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I am submitting herewith a thesis written by Walter S. Borowski entitled "Petrology, Depositional Environments, and Stratigraphic Analysis of a Part of the Middle Ordovician Chickamauga Group Limestones near Clinton, Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

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4

PETROLOGY, DEPOSITIONAL ENVIRONMENTS, AND STRATIGRAPHIC ANALYSIS OF A PART OF THE MIDDLE ORDOVICIAN CHICKAMAUGA GROUP LIMESTONES NEAR CLINTON, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

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3064995

DEDICATION

This volume is dedicated with love to my parents, Evelyn and Clarence, for their continued guidance and support throughout my early life and academic career. Without them, none of my successes could have been possible.

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I would like to thank Kenneth R. Walker, my committee chairman, for reading numerous drafts of this thesis and making many helpful suggestions. My other committee members, Robert L. McLaughlin and Thomas W. Broadhead, also read drafts of this thesis with utmost care and suggested many useful amendments concerning both grammar and content. Many if not most of the ideas contained within this thesis came from informal discussions with each of these three men. Fred B. Keller also contributed many ideas which appear in this thesis.

I would also like to thank all my friends and colleagues who helped me maintain my sanity throughout most of the work on this thesis. Special thanks go out to the Hopsons - in particular Janet, Nancy and Doug Schnoebelen, the Asreens, the Ghazizadehs, and Tom Webster for their kindness and guidance. Nancy Schnoebelen also generously typed a draft of my thesis when I was greatly pressed for time.

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and Mrs. David B. Jones, and Mr. and Mrs. William M. Taylor for granting me permission to scurry all over their property.

ABSTRACT

The Middle Ordovician Chickamauga Group carbonates exposed near Clinton, Anderson County, Tennessee were deposited in water depths less than 20 m. Of the 450 meters of stratigraphic section, the basal 200 m are composed of interbedded tidal flat and associated restricted subtidal sediments. Tidal channel deposits are comprised largely of peloids and bioclastic grains in planar laminations, starved ripples, and cross-ripple laminations. Levee crest sediments are laminated with alternating, discontinuous grainstone laminae and flat, continuous, mud-rich laminae. Relict laminae identical to that of levee crest sediments are found within bioturbated peloid packstones/grainstones; these deposits are interpreted to represent levee interiors. Thin-bedded rocks with or without internal laminations, mudcracks, and robust vertical burrows are inferred to be algal flat sediments somewhat analogous to Recent Andros Island inland algal marsh environments. Tidal pond sediments are completely bioturbated and possess an indigenous restricted-water biota including ctenodontid(?) clams, ostracodes, gastropods, and trilobites. Other rocks which closely resemble tidal pond deposits have a greater quantity of calcareous algae and lesser amounts of ctenodontid(?) bivalves. Tidal pond margin and/or adjacent marine margin rocks exhibit rare or absent macrofossils and common spar-filled, vertical burrows.

From 200 to 300 m in the section, a major deepening trend culminated in the deposition of peloid-fossil packstones and grainstones with a diverse biota. These rocks are interpreted to be storm

deposits since most beds display basal scour surfaces with overlying fossil lag layers which grade upwards into laminated peloid or mudstone horizons.

The upper 100 m of the section is dominated by bioturbated mudstones inferred to represent restricted lagoon deposition. This lagoon sequence is interrupted by beds containing 10 cm high, hemispherical Tetradium heads, indigenous restricted-water fossils, and current-oriented peloids and fossil grains which were also deposited in restricted lagoon environments. Associated facies include Tetradium-bearing packstones and grainstones, and the remnants of intertidal algal mats. These deposits are inferred to represent mudbank islands and fringing environments analogous to the Porites-Goniolithon build-up ringing Rodriguez Key in the present-day Florida Keys.

A holistic approach using petrographic and fabric data, vertical-contact data, recurrent stratigraphic sequences, and a knowledge of processes operating in modern environments allowed the recognition of seven subenvironments within a 40 m tidal flat sequence. This approach not only aids in the recognition of subenvironments, but it also relates these subenvironments to each other as components of a depositional complex. The frequency of vertical contact between specific rock types is not random. Genetically related sediments deposited in roughly adjacent environments are more often in vertical contact with one another than sediments which were deposited in more distal environments. Recurrent stratigraphic sequences reinforce this relationship but they also record the migration of environments through time. Two idealized sequences were documented; both possess

laminite caps and represent regressive cycles. Migration from tidal pond center to tidal pond margin to levee interiors to levee crest environments generated the Lithotype 4 idealized sequence. The Lithotype 5 idealized sequence was produced by migration from tidal pond center to tidal pond margin to algal flat environments. The sediments contained within the idealized sequences reflect increasing degrees of exposure as indicated by increased vertical burrow abundance, the increased occurrence of spar-fillings within burrows, decreased fossil diversity, the increased number of desiccation structures such as mudcracks and desiccation fenestrae, and the survival of lamination.

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CHAPTER I

INTRODUCTION

General Background

The Middle Ordovician carbonate and clastic rocks of the Appalachian Valley and Ridge province represent a complex, interfingering mosaic of both distinct and gradational depositional environments. K.R. Walker and his students have studied these rocks for the last 10 years and have increased the understanding of the Middle Ordovician in eastern Tennessee.

Stratigraphic sections have been measured at strategic locations in the Valley and Ridge belt (Fig. 1). These sections have been studied both individually and collectively with an environmental emphasis. In order to eliminate the effects of thrust fault telescoping, all sections have been studied within the context of a palinspastic map developed by Roeder and Witherspoon (1978) (Fig. 2). Walker and his students have generated a number of cross-strike and along-strike cross sections which have increased understanding of the evolution of the Appalachian Basin.

This basin has undergone three major periods of sedimentation as induced by tectonic events. During tectonic quiescence, the first pulse of a major transgression deposited shallow-water carbonates of the Chickamauga Group over a ramp which sloped gently southeastward and was underlain by the Lower Ordovician Knox Group. Then, a tectonic event related to the Blountian Phase of the Taconic Orogeny (Rodgers, 1970) to the southeast caused rapid shelf subsidence

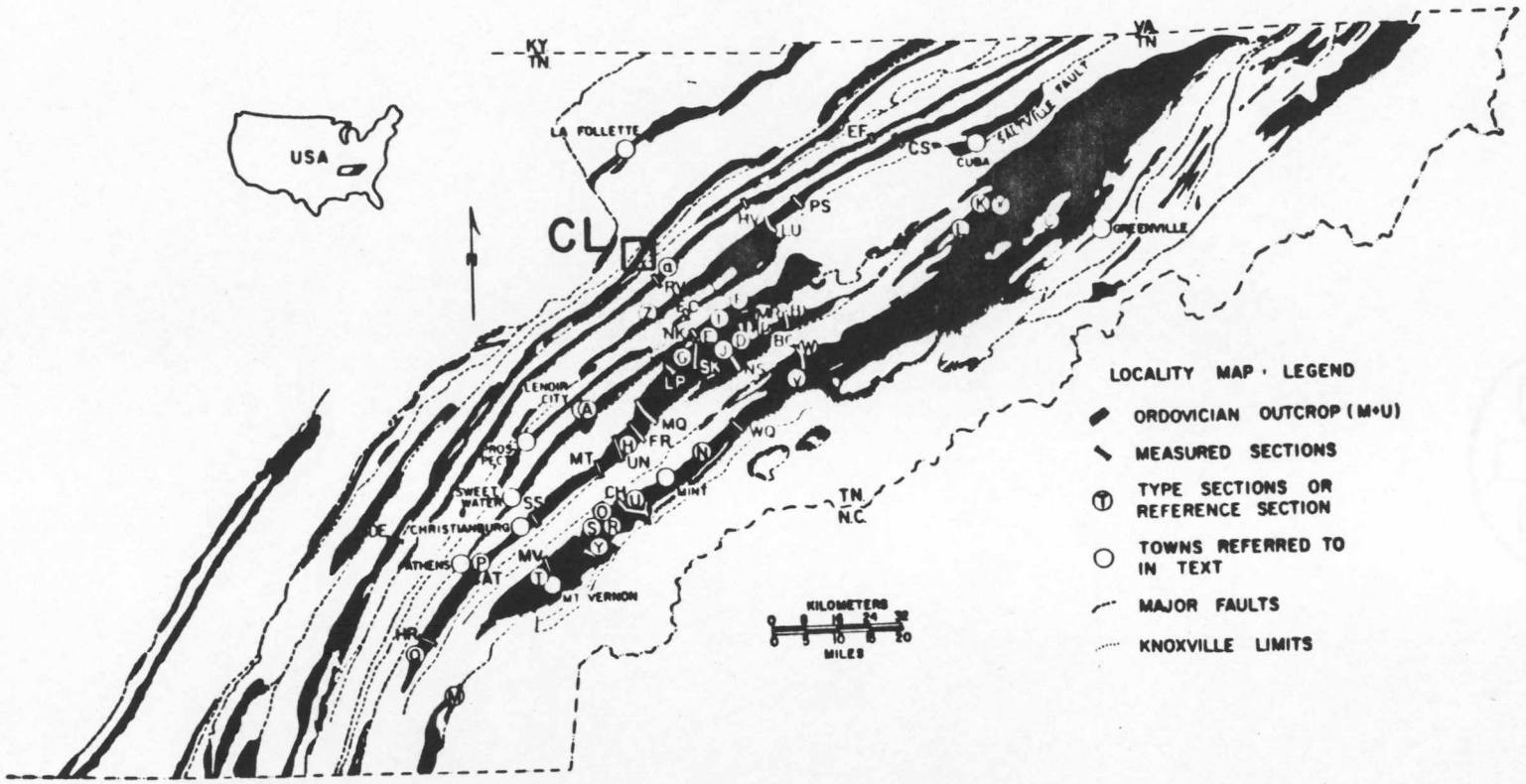


Figure 1. Location of Middle and Upper Ordovician outcrops in eastern Tennessee showing locations of measured sections. The location of the present study area appears at the area labeled "CL." Modified after Walker (1980).

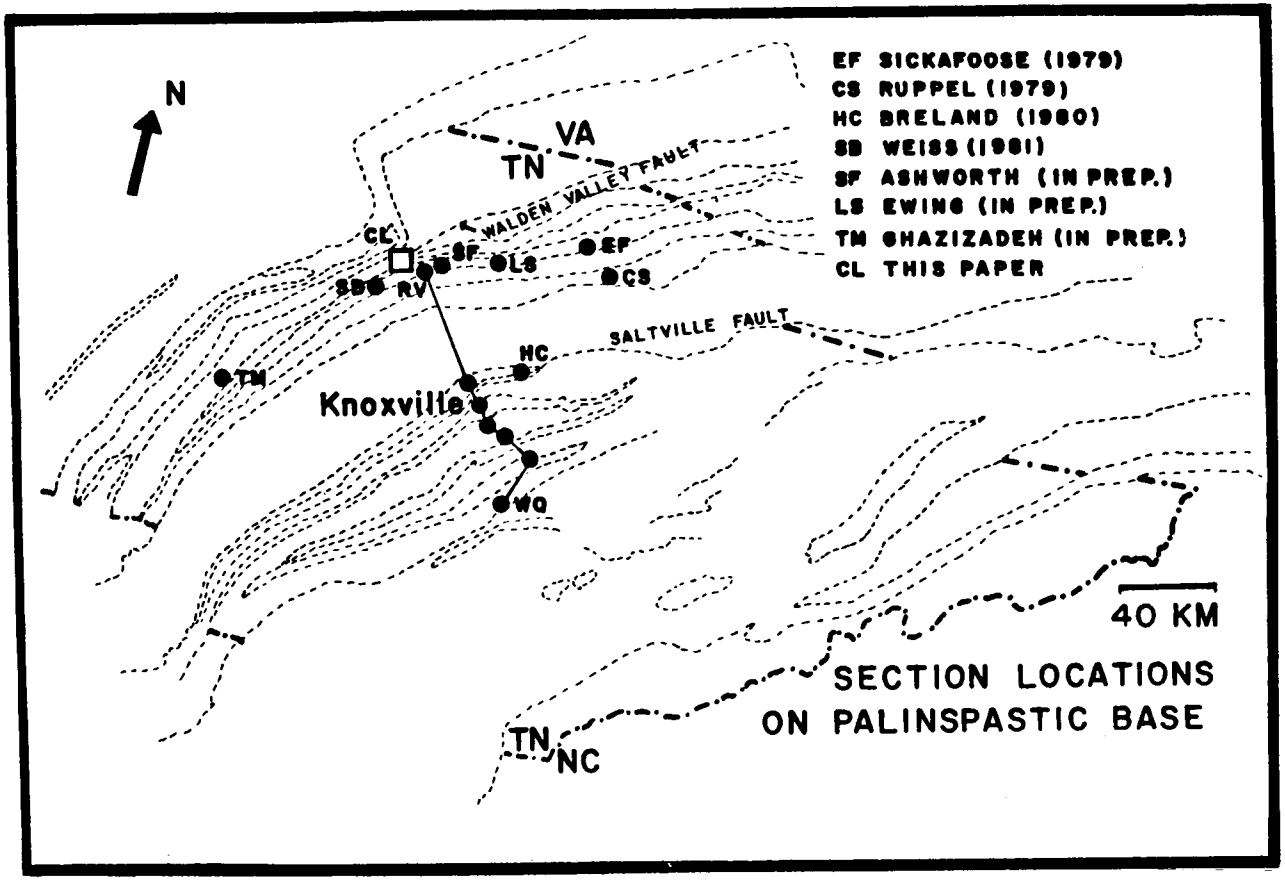


Figure 2. Location of pertinent stratigraphic sections on a palinspastic base map. The section line RV-WQ corresponds to the cross section in Fig. 3. The location of the present study area (CL) is marked by the square. Modified after Roeder and Witherspoon (1978).

to the south of Knoxville. This event produced a deep basin (Shanmugam and Walker, 1978, 1980). Creation of this basin generated three separate, but coeval, magnafacies as recognized by Walker (1977) (Fig. 3). To the northwest, carbonate deposits dominated sedimentation on a broad shelf; in places it displayed a prominent shelf-edge declivity. To the extreme southeast, a wedge of mixed fine-grained clastics and carbonates, and, slightly later, proximal turbidites were deposited. A deep, starved basin was produced between these two areas. As time progressed sedimentation outpaced subsidence and the basin was totally filled with sediments derived from the rising tectonic land to the southeast. During this final event, pulses of terrigenous clastic sedimentation, now represented by the Bays and Ottosee formations, gradually choked-off carbonate production. The final domination of clastic over carbonate sedimentation in the Upper and latest Middle Ordovician is represented by the Reedsville Shale (Upper Ordovician) to the northwest and by the Martinsburg Shale (Middle and Upper Ordovician) to the northeast in the study area (Rodgers, 1953). Unlike the Sevier, Ottosee, Moccasin, and Bays deposits, Reedsville and Martinsburg sediments were derived from the northeast from tectonic lands uplifted by a different phase of the Taconic Orogeny (Rodgers, 1970).

The rocks in the study area (see Figures 1, 2, and 3) were formed up onto the carbonate shelf throughout the Middle Ordovician. Unlike more southerly localities, sedimentation near Clinton was unaffected by clastic influx until almost the end of the Middle Ordovician. Then, tongues of clastic material prograded westward

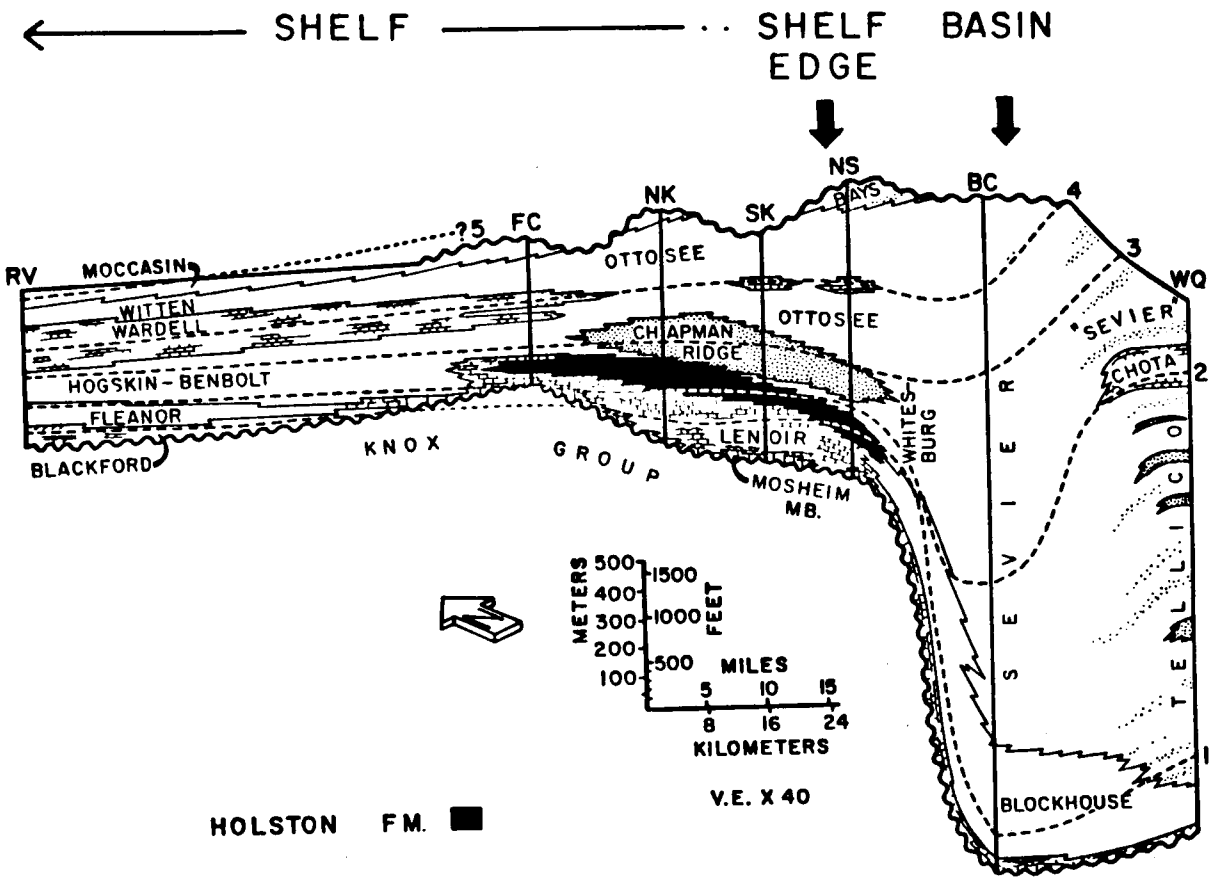


Figure 3. Reconstruction of regional facies patterns across a portion of the Middle Ordovician shelf, shelf-edge, and deep basin in eastern Tennessee. Cross section line is labeled in Fig. 2. Modified after Walker (1977).

and southward into the field area and carbonate production eventually ceased. The Middle Ordovician section at Clinton is therefore composed primarily of limestone capped by a much thinner sequence of terrigenous clastics (Fig. 4).

Purpose and Significance

The purposes of this investigation were threefold. First, this study involved the detailed measurement and sampling of a stratigraphic section in order to deduce the depositional environments represented by the characteristic lithologies appearing in the section.

The second purpose of this study was to dissect a 40 m thick tidal flat sequence in order to examine the vertical succession of depositional environments in a detailed manner. By using vertical contact data, a detailed understanding of lateral relationships between lithotypes can be attained. This information used in concert with observations of lithotype occurrences in recurrent stratigraphic sequences led to the recognition of environments and subenvironments within the tidal flat sequence.

Finally, the study area lies in a previously unstudied strike belt - two strike belts to the northwest of any recently studied stratigraphic section.

Thus, an environmentally-based stratigraphic study will extend knowledge of the Appalachian Middle Ordovician basin farther westward. Ultimately, an array of stratigraphic sections in this area could be the means to connect the depositional systems of the

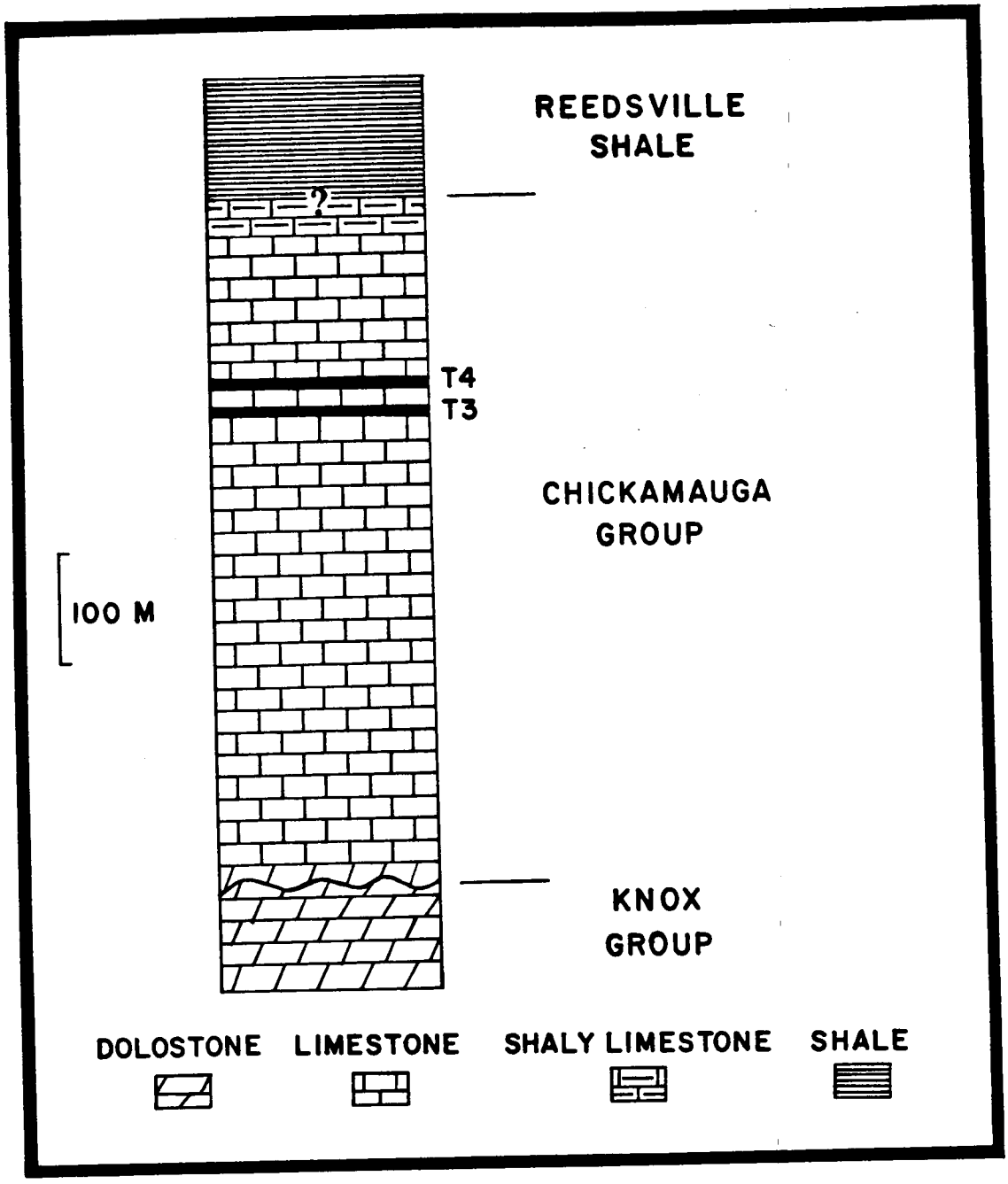


Figure 4. Schematic stratigraphic section of the rocks exposed near Clinton. T3 and T4 refer to the bentonites within the field area. The thickness of the shaly limestone comprising the topmost portion of the Chickamauga Group is unknown, but it is at least 20 m thick.

Valley and Ridge province, the Tennessee Central Basin, and Sequatchie Valley.

Study Locality and Stratigraphic Sections

The study area is a part of the Valley and Ridge province of the Appalachian Mountains northeast of Clinton, Anderson County, Tennessee (Fig. 5). Cambrian, Ordovician, and Silurian strata are exposed within the Kingston allochthon which is bounded by the Kingston thrust fault to the north, and by the White Oak Mountain/ Walden Valley thrust fault to the south. This section is the first studied with environmental emphasis northwest of the Hunter Valley allochthon.

Three sections were measured for this study. Two of these sections, the Clinton section (Location 1 - L1) and the Clinch River section (Location 3 - L3), originate at the Knox Group-Chickamauga Group contact (Fig. 6). This contact is unconformable; evidence from sections L1 and L3 indicates that at least 63 m of relief exists on the Knox surface between these two locations. Both sections were measured from the Knox unconformity through the T3 and T4 ash beds (central Tennessee terminology after Wilson, 1949 - see Coker, 1962 for a detailed petrographic description) and into a packstone/grainstone package. Each section was arbitrarily terminated within this grain-supported package of rocks. The Clinton and Clinch River sections are 405 and 453 m thick respectively. At L3, carbonate rocks are exposed for an additional 130-150 m until overlain by terrigenous clastics.

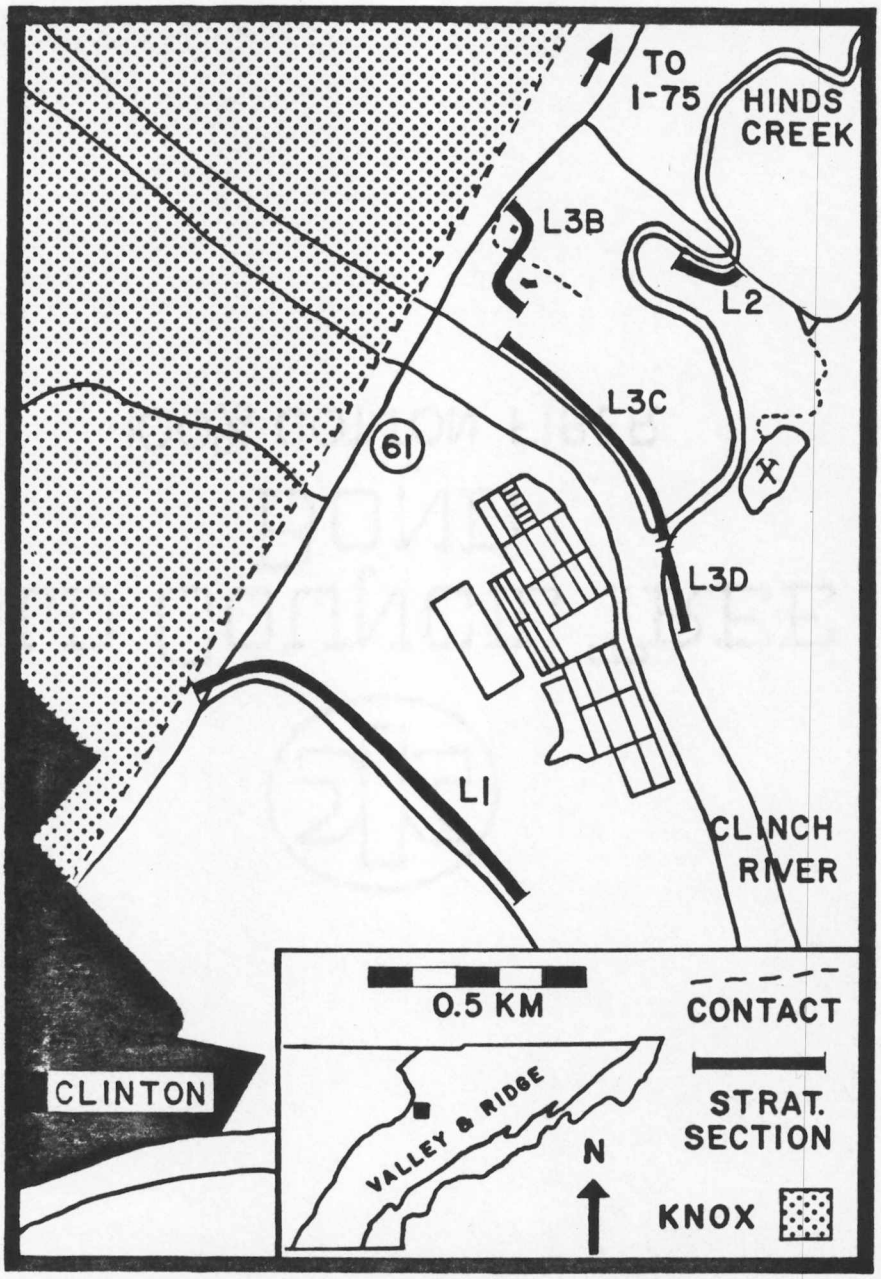


Figure 5. Location of the study area and stratigraphic sections.

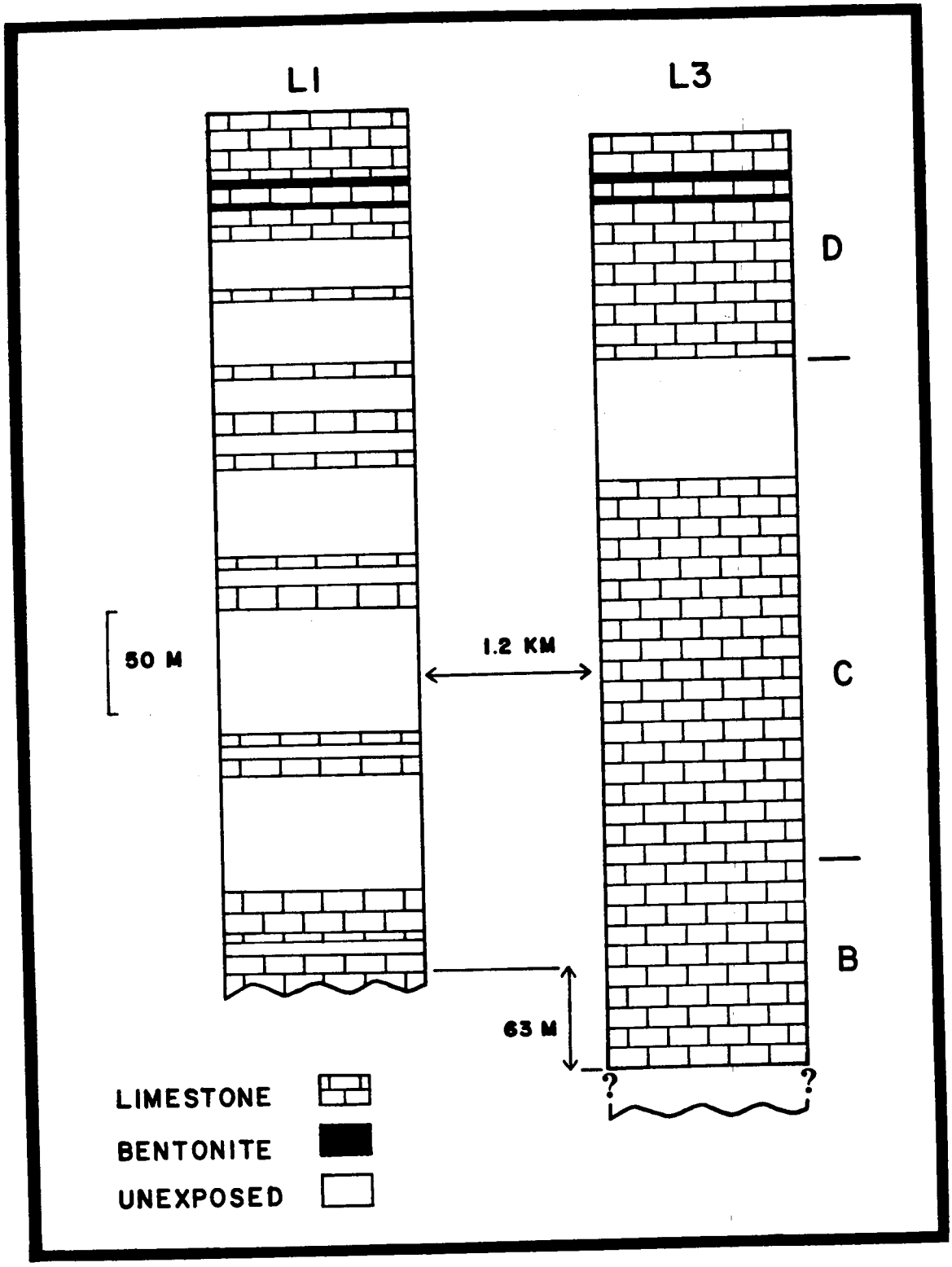


Figure 6. Stratigraphic sections at locations 1 and 3. The lower T3 bentonite was used as a time line to "hang" the sections. Note the difference of 63 m at the bottom of the sections.

The section at L1 is essentially complete for the basal 50 m, but is poorly exposed upsection. At most, the basal 27 m of the Chickamauga Group are covered at L3 but the rocks are fairly to excellently exposed in the rest of the sequence. Thus, the basal portion of section L1 and most of section L3 were combined to yield a more nearly complete, composite section.

As a convenience, section L3 was subdivided into three separate outcrop zones (see Figures 5 and 6). Outcrop L3B is characterized by beds and sets of beds 0.1 to 7.0 m thick interbedded with unexposed intervals averaging about 1.7 m thick. Outcrop L3C is poorly exposed in the interval from 129.8 to 178.3 m and a major unexposed interval occurs above 296.7 m. Outcrop L3D begins at the end of this covered portion and it is characterized by good exposure. Beds can often be traced laterally for up to 50 m; poor lateral exposure is inherent at outcrops L3B and L3C.

In addition to the L1 and L3 sections, a perfectly exposed sequence of rocks was measured at Location 2 along Hinds Creek (see Fig. 5). This section was used to gain insight into the intercalation patterns of a Middle Ordovician tidal flat sequence.

Methods

Reconnaissance field work in the Clinton area pinpointed all noteworthy outcrops. Three sections were chosen on the basis of quality of exposure and potential for inclusion in a composite stratigraphic section. Prominent outcrops which were not utilized either could not be correlated precisely into section L3 or were

repetitions of parts of the sequence which were better exposed elsewhere. The quarry near Hinds Creek indicated in Fig. 5 was not used since the rocks along the Clinch River were almost as well exposed but much less dangerous to study.

In each section, samples were taken when different succeeding lithologies were recognized in the field or when interesting beds were encountered. Samples were taken just above and below unexposed intervals even when these rocks appeared to be identical. Large field units were also sampled frequently to test if cryptic changes in lithology had taken place within the field units. Except for covered intervals, no two samples are separated by more than 6.0 m; the average stratigraphic distance between samples is 2.1 m despite unexposed intervals. Sampling was more detailed at sites of rapid vertical environmental change. A total of 47 samples was taken from section L1 and 224 samples were collected from L3.

All samples were slabbed, and selected samples were processed into 5 by 7.5 cm thin sections. A total of 219 thin sections represent the Clinch River section and 44 thin sections were made from L1 samples. Field, polished slab, and thin section data were used to erect the informal units described in Appendix A. Field unit numbers have been painted onto outcrops to facilitate future work within the stratigraphic and environmental framework established by this paper. Appendix B integrates field units, Appendix A units, and sample locations within the stratigraphic framework.

Point counts were made of 59 selected thin sections. Slides were selected on the basis of similar lithology - 2 to 6 slides from

each of the lithologies discussed in Chapter 2 were point counted. The stratigraphic distribution of point-counted slides was of secondary importance since rocks representing identical environments would possess very similar component percentages regardless of stratigraphic position. A true characterization of any particular lithology is the primary concern of point count data in this paper.

Field and laboratory methods were slightly different for samples collected at section L2. This section was used for a detailed description of environmental successions within a perfectly exposed interval of rocks along Hinds Creek (see Fig. 5). As a result, every bed was sampled (411 samples) and its stratigraphic position noted. All samples were slabbed, polished, described, and catalogued into one of 7 lithotypes. Twenty-seven thin sections and acetate peels were made of interesting, typical, or problematical samples.

Stratigraphic Problems

A state of confusion has existed over the stratigraphy of the Southern Appalachians for the last century. Because of the complex facies mosaic displayed by the Middle Ordovician units, this controversy is no more apparent than in the Chickamauga Group and its equivalents.

The Knox Group is unconformably overlain by the Chickamauga Group. The Knox unconformity is found throughout the northwestern Appalachian basin of Tennessee and is taken to represent the boundary between the Lower and Middle Ordovician although the basal Chickamauga

units are by no means synchronous (McLaughlin, 1973). As a consequence of this wide areal extent, the Middle Ordovician rocks which lie on the Knox surface are easily recognized. However, different stratigraphic terminology has been proposed in studies of type sections located in the Tennessee Central Basin, the Tennessee Valley and Ridge, and the Virginia Valley and Ridge (Figs. 7 and 8).

Stratigraphic Usage of This Paper

The stratigraphy of Middle Ordovician units within the Appalachian Valley and Ridge province is a complex and as yet unsolved problem. This problem is particularly acute for belts north of the White Oak Mountain/Walden Valley fault because the lack of clastic deposition encourages correlation with Central Basin units while the presence of similar lithologies (i.e. facies) immediately southeast of the study area invites correlation with rocks named in type sections in southwest Virginia. Formal rock units recognized by workers in strike belts immediately to the northwest and southeast of the Clinton section are not applicable to rocks of the Clinton vicinity. Neither the rocks described by Weiss (1981) in the Hunter Valley allochthon (Fig. 7) nor the rocks described by Milici and Smith (1969) in the Chattanooga allochthon (Fig. 8) correspond to the rocks of the present study.

The use of stratigraphic terms in this study seems counterproductive. Repetitive occurrences of rocks with specific environmental meaning occur throughout the study section regardless of stratigraphic position. The whole approach of this investigation is to look at the intercalation patterns of these packages in the context

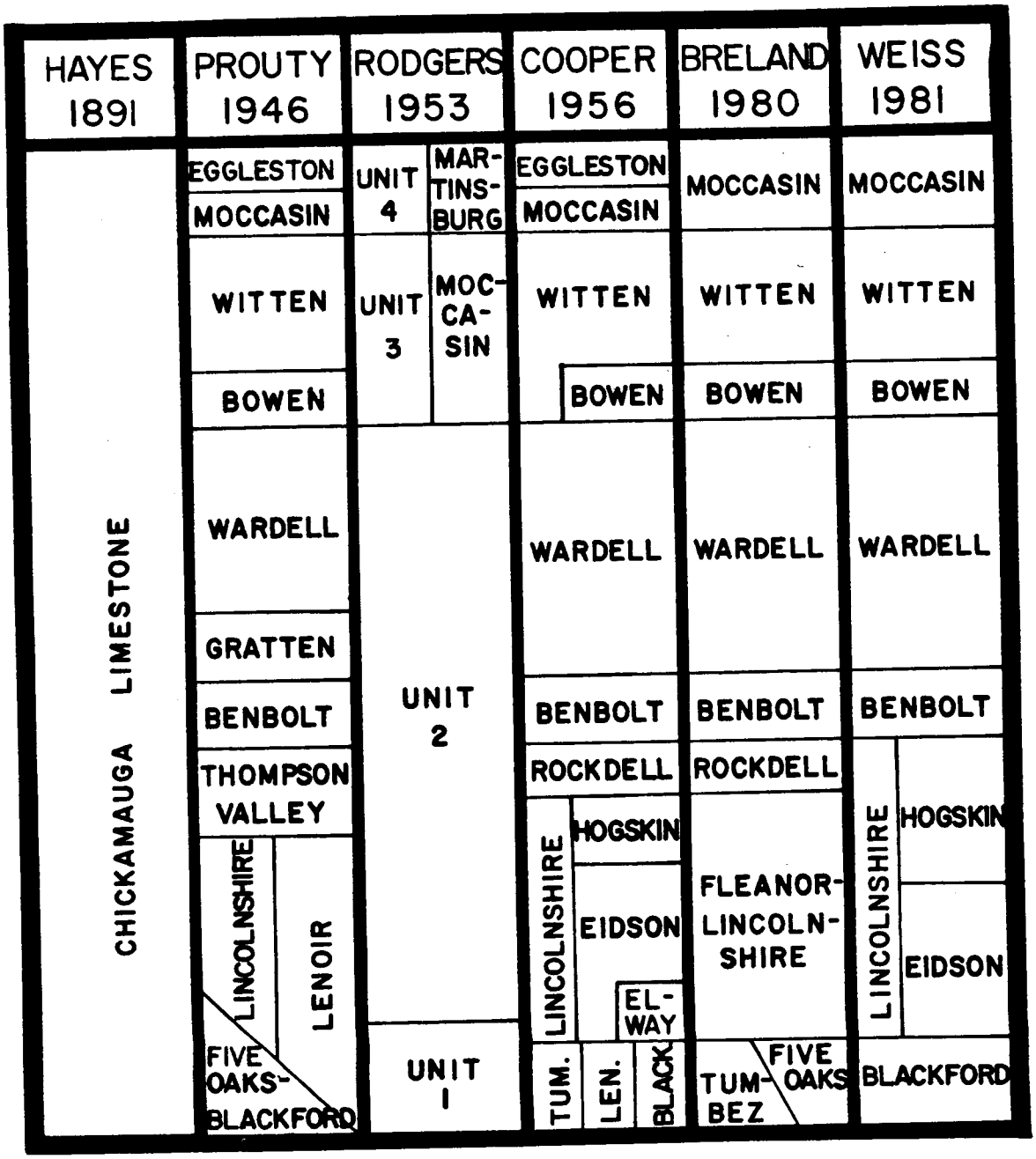


Figure 7. Stratigraphic nomenclature for the Middle Ordovician rocks of the Valley and Ridge north of the Saltville fault. This diagram should not be used to correlate or differentiate between formal units at any specific position in the rock column.

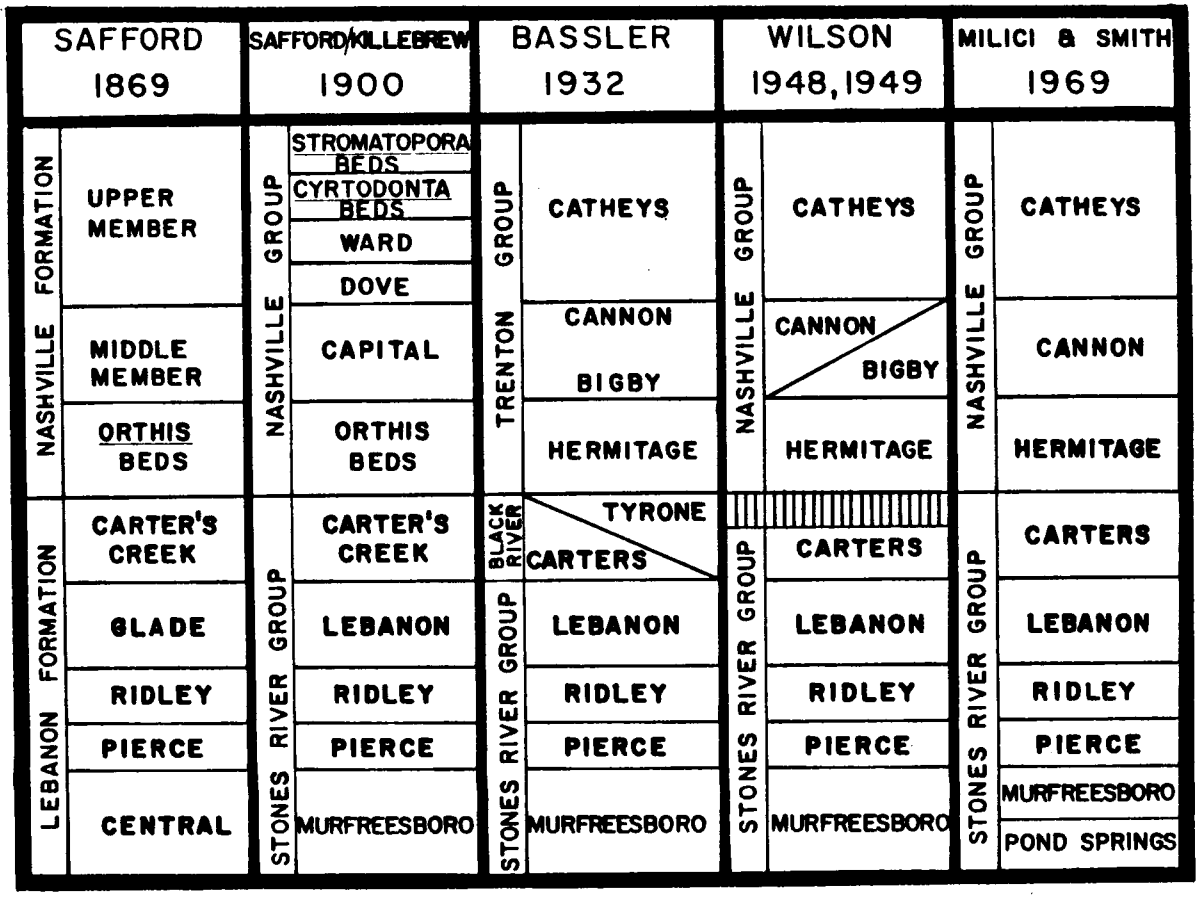


Figure 8. Stratigraphic comenclature for the Middle Ordovician rocks of the Tennessee Central Basin and part of the Valley and Ridge Province. The terminologies of Safford, Safford and Killebrew, Bassler, and Wilson were developed for the Central Basin area. The terms of Millici and Smith (right-most column) represent application and alteration of Central Basin terms to an area in the Valley and Ridge near Chattanooga.

of a particular depositional environment, not as a means of correlating rock units over basin-wide distances. Indeed, an isolated study of this nature cannot hope to ascribe rock units correctly in the absence of additional environmental and biostratigraphic information. As more studies are completed in this and in neighboring strike belts, the environmental and biostratigraphic data from these localities can be used to integrate to detailed facies and time-correlative relationships over a wide area.

This paper will consequently consider only one rock unit - the Chickamauga Group, defined as all rocks stratigraphically between the Lower Ordovician Knox Group and the Upper Ordovician Reedsville Shale within the Kingston allochthon.

CHAPTER II

PETROLOGY, FABRIC ANALYSIS, AND INFERRED DEPOSITIONAL ENVIRONMENTS OF THE CLINTON SECTION

Introduction

Ruppel and Walker (1977), Walker et al. (1980) and numerous theses and dissertations completed at The University of Tennessee have documented the complex facies mosaic exhibited by Middle Ordovician deposits in the Tennessee Valley and Ridge province. Sediments encountered along a northwest-southeast transect across the Middle Ordovician Appalachian basin change from shelf and shelf-edge carbonates to deep-water turbidites to proximal clastics (Fig. 3, p. 5). Clastic sediments derived from a rising tectonic land to the south and east eventually spilled into the basin and filled it up to interfinger with the shelf and shelf-edge carbonates. Facies relationships within the carbonate shelf package are also complex. The rocks of the study area were deposited far up onto the carbonate shelf.

The purpose of this paper is to describe the rocks exposed within the study area and determine their depositional environments.

Concepts and Assumptions

Before discussing the carbonates and their inferred depositional environments, it is best to review some of the important concepts and assumptions concerning tidal flat sedimentation in microtidal settings, biogenic reworking in tidal flat sediments,

salinity-controlled assemblages, vertical burrows as environmental indicators, and the inferred climate in eastern Tennessee during the Middle Ordovician.

Tidal Flat Sedimentation

Many of the rocks described and discussed in this study were formed in a tidal flat complex. Laporte (1971) has summarized some criteria aiding in the recognition of tidal flat sequences; most are observable in the study rocks. The most illuminating investigations of tidal flat sediments, however, have been those carried out in Recent settings. These studies have provided a process-oriented understanding of modern and, by analogy, ancient tidal flat systems.

Workers in Andros Island, Shark Bay, and the Persian Gulf have established a number of generalizations about sedimentary processes operating in tidal flat systems. Illing et al. (1965), Davies (1970a), Shinn et al. (1965), Shinn et al. (1969), and Hardie (1975) have all shown that sediment deposited on tidal flats is derived from adjacent offshore environments. Although this relationship has been recognized for quite some time, most tidal flat sedimentation was perceived to occur during diurnal or spring-tide flooding before studies on modern carbonate tidal flats were performed.

In microtidal settings such as Andros Island, most deposition takes place during storms (Shinn et al., 1969; Hardie, 1975). Wanless (see Hardie and Ginsburg, 1975) has observed storm accretion on beach ridges, beach washovers, levees, levee backslopes, and high algal marshes during a "normal" (winds = 30-40 km/hr) storm. Sedimentation in inland algal marshes and tidal ponds seems to require storms of

hurricane or near-hurricane strength for Ball et al. (1967) and Perkins and Enos (1968) have documented 1 to 4 inches of lime-mud accumulation on tidal flats after hurricanes Donna and Betsy. These figures are comparable with bed thicknesses of up to 10 cm (3.9 inches) for inland algal marsh sediments (Hardie and Ginsburg, 1975). Garrett (1975) has also reported 2-4 cm thick layers of sediment at tidal pond edges.

