahr, 1971). The presence of oncolites, micritic intraclasts and aggregate grains in association with digitate stromatolites and flaser bedding indicates deposition in a shallow subtidal to intertidal setting (Logan, Rezak & Ginsburg, 1964; Davies, 1970; Ahr 1971; Read, 1974; Loucks & Anderson, 1980). This interpretation is supported by the fact that this endmember occurs immediately subjacent to the supratidally deposited dolomitic algal laminites. In Shark Bay, Western Australia, Davies (1970) has demonstrated that broad sand shoals exist in a shallow subtidal setting which grade laterally into both a quiet water subtidal environment and an intertidal environment. This interpretation is also consistent with that derived for Standard Micro Facies 10 and 11 (Flugel, 1982). The various rock types for the coarse-grained calcarenites have similar faunal characteristics, the only difference being that the current laminated calcarenites show ever increasing fossil abrasion plus fragmentation and incorporation of shell debris into micritic bioclasts (upward in section). The bioclasts were derived from semi-lithified biomicrite which co-existed at greater depths with the bioclastic grainstones. The bioclasts increase upward in amount, presumably because the quiet water biomicrites had an ever decreasing chance of being preserved as the sediments aggraded to more shallow depths (where they are more likely to be abraded by wind or tide induced currents). As aggradation continued, more bioclasts were produced and less biomicrite was preserved as complete beds.

The totally bioturbated nature of the fine-grained calcarenite, associated pelmicrite and biopelmicrite, and the associated non-diverse fauna, indicates a restricted subtidal environment. These rocks grade upward into planar current-laminated and ripple cross-stratified pelsparite indicating shoaling to a more agitated environment.

In summary, Lithofacies 4 includes a range of rock types that are related in vertical sequence. The variation from biomicrite to bioclastic sparite biointrasparite (in the coarse calcarenites) and from biopelmicrite to pelsparite (in the fine-calcarenites) is interpreted to reflect aggradation of a quiet water lagoon into periodically current-agitated intertidal shoals. The micritic endmembers indicate low energy, quiet water, subtidal deposition, while the sparry lithologies indicate very shallow, shoal water deposition. The most frequently encountered subfacies is the ripple-scale, trough cross-stratified bioclastic and intraclastic, coarse-grained calcarenites which may exhibit flaser bedding and may be associated with clotted algal heads and digitate stromatolites. These subfacies reflect the deposition of sediments in an environmental setting ranging from relatively high energy subtidal to intertidal sand shoal deposits. The subfacies containing the interbedded wackestone and grainstone and the biomicrite (fossiliferous mudstone) reflect deposition in a sand shoal fringe, to a quiet water subtidal environment, respectively.

FACIES 5 - The Medium-Bedded Limestone Facies

Description

The Medium-Bedded Limestone Facies is characterized by 8 to 20 cm beds of dark gray, fossiliferous generally fine-grained limestone separated by thin beds (< 1cm), of brown weathering, calcareous shale (Figure 14). The lithology within each bed is variable. Some portions are composed of current laminated skeletal debris, while the bulk lithology is micritic. These beds are usually continuous across an outcrop but they do occasionally pinch out or join to form a larger bed. At the base of each bed is a sharp contact with the underlying shale. The top of the limestone bed exhibits a gradational transition between the lithology within the limestone bed and the overlying calcareous shale. The topmost portion of each bed is often undulatory and can be rippled (symmetrical ripples). Beds often exhibit burrows which extend 1 cm into the limestone from the top of the bed.

Petrographic analysis reveals that the internal characteristics of the limestone beds are complex. The lithologies include micrite, biomicrite, biopelmicrite, poorly washed biopelsparite, biopelsparite, and biosparite. Internally the limestone beds are often marked by sharp contacts between lithologies; occasionally these contacts exhibit erosional features (Figure 15).

Figure 14: Photograph of medium-bedded limestones of Facies 5 and massive-bedded, planar laminated, coarse-grained calcarenite of Facies 4 (PAC 5,6,7 & 8 at Locality 74).

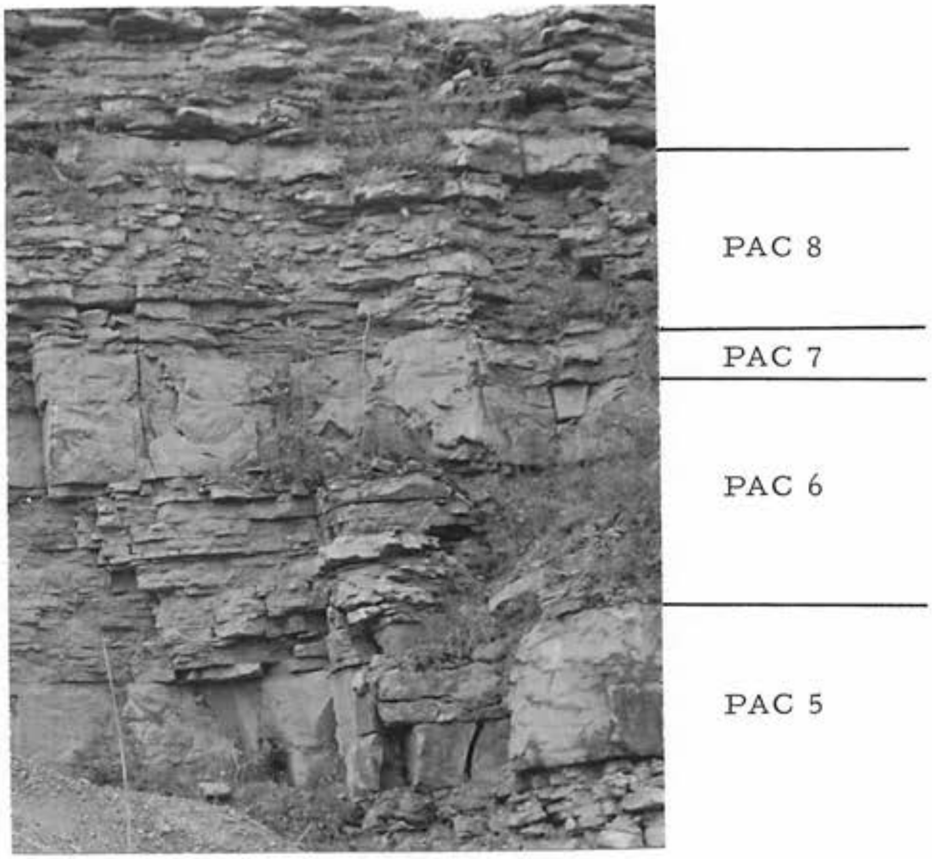


Figure 14

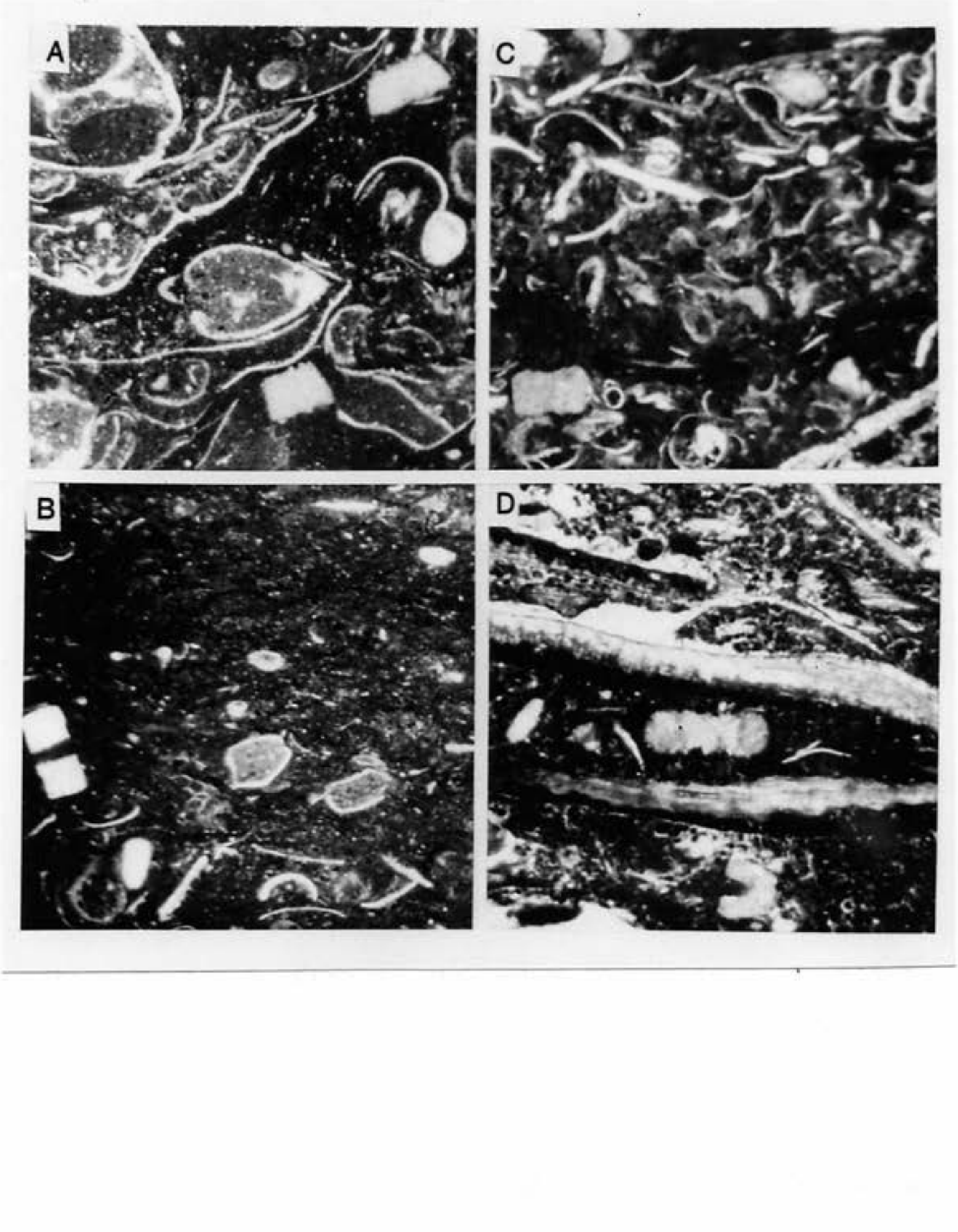
Figure 15: Photographs of Facies 5. (x15).