During the Middle Ordovician, the study area must have experienced low tidal amplitudes very much like the present-day Andros Island tidal flats. Ruppel and Walker (1977) and Walker et al. (1980) have shown that the shelf was at least 75 km wide and averaged 100 km or more in width. Due to this wide shelf, tidal ranges must have been quite low.

In microtidal settings, two generalizations concerning tidal flat sedimentation can be applied to ancient systems:

1. Sediment - mud, peloids, and bioclastic material - observed in tidal flats systems has been largely derived from adjacent, offshore sedimentary environments.
2. Sediment is accreted onto tidal flats by episodic storm events. Thus each lamina or layer reflects a depositional storm event of some magnitude.

Layering and Biogenic Reworking

It has long been recognized that the preservation of physical sedimentary structures is dependent on the ratio between physical and biogenic reworking rates. Moore and Scruton (1957) have documented this for Mississippi River delta sediments. In areas of rapid

sedimentation rates, layering and physical sedimentary structures are preserved since biogenic reworking rates are insufficient to obliterate these structures. Quantitative studies of biogenic reworking have been performed by Rhoads (1967) in both field and laboratory situations. Ginsburg (1957) also demonstrated that artificially-created laminae are destroyed by burrowers in tank experiments.

This concept is important for understanding the preservation potential of layered sediments in tidal flats. Tidal flat sedimentation is episodic and as a consequence sediments deposited on tidal flats are contained in discrete layers; each layer represents a single depositional event. But layering is not present everywhere on tidal flats. Shinn et al. (1969) observed that layering in the Andros Island tidal flats is preserved only in intertidal and supratidal sediments. Most lamination or bedding produced elsewhere by sedimentation events is obliterated by subsequent burrowing activity. Hardie and Ginsburg (1975) have also documented that layering will never be preserved below mean tide level. Garrett (1975) has substantiated this observation and has shown that only the thickest storm layers with a "sufficiently different constituency" will survive homogenization in Andros Island tidal ponds.

Layering in Andros Island tidal flat sediments (and presumably other tidal flat deposits) survives for two reasons. Laminated sediment on levees, levee backslopes, beach ridges, beach-ridge backslopes, and high and low algal marshes persists because it is formed in dry, exposed environments. Marine organisms are unable to

live and rework sediment in these stressful, desiccated environments. In addition, exposure causes sediment to harden so that burrowers are unable to dig through the sediment. Inland algal marsh sediments are wet but the standing and connate water in fresh; layering is preserved because burrowing marine organisms are excluded by a salinity barrier. The opposite effect is seen in Shark Bay and the Persian Gulf. Burrowing and browsing organisms do not destroy intertidal algal mats because they are forming in hypersaline environments (Davies, 1970b; Logan et al., 1974).

As a consequence of the above findings, any rock exhibiting algal laminae or thin beds will be assumed to have formed in environments above mean tidal level, or in transitional fresh-water environments.

Fossil Assemblages and Salinity

There is no doubt that salinity is a major controlling factor of organism distribution and abundance. Brackish water and hypersaline environments are difficult to invade and occupy because of osmotic considerations (Valentine, 1973). As a result, these environments display decreased diversity in contrast with marine environments with normal salinity (33-36 ppt). Such assemblages with limited diversity are termed "restricted" or "restricted-water".

Salinity effects on organism diversity are well documented. Remane (1934) discovered that species diversity in the Bay of Kiel, an estuary, was lowest in brackish water while fresh-water and marine waters had comparable diversities. Brackish-water species diversity was also at a minimum in a number of Denmark estuaries (Alexander

et al., 1935). Since these landmark investigations, many reports have supported this salinity-diversity relationship leading Emory et al. (1957) to accept the "general utility" of the concept. Similarly, hypersaline environments display reduced diversities.

A number of generalizations have been formulated by Simmons (1957), Parker (1959), and Gunter (1961):

1. If salinity is variable, the number of species decreases in respect to environments with more invariant marine salinities.
2. The abundance of individuals of a certain species may be very high in brackish or hypersaline waters.
3. Environments with normal marine salinities display many species but fewer individuals per species.

Laporte (1967, 1971), Walker and Laporte (1970), and Walker (1972) have extended the concept of restricted assemblages to the fossil record. Walker (1972) documented a decrease in the number of indigenous taxa from offshore to onshore environments. These studies have gone a step further, however, and have identified various fossil organisms tolerant of salinity variations. Laporte (1967) has reported tentaculitids, leperditid ostracodes, a single brachiopod species, spirorbid worms, and a species of trepostome bryozoan in restricted-water environments of the Devonian Manlius Formation. In the Appalachian basin, trilobites and ostracodes constitute the principle tidal flat fauna; trilobites tend to dominate in the Cambrian and early Ordovician while ostracodes prevail in the mid-Ordovician to early Devonian (Laporte, 1971). Auxiliary taxa include gastropods, clams, tentaculitids, and brachiopods. Walker and Laporte (1970) have recognized a number of congruent fossil assemblages in Middle Ordovician and Devonian tidal flat facies. Also, both have

found that certain species of strophomenid and spiriferid brachiopods appear to have been euryhaline in both periods.

The present study has also recognized a characteristic restricted-water biota. In low diversity assemblages, ostracodes and trilobites are most numerous, and have been assumed to be restricted-water fauna. By association, a small (1-3 mm) variety of ctenodontid (?) clam and many gastropods were also euryhaline. A species of orthid brachiopod occurs as articulated, sporadic specimens within the above assemblage.

The presence of a diverse, indigenous biota indicates subtidal environments with open-marine salinities. Bryozoans, the large majority of brachiopods, and all echinoderms are generally stenohaline organisms. It is important to note that restricted-water fauna may still be indigenous to open-marine environments since they are euryhaline, and that many species of ostracodes, gastropods, bivalves, and especially trilobites are probably stenohaline organisms. The presence of a diverse indigenous, stenohaline biota is the critical clue.

Vertical Burrows as Environmental Indicators

The generalization that vertical (and U-shaped) burrows are characteristic of, and perhaps indicative of, intertidal environments does have substance. Seilacher (1964) has noted that vertical burrows tend to be more numerous in shallow-water environments and he believed that burrows could be used as paleobathymetric indicators. Rhoads (1967) has observed that deep (20-30 cm) vertical burrows are "common in nearshore sediments, especially in the intertidal" sediments while

horizontal burrows are "best developed in offshore level bottoms" (p. 475). He also suggested that burrows might be used as paleobathymetric indicators in the absence of other information. Vertical burrows have been demonstrated to buffer variable physical parameters such as salinity and temperature in the intertidal zone so that deep burrowing is advantageous to organisms (Rhoads, 1975). He concluded that intertidal environments are dominated by vertical burrows whereas subtidal shelf sediments display horizontal grazing traces more commonly than vertical burrows. Studies of other modern intertidal areas such as that by Evens (1965) have discovered a preponderance of vertical burrows (and surface trails) over horizontal burrows. Although there is evidence to prove that vertical burrows are much more common in intertidal areas, they are by no means unusual in subtidal environments.

Studies of ancient nearshore systems have been cautious in using vertical burrows as depth indicators. Authors use the presence of vertical burrows as supportive or suggestive evidence. Laporte (1971) states that burrows in Paleozoic tidal flats "tend" to be vertical. Walker (1973) notes that U-shaped and vertical burrows are very abundant in his intertidal limestone facies, but uses other criteria such as algal mat morphology and desiccation features to establish his interpretation.

The present study has found that vertical burrows are a useful environmental indicator if used as a ratio with the comparative abundance of horizontal burrows. Vertical burrows occur in the subtidal environment but horizontal burrows are much more plentiful.

In bioturbated rocks which are obviously subtidal as indicated by diversity trends, vertical burrows are rare; this dearth may be due to a preservational bias, however, for horizontal burrows may be cryptic.

Stronger evidence may be found in sediments which have experienced desiccation. If burrows are present, only vertical burrows are found. In rocks in which vertical burrows are dominant, distinct burrow walls, undeformed cross-cut laminae, and spar-filled burrows attest to the low water content of the sediment. Vertical burrows also tend to dominate in rocks which support extremely low organism diversity.

The above evidence suggests that horizontal burrowers are excluded from desiccated or more aerially exposed environments. Subsurface, mining deposit feeders would have a difficult time processing especially firm sediments through their guts. In short, the absence of horizontal burrows is more diagnostic than the presence of vertical burrows so that a ratio of their abundance should characterize a given depositional environment.

Climatic Setting

All Recent carbonate tidal flats occur in subtropical or tropical settings. Shark Bay and Persian Gulf tidal flats experience semi-arid and arid climates respectively, and, as a consequence, their sediments contain gypsum and/or halite. In contrast, south Florida and Bahamiam carbonate terrains are subject to a wet, subtropical climate and display no evaporite minerals.

During the Middle Ordovician, the southern Appalachian region, including the Clinton vicinity, was located between 20° and 30° south

of the equator (Bambach et al., 1980) and therefore experienced a subtropical climate. Furthermore, the absence of evaporite minerals or their pseudomorphs in Middle Ordovician Appalachian tidal flat sediments (see Blythe, 1974; Grover and Read, 1976; Ruppel, 1979; Sickafoose, 1979; Breland, 1980; Weiss, 1981) denotes a "wet climate", or at least not an arid or semi-arid climate. Based on these climatic considerations, the Chickamauga sediments in the Clinton area should be more similar to Florida and Bahamian deposits.

Lithologic Descriptions and Inferred Depositional Environments

The measured stratigraphic section contains repetitive beds and occurrences of certain distinctive, environmentally significant rocks throughout its extent. In order to avoid redundant petrographic descriptions and discussions of inferred depositional environments, similar lithologies are discussed without regard to stratigraphic position. Some lithologies occur only within a specific stratigraphic interval whereas others occur throughout the entire stratigraphic section.

Lithologies were categorized on the basis of constituent fossil and non-fossil allochems, grain transportation considerations, texture, sedimentary structures, and overall fabric. Depositional environments are assigned to each lithology following numerous lines of evidence. Petrology and fabric define a rock type which may be similar in origin to Recent sediments formed in specific (or general) depositional environments. Thus depositional environments are mainly established by analogy. Also, vertical associations of certain

lithologies, that is vertical contacts or stratigraphic proximity to beds of different lithology, are used to infer depositional environments by applying Walthers' Law.

Twelve major lithologies were recognized in this investigation. Their characteristics and salient differences are tabulated in Table 1 along with their inferred depositional environments. Also each sample is listed under its parent lithology in Appendix C. In order to provide a general overview of the stratigraphic distribution of these lithologies, Figs. 9 through 12 illustrate their stratigraphic locations.

Grain-size conventions are after Wentworth (1922) and the terminology for bedding thickness is after McKee and Weir (1953) as modified by Ingram (1954) (see Appendix A). Roundness terms are those of Powers (1953), and sorting classes are after Folk (1974). The application of carbonate rock names follows the usage of Dunham (1962). Unless otherwise noted, all grain size measurements refer to median diameter.

Lithology 1

Lithology 1 rocks are tan or maroon, silty, bioturbated packstones/grainstones. This lithology can be distinguished from lithologies 2 and 3 by its numerous allochems or grain-supported fabric. Lithology 1 rocks occur commonly within this study's stratigraphic section. These rocks are the main components of sections L1 and L3B, form some of section L3C, and are absent in section L3D.

TABLE 1

LITHOLOGY CHARACTERISTICS AND DEPOSITIONAL ENVIRONMENTS

Number	Characteristics and Distinguishing Features	Depositional Environment
1	Tan or maroon, silty bioturbated packstones/grainstones. Transported fauna and peloids ± intraclasts. Often algal laminated, with cross laminae, or completely bioturbated. Vertical and U-shaped burrows common. Distinguished from Lithology 2 and Lithology 3 by appreciable fossil content and grain-supported fabric.	Intertidal and supratidal positions on tidal flat.
2	Maroon, tan, or gray mudstones with scarce allochems. Occurs as superimposed thin beds with limited vertical burrows. Thin beds may be composed of algal laminae. Mud-crack and desiccation fenestrae occasional.	Algal marsh analogous to Andros Island inland and high algal marsh.
3	Afossiliferous tan or gray mudstones. Desiccation fenestrae are the salient feature.	Desiccated algal marsh.
4	Greenish-gray, thoroughly bioturbated mudstones, wackestones, and packstones. Restricted-water fauna dominant and indigenous. Horizontal burrows only. Distinguished from Lithology 5 and Lithology 6 by greater abundance of ctenodontid(?) clams, articulated ostracodes, and gastropods.	Tidal pond or restricted adjacent marine.
5	Greenish-gray bioturbated mudstones and wackestones. Horizontal burrows only. Distinguished from Lithology 4 and Lithology 6 by increased abundance of calcareous algae and Tetradium.	Tidal pond or restricted adjacent marine.

TABLE 1 (Continued)

Number	Characteristics and Distinguishing Features	Depositional Environment
6	Gray bioturbated mudstone. Scarce biota. Vertical burrows are common. Distinguished from Lithology 4 and Lithology 5 by presence of vertical burrows; also lack of calcareous algae, *Tetradium*, and ctendontonid(?) bivalves.	Pond margin or restricted adjacent marine margin.
7	Algal laminated sediments. Scarce fauna, occasional vertical burrows and desiccation features.	Intertidal restricted marine.
8	Planar and cross laminated fossil-peloid grainstone. Restricted-water fauna dominant.	Tidal-flat channel, marine channel, or shoal.
9	Peloid packstone and storm-generated fossil-peloid grainstones. Scour surfaces, fossil lags, fining-upwards sequences. Subequal open-marine and restricted biota.	Shallow-water, level-bottom marine.
10	Bioturbated mudstones with restricted-water fauna. Horizontal burrows numerous and ubiquitous.	Shallow-water lagoon.
11	Storm-generated fossil-peloid grainstones. Indistinguishable from Lithology 9 sediments but interbedded with Lithology 10.	Storm accumulation in shallow-water lagoon.
12	*Tetradium*-bearing packstones and grainstones. *Tetradium* build-ups present. Grainstones are storm deposits but distinguishable from Lithology 9 and Lithology 11 by increased *Tetradium* content.	Restricted-water lagoon *Tetradium*-wave-baffle and its windward and leeward deposits.

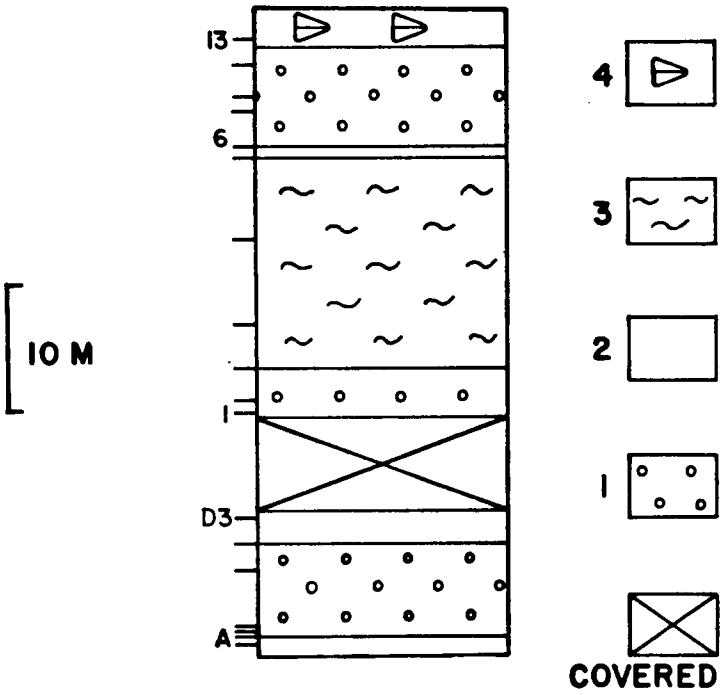


Figure 9. Stratigraphic distribution of lithologies in section L1. Each symbol refers to the lithologies recognized in this study; refer to Table 1 for lithology characteristics. Lines and numbers to the left of the stratigraphic column correspond to samples taken within section L1.

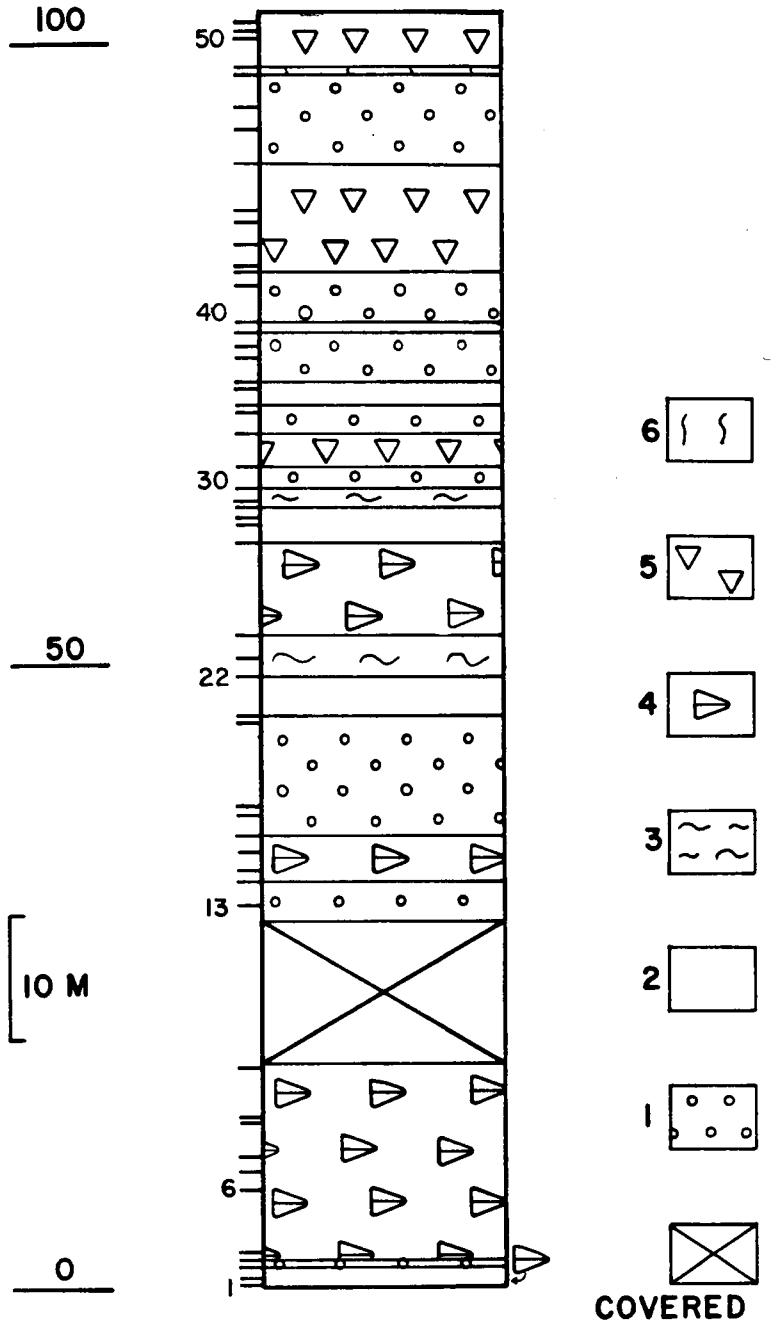


Figure 10. Stratigraphic distribution of lithologies in section L3B. Each symbol refers to the lithology recognized in this study; refer to Table 1 for lithology characteristics. Lines and numbers to the immediate left of the stratigraphic column correspond to samples taken within section L3B. Numbers in bold print refer to the number of meters above the base of section L3.

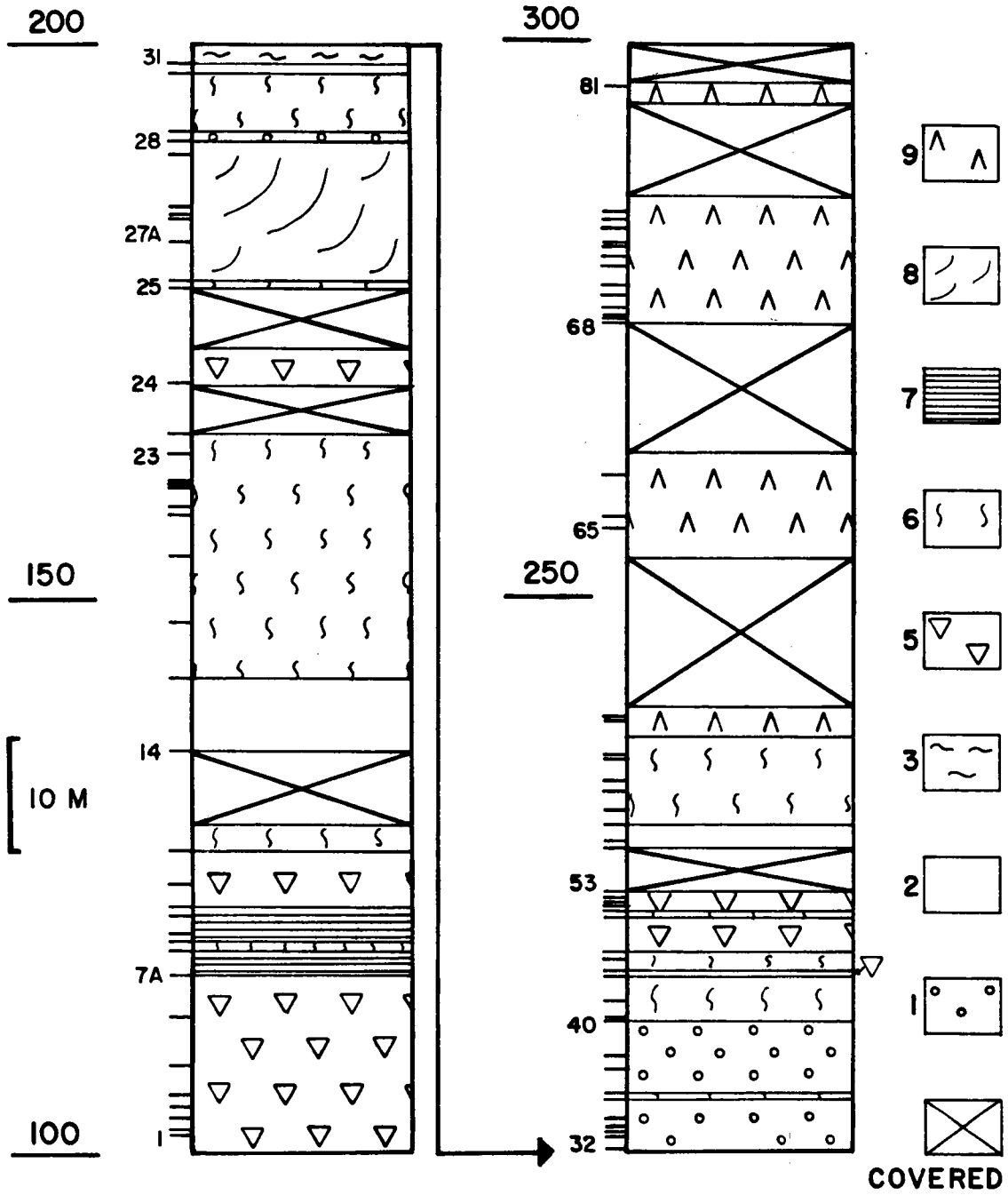


Figure 11. Stratigraphic distribution of lithologies in section L3C. Each symbol refers to the lithologies recognized in this study; refer to Table 1 for lithology characteristics. Lines and numbers to the immediate left of each column correspond to samples taken within section L3C. Numbers in bold print refer to the number of meters above the base of section L3.

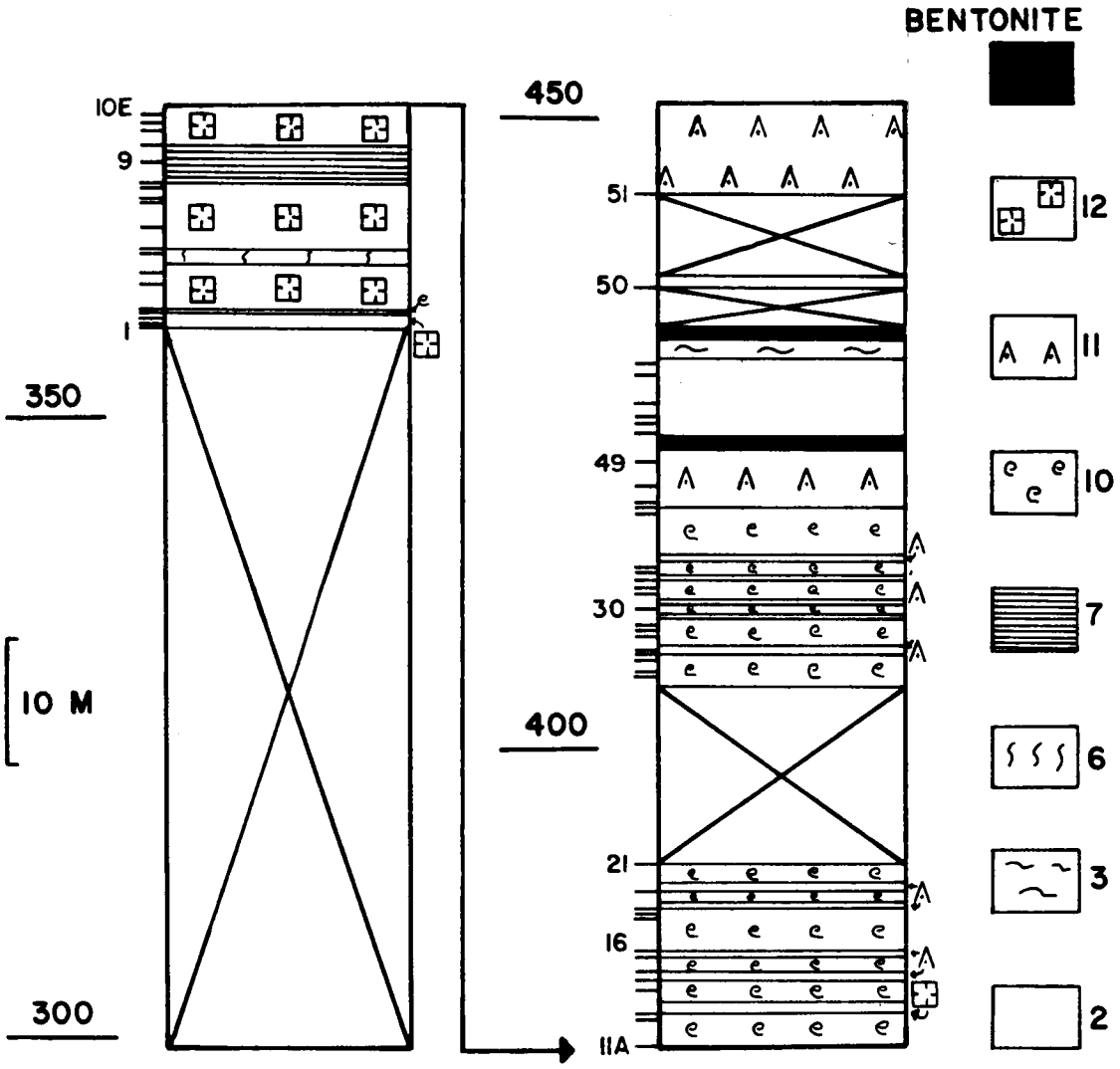


Figure 12. Stratigraphic distribution of lithologies in section L3D. Each symbol refers to the lithologies recognized in this study; refer to Table 1 for lithology characteristics. Lines and numbers to the immediate left of each column correspond to samples taken within section L3D. Numbers in bold print refer to the number of meters above the base of section L3.

Petrology. Peloids, unidentifiable fossil fragments, detrital quartz, and bioclastic material comprise these rocks. The fossil content is variable; some samples contain up to 10% fossil material (L3B-26) while others are composed mainly of peloids (L3B-30, L3C-37A). Ostracodes, trilobites, echinoderms, and bryozoans are the most numerous faunal elements but ancillary organisms include gastropods, sponges, inarticulate brachiopods, Hedstroemia, Girvanella, and Nuia. Silt-sized to fine sand-sized, unidentifiable fossil debris is ubiquitous and may be the most abundant fossil constituent.

Generally, restricted-water faunal elements - ostracodes, trilobites, and gastropods - outnumber open-marine fossils. Open-marine organisms are always broken and abraded to heavily abraded (Fig. 13A) while restricted-water forms exhibit minor transportation effects. Most specimens are relatively unabraded but other individuals display abraded and broken hard parts (Fig. 13A). Restricted-water fossils show more evidence of being indigenous than open-marine fossils although restricted-water forms may also be transported.

Non-fossil allochems are also important constituents of this rock. Peloids form most of this fraction; they are usually rounded, circular to ovoid in cross-section, and range in size from very fine to medium sand. In most samples, peloids appear to be well sorted and are probably hydrodynamically equivalent to fossil debris. Detrital quartz silt and very fine sand is present in appreciable amounts (1-2%) in almost every sample. Grains are typically angular to subrounded and are not well sorted within any size class. Intraclasts were observed in only one sample (L1B-B1). They are slightly

Figure 13. Photomicrographs of features observed in Lithology 1, 2, 3, and 4 rocks.

A. Fragmented and abraded fossils in Lithology 1. Bar scale is 0.5 mm. (Sample L1B-B1).

B. Probable Lithology 2 intraclast in an Lithology 1 traction layer. Bar scale is 0.5 mm. (Sample L1B-B1).

C. Concave-down valves in a probable relict traction layer. Bar scale is 0.5 mm. (Sample 41).

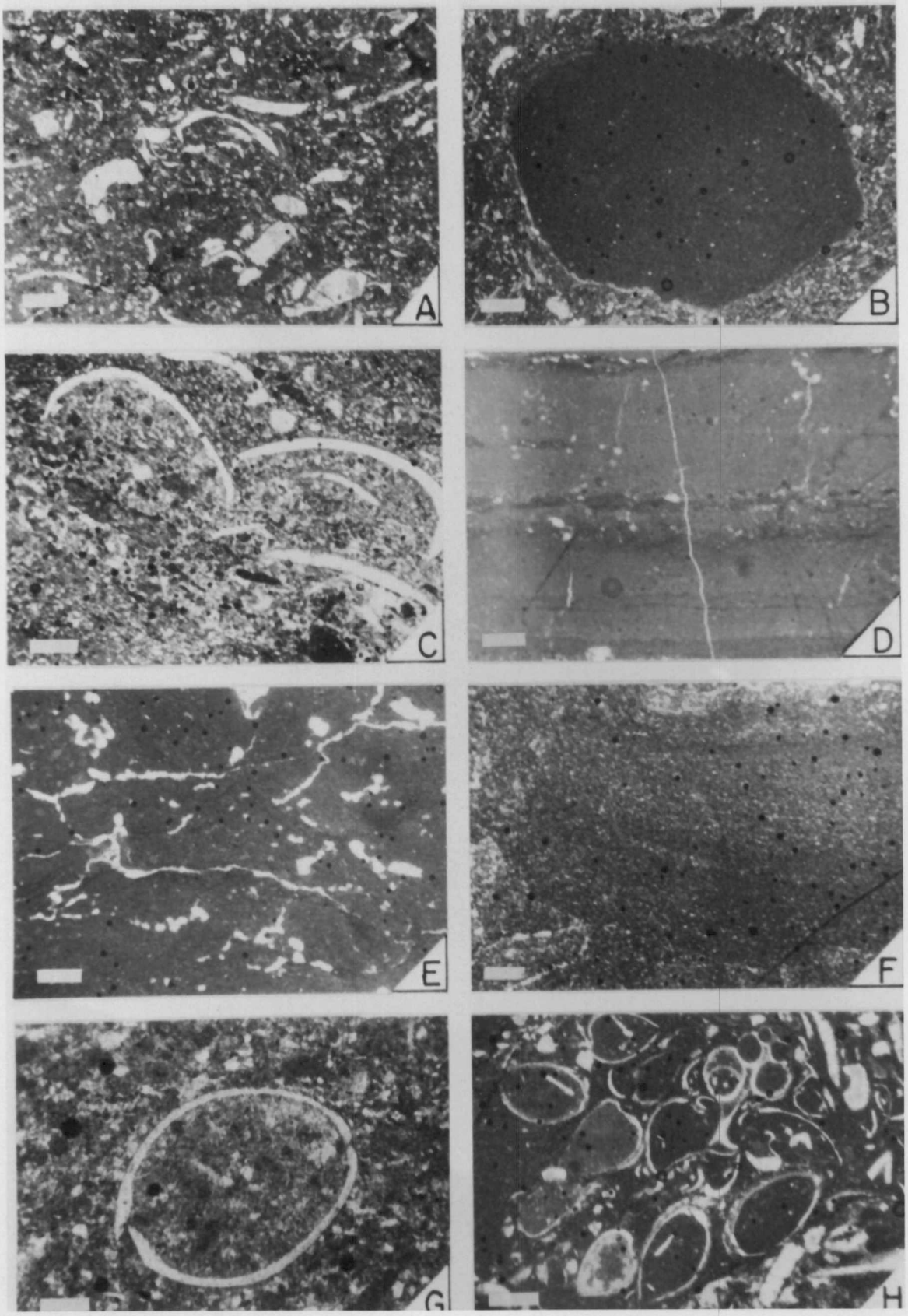
D. Laminae within Lithology 2 rocks. Note that laminae are separated by interlaminar fenestrae and that layers appear identical in lithology. Bar scale is 0.5 mm. (Sample L3C-14).

E. Fenestrate lithology of Lithology 3 rocks. Bar scale is 0.5 mm. (Sample L3B-28).

F. Relict laminae present in Lithology 3 rocks. This laminated zone is the same one illustrated in the upper left-hand corner of Fig. 16C. Bar scale is 0.5 mm. (Sample L3B-22).

G. Articulated ostracode of Lithology 4. Bar scale is 0.5 mm. (Sample L3B-12).

H. Numerous articulated ctenodontid(?) clams of Lithology 4. Bar scale is 0.5 mm. (Sample L3B-12).


A
B
C
D
E
F
G
H

elongate to equant with well-rounded edges and appear to be derived from the underlying lithology (Lithology 2) implying that an erosional event preceeded the deposition of the overlying Lithology 1 layer (Fig. 13B).

Fabric. Beds are typically 3 to 12 cm in thickness. Most bed interiors possess a roughly homogeneous, bioturbated fabric although some samples display laminae and/or grainstone layers. Thus, a full spectrum of laminated, partially bioturbated, and thoroughly bioturbated examples occur.

A number of samples have a series of sedimentary structures unmarred by bioturbation; lamination is the most prevalent. Laminae consist of alternate mud-rich and peloid grainstone layers and they usually have quartz silt and silt-sized fossil fragments suspended in the mud matrix (Fig. 14A). Pressure solution seams appear to have preferentially formed coincident with the wackestone layers. Grainstone horizons are composed of rounded, ovoid, and well-sorted peloids and fossil fragments (Fig. 14B). Rarely, grainstone laminae exhibit interlaminar fenestrae. Mud-rich laminae are usually continuous over ten's of centimeters despite laminae thickness or thinness. Thicker grainstone laminae (L3B-32) form discontinuous pods or lenses 1-3 cm in length while thin (about 1 mm) laminae are often as continuous as mud rich layers (L3B-40). Samples L3B-32 and L3B-46 have a 6.5 cm and 11 cm portion of bioturbated fabric overlain by a laminite cap approximately 0.5 cm thick (Figs. 14A and 15A). Similar to identical lamination has been described by Davies (1970b) and Hardie and Ginsburg (1975) in algally bound sediment; therefore, these laminae are interpreted to be remnants of algal structures.

Figure 14. Thin-section negative prints of lamination in Lithology 1 rocks.

A. Alternate grainstone and peloid packstone layers in some Lithology 1 rocks. Note the bioturbated interior, laminite cap, and the discontinuity of the grainstone layers. Rectangle is area shown in B. (Sample L3B-32).

B. Alternate grainstone and peloid packstone layers in Lithology 1 rocks; detail of the enclosed portion of Fig. 14A. (Sample L3B-32).


5 MM
A


2 MM
B

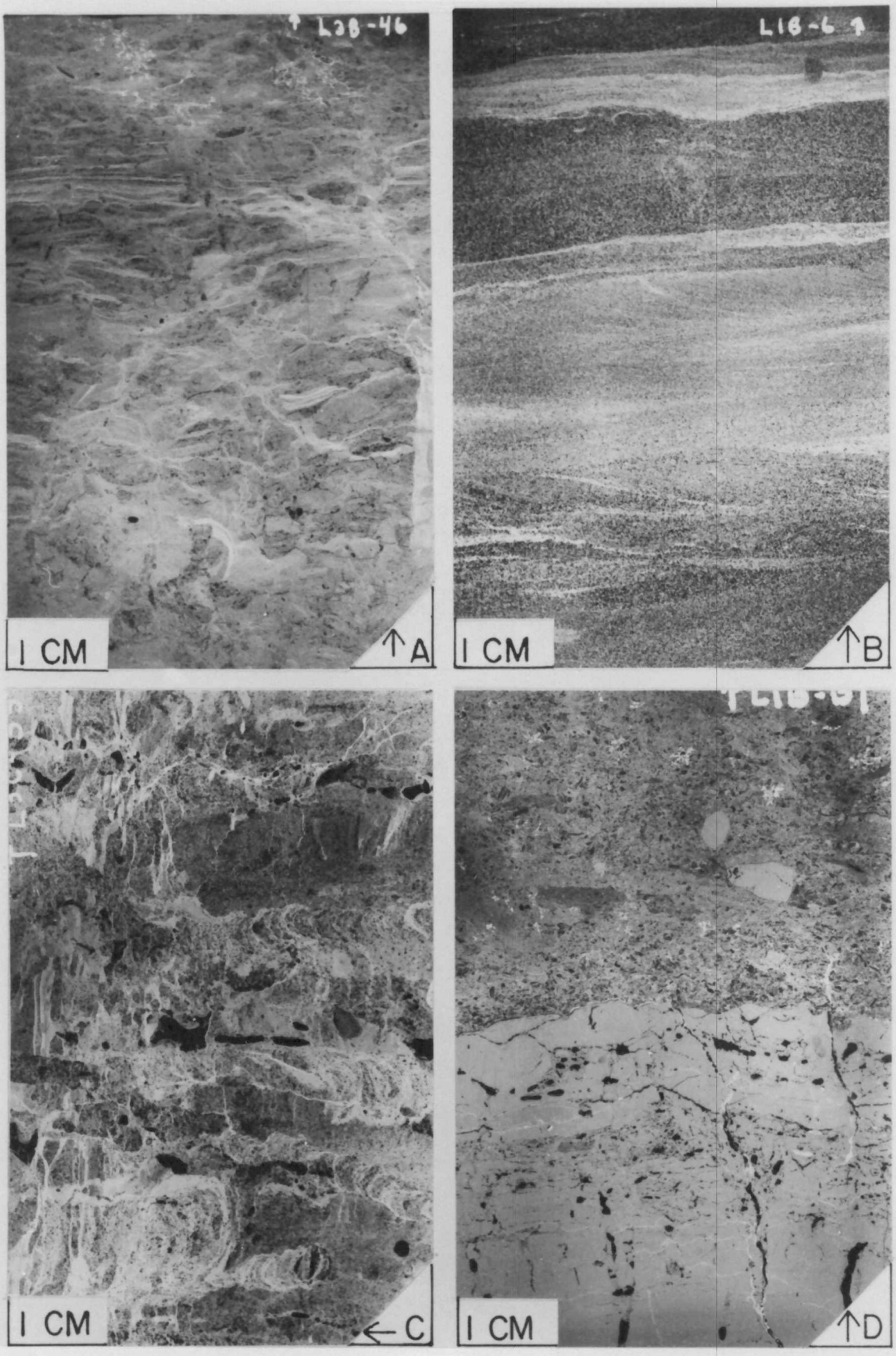
Figure 15. Thin-section negative prints of the characteristic fabrics of Lithology 1 and Lithology 2 rocks.

A. A Lithology 1 rock. Most of the rock is bioturbated but a unbioturbated, laminated portion is visible near the top of the thin-section. (Sample L3B-46).

B. A Lithology 1 rock. Note the presence of abundant peloids oriented into plane and cross laminae. Scour surfaces are also abundant. (Sample L1B-6).

C. Robust, vertical burrows with spriete in Lithology 1. Also note the occurrence of relict laminae near the top center of the print. (Sample L3C-35).

D. Contact between Lithology 1 and Lithology 2. Note the scour surface exhibited by the lower, Lithology 2 layer and the presence of intraclasts which are apparently identical to Lithology 2 in the upper, Lithology 1 layer. (Sample L1B-B1).


L28-46
1 CM
↑A
L16-6
1 CM
↑B
1 CM
←C
1 CM
↑D

Cross lamination also occurs in unburrowed samples. Peloids and fossils are oriented into ripples, cross laminae, and planar laminae (Fig. 15B). In one sample, current-formed cross beds are succeeded by a laminite cap.

Bed interiors are also partially to totally bioturbated. Partially bioturbated samples (L3B-30, L1B-B2) have relict laminae which are isolated and surrounded by burrowed areas. Thoroughly bioturbated rocks usually possess wispy, fossil-rich pods surrounded by peloid and mud zones. Most of these pods have been formed by burrowers - mud has either been selectively concentrated in or removed from burrowed areas. Other grainstone pods may be relict traction layers since they contain many concave-down oriented ostracode valves, implying current deposition (L3B-41, Fig. 13C).

Vertical burrows are more numerous than horizontal burrows. Both robust (1-4 mm diameter, 20-45 mm in length - 1-4 X 20-45 mm) peloid-filled, and 1-2 X 10-20 mm spar-filled burrows are present. Spreite are often observed within burrows (Fig. 15C). U-shaped burrows also occur in this lithology (L3B-27, 36). In addition, pellet-filled horizontal burrows 2 to 5 mm in diameter are common. Partial spar-fillings within vertical and horizontal burrows, and the characteristic sharp burrow walls indicate that the sediment water content of the burrowed sediment was less than 50% (Walker, 1974).

Desiccation features are rarely observed but shrinkage fenestrae are seen within some grainstone layers in laminated samples. This occurrence suggests that these rocks had a potential for exposure or were actually aerially exposed much of the time.

The most notable feature about supratidal deposits in the Andros Inland tidal flats is that they seldom display mudcracks or desiccation fenestrae even though they are exposed 90% of the time (Hardie, 1975).

Rock associations. Lithology 1 units are vertically associated with lithologies 2 and 3, and other beds of Lithology 1.

Sample L1B-B1 exhibits a scour surface cutting down into a Lithology 2 layer (Fig. 15D). Some minor relief is observed on the contact and ostracode valves and quartz grains are concentrated along this surface. All valves are positioned concave-down; an orientation which is most stable in current regimes (Johnson, 1957; Emery, 1968; Clifton, 1971). Such scour surfaces are common and are present in other samples.

Thus, it appears that Lithology 1 rocks are current-emplaced deposits. Vertical contacts and association with both lithologies 2 and 3 suggest laterally adjacent or proximal depositional environments for all these rock types.

Depositional environment. Studies of modern tidal flats have revealed that virtually all the sediment deposited in tidal flats is derived from environments offshore. Little of the sediment volume on tidal flats is actually produced *in situ* although much may be modified once deposited. Post-depositional compaction of soft peloids may form a "pseudomatrix" in which fossils and indurated peloids "float". Thus, sediments deposited as grainstones could be converted to mudstones and wackestones and accordingly be interpreted as quiet water deposits. Bioturbation can also be a modification mechanism which

converts grainstones to packstones by mixing mud with allochems.

By analogy, Lithology 1 rocks are interpreted to form in such a way. Selected samples have readily recognizable peloids occurring with fossil allochems and quartz silt to form packstones or grainstones. These peloids are roughly equal in size to each other, to the fossil material, and probably to the detrital quartz thereby implying transport. Scour surfaces, intraclasts of underlying lithologies, and current-produced planar and cross lamination also suggest a traction origin. Since many of the samples of Lithology 1 have similar desiccation and bioturbation structures and non-peloid allochems, but appear to be mudstones or wackestones, by inference these rocks were also probably deposited as grainstones. Additional evidence includes the occurrence of packed peloids in vague, patchy areas which Hardie and Ginsburg (1975) have termed a "clotted" texture or fabric.

Although all these rocks were deposited in intertidal or supratidal tidal flat environments, a number of subenvironments are represented by Lithology 1. Rocks with bioturbated interiors and laminite caps are very similar to levee, levee backslope, and exposed channel bar deposits described by Hardie and Garrett (1975). Such sequences could also be produced in Persian Gulf sebhka channels as indicated by Shinn (1973) or on broad belt-like intertidal/supratidal flats in positions above mean tidal level.

Thoroughly bioturbated sediments could have formed in levee, levee backslope, beach-ridge backslope, channel bar, or intertidal

flat environments. Hardie and Garrett (1975) have noted that lamination below levee, levee backslope, and beach-ridge backslope is absent although the sediment at the surface is laminated to a depth of 5-10 cm. Bioturbated, silty lithologies may represent the interiors of these tidal flat structures. Alternatively, these rocks are consistent with a belt-like, intertidal shoreface environment. Deposition probably occurred below mean tidal level to allow total bioturbation to occur; however, because of fortuitous circumstances relict laminae are sometimes preserved.

Rocks with dominant current-produced fabrics are probably tidal channel deposits. The paucity of mud in these rocks indicates the presence of mud-winnowing currents. Bidirectional cross laminae also support this interpretation.

Lithology 2

Lithology 2 rocks are maroon, tan, or gray mudstones and rarely wackestones with or without fossil material. They occur most commonly in sections L1 and L3B but are also found in the lower part of section L3C, and in section L3D between the T3 and T4 bentonites.

Petrology. Fossils are rare to absent. Ostracodes, sponge spicules, and unidentifiable fossil debris occur in subequal abundance although any form may be absent in a given sample. Silt- to very-fine sand-sized, unidentifiable fossil debris is ubiquitous. Sponge spicules are also ubiquitous and include both monaxon and triaxon varieties. Ostracode valves, both broken and unbroken, are found in some samples and, with some exceptions, are abraded.

Non-fossil allochems are uncommon. Quartz silt is present in some samples and in situ ovoid peloids are observed within some burrows.

Fabric. This lithology is characterized by internal thin beds 2-3 cm in thickness forming external, 10-15 cm beds (Figs. 16A and 13D, p. 36), or by homogeneous beds up to 15 cm in thickness. In sample L1B-D3, thin beds contain internal laminae (Fig. 16B). Alternate 1-3 mm clay-rich and 4-6 mm mud laminae impart this lamination. Incipient stylolites are present within clay-rich laminae but not within carbonate mud-rich laminae. Laminae are continuous and do not pinch or swell. Some laminae are cross-cut by vertical burrows. Clay-rich laminae appear to be thin stylocumulate zones; Laporte (1967) has reported similar layers and has used their presence as evidence of algal trapping and binding activity. However, no oversteepened structures were observed in thin section so the clay laminae may not be algal structures.

Burrows in these rocks are common; vertical and U-shaped burrows are up to 8 mm in apparent diameter and 100 mm long. Vertical burrows are mud- and/or spar-filled, but the spar-filled, wispy, discontinuous vertical burrows are much more common. Horizontal burrows are auxiliary structures. Burrows may cross-cut laminae within thin beds or cross-cut a number of thin beds. Sharp burrow walls, the presence of spar fillings in burrows, and undeformed cross-cut laminae all indicate low sediment water content.