A. Biomicrite containing brachiopods, crinoid columnals, gastropods and ostracodes (Sample 72-b-13).

B. Biomicrite containing crinoid columnals, brachiopod, bryozoan, ostracode and gastropod debris.

C. Pelmicrite overlain by biopelsparite with aggregate grains of pelmicrite. (Sample 74-4a).

D. Biopelsparite containing a psuedopunctate brachiopod (*Mesodouvillina varistrata*) crinoid columnals, ostracodes and impunctate brachiopod debris (Sample 72-b-12).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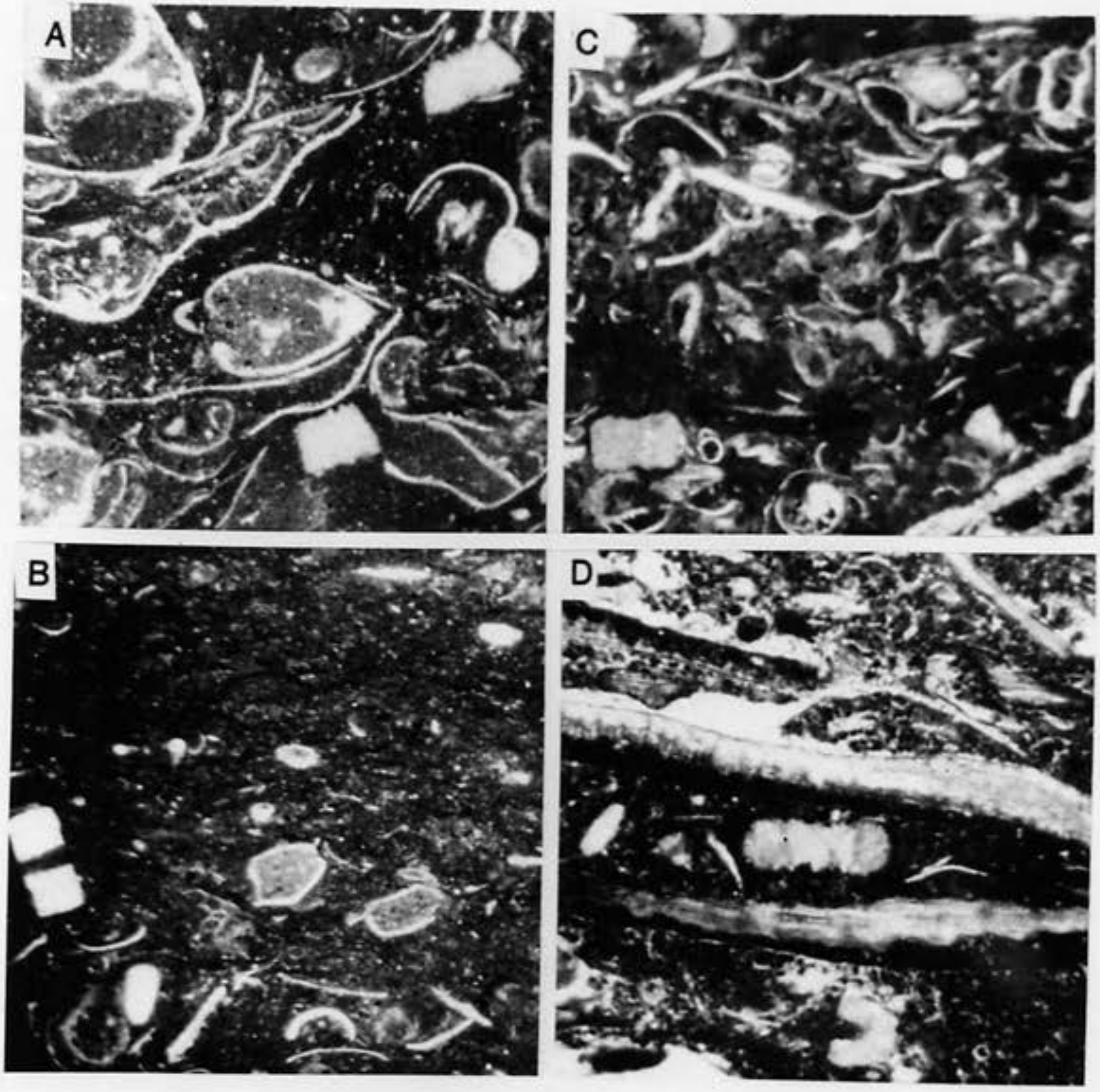