Lithology 2 also possesses desiccation features. Mudcracks with 6-15 cm polygons are not uncommon. Horizons within laminated

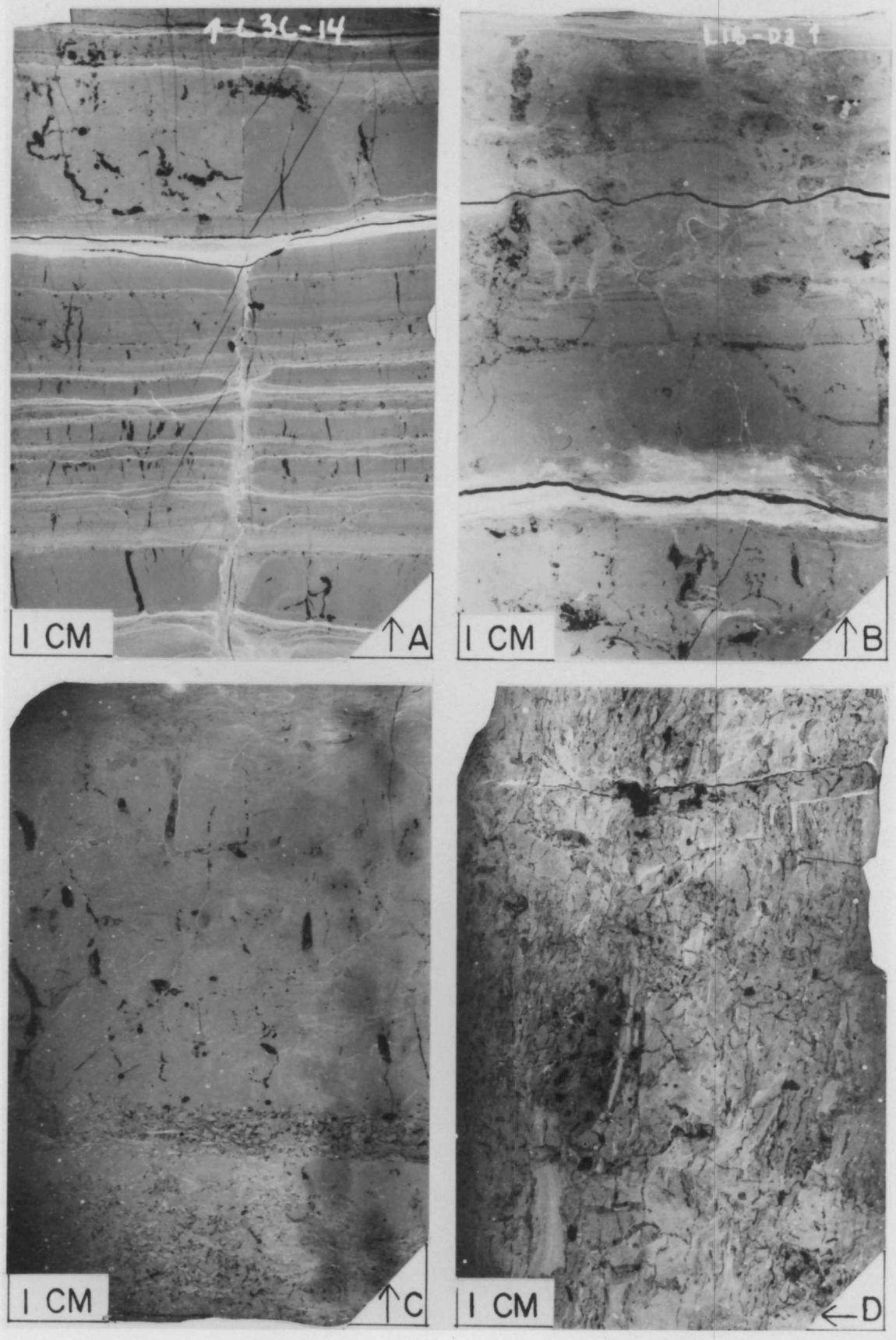
Figure 16. Thin-section negative prints of the characteristic fabrics to Lithology 2 and Lithology 3 rocks.

A. A typical Lithology 2 rock. Note the alternate laminae which are identical in lithology and are separated by interlaminar fenestrae. Also notice the boundary of the mudcrack polygon bissecting the rock. (Sample L3C-14).

B. A typical Lithology 2 rock showing three external beds separated by cracks (now filled with epoxy as a result of sample preparation). The middle bed displays millimeter-scale internal laminae. (Sample L1B-D3).

C. A typical Lithology 3 rock showing a robust vertical burrow in the right-hand portion of the sample and an area with relict laminae in the upper, left-hand portion of the slide. Fig. 13F shows a close-up photomicrograph of this laminated region. (Sample L3B-22).

D. Contact between Lithology 3 (bottom) and Lithology 2 (top) rocks. Note the fenestrae in the lower layer and the spar-filled vertical burrows in the upper layer. (Sample L2C-23).


1 CM
A
1 CM
B
1 CM
C
1 CM
D

beds show common desiccation fenestrae which also connote aerial exposure.

Associated rocks. Lithology 2 rocks are in vertical contact with both lithologies 1 and 3 suggesting that these sediments were laterally related at the time of deposition. Vertical Lithology 1 (top) - Lithology 2 contacts are erosive and Lithology 2 intraclasts are present within Lithology 1 beds.

Depositional Environment. Layers or laminae within Lithology 2 rocks have survived homogenization by burrowers. This indicates that these sediments were deposited above mean tide level. The presence of common desiccation features such as mudcracks and interlaminar fenestrae supports this inference. Organism diversity in these rocks is low implying environments possessing wide salinity fluctuations, frequent aerial exposure, or both.

Lithology 2 rocks are interpreted to be analogous to algal marsh deposits of the Andros Island tidal flats. Both Lithology 2 and algal marsh sediments are characteristically thin-bedded; layering has not been appreciably disturbed by either desiccation or bioturbation. Limited burrowing activity and desiccation features are accordant with algal marsh sediment properties.

Lithology 3

This lithology is characterized by mudstones with prominent desiccation fenestrae. Lithology 3 rocks occur mainly within the middle portions of sections L1 and L3B. More rarely, they are

present in section L3C intercalated with lithologies 1 and 2, or in section L3D between the bentonites.

Petrology. Both fossil and non-fossil allochems are present in only trace amounts. Ostracodes are the only fossils; valves may be broken or unbroken but are generally unabraded. Detrital quartz is sometimes present and may comprise about 1% of the rock.

Fabric. The most noticeable feature of this rock type is the presence of desiccation fenestrae (Fig. 13E, p. 36). Irregular, interlaminar, and tubular fenestrae are all present and comprise up to 10% of the rock volume (fenestrae terminology after Grover and Read, 1978). Other desiccation features include shrinkage cracks with 2-3 cm polygons.

Sample L3B-22 exhibits relict laminae. A laminated portion is surrounded in three dimensions by burrowed and desiccated regions (Fig. 16C and 13F, p. 35). Lamination is characteristic of some Lithology 2 samples and the occurrence of relict laminae in sample L3B-22 suggests that lithologies 2 and 3 might be linked genetically. In addition, both rocks types contain sparse allochems and identical matrix, and both possess desiccation features.

Vertical burrows far outnumber horizontal burrows. Most vertical burrows are 1-3 X 12-20 mm in size and are spar-filled. Robust (3-4 X 33-40 mm) mud-filled burrows are also present. Low sediment water content is indicated by distinct burrow walls and partial spar-fillings.

Associated rocks. Lithology 3 rocks are stratigraphically associated with other tidal flat accumulations such as Lithology 1 and Lithology 2, strongly implying a tidal flat depositional environment for Lithology 3 as well. Furthermore, lithologies 2 and 3 are sometimes in direct vertical contact.

In sample L3B-23, a Lithology 2 layer abruptly overlies a fenestrate mudstone layer of Lithology 3 (Fig. 16D). Thus, desiccated mudstones were succeeded by mudstones which were not subject to as much desiccation.

Depositional environment. Lithology 3 rocks display fenestrae or "birdseye" structures. In modern environments, similar to identical voids or vugs are present in supratidal and intertidal sediments. Shinn (1968) has demonstrated that desiccation of carbonate mud forms planar and isolated bubble-like vugs. Grover and Read (1978) have invented a terminology to describe fenestrate deposits and have also noticed that root molds or open burrows may also produce "birdseyes". Ordovician deposits contain no root molds, and burrows are easily distinguished from desiccation fenestrae by their larger size and different form. The presence of irregular and interlaminar fenestrae in this suite is an indicator of sediment aerial exposure.

The high similarity between Lithology 2 and Lithology 3 in terms of matrix, constituent allochems, and sedimentary structures implies a genetic relationship. At the very least they were formed in proximal or adjacent environments since they are in vertical contact. Desiccation shown in sample L3B-22 (Fig. 16C) place subsequent to the formation of its large vertical burrow, for

interlaminar fenestrae cross-cut burrow walls and the matrix surrounding the burrow margin is separated from the host matrix by a spar-filling - an indication of desiccation. The mud-filled burrow reacted differently to exposure than the surrounding matrix. This sequence of events suggests that Lithology 3 sediments were once wet enough to be burrowed but were then desiccated. If Lithology 2 sediments had been subjected to the same series of events, they would appear identical to Lithology 3. Thus, by inference, Lithology 2 and Lithology 3 may have been deposited in identical depositional environments but underwent slightly different histories after deposition.

Lithology 4

This lithology consists of greenish gray, thoroughly bioturbated mudstones, wackestones, and packstones with indigenous restricted-water biota. This group of samples can be distinguished from other rock types by the almost total exclusion of open-marine organisms and the paucity of calcareous algae. Lithology 4 rocks occur only as a single package in the lower portion of section L3B.

Petrology. Fossils are the only allochems present in this suite. Ostracodes and ctendontid (?) clams are the principal faunal elements but gastropods and trilobites are also common and may be abundant within a given sample. Both ostracodes and bivalves are articulated; in some samples virtually all individuals are articulated (Figs. 13G and 13H, p. 36). Abrasion and fragmentation are negligible on ostracode and clam valves. Gastropods are usually preserved as whole unabraded, shells (Fig. 17A). Trilobites occur as both abraded

Figure 17. Photomicrographs of features observed in Lithology 4 and Lithology 5 rocks.

A. Typical gastropod in Lithology 4. Bar scale is 0.5 mm. (Sample L3B-12).

B. Abraded and fragmented nicholsonellid bryozoan in Lithology 4. Bar scale is 0.5 mm. (Sample L3B-10).

C. Hedstroemia algae encrusting a trilobite fragment in Lithology 4. Bar scale is 0.5 mm. (Sample L2C-43).

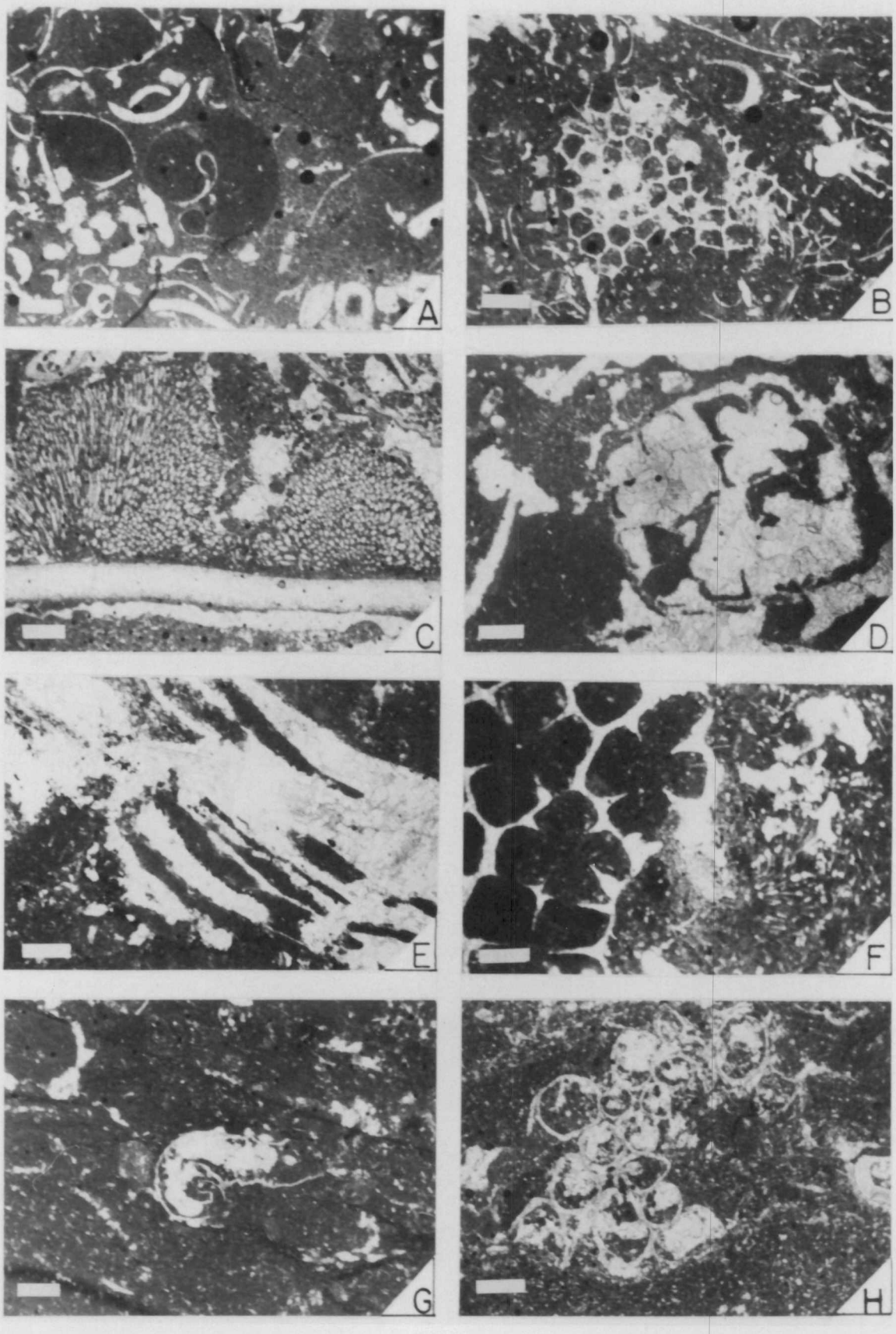
D. Hedstroemia algae encrusting a Tetradium corallite in Lithology 4. Bar scale is 0.5 mm. (Sample 52B).

E. Longitudinal section through a finger-like Tetradium corallite in Lithology 4. Bar scale is 0.5 mm. (Sample L3C-52B).

F. The head-like form of Tetradium in Lithology 5. Note the cavity/boring to the right of the typical clover-like Tetradium and the type of sediment and allochems within the cavity. peloids, Hedstroemia plates, and ostracode valves are present. Bar scale is 0.5 mm. (Sample L3C-53).

G. Longitudinal section of a serpulid(?) worm tube present in Lithology 5. Bar scale is 0.5 mm. (Sample L3C-44).

H. Transverse section through serpulid(?) worm tubes present in Lithology 5. Bar scale is 0.5 mm. (Sample L3C-43).


A
B
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H

fragments and as unabraded, articulated specimens up to 15 mm wide. As a whole, restricted-water organisms are much more numerous and display limited transportation effects, and are therefore interpreted as indigenous.

Open-marine fossils are also present but rare. Abraded echinoderm plates and columnals are usually most abundant, but abraded fragments of brachiopods and nicholsonellid bryozoans also occur (Fig. 17B).

The algae Solenopora and Hedstroemia and the coral Tetradium are also rare components. It is difficult to assess the amount of abrasion to algal grains, but these allochems do seem to be abraded suggesting transport from a proximal environment. Sample L3B-14 has unbroken and unabraded Tetradium corallites comprising 5% of the rock.

Fabric. This lithology exhibits beds 5-15 cm thick. Bed interiors are thoroughly bioturbated as evidenced by allochems which exhibit no preferred orientation (Fig. 18A). Valves are present in all configurations - concave-up, concave-down, and rotated through all intermediate positions. Large, linear fossils do not always lie parallel to bedding. Burrow walls are diffuse, hence the water content of the original sediment was very high.

Rock associations. Lithology 4 rocks are associated with the silty fossil wackestones and packstones of Lithology 1, and the mudstones of lithologies 2 and 3. Actual interbedding of lithologies 1 and 4 takes place at the base of L3 and further upwards in the section

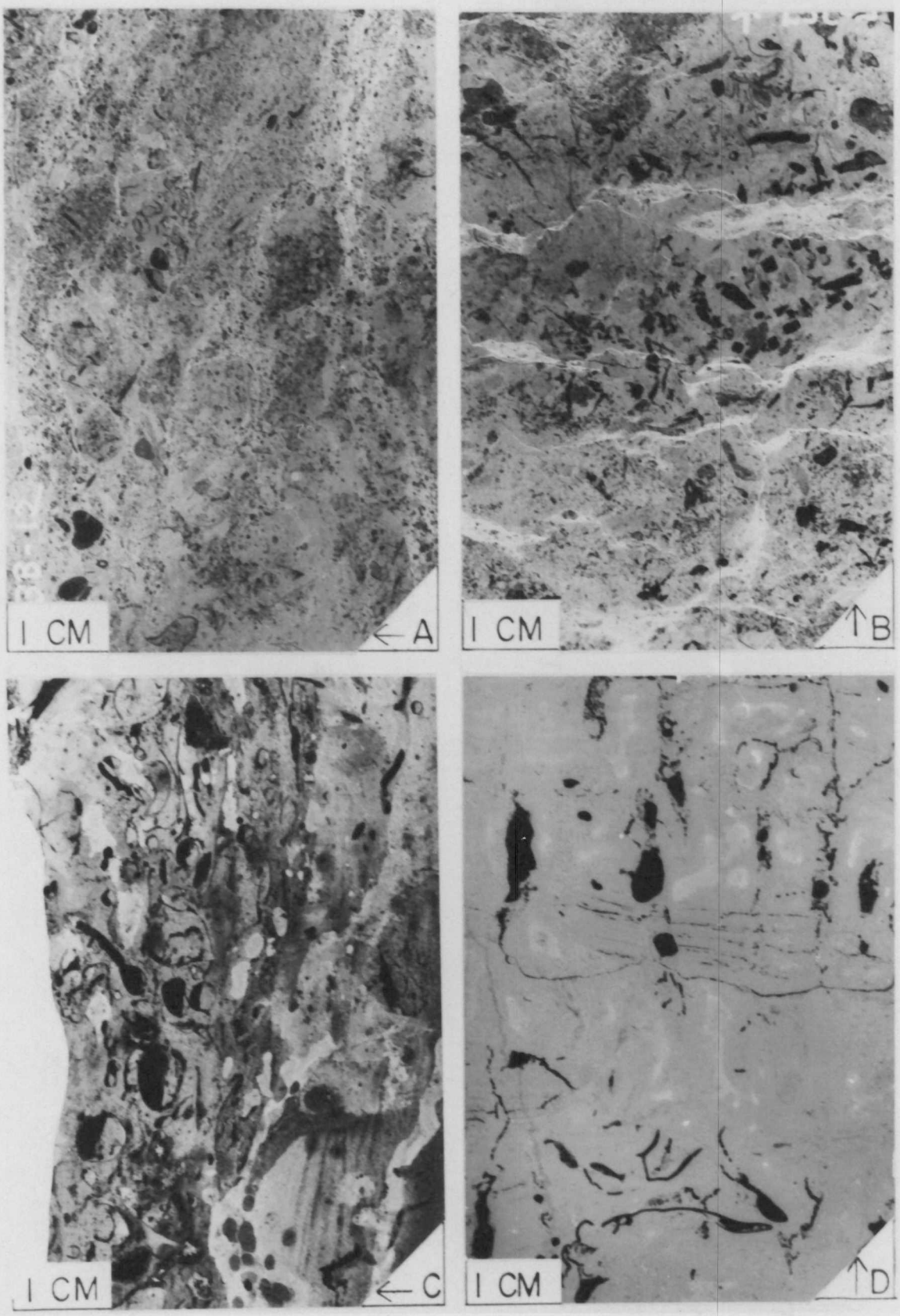
Figure 18. Thin-section negative prints of the characteristic fabrics of lithologies 4, 5, 6, and associated rocks.

A. Typical Lithology 4 fabric. Note the thoroughly bioturbated fabric and the presence of trilobites, ostracodes, ctenodontid(?) clams, gastropods, and algal plates. (Sample L3C-12).

B. Typical Lithology 5 sample. Note the mud-rich, bioturbated fabric. Most of the dark square- and rectangle-shaped bodies are Tetradium corals. (Sample L3C-5).

C. A sample associated with Lithology 5 rocks. Note the lower, laminated peloid layer overlain by the upper, fossil-peloid grainstone layer. These horizons are separated by a scour surface. (Sample L3C-46).

D. Typical Lithology 6 sample. Note the bioturbated fabric, desiccation fenestrae, and spar-filled vertical burrows. (Sample L3D-7).


1 CM
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1 CM
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1 CM
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where Lithology 4 is also intercalated with Lithology 2 and Lithology 3 rocks. Thus, Lithology 4 is intercalated with rocks interpreted to be tidal flat deposits and the entire Lithology 4 package lies stratigraphically between these tidal flat deposits.

Depositional environments. These sediments were definitely deposited in shallow, subtidal environments of variable salinities. Both the presence of indistinct horizontal burrows and indigenous restricted-water fauna support this interpretation.

The characteristics of this lithology are consistent with tidal pond or belt-like shore environments similar to those of Andros Island (Hardie et al., 1975). The association of Lithology 4 rocks with the silty, intertidal and supratidal rocks of Lithologies 1, 2, and 3 - which are all very similar to specific depositional environments within the Andros Island tidal flat complex - seems to suggest a tidal pond environment.

Biological information also suggests a tidal pond depositional environment. Nowhere else in the L3 stratigraphic section are ctenodontid clams and ostracodes more densely distributed or present as articulated specimens. The similar lithologies 5 and 6 do not contain appreciable amounts of ctentodontid bivalves nor are ostracodes articulated as often. Also, the paucity of both open-marine biota and calcareous algae is nowhere more striking than within this suite of rocks. The lack of open-marine biota may be attributed to a distance effect - the greater the distance away that open-marine environments are located, the rarer will be the occurrence of open-marine organisms. Tidal ponds would be the most distal environment

in respect to open-marine waters. Furthermore, provided that calcareous algae are not limited by turbidity considerations in lithologies 4, 5, and 6, the paucity of calcareous algae in Lithology 4 may be explained by highly variable salinities. Salinity variation is quite high in tidal pond environments. Andros Island tidal ponds do not regularly contain calcareous algae; only rare specimens of Penicillus occur (Hardie and Garrett, 1975).

The above arguments suggest but do not prove that Lithology 4 rocks were deposited in tidal ponds. The petrology and fabric of this facies are also consistent with an offshore environment. Furthermore, Hardie and Garrett (1975), Hardie and Ginsburg (1975), and Garrett (1975) all point out that the offshore marine and tidal pond sediments of Andros Island are virtually identical - only the presence of mangrove root casts indicate tidal pond deposits, a criterion not applicable to Ordovician deposits. Thus, because only differences in biota distinguish these environments today, no unequivocal analog can be compared with Lithology 4.

Lithology 5

Lithology 5 rocks are algae-bearing, bioturbated wackestones. They may be distinguished from Lithology 4 rocks by increased abundances of both calcareous algae and Tetradium. Lithology 5 occurs in the uppermost portion of section L3B and in the basal and middle parts of section L3C.

Petrology. Restricted-water fossils are more numerous than open-marine fossils. Ostracodes and trilobites are most common

although gastropods are also important in this assemblage. Articulated ctendontid(?) clams are minor faunal elements. Ostracodes are commonly articulated but separate valves are more abundant; articulation is not as common as it was in Lithology 4. Low abrasion and fragmentation indicate an indigenous assemblage.

Open-marine fossils include echinoderm elements, bryozoans, and brachiopods. All these forms are rare in abundance but echinoderm plates and columnals, and bryozoan fragments are more common than brachiopod fragments. All open-marine fossil grains are abraded implying transport.

Calcareous algae, mainly Hedstroemia but in places Solenopora, are important components and are much more numerous than in lithologies 4 and 6. These forms usually occur as isolated, discrete particles, but Hedstroemia also encrusts trilobite fragments and Tetradium corallites (Figs. 17C and 17D, p. 54). Most algal grains seem to be lightly abraded to unabraded suggesting that they are indigenous.

Tetradium corals are also common, comprising between 1% to 15% of the rock. These corals do not typically occur as massive colonies as in Lithology 12, but are present as slender, finger-like colonies up to 11 mm in height which appear as elongated V's in longitudinal section (Fig. 17E, p. 54). The number of characteristic, clover-like cells increases systematically from 1 to 4 to 16 as transverse sections are taken from successively higher positions on the colony. Tetradium colonies have often dissolved to create moldic fabrics but mud-filled corallites survived the solution

process. Walker (1970) has discussed the life orientations of similar growth forms of his "Tetradium wave-baffle" community. Tetradium also occurs as a more massive head-like form in sample L3C-53 (Fig. 17F, p. 36).

Both Tetradium growth forms (ecophenotypes? - Walker, personal communication; T.W. Broadhead, personal communication; see also Webby and Semeniuk, 1970) seem to have lived in environments with abundant mud and high variations in salinity. The environment for both of these growth forms is presumed to have been unagitated as evidenced by abundant mud. In addition, finger-like colonies are not attached to epifaunal biota. Walker (1970) believed that this growth form was supported in an upright position by the mud substrate. If so, agitation must have been very low. Tetradium did not seem to be inhibited by the presence of fine-grained sediment.

The Tetradium-associated, indigenous fauna consists of restricted-water forms such as ostracodes and gastropods. Associated open-marine fossils - echinoderms, bryozoans, and brachiopods - are definitely a transported assemblage. Tetradium is therefore interpreted to be eurytopic in response to salinity variations.

Interesting occurrences of serpulid(?) worm tubes are present in this lithology. Specimens of the same or different species exhibit both solitary and colonial life modes (see Figs. 17G and 17H, p. 36). Laporte (1967) has also found serpulid worm tubes in Devonian tidal flat rocks.

Unidentifiable fossil debris and sponge spicules are ubiquitous if not common allochems. They may comprise up to 5% and 1% of a rock's volume respectively.

Peloids are the only non-fossil allochem present in this lithology. Excluding pellets found within burrows, peloids are present in only some samples. If present, they are ellipsoidal, rounded, about 0.10 mm in long dimension, and appear to be well sorted.

Fabric. Beds are generally 5-50 cm thick with completely bioturbated interiors. Fossil allochems display no preferred orientation but are rotated in a random pattern (Fig. 18B, p. 57). Burrows are cryptic with extremely diffuse walls indicating high sediment water content. Some burrows contain 0.2 mm diameter *in situ* pellets. Burrowing is exclusively horizontal; apparent burrow diameters range from 2 to 5 mm.

The peloids not found in burrows are usually contained within clotted areas or in irregularly-shaped lenses. The mud matrix, in part or in whole, actually may be composed of compressed peloids rather than primary mud. The good sorting displayed by peloids seems to support a transported origin, but sorting could be ascribed to *in situ* pelleting by a single species of deposit-feeder. The isolated peloids may also be transported indurated peloids such as those described by Garrett (1975) from Andros Island tidal ponds.

Associated rocks. Lithology 5 rocks are commonly intercalated with the intertidal and supratidal rocks of lithologies 1, 2, and 3, or stratigraphically near them. Lithology 5 rocks are most closely associated with Lithology 6 rocks being most commonly interbedded with them. The depositional environments of these two lithologies were probably adjacent to one another. This association will be fully discussed in the Lithology 6 section.

A volumetrically unimportant rock type represented by sample L3C-46 occurs in the bed beneath sample L3C-47 (Lithology 5). Sample L3C-46 is a peloid packstone/grainstone displaying two sedimentation events (Fig. 18C, p. 57). A lower plane-laminated peloid grainstone layer grades into a packstone horizon which is in turn overlain by a fossil-peloid grainstone layer. The lower contact of the grainstone appears to be a scour surface because: (1) relief in excess of 5 mm is visible on the contact; (2) a number of large fossil allochems lie in current-oriented positions; (3) a partially exhumed allochem projects out of the lower layer; and (4) irregular intraclasts identical to the lower-layer lithology are present in the overlying layer. These features are all consistent with channel or storm deposits, the presence of multiple sedimentation events more strongly suggests a channel origin. These deposits could be either tidal flat or subtidal channels; however, because Lithology 5 rocks are associated with tidal flat sediments and biotic assemblages within L3C-46 are not diverse, a tidal flat channel origin is implied.

Depositional environment. Lithology 5 was deposited in restricted subtidal conditions. The relative increase in diversity in comparison to Lithology 1, 2, and 3 rocks; the dearth of vertical burrows; and the presence of ubiquitous horizontal burrows all point to a subtidal origin. Restricted-water conditions are indicated by numerous indigenous restricted-water fossils while open-marine fossils are scarce and obviously transported. Beyond a subtidal, restricted-water origin, many specific environments seen in modern systems are consistent with the above characteristics.

If Lithology 4 rocks are tidal pond deposits, the decreased abundance of ctenodontid clams and gastropods, and the increased abundance of calcareous algae might imply that Lithology 5 rocks were deposited in offshore marine environments where salinities permitted a more diverse biota. Still, this evidence is by no means conclusive and does not preclude a tidal pond origin for Lithology 5 rocks or an offshore marine origin for Lithology 4 rocks. Lithology 5 sediments, like Lithology 4 sediments, are interbedded with intertidal and supratidal rocks, thus either an offshore marine or a tidal pond depositional environment is plausible for either lithology.

Lithology 6

Lithology 6 rocks are gray, bioturbated mudstones. Unlike Lithology 5, algae are scarce to absent as are most other biota. Lithology 6 rocks may be distinguished from Lithology 4 rocks by the dearth of ctendontid(?) bivalves, the decreased numbers of gastropods, and the increase in the number of vertical burrows. Lithology 6 is closely associated with Lithology 5 in its occurrence. Like Lithology 5, it occurs mainly in the upper portion of section L3B and in the middle of section L3C.

Petrology. Fossil material is the predominant allochem type. Ostracodes and gastropods are common fossils; trilobites and monaxon triaxon sponge spicules are less abundant but ubiquitous. All these organisms exhibit minor abrasion and fragmentation and are therefore interpreted to be an untransported assemblage.

Abraded echinoderms or, more rarely, abraded bryozoan fragments are the only open-marine faunal elements. Due to their abraded nature, they are interpreted to be exotic.

Fabric. Beds are typically 4-13 cm thick. Bed interiors are completely bioturbated (Fig. 18D, p. 57). Either vertical or horizontal burrows may be present in any given sample, but vertical burrows are generally more numerous. Beds which are stratigraphically nearer to rocks representing desiccated or intertidal environments either display vertical burrows much greater in number than horizontal burrows, or display only vertical burrows. Vertical burrows may be mud-, pellet-, or spar-filled; typical observed dimensions are 1-2 X 12-17 mm but robust burrows up to 3 X 35 mm occur. Horizontal burrows are usually 2-4 mm in diameter. As a result of burrowing activity, allochems display no preferred orientation. Distinct burrow walls and burrow spar-fillings are indicative of lower sediment water contents. In addition, sample L3C-15 contains a robust vertical burrow clearly formed in a firm substrate (Fig. 19A). Fossil allochems protrude from the matrix into the burrow cavity and appear to have controlled the burrower's actions (Fig. 19C). The sediment must have been firm enough to keep the allochems embedded in the burrow wall despite the burrowing activity.

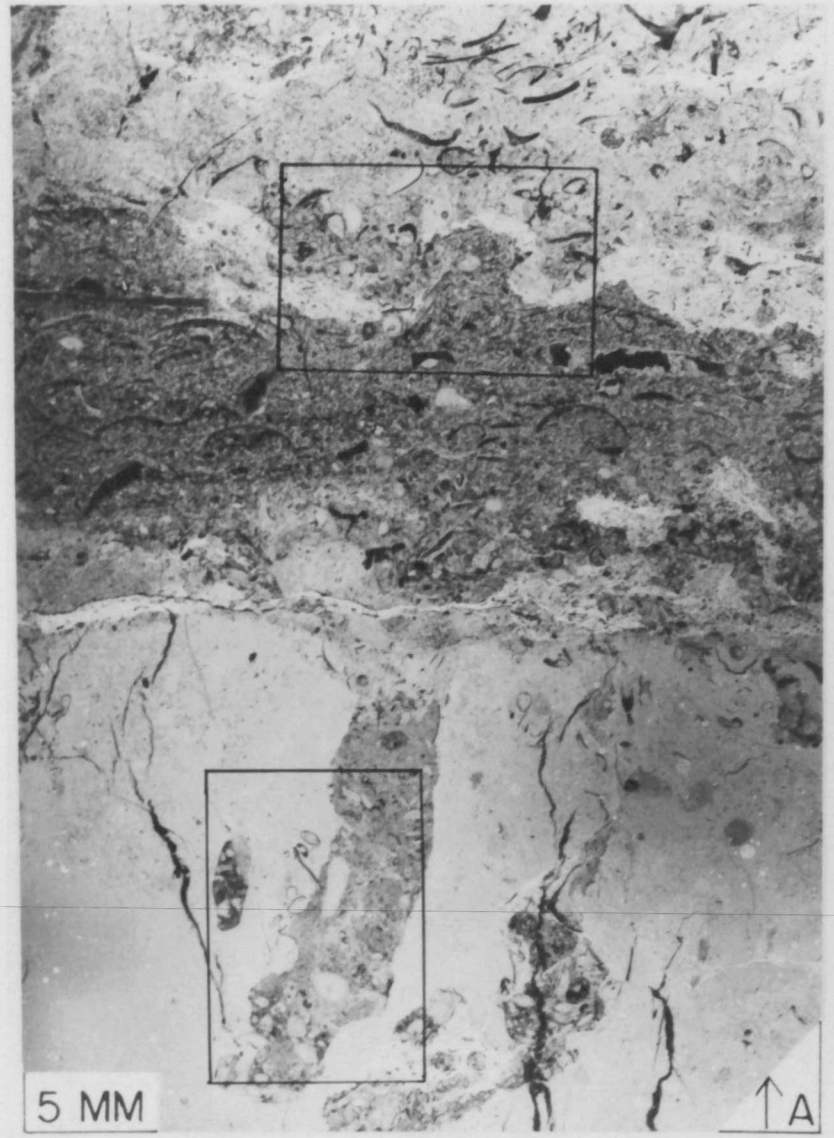
As in Litholotype 5, peloids are observed in vague, clotted masses. This observation might indicate that the mud fabric is secondary and was produced from the compaction of soft, transported peloids. As for Lithology 5, the notion is unprovable; however, the lack of transported fauna in these rocks points to *in situ* peloid formation.

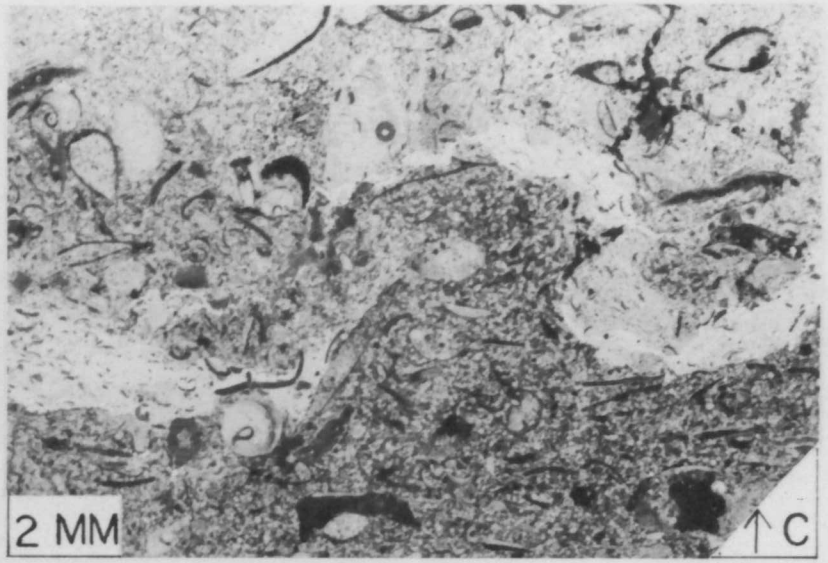
Figure 19. Thin-section negative prints of features observed in Lithology 6 rocks.

A. Lithology 6 mudstone layer overlain by a probable grainstone traction layer which is in turn overlain by a packstone layer. Note the robust vertical burrow in the Lithology 6 mudstone. Upper rectangle is area of photograph B; lower rectangle is area of photograph C. (Sample L3C-13).

B. Burrow pictured in Fig. 19A. Note that the burrow wall is coincident with a number of fossil allochems which seem to have controlled the burrower's actions.

C. Grainstone-packstone contact illustrated in the upper portion of Fig. 19A.


5 MM
A


2 MM
C


2 MM
B

Associated rocks. Lithology 6 rocks are associated with a number of different lithologies which represent intertidal or supratidal environments. Association with the silty, peritidal deposits of Lithology 1 is displayed by samples L3B-40 and L3B-48. Likewise, samples L3C-40 through 42 lie just above a package of Lithology 1 rocks. Associations with sediments from desiccated environments include samples L3C-29 and L3C-32 which were taken from beds that lie immediately above and below mudcracked and fenestrate mudstones.

Sample L3C-15 exhibits a contact between a lower 3 cm layer of Lithology 6 overlain by a 4 cm horizon of peloid-fossil packstone/grainstone (Figs. 19A and 19B). The mudstone layer exhibits a large robust vertical burrow (see Fig. 19A) with a number of fossil allochems suspended in a mud matrix. The grainstone-Lithology 6 contact is probably erosive in nature since: (1) 5 mm of relief is seen on the Lithology 6 surface; and (2) intraclasts identical to Lithology 6 are incorporated into the grainstone layer. The packstone/grainstone layer is actually a grainstone at the base and is capped by a packstone with an irregular boundary. The grainstone-packstone contact may itself be a scour surface but a stylocumulate zone obscures the true nature of the contact. The grainstone layer is moderately sorted and composed of irregularly-shaped to rounded peloids, fossils, and Lithology 6 intraclasts. Larger ($>$ 3 mm) valves in the grainstone are all concave-down while acicular grains lie parallel to bedding suggesting current emplacement. This grainstone may be either a channel or a storm deposit. Sample L3C-17 (Fig. 20A) also displays laminated peloids and current-oriented fossils and it is interpreted to be of similar origin as the grainstone layer of sample L3C-15.

Figure 20. Photographs of features observed in lithologies 9, 10, 11, and 12 rocks.

A. Thin-section negative print of peloid packstone/grainstones that are related to Lithology 6 rocks. Note the preponderance of peloids, horizontally burrowed regions, and relict plane laminae composed of peloids. Bar scale is 5.0 mm. (Sample L3C-17).

B. Photomicrograph of a peloid intraclast characteristic of Lithology 9 deposits. Bar scale is 0.5 mm. (Sample L3C-69).

C. Photograph of a Lithology 10 bedding plane with gastropods. Bar scale is 10 mm.

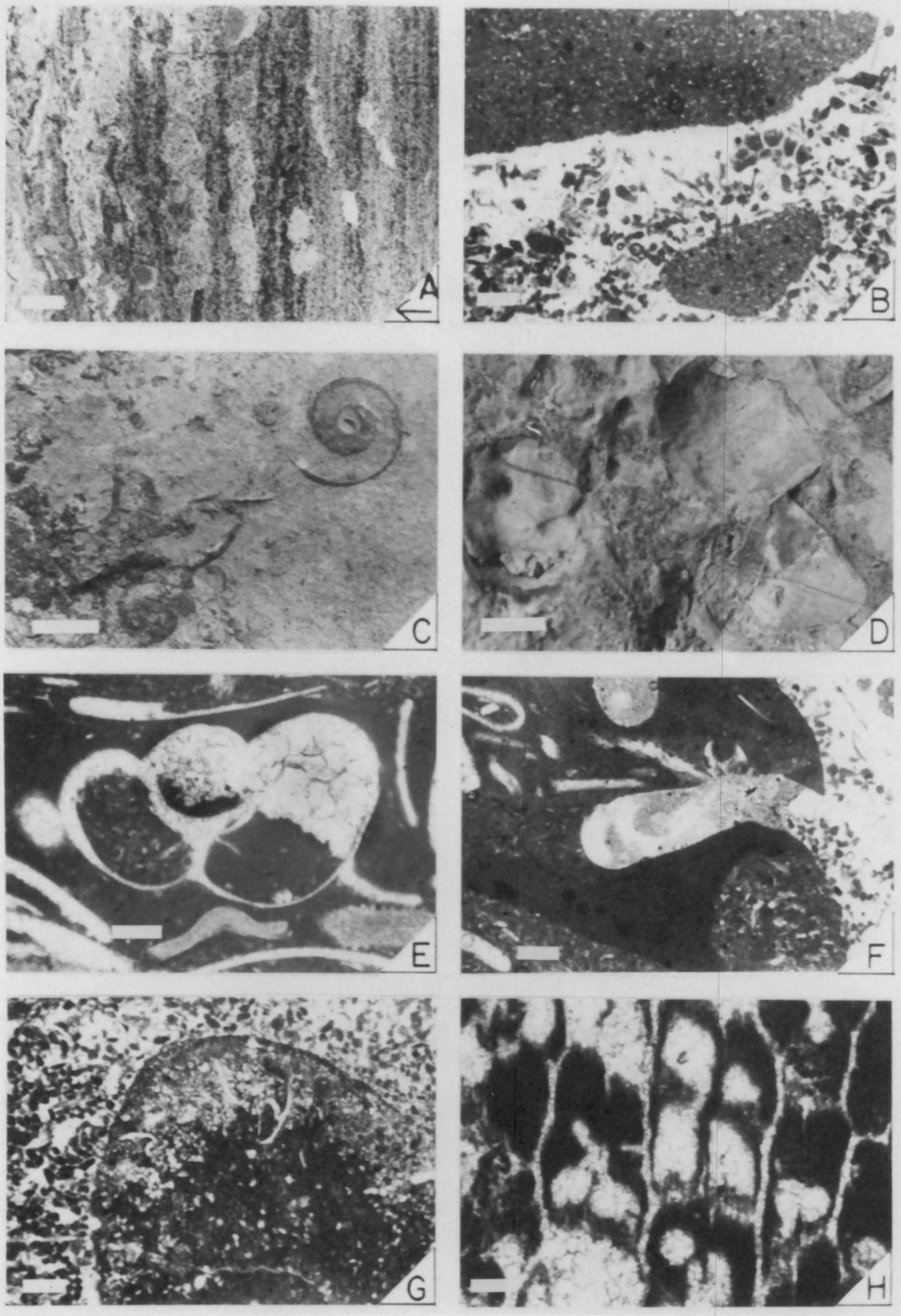
D. Photograph of a Lithology 10 bedding plane with strophomenid brachiopods. Bar scale is 10 mm.

E. Photomicrograph of a gastropod containing discrete peloids within its test which have not been compacted because of the sheltering effect provided by the gastropod. Bar scale is 0.5 mm. (Sample L3D-32).

F. Photomicrograph of a bored intraclast in a Lithology 11 sample. Bar scale is 0.5 mm. (Sample L3D-19).

G. Photomicrograph of a bored intraclast in a Lithology 11 sample. Bar scale is 0.5 mm. (Sample L3D-35).

H. Photomicrograph of a Lithology 13, massive Tetradium head. Bar scale is 0.5 mm. (Sample L3D-10B-1).


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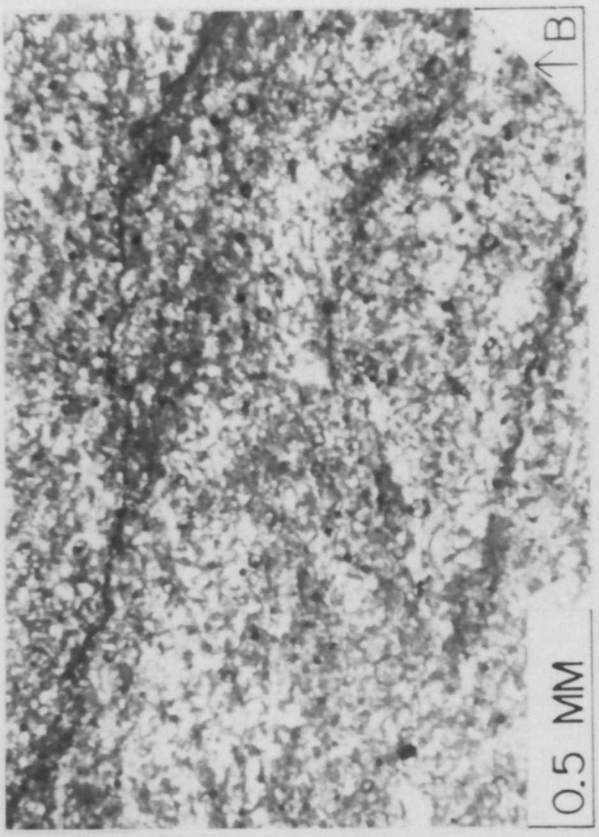
Lithology 6 rocks are also associated with rocks possessing weak algal lamination. Internal portions of samples L3C-20A and 20B contain inclined cross laminae which suggest current deposition, but alternate 1 to 5 mm peloid grainstone and peloid packstone laminae also occur (Fig. 21A). Grainstone layers are usually separated by planar solution seams; these stylocumulate layers appear to be coincident with peloid packstone layers (Fig. 21B). Although no anti-gravitational structures were observed, these laminae are interpreted to be algal laminations. The occurrence of alternate layers with different packing modes and the coincidence of stylocumulate layers in positions where organic material should occur support this interpretation. Laporte (1967) has made similar inferences, but has apparently confused stylocumulate layers and solution seams with organic films. In the absence of anti-gravitational structures, the presence of former algal mats or algally-bound sediment cannot be determined with any certainty. The fabric of these rocks is consistent with levee crest, levee backslope, and channel bar as described by Hardie (1975). Thus, Lithology 6 appears to be associated with tidal flat channel rocks.

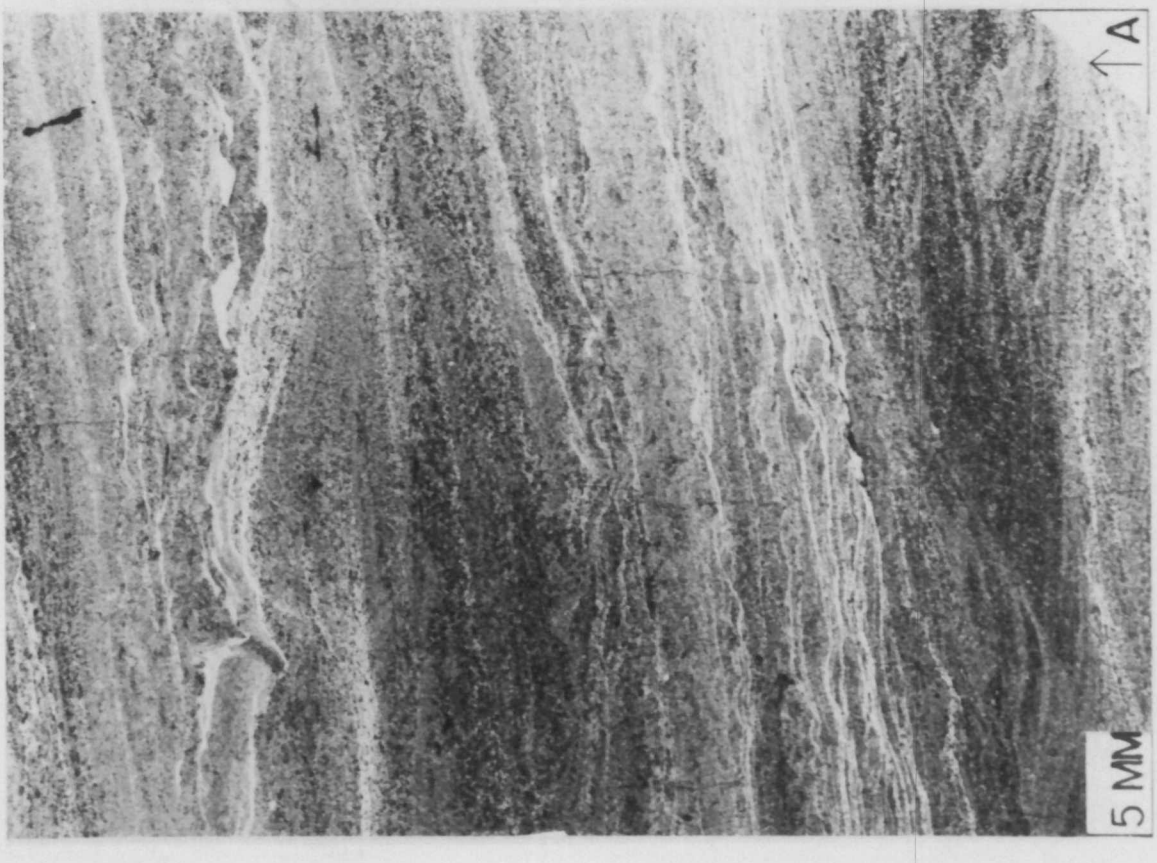
Finally, Lithology 6 rocks are usually located stratigraphically between intertidal and supratidal rocks (Lithology 7), and Lithology 5 rocks. Transitions from Lithology 5 rocks (samples L3B 49-53 - L3C A-5) through Lithology 6 rocks (samples L3C 6 and 7) and into algal mat deposits (Lithology 7; samples L3C 7A, 9, 10, and 11?) occur. This transition is accompanied by a decrease in the total number of fossil allochems (Fig. 22), and a decrease in both calcareous

Figure 21. Thin-section negative prints of rocks associated with Lithology 6 rocks.