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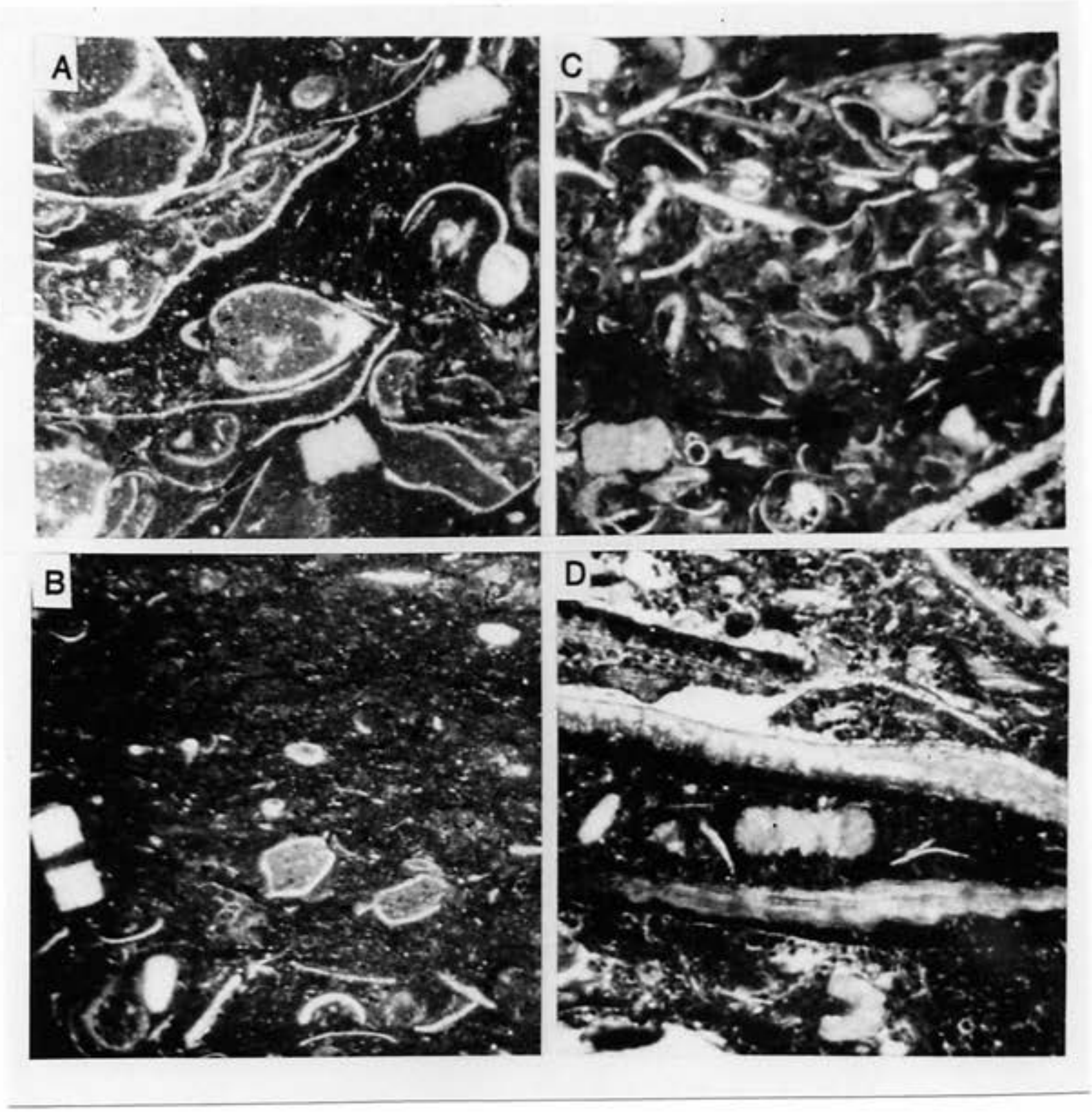
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Burrows are also common at these interfaces (Figure 15 & 16). The internal laminae which contain the sparry lithologies are most often normally graded but may also show no apparent grain-size trend. Frequently beds are sufficiently bioturbated that no original sedimentary structures remain.

The fauna of this facies is the most diverse in the Thacher Member. It includes pelmatozoans, gastropods, trilobites, calcareous algae, bryozoa, ostracodes, a spiriferid brachiopod (Howellella vanuxemi) and a strophomenid brachiopod (Mesodouvillina varistriata). There are occasionally stromatoporoids, rugosan corals and tentaculities when this facies occurs in proximity to Facies 2 or 3.

The calcareous shales contain a fauna similar to that of the limestone beds with the addition of plant stems (Brown Algae ?) which may be observed on freshly broken bedding plane surfaces of the shale.

Stratigraphically Facies 5 occurs in conjunction with and lateral to Facies 2 (as in the upper Thacher at loc. 59). Facies 5 often occurs below Facies 1, 2, 3, and 4. Facies 5 also apparently occurs adjacent to Facies 4. This is evidenced by the fact that closely spaced outcrops (74 to 106-b), when correlated with well-known key beds (such as the waterlime bed used by Rickard, 1962), show that Facies 5 exists lateral to Facies 4. This Facies

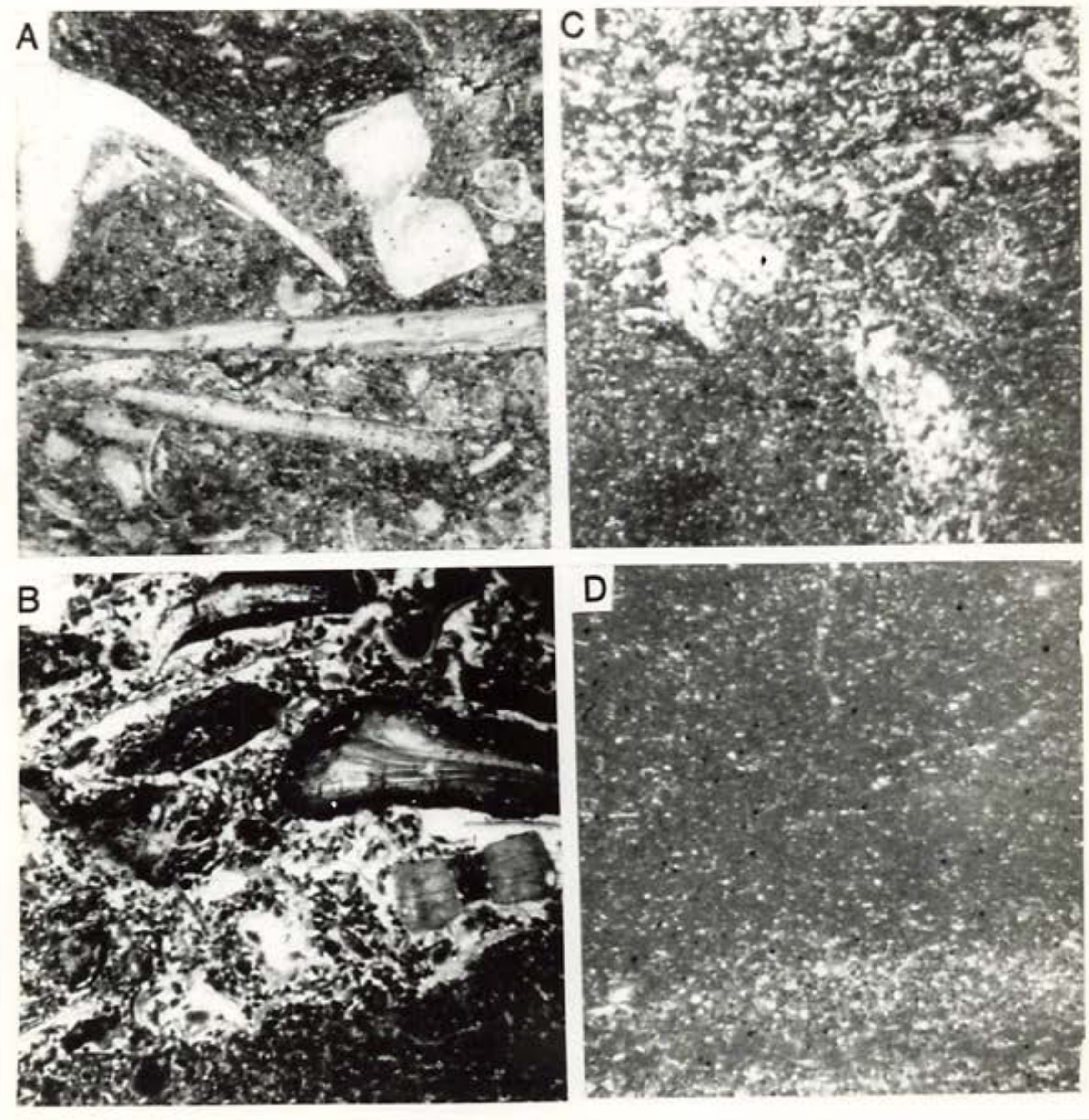
Figure 16: Photomicrographs of Facies 5. (x15).