A. A sample interbedded with Lithology 6. Note the cross-laminae at the bottom of the slide and the laminated peloids at the top of the photograph. Subparallel stylocumulate zones occur near the middle of the sample. (Sample L3C-20A).

B. Laminated portion of the above sample, Fig. 21A. Peloid grainstone and peloid packstone layers alternate to generate lamination. Stylocumulate zones tend to preferentially occur at peloid packstone horizons. (Sample L3C-20B).


B
0.5 MM


A
5 MM

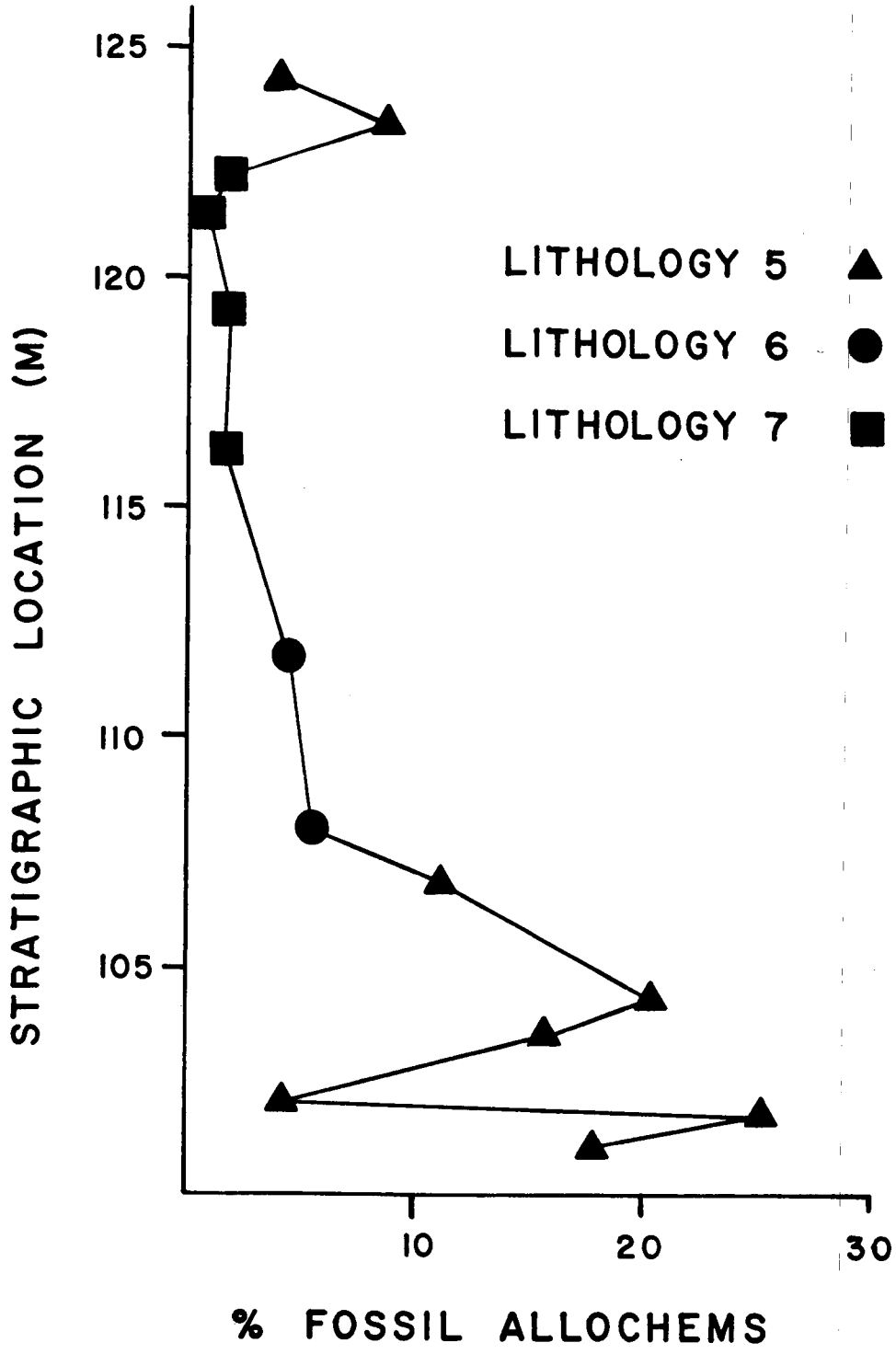


Figure 22. Systematic decrease in % fossil allochems in the basal portion of section L3C. Note that the fossil content of the rocks decreases concomitant with the transition from Lithology 5 to Lithology 6 to Lithology 7 rocks.

algae and Tetradium abundance. This systematic decrease in total biota probably represents an environmental cline with respect to more variable salinities and increased exposure as indicated by biotic distributions and abundances. The opposite transition from intertidal algal mats to Lithology 5 rocks was not observed - perhaps due to a lack of detailed sampling. In any event, the Lithology 6 environment was genetically related to both intertidal, supratidal, and restricted, subtidal environments.

Depositional environment. Lithology 6 rocks were deposited in shallow, restricted waters below mean tide level. The biota is sparse and are represented by restricted-water taxa. The thoroughly bioturbated nature of the rock fabric is indicative of formation in totally or regularly submerged environments.

Lithology 6 is particularly instructive since its beds often lie stratigraphically between Lithology 5 beds and obvious intertidal and supratidal sediments represented by Lithology 7. Lithology 6 is similar to both Lithology 4 and Lithology 5, yet it is distinctive in its lack of calcareous algae and other biota. A less abundant biota implies either variable salinities or increased aerial exposure or both. The dominance of restricted-water organisms, the increased incidence of vertical burrows, and the appearance of features which indicate low sediment water content all suggest both of these environmental conditions.

Lithology 5 and 6 environments are inferred to have been immediately adjacent to one another since they are commonly interbedded. Both are associated with intertidal and supratidal deposits

and this accordantly suggests a tidal flat origin for these rocks. If this is true, Lithology 5 and Lithology 6 rocks most probably represent pond and pond margin deposits respectively; however, the above data are also in agreement with offshore and marginal-offshore environments. As mentioned above, Hardie (1975) repeatedly asserted that pond and adjacent marine sediments are virtually identical.

Lithology 7

Lithology 7 consists of thinly laminated rocks which contain organo-sedimentary structures produced by algal mats. Only two occurrences were noted; one in the basal portion of section L3C and another near the base of section L3D.

Petrology. Fossil allochems are extremely rare in these rocks. Ostracodes are the most common fossil and are represented by abraded and unabraded, and broken or unbroken valves. Heavily abraded echinoderms and bryozoans are rare.

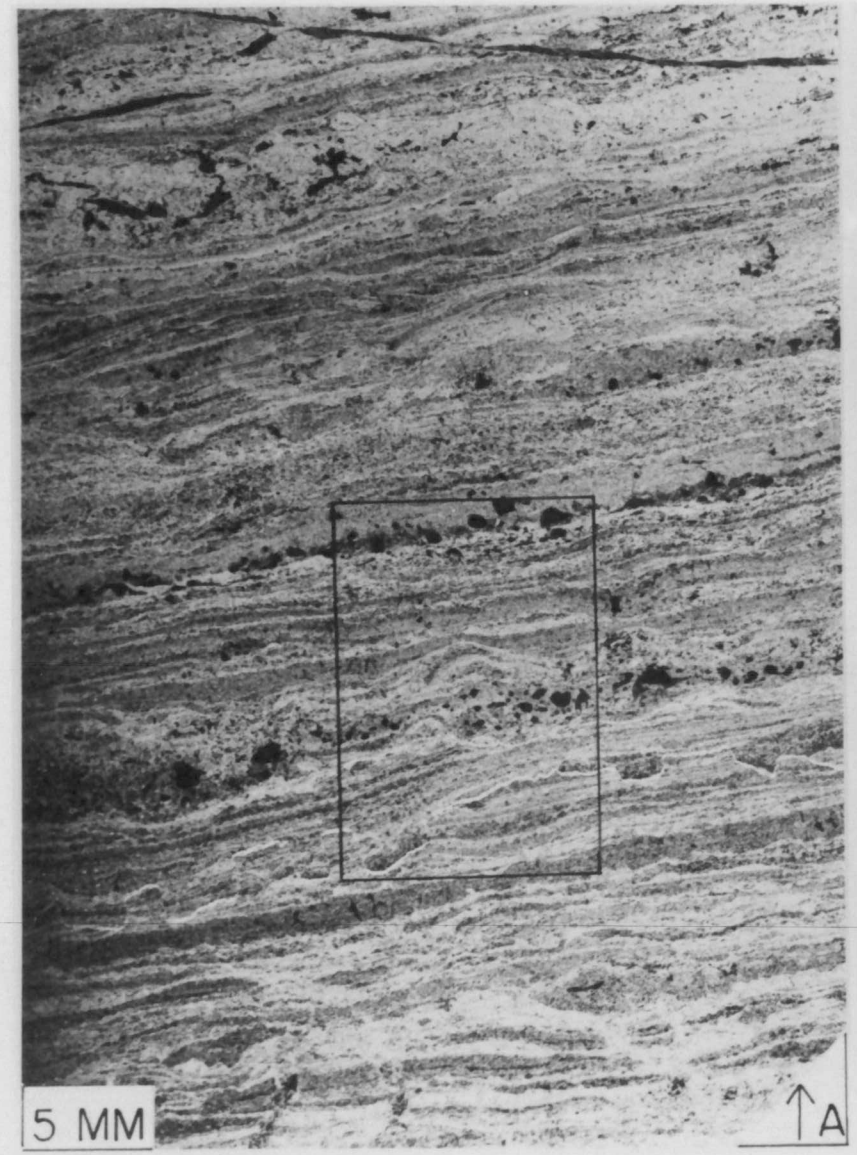
Peloids are the dominant allochem. They are generally ellipsoidal, rounded, well sorted, and approximately 0.05 mm in apparent long dimension. Their origin is problematical; they may be transported fecal pellets, eroded but size-selectively transported intraclasts, micritized fossils, or any combination thereof.

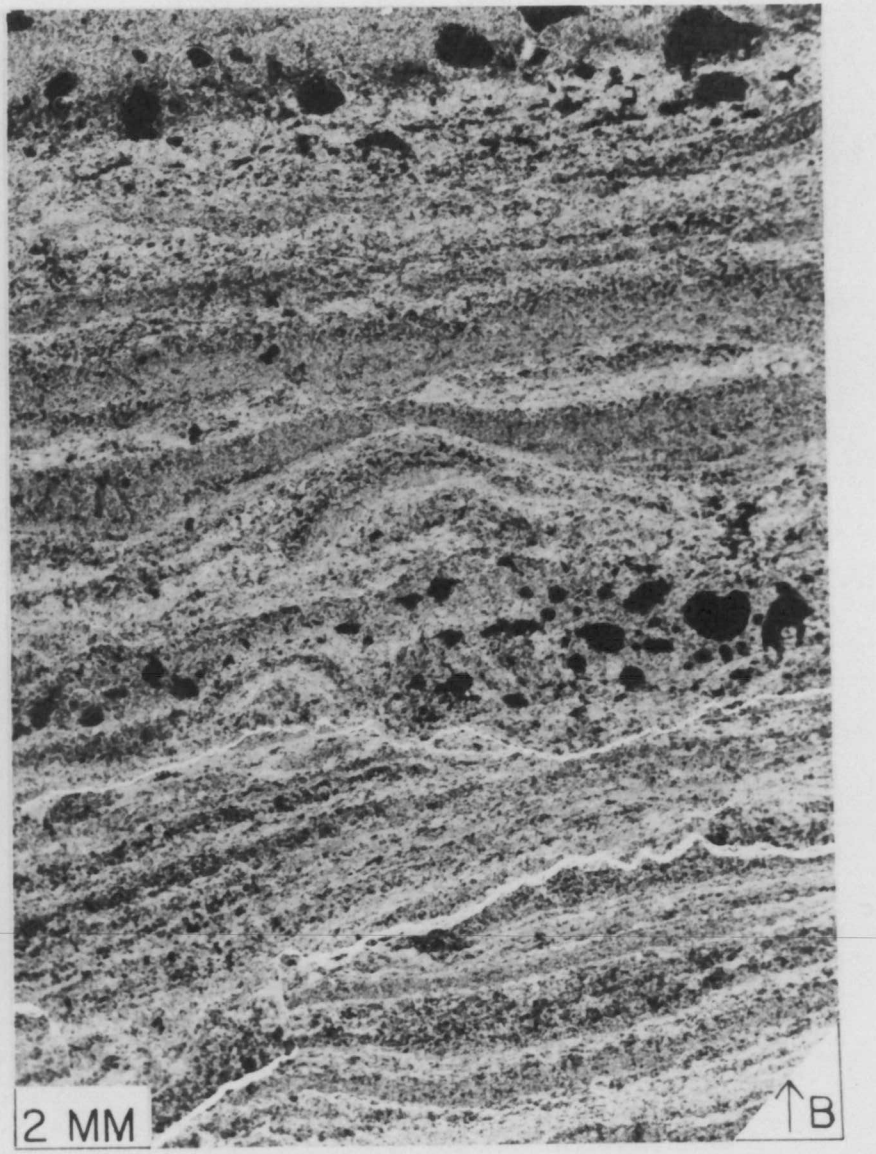
Fabric. Structures within these rocks are definitely cryptalgal. Fossil-peloid grainstone and peloid wackestone/packstone laminae, typically between 1-5 mm in thickness, alternate to produce this rock fabric (Figs. 23A and 23B). If different laminae thicknesses occur, grainstones are usually the thicker lamina. Grainstone laminae

Figure 23. Thin-section negative print of algal structures within Lithology 7 rocks.

A. Laminated fabric of Lithology 7. Rectangle is area of photograph B. (Sample L3C-10).

B. A portion of the sample in Fig. 23A. Note the oversteepened laminae in the center of the photo and the alternation of peloid packstone and peloid grainstone layers. (Sample L3C-10).


5 MM
A


2 MM
B

are often discontinuous over centimeters or fractions of centimeters but thicker grainstone laminae may be continuous across an entire thin section (5 or 7 cm). Mudrich laminae may be either planar or wavy. Oversteepened laminae and laminae with thicker portions on topographic highs are common features (Fig. 23B), but laminae are for the most part flat or crinkled.

Associated structures include desiccation fenestrae, burrows, and disrupted laminae. Desiccation fenestrae include mainly interlaminar and irregular "birdseye" although some tubular fenestrae occur. Many tubular fenestrae are probably spar-filled burrows. Disrupted laminae, produced by either desiccation or currents, are also present.

Associated rocks. As mentioned above, these algally laminated sediments are most often associated with Lithology 6. However, they also occur between packages of Lithology 10 and Lithology 12.

Depositional environment. Algal mats occur in a number of Recent environments. The most spectacular algal mats are those forming in Shark Bay and described by Davies (1970b) and Logan et al. (1974). These mats are only developed in hypersaline ($>$ 60 ppt) environments. These mats are definitely intertidal in origin and the Shark Bay workers have correlated a number of different mat forms with certain distinct, albeit overlapping, zones based on the amount of aerial exposure.

Algal mat morphologies recognized in the present study most closely resemble the "smooth" algal mat recognized by Davies (1970b)

and Logan et al. (1974). Smooth algal mats are present in the low (outer) intertidal to shallowest subtidal zones where frequent wettings occur. Davies (1970b) has documented smooth organo-sedimentary structures formed in smooth algal mats up to 50 cm thick; other mat types are represented by veneers or mat thicknesses less than 10 cm. This seems to be due to accretion rate; Logan et al. (1974) have established a 10 mm/yr sedimentation rate for sediments trapped by smooth algal mats. This rate is an order of magnitude more than rates for other mat types (1-2 mm/yr). However, other factors are involved for tufted algal mats also experience sedimentation rates up to 10 mm/yr although their growth rates are quite variable. Davies (1970b) has noted that tufted mats are generally only 1 cm thick. Thus, it appears that smooth algal mats would be most important in the fossil record.

Newell, et al. (1959), Monty (1967), and Bathurst (1967) have studied the occurrence of modern subtidal algal mats in Florida and the Bahamas. Mats are generally less than 1 cm thick, seem to be patchy in distribution, and are not nearly as coherent as intertidal mats; however, they are important sediment binders and trappers. Bathurst (1971) and Neumann et al. (1970) have pointed out that due to burrowing and browsing activity, subtidal algal mats do not survive burial. They are therefore not preserved in the fossil record and as a consequence the remnant mats of this study are interpreted to be of intertidal origin.

Lithology 7 deposits are most probably intertidal in origin since all modern algal mat occurrences with high preservation potential

are found in intertidal environments. Garrett (1970) has suggested that the great abundance of Precambrian algal structures is due to the absence of, or reduced numbers of, browsing macrofauna. The importance of a browsing macrofauna seems to increase in the late Cambrian as stromatolitic structures become less common then and thereafter. It is probably no coincidence that most modern algal mats also form in hypersaline environments. Lithology 7 rocks no doubt formed in restricted environments, as indicated by the dominance of restricted-water fauna, but it is problematical whether hypersaline conditions were present or whether Ordovician algal mat occurrences necessitate hypersaline conditions.

Lithology 8

Lithology 8 rocks are dominantly well sorted grainstones with rare occurrences of packstones. This lithology occurs only between two tidal flat packages in the interval between 183 and 192 meters in section L3C.

Petrology. Fossil grains comprise 18-21% of these rocks. Echinoderm plates and columnals are the predominant fossils. In sample L3C-26 much of the spar is probably syntaxial overgrowths and echinoderm substrate which have merged to render the fossil core unrecognizable. Ostracodes, trilobite fragments, bryozoan fragments, gastropods, bivalves, and Hedstroemia plates are additional fossils in order of decreasing abundance. All grains tend to be abraded to heavily abraded and fragmented; some ostracodes and trilobites are articulated, however, and do not appear to be abraded.

Despite echinoderm dominance, restricted-water organisms are slightly more abundant than the open-marine fauna. This fact may suggest a greater proximity to restricted-water environments but the data do not preclude an environment with open-marine salinity.

Intraclasts and peloids are the only other allochems. Intraclasts are usually no larger than 3 mm and may be angular to rounded and irregular in shape. Peloids are ellipsoidal to spherical, generally well rounded, and range from 0.05 to 0.10 mm in size. The peloids may be splinters of eroded intraclasts, transported pellets, or micritized fossils.

Fabric. The fabric of this rock type is current-produced. Unit 40 displays ripple marks at the base and planar cross beds with internal current-laminated peloids and fossils. Unit 41 exhibits planar beds but planar and cross laminae are commonplace within bed interiors (Fig. 24A).

Burrowing is generally absent but some vertical, pellet- and spar-filled burrows occur.

Associated rocks. This lithology is sandwiched between rocks of intertidal and supratidal origin thereby implying a tidal flat, or at the very least, a very shallow-water depositional environment at the shore margin.

Depositional environment. Lithology 8 rocks were deposited in an agitated, restricted subtidal environment. The presence of currents or waves in the Lithology 8 depositional environment is indicated by the paucity of mud, the presence of plane and cross

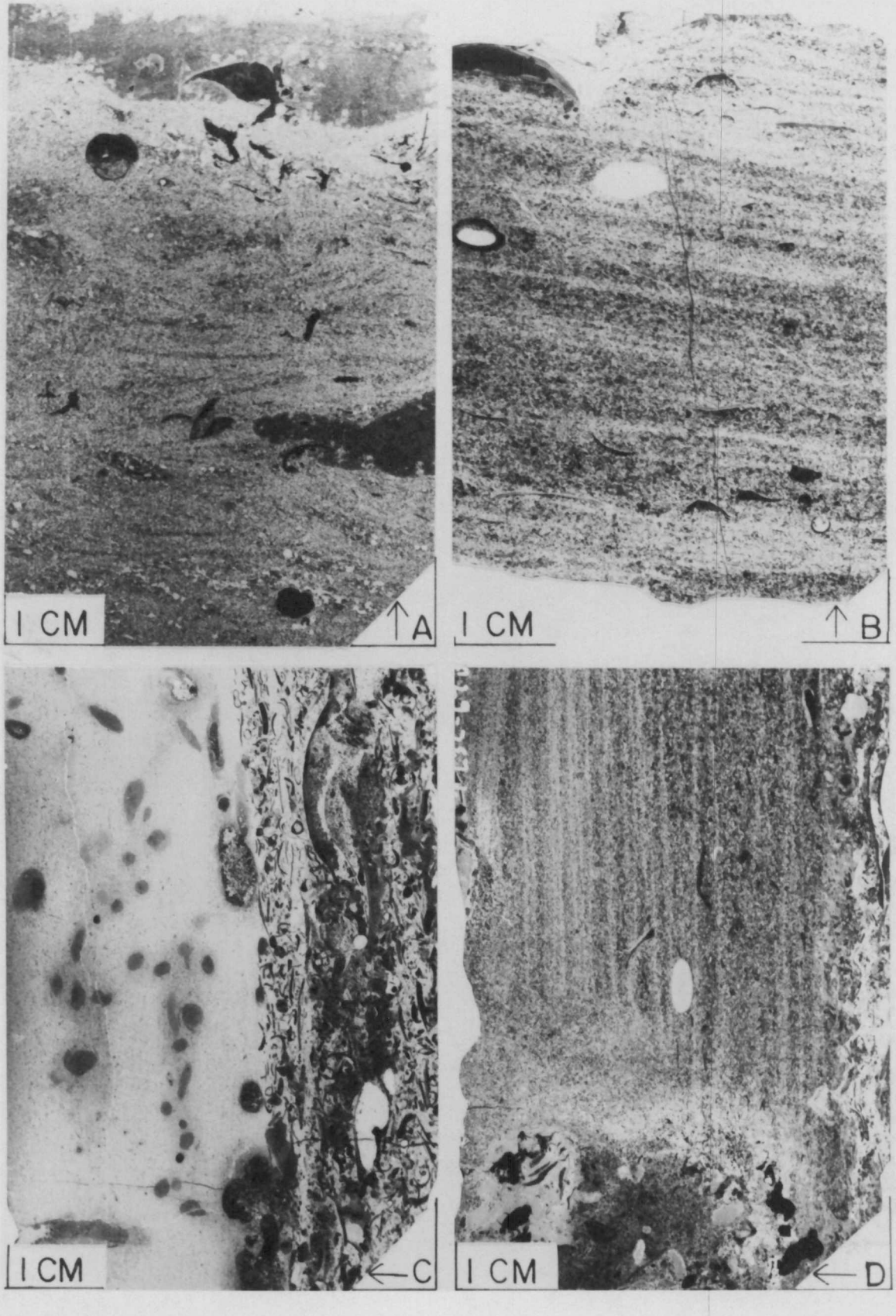
Figure 24. Thin-section negative prints of the characteristic fabrics of Lithology 8 and Lithology 9 rocks.

A. A Lithology 8 sample. Note the presence of abundant peloids oriented into planar and cross laminae. Darker portions of the slide appearing at the top and middle right-hand side of the photograph are chert nodules. (Sample L3C-27A).

B. A Lithology 9 sample. Note the successive laminated peloid layers. This sample appears to fine-upwards in the lower nine-tenths of the slide. (Sample L3C-72).

C. A Lithology 9 fossil-peloid grainstone. Note the current-laminated fossils and peloids which generally fine upwards. The chaotic region at the far left-hand side is bioturbated and may represent an escape burrow. (Sample L3C-67B).

D. A Lithology 9 sample. This sample directly overlies sample L3C-67B (Fig. 24C) and is separated from L3C-67B by a scour surface. Note the general fining-upwards sequence in the fossil-peloid grainstone (bottom) and the mudstone cap. (Sample L3C-67T).


1 CM
A
1 CM
B
1 CM
C
1 CM
D

laminae within beds, and the occurrence of cross beds. The fauna, except for easily transported echinoderm debris, is largely of the restricted-water variety and suggest that this suite was deposited in waters of variable salinity.

The rock fabric shows that physical reworking rates were higher than biogenic reworking rates - current lamination is largely unaffected by any burrowing activity. While this is a feature of many specific environments, the paucity of open-marine organisms suggests a restricted-water environment thus ruling out shelf-edge and platform-edge depositional environments. Restricted-water agitated environments are few but include shoals, subaqueous tidal channels, and tidal flat channels.

This deposit probably formed in a tidal flat channel. Intercalation patterns indicate that this sequence is closely associated with tidal flat deposits and this fact strongly suggests tidal flat deposition. However, this association does not preclude a subaqueous tidal channel origin for Lithology 8 deposits.

Lithology 9

These rocks are fossil-peloid grainstones and packstones. Packstones occur mainly at the base of this sequence while grainstones dominate upsection. These rocks may be distinguished from Lithology 8 by the greatly increased diversity of the fossil assemblage. Lithology 9 deposits occur only at the top of section L3C. Lithology 11 is very similar if not identical to Lithology 9, but it is intercalated with the low-energy deposits of Lithology 10.

Petrology. Fossil content varies widely in this lithology. In some samples, fossils are the predominant allochem composing up to 29% of the rock volume; other samples may be totally dominated by peloids. Samples with subequal amounts of fossils and peloids also occur.

Echinoderms, bryozoans, brachiopods, and ostracodes are the principal fauna; any group may be the most plentiful in a given sample but ostracodes are only dominant in peloid-rich rocks. Ancillary fauna include in decreasing abundance, trilobites, bivalves, gastropods, Hedstroemia, Solenopora Type P (Moore, 1978), and Tetradium. Unidentifiable fossil debris is ubiquitous and forms up to 3% of the rock in some samples. Many fossil grains exhibit bored rims and micrite envelopes.

All organisms display variable abundance, and shell abrasion and fragmentation. Restricted-water forms tend to be more abundant in peloid-dominated rocks. Fossil-dominated samples may exhibit either open-marine or restricted-water fossils as the most abundant group. Fragmentation and abrasion is variable within every taxon; taxa tend to be represented by both unabraded and worn specimens. Thus either assemblage may be indigenous, but the marked increase in diversity within this suite seems to indicate open-marine, subtidal conditions.

Intraclasts and peloids are the other constituents of this rock type. Intraclasts are ubiquitous and peloids may comprise up to 37% of the rock. Intraclast shape is highly variable and includes irregular, elongate, or subspherical to spherical forms.

Peloid-grainstone intraclasts are the only kind observed (Fig. 20B, p. 70). Intraclasts are up to 12 mm long.

Peloids are generally moderately to well sorted and are usually rounded to ellipsoidal to spherical in shape. However, many irregular and subangular grains do occur. Mean peloid grain size ranges from 0.1 to 0.2 mm from sample to sample. In many samples peloids grade into intraclasts in terms of size. Many fossil grains are observed in various stages of micritization so that peloids probably arose from a combination of transported fecal pellets, abraded intraclasts, and micritized skeletal material. The dominant mechanism of peloid formation is problematical and probably varies from sample to sample. The sorting of peloids in this lithology is probably due to current emplacement rather than similar origin.

Fabric. Beds are typically 7-20 cm thick and exhibit current-oriented allochems. The lower package of packstones is bioturbated but contains many relict current-oriented features such as large, apparently current-oriented allochems, unburrowed current-laminated zones, and rough grading. Many grainstones have packstone caps interpreted to be formed through burrowing activity. Plane-laminated layers of peloids and fossil grains are characteristic of this lithology and many samples exhibit scour surfaces (Fig. 24B). Graded beds are common.

This suite is largely dominated by current-emplaced deposits. Basal layers of coarse, pebble-sized skeletal material are overlain by plain-laminated fossils and peloids to produce graded beds. These

sequences are usually found above pronounced scour surfaces. Depositional units do not always exhibit a basal lag; fossil allochems may be only granule- or sand-sized or absent so that the entire layer may be exclusively composed of plane-laminated peloids. Some sequences do not show grading - coarse fossil lag layers may be truncated by scour surfaces and overlain by typical fining-upward sequences. Individual sequences representing one depositional event range from 5 to 15 cm in thickness.

Sample L3C-67 is a typical sequence with two couplets (Figs. 24C and 24D). The first couplet has a fossil lag layer which is developed above basal scour surfaces and then grades upward into plane-laminated peloids. Another scour surface with 5 mm of relief lies on the peloid layer which is succeeded by a fossil lag horizon which exhibits crude grading. Finally, the sequence is capped by a 2.5 cm thick mud layer. Possible escape burrows occur within each couplet.

Fabrics in this lithology are dominated by physical rather than biological processes but burrows do occur. Burrowing, except for vertical escape(?) burrows, is exclusively horizontal implying a subtidal environment. Burrowing is prevalent in the lower packstone unit of this lithology and in the top 0.5-1.5 cm of many grainstone samples. This activity has converted the topmost layer of grainstone into packstone by the break-down of peloids to mud; current-generated structures lying deep within rock interiors have not been subject to bioturbation.

Associated rocks. These rocks lie stratigraphically above the restricted-water environments represented by Lithology 5 and Lithology 6. A substantial covered interval begins at the top of this lithology. Thus, Lithology 9 rocks may be genetically related to lithologies 5 and 6 suggesting deposition adjacent to restricted-water environments.

Depositional environment. Lithology 9 was deposited in a subtidal, level-bottom, agitated environment. Since these rocks possess little mud matrix and exhibit current-generated fabrics, a turbulent depositional environment is indicated. The high-diversity fossil assemblage points to an environment with normal marine salinities.

The packstones represented by samples 62-66 seem to be transitional between the restricted subtidal rocks of Lithology 5 and the grainstones of this suite. They are bioturbated with relict current-oriented features which imply that they were deposited as grainstones. Unlike the grainstones in the middle and upper portions of this suite, these rocks have been converted into packstones by burrowing activity. Upsection, within the grainstones, burrowing has not modified the original depositional fabric except at the top of depositional units. Beds or layers which represent a single depositional event are no thicker in the grainstones so that the lack of burrowing cannot be attributed to greater burial depths. Perhaps more mud was present during packstone deposition and this encouraged burrowing. Purdy (1964) has found that deposit-feeding organisms are

much more plentiful in mud substrates because of concomitant deposition of organic matter.

This entire suite seems to be dominated by samples representing storm deposition which display their characteristic sedimentary structures. Plane-laminated sands produced by storms have been interpreted to form during a transition from upper flow regime to lower flow regime (Kumar and Sanders, 1976). Reineck and Singh (1972) have also noted this occurrence and plane laminae have been observed in definite storm deposits by Ball et al. (1967). Not all storm-produced fabrics have oriented grains. Kumar and Sanders (1976) demonstrated that basal lags are composed of randomly-oriented, pebble-sized (or larger) shell debris. Cores taken by Ball et al. (1967) in the Florida-Bahamas area also displayed such chaotic layers. Both plane-laminated layers and coarse lags with randomly-oriented fossils occur in Lithology 9.

Kumar and Sanders (1976) formulated a number of ideal sequences for storm deposits. Graded beds have long been recognized as characteristic of waning flow, but waning flow does not occur exclusively in storm deposition (Reineck and Singh, 1975). However, storm deposits display other characteristic features. Classic and complete storm layers should display size-grading developed over a reactivation surface. Typical graded beds exhibit a coarse basal lag which grades into and is overlain by laminated sand. Depending on their location, storm layers will be modified by different fair-weather processes. Kumar and Sanders believe that in environments where physical processes are dominant, such as above wave base, storm layers should be capped

by rippled sands. If biogenic reworking is more important - such as below wave base, in typically non-turbulent environments, or in the presence of an abundant burrowing fauna - storm sequences will be overlain by bioturbated sediments. Subsequent storms may erase any part of the above sequences by scour and resuspension of sediment.

Kumar and Sanders' ideal storm sequences explain many of the sequences in Lithology 9. Incomplete graded beds with or without basal fossil lags may be attributable to storms which have truncated pre-existing storm sequences. Complete sequences show a basal lag developed on a scour surface overlain by plane-laminated peloids and fossils. The top of the sequence may or may not be modified by burrowing.

The depth of deposition for Lithology 9 rocks is problematical. This suite is largely unbioturbated; according to Kumar and Sanders (1976) the environment should lie above wave base but the lack of burrowing may be explained by the low abundance of fine-grained sediment. Purdy (1964) has shown that deposit-feeders favor fine grained substrates so that sediments without mud may escape bioturbation. The paucity of calcareous algae (0-1%) supports a deeper-water origin but turbidity may have excluded algae from this environment. The association of Lithology 9 rocks with the shallow subtidal rocks of Lithology 5 strongly suggests a shallow-water origin for Lithology 9 rocks also.

Lithology 10

Lithology 10 rocks are bioturbated mudstones with a restricted-water biota. They are intercalated with the grainstones of Lithology 11 and occur throughout section L3D.

Petrology. Fossils generally compose much less than 10% of the rock volume. Restricted-water organisms far outnumber open-marine organisms and include ostracodes, trilobites, and gastropods. These fossils are usually unfragmented and unabraded. Open-marine fossils such as echinoderms and bryozoans are always broken and abraded indicating transport. Thus the restricted-water fauna is interpreted to be an indigenous assemblage.

Peloids are also important allochems. They are generally ellipsoidal to spherical, rounded, and 0.2-0.4 mm in size. Also, they are generally well sorted but do not occur with any transported elements such as open-marine fauna so they are interpreted to be the product of in situ pelleting.

Other rare fossils include bivalves, Tetradium, brachiopods, and Hedstroemia algae. Bivalves are rare and are present as separate valves only. Tetradium and Hedstroemia are found only in the two stratigraphically lowest samples of this lithology. They appear to be untransported or derived from contiguous environments. Brachiopods occur as fragmented and abraded valves, or more rarely as articulated 1.0 cm individuals.

Bedding-plane fossil assemblages may be quite different from bed-interior assemblages. Many surfaces display numerous gastropods up to 2.5 cm in size (Fig. 20C, p. 70). Other surfaces are littered with apparently in situ articulated and disarticulated strophomenid brachiopods (Fig. 20D, p. 70) occurring with gastropods, clams, rugose corals, and cephalopods. Articulated ostracodes dominate still other bedding planes. Other surfaces display sparse orthid

brachiopods. Clearly, bedding planes may possess either restricted-water, open-marine, or mixed assemblages.

Several explanations may resolve this occurrence. Through time salinity levels must have fluctuated within this environment to allow the establishment of open-marine communities and restricted-water communities at different times or the occurrence of a mixed assemblage. Mixed assemblages could either represent time-averaged accumulations of organisms in response to seasonal, annual, or perennial salinity changes (see Parker, 1959); or communities with both euryhaline and stenohaline organisms co-existed when salinities hovered about the threshold level of open-marine fauna salinity tolerance.

Fabric. Bed interiors are essentially homogeneous with sporadic occurrences of horizontal burrows (Fig. 25A). Burrows are filled with microspar or dolomite rhombs. In places a vague, clotted fabric of peloids is evident. These peloids are interpreted to have formed in situ through pelleting by deposit-feeders. By inference, most of this rock was probably composed of peloids which have since been compacted to form a "pseudomatrix".

These mudstones are thoroughly bioturbated and display both horizontal and rare vertical burrows. The substrate water content was variable; some samples record extremely diffuse burrows while other burrow walls are distinct. As a consequence of burrowing, fossils within bed interiors are randomly oriented.

Many samples of this lithology have thin (2-10 mm) packstone layers or tongues of fossil material (Figs. 25A and 25B) which appear

Figure 25. Thin-section negative prints of the characteristic fabrics observed in Lithology 10 and Lithology 11 rocks.

A. A Lithology 10 sample. The upper part of the photograph displays the typical bioturbated mudstone indicative of Lithology 10 rocks. The lower portion of the illustration shows the wackestone and packstone layers which are interpretated to have been formed by storms. Note the consistent concave-down orientation of larger valves. (Sample L3D-32).

B. A Lithology 10 sample. Note the thin packstone horizon in the center of the photograph. Also notice the probable escape burrow eminating from the packstone layer. (Sample L3D-27).

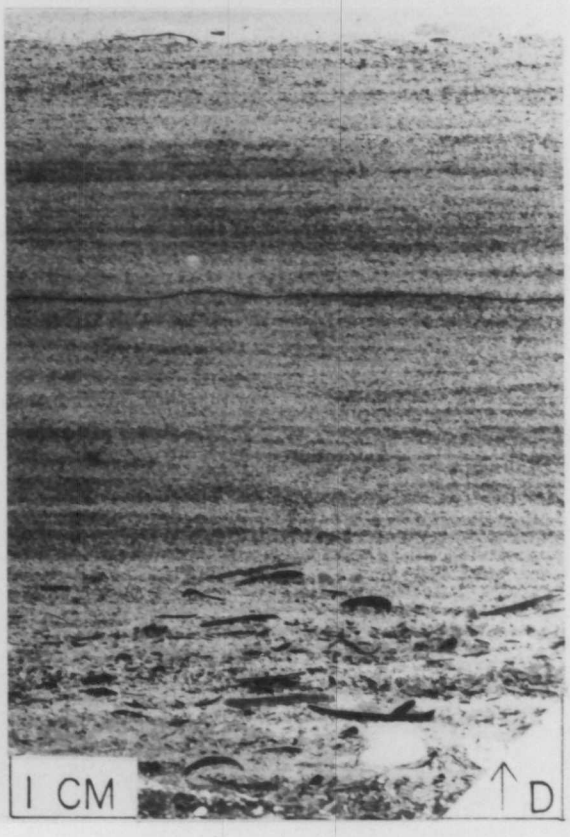
C. A typical Lithology 11 sample. Note that a scour surface is present at the mudstone-grainstone contact and the current-laminated fossils and peloids in both grainstone layers. (Sample L3D-15).

D. A typical Lithology 11 sample. Note the fining-upwards sequence in this fossil-peloid grainstone. (Sample L3D-31).


1 CM
A


1 CM
B


1 CM
C


1 CM
D

to be traction deposits. These packstone layers are discontinuous over 10's of centimeters. Fossils within the deposit include fragmented and abraded open-marine forms as well as typically unabraded ostracodes. Valves are usually oriented concave-down and elongate allochems always lie parallel to bedding suggesting current deposition. These layers are now packstones but there is no doubt that they were deposited as grainstones. In sheltered areas under concave-down valves, within gastropod cavities, or in open interstices well-sorted, rounded peloids are evident (Fig. 20E, p. 70). This indicates that interstitial mud is actually secondary - the mud was formed by the compaction of soft peloids creating a pseudomatrix. Thus, the discontinuous nature of the packstone tongues, coupled with the appearance of current-oriented fossils and peloids denotes a current-emplaced origin.

Associated rocks. These rocks lie directly above the remnants of algal mats and are interbedded with the Tetradium-bearing Lithology 12. A full discussion of these associations appears in the Lithology 12 section below. Lithology 10 deposits are also intercalated with Lithology 11 rocks.

Depositional environment. Lithology 10 was deposited in a quiet, shallow subtidal, restricted environment. The nature of the fauna indicates an environment with variable salinities so that both restricted-water and open-marine fossils are found on both separate and identical bedding planes. The rather low diversity suggests that normal marine salinities were not prevalent. The lack of

vertical burrows and the abundance of horizontal burrows establishes a subtidal environment while association with desiccating environments such as the algal mat deposits implies shallow-water conditions. Quiet, non-turbulent settings are indicated by the predominance of mud in these sediments.

This lithology is consistent with a quiet, lagoon environment. Pellet-mud environments are present in the lee of Andros Island and in Florida Bay, and these settings are characterized by variable salinities (Ginsburg, 1956; Purdy, 1963a and 1963b).

Packstone tongues or wedges are definitely current-emplaced. These lens-like deposits were probably deposited by storms. Lithology 10 mudstones are intercalated with the Lithology 11, storm-generated grainstones so that packstone tongues probably represent storm accumulations of lesser intensity than those which formed Lithology 11 grainstones.

Lithology 11

Lithology 11 rocks are fossil-peloid and peloid grainstones. Lithology 11 deposits are quite similar to those comprising Lithology 9 and Lithology 12. Lithology 11 differs from Lithology 9 in that this suite is intercalated with the mudstones of Lithology 10. Lithology 12 grainstones contain much more Tetradium grains than Lithology 10.

Lithology 11 occurs exclusively within section L3D interbedded with the upper portion of Lithology 12 and intimately interbedded with Lithology 10. Although Lithology 11 is essentially identical to Lithology 9, it was formed in quite a different depositional environment as evidenced by its stratigraphic association with

the restricted lagoon deposits of Lithology 10. For this reason, Lithology 11 is discussed separately below.

Petrology. The principal faunal components include bryozoans, echinoderms, brachiopods, gastropods, ostracodes, and trilobites. Open-marine fossils are generally more abundant than restricted-water fossils. Auxiliary organisms include Tetradium, Hedstroemia, and cephalopods. All taxa exhibit a continuum of abrasion and fragmentation effects; fossils are generally abraded and broken but both unabraded and highly abraded and broken specimens occur.

Peloids and intraclasts are also important constituents. Peloids comprise up to 41% of a rock by volume. They are generally well to moderately sorted in any one sample being from 0.1-1.5 mm in size. Rounding is prevalent and most peloids are ellipsoidal to spherical although irregular grains are present. In many slides (e.g. L3D-15), peloids and intraclasts are gradational in size suggesting that some peloids have been derived from disintegrating intraclasts. However, the wide variation in mean peloid size from sample to sample implies different origins for the peloids, so that peloids may have also originated as transported fecal pellets or micritized fossils. Since samples display moderately to well sorted peloids, currents seem to have deposited hydrodynamically similar peloids in this environment irrespective of their mechanism of formation.

Intraclasts comprise up to 3.5% of the rock volume and are up to 19 mm in size. Peloid-wackestones and less common mudstone intraclasts represent the predominant intraclast lithologies. Most clasts are ovoid to spherical with rounded edges, but many occur as very irregular shapes.

Many grains in this lithology exhibit bored rims or micrite envelopes (Figs. 20F and 20G, p. 70). The most frequent bored grains are intraclasts and mollusks.

Fabric. Beds are typically 0.20 m in thickness and are laterally continuous for 30 m in tabular sheets. Many beds contain current-oriented allochems. Plane-lamination, scour surfaces, fining-upwards sequences, basal lag layers, and superimposed current-emplaced layers are common (Figs. 25C and 25D, p. 95). In addition, most beds display intraclasts identical in lithology to Lithology 10 mudstones.

Burrowing is scarce in these deposits. Some grainstone beds have their topmost layers burrowed and/or grade upward into packstones. Burrowing activity has probably converted the tops of grainstones into packstones.

Associated rocks. Lithology 11 rocks are interbedded with Lithology 10 beds. In addition, Lithology 11 rocks usually display erosional contacts with Lithology 10 rocks.

Depositional environment. Most if not all these grainstones are believed to represent storm sequences. Graded bedding, fossil lags, plane-laminated peloids, and the presence of extremely fossil-rich lithologies occurring between almost unfossiliferous mudstones support this notion. In addition, grainstone beds occur as tabular bodies laterally traceable for 30-50 m.

These storm deposits are interbedded with the lagoon deposits of Lithology 10. They were deposited in a shallow, restricted, protected subtidal environment despite the rich open-marine fauna and

current-produced fabrics of this lithology. The open-marine forms are interpreted to be exotic and were deposited in this environment by storms.

Lithology 12

Lithology 12 rocks are Tetradium-bearing packstones and grainstones easily distinguished from any other lithology. They occur only in the basal portion of section L3D.

Petrology. Tetradium is the most abundant fossil allochem. Although it is not present in every sample it is the dominant organism when present. Other important organisms include ostracodes, echinoderms, gastropods, and bivalves in order of decreasing abundance. Auxiliary fossils include trilobites, bryozoans, brachiopods, Hedstroemia, and Solenopora Type P (Moore, 1978). In general, restricted-water fossils outnumber open-marine fossils.

Restricted-water fossils also appear to exhibit less fragmentation and abrasion and are therefore interpreted as indigenous. Ostracodes and trilobites display a spectrum of transportation effects. Ostracodes tend to be abraded but not fragmented; some specimens are articulated. Trilobites are usually fragmented but not abraded. Ctenodontid(?) clams are commonly articulated whereas the valves of larger bivalves (possibly a different species) are broken and display micrite envelopes. Gastropods are usually whole and appear to be unabraded. In contrast, bryozoans and echinoderms are heavily abraded and may or may not be fragmented. Brachiopods are usually fragmented and abraded but some unabraded, articulated

specimens occur. In the light of the above evidence, these rocks are interpreted to have been deposited in a restricted environment.

Tetradium is present as 10-cm high heads and as 1-25 mm fragments. The fragments are interpreted to have been derived from the Tetradium heads nearby so they are largely indigenous; the large coral heads must be indigenous due to their large size. The Tetradium heads occur in three, 20-30 cm thick beds (Sample L3D-10B; see Figs. 20G, p. 70 and 26A). Inter-head lithologies contain plane-laminated peloids and fossils similar if not identical to those comprising the Lithology 12 grainstones (Figs. 26A, 26B, and 26C). The associated indigenous fauna of these Tetradium buildups consists of articulated ostracodes and Ctenodontid(?) claims, and a species of brachiopod. Tetradium heads were found right-side-up or toppled. Currents and waves and probably responsible for the low abundance of fine-grained sediments, toppled heads, and plane-laminated deposits. This Tetradium buildup represents a wave baffle very similar to the Tetradium wave baffle described by Walker (1970).

Intraclasts and peloids are also important allochems. Intraclasts reach sizes up to 13 mm in long dimension. Most grains are rounded with ellipsoidal and spherical shapes. All intraclasts consist of (fossil)-peloid grainstones.

Peloids are often the most abundant allochem and may comprise up to 45% of the rock. They are generally ovoid to circular in cross section although many grains have irregular shapes. Peloids are highly variable in size and range from 0.2 to 1.5 mm. In samples containing intraclasts, peloids and intraclasts are gradational in size implying

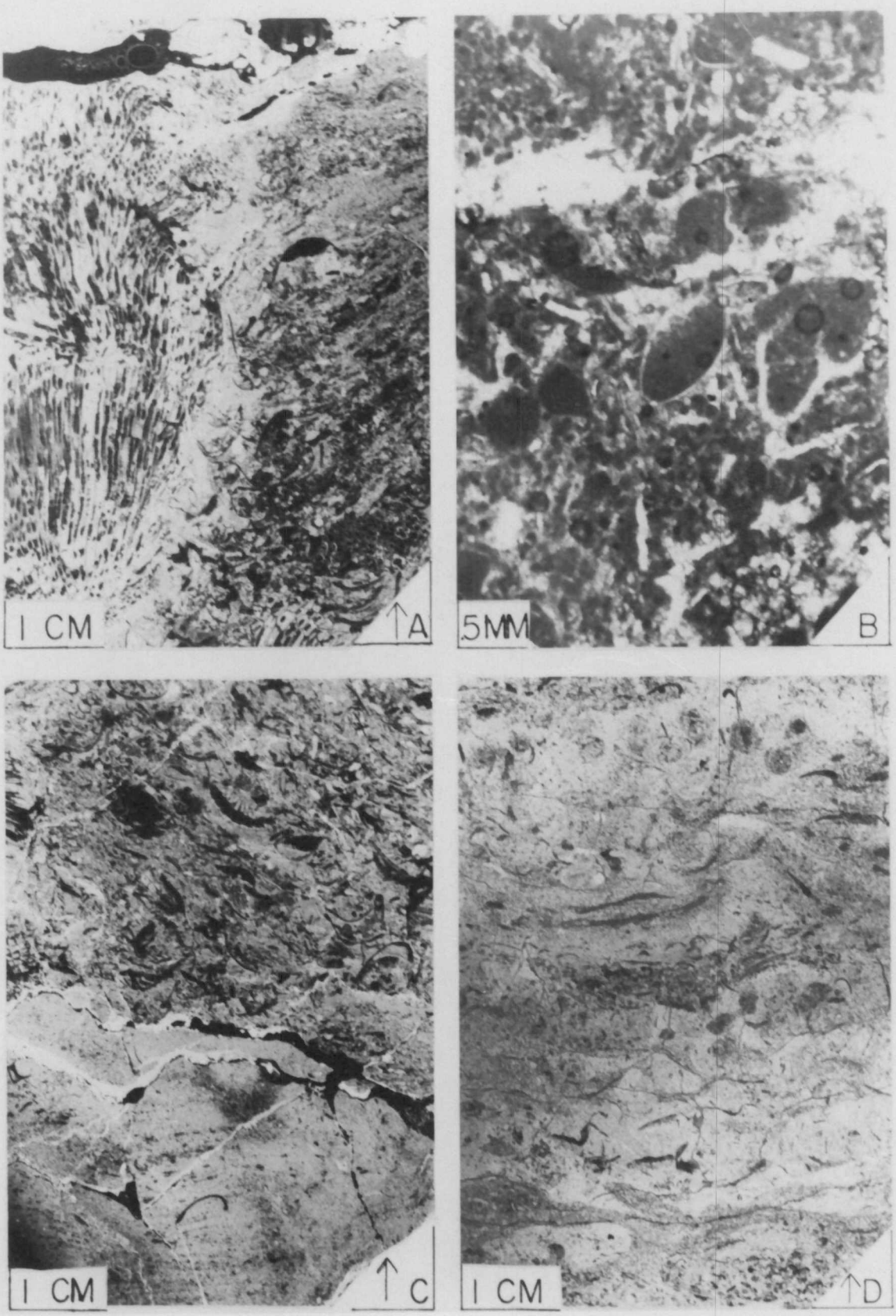
Figure 26. Photographs of characteristic features observed in Lithology 12 rocks.

A. Thin-section negative print of a portion of the massive, head-like Tetradium growth-form of Lithology 12. Also note the character of the inter-head sediment to the right within the photograph. Peloids, ostracode valves, and Tetradium fragments are the most prevalent allochems. (Sample L3D-10B-1).

B. Photomicrograph of some typical inter-Tetradium head sediment of Lithology 12. (Sample L3D-10B-4).

C. Thin-section negative print of Lithology 12, inter-Tetradium head sediment overlying a Lithology 10 mudstone. (Sample L3D-10B-4).

D. Thin-section negative print of a Lithology 12, bioturbated packstone. Numerous Tetradium fragments appear in this sediment along with clam and ostracode valves. (Sample L3D-10A).


1 CM
A
.5MM
B
1 CM
C
1 CM
D

that peloids may have been derived by abrading intraclasts. Peloids may also be micritized fossil grains or current-emplaced fecal pellets.

Fabric. Tetradium-bearing packstones are the most abundant rock type and are intercalated with plane-laminated, Tetradium-bearing grainstones. Some packstones contain current-produced features but most packstones are thoroughly bioturbated (Fig. 26D).

Grainstone beds are generally tabular with internal plane laminae. Plane-laminated peloids and fossils are common and graded sequences also occur. Scour surfaces are commonplace. The above sedimentary structures and the paucity of mud indicate that these rocks were formed under turbulant conditions.

Packstones are bioturbated; only horizontal burrows are present. Most grainstones exhibit no burrowing. However, some grainstones grade into packstone areas which were probably produced by the activity of burrowers which broke down peloids to mud.

Associated rocks. The Tetradium-rich rocks of Lithology 12 are interbedded with and encapsulated by Lithology 10 rocks. Also, an intertidal sequence no more than 3 m thick complete with algal mats and related features, interrupts this package of Tetradium-bearing rocks.

Depositional environment. Lithology 12 was deposited in an agitated, restricted subtidal environment. Turbulent conditions are indicated by the limited occurrence of mud and the presence of current-generated beds. Restricted-water fossils are dominant and exhibit variable transportation effects; open-marine fossils are

always abraded and fragmented. This denotes that the environment experienced variable salinities. The diversity of the indigenous fossil assemblage and the presence of abundant horizontal burrows indicate subtidal conditions.

This lithology seems to be associated with mudbank or island deposits as indicated by the algal mat deposits of unit 79. These algal-mat remnants are indicative of intertidal depositional environments and desiccation fenestrae within the remnant mats denote aerial exposure. Since this intertidal sequence is no more than 3 m thick and occurs between Lithology 12 deposits, this occurrence is interpreted to represent a mudbank island.

Tetradium build-ups probably flanked the above island much as Porites and Goniolithon ring the windward portion of Rodriguez Key in the Florida Keys today (Turmel and Swanson, 1976). The Tetradium build-ups were subject to erosion by waves and yielded abundant Tetradium debris (the characteristic feature of Lithology 12).

Tetradium packstones are interbedded with the Tetradium build-up. These bioturbated packstones probably represent sediments deposited in front of and behind the Tetradium build-up. Turmel and Swanson (1976) have documented that "muddy sands" (packstones) occur both on the windward and leeward sides of the Porites-Goniolithon wave baffle. In accordance, Lithology 10 rocks, which are interbedded with the packstones, probably represent inter-bank deposits.

The current-produced grainstones are interpreted to be storm deposits. Their sedimentary structures and fabrics are identical to the other presumed storm-generated sediments of Lithology 9 and

Lithology 11. These rocks differ only in petrology - Lithology 12 grainstones contain much more Tetradium grains due to their proximity to the Tetradium buildups.

Succession of Environments

The Chickamauga Group carbonates exposed near Clinton all reflect shallow-water deposition. Depositional environments ranged from tidal flat to restricted-water tidal ponds and lagoons to open-marine shelf. Microtidal environments indicate water no deeper than 3 m (in channels); water depth does not usually exceed 1 m (in tidal ponds) in most environments. By analogy with Recent Florida and Bahamas depositional settings, the water depth for the restricted marine facies of the present study was probably no more than 10 m and probably closer to 5 m (see Ginsburg, 1956; Enos and Perkins, 1979). Depth of formation for the open-marine facies is problematical but the close association of lithologies 9 and 11 with restricted subtidal deposits strongly suggests a shallow-water origin. Water depth was probably 20 m or less - this figure is congruent with depths on the immediate seaward side of the Florida reef tract (Ginsburg, 1956).

Although water depths were quite shallow, several broad shifts in depositional environment did occur at this locality. Supratidal, intertidal, restricted subtidal, or open-marine subtidal environments have no specific bathymetric meaning but they do approximate water depth. Fig. 27 shows that deposition on the Knox unconformity began in intertidal and supratidal environments. Restricted subtidal environments eventually succeeded these sediments but then supratidal,

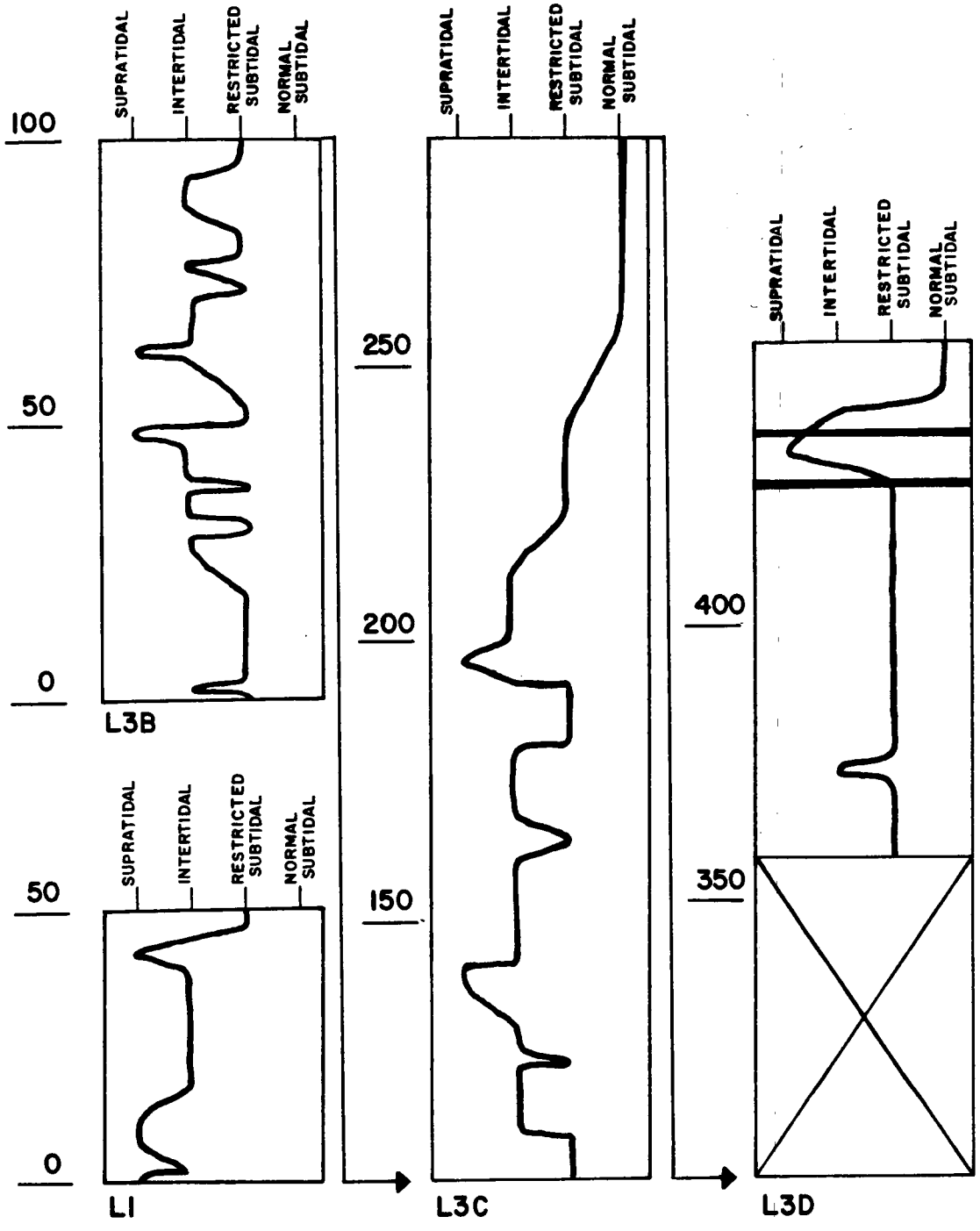


Figure 27. Inferred paleobathymetry of the Clinton section. The terms supratidal, intertidal, restricted-subtidal, and open-marine subtidal have no specific bathymetric meaning but may be used to approximate water depth. The lower portion of section L3B and L1 both represent the basal 50 m of the section near Clinton. Scale is in meters.

intertidal, and restricted subtidal environments migrated laterally through time to generate intercalated sediments representing these environments. A major deepening trend occurred later, which culminated in the deposition of open-marine sediments (250-296 m). Restricted subtidal environments accounted for the most of the deposition represented by the stratigraphic interval 358 to 424 m. This dominance was interrupted by deposition of intertidal sediment interpreted to represent a mudbank or island. Concomitant with the formation of the T3 and T4 bentonites overlying the Lithology 10 restricted subtidal sequence, intratidal and supratidal sediment was deposited. Finally, deposition shifted to open-marine environments represented by the topmost unit in the Clinton section.

CHAPTER III

DETAILED STRATIGRAPHIC ANALYSIS OF A MIDDLE ORDOVICIAN TIDAL FLAT SEQUENCE

Introduction

Intercalation patterns within stratigraphic sequences can be used as a tool for resolving depositional environments and subenvironments. Past workers have either relied exclusively on modern analogs for depositional environments or have neglected to adopt detailed and rigorous models of environmental settings. Depositional environments are often ascribed to rocks merely because of similarity to like sediments in modern terrains. This approach is certainly valid, but limited in its ability to demonstrate any lateral or genetic relationships between rocks and their inferred depositional environments.

Environments and subenvironments can best be recognized and understood as components of a depositional complex through study of stratigraphic associations. The analysis of vertical contacts between certain rock types (which represent specific depositional environments or subenvironments) and examination of repetitive stratigraphic sequences can be used to document interrelationships between rock types. Combined with petrographic and fabric data, and with knowledge of processes gained from the study of modern depositional systems, this approach can provide detailed information concerning the genetic relationship between rock types and their inferred depositional environments.

Most of the rocks described and discussed in the present study were formed in a tidal flat complex. Laporte (1971) has summarized some general criteria which aid in the recognition of tidal flat sediments and their respective environments; most characteristics are observable in rocks examined in this study. Scour surfaces, mudcracks, numerous vertical and U-shaped burrows, desiccation fenestrae, low fossil diversities, a preponderance of peloids, and flat algal laminations are some of the diagnostic features of tidal flat deposits.

Stratigraphic analysis is ideally suited to the investigation of ancient carbonate tidal flats. Tidal flat sequences are characterized by many subenvironments which interfinger and vertically succeed one another in a complex manner. Recent Andros Island tidal flats contain more than a dozen subenvironments with particular fabrics and sedimentary structures (Shinn et al., 1969; Hardie, 1975). Hardie (1975) maintained that tidal flat sediments are an extremely sensitive record of depositional environments and subenvironments; he was able to unambiguously recognize 15 subenvironments.

Laporte (1971) has noted that tidal flat rocks display frequent lateral and vertical changes in lithology. In outcrop, beds pinch out, grade quickly into other units, or have been scoured and capped by other beds. Between outcrops, the correlation of individual beds is usually impossible. These numerous and abrupt vertical successions of a varied array of recognizable rock types should allow detailed analysis of stratigraphic patterns within relatively thin tidal flat sequences.

Methods

The L2 section was measured and sampled in detail. Samples (411) were taken from every bed so that the entire 40 m sequence was represented by a continuous sample set. All samples were slabbed, polished, and catalogued into 7 categories (lithotypes) described below.

Twenty-five thin sections were made from section L2 samples. Experience gained in examining L1 and L3 samples and thin sections enabled recognition of lithotypes from polished slabs. Virtually all the rocks observed in section L2 were also observed in sections L1 and/or L3.

Lithotype Descriptions

Lithotypes should not be confused with the lithologies in Chapter II; rather they are separate rock types or subsets of some Chapter II lithologies. Some lithotypes represent discrete environments or subenvironments whereas other lithotypes contain 2 or 3 separate rock types probably formed in different depositional environments.

Seven lithotypes were recognized. These lithotypes are categorized on the basis of petrographic constituents, sedimentary structures, and overall fabric. A list of the study lithotypes with their characteristics and affinities with Chapter II lithologies appears in Table 2. Although these lithotypes are listed and referred to as discrete entities, most lithotypes are actually end members of a continuum between several lithotypes. It was sometimes difficult to

TABLE 2

LITHOTYPE CHARACTERISTICS AND THE RELATION OF LITHOTYPES

TO CHAPTER II LITHOLOGIES

Lithotype	Lithotype Characteristics	Chapter II Lithology
1	Gray or greenish-gray wackestone/packstone with eurytopic organisms + Tetradium and/or calcareous algae (usually Hedstroemia). Horizontal burrows only.	5
2	Gray or greenish-gray mudstone/wackestone with eurytopic fossils. Tetradium and calcareous algae absent. Noticeably less macrofossils than Lithotype 1. Vertical and horizontal burrows present; horizontal burrows greater in number than vertical burrows.	subset of 6
3	Greenish-gray or gray mudstones with rare or absent macrofauna. Vertical burrows much greater in abundance than horizontal burrows; burrows tend to be spar-filled. Desiccation fenestrae common.	subset of 6
4	Laminated rocks with alternate mud-rich and grainstone laminae. Laminae range from 0.2 to 6.0 mm in thickness. Macrofossils absent or rare. Commonly with burrows; burrows robust (4-8 X 10-60 mm) and peloid- and spar-filled.	subset of 1
5	Gray, laminated mudstone. Each lamina composed of mud which grades into a thin peloid layer or zone usually 0.1 mm thick. Layers may be 1 to 15 mm thick. Biota rare or absent. Usually unburrowed. Mudcracks and desiccation fenestrae common.	2

TABLE 2 (Continued)

Lithotype	Lithotype Characteristics	Chapter II Lithology
6	Tan or maroon, (fossil)-peloid packstones with common robust vertical and U-shaped burrows. Burrows typically spar-filled with sharp boundaries. Biota rare to absent. Desiccation fenestrae common.	subset of 1
7	Brown or gray intraclast-fossil-peloid grainstone/packstone. Fossils scarce but include eurytopic forms. Horizontal burrowing generally absent. Physical sedimentary structures dominate over biogenic structures.	8?

make distinctions between lithotypes from polished slab surfaces alone, consequently thin sections were used to resolve such difficulties.

Generally, all the recognized lithotypes occur throughout the L2 section. However, patterns of association among them are not random. In order to illustrate the composition of the L2 section and to provide a general overview of lithotype occurrences, a generalized stratigraphic section appears in Fig. 28. The patterns observed within the L2 section are much too small in scale to reproduce adequately in this figure (see Appendix E for a detailed account of the L2 stratigraphic successions). The relative frequency of lithotypes is displayed in Fig. 29.

Lithotype 1

Lithotype 1 rocks are gray or greenish-gray, thoroughly bioturbated wackestones and packstones with indigenous, probably eurytopic fossils such as trilobites, ostracodes, gastropods and ctenodontid(?) clams (Fig. 30A). Less abundant fossils include Hedstroemia, Tetradium, and serpulid worms. Hedstroemia algae are usually rare but Tetradium may comprise up to roughly 12% of a given rock volume. Horizontal burrows are ubiquitous; burrow walls are diffuse indicating a relatively high sediment-water content. Fossil allochems are oriented randomly due to burrowing activity.

Lithotype 1 is defined on the basis of the presence of indigenous calcareous algae and Tetradium, and on the absence of vertical burrows. Lithotype 1 is gradational with Lithotype 2 in terms of Tetradium and Hedstroemia abundance.

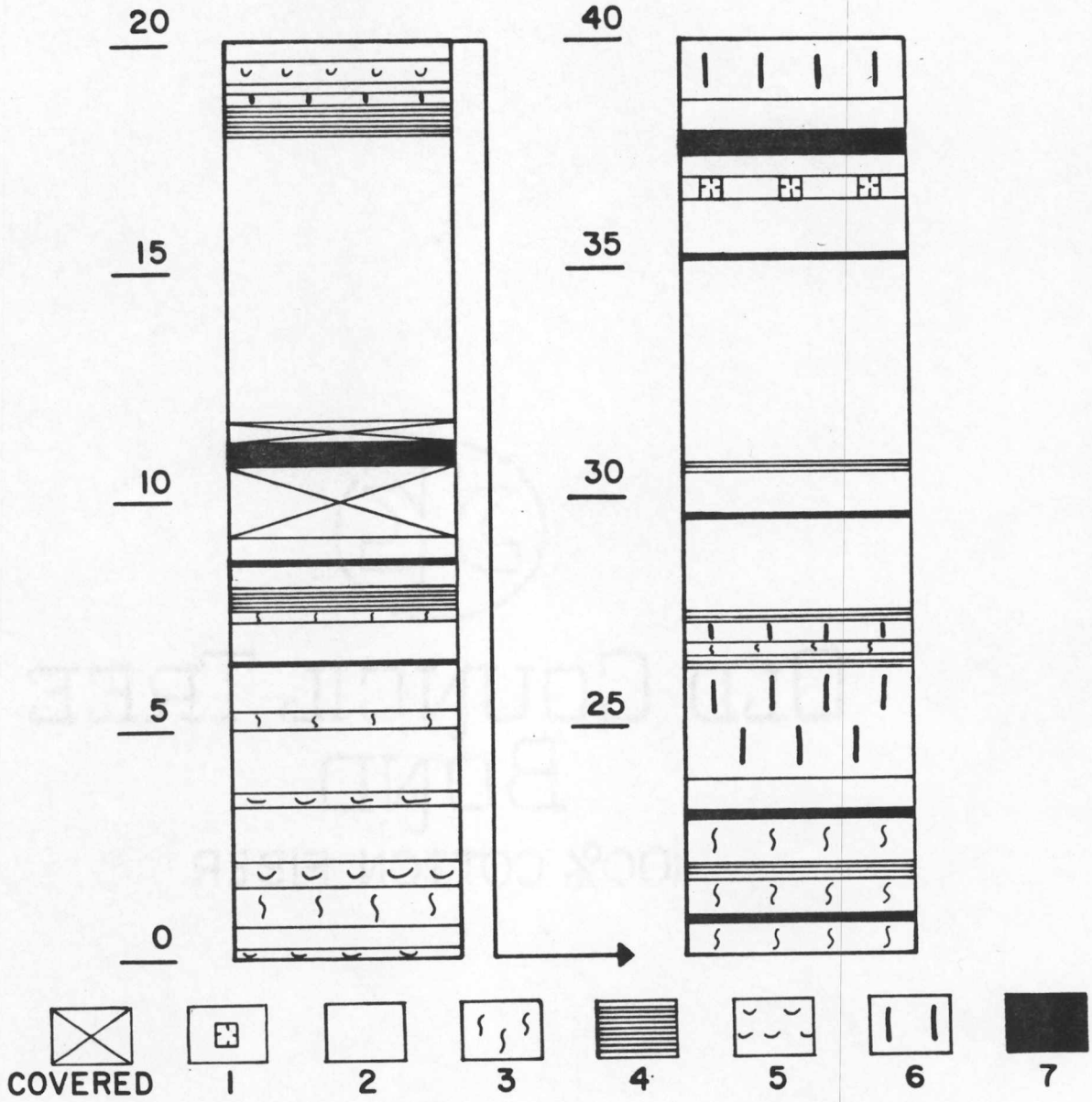


Figure 28. Stratigraphic distribution of lithotypes in section L2. Scale in meters. Numbers and symbols refer directly to the lithotypes of this study. Refer to Table 2 for lithotype characteristics.

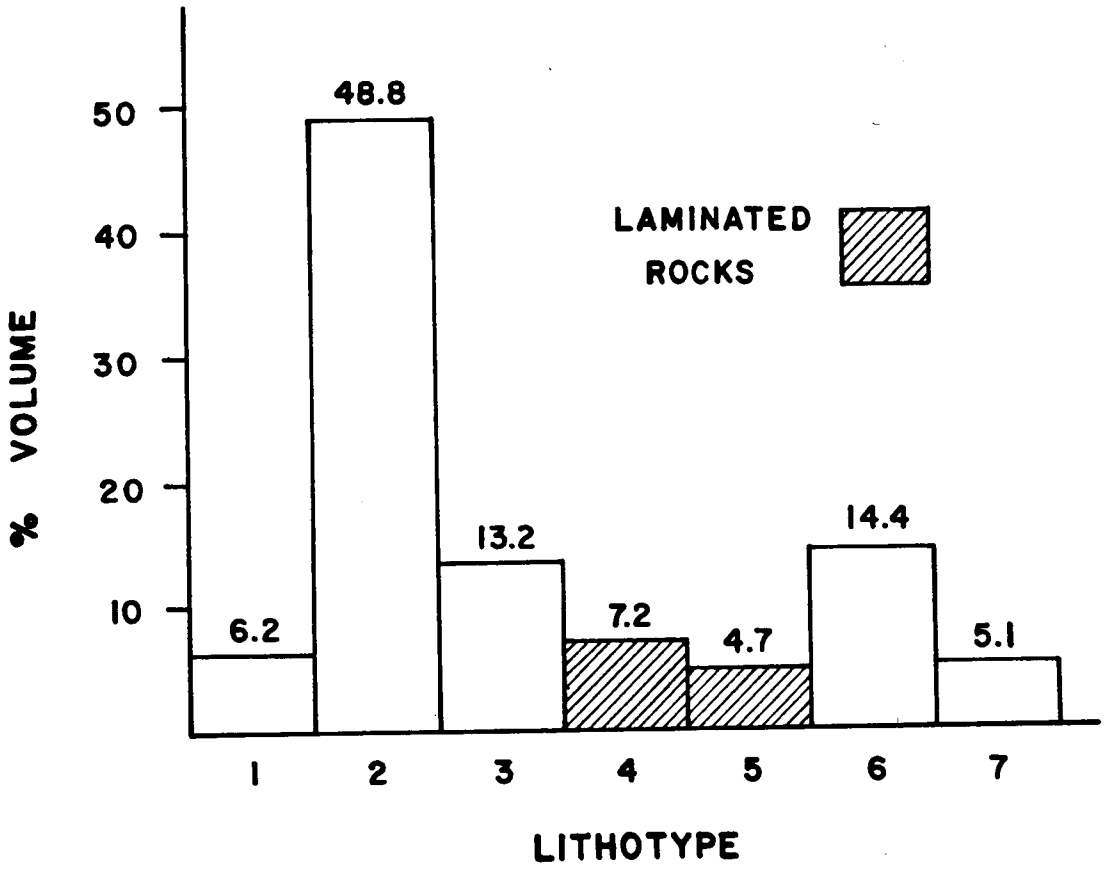


Figure 29. Abundance of lithotypes expressed in volume per cent. Cross-hatched lithotypes are laminated rocks. Numbers on the bar graph refer to the actual % volume of a given lithotype. An approximation of volume was calculated by using the total thickness of each lithotype with respect to the 34.39 m of rocks exposed in the L2 section.

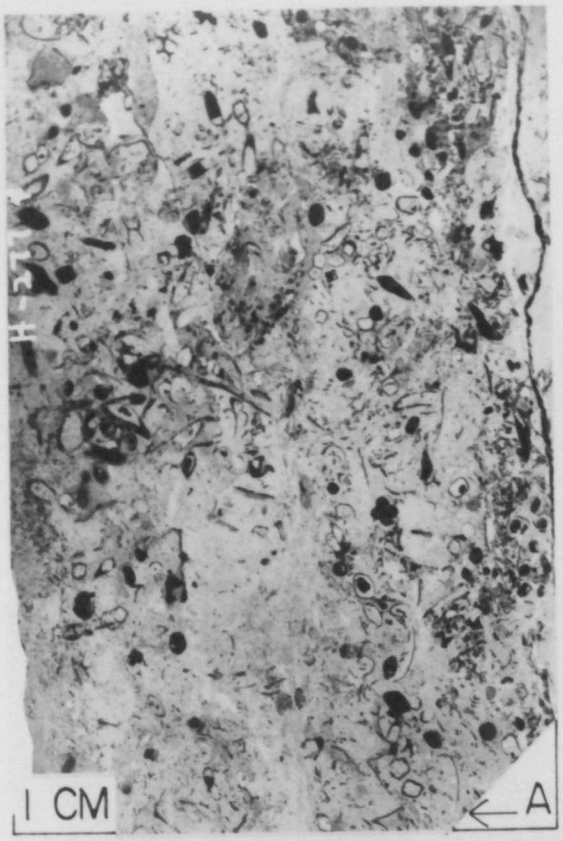
Figure 30. Thin-section negative prints of the characteristic fabrics of Lithotype 1, Lithotype 3, and Lithotype 4 rocks.

A. A typical Lithotype 1 sample. Notice the abundance of single Tetradium corallites. (Sample H-277).

B. A typical Lithotype 3 sample. Note the thin (3 mm), spar-filled vertical burrows and the preponderence of interlaminar desiccation fenestrae. (Sample H-262).

C. Type I lamination in Lithotype 4. Part of the sample is bioturbated but notice the thicker grainstone lamina near the center of the photo. (Sample H-26).

D. Type II lamination in Lithotype 4. Note the thin, millimeter scale lamination and that grainstone and packstone laminae exhibit similar thicknesses. (Sample H-176).


1 CM
A


1 CM
B


1 CM
C


1 CM
D

Lithotype 2

Lithotype 2 rocks are gray or greenish gray, bioturbated mudstones and wackestones with a eurytopic fauna. Ostracodes and trilobites are the most common fossils; gastropods also occur. Unlike Lithotype 1, calcareous algae and Tetradium are absent from this rock type. Vertical burrows may or may not be present but horizontal burrows are always more abundant than vertical burrows. As a consequence of bioturbation, allochems exhibit no preferred orientation.

As stated above, Lithotype 2 rocks are gradational with Lithotype 1. They are also gradational with Lithotype 3. Macrofaunal abundance decreases systematically from Lithotype 1 to Lithotype 2 and finally to Lithotype 3 rocks (Fig. 31) as does horizontal burrow abundance.

Lithotype 3

Lithotype 3 rocks are gray or greenish-gray, thoroughly bioturbated mudstones (Fig. 30B). Macrofossils are rare and include ostracodes, trilobites, and gastropods. Hedstroemia and Tetradium are absent. Both vertical and horizontal burrows may be present but vertical burrows far outnumber horizontal burrows. Burrow walls are distinct to sharp indicating sediment with a much lower water content than Lithotype 1 sediments. In addition, many 1-2 mm wide, spar-filled vertical burrows occur. Desiccation fenestrae are common.

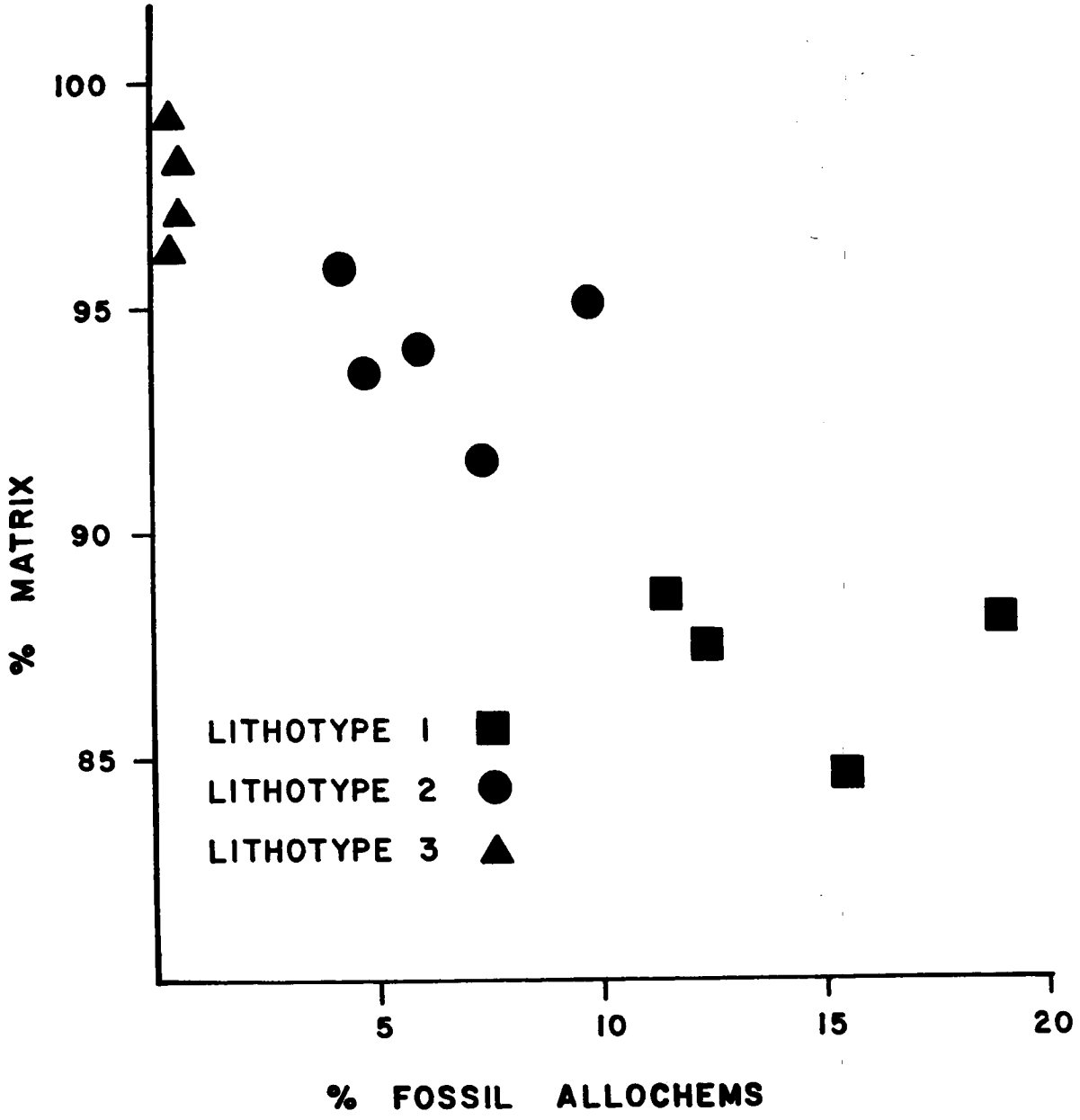


Figure 31. Fossil allochem abundance in lithotypes 1, 2, and 3. Note that there is a systematic decrease in fossil abundance from Lithotype 1 to Lithotype 2 to Lithotype 3.

Lithotype 4

Lithotype 4 rocks are tan or gray, laminated rocks with (fossil)-peloid grainstone and peloid wackestone/packstone laminae. Each lamina is from 0.2 to 2 mm thick, and laminae are generally flat or gently undulatory, and continuous. However, three different types of lamination occur. In Type I, grainstone laminae are usually 0.2 to 6 mm in thickness whereas mud-rich laminae are 0.2 to 1.8 mm thick (Fig. 30C). Type II rocks possess grainstone and packstone laminae which are roughly equilivalent in thickness (Fig. 30D). Type III lamination is produced by alternate grainstone laminae and planar stylocumulate layers 0.2 to 1 mm thick (Fig. 32A).

The origin of the lamination of Lithology 4 is problematical. Lamination Types I and II are believed to be algally produced. However, alternate grainstone and mud-rich laminae can be generated by purely physical processes in tidal flat environments (see Reineck and Singh, 1973). Lamination Type III may also be algally produced. Laporte (1969) has used stylocumulate or clay layers, which alternate with grainstone laminae, as evidence for the existence of rotted algal mats which have since decayed. The organic film derived from rotted algal filaments is either preserved directly or induces selective pressure solution to produce planar stylocumulate zones. However, this inference is rather speculative since the action of algal trapping and binding cannot be demonstrated.

In short, in the absence of anti-gravitational structures, an algal origin cannot be demonstrated for these laminated rocks. However, the universal distribution of algally laminated sediments

Figure 32. Photographs of characteristic features observed in Lithotype 4, 5, and 7 rocks.

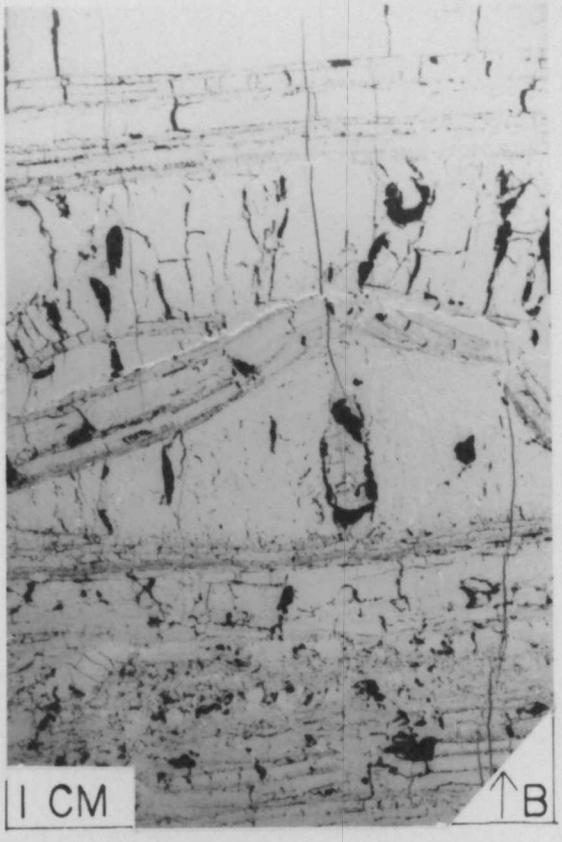
A. Thin-section negative print of Type III lamination in Lithotype 4. Note the occurrence of thin, millimeter-scale sediment lamina and planar stylolites in the middle portion of the slide. Also note the numerous irregular fenestrae near the top of the photograph. (Sample H-173).

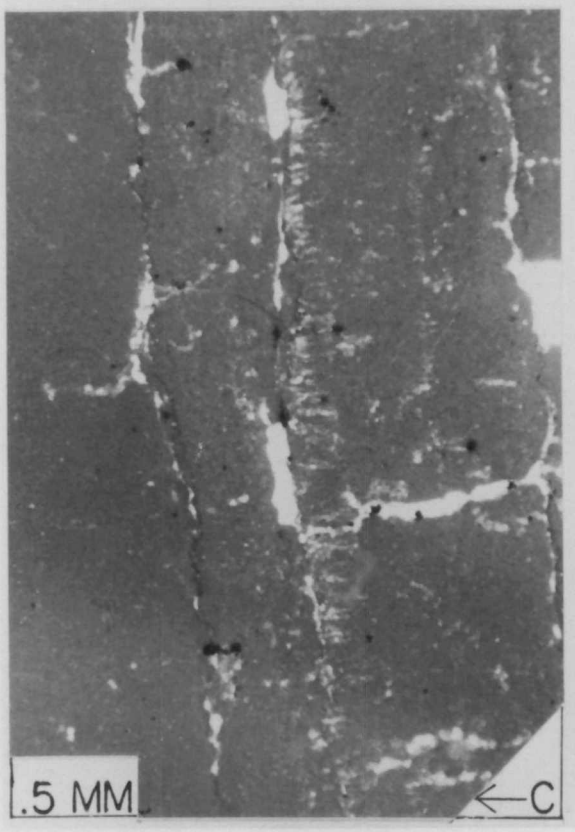
B. Thin-section negative print of a typical Lithotype 5 sample. Note the discrete layers of identical sediment separated from each other by interlaminar fenestrae. Also note the numerous mudcracks. (Sample H-1).

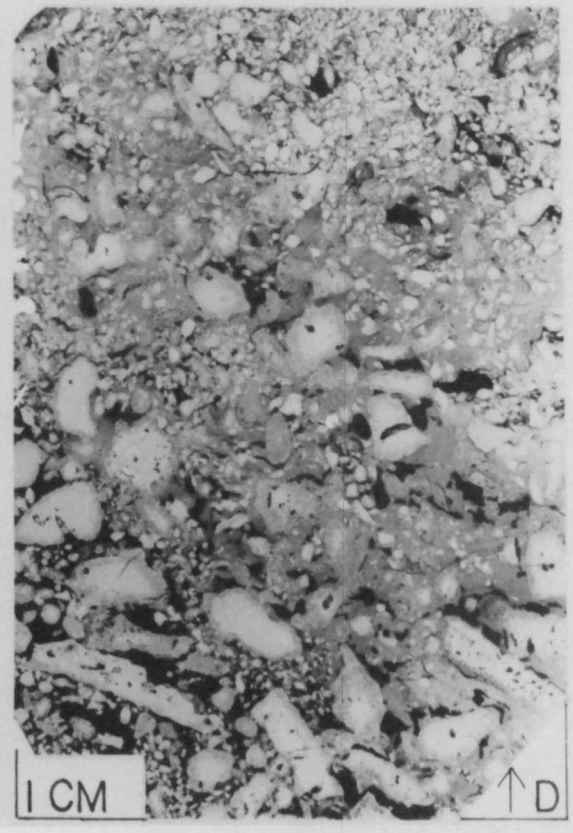
C. Photomicrograph of several laminae of Lithotype 5. Note the peloid zone at lamina tops. (Sample H-1).

D. Thin-section negative print of a Lithotype 7 sample. Note the abundant intraclasts which exhibit crude positive grading. (Sample H-242).


1 CM
A


1 CM
B


.5 MM
C


1 CM
D

in modern carbonate tidal flat terrains strongly suggests an algal origin for alternate laminae of different mud contents. In any event, the preservation of lamination indicates an environment of deposition above mean tide level.

Lithology 4 rocks display other sedimentary structures besides lamination. The occurrence of both desiccation fenestrae and robust (5-7 X 15-20 mm), peloid- and spar-filled vertical burrows is commonplace.

Lithotype 5

Lithotype 5 rocks are gray, layered rocks. Layering may be in the form of thin beds or laminae ranging from 0.1 to 1.5 cm in thickness. External thin beds usually display internal lamination. Unlike Lithotype 4, lamination is not produced by alternate grainstone and mud-rich layers. Instead, lamination is created by successive layers of identical sediment which record a number of discrete, depositional events (Figs. 32B and 32C). Laminae grade upwards from mud into diffuse peloid zones which occur at the top. The mud fabric of this rock type was probably produced from the compaction of peloids. Peloids are more evident at lamina tops where exposure caused peloids to harden and therefore prevented them from being compacted after burial. Fossils and vertical burrows are rare. Desiccation features such as interlaminar fenestrae and mudcracks may also be present (see Fig. 32B).

Lithotype 6

Lithotype 6 rocks are maroon or tan, bioturbated, fossil-peloid packstones. Fossils are rare but include trilobites and ostracodes. Relict laminae are sometimes present. Robust (5-7 X 40 mm), peloid- and spar-filled vertical and U-shaped burrows are common. Unlike Lithotype 3 burrows, Lithotype 6 burrows are larger in diameter and are partially or completely filled with peloids. Desiccation fenestrae are also common.

Lithotype 7

Lithotype 7 rocks are gray or tan, (intraclast)-fossil-peloid packstones/grainstones. Generally the thickness of these grainstone beds is about 3 to 4 cm but one bed (sample 48) was 90 cm thick. This sample represents one of the three rock types present in Lithotype 7. Sample 48 is a massive bed identical in lithology to unit L3C-40 of stratigraphic section L3. Another occurrence of Lithotype 7 displays three, 10 cm beds composed almost wholly of intraclasts which display crude grading (Fig. 32D). Other examples of Lithology 7 rocks are thin beds composed of current-oriented peloids, and abraded ostracodes, trilobites, and clam fragments. Scour surfaces are often discernible and some beds are roughly graded. Although burrows are generally absent, some Lithotype 7 grainstones have been converted into packstones through burrowing activity, presumably by breaking down peloids into mud.

Stratigraphic Analysis

Resolution of depositional environments and subenvironments can be achieved through stratigraphic analysis. Stratigraphic analysis entails the study of stacking patterns and vertical successions of rocks (lithotypes) which represent specific environments or subenvironments. Vertical-contact data, i.e. data which document the frequency of vertical contacts between lithotypes, can be used to suggest the "adjacentness" of subenvironments. Repetitive stratigraphic sequences can aid in the characterization of subenvironments and identify characteristic environment migration patterns.

Analysis of Vertical Contacts

Walther's Law suggests that sediments forming in adjacent sedimentary environments will be found more commonly in vertical contact than sediments forming in laterally separated environments (Walther, 1894; see Walker, 1973 for an English translation). Thus recurrent vertical contacts should exist between certain lithotypes which represent laterally adjacent environments (see Walker, 1970 and 1973). If random lithotype occurrences, such as those created by storm events or the non-characteristic migration of environments, are statistically eliminated, recurrent vertical contacts between different lithotypes would suggest that these rocks formed in roughly adjacent environments.

Occurrence patterns of the studied lithotypes are not random. The frequency of vertical contacts between lithotype pairs is tabulated in Fig. 33 for a total of 148 contacts. Lithotype 1 is

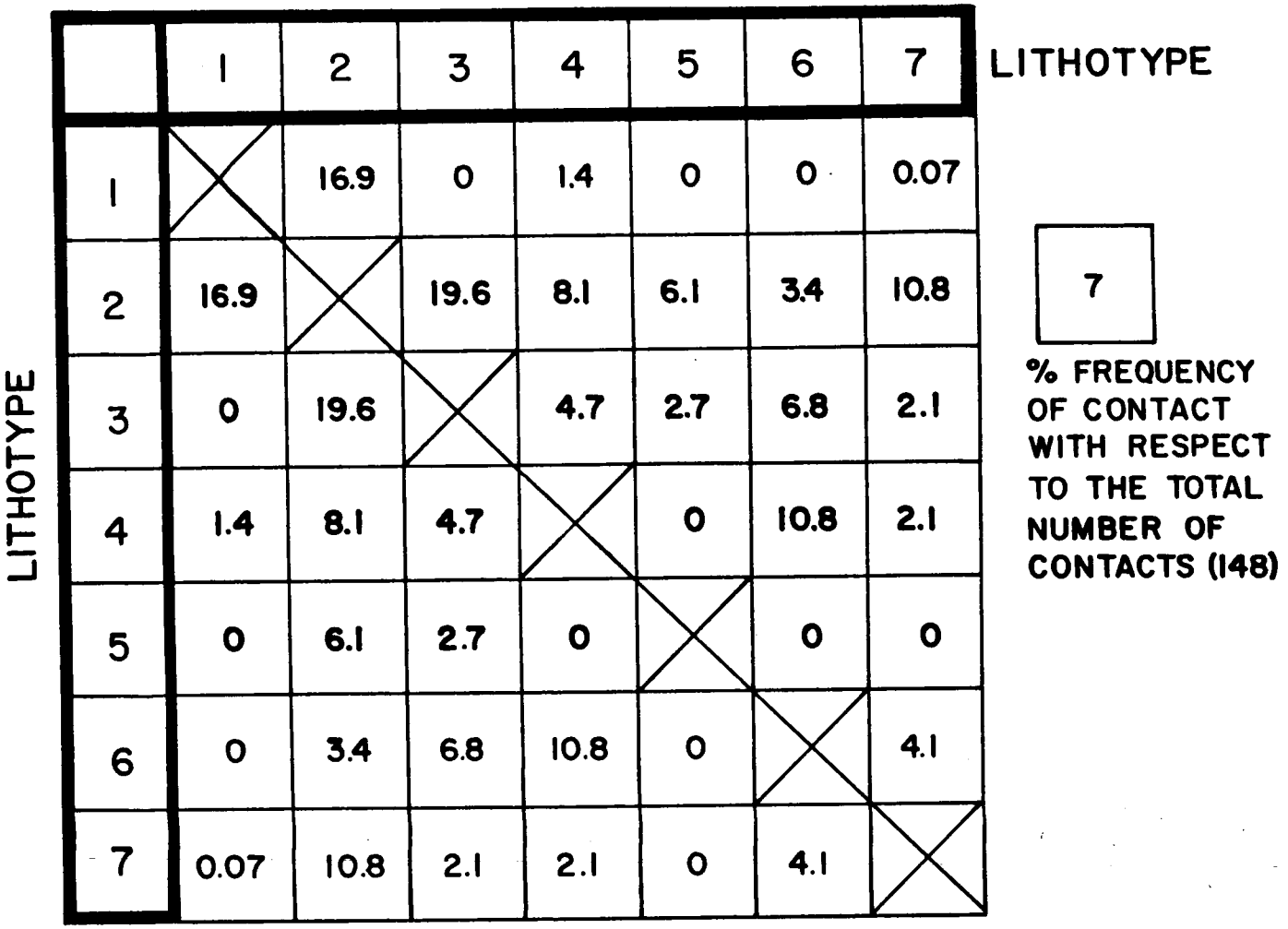


Figure 33. Per cent frequency of vertical contacts between lithotypes. For example, Lithotype 3 is in vertical contact with Lithotype 4, 4.7% of the time Lithotype 4 and 5, 0%; Lithotype 6 and 7, 4.1%.

strongly associated with Lithotype 2, and is also associated with lithotypes 4 and 7. Lithotype 2 is in vertical contact with Lithotype 3 most often, but is also allied with lithotypes 4, 5, 6, and 7. Excluding Lithotype 2, Lithotype 3 is most closely associated with Lithotype 4 and Lithotype 6. Lithotype 4 is most commonly in vertical contact with lithotypes 6, 2, and 3 in that order. Lithotype 5 is most closely associated with Lithotype 2. Except for Lithotype 4, Lithotype 6 is most commonly in vertical contact with Lithotype 3. Lastly, Lithotype 7 is usually in contact with Lithotype 2.

The above relationships can also be observed in stratigraphic sequences. The stacking patterns of lithotypes reinforce the above associations but at a higher "order". Vertical-contact analysis can only document the relationship between lithotype pairs whereas stratigraphic sequences can establish associations between two, three, or even more lithotypes.

Stratigraphic Sequences

Since rocks which represent adjacent environments should be in vertical contact with one another most often, when migration of depositional environments occurs characteristic and recurrent stratigraphic sequences should be generated. All subenvironments might not be present in a sequence. Rather both complete and incomplete records of environment migration occur but the stacking order of lithotypes is reversed in transgressive and regressive sequences.

As expected, both complete and incomplete stratigraphic sequences are observed in the studied section. All lithotypes occur

in recurrent stratigraphic sequences and are therefore part of the same pattern. Idealized sequences can be generated from recurrent stratigraphic associations by matching repetitive lithotype pairs or sets with other lithotype pairs or sets. For example, imagine that Lithotype B always lies below Lithotype C, Lithotype B always lies above Lithotype A, and Lithotype A is sometimes overlain by Lithotype C. The idealized sequence for these hypothetical rock types is A overlain by B, B overlain by C.

Two idealized sequences were recognized in the present study. Lithotypes 4 and 5 are both composed of laminae, but the origin of the lamination is distinctly different. Consequently, separate idealized sequences were prepared for each of these lithotypes. Laminae are usually preserved only above mean tide level, thus lithotypes 4 and 5 must have formed in the highest and driest (or fresh-water dominated) environments on the tidal flat. Thus, both lithotypes are natural termination points for the idealized sequences. The idealized sequences for lithotypes 4 and 5 appear in Fig. 34 and Fig. 35 respectively along with their parent sequences. Regressive sequences were used to construct the idealized sequences for convenience, but similar transgressive sequences are also observed. Transgressive sequences display the same lithotypes but in reverse order.