A. Bimicrite containing impunctate brachiopods (Howellella vanuxemi), crinoid columnals, ostracodes and other skeletal debris (Sample 74-19).

B. Biopelsparite containing bored brachiopod debris with micritic envelopes, echinoderms osracodes and intraclasts overlying a pelmicrite (Sample 87-8).

C. Pelmicrite overlain by biopelsparite which also infills burrow (Sample 72-b-12).

D. Biomicrite with sponge spicules. (Sample 74-10)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ranges in thickness from 0.3 to 1 meter to deposits of approximately 3 meters.

An important upward-fining trend accompanied by a dramatic decrease in faunal elements is exhibited by this facies at many locations and in several different PACs (Figures 33 to 37). The lithologies within this trend range from mixed biosparite, biopelsparite, poorly washed biopelsparite, biopelmicrite and biomicrite, to almost pure micrite with only gastropods as faunal elements. This trend is evident in PACs 5, 6, & 8 at Localities 74 (Howes Cave), 70, and 72-b,137 (Munnsville, N.Y.) and 144 (Clockville, N.Y.). At each of these localities the transition from fossiliferous medium-bedded limestones to unfossiliferous medium-bedded micritic limestone is complete. That is, the rocks near the base of the medium-bedded rocks are dominated by limestones of variable lithologies containing an abundant and diverse fauna whereas this facies nearer the top become more micritic and less fossiliferous.

Interpretation

Because the faunal diversity is high, and normal marine fossils such as crinoids are abundant, the Medium-bedded Limestone Facies is interpreted as having been deposited in a relatively open (unrestricted) subtidal setting. The large amount of micrite suggests a quiet water depositional setting such as a carbonate bank or lagoon. The presence of variable lithologies including biosparites indicates that the substrate was effected by variable energy conditions. Storm induced currents are hypothesized to explain these occurrences.

The upward fining trend which is often exhibited by this facies is probably due to aggradation in a quiet water bank setting, from relatively deep subtidal deposits to shallow mud deposits leeward of a physical barrier. Analogous patterns of sedimentation and upward loss of faunal diversity may be seen today in the island stratigraphy of Florida Bay (Enos & Perkins 1977) and from the bank deposits of Rodriguez Key (Turmel & Swanson, 1976). The sparsely fossiliferous micrites are often overlain by bioclastic and intraclastic, shoal water grainstones of Facies 4 indicating that the restricted marine setting had shallowed to a point where shoal deposits could form over it. Similar deposits might be recognized in Florida Bay over the mud accumulations except that mangroves stabilize the substrate.

In summary, Facies 5 represents the most unrestricted and open marine subtidal facies within the Thacher Member. The fossiliferous biomicrite records normal marine, neritic deposition while the unlaminated, sparsely fossiliferous micrite indicates deposition in a very shallow, restricted marine environment.