Origin of Lithotypes

Both idealized sequences can be explained in terms of increasing aerial exposure and/or dominance of fresh-water conditions

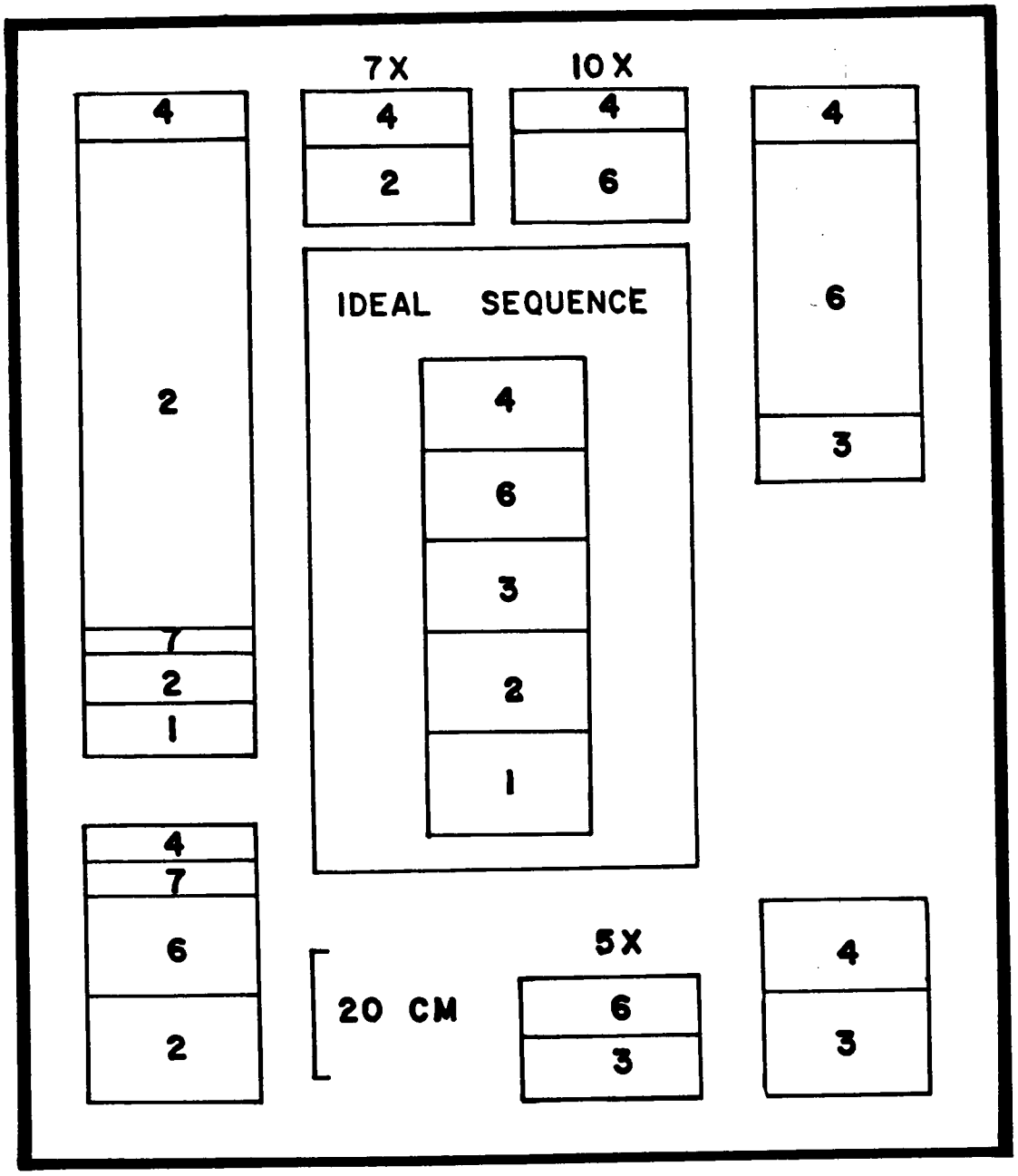


Figure 34. Lithotype 4 recurrent stratigraphic sequences and the idealized sequence. The numbers "7X" or "10X" refer to the number of occurrences of a given sequence. Other sequences were observed only once.

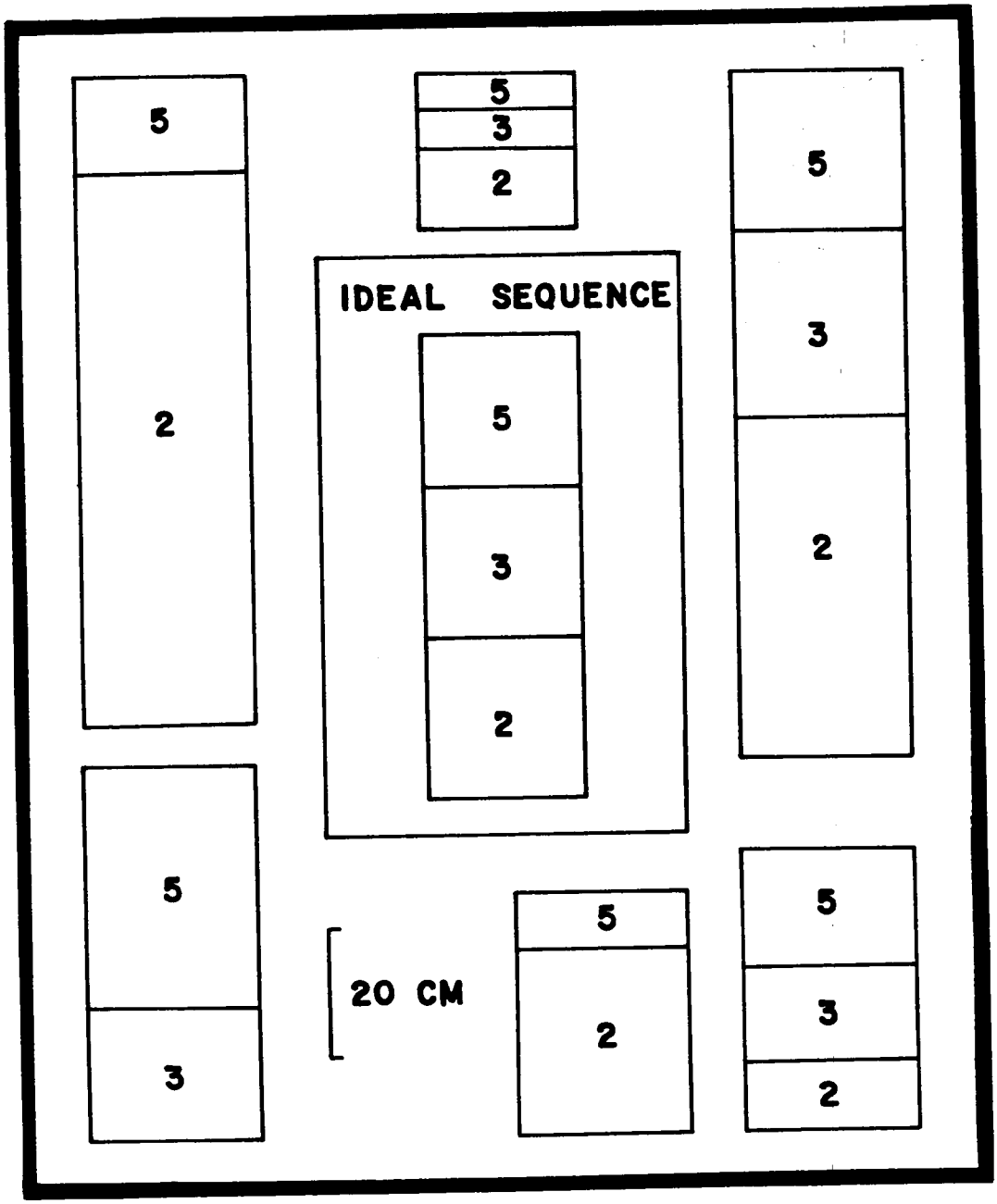


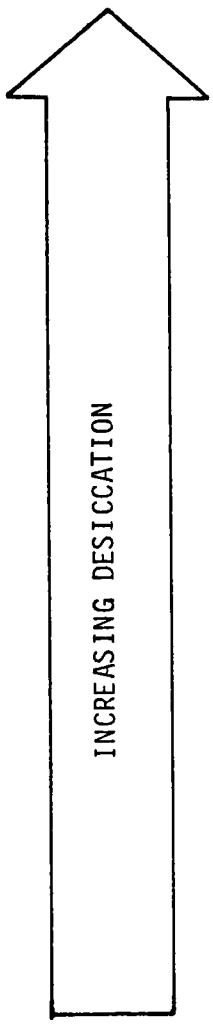
Figure 35. Lithotype 5 recurrent stratigraphic sequences and the idealized sequence.

in their respective lithotypes and inferred depositional environments. The Lithotype 4 idealized sequence is the result of increased aerial exposure (Fig. 36). Lithotypes in the Lithotype 5 idealized sequence also display features which indicate increasing exposure but analogy with modern Andros Island tidal flats suggests that the dominance of fresh-water in similar environments also plays a role in the survival of lamination (Fig. 37). The origin of component lithotypes is discussed below and includes independent evidence which supports the hypothesis that the idealized sequences are products of increased aerial exposure.

Lithotypes 1, 2, and 3

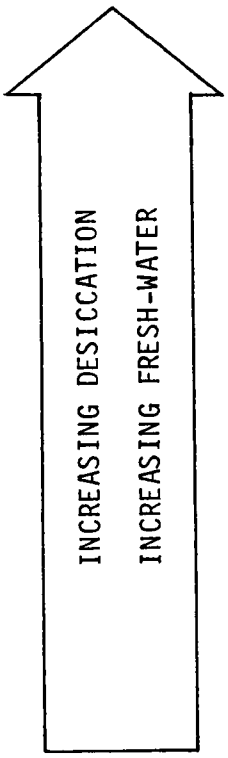
In both idealized sequences, lithotypes 1, 2, and 3 succeed one another and are eventually capped by laminated rocks represented by either Lithotype 4 or Lithotype 5. Lithotypes 1, 2, and 3 grade into one another in terms of macrofossil and horizontal burrow abundance and they also display gradational contacts with each other. Several lines of evidence indicate that lithotypes 1, 2, and 3 respectively are the result of increasing aerial exposure.

First, the ratio between vertical and horizontal burrows increases from Lithotype 1 to Lithotype 3. Horizontal burrows decrease in abundance in a systematic manner from Lithotype 1 to Lithotype 3 due to increasing firmness of the sediment. Sharp burrow walls and spar-filled vertical burrows indicate a decrease in sediment water content in Lithotype 3 rocks. Lithotype 1 rocks display only diffuse, horizontal burrows. Distinct burrow walls and partial spar-filled burrows in lithotypes 6, 5, and 4 denote low sediment water contents in these sediments also.



CHARACTERISTICS	LITHOTYPE
Algal(?)-laminated sediment with sparse transported biota. Robust vertical and U-shaped burrows with spar-fillings and distinct boundaries. Desiccation fenestrae common.	4
Tan or maroon bioturbated packstone with robust vertical and U-shaped burrows, relict algal(?) laminations, and desiccation fenestrae. Sharp burrow boundaries indicate firm substrate.	6
Mudstone with sparse restricted-water organisms. Vertical, spar-filled burrows are greater in abundance than horizontal burrows. Burrow boundaries are distinct indicating a firm substrate.	3
Mudstone/wackestone with eurytopic fossils. Hedstroemia and Tetradium absent. Horizontal burrows much greater in abundance than vertical burrows. A soft substrate is indicated by diffuse burrow walls.	2
Wackestone/packstone with restricted-water organisms + Tetradium and Hedstroemia. Horizontal burrows only with diffuse boundaries denoting a soft substrate.	1

Figure 36. Explanation of the Lithotype 4 idealized sequence.



CHARACTERISTICS	LITHOTYPE
Non-algal layers 0.1 to 1.5 cm thick. Macrofauna absent. Mudcracks and interlaminar fenestrae are common.	5
Mudstone with sparse restricted-water organisms. Vertical spar-filled burrows are greater in abundance than horizontal burrows. Burrow boundaries are distinct indicating a firm substract.	3
Mudstone/wackestone with eurytopic fossils. *Hedstroemia* and *Tetradium* absent. Horizontal burrows much greater in abundance than vertical burrows. A soft substrate is indicated by diffuse burrow walls.	2
Wackestone/packstone with restricted-water organisms ± *Hedstroemia* and *Tetradium*. Only horizontal burrows are present. Burrow boundaries are diffuse denoting a soft substrate.	1

Figure 37. Explanation of the Lithotype 5 idealized sequence.

Second, desiccation features are common in Lithotype 3 rocks. Irregular, tubular, and interlaminar fenestrae are all present in Lithotype 3 sediments. Lithotype 2 or Lithotype 1 rocks do not possess desiccation fenestrae.

Lastly, fossil diversity decreases from Lithotype 1 to Lithotype 3. Lithotype 1 sediments possess indigenous Tetradium, Hedstroemia, gastropods, trilobites, ostracodes, ctenodontid(?) bivalves, and serpulid worms. Only ostracodes, trilobites, and gastropods are common in Lithotype 2 rocks and macrofossils are rare to absent in Lithotype 3 sediments.

In the light of the above evidence, transitions from Lithotype 1 to Lithotype 2 to Lithotype 3 are interpreted to represent an environmental cline from subtidal to intertidal conditions. The intertidal deposits were formed below mean tide level since layering is absent. Specifically, this cline might represent transitions from pond centers to pond margins, or from offshore subtidal marine to marginal marine environments. The association of lithotypes 1, 2, and 3 with the laminated rocks of Lithotype 4 and Lithotype 5 suggests that these lithotypes represent tidal flat sediments and the absence of beach-ridge lithologies seems to preclude an offshore marine origin. If migration from offshore environments to tidal flat environments had occurred, rocks of beach-ridge environments would be expected to be stratigraphically associated with rocks representing these other environments since beach-ridge environments are laterally adjacent to both of these environments.

Lithotypes 4, 6, and 3

Lithotypes 4 and 6 are genetically related. They are most often in vertical contact with one another, very similar petrographically, exhibit gradational contacts, and in terms of other salient features grade into each other. Both rock types are composed of peloids and abraded fossils although their fabrics may be quite different. However, Lithotype 4 and Lithotype 6 are also gradational with respect to the presence or absence of lamination. Lithotype 6 rocks often contain isolated laminae surrounded in three dimensions by bioturbated sediment. Also, portions of Lithotype 4 samples are burrowed (see Figs. 30C and 30D, p. 118); these burrowed portions are identical to the Lithotype 6 lithology. Thus, lithotypes 4 and 6 can be viewed as end members with respect to burrowing activity. The Lithotype 4 modification sequence is illustrated in Fig. 38. Laminated Lithotype 4 rocks and the bioturbated fabric of Lithotype 6 sediments display a spectrum of burrowing effects. Lithotype 4 rocks can either be totally unmodified by burrowing. Likewise Lithotype 6 can either be totally bioturbated or exhibit varying amounts of layered, undisturbed sediment.

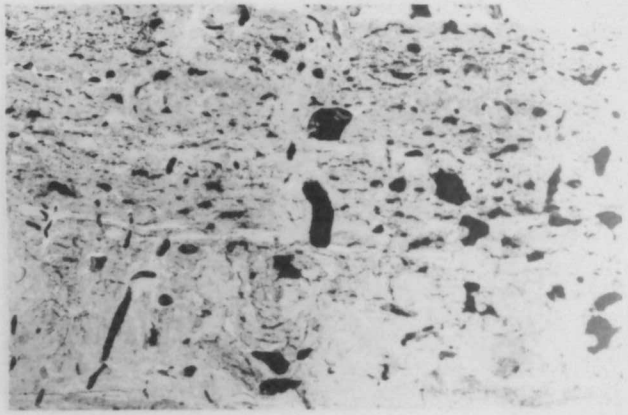
Lithotype 2 and Lithotype 3 rocks are commonly associated with both Lithotype 4 and Lithotype 6 deposits. They appear together in the Lithotype 4 idealized sequence in a specific manner. Lithotypes 3 and 6 display similar lithologies; both are characterized by sparse macrofossils, vertical burrows, the presence of peloids, and bioturbated fabrics. Except for the presence of relict laminae and the presence of robust, U-shaped burrows in Lithotype 6, lithotypes 3 and 6 differ

Figure 38. Lithotype 4 modification sequence. Note the spectrum of burrowing effects which can be observed in Lithotype 4 rocks. Lithotype 4 rocks can either be completely devoid of burrows or may possess rare occurrences of them. Other lithotype 4 samples are severely altered by burrowing. Finally Lithotype 6 rocks, which are interpreted to have been derived from the homogenization of Lithotype 4 rocks, commonly possess relict laminae. These occurrences are interpreted to be a result of decreasing aerial exposure since more bioturbation would occur in more frequently wetted environments.



1 CM





LAMINATED

PARTIALLY BIOTURBATED

COMPLETELY BIOTURBATED

DECREASING EXPOSURE

only in color. All the above differences in these two lithologies are believed to be a consequence of increased aerial exposure in the Lithotype 6 deposition environment. The relict laminae in Lithotype 6 exist because Lithotype 6 rocks have been derived from the laminated Lithotype 4 deposits. U-shaped burrows also imply increased exposure.

In summary, Lithotype 6 is interpreted to be a part of an increasing exposure cline from Lithotype 1 to Lithotype 4 in the Lithotype 4 idealized sequence. Supportive evidence includes: (1) the presence of robust U-shaped and vertical burrows; (2) the presence of common desiccation fenestrae; (3) the occurrence of relict laminae; and (4) the close association of Lithotype 6 with Lithotype 4. Since Lithotype 6 rocks are bioturbated, they probably formed below mean tide level or at levels slightly above mean tide level so that disruption of layering could occur periodically. In the context of a Bahamas tidal flat model, these conditions are satisfied by extreme tidal pond margins or levee interiors.

Lithotype 5

Lithotype 5 is closely associated with lithotypes 2 and 3. It is characterized by laminations so its depositional environment was probably above mean tide level. Mudcracks and fossil diversity within Lithotype 5 rocks also imply deposition in exposed environments. It is interesting to note that Lithotype 5 rocks are never in vertical contact with Lithotype 1 rocks which represent subtidal environments which are never or very infrequently exposed.

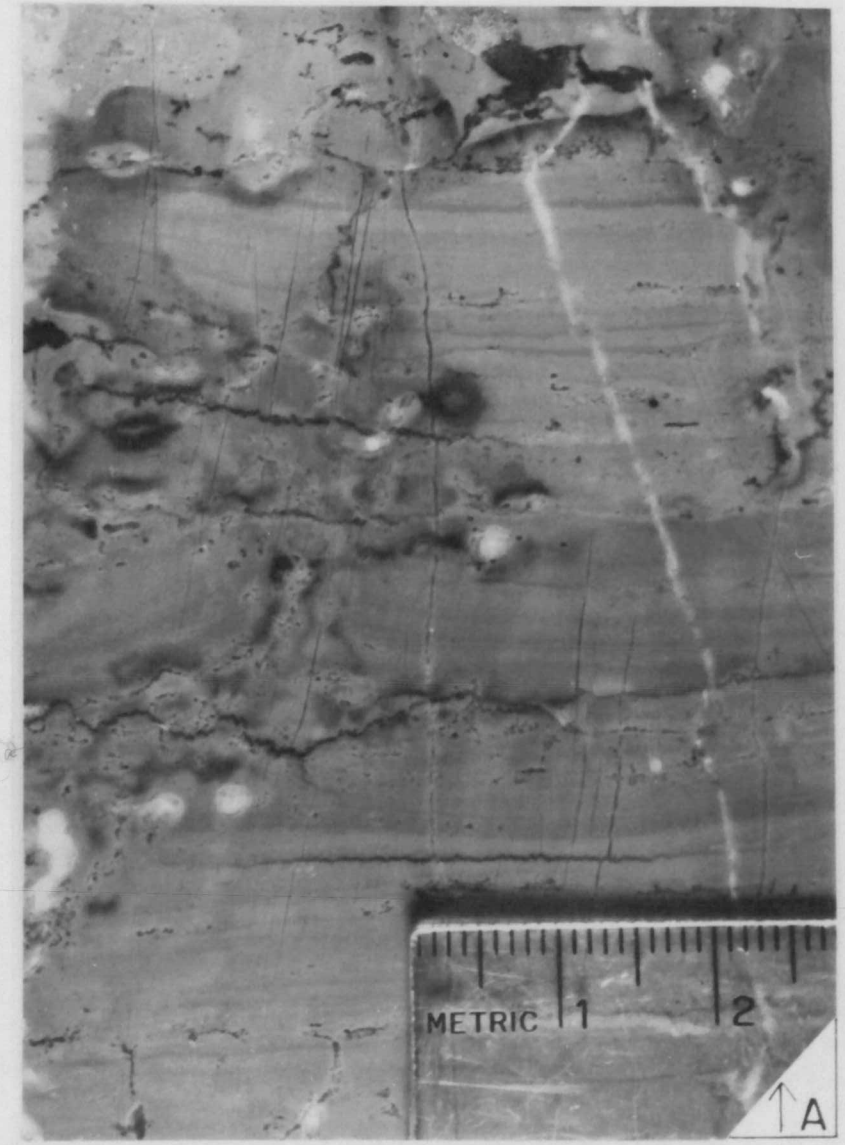
Lithotype 5 rocks grade into Lithotype 3. Bioturbated Lithotype 5 rocks would look exactly like Lithotype 3 since their petrography is identical. Macrofossils are absent to rare and the mud in each rock type is formed by squashed peloids. Contacts with Lithotype 3 and 5 are gradational. No Lithotype 3 rocks with relict laminae were found but partially bioturbated Lithotype 5 samples do occur (Fig. 39A); the burrowed portions with no laminae are identical to Lithotype 3 (or Lithotype 2) rocks.

The most logical depositional environment for Lithotype 5 rocks is that of the algal marsh. Hardie and Garrett (1975) have shown that thin-bedded to laminated deposits of mud occur within both the inland and low algal marsh environments of Andros Island. Due to low sediment-input (or fresh-water conditions) characteristic of these environments, Scytonema algae dominate over Schizothrix algae. However, in the present study, Lithotype 5 sediments are not composed of, or associated with relict algal structures. Only one instance of possible Scytonema-like lamination was observed (Fig. 40) but not in contact with Lithotype 5 rocks. The most stratigraphically proximal laminated rocks near this occurrence of possible Scytonema-like lamination are Lithotype 5 rocks, however (Fig. 41). This may suggest that Scytonema-like algae were patchily distributed within algal marsh environments and are thus characteristic of Lithotype 5 rocks but data are lacking. On the basis of layering thickness exhibited by Lithotype 5 rocks, their depositional environment is inferred to be similar to the low and inland algal marsh environments of Andros Island.

Figure 39. Photographs of Lithotype 5 and Lithotype 7 rocks.

A. Photograph of a partially bioturbated Lithotype 5 sample. Note that the burrowed portion of this rock is identical in lithology to either Lithotype 3 or Lithotype 2. (Sample H-13).

B. Thin-section negative print of a Lithotype 7 sample. Three discrete layers are visible in this sample. The lower layer exhibits a truncated surface overlain by successive layers of current-oriented peloids and fossils.



.5 MM



Figure 40. Photographs of Scytonema-like lamination and tubules in Lithotype 5 rocks.

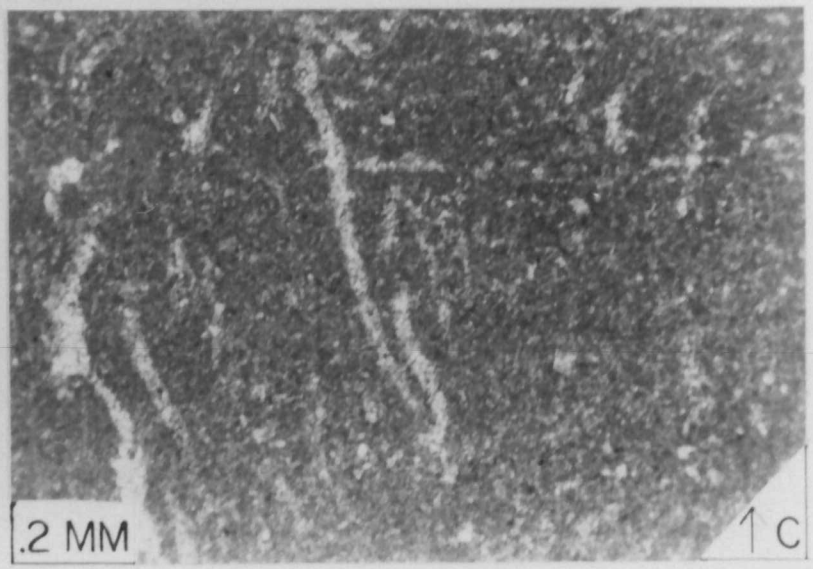
A. Thin-section negative print of Scytonema-like lamination. Note the very fine laminations. (Sample H-88).

B. Photomicrograph of Scytonema-like filament molds(?). Note the consistent vertical orientation of the tubules.

C. Photomicrograph of a single Scytonema-like, filament mold (?).


5 MM
A


1 MM
B


.2 MM
C

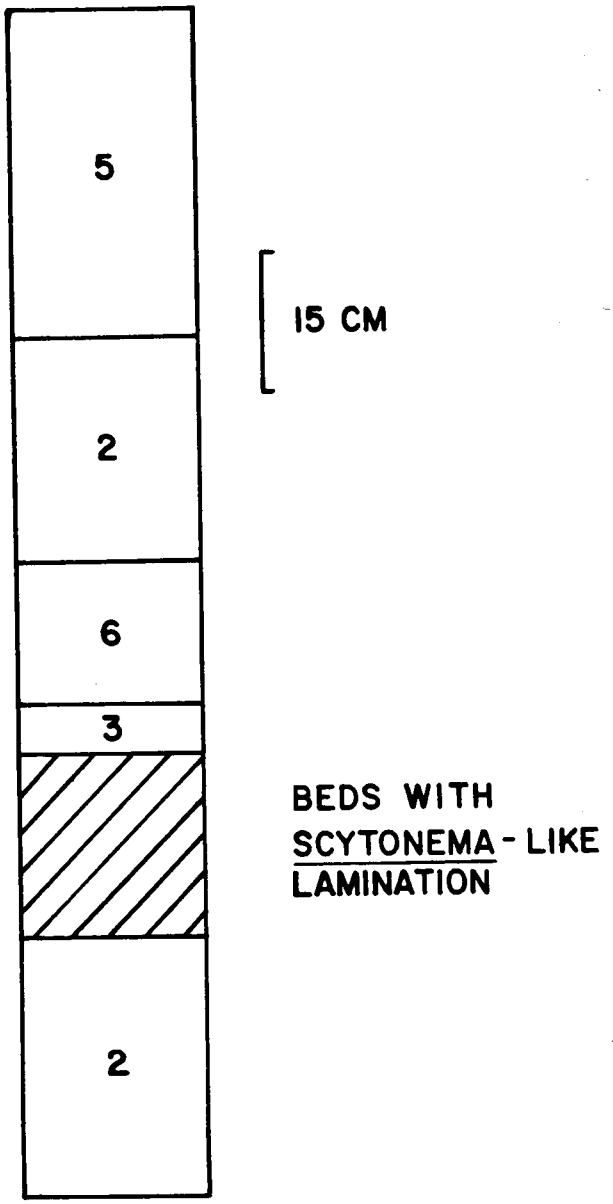


Figure 41. Lithotypes associated with possible Scytonema-like laminations. Numbers are equivalent to lithotypes.

Lithotype 7

Lithotype 7 grainstones do not represent one depositional environment. Samples 48 and 340-342 are interpreted to be channel deposits whereas other Lithotype 7 samples are probably storm deposits. The mean thickness of all Lithotype 7 beds is 4.7 cm. Both samples 48 and 340-342 are much thicker, 90 cm and 22 cm thick respectively. These thicknesses probably preclude a storm origin, for no storm deposits thicker than 10 cm have been documented on modern tidal flats (Ball et al., 1967; Perkins and Enos, 1968; Hardie, 1975).

The lower part of sample 48 contains cross-laminae composed of peloids and abraded and fragmented fossil fragments. The upper 80 cm is massive and composed largely of echinoderm plates and columnals derived from offshore, normal marine environments. Samples 340-342 are bounded by scour surfaces and appear to be cross laminated. Sample 342 is composed largely of 0.5 to 2.0 cm intraclasts which appear to be crudely graded (Fig. 32D, p. 122). Because of these features and the association of these Lithotype 7 samples with laminated tidal flat sediments, these rocks are interpreted to be channel deposits.

If these rocks are indeed channel deposits, only 0.3% of the rocks in the L2 section were formed in channels. This rarity of channel deposits may be due to insufficient lateral exposure. However, if common, certainly more grainstone deposits would have been ascribed to channel environments. If channels actively migrated, only levee interiors, levee crests, and abandoned channels would be preserved. The presence of channels might also be masked by biogenic reworking

subsequent to the deposition of channel grainstones. Lastly, Hardie (1975) found that 14% of the channeled belt and only approximately 7% of the entire Andros Island tidal flat are occupied by active or abandoned channels. It is possible that the absence of channel deposits in section L2 is fortuitous.

Other Lithotype 7 rocks are distinctly different and are interpreted to be storm deposits. They are thin (1 - 5 cm), fining-upwards (intraclast)-fossil-peloid grainstones with planar or cross laminations. These beds often truncate lower layers (Fig. 39B) and are found intercalated with typically low-energy deposits such as lithotypes 3 and 2. These storm layers survived bioturbation because they are deposited above mean tide level, or because they are unfavorable substrates for burrowing. Because they are cleanly washed, they may have contained little organic material when deposited, and thus may have been poor deposit-feeding resources. Garrett (1975) has noted that beds with noticeably "different constituencies" survive biogenetic reworking in the modern tidal ponds of Andros Island.

Vertical-contact data also suggest that Lithotype 7 rocks are storm deposits. Jones and Dixon (1976) have noted that storms are essentially random processes. If storms and their resultant deposits are random in their occurrence, the number of vertical contacts between storm deposits and a given lithotype should be proportional to the amount of area that lithotype's depositional environment occupies on the tidal flat. For the present study, volume can be used as an approximation of area. There is a direct relationship between the

number of vertical contacts observed between Lithotype 7 rocks and a given lithotype's volume in the L2 section (Fig. 42). The greater the volume of a lithotype, the greater number of vertical contacts between it and Lithotype 7 rocks. This relationship along with the above evidence suggests that Lithotype 7 rocks are storm deposits. Their appearance in the stratigraphic column is therefore random.

Migration of Environments

The Lithotype 4 and Lithotype 5 idealized sequences were produced by the migration of environments and subenvironments. According to the inferred depositional environments of the studied lithotypes, there are several ways environments may have migrated to produce the idealized sequences. Figure 43 depicts a simplified Andros Island- type tidal flat modified after Hardie (1975).

Several migration patterns could have generated the observed idealized sequences. The Lithotype 4 idealized sequence can be produced by migration from pond centers to levee crests (Fig. 43). Andros Island tidal ponds display lower organism diversity than offshore subtidal environments but calcareous algae as well as other creatures do live in tidal ponds (Hardie and Garrett, 1975; Garrett, 1975). Only certain portions of tidal ponds remain submerged through an entire seasonal cycle. The most permanent subtidal locations should display increased organism diversity. The portions of the ponds which are subjected to desiccation, such as pond margins, would record relatively lower diversities and a host of features formed in sediments with lower sediment water content. Millimeter-scale algal

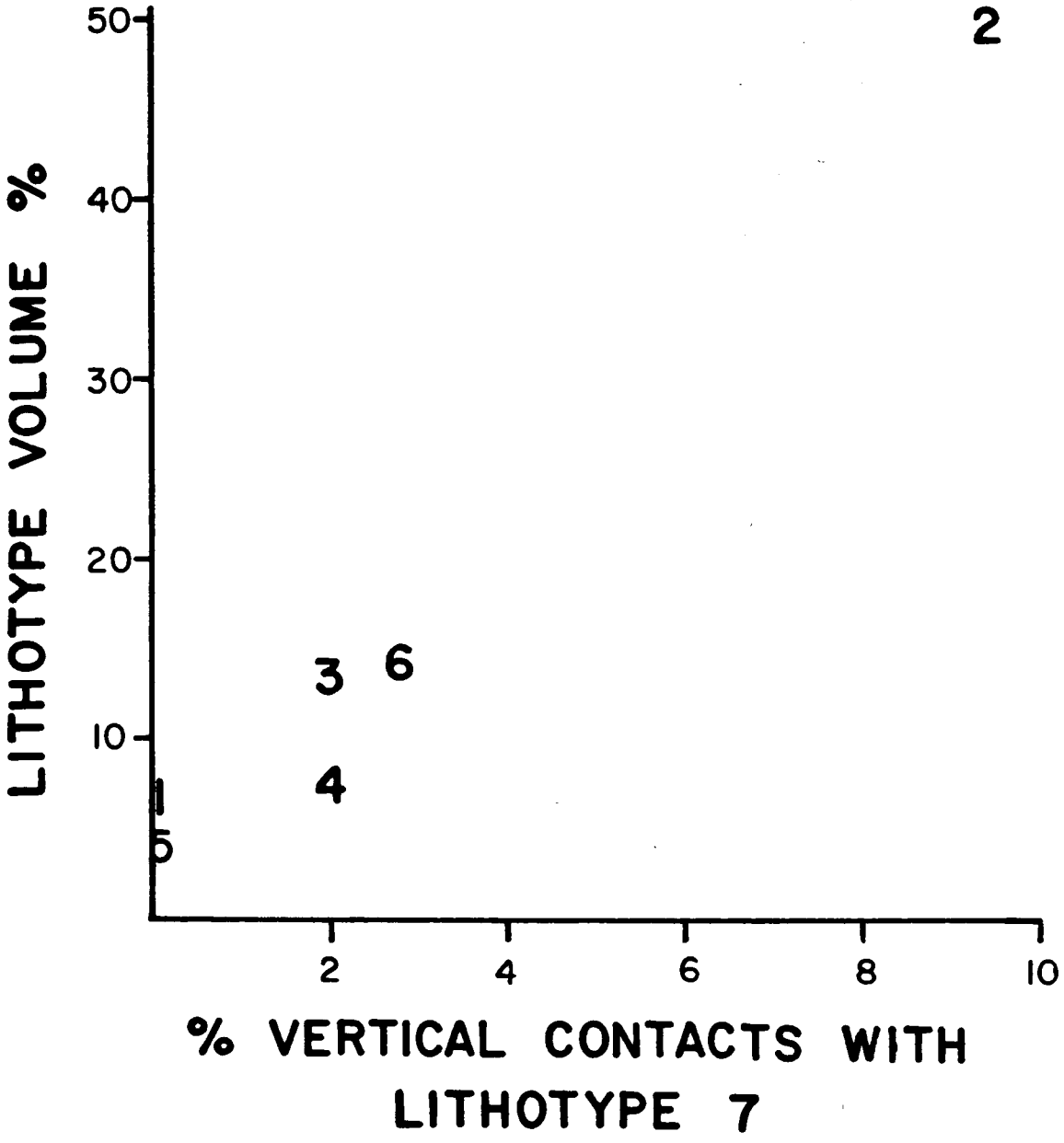


Figure 42. Graph of % vertical contacts of lithotypes with Lithotype 7 versus lithotype volume %. Numbers represent points and are actual lithotype numbers. Samples 340-342, and sample 34 were not included in the calculations since they are not storm deposits.

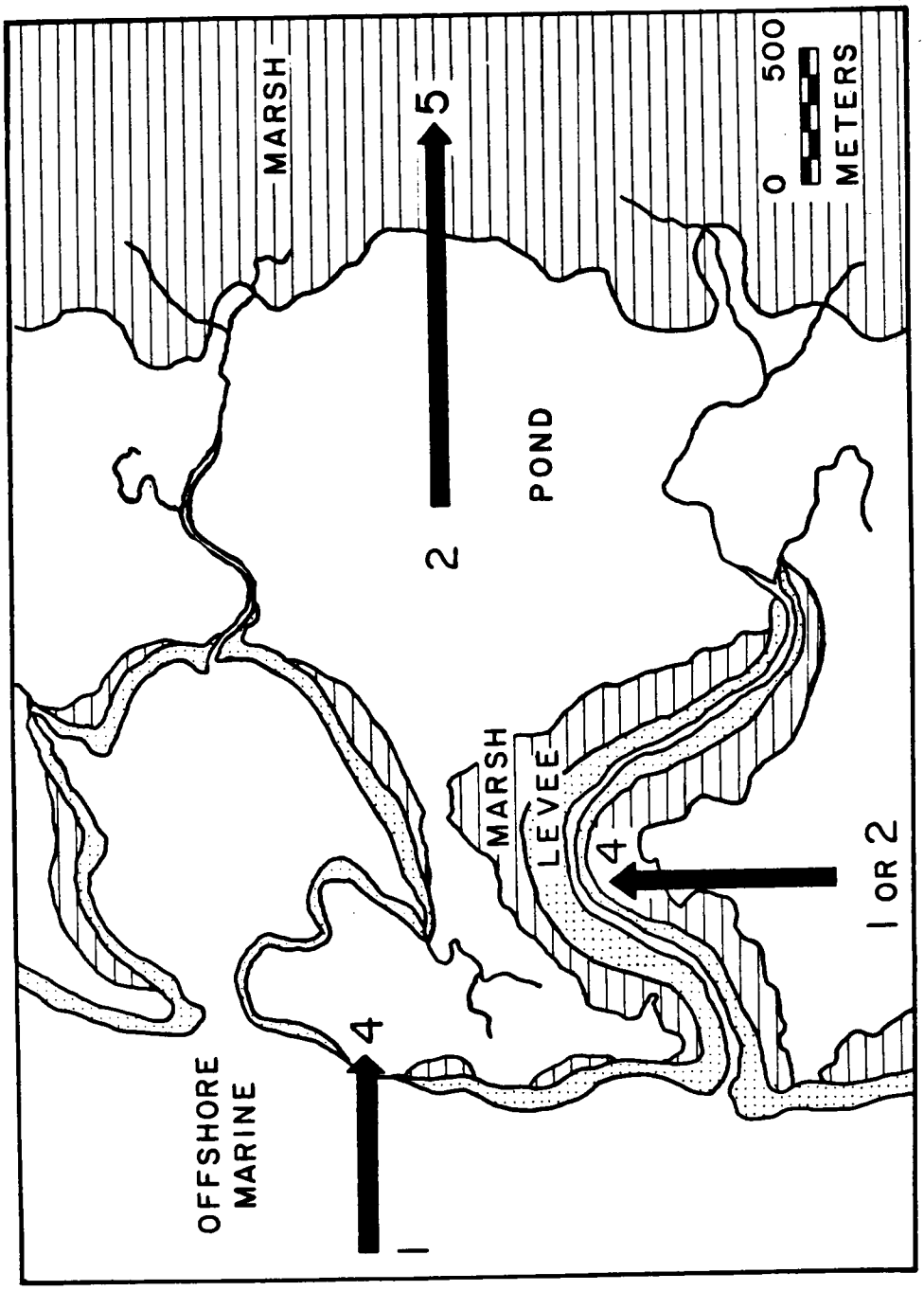


Figure 43. Migration of environments which are interpreted to have generated the idealized sequences. Drawing modified after Hardie (1975).

laminations would be most commonly preserved in environments above mean tide level, thus Lithotype 4 rocks represent levee crest or backslope environments. Lithotype 6 rocks either represent levee interiors or extreme pond margins.

The Lithotype 5 idealized sequence probably represents migration from ponds to inland or low algal marshes (Fig. 43). These are the environments which display laminations and thin beds in modern settings. The absence of contacts between algal-laminated rocks (Lithotype 4) and Lithotype 5 sediments argues against a pond to low algal marsh migration.

If the rocks of the present study were not formed in a channeled tidal flat complex, environment migration from offshore marine through progressively more exposed environments marginal to the offshore environment would generate the idealized sequences. Lamination would most probably be preserved only above mean tidal level. Lithotypes 4 and 5 would have formed in slightly different environments depending on the distribution of algae. However, the absence of possible beach ridge lithologies argues against an offshore, adjacent marine origin.

CHAPTER IV

SUMMARY AND CONCLUSIONS

1. The Middle Ordovician carbonates exposed in the Kingston allochthon of eastern Tennessee are dissimilar to rocks located in the Central Basin of Tennessee and south of the White Oak Mountain/ Walden Valley faults of the Tennessee Valley and Ridge. As a consequence, the author did not attempt to attribute the already established Central Basin and Valley and Ridge stratigraphic nomenclature to the Middle Ordovician rocks near Clinton, but instead concentrated on an environmental interpretation of the exposed section. The only formal stratigraphic unit recognized was the Chickamauga Group which is defined as those rocks which lie above the Lower Ordovician Knox Group and below the Upper Ordovician Reedsville Shale.

2. The study area was located well onto the carbonate shelf during the Middle Ordovician and as a result, did not receive any terrigenous clastic sediment until the latest Middle Ordovician. The Reedsville Shale represents the initial phase of clastic-dominated deposition in this area.

3. The lack of evaporite minerals or their pseudomorphs in the Clinton rocks strongly suggests that the Middle Ordovician climate of this area was "wet," or at least not arid or semi-arid.

4. Deposition of the Middle Ordovician Chickamauga Group carbonates occurred in waters depths less than 20 meters. Inferred environments include Bahamian-type tidal flats, restricted lagoons, and shelf environments with normal marine salinity. Sedimentation on the

Knox surface began with the deposition of intertidal and supratidal sediments followed by the migration of supratidal, intertidal, and restricted subtidal environments to generate a 200 m thick stratigraphic sequence of these sediments. The L3 stratigraphic interval from 200 to 295 m represents a major deepening trend culminating in the deposition of shallow-water, open marine shelf sediments. Section L3D is dominated by restricted lagoon sediments.

5. Tetradium growth forms include a slender, 1 to 10 mm tall, finger-like colony and a massive, 10 cm diameter, hemispherical head-like form. These growth forms may represent ecophenotypes. Through association with established restricted-water fossils, Tetradium corals are interpreted to be eurytopic organisms. These corals are also found in rocks with high micrite contents so the presence of mud apparently did not limit Tetradium distribution.

6. Relief on the Knox unconformity between the two measured section locations (L1 and L3) is at least 63 m. The T3 bentonite was used as a time line to "hang" the stratigraphic sections. A 63 m difference occurs at the bottom of these sections.

7. A holistic approach using petrographic and fabric data, vertical-contact data, recurrent and idealized stratigraphic sequences, and knowledge of processes operating in modern tidal flat environments led to the recognition of subenvironments and their interrelationships as components of a depositional complex. At least eight, and possibly ten subenvironments were recognized by this study. The subenvironments include tidal pond centers, tidal pond margins, algal marshes, levee crests, levee interiors, and tidal channels.

8. Vertical-contact associations of the study rock types are not random (except for Lithotype 7). Genetically related lithotypes are most often in vertical contact with each other. This phenomenon is interpreted to be the result of deposition in adjacent depositional environments or subenvironments.

9. Stratigraphic sequences of rock types which represent specific environments or subenvironments record the migration of these environments through time. Recurrent stratigraphic sequences can be used to generate idealized sequences which represent migration of genetically related and proximal or adjacent environments of deposition. In this way, the relation of subenvironments to other subenvironments and to the depositional complex can be achieved.

10. Two idealized sequences were recognized in this study; both display laminite caps and thus record regressive cycles. The Lithotype 4 idealized sequence was generated when environments shifted from tidal pond centers to tidal pond margins to levee crests. The sediments contained within this sequence reflect increasing degrees of exposure upsection. The Lithotype 5 idealized sequence was produced when environments on the tidal flat migrated from pond centers to pond margins to algal marshes. The sediments in this sequence also display increased exposure effects.

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APPENDICES

APPENDIX A

MEASURED SECTION DESCRIPTIONS

The study area is located on the outskirts of Clinton, Anderson County, Tennessee within the U.S.G.S. Norris and Powell 7 1/2' quadrangles (see Fig. 1, p. 2). Two stratigraphic sections were measured. Both sections start as near as possible to the Knox unconformity and continue upward through the T3 and T4 bentonites (Central Tennessee terminology - see Wilson, 1949) into a final package of fossil grainstones. The Clinton railroad section (L1), although incomplete, has the basal portion of the Chickamauga Group well exposed. The Clinch River section (L3), although incomplete at the base, is fairly well exposed upsection. Use of both measured sections in concert produces a more complete composite section. As a consequence, only the bottom portion of section L1 was measured in detail.

Each section is described below in detail. Sections are described from bottom to top, from oldest to youngest units. Sample numbers and the cumulative stratigraphic position of sample bottoms are given in the right hand column. Unit thicknesses are tallied with the start of the first exposed Chickamauga Group rock. Thicknesses are measured to the nearest centimeter for convenience, but the author realizes that the measurements are not that precise. Units are informal and were determined from field, slab, and thin-section study. Units are <u>not</u> correlative between the two sections. Bedding thickness and grain-size conventions are listed on the next page. The colors referred to below are <u>not</u> standardized.

Measurement Conventions

Grain size conventions are after Wentworth (1922). Terminology for bedding thicknesses is after McKee and Weir (1953) as modified by Ingram (1954).

Grain Size

Pebbles	4 - 64 mm
Granules	2 - 4 mm
Sand	
Very coarse	1 - 2 mm
Coarse	1/2 - 1 mm
Medium	1/4 - 1/2 mm
Fine	1/8 - 1/4 mm
Very fine	1/16 - 1/8 mm
Silt	1/256 - 1/16 mm
Clay	less than 1/256 mm

Bed Thickness

Very thick bedded	greater than 1.0 m
Thick bedded	0.3 - 1.0 m
Medium bedded	0.1 - 0.3 m
Thin bedded	0.03 - 0.1 m
Very thin bedded	0.01 - 0.03 m
Laminated	0.003 - 0.01 m
Thin laminated	less than 0.003 m

CLINTON RAILROAD SECTION (L1)

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
1	11.05	11.05	Greenish gray, maroon, or tan thin to medium bedded; clayey mudstone. Horizontal and vertical burrowing is prominent with vertical burrows being more common than horizontal burrows. Mudcrack polygons, 6 to 10 cm in diameter, occur near the top of this unit. Fossils are usually restricted to bed surfaces and are absent to sparse in rock interiors. Fossils include ostracodes, echinoderm elements, bryozoan fragments, whole and fragmented trilobites, and rare Hedstroemia and Girvanella clasts. Fragmentation and abrasion is usually severe on bryozoan and echinoderm grains. Ostracodes, trilobites, and algae may or may not display breakage and abrasion. Samples. L1B-A, 0.00; L1B-B1, 0.05; L1B-B2, 0.10; L1B-C1, 0.20; L1B-C2, 1.00; L1B-D1, 6.70; L1B-D2, 7.85; L1B-D3, 10.97.
-	6.75	17.80	UNEXPOSED
2	0.78	18.58	Tan, thin to medium bedded, very fine to medium grained, quartz silt grainstone. Clotted fabric is conspicuous. Planar and cross laminations are common. Vertical burrows are up to 7 mm in diameter and 40 mm deep (7 X 40 mm). Fossils are absent. Samples. L1B-1, 18.08; L1B-3, 18.45.
3	19.69	38.27	Maroon or tan, thin to medium bedded mudstone. Fabric is thoroughly bioturbated; vertical, horizontal, and inclined burrows are all common. Desiccation fenestrae and 2.5-3.0 mudcrack polygons are present in the middle portion of the unit. Fossils are rare but include unabraded ostracode valves and 2 cm trilobite fragments. Samples. L1B-5, 18.58; L1B-5A, 19.61; L1B-5B, 20.75; L1B-5C, 27.85.
4	0.50	38.77	Gray, thin-bedded, homogeneous mudstone. Vertical and horizontal burrows are ubiquitous. Random shrinkage cracks filled with drusy

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			calcite spar are also present. Rare fossils include disarticulated and articulated ostracodes. Samples. L1B-5D, 38.27.
5	1.00	39.77	Tan, thin to medium bedded, peloid-quartz silt grainstone. Common planar and cross-ripple laminations occur. Fossils are absent. Samples. L1B-6, 38.77.
6	9.00	48.77	Tan, thin to medium bedded, fossil-peloid wackestone/packstone. 2 to 4 cm peloid and fossil grainstone beds are intercalated with mud-rich layers. Bryozoans, algal plates, and trilobites are always abraded. Ostracodes are abraded and unabraded, and articulated and disarticulated. Quartz silt is ubiquitous with a significant amount of detrital feldspar. Samples. L1B-8, 41.27; L1B-10, 42.47; L1B-12, 45.30; L1B-13, 47.90.
-	54.00	102.77	UNEXPOSED
7	8.55	111.32	Tan or greenish gray, thin-bedded mudstones. Some beds are characterized by well developed desiccation fenestrae; others display mud-cracks. Fossils are absent. Samples. L1C-1; 105.12; L1C-2, 106.62; L1C-3; 109.07.
-	1.40	112.72	UNEXPOSED
8	1.10	113.82	Greenish gray, thin to medium bedded, fossil wackestone/packstone. Allochems are randomly oriented due to horizontal burrowing activity. Fossils include bryozoans, brachiopods, echinoderms, ostracodes, trilobites, gastropods, Tetradium, and sponge spicules. Fragmentation is displayed by bryozoans, brachiopods, echinoderms. Tetradium usually display fragmentation and abrasion. Ostracodes, trilobites, and gastropods may or may not possess abraded and broken skeletons. Samples. L1C-4, 113.71.
-	63.00	176.82	UNEXPOSED

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
9	11.00	187.82	Intercalated, thin beds of gray mudstones and greenish gray wackestone/packstones. Mudstones display prominent burrow mottling produced by vertical burrows. Organisms are sparse but include unabraded ostracode valves or articulated individuals, severely abraded echinoderm elements, and fragmented but usually unabraded trilobite pieces. Wackestone/packstones contain the above fauna as well as broken and abraded brachiopod and bryozoan fragments. Samples. L1D-1, 182.12; L1D-2, 185.12.
-	8.65	196.47	UNEXPOSED
10	6.43	202.90	Mottled; tan, brown and gray; thin-bedded; peloid and fossil grainstone. Peloid and fossil grainstone. Peloids outnumber fossil allochems 3 to 1 and are generally very fine to fine sand. Fossil allochems are generally abraded and may be broken or unbroken. Bryozoans, echinoderm elements, brachiopods, gastropods, ostracodes, trilobites, and Hedstroemia occur as randomly oriented grains. Both vertical and horizontal burrows are evident. Black chert nodules are present in several lower beds. Samples. L1E-1, 196.47; L1E-2, 199.37; L1E-3, 200.45; L1E-4, 200.52; L1E-5, 202.84.
--	43.80	246.70	UNEXPOSED
11	26.10	272.80	Intercalated thin to medium beds of tan or greenish-gray mudstone and tan grainstone. Mudstones are afossiliferous but are vertically burrowed. Near the top of the unit desiccation fenestrae and mudcracks are common structures. Stromatolites up to 10 cm high are associated with lower mudstones. Grainstones are present as (discontinuous?) layers 0.5-3.0 cm thick. Allochems include peloids, intraclasts, unabraded to highly fragmented and abraded ramose bryozoans, fragmented brachiopods, whole or broken but unabraded trilobites, abraded Hedstroemia plates, unabraded ostracode valves, and generally whole gastropods.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			Samples. L1-14A, 247.55; L1-14B, 252.27; L1-14C, 252.86; L1-14D, 252.99; L1-14E, 255.35; L1-14F, 256.91; L1-14G, 260.52; L1-14H, 263.27; L1-14I, 265.63; L1-14J, 272.70.
--	13.50	286.30	UNEXPOSED
12	1.28	287.58	Gray, thin-bedded wackestone/packstone and gray grainstone. Wackestone/packstones have both horizontal and vertical burrows. Wackestones are largely composed of abraded and unabraded bryozoans, and ostracodes valves with auxiliary amounts of trilobites, abraded echinoderm elements, Tetradium, gastropods, and articulated brachiopods. Grainstones are in erosive contact with mud-supported rocks and display intraclasts up to 1 cm of the same lithology as wacke/packstones. Top surfaces of some wackestone/packstone beds are hardgrounds or at least "firmgrounds", or ommission surfaces. Intraclasts and peloids are common. The same fauna is present in grainstones as in wacke/packstones, but allochems exhibit more abrasion and fragmentation. Samples. L1F-3, 286.70; L1F-2, 287.37.
--	31.10	318.68	EXPOSED
13	1.65	320.33	Mottled; gray, black, and brown; thin-bedded wackestone. Both horizontal and vertical burrows are present. Fossils include abraded and unabraded bryozoans, unfragmented Tetradium, articulated and disarticulated ostracodes, trilobites, and minor amounts of Hedstroemia and gastropods. Samples. L1G-1, 318.98; L1G-2, 319.83.
14	3.55	323.88	Thin-bedded, tan to gray mudstones; and brown fossil and peloid grainstone. Grainstones are composed of traction packages that are typically fining-upward with a basal lag of coarse sand to pebble fossil debris succeeded by plane laminated peloids. Peloids at the tops of these packages are usually compacted to form peloid packstones which are cut by horizontal burrows. Contacts between grainstone layers and mudstones are usually erosive. Some mudstone/wackestone top

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			surfaces are bonofide hardgrounds displaying borings. Mudstones are always bioturbated with horizontal burrows greater in number than vertical burrows. Bryozoans, trilobites, and ostracodes are the principal grainstone fossils, and all show varying degrees of fragmentation and abrasion. Ancillary fossils include abraded echinoderms, bivalve valves, and gastropods. Samples. L1G-3, 320.33; L1G-4, 322.96; L1G-5, 323.03; L1G-6, 323.08.
--	23.00	346.88	UNEXPOSED
15	0.45	347.33	Gray, thin-bedded mudstone and wackestone. Bivalves and gastropods are common; algal plates are also present.
16	6.90	354.23	Tan to brown shale with interbeds of gray cherty mudstone near the bottom of the unit. Only shale appears to contain a weathered ash component.
17	2.60	356.83	Gray, thin-bedded, fossiliferous wackestone/ packstone with ubiquitous horizontal burrows. Chert nodules are present.
18	2.90	359.73	Tan shale.
19	0.55	360.28	Light gray packstone with bryozoans, articulated crinoids, pelmatozoan debris, brachiopods, and bivalves.
20	1.45	361.73	Brown shale.
21	0.50	362.23	Bentonite. Weathers apple green. Probably equivalent to the T3 bentonite of central Tennessee terminology.
22	8.65	370.88	Tan to brown, thin to medium bedded, silty mudstone. 10 cm mudcrack polygons are common. Fossils are generally absent but ostracodes and clams are present in the upper portion of this unit.
23	0.75	371.63	Bentonite. Probably the T4 bentonite of central Tennessee.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
24	18.00	389.63	Brown shale(?). Probably the weathered remains of packstones and/or grainstones. Gradational contact with unit 25.
25	15.05	404.68	Gray fossil packstones and grainstones. Fossils are very diverse and include brachiopods, bryozoans, echinoderm plates and columnals, rugose corals, ostracodes, trilobites, sponges, bivalves, and cephalopods.

CLINTON CLINCH RIVER SECTION (L3)

This section starts well above the Knox unconformity, within the Chickamauga Group. The Knox-Chickamauga contact is covered but the true stratigraphic thickness of the missing basal section lies between an additional 0 and 27 meters.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
1	17.90	17.90	Gray and greenish-gray mud-, wacke-, and packstones. Bedding is thin to medium usually with a nodular appearance on both weathered and polished surfaces. Nodules are "islands" of rock which have not experienced pressure solution. Bed surfaces are not level but exhibit 1-2 cm of relief. Allochems within this unit are randomly oriented due to bioturbation. Burrows are cryptic due to the high sediment water content at the time of deposition. Restricted-water fossils dominate these rocks. Bivalves and ostracodes are subequal in abundance, unbroken, unabraded, and may be either articulated or disarticulated. Trilobites are always unabraded and may be present as unbroken carapaces up to 5.5 mm in width. Gastropods, Hedstroemia, and Solenopora (type R) are rare forms. Open-marine fossils such as echinoderms and nicholsonellid bryozoans are broken and abraded.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			Samples. L3B-1, 0.00; L3B-2, 0.83; L3B-3, 2.00; L3B-5, 2.20; L3B-4, 2.80; L3B-6, 7.81; L3B-7, 9.63; L3B-8, 10.86; L3B-9, 13.39; L3B-10, 13.64; L3B-11, 17.45; L3B-12, 17.60.
-	11.50	29.40	UNEXPOSED
2	1.20	30.85	Gray, medium-bedded, very fine to fine grained, moderately to well sorted, peloid and fossil grainstone. Any physical sedimentary structures have been destroyed by burrowing. Peloids comprise about one-half the allochems. Echinoderms, articulated ostracodes, detrital quartz and feldspar silt, trilobite fragments, and Hedstroemia plates are the other allochems listed in decreasing abundance. Except for ostracodes, fossils are generally broken and severely abraded. Samples. L3B-13, 30.60.
3	5.65	36.50	Greenish gray, thin to medium bedded mudstones, wackestones and packstones. This unit is virtually identical to unit 1. Samples. L3B-14, 32.70; L3B-15, 33.35; L3B-16, 35.25.
4	0.20	36.70	Mottled; tan, gray, and brown; thin to medium bedded wackestone/packstone. Both vertical and horizontal, pellet-filled burrows occur. Allochems have no preferred orientation. Peloids are of uniform size between 0.05-0.06 mm. Fossils include unabraded trilobites; lightly abraded to unabraded ostracode valves and articulated individuals; and rare, heavily abraded bryozoans and gastropods. Samples. L3B-17, 36.50.
-	1.20	37.90	UNEXPOSED
5	0.65	38.55	Greenish gray, thin to medium bedded packstones/grainstones. Scour surfaces are common. Well sorted peloids comprise most of the rock along with clastic quartz grains. Horizontal burrows, about 1.6 mm in diameter, are ubiquitous and have destroyed any primary sedimentary structures. Fossil allochems are

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			less common and are represented by trilobites, brachiopods, and gastropods. Samples. L3B-18, 38.30.
6	0.15	38.70	Greenish gray, thin-bedded, fine to medium grained, intraclast-ooid-peloid grainstone/ mudstone. This rock is composed of several 0.1-0.4 mm amplitude ripples with intervening mud layers or mud drapes. Omission surfaces are common. Ooids are superficial, reaching 1.3 mm in size, with intraclast or echinoderm-element nuclei. Dismicrite intraclasts may be much larger and elongate. Peloids are ubiquitous, well rounded, and poorly sorted. Fossils are absent. Samples. L3B-19, 38.55.
-	6.00	44.70	UNEXPOSED
7	6.04	50.74	Tan to gray, thin-bedded, silty, bioturbated mudstone. Vertical burrows may be robust (4 X 40 mm) and pellet-filled, or smaller (1 X 40 mm) and pellet- or spar-filled. Vertical burrows outnumber horizontal burrows. Burrow walls are distinct but not sharp. Poorly developed, incipicent desiccation fenestrae are also common. Restricted-water fossils - ostracodes and trilobites - do not display any transportation effects. Heavily abraded echinoderms are the only open marine fauna. Hedstroemia plates are lightly abraded. Samples. L3B-20, 45.40; L3B-21, 45.71; L3B-22, 48.20; L3B-23, 50.67.
-	1.40	52.14	UNEXPOSED
8	0.40	52.54	Gray, medium-bedded wackestone or packstone. Horizontal burrowing is ubiquitous and has obliterated any traction layers within the sediment. Restricted-water fossils - ostracodes, clams, and gastropods - exhibit little transportation affects. Peloids and intraclasts, entirely gradational in size, are present and probably are transported grains. Samples. L3B-24, 52.14.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
--	7.30	59.84	UNEXPOSED
9	4.30	64.14	Tan, thin to medium bedded, silty mudstone. Horizontal, vertical, and U-shaped burrows are present; generally vertical forms are greater in abundance. Vertical burrows average 5 X 35 mm. Burrow walls are distinct. This rock is thoroughly bioturbated; however, relict laminae are present in some samples. Desiccation fenestrae are notable. Fossils are rare; some samples have no fossils whatsoever. Ostracodes and trilobites occur with or without fragmentation and abrasion. Encrusting and nicholsonellid bryozoans and echinoderms are heavily abraded and were therefore transported. Girvanella and Hedstroemia clasts may or may not display abrasion. Monaxon sponge spicules are also present. Samples. L3B-25, 59.84; L3B-26, 61.14; L3B-27, 61.54; L3B-28, 62.64; L3B-29, 63.14; L3B-30, 64.04.
10	1.65	65.79	Gray, thin-bedded, wackestone. Horizontal burrowing is ubiquitous and as a consequence allochems are randomly oriented. Very fine-grained peloids are present in significant numbers. Ostracodes are dominant and are generally unbroken and unabraded with many articulated individuals. Hedstroemia plates are common and are not abraded. Gastropods also seem to be untransported. Samples. L3B-31, 65.69.
--	0.85	66.64	UNEXPOSED
11	5.45	72.09	Tan, thin to medium bedded, silty mudstone. Both horizontal and vertical burrows are present; both are also pellet-filled. Vertical burrows may be up to 5 X 40 mm in size. The fabric is usually completely bioturbated but some samples possess relict laminae. 1 to 2 mm mud-rich and peloid-grainstone laminae are usually intercalated. Fossils are few in number but include abraded or unabraded, whole ostracodes; severely abraded echinoderm elements, and monaxon and hexagonal (Chancelloridae?) sponge spicules.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			Samples. L3B-32, 68.64; L3B-33, 70.74; L3B-34, 70.89.
12	0.35	72.44	Gray, thin to medium bedded mudstone. Horizontal burrows are up to 1.5 mm in diameter and are pellet-filled. Vertical burrows are more numerous and are represented by 1 X 30 mm sparry calcite tubules. Allochems are randomly oriented due to bioturbation. Ostracodes are represented by valves and valve fragments 0.2-0.3 mm in size which display little abrasion. Triaxon sponge spicules are common yet comprise little of the rock volume. Sample. L3B-35, 72.09.
13	2.25	74.69	Tan, thin to medium bedded, silty mudstone. Sediment is bioturbated; U-shaped and vertical burrows 5 mm in diameter are common. Detrital quartz is ubiquitous. Fossils are absent. Samples. L3B-36, 72.44.
14	0.30	74.99	Tan and gray, thin to medium bedded, silty wackestone. Burrowing is cryptic and horizontal; allochems have no preferred orientation. Ostracodes, trilobites, and gastropods display low to moderate fragmentation and abrasion. Severely abraded echinoderms and nicholsonellid bryozoans are present. Samples. L3B-37, 74.69.
--	0.50	75.49	UNEXPOSED
15	0.40	75.89	Tan, thin-bedded, silty wackestone/packstone. Burrowing, if present, is cryptic. Bryozoans are the dominant allochems; they are up to 2.2 cm in long dimension and lie parallel to bedding. Echinoderm elements and trilobites are also common. All fossils are fragmented and abraded, although some trilobite skeletal material is unabraded. Silt to very fine sand-sized unidentifiable fossil debris is common and this occurrence together with the abraded nature of all fossils suggests transportation for virtually all fossil allochems. Samples. L3B-38, 75.49.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
--	0.60	79.49	UNEXPOSED
16	0.30	76.79	Mottled, gray, thin-bedded mudstone. Vertical burrows (1.5 X 20 mm) are greater in abundance than horizontal burrows. Fossils are very sparse - only unabraded ostracode valves and monaxon sponge spicules are present. Samples. L3B-39, 76.49.
17	0.07	76.86	Gray, thin-bedded mudstone/wackestone. Only horizontal burrows with diffuse walls occur. As a result of bioturbation, all allochems are randomly oriented. Ostracodes and gastropods are the co-dominants. Ostracodes are usually articulated, unabraded, and unbroken. Gastropods are also untransported. Bryozoans and echinoderm plates are both abraded and fragmented. Samples. L3B-40, 76.79.
18	0.93	77.79	Tan, thin-bedded silty wackestone. Burrowing is cryptic. Restricted-water forms - ostracodes and trilobites - display both articulated, unabraded, and abraded and fragmented individuals. Bryozoans and echinoderms are always broken and abraded. Samples. L3B-40B, 77.20.
--	1.95	79.14	UNEXPOSED
19	1.20	80.94	Mottled, tan, thin to medium bedded, silty wackestone. Horizontal burrowing is ubiquitous and allochems within this rock are randomly oriented. Echinoderm elements and bryozoans are broken and severely abraded. Light abrasion is exhibited by Hedstroemia and Girvanella clasts. Ostracodes and trilobites display low to moderate abrasion and fragmentation. Samples. L3B-41, 80.84.
--	0.45	81.39	UNEXPOSED
20	9.62	91.01	Gray and brownish gray, thin to medium bedded wackestone. Diffuse horizontal burrows are often observed. Fossil allochems have no special orientation. Restricted-water

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			forms are much greater in abundance than open-marine fossils. Bryozoans are rare, broken, and abraded. Ostracodes vary in size from 1.25-4.0 mm. Few are articulated, valves may be broken but are usually not abraded. Trilobites are also unabraded and largely unfragmented. Hedstroemia plates are not abraded. Tetradium are up to 15 mm high and are broken but not abraded. Monaxon sponge spicules are common. Samples. L3B-42A, 81.39; L3B-42B, 81.46; L3B-43, 83.51; L3B-44A, 84.96; L3B-44B, 85.56; L3B-45, 90.31.
--	9.95	92.96	UNEXPOSED
21	2.10	95.06	Tan, thin to medium bedded, silty mudstone. Upper portions of some samples are laminated; alternate 1 mm laminae of mud and packstone/grainstone are present. Vertical burrows with distinct burrow walls are conspicuous. Monaxon sponge spicules are abundant. Ostracodes may be articulated, and their valves may or may not be broken and abraded. Samples. L3B-46, 92.96; L3B-47, 94.86.
--	0.95	96.01	UNEXPOSED
22	1.80	97.81	Gray, thin-bedded mudstone/wackestone-packstone. Parts of the rock are homogeneous mudstone while other portions are gastropod-ostracode wackestones or packstones. Horizontal burrowing is ubiquitous and has taken place in sediment with a moderate water content. Echinoderms and bryozoans are rare and exhibit high degrees of fragmentation and abrasion. Gastropods are whole and ostracodes are frequently articulated. Trilobites and Hedstroemia are present in low amounts but are only lightly abraded if at all. Samples. L3B-48, 97.11.
23	10.22	108.03	Gray, thin to medium bedded mud-, wacke-, and packstone. Diffuse horizontal burrows are present to the exclusion of vertical burrows. No preferred orientation is exhibited by allochems. In situ peloids are common, ranging from 0.1-0.25 mm in size. Restricted-water fossils are much more abundant than

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			open-marine fossils. Ostracodes, Hedstroemia, and 1 mm corallites of Tetradium are most prolific - all organisms showing little fragmentation and abrasion. Gastropods and trilobites are less abundant. Echinoderms and bryozoans always display fragmentation and abrasion. Samples. L3B-49, 97.81; L3B-50, 100.21; L3B-51, 101.16; L3C-A, 101.70; L3C-1, 101.78; L3C-2, 102.06; L3C-3, 103.51; L3C-4, 104.36; L3C-5, 106.93.
24	8.20	116.23	Gray, thin to medium bedded wackestone. Horizontal burrowing is cryptic but is responsible for the lack of orientation displayed by allochems. Allochems are dominated by silt to very fine sand-sized unidentifiable fossil fragments. Triaxon sponge spicules, ostracodes, and gastropods are common faunal elements. Trilobites are uncommon, always fragmented, but never abraded. Algae and Tetradium are rare. Bryozoans are rare and are always broken and abraded. Samples. L3C-6, 108.03; L3C-7, 112.53.
25	6.10	122.33	Gray, laminated mudstone. Laminae are 1 mm or less in thickness, are fairly continuous, and pinch and swell laterally. Typically, mud-rich and peloid-grainstone laminae are intercalated. Mud-rich laminae often exhibit thickening on topographic highs. Vertical burrows (1 X 3 mm) disrupt laminae to varying degrees. Desiccation fenestrae are common. Peloids are rounded to subangular and are approximately 0.05 mm in apparent diameter. Open-marine fossils are exceedingly rare but if present, exhibit fragmented and abraded skeletons. Ostracodes may or may not be present in any one sample; if present, they are commonly fragmented but never abraded. Samples. L3C-7A, 116.23; L3C-8, 118.53; L3C-9, 119.33; L3C-10, 121.56; L3C-11A, 121.83.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
26	3.50	125.83	Gray, thin to medium bedded wackestone. Horizontal burrow walls are very diffuse. Allochems are randomly oriented due to bioturbation. In situ Tetradium corallites dominate this lithology. Ancillary articulated, unbroken, and unabraded ostracodes; unabraded trilobites; and unabraded Hedstroemia also occur. Samples. L3C-11B, 122.33; L3C-12, 124.43.
--	1.80	127.63	UNEXPOSED
27	2.20	129.83	Gray, thin to medium bedded mudstone. Diffuse horizontal burrows are common. Allochems display no preferred orientation. Silt-sized unidentifiable fossil fragments are ubiquitous. Ostracodes are the only fauna and appear as possibly fragmented, but never abraded valves. Samples. L3C-13, 127.63.
--	6.70	136.53	UNEXPOSED
28	6.40	142.93	Gray, laminated, abiotic mudstone. Laminae are 1 to 1.5 mm thick, continuous, and regular. No anti-gravitational structures are present. 15 cm mudcrack polygons are common and occur throughout the unit. Spar- or mud-filled, 3-4 X 12 mm vertical burrows are rare to common within different lamina. Samples. L3C-14, 136.53.
29	0.60	143.53	Gray, cobbly weathered, medium to thick bedded wackestone layers are truncated by scour surfaces and are overlain by peloid-fossil grainstones which grade upward into packstones. Wackestones were "firmgrounds" when burrowed and scoured. Robust (7 X 40 mm) vertical burrows are common. Grains are current-oriented in grainstone layers but lose their preferred orientation in packstone areas where indistinct horizontal burrows are common. Restricted-water fossils are more numerous than open-marine fossils within wackestones. Ostracodes and bivalves may be articulated. Ostracodes, clams, trilobites, and gastropods are all unabraded. Echinoderm elements are few and always abraded.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			Grainstones-packstones generally consist of subrounded 0.10-0.15 mm peloids, coarse grained intraclasts, and medium to coarse grained fossils. Fossils are represented by subequal amounts of restricted-water and open-marine organisms. All fossils are somewhat broken and abraded. Samples. L3C-15, 143.00.
30	9.37	152.93	Mottled, gray, medium-bedded mudstone. Horizontal burrows are present. Allochems are randomly oriented. Fossils are rare but include unfragmented and unabraded trilobites and ostracode valves. Samples. L3C-16
--	1.30	154.23	UNEXPOSED
31	0.50	154.73	Gray, thin to medium bedded, fine to medium grained peloid grainstone. Patches of horizontally bioturbated areas occur in about one-half the rock; burrowing has apparently destroyed any current orientation displayed by allochems. Peloids are rounded and fine to medium grained. Intraclasts are also rounded and are up to 1 mm in apparent diameter. Restricted-water fossils are more abundant and less abraded than open-marine fossils but all allochems have experienced fragmentation to some degree. Fossils include ostracodes, echinoderms, trilobites, bryozoans, and Tetradium in decreasing abundance. Samples. L3C-17, 154.23.
--	1.50	156.23	UNEXPOSED
32	2.80	159.03	Mottled; tan, gray, black, and red; thin-bedded mudstone/wackestone. Horizontal, mud-filled, 4 mm diameter burrows are generally more abundant than 2 X 10 mm vertical burrows. Sediment water content is variable from bed to bed. Ostracodes and trilobites are the most abundant forms. Ostracodes are often articulated, and never fragmented or abraded. Trilobites are also unabraded. Rare, heavily abraded echinoderm elements also occur. Samples. L3C-18, 157.53; L3C-19, 158.53; L3C-19A, float.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
--	1.10	160.13	UNEXPOSED
33	0.60	160.73	Brownish gray, thin to medium bedded, very fine-grained peloid grainstone. Plane, starved-ripple, and cross lamination are present. Some laminae pinch and swell, and are more mud-rich than others. Mud-rich laminae are common near the tops of beds; current-formed laminae are more prominent at bed bases. Burrowing is rare. Sub-rounded peloids and very fine-grained fossil fragments, much of it ostracode debris, are also common. All fossil groups exhibit varying degrees of abrasion. Samples. L3C-20, 160.13; L3C-20B, 160.20.
34	0.50	161.23	Mottled, gray, thin-bedded mudstone. Vertical, pellet-filled, 1 X 12-18 mm burrows are common. As a result, allochems are randomly oriented. Ostracodes are the only fauna and are unabraded and unbroken. Samples. L3C-21, 160.73.
--	1.95	163.18	UNEXPOSED
35	2.10	165.28	Mottled; gray, black and brown; thin-bedded wackestone/packstone. Horizontal burrows are numerous but often cryptic. Allochems have no preferred orientation. Restricted-water fossils are much more abundant than open-marine fossils. Tetradium corals are dominant ranging from 6-30 mm in length for single coralites and up to 10 cm in diameter for heads. This rock displays a prominent moldic fabric, probably due to leaching and subsequent recrystallization of Tetradium skeletons. Common ostracodes and trilobites are neither broken or abraded. Bivalves and gastropods are less numerous but also unabraded. Hedstroemia clasts are not abraded. Nicholsonellid bryozoans and echinoderms are heavily fragmented and abraded. Samples. L3C-22, 163.18; L3C-23, 165.18.
--	4.10	169.38	UNEXPOSED

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
36	1.20	170.58	Gray, thin-bedded wackestone/packstone. Horizontal and vertical burrows are common; some are pellet-filled but most display extremely diffuse walls. Allochems are randomly oriented. Restricted-water fossils outnumber open-marine fossils. Ostracodes may be articulated and, like trilobites, exhibit few transportation affects. Gastropods, Tetradium, and Hedstroemia seem to exhibit light abrasion. Bryozoans and echinoderms are heavily abraded. Samples. L3C-24, 169.38.
37	2.20	172.78	Gray, laminated to very thin-bedded wackestone.
38	0.20	172.98	Gray, medium-bedded, homogenous mudstone.
--	5.30	178.28	UNEXPOSED
39	4.17	182.45	Gray, very thin to thin bedded mudstone/ wackestone. Layers in the lower part of the unit are generally 1-2 cm thick or so and bedding increases in thickness upsection. Bioturbation is present within thick laminae but does not disturb layering. Upsection bioturbation is interlaminar. Vertical burrows occur up to 28 mm in length and are much more common than horizontal burrows. Allochems display no preferred orientation. Most fossils are fragmented: abrasion is more prevalent in open-marine fossils in respect to restricted-water fossils. In order of decreasing abundance, biota include ostracodes, trilobites, gastropods, echinoderms, bryozoans, and bivalves. Samples. L3C-25A, 178.28; L3C-25B, 179.80; L3C-25C, 182.41.
40	1.25	183.70	Brownish; medium to thick, planar, and cross-bedded; very coarse-grained grainstone. Bottom-most surface of this unit is ripple-marked. Tabular cross beds predominant upsection. Fossils include echinoderms; ostracodes, trilobites, and bryozoans in subequal abundance; brachiopods, and Hedstroemia. Abrasion is variable in all taxa, but all exhibit fragmentation. Samples. L3C-26, 182.45.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
41	7.90	191.60	Gray, thin to thick bedded, very fine to medium grained peloid-fossil grainstone. Bedded black chert nodules 1-2 cm thick and 15 cm in length are present throughout the unit. Planar and cross lamination is ubiquitous as are ommission surfaces. Bioturbation is sparse to absent. Peloids are generally 0.10-0.30 mm in diameter but their size grades into 0.6-0.8 mm mudstone intraclasts. Fossils are usually fragmented and are abraded to varying degrees. Fossils include, from most to least abundant, pelmatozoan plates and columnals; ostracodes; trilobites; bryozoans; gastropods; and Hedstroemia plates. Samples. L3C-27A, 184.90; L3C-27B, 185.00; L3C-27C, 185.70; L3C-27D, 191.50.
42	0.50	192.10	Mottled, gray, medium to thick bedded wackestone. Black chert nodules are ubiquitous. Diffuse horizontal burrows are numerous; burrowing activity has rotated allochems. Restricted-water and open-marine fossils are equal in number but open-marine fossils display transportation affects. Fossils include ostracodes, Hedstroemia, gastropods, bryozoans, and echinoderms. Samples. L3C-28, 191.60.
43	2.90	195.00	Brown, thin-bedded, cherty mudstone. Horizontal burrows are much greater in abundance than vertical burrows. Burrow walls are distinct. Allochems are randomly oriented. In decreasing abundance, organisms include unabraded trilobite pieces and whole trilobites; articulated, unabraded, and unbroken ostracodes; and heavily abraded echinoderms. Samples. L3C-29, 192.10.
44	4.45	199.45	Gray and brown, thin-bedded, cherty mudstone. 15 cm mudcrack polygons are evident near the base and middle of the unit; desiccation fenestrae predominant upsection. Beds are composed of continuous millimeter-scale laminations. Mud-rich pellet grainstone laminae alternate in most samples but no anti-gravitation structures observed. Burrows

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			sometimes disrupt laminae. Burrowing is limited to absent; only rare, 1 X 11 mm, vertical burrows exist. Monaxon sponge spicules and mildly fragmented, unabraded ostracode valves are the only fossil allochems present. Samples. L3C-30, 197.40; L3C-31, 198.70.
45	2.30	201.75	Mottled, gray, cobbly weathered, thin-bedded mudstone/wackestone. Vertical burrows are much more numerous than horizontal burrows. The sediment is thoroughly bioturbated; allochems are randomly oriented. Sponge spicules are ubiquitous. Ostracodes are usually articulated while some valves are fragmented but never abraded. Trilobites are unfragmented and unabraded. Samples. L3C-32, 200.20.
46	2.83	204.58	Brown-red and gray, thin-bedded, peloid packstone/grainstone. Thoroughly bioturbated fabric. Robust (5 X 50 mm) vertical and U-shaped burrows are predominant. Peloids grade into intraclasts in respect to size. Usually abraded pelmatozoan elements are the most abundant fossil. Sponge spicules are common. Ostracodes and trilobites are subequal in abundance - both exhibit little breakage or abrasion. Samples. L3C-33, 201.75; L3C-34, 202.10; L3C-35, 202.20; L3C-36, 203.08.
47	2.00	206.58	Intercalated tan, cobbly weathered, medium-bedded mudstone; and gray, very thin to thin bedded, peloid grainstone. Peloid grainstones form the last 1.00 m of this unit. Mudstones possess both vertical and horizontal burrows. Monaxon sponge spicules are the only allochem. Grainstones are composed of moderately to well sorted, very fine-grained peloids; abraded echinoderm plates; and sometimes fragmented, unabraded, or lightly abraded trilobites and ostracode valves. Desiccation fenestrae are present in some beds. Samples. L3C-37A, 205.49; L3C-37, 205.63.
--	1.20	207.78	UNEXPOSED

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
48	?.60	209.38	Tan-gray and tan, cobbly weathered, thin to medium bedded, silty mudstone/wackestone. The entire rock is bioturbated with vertical mud- and spar-filled, 1 X 15 mm burrows. Allochems consequently have no preferred orientation. Trilobite spines and more numerous unabraded, unbroken, and sometimes articulated ostracodes are the only fossils. Samples. L3C-38, 207.78; L3C-39, 208.98.
--	1.05	210.43	UNEXPOSED
49	2.00	212.43	Tan, silty mudstone. Identical to unit 48.
50	2.90	215.33	Mottled; brown and gray, thin-bedded wackestone/packstone. Vertical burrows are more abundant than horizontal burrows. Allochems have no preferred orientation. Ostracodes are the most numerous fauna; they are sometimes articulated, sometimes broken, and usually unabraded. Unabraded trilobites and gastropods are also present. Tetradium occurs near the top of this unit. Hedstroemia increases in abundance concomitant with Tetradium. Abraded bryozoans and echinoderms are also present in significant numbers. Samples. L3C-40, 212.43; L3C-41, 212.53; L3C-42, 213.83.
--	1.10	216.43	UNEXPOSED
51	0.30	216.73	Greenish gray to gray, medium-bedded wackestone/packstone. This rock has a thoroughly bioturbated fabric; horizontal and vertical burrows are subequal in number. Allochems are randomly oriented. Peloids appear to be in situ and average 0.10 mm in apparent diameter. Trilobites, ostracodes, and Hedstroemia plates are unfragmented and unabraded. Bryozoans are somewhat common and are broken but not highly abraded. Echinoderms exhibit severe abrasion. Samples. L3C-43, 216.43.
52	1.05	217.78	Mottled, gray, thin-bedded wackestone. Similar to unit 50. Samples. L3C-44, 216.73; L3C-45, 217.28.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
53	0.44	218.22	Mottled, brown-gray, thin-bedded peloid packstone/grainstone. The bottom portion of this bed is composed of current-formed planar laminations which have been partially obliterated by burrowing. The upper part of the bed is also a grainstone but allochems have been rotated by burrowing. Most horizontally burrowed areas have been converted to packstone. Articulated brachiopods are the most abundant organism. Ostracodes, trilobites, and gastropods are common, and are unabraded and unfragmented. Intact Tetradium, and broken and abraded bryozoans are rare fauna. Samples. L3C-46, 218.18.
54	0.61	218.83	Gray, thin-bedded wackestone. Diffuse horizontal burrows are ubiquitous. As a result, allochems exhibit no preferred orientation. Unabraded Tetradium, ostracodes, and trilobites are present in subequal amounts. Articulated bivalves and gastropods are also common. Bryozoans and echinoderms are rare, and are broken and/or abraded. Samples. L3C-47, 218.63.
--	0.90	219.73	UNEXPOSED
55	0.45	220.18	Same as unit 53.
56	3.62	223.90	Mottled; light brown to gray or greenish gray; thin to medium bedded wackestone/packstone. This unit is thoroughly bioturbated; allochems are all rotated. Restricted-water fossils outnumber open-marine fossils. Ostracodes, trilobites, and bivalves display limited transportation affects. Tetradium and Hedstroemia are significant components. Bryozoans and echinoderms exhibit moderate to severe abrasion. Sponge spicules are also common. Samples. L3C-48, 221.68; L3C-49, 222.13; L3C-50, 222.28; L3C-51, 222.38; L3C-52A, 223.00; L3C-52B, 223.07; L3C-53, 223.30.
--	3.80	227.70	UNEXPOSED

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
57	0.80	228.50	Gray, thick-bedded, silty, unfossiliferous mudstone. Most beds are homogenous micrite. However, some beds are composed of alternate micrite layers with rare articulated ostracodes and quartz silt; and micrite layers with interlaminar and irregular fenestrae. Laminae range in thickness from 1 to 10 mm. Burrowing is rare; only sparse vertical burrows occur. Samples. L3C-54, 227.70.
58	1.45	229.95	Mottled, gray, medium-bedded, very fine-grained, peloid packstone. A hint of cross lamination is visible which has since been modified through horizontal burrowing. Rounded 0.05 mm peloids, unidentifiable fossil fragments, and macrofossils are contained within a mud matrix. Only restricted-water macrofossils occur. Ostracodes may or may not be articulated, but they are somewhat abraded. Solenopora clasts are also common, and may or may not exhibit abrasion. Rare, whole gastropods are also present. Samples. L3C-55, 228.50.
59	6.55	236.50	Mottled, brown and gray, thin to medium bedded mudstone/wackestone. Horizontal and vertical burrows are present; vertical burrows are greater in number. Allochems have no preferred orientation; however, some thin (2-3 mm), discontinuous, current-emplaced packstone layers occur. Open-marine fossils are outnumbered by restricted-water fossils. Ostracodes and bivalves are generally articulated or disarticulated, unfragmented, and unabraded. Trilobites display a full spectrum of abrasion and breakdage. Brachiopods are rare but are commonly articulated and display varying degrees of abrasion. Bryozoans and echinoderms are always fragmented and abraded. Gastropods are present in trace amounts. Samples. L3C-56, 229.95; L3C-57, 231.20; L3C-58, 232.70; L3C-59, 233.79; L3C-60, 235.80; L3C-61, 236.10.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
60	1.35	237.85	Gray, thin to medium bedded, medium sand to pebble sized grains, peloid-fossil packstone. Horizontal burrowing has created a packstone fabric. Thus current-induced, allochem preferred orientation has been destroyed; however, allochems near bed bottoms tend to maintain a preferred orientation. Peloids are rounded to subrounded and range from 0.25-0.50 mm in size. Open-marine fossils are more abundant than restricted-water fossils; open-marine forms exhibit more transportation affects. Samples. L3C-62, 237.75.
61	1.47	239.32	Gray, medium-bedded, very fine to very coarse-grained sand and pebble-sized grainstone. Scour surfaces are common. Grains are oriented into plane laminae. In decreasing abundance, grains include abraded and rounded echinoderms with well developed micrite envelopes; angular to rounded mudstone intraclasts; abraded Hedstroemia and Solenopora (Type P) algal clasts; rounded, very fine to fine grained peloids; and macrofossils. Restricted-water fossils are greater in abundance than open-marine fossils; all skeletons tend to be broken and abraded and display micrite envelopes. Hedstroemia-encrusted Tetradium corallites also occur. Samples. L3C-63, 239.20.
62	1.18	240.50	Gray, thin-bedded, very fine to very coarse grained packstone/grainstone. Current-produced deposits seem to have been modified by subsequent horizontal burrowing to produce allochems with random orientations. Rounded, 0.07-1.7 mm peloids are the dominant allochems. Echinoderms are plentiful, severely abraded, and often possess micrite envelopes. Hedstroemia plates are somewhat abraded. Samples. L3C-64, 239.32.
--	14.70	255.20	UNEXPOSED
63	6.35	261.55	Gray, thin to medium bedded, very fine to very coarse grained grainstone. Similar to unit 62. Samples. L3C-65, 256.45; L3C-66, 257.45.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
64	1.65	263.20	Intercalated dark brown, very thin-bedded mudstone with more common dark brown, very thin to medium bedded, very fine to very coarse grained and pebble-sized fossil grainstone. Grainstone-mudstone contacts are somewhat gradational while grainstone-grainstone and mudstone-grainstone contacts are erosive. Grainstones usually display planar laminae or current-oriented allochems; mudstone allochems have no preferred orientation due to horizontal burrowing. In decreasing importance, grainstones include rounded to subangular, very fine to fine grained peloids; silt-sized to very fine grained unidentifiable fossil debris; abraded echinoderm plates and columnals; generally unabraded foliate bryozoans with mud-filled zooecia; unbroken and unabraded brachiopods; fragmented but unabraded ostracode valves; rounded, 8 mm wackestone intraclasts; whole gastropods; and rare, abraded algal clasts, articulated clams, unabraded trilobites, and Tetradium. Samples. L3C 67, 261.55.
--	11.85	275.05	UNEXPOSED
65	0.80	275.85	Brown peloid-fossil grainstone. Same as units 61 and 64. Samples. L3C-68, 275.60; L3C-69, 275.79.
66	0.60	276.45	Brown peloid packstone. Similar to unit 62. Samples. L3C-70, 275.85.
67	5.76	282.21	Brown peloid grainstone. Restricted-water fossils are greater in abundance than open-marine fossils. Similar or identical to units 61 and 65. Samples. L3C-71, 276.45; L3C-72, 277.45; L3C-73, 278.50; L3C-74, 280.17; L3C-75, 281.37; L3C-76, 282.17.
68	0.25	282.46	Brown, medium-bedded, very fine grained to pebble-sized peloid-fossil grainstone. Open marine forms are greater in abundance than restricted-water forms. Similar to unit 67. Samples. L3C-77, 282.36.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
69	1.38	283.84	Brown, medium-bedded, very fine-grained to pebble-sized peloid-fossil grainstone. Similar to units 61, 65, and 67. Samples. L3C-78, 283.47.
70	1.55	285.39	Brown, medium-bedded, very fine to very coarse-grained peloid-fossil grainstone. Similar to units 67 and 68. Samples. L3C-79, 284.47.
71	1.38	286.77	Brown, thin to medium bedded, very fine to medium grained peloid-fossil grainstone. Similar to units 61, 65, 67, and 69. Samples. L3C-80, 288.12.
--	8.45	295.22	UNEXPOSED
72	1.45	296.67	Brown, thin to medium bedded, very fine-grained to pebble-sized grainstone. Similar to units 61, 65, 67, 69, and 71. Samples. L3C-81, 297.12.
--	61.90	358.57	UNEXPOSED
73	0.20	358.77	Mottled, gray, medium-bedded wackestone/packstone. Long, continuous, interlaminar desiccation fenestrae are present at the bottom of the bed. Horizontal burrows are common and burrowing activity has rotated allochems. Restricted-water fossils are more common than open-marine fossils and display less transportation affects. Fossils include articulated and disarticulated, unbroken, and unabraded ostracodes; large (6 mm), unbroken and broken Tetradium corallites; fragmented but unabraded bryozoans; and abraded echinoderms. Samples. L3D-1, 358.57.
74	0.22	358.99	Gray, thin to medium bedded wackestone/packstone. A striking moldic fabric is present. Pellet-filled horizontal burrows are common; allochems are rotated. Restricted-water fossils outnumber open-marine fossils. Open-marine forms - bryozoans, brachiopods, and echinoderms - exhibit fragmentation and abrasion. Ostracodes, trilobites, gastropods, and clams may be fragmented but

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			they are generally unabraded. Hedstroemia and Tetradium are also present in trace amounts. Samples. L3D-2, 358.77; L3D-3, 358.92.
75	0.45	359.44	Mottled, brown and gray, thin-bedded mudstone. Diffuse horizontal burrows are pellet-filled and comprise at least 50% of the rock volume. As a consequence, allochems have no preferred orientation. Ostracodes and trilobites are common, unbroken and unabraded. Brachiopods are rare but are articulated, unfragmented, and unabraded. Rare echinoderm columnals are severely abraded. Samples. L3D-4, 358.99.
76	3.90	363.34	Brown, thin to medium bedded, very fine-grained to pebble-sized peloid-fossil grainstone. Lenses of mudstone/wackestone also occur. Generally the fabric is churned, however, some relict current-emplaced and oriented allochems are present. Peloids are subangular to rounded, very fine to medium grained, and moderately to well sorted. Ostracodes, trilobites, bivalves, and gastropods are more abundant than open-marine forms such as bryozoans and echinoderms. Most allochems are abraded, although fragmentation and abrasion is severe in restricted-water fossils. Large (9.0 mm) Tetradium corallites are common as are Hedstroemia plates and Solenopora (Type R). Samples. L3D-5, 359.99; L3D-6A, 362.14; L3D-6B, 362.79.
77	1.95	365.29	Mottled; gray, black, and red; fine to medium bedded mudstone. Burrow mottling is conspicuous; spar-filled, 3-5 X 45 mm vertical burrows are much more abundant than horizontal burrows. Fossils are sparse. Ostracodes and trilobites may be articulated or disarticulated; they are never fragmented or abraded. Rare Tetradium, and heavily abraded bryozoans also occur. Samples. L3D-7, 365.19.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
--	0.80	366.09	UNEXPOSED
78	5.20	371.29	Brown, medium-bedded, very fine-grained to pebble-sized, peloid-fossil grainstone/ packstone. Black chert nodules and beds up to 3 cm thick are prominent. Scour surfaces are common. Some samples display current-generated planar laminae of peloids and fossils; other samples have a fabric which has been modified by horizontal burrowing. Burrowing has also converted grainstone areas into packstone. Peloids are generally well sorted and range in size from 0.05-0.30 mm. All fossil allochems are somewhat abraded, however restricted-water fossils display less fragmentation and greater numbers than do open-marine fossils. Fossils include ostracodes, Tetradium, gastropods, echinoderms, bryozoans, bivalves, trilobites, and Hedstroemia and Solenopora algae in decreasing abundance. Samples. L3D-8A, 366.84; L3B-8B, 367.44; L3D-8C, 369.74; L3D-8D, 369.89; L3D-8E, 370.69.
79	1.75	373.04	Brown, thin to medium bedded, laminated, peloid mudstone/packstone. Laminae are 1-5 mm thick and alternate between mud-rich peloid packstone and peloid grainstone laminae. Burrowing has often destroyed or cross-cuts lamination. Horizontal and vertical burrows occur; vertical burrows become more numerous upsection as do desiccation fenestrae. Fossils are rare but include unbroken and unabraded ostracode valves; fragmented but unabraded trilobites; Tetradium fragments; and articulated, unabraded, and unfragmented brachiopod; and broken and abraded bryozoans. Samples. L3D-8F, 371.29; L3D-9, 371.14.
80	4.20	377.24	Gray, thin to medium bedded, very fine-grained to pebble-sized, peloid-fossil grainstone. Allochems may be oriented in plane and cross laminae or rotated by burrowing. Horizontal burrows are more common than vertical burrows. Peloids are rounded, equant to subequant, and gradational in size with mudstone/wackestone intraclasts.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			Tetradium corals are dominant in the middle portion of this unit, either as 5-30 cm diameter hemispherical heads or as debris. Restricted-water organisms are generally more abundant than open-marine forms. Fossils include articulated, sometimes fragmented and sometimes abraded ostracodes; heavily abraded echinoderms; abraded and sometimes fragmented bryozoans; broken and at times abraded trilobites; small, articulated and larger bivalves with micrite envelopes; and rare, brachiopods, Hedstroemia, and gastropods. Samples. L3D-10A, 374.09; L3D-10B, 375.39; L3D-10C, 375.89; L3D-10D, 382.09.
81	1.05	378.29	Mottled, brown, thin-bedded mudstone. Wackestone lenses also occur. Horizontal burrowing is ubiquitous; as a result, allochems display no preferred orientation. Ostracodes and bivalves occur as articulated individuals, or as valves which are unbroken and unabraded. Unfragmented Tetradium corallites and gastropods are also present. Samples. L3D-10E, 377.24.
82	1.65	379.94	Intercalated thin-bedded, very fine to very coarse grained peloid packstones/grainstones and wackestones. Abundant horizontal and rare vertical (8 X 45 mm) burrows are present. Allochems tend to possess no preferred orientation in packstones but grainstones display plane laminae. Open-marine fossils - brachiopods, bryozoans and echinoderms - are abraded, with or without fragmentation. Restricted-water fossils - ostracodes, trilobites, and bivalves - are unbroken, unabraded, and sometimes articulated. Hedstroemia clasts are abraded. Samples. L3D-11A, 379.69; L3D-11B, 379.79.
83	1.10	381.04	Gray, cobbly-weathered packstone.
84	1.40	382.44	Brown, thin-bedded, very fine-grained to pebble-sized, poorly sorted, fossil grainstone. Abundant Tetradium corallites impart a moldic fabric. Ostracodes and trilobites are common, unfragmented, and unabraded.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			Rare biota include abraded bryozoans, abraded or unabraded brachiopod valves, abraded Hedstroemia, and gastropods. Samples. L3D-13A, 381.04.
85	0.85	383.29	Brown, thin-bedded wackestone. Contacts with the stratigraphically lower packstones/ grainstones can be either scour surfaces, ommission surfaces (hardgrounds?), or both. Wackestones display prominent horizontal burrows. Ostracodes range from 0.12-0.40 mm in size, are never abraded, and are sometimes fragmented. Heavily abraded echinoderm elements also occur. Samples. L3D-13B, 382.44.
86	0.06	383.35	Brown, thin-bedded, very fine-grained to pebble-sized, poorly sorted fossil-intraclast grainstone. Intraclasts are usually elongate, rounded, 0.40-5.0 mm in size wackestones and peloid grainstones. Open-marine forms are more abundant than restricted-water forms. All organisms appear transported but ostracodes and trilobites exhibit the least abrasion. In decreasing abundance, fossils include echinoderms, trilobites, bryozoans, brachiopods, ostracodes, gastropods, bivalves, and cephalopods. Samples. L3D-13C, 383.29.
87	0.04	383.39	Brown, thin-bedded mudstone. Vertical burrows are greater in number than horizontal burrows. Detrital quartz, unabraded ostracodes, perfectly preserved Tetradium, and heavily fragmented and abraded bryozoans are present in decreasing abundance. Samples. L3D-14, 383.35.
88	0.05	383.44	Brown, thin-bedded, very fine-grained to pebble-sized, moderately sorted, peloid-fossil grainstone. Rounded, ellipsoidal, fine-grained, well sorted peloids are the principal allochem. Restricted-water organisms are lower in abundance than open-marine forms. Bivalves with micrite envelopes, and brachiopod fragments are the most common organisms. Ancillary fauna include broken but unabraded ostracodes and trilobites;

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			severely abraded echinoderms; and whole gastropods. Samples. L3D-15, 383.39.
89	0.30	383.74	Gray, thin-bedded mudstone. Prominent vertical burrows (3-5 mm diameter) extend from bed bases to tops. Sparse fossils include monaxon sponge spicules, fragmented and abraded bryozoans, severely abraded echinoderms, and articulated ostracodes which are unbroken and unabraded. Samples. L3D-16, 383.44.
--	1.25	384.99	UNEXPOSED
90	1.40	386.39	Brown, cobbly weathered, thin to medium bedded mudstone/wackestone. Prevalent horizontal and vertical burrows are subequal in abundance. As a result, allochems have no preferred orientation. Some bed surfaces have 1-2 cm rugose coral colonies. Acicular, 0.05 mm unidentifiable fossil fragments are ubiquitous. Macrofossils are sparse but include articulated, unbroken, and unabraded ostracodes; abraded foliate bryozoans; and articulated brachiopods with abraded valves. Samples. L3D-17, 386.19.
91	4.38	390.77	Brown, thin to medium bedded, very fine-grained to pebble-fossil grainstone. Burrows, if present, are horizontal. This unit displays both current-oriented allochems in planar and cross laminae, and bioturbated peloid packstone/grainstones with no current lamination. Scour surfaces are common. Bed surfaces commonly display rugose corals and strophomenid brachiopods. Peloids are very fine-grained and generally well sorted. Fossil wackestone and packstone intraclasts range in size from 0.5-17.0 mm. They are generally elongate to equant, and rounded. Open-marine fossils are greater in abundance than restricted-water fossils. All fossil allochems exhibit fragmentation and abrasion. In decreasing abundance fossils include echinoderms, bryozoans, brachiopods, bivalves, gastropods, ostracodes, and trilobites.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			Samples. L3D-18, 386.74; L3D-19, 387.09; L3D-20, 388.84.
92	0.07	39.84	Brown, thin-bedded wackestone. Horizontal burrows are present; allochems are therefore rotated. Detrital quartz, unidentifiable fossil fragments, and unabraded ostracode valves are the main allochems. Subsidiary abraded echinoderms occur. Sample. L3D-21, 390.77.
--	14.45	40.29	UNEXPOSED
93	1.90	40.19	Brown, thin to medium bedded wackestone. Common horizontal burrows and auxiliary vertical burrows are randomly oriented. Bed surfaces exhibit approximately 2 cm strophomenid brachiopods and gastropods. Bed interiors generally possess little fauna. Articulated bivalves, unfragmented and unabraded ostracodes, abraded brachiopods, and thoroughly abraded echinoderms are among these fossils. Samples. L3D-22, 405.54; L3D-23, 406.04; L3D-24, 407.94; L3D-24A, 407.04.
94	1.10	408.29	Brown, thin to medium bedded, very fine-grained to pebble-sized, poorly sorted, peloid and fossil grainstone. Allochems possess no current orientation but burrows are absent. Bed surfaces display 1-2 cm diameter ramose bryozoans, brachiopods, and gastropods. Restricted-water and open-marine forms are generally subequal in abundance; both faunal groups exhibit fragmentation and abrasion. Fossils include ostracodes, trilobites, bryozoans, brachiopods, gastropods, echinoderms, Tetradium, and Hedstroemia plates. Samples. L3D-25, 407.19; L3D-25A, 407.34; L3D-26, 407.64.
--	0.70	408.99	UNEXPOSED
95	0.35	409.34	Brown, thin-bedded mudstone. Similar to unit 93. Samples. L3D-27, 409.99.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
96	0.15	409.49	Brown, medium-bedded, fossiliferous packstone. Black, 1.5 cm thick chert nodules are present. Gastropods on bed surfaces are large as 3 cm. Fossils display no preferred orientation. Subequal amounts of restricted-water and open-marine organisms occur; both groups exhibit fragmentation and abrasion. Bivalves and gastropods are co-dominant with bryozoans; brachiopods, ostracodes, trilobites, and echinoderms occur as subsidiary fauna. Samples. L3D-28, 409.34.
97	0.25	409.74	Brown, thin-bedded, cherty mudstone. Similar to units 93 and 95. Vertical burrows are more abundant than horizontal burrows. Wackestone/packstone lenses occur. Samples. L3D-29, 409.49; L3D-29A, 409.49; L3D-30, 409.64.
98	0.10	409.84	Brown, medium-bedded, moderately to well sorted, cherty, peloid-fossil grainstone. Generally similar to unit 94. Well developed current planar laminae and fining-upward sequences occur within this bed. The lower surface of this bed is ripple-marked. Samples. L3D-31, 409.74.
99	1.70	411.54	Brown, thin-bedded mudstone. Similar to units 93, 95, and 97. Samples. L3D-32, 409.84; L3D-33, 410.39; L3D-34, 410.84.
100	0.12	411.66	Brown, current-laminated, peloid grainstone. Identical to unit 98.
101	0.07	411.73	Brown, thin-bedded, very fine-grained to pebble-sized, poorly sorted, peloid and fossil grainstone. Very similar to units 94 and 98. Poorly developed fining-upwards sequences occur. Samples. L3D-35, 411.66.
102	1.61	413.34	Brown thin-bedded, cobbly weathered mudstone. Identical to units 93, 95, and 97. Samples. L3D-36, 412.67; L3D-37, 412.91; L3D-91, 412.99.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
103	1.35	414.69	Brown, thin to medium bedded, peloid-fossil grainstone. Similar to units 94, 98, and 101. Samples. L3D-39, 413.34; L3D-40, 414.59.
104	4.45	419.14	Brown, thin-bedded, cobbly weathered mudstone. Identical to units 93, 95, 97, and 102. Samples. L3D-41, 414.69.
105.	0.50	419.64	Brown, thin to medium bedded, peloid-fossil grainstone. Similar to units 94, 98, 101, and 103. Samples. L3D-42, 419.14.
106	0.85	420.49	Brown, thin to medium bedded, cobbly weathered mudstone. Similar to units 93, 95, 97, 102, and 104. Samples. L3D-43, 419.64; L3D-44, 420.34; L3D-45, 420.44.
107	3.50	423.99	Brown, thin to medium bedded, very fine-grained to pebble-grained to pebble-sized, poorly sorted peloid-fossil grainstone. Similar to units 94, 98, 101, 103, and 105. Samples. L3D-46, 420.49; L3D-47, 420.54; L3D-48, 420.94; L3D-49, 423.19; L3D-49A, 423.98.
108	0.07	424.06	Chert zone below T3 bentonite.
109	0.40	424.46	Well-exposed T3 bentonite layer. Equivalent to unit 21 in Clinton railroad section.
110	1.45	425.91	Tan, thin-bedded, medium-grained to pebble-sized, fossil packstone/grainstone. Somewhat chertified due to proximity of bentonites. Very thin beds of laminated peloids also occur intercalated with packstone units. Vertical burrows are ubiquitous and occur as 2-3 mm diameter, spar-filled tubules. Samples. L3D-49B, 425.46.
111	7.75	433.66	Tan, thin to medium bedded, silty, abiotic mudstones with sporadic lenses of intraclast grainstone. Mudstones are thoroughly bioturbated displaying prominent vertical and less numerous horizontal burrows.

UNIT	UNIT THK(m)	CUML. THK(m)	DESCRIPTION
			Desiccation fenestrae are ubiquitous. Mud-cracks with 5 cm polygons occur in various beds throughout the unit. Intraclasts within intraclast grainstones are rounded, both equant but dominantly elongate, and up to 3.0 cm in length. All intraclasts were derived from fenestrate, laminated mud-stones. Samples. L3D-49C, 425.91; L3D-49D, 426.11; L3D-49E, 426.56; L3D-49F, 430.91; L3D-49G, 433.56.
112	0.60	434.26	Very poorly exposed T4 bentonite. Equivalent to unit 23 of Clinton Railroad section.
---	2.80	437.06	UNEXPOSED
113	0.33	437.39	Tan, silty, thin to medium bedded mudstone/ wackestone. Distinct burrows are ubiquitous; horizontal burrows are more numerous than vertical burrows. Allochems are randomly oriented. Restricted-water fossils greatly outnumber open-marine fossils. In decreasing abundance, fossils include usually unfragmented and unabraded trilobites and ostracode valves; severely abraded echinoderm elements; and abraded, sometimes fragmented bryozoans. Samples. L3D-50, 437.16.
---	4.22	441.61	UNEXPOSED
114	10.35	451.96	Gray, thin to medium bedded; very fine-grained to pebble-sized, peloid and fossil grainstone. Scour surfaces are commonplace. Many beds exhibit planar and cross laminae 3-15 cm thick. Some fining-upward sequences are also present. All fossils are abraded and fragmented to some degree. Open-marine fossils are much more abundant than restricted-water fossils. Organisms include, in decreasing abundance, bivalves, brachiopods, echinoderms, trilobites, ostracodes, bryozoans, and rare Hedstroemia plates. Samples. L3D-51, 441.61; L3D-52, 442.26; L3D-53, 442.41; L3D-54, 442.56; L3D-55, 442.71; L3D-56, 446.36; L3D-57, 447.36; L3D-58, 4 9.86; L3D-59, 451.46.

APPENDIX B

MEASURED SECTION FIELD UNITS

Unit numbers have been painted onto study outcrops. This should enable any future workers to use the Clinch River section for their study and fit their data into the author's stratigraphic and depositional environment framework. However, the numbers on the outcrops do not correspond to the units listed in Appendix A. Outcrop numbers refer to field unit numbers. The following table relates sample numbers to field unit numbers.

FIELD UNIT	UNIT THK(M)	CULM. THK(M)	SAMPLES
1	0.50	0.50	L3B-1
2	0.33	0.83	NONE
3	0.50	1.33	L3B-2
4	0.33	1.66	NONE
5	0.34	2.00	NONE
6	0.20	2.20	L3B-3
7	0.60	2.80	L3B-5
8	0.37	3.17	L3B-4
9	0.45	3.62	NONE
10	0.45	4.07	NONE
--	1.25	5.32	UNEXPOSED
11	0.17	5.49	NONE
--	2.25	7.74	UNEXPOSED
12	0.07	7.81	NONE
13	0.17	7.98	NONE
14	0.20	8.18	NONE
15	0.10	8.28	L3B-6
--	1.35	9.63	UNEXPOSED
16	0.21	9.84	L3B-6
17	0.22	10.06	NONE
--	0.25	10.31	UNEXPOSED
18	0.30	10.61	NONE
19	0.25	10.86	NONE
20	0.23	11.09	L3B-8
--	1.35	12.44	UNEXPOSED
21	0.35	12.79	NONE
--	0.60	13.39	UNEXPOSED
22	0.25	13.64	L3B-9
23	0.13	13.77	L3B-10
24	0.12	13.89	NONE
25	0.15	14.04	NONE
--	0.31	14.35	UNEXPOSED
26	0.20	14.55	NONE
27	0.20	14.75	NONE
28	0.15	14.90	NONE
--	0.55	15.45	UNEXPOSED
29	0.20	15.65	NONE
--	0.35	16.00	UNEXPOSED
30	0.10	16.10	NONE
31	0.20	16.30	NONE
32	0.15	16.45	NONE
--	1.00	17.45	UNEXPOSED
33	0.20	17.65	L3B-11
34	0.25	17.90	L3B-12
--	11.50	29.40	UNEXPOSED
35-46	7.10	36.50	L3B-13,14,15,16
47	0.20	36.70	L3B-17
--	1.20	37.90	UNEXPOSED

FIELD UNIT	UNIT THK(M)	CULM. THK(M)	SAMPLES
48	0.30	38.20	NONE
49	0.35	38.55	L3B-18
50	0.15	38.70	L3B-19
--	6.00	44.70	UNEXPOSED
51	0.15	44.85	NONE
--	0.55	45.40	UNEXPOSED
52-55	0.35	45.75	L3B-20
--	0.15	45.90	UNEXPOSED
56	0.05	45.95	L3B-21
--	3.25	49.20	UNEXPOSED
57	0.17	49.37	L3B-22
--	1.30	50.67	UNEXPOSED
58	0.07	50.74	L3B-23
--	1.40	52.14	UNEXPOSED
59	0.40	52.54	L3B-24
--	7.30	59.84	UNEXPOSED
60	1.75	61.59	L3B-25,26,27
--	1.05	62.64	UNEXPOSED
61	1.50	64.14	L3B-28,29,30
62	0.50	64.64	NONE
63	1.15	65.79	L3B-31
--	0.85	66.64	UNEXPOSED
64	2.15	68.79	L3B-32
65	2.10	70.89	L3B-33
66	1.20	72.09	L3B-34
67	0.35	72.44	L3B-35
68	2.25	74.69	L3B-36
69	0.30	74.99	L3B-37
--	0.50	65.49	UNEXPOSED
70	0.40	65.89	L3B-38
--	0.60	76.49	UNEXPOSED
71	0.30	76.79	L3B-39
72	1.00	77.79	L3B-40,40B
--	1.95	79.74	UNEXPOSED
73	1.10	80.84	NONE
74	0.10	80.94	L3B-41
--	0.45	81.39	UNEXPOSED
75	0.07	81.46	L3B-42A
76	0.50	81.96	L3B-42B
--	1.55	83.51	UNEXPOSED
77	0.05	83.56	L3B-43
--	1.40	84.96	UNEXPOSED
78	0.60	85.56	L3B-44
79	0.45	86.01	L3B-44B
--	4.30	90.31	UNEXPOSED
80-81	0.70	31.01	L3B-45
--	1.95	92.96	UNEXPOSED
82	0.85	93.81	L3B-46
--	1.05	94.86	UNEXPOSED
83	0.20	95.06	L3B-47

FIELD UNIT	UNIT THK(M)	CULM. THK(M)	SAMPLES
--	0.95	96.01	UNEXPOSED
84	4.20	100.21	L3B-48,49
85	1.50	101.71	L3B-50,51
		L3C	
A	0.40	------	L3C-A
1	0.35	102.06	L3C-1
2	0.65	102.71	L3C-2
3	0.80	103.51	NONE
4	0.85	104.36	L3C-3
5	0.15	104.51	L3C-4
6	0.92	105.43	NONE
7	2.60	108.03	L3C-5,5B
8	10.50	118.53	L3C-6,7,8
9	3.30	121.83	L3C-9,10
10	0.50	122.33	L3C-11A
11	3.50	125.83	L3C-11B,12
--	1.80	127.63	UNEXPOSED
12	2.20	129.83	L3C-13
--	6.70	136.53	UNEXPOSED
13	6.40	142.93	L3C-14
14	0.60	143.53	L3C-15
15	5.10	148.62	L3C-16
--	3.00	151.63	UNEXPOSED
15	1.30	152.93	NONE
--	1.30	154.23	UNEXPOSED
16	0.50	154.731	L3C-17
--	1.50	156.23	UNEXPOSED
17	2.80	159.03	L3C-18,19,19B
--	1.10	160.13	UNEXPOSED
19	0.60	160.72	L3C-20A,20B
20	0.50	161.23	L3C-21
--	1.95	163.18	UNEXPOSED
21	2.10	165.28	L3C-22,23
--	4.10	169.38	UNEXPOSED
22	1.20	170.58	L3C-24
23	2.20	172.78	NONE
24	0.20	172.98	NONE
--	5.30	178.28	UNEXPOSED
25	4.17	182.45	L3C-25,25B,25C
26	1.25	183.70	L3C-26
27	7.00	191.60	L3C-27A,27B,27C,27D
28	0.50	192.10	L3C-28
29	7.35	199.45	L3C-29,30,31
30	2.30	201.75	L3C-32
31	0.35	202.10	L3C-33
32	0.10	202.20	L3C-34
33	0.03	202.23	L3C-35

FIELD UNIT	UNIT THK(M)	CULM. THK(M)	SAMPLES
34	2.35	204.58	L3C 36
35	2.00	206.58	L3C-37A,37B
--	1.20	207.78	UNEXPOSED
36	0.90	208.68	L3C-38
--	0.30	208.98	UNEXPOSED
37	0.40	209.38	L3C-39
--	1.05	210.43	UNEXPOSED
38	2.00	212.43	NONE
39	0.10	212.53	L3C-40
40	1.10	213.63	L3C-41
41	1.30	214.93	L3C-42
42	0.40	215.33	NONE
--	1.10	216.43	UNEXPOSED
43	0.30	216.73	L3C-43
44	0.55	217.28	L3C-44
45	0.50	217.78	L3C-45
46	1.05	218.83	L3C-46,47
--	0.90	219.73	UNEXPOSED
47	0.45	220.18	NONE
48	1.85	222.03	L3C-48
49	0.10	222.13	NONE
50	0.15	222.28	L3C-49
51	0.10	222.38	L3C-50
52	0.12	222.50	L3C-51
53	0.80	223.30	L3C-52A,52B
54	0.60	223.90	L C-53
--	3.80	227.70	UNEXPOSED
55	0.80	228.50	L3C-54
56	1.45	229.95	L3C-55
57	1.25	231.20	L3C-56
58	1.50	232.70	L3C-57
59	1.00	233.70	L3C-58
60	2.10	235.80	L3C-59
61	0.30	236.10	L3C-60
62	0.40	236.50	L3C-61
63	4.00	240.50	L3C-62,63,64
--	14.70	255.20	UNEXPOSED
64	8.00	263.20	L3C-65,66,67
--	11.85	275.05	UNEXPOSED
65	0.80	275.85	L3C-68,69
66	0.60	276.45	L3C-70
67	2.05	278.50	L3C-71,72
68	0.07	278.57	L3C-73
--	1.40	279.97	UNEXPOSED
68	6.80	286.77	L3C-74,75,76,77,78,79,80
69	1.45	296.67	L3C-81
--	61.90	258.57	UNEXPOSED

FIELD UNIT	UNIT THK(M)	CULM. THK(M)	SAMPLES
		L3D	
1	0.20	358.77	L3D-1
2	0.15	358.92	L3D-2
3	0.07	358.99	L3D-3
4	0.45	359.44	L3D-4
5	0.80	360.24	L3D-5
--	1.90	362.14	UNEXPOSED
6	1.20	363.34	L3D-6A,6B
7	1.95	365.29	L3D-7
--	0.80	366.09	UNEXPOSED
8	6.05	372.14	L3D-8A,*B,8C,8D,8E,8F
9	0.90	373.04	L3D-9
10	5.25	378.29	L3D-10A,10B,10C,10D,10E
11	1.65	279.94	L3D-11A,11B
12	1.10	381.04	NONE
13	3.70	384.74	L3D-13A,13B,13C,14,15,16
--	1.25	385.99	UNEXPOSED
14	1.40	387.39	L3D-17
15	4.45	391.84	L D-18,19,20,21
--	14.45	406.29	UNEXPOSED
16	0.75	407.04	L3D-22
17	0.25	407.29	L3D-23
18	0.90	408.19	L3D-24,24A
19	0.45	408.64	L3D-25,25A,26
20	0.65	409.29	L3D-26
--	0.70	409.99	UNEXPOSED
21	0.35	410.34	L3D-27
22	0.15	410.49	L3D-28
23	0.15	410.64	L3D-29
24	0.10	410.74	L3D-30
25	0.10	410.84	L3D-31
26	0.95	411.79	L3D-32,33
27	0.75	412.54	L3D-34
28	0.12	412.66	NONE
29	1.33	413.99	L3D-35,36,37
30	0.10	414.09	L3D-38
31	0.25	414.34	NONE
32	0.55	414.89	L3D-39
33	10.10	424.99	L3D-40,41,42,43,44,45,46,47, 48,49,49A
34	0.07	425.06	NONE
35	0.40	425.46	NONE
36	9.20	434.66	L3D-49B,49C,49D,49E,49F,49G
37	0.60	435.26	NONE
--	2.80	438.07	UNEXPOSED
38	0.33	438.40	L3D-50
--	4.22	442.62	UNEXPOSED
39	10.35	452.97	L3D-51,52,53,54,55,56,57,58, 59

APPENDIX C

LITHOLOGY SAMPLE DESIGNATIONS

Samples are listed by lithology below (see Table 1, p. 29). Samples that have been point-counted are marked with an asterisk (*).

LITHOLOGY 1

L1B - B1(top)
B2
C1 *
C2
D1
3
6
8
10
12

L3B - 3
13 *
17
18 *
20
25
26 *
27
30
32 *
33
36

L3B - 37 *
38
40B
41
46
27
L3C - 28
33
34
35
37A
38
39

LITHOLOGY 2

L1B - A *
B1(bottom)
D2
D3
5D

L3B - 21 *
23
34
35 *
39

L3C - 14
25A
30

LITHOLOGY 3

L1B - 5
5C

L3B - 22
23
28
29 *

L3C - 31

L3D - 49F

LITHOLOGY 4

L3B - 1
4 *
5
6

L3B 7
8
9
10

L3B - 11
12 *
14
15 *
24

LITHOLOGY 5

L3B - 31
42A
42B
44
44B
49
50
51
52

L3C - A *
1 *
2 *
3 *
4 *
5 *
11B *
12 *
43 *

L3C - 47 *
49 *
50 *
51 *
52A
52B *
53 *

LITHOLOGY 6

L3B - 40
48

L3C - 6 *
7 *
9
13
15(bottom)
16

L3C - 18
19A
21
25B
25C
29
32
40 *
41 *

L3C - 42 *
44 *
45 *
48 *
56 *
57
58
59
61

LITHOLOGY 7

L3C - 7A *

L3C - 9 *

L3C - 10 *

L3C - 11A *

L3D - 9 *

LITHOLOGY 8

L3C - 26 *
27A

L3C - 27B
27C *

L3C - 27D

LITHOLOGY 9

L3C - 62 *
63
64
65
66
67

L3C - 69 *
70 *
71
72 *
76
77 *

L3C - 78
79
80
81 *

LITHOLOGY 10

L3D - 4
10E
11A *
13B
14
16
17
18

L3D - 21
22
23
24
27 *
29
29A
30
32

L3D - 33
36 *
37
38
41
43
44
45

LITHOLOGY 11

L3D - 11B
13C
15
19
20
25

L3D - 25A
26
31 *
35
39
40

L3D - 42 *
46
47 *
48
49
49A

LITHOLOGY 12

L3D - 2 *
3
5
6A
6B

L3D - 8A
8C *
8D
*E
10A

L3D - 10B *
10C *
10D
10E
13A

APPENDIX D

POINT COUNT DATA

A minimum of 300 points per slide was counted. The distance between any two points was larger than the grain size of most of the rock components (Van der plas and Tobi, 1965). However, in some rocks a volumetrically small portion of the rock is composed of grains significantly larger than most of the other components. A grid spacing based on Van der Plas and Tobi's criteria would be prohibitive due to the small size of a thin section. Therefore, it was considered best to ignore this grid spacing bias since only an approximation of the volume per cent of each component is necessary for this study.

The table below lists the per cent variation for various component percentages based on 300 point counts with a 95% confidence. For example, if ostracodes comprise 50% of the rock volume as determined by point counting, the true ostracode volume per cent actually lies between 44.3% and 55.7%, or 50 $\pm$ 5.7%.

% Constituent	$\pm$	Value (%)
1.5		1.0
10.0		3.6
50.0		5.7
90.0		3.6
98.5		1.0

Data after Van der Plas and Tobi (1965).

All the following tables list constituents by percent. Those elements seen in thin section but not point-counted were considered to be present in trace (TR) amounts.

LITHOLOGY 1 POINT COUNT DATA

	L1B-C1	L3B-13	L3B-18	L3B-26	L3B-32	L3B-37
Micrite	76.3	12.5	10.7	43.2	48.9	57.4
Spar	-	45.8	30.0	6.6	4.7	6.0
Intraclasts	-	-	TR	-	-	-
Peloids	-	27.4	49.0	30.0	33.4	24.3
Algae	-	TR	-	1.2	-	0.6
Sponge	-	-	-	TR	TR	-
Brachiopods	-	-	TR	-	TR	-
Bryozoans	3.2	-	-	4.7	-	3.0
Bivalves	-	0.7	-	-	-	TR
Gastropods	-	-	TR	-	-	TR
Mollusk debris	-	0.3	-	0.9	-	1.0
Echinoderms	0.3	8.9	5.0	0.3	TR	1.7
Ostracodes	0.3	0.3	-	TR	0.9	0.3
Trilobites	0.9	TR	TR	0.3	-	1.0
Unidentifiable fossil debris	4.4	0.3	-	2.8	4.4	0.7
Quartz	12.6	3.6	5.3	4.1	7.2	2.6
Stylocumulate	1.3	0.7	-	5.7	0.3	1.0

LITHOLOGY 2 POINT COUNT DATA

	L1B-A	L3B-21	L3B-35
Micrite	96.7	93.7	96.7
Spar	1.3	3.0	1.6
Sponge	-	-	TR
Ostracodes	-	-	0.6
Unidentifiable fossil debris	0.7	0.7	0.6
Quartz	-	2.3	-
Stylocumulate	1.3	0.3	0.3

LITHOLOGY 3 POINT COUNT DATA

	L3B-29
Micrite	93.0
Spar	6.3
Ostracodes	TR
Quartz	0.7

LITHOLOGY 4 POINT COUNT DATA

	L3B-4	L3B-15	L3B-12
Micrite	70.0	80.0	81.0
Spar	7.1	3.5	0.0
Brachiopod	-	TR	0.3
Bryozoan	TR	TR	0.6
Bivalve	3.6	2.5	3.3
Gastropod	2.4	6.7	1.5
Mollusk debris	0.6	1.3	0.0
Echinoderm	1.8	TR	4.5
Ostracode	4.4	4.1	1.8
Trilobite	2.4	0.3	1.5
Unidentifiable fossil debris	5.3	0.9	2.7
Quartz	2.4	0.6	0.0
Stylocumulate	0.0	0.0	2.7
Algae	0.0	0.0	TR

LITHOLOGY 5 POINT COUNT DATA

	L3C-A	L3C-1	L3C-2	L3C-3	L3C-4	L3C-5	L3C-11B	L3C-12
Micrite	64.8	69.7	91.8	73.0	70.6	77.4	82.1	76.3
Spar	7.6	2.0	2.7	2.9	4.2	0.3	-	13.3
Peloids	-	-	-	-	-	-	1.6	-
Algae	8.6	6.2	1.7	2.6	9.4	0.6	TR	TR
Sponge	-	2.6	-	-	TR	-	TR	-
Tetradium	8.0	15.0	1.7	11.7	8.9	7.5	7.9	4.2
Brachiopods	-	-	-	-	-	-	-	-
Bryozoans	-	-	-	-	0.3	-	-	-
Bivalves	TR	-	TR	-	-	-	-	TR
Gastropods	TR	TR	TR	0.3	1.2	-	-	-
Mollusk debris	-	-	-	-	-	-	-	-
Echinoderms	-	TR	TR	-	0.3	0.3	-	-
Ostracodes	1.0	TR	TR	0.3	TR	0.3	0.7	TR
Trilobites	-	-	0.7	-	0.3	-	TR	TR
Unidentifiable Fossil debris	-	1.6	-	1.0	-	2.3	TR	0.3
Stylocumulate	7.6	2.2	-	6.5	-	10.2	6.7	5.5
Quartz	-	-	0.3	-	1.8	-	1.0	-
Microspar	1.6	0.6	1.0	1.6	2.4	1.0	-	0.3

LITHOLOGY 5 POINT COUNT DATA (Continued)

	L3C-43	L3C-47	L3C-49	L3C-50
Micrite	67.5	33.7	76.8	73.3
Spar	18.8	9.8	11.5	11.4
Peloids	5.9	41.2	2.5	4.9
Algae	2.0	0.3	2.2	0.3
Sponge	TR	-	TR	-
Tetradium	-	8.5	-	-
Brachiopods	-	-	-	-
Bryozoans	TR	TR	-	-
Bivalves	-	0.3	-	TR
Gastropods	-	1.0	-	-
Mollusk debris	0.3	0.3	-	0.3
Echinoderms	-	TR	1.3	0.3
Ostracodes	0.3	TR	1.0	1.0
Trilobites	1.3	2.6	-	0.3
Unidentifiable fossil debris	2.0	2.3	4.1	5.2
Stylocumulate	0.7	-	0.3	1.3
Quartz	2.0	-	-	1.6
Microspar	-	-	0.3	-

LITHOLOGY 6 POINT COUNT DATA

	L3C-5	L3C-6	L3C-40	L3C-41	L3C-42	L3C-44	L3C-45	L3C-48
Micrite	82.3	86.1	91.1	57.1	89.8	94.5	96.4	82.7
Spar	5.6	3.0	7.9	22.7	2.2	2.6	1.6	6.2
Peloids	-	0.3	TR	2.0	0.3	0.3	0.3	3.2
Sponge	2.0	3.2	-	-	-	0.3	0.3	3.2
Algae	-	-	-	TR	TR	-	TR	-
Tetradium	TR	-	-	0.5	3.5	-	-	-
Brachiopods	-	-	-	-	TR	-	-	-
Bryozoans	-	TR	TR	0.5	TR	-	-	-
Bivalves	-	-	0.3	0.5	TR	-	-	-
Gastropods	-	TR	-	7.4	-	-	-	-
Mollusk debris	0	0.3	-	2.0	1.6	-	-	-
Echinoderms	-	-	TR	0.5	TR	TR	TR	TR
Ostracodes	-	0.3	0.7	0.5	1.0	0.3	TR	TR
Trilobites	-	TR	TR	1.5	0.3	0.3	TR	-
Unidentifiable fossil debris	3.6	0.7	-	1.0	1.0	1.3	1.0	4.2
Stylocumulate	4.9	1.7	-	3.4	-	-	-	-
Quartz	-	0.3	-	-	-	0.6	0.7	0.3
Microspar	1.3	4.0	-	0.5	-	-	-	-

LITHOLOGY 7 POINT COUNT DATA

	L3C-7A	L3C-9	L3C-10	L3C-11A	L3D-9
Micrite	40.0	93.1	33.0	37.5	33.3
Spar	27.7	2.2	38.7	31.0	31.0
Peloids	29.2	0.06	24.0	28.4	26.3
Bryozoans	-	-	-	-	TR
Echinoderms	-	TR	0.3	TR	-
Ostracodes	TR	0.09	TR	0.9	TR
Unidentifiable fossil fragments	1.8	1.6	-	0.9	-
Stylocumulate	1.3	1.6	1.3	-	9.3
Quartz	TR	TR	2.7	1.3	-

LITHOLOGY 8 POINT COUNT DATA

	L3C-26	L3C-27C
Micrite	3.5	0.6
Spar	72.9	59.7
Intraclasts	-	0.6
Peloids	1.9	20.1
Algae	TR	-
Brachiopods	1.6	0.3
Bryozoans	3.5	0.6
Mollusk debris	2.2	0.3
Echinoderms	12.6	15.6
Ostracodes	0.6	1.0
Trilobites	0.6	0.3
Unidentifiable fossil debris	0.3	0.6

LITHOLOGY 9 POINT COUNT DATA

	L3C-62	L3C-69	L3C-70	L3C-72	L3C-77	L3C-81
Micrite	24.4	0.3	6.0	-	1.6	1.6
Spar	15.3	40.7	51.7	54.2	32.3	46.0
Intraclasts	0.3	8.6	8.3	1.0	10.4	6.2
Peloids	20.9	24.7	32.7	36.6	28.5	14.0
Algae	0.6	-	-	-	-	TR
Tetradium	0.6	-	-	-	-	-
Bivalves	TR	-	-	-	TR	-
Gastropods	TR	-	-	-	7.3	TR
Mollusk debris	1.6	1.0	-	0.3	3.5	5.9
Echinoderms	3.4	11.5	1.3	5.6	5.7	9.6
Ostracodes	1.2	1.0	TR	0.3	0.3	2.2
Trilobites	1.2	0.3	-	TR	TR	0.9
Unidentifiable fossil material	0.3	2.6	TR	0.3	0.3	1.6
Stylocumulate	-	1.3	-	-	TR	-
Microspar	22.8	0.3	-	-	3.2	2.2
Brachiopods	4.4	5.8	-	1.0	4.4	5.6
Bryozoans	2.8	1.9	-	0.6	1.5	4.3

LITHOLOGY 10 POINT COUNT DATA

	L3D-11A	L3D-27	L3D-36
Micrite	8.7	88.9	80.6
Spar	1.7	1.1	1.6
Peloids	18.7	-	-
Sponge	-	-	1.3
Brachiopods	-	-	TR
Bryozoans	-	-	1.3
Bivalves	-	0.4	-
Mollusk debris	-	1.5	-
Echinoderms	TR	0.7	-
Ostracodes	TR	TR	TR
Trilobites	-	0.4	-
Unidentifiable fossil debris	TR	0.4	-
Quartz	TR	0.4	-
Stylocumulate	TR	5.7	10.0
Microspar	71.0	-	6.2

LITHOLOGY 11 POINT COUNT DATA

	L3D-31	L3D-42	L3D-47	L3D-49
Micrite	-	3.2	3.4	10.7
Spar	47.6	30.5	37.0	15.7
Intraclasts	-	3.5	3.1	2.8
Peloids	41.4	5.1	24.8	27.3
Algae	-	0.3	0.3	TR
Brachiopods	0.3	1.6	1.6	3.8
Bryozoans	TR	12.7	1.6	8.2
Bivalves	TR	-	TR	TR
Gastropods	-	TR	3.1	-
Cephalopods	-	-	3.1	-
Mollusk debris	1.6	2.5	5.6	5.7
Echinoderms	7.8	24.8	15.4	6.6
Ostracodes	1.0	TR	0.3	0.3
Trilobites	0.3	0.3	0.6	1.2
Unidentifiable fossil debris	-	-	TR	-
Quartz	-	-	TR	-
Stylocumulate	-	15.6	0.3	6.9
Microspar	-	-	-	10.7

LITHOLOGY 12 POINT COUNT DATA

	L3D-2	L3D-8C	L3B-10B-5	L3D-10C
Micrite	69.1	5.0	9.3	0.6
Spar	21.1	15.4	25.0	27.9
Intraclasts	-	-	0.3	0.9
Peloids	TR	38.6	20.2	48.2
Algae	TR	1.2	0.6	0.9
Tetradium	1.3	-	12.8	0.3
Brachiopods	0.6	TR	0.6	1.8
Bryozoans	1.3	2.4	6.4	0.9
Bivalves	0.3	0.9	TR	0.3
Gastropods	2.2	9.8	0.3	0.3
Mollusk debris	-	3.3	1.0	2.9
Echinoderms	0.6	4.4	7.0	4.5
Ostracodes	0.6	3.3	1.0	2.1
Trilobites	0.9	0.6	1.9	1.5
Serpulid worm	-	0.3	-	-
Unidentifiable fossil debris	1.9	2.7	1.6	1.8
Stylocumulate	-	0.6	6.0	0.3
Microspar	-	11.6	6.0	4.8

SECTION L2 POINT COUNT DATA

LITHOTYPE 1 POINT COUNT DATA

	H-113	H-277	H-278A	H-292
Micrite	84.5	79.0	86.2	84.1
Spar	-	3.9	2.2	3.2
Peloids	-	-	-	-
Algae	-	0.3	-	TR
Tetradium	12.9	11.3	7.5	7.9
Bivalves	-	TR	-	TR
Gastropods	-	2.2	-	-
Mollusk fragments	-	1.3	-	1.3
Brachiopods	-	-	-	0.6
Bryozoans	TR	-	-	-
Ostracodes	2.6	1.0	2.5	1.3
Trilobites	-	1.0	1.6	1.9
Serpulid(?) worms	-	-	-	-

LITHOTYPE 2 POINT COUNT DATA

	H-20	H-69	H-82B	H-216A	H-266
Micrite	89.1	93.9	92.9	85.2	87.1
Spar	2.5	0.6	2.9	4.8	-
Peloids	-	-	-	-	-
Algae	-	-	-	0.3	TR
Tetradium	-	-	-	-	-
Bivalve	-	-	-	TR	-
Gastropod	-	-	-	-	-
Echinoderm	-	-	-	TR	TR
Ostracodes	6.2	4.5	4.2	6.4	3.2
Trilobites	0.3	0.3	TR	3.2	0.6
Serpulid(?) worms	-	-	-	-	2.2
Unidentifiable fossil fragments	1.9	-	-	-	-
Quartz	TR	TR	-	TR	-

LITHOTYPE 3 POINT COUNT DATA

	H-126	H-148	H-149	H-262
Micrite	96.4	90.6	90.0	88.3
Spar	3.5	7.1	8.1	11.7
Peloids	-	1.6	1.2	-
Ostracodes	TR	0.6	0.6	-
Trilobites	TR	TR	-	-
Echinoderms	TR	-	-	-
Quartz	TR	TR	-	TR

APPENDIX E

L2 STRATIGRAPHIC SECTION DATA

Samples collected from stratigraphic section L2 are listed below from bottom to top. The thickness of the bed that a sample was collected from is tabulated along with the cumulative thickness in meters. Finally the lithotype designation for that sample appears to the far right (see Table 2, Chapter III). Bed thicknesses are listed to the nearest centimeter for convenience only; the author realizes that the measurements were not that precise.

Some beds have two lithotype numbers (2$\longrightarrow$7). This means that a lithotype was capped by a different lithotype within that sample. The arrow points to the stratigraphically higher layer.

Sample Number	Bed Thickness(m)	Cumulative Thickness(m)	Lithotype
1	0.15	0.15	5
2	0.05	0.20	5
3	0.065	0.265	2
4	0.045	0.31	2
5	0.035	0.345	2
NO SAMPLE	0.30	0.645	-
6	0.80	1.445	3
7	0.60	2.045	5
8	0.89	2.935	2
9	0.30	3.235	2
10	0.07	3.305	2
11	0.02	3.325	5
12	0.05	3.375	5
UNEXPOSED	0.05	3.425	-
13	0.09	3.515	5
14	0.60	4.115	2
15	1.10	5.215	2
16	0.06	5.275	3
17	0.03	5.305	2
18	0.05	5.355	1
NO SAMPLE	0.60	5.955	-
18A	0.08	6.035	2
19	0.06	6.095	7 → 2
20	0.035	6.13	2
21	0.025	6.155	2
NO SAMPLE	0.12	6.275	-
22	0.05	6.325	2
23	0.15	6.475	2
24	0.35	6.825	2
25	0.20	7.025	2
26	0.07	7.095	4 → 7
NO SAMPLE	0.08	7.175	-
28	0.09	7.265	2
29	0.05	7.315	2
30	0.09	7.405	3
31	0.075	7.48	2
32	0.07	7.55	4
33	0.10	7.65	2
34	0.06	7.71	4
35	0.18	7.89	2
UNEXPOSED	0.10	7.99	-
36	0.03	8.02	2
37	0.10	8.12	2
38	0.15	8.27	2
UNEXPOSED	0.25	8.52	-
39	0.05	8.57	4
40	0.07	8.64	2
41	0.07	8.71	2
42	0.05	8.76	2
UNEXPOSED	0.20	8.96	-

Sample Number	Bed Thickness(m)	Cumulative Thickness(m)	Lithotype
43	0.04	9.00	2
44	0.02	9.07	2
45	0.05	9.11	2
46	0.04	9.17	2
47	0.06	10.82	2
UNEXPOSED	1.65	11.72	-
48	0.90	13.72	7
UNEXPOSED	2.00	13.81	-
49	0.09	13.86	2
50	0.05	13.91	2
51	0.05	14.21	2
52	0.30	14.41	2
53	0.20	14.46	2
54A	0.05	14.57	2
54B	0.11	15.27	2
UNEXPOSED	0.70	15.32	-
55	0.05	15.395	2
56,57	0.075	15.465	2
58	0.07	15.535	2
59	0.07	15.595	2
60	0.06	15.655	2
61A	0.06	15.695	2
61B	0.04	16.045	2
62-69	0.35	16.175	2
70	0.13	16.575	2
71-74	0.40	16.875	2
75	0.30	16.905	2
76	0.03	16.975	2
77	0.07	17.035	2
78	0.06	17.235	2
79	0.20	17.315	2
80	0.08	17.385	2
81	0.07	17.435	2
82A	0.05	17.545	2
82B	0.11	17.645	2
83	0.10	17.705	2
84	0.06	17.795	2
85	0.09	17.855	2
86	0.06	17.955	4
87	0.10	18.055	4
88	0.10	18.105	3
89	0.05	18.225	6
90A	0.12	18.265	6
90B	0.04	18.325	2
92	0.06	18.395	2
92	0.07	18.455	2
93	0.06	18.505	2
94	0.05	18.555	5
95	0.05		

Sample Number	Bed Thickness(m)	Cumulative Thickness(m)	Lithotype
96	0.035	18.59	5
97	0.065	18.655	5
98A	0.20	18.855	5
98B	0.045	18.90	2
99	0.08	18.98	2
100	0.14	19.12	3
101,102	0.14	19.26	5
103	0.03	19.29	5→2
104	0.03	19.32	2
105	0.03	19.35	5
106	0.03	19.38	2
107	0.03	19.41	2
108	0.15	19.56	3
109	0.05	19.61	3
110	0.05	19.66	3
111	0.035	19.695	2
112	0.12	19.815	2
113	0.04	19.855	1
114	0.10	19.955	2
115	0.05	20.005	2
116	0.05	20.055	2
117-119	0.14	20.195	2→1
120	0.03	20.225	2
121	0.035	20.26	2
122,123	0.09	20.35	2
124,125	0.18	20.53	3→2
126	0.07	20.60	3
127	0.06	20.66	3
128	0.09	20.75	7
129	0.07	20.82	4
130	0.08	20.90	6
UNEXPOSED	0.20	21.10	-
131	0.07	21.17	6
132	0.08	21.25	6
133,134	0.11	21.36	4
135	0.12	21.48	6
136	0.02	21.50	3
137	0.05	21.55	3
138	0.20	21.75	3
139	0.05	21.80	3
140	0.035	21.835	4
141	0.035	21.87	4
142	0.035	21.905	4
143	0.065	21.97	4
144	0.07	22.04	4→3
145	0.08	22.12	3
146	0.10	22.22	3
147	0.09	22.31	3
148	0.06	22.37	3

Sample Number	Bed Thickness(m)	Cumulative Thickness(m)	Lithotype
149	0.15	22.52	3
150-153	0.40	22.92	6
154	0.07	22.99	3
155	0.06	23.05	7
156	0.09	23.14	2
NO SAMPLE	0.20	23.24	-
157	0.07	23.31	2
158	0.035	23.445	2
159,160	0.09	23.535	2
161	0.05	23.585	2
161B	0.06	23.645	7
162	0.04	23.685	2
163	0.05	23.735	2
164	0.05	23.785	2
165	0.04	23.825	2
166	0.12	23.945	6
167	0.04	23.985	6
168	0.03	24.015	6 → 7
169	0.02	24.035	7
170	0.02	24.055	4
171	0.03	24.085	6 → 7
172	0.05	24.135	6
UNEXPOSED	0.07	24.205	-
173	0.02	24.225	4 → 6
174	0.02	24.245	6
175	0.09	24.335	6
UNEXPOSED	0.20	24.535	-
176	0.07	24.605	4 → 6
177	0.10	24.705	4 → 6
177B	0.05	24.755	4 → 6
NO SAMPLE	0.20	24.955	-
178	0.10	25.055	6
179	0.07	25.125	6
180	0.13	25.255	6
181	0.06	25.315	6
182	0.05	25.365	6
183	0.075	25.44	6
184	0.05	25.49	6
185	0.07	25.56	4 → 6
186	0.06	25.62	6
UNEXPOSED	0.10	25.72	-
187	0.06	25.78	6
188	0.06	25.84	6
189	0.04	25.88	6
190	0.11	25.99	6
191	0.03	26.02	6
192	0.07	26.09	6
193	0.10	26.19	6
194	0.09	26.28	6

Sample Number	Bed Thickness(m)	Cumulative Thickness(m)	Lithotype
195	0.09	26.37	4
196	0.15	26.52	4
197	0.11	26.63	3
198	0.09	26.72	3
199	0.075	26.795	3
200	0.035	26.83	6
201	0.06	26.89	6
202	0.07	26.96	6
203	0.03	26.99	6
204	0.08	27.07	6
205	0.05	27.12	6
206	0.07	27.19	6
207	0.05	27.24	6
208	0.04	27.28	4
209	0.03	27.31	4
209B	0.04	27.35	3
210,211A	0.07	27.42	6
211B	0.065	27.485	6
212	0.07	27.555	3
213A	0.05	27.605	6
213B	0.06	27.665	2
214A	0.04	27.705	2
214B	0.03	27.735	2
215A	0.04	27.775	2
215B	0.04	27.815	2
216A	0.11	27.925	2
216B	0.10	28.025	3
217A	0.035	28.06	2
217B	0.07	28.13	1
218A	0.04	28.17	2
218B	0.08	28.25	1
219	0.04	28.29	2
220	0.04	28.33	2
227	0.08	28.41	2
228	0.15	28.56	2
229	0.11	28.67	3
230,231	0.08	28.75	2 → 3
232-235	0.13	28.88	6
236	0.12	29.00	2
237	0.035	29.035	1
238-240	0.11	29.145	2
241	0.05	29.195	2
242	0.07	29.265	2
243	0.06	29.325	2
244	0.06	29.385	2
245	0.11	29.495	7
246-250	0.40	29.895	2
251	0.045	29.94	2
252,253	0.09	30.03	3
254	0.04	30.07	2

Sample Number	Bed Thickness(m)	Cumulative Thickness(m)	Lithotype
255,256	0.13	30.20	2
257	0.10	30.30	2
258	0.05	30.35	2
259	0.05	30.40	1
260	0.075	30.475	4
261	0.07	30.545	4
262	0.05	30.595	4
263	0.07	30.665	3
264	0.035	30.70	2
265	0.11	30.81	2
266	0.10	30.91	2
267	0.11	31.02	2→6
268,269	0.065	31.085	6
270	0.08	31.165	7
271-274	0.30	31.465	2
275	0.035	31.50	2
276	0.80	32.30	4
NO SAMPLE	0.40	32.70	1
277	0.10	32.80	1
278A	0.10	32.90	1
278B	0.05	32.95	1
279	0.05	33.00	2
280	0.05	33.05	2
281	0.08	33.13	7
282	0.045	33.175	2
283	0.03	33.205	2
284	0.055	33.26	3
285A	0.055	33.315	3
285B	0.02	33.335	3
286	0.02	33.355	3
287	0.04	33.395	3
288	0.10	33.495	3
289	0.07	33.565	2
290	0.06	33.625	2
291	0.06	33.685	2
292	0.24	33.925	2→1
293	0.05	33.975	2
294	0.15	24.125	2
295	0.07	34.195	2
296	0.055	34.25	2
297	0.07	34.32	2
298	0.07	34.39	2
299	0.12	34.51	2
300	0.11	34.62	2
301A	0.03	34.65	2
301B	0.03	34.68	1
302	0.03	34.71	2
303	0.12	34.83	2→3
304	0.23	35.06	3→7
305	0.03	35.09	2

Sample Number	Bed Thickness(m)	Cumulative Thickness(m)	Lithotype
306	0.04	35.13	2
307	0.03	35.16	2
308	0.03	35.19	7
309	0.04	35.23	2
310	0.03	35.26	3
311	0.04	35.30	3
312	0.04	35.34	2
313	0.04	35.38	3
314	0.04	35.42	3
315	0.04	35.46	2
316	0.095	35.555	3
317	0.055	35.61	3
318	0.08	35.69	2
319	0.10	35.79	2
320A	0.08	35.87	3→5
320B	0.04	35.91	3
321	0.11	36.02	2
322	0.09	36.11	2
323	0.05	36.16	2
324	0.06	36.22	2
325	0.08	36.30	5
326	0.045	36.345	2
327	0.07	36.415	2
328	0.05	36.465	2
329	0.11	36.575	2
330	0.27	36.845	2→1
331	0.06	36.905	1
332	0.12	37.025	1
333	0.40	37.425	1
334	0.09	37.515	2
335,336	0.035	37.55	1→2
337	0.08	37.63	4
338	0.08	37.71	2
339	0.05	37.76	2
340	0.05	37.81	7
341	0.06	37.87	7
342	0.11	37.98	7
343	0.07	38.05	1
344,345	0.10	38.15	1
346	0.12	38.27	2
347	0.06	38.33	2
348	0.06	38.39	1
349A	0.10	38.49	1
349B	0.03	38.52	2
350	0.025	38.545	4
351	0.09	38.635	3
352	0.03	38.665	6
353	0.06	38.725	6
354-358	0.20	38.925	6
359-361	0.15	39.075	6

Sample Number	Bed Thickness(m)	Cumulative Thickness(m)	Lithotype
362	0.02	39.095	7
363	0.04	39.135	6
364	0.045	39.18	6
365	0.03	39.21	6
366	0.06	39.27	6
367	0.07	39.34	6
368,369	0.10	39.44	4
370	0.04	39.48	6
371	0.04	39.52	6
372	0.06	39.58	6
373	0.15	39.73	6
374	0.13	39.86	6
375	0.09	39.95	6
376	0.05	40.00	6
377	0.07	40.07	6

VITA

Walter Steven Borowski was born on 6 November 1956 in Cleveland, Ohio. His father whetted his curiosity so that his early life was spent devouring books and collecting insects and various aquatic organisms. As a consequence, well before graduating from James Ford Rhodes High School, he was destined to enter college and study ecology. While pursuing a major in biology at Case Western Reserve University, he also became intrigued with geology and added the discipline as a second major. Wally graduated from Case with a major in both biology and geology in May 1978. For a year, guided in research by Peter McCall at Case, he investigated sediment selection by benthic tubificid worms and bacteria-tubificid interactions within Lake Erie sediments. In the Fall of 1979, Wally entered the graduate program at The University of Tennessee and was awarded a Master's degree in December, 1982. At this writing, he is employed as a geologist for Atlantic-Richfield Company in Lafayette, Louisiana.