

To the Graduate Council:

I am submitting herewith a thesis written by James E. Wedekind entitled "The Stratigraphy, Depositional Environments, Bryozoan Paleoecology, and Taphonomy of the Middle Chickamauga Group Near Thorn Hill, Grainger County, Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted for the degree of Master of Science, with a major in Geology.

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THE STRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS, BRYOZOAN
PALEOECOLOGY, AND TAPHONOMY OF THE MIDDLE
CHICKAMAUGA GROUP NEAR THORN HILL,
GRAINGER COUNTY, TENNESSEE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

James E. Wedekind

June 1986

ACKNOWLEDGEMENTS

I express my deepest appreciation to my primary advisor, Dr. Kenneth R. Walker, who in addition to suggesting this research topic, introduced me to paleoecology and carbonate sedimentology. I am grateful to Dr. Robert E. McLaughlin whose help as editor, field advisor, and scientist was instrumental in the completion of this thesis. Dr. Thomas W. Broadhead was an editor, and identified the echinoderms. Dr. Frank B. McKinney of Appalachian State University provided invaluable assistance in the identification of bryozoans, along with sharing his expertise on bryozoan biology. Financial assistance was provided by the Mobil Carbonate Fund, Appalachian Basin Industrial Associates, and the Discretionary Fund.

I offer my sincerest thanks to Anita Cristil, whose typing skill is only matched by her kindness and understanding. I thank Eric Johnson, Steve Knapp, Charles Lutz, John Simonson and the Carbonate Bankers for numerous discussions, both scientific and otherwise, which aided immeasurably in the completion of this project. Additionally, I am thankful for the friendship of Nancy Chaffin, Brian O'Neil, Greg and Nola Patterson, Dr. Michael Reed, and Mack Wynegar.

Finally, I am indebted to the support, understanding and love of my parents; Dr. and Mrs. Roy A. Wedekind, and my family members; Janet, Suzanne, Troy, Helen, and David, and my "landlady" Mrs. J. E. Willard.

ABSTRACT

The Benbolt, Wardell, Bowen, and Witten formations (middle Chickamauga Group) in upper East Tennessee near Thorn Hill measure 198.8m in thickness. The four formations represent a regressive carbonate sequence deposited on a broad shelf during Middle Ordovician time. Detailed petrographic analysis reveals thirteen lithologies which depict deeper subtidal deposition, overlain by sediments of shallow subtidal, nearshore, and tidal flat environments.

The Benbolt Formation is irregularly bedded, cobbly weathering, fossiliferous wackestone, packstone and calcareous shale, containing diverse marine fossil assemblages, particularly echinoderms, bryozoans, brachiopods and trilobites. The Benbolt represents wholly subtidal deposition, typically below fairweather wave base, but occasionally on shallower bioclastic sand shoals. Calcareous shale near the top of the formation indicates an influx of terrigenous silt and mud, which greatly decreased carbonate production. The Wardell Formation consists of lime mudstone and highly fossiliferous wackestone and peloidal packstone deposited nearshore within fairweather and storm wave base. Wardell environments supported a rich and varied marine fauna of bryozoans, tabulate corals, calcareous algae, echinoderms, and brachiopods. The Bowen Formation is predominately reddish-brown, thinly bedded, internally laminated, sparsely fossiliferous, argillaceous lime mudstone, deposited in shallowest subtidal, intertidal, and supratidal environments. Dessication features, such as mudcracks and birdseye fenestrae are common, as are large vertical

burrows. The Witten Formation consists of interbedded lime mudstone, fossiliferous wackestone, and thinly bedded, intraclastic packstone deposited in partially restricted, inner shelf, shallow subtidal, intertidal, and supratidal environments. Fossils consist predominately of molluscs, bryozoans, trilobites, ostracodes, and brachiopods. The middle Chickamauga represents a regressive sequence of carbonate deposition in middle and inner shelf environments.

Ectoproct bryozoans from the middle Chickamauga show some degree of facies specificity. The muddy subtidal environment represented by the Benbolt is dominated by very small, ramose growth forms (such as "Phylloporina", arthrostylids, and various cryptostomes), sheet-like encrusting cystoporates, and mound-shaped Monotrypa zooaria. Skeletal sand shoals in the Benbolt contain mostly robust trepostomes (e.g. Nicholsonella) and encrusters. The Wardell contains over twenty-five genera of bryozoans. This nearshore, turbulent environment, is dominated by "Phylloporina", ceramoporids, and Parvohallopora in the less agitated facies, but the ramose Amplexopora and the encrusting Constellaria overwhelmingly dominate the current-reworked skeletal sands. The restricted subtidal environment (Witten Formation) contains very few phylloporinids or ceramoporids, but the ramose trepostomes Homotrypa and Amplexopora are locally very abundant, suggesting they were adapted to conditions of varying temperature or salinity.

Some taphonomic studies have cast doubt on the preservability of community information in fossil assemblages. Although taphonomic processes destroy information, petrographic analysis suggests some syndepositional processes enhance preservation of assemblages. In

muddy environments, invertebrate colonization and subsequent encrustation produce well preserved "microbioherms" which record biotic interactions in firm-substrate-starved environments. Substrate modification by disturbance, meiobenthic interactions, invertebrate colonization, marine cementation, and early water loss results in a gradually firming substrate that resists mixing by benthic burrowers and sediment resuspension by high current energy. Rapid burial or "obstruction" also serves to preserve some fossil assemblages. Coarse grained, bioclastic storm deposits not only serve to catastrophically bury an assemblage, but may also provide firm substrata for subsequent colonization. The above processes are responsible for preservation of fossil community information in the middle Chickamauga. In addition, recent studies suggest that during the Ordovician, lower rates of bioturbation and more intense marine cementation may have also enhanced preservation.

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CHAPTER 1

INTRODUCTION

General

The stratigraphic units of the Middle Ordovician crop out in a series of northeast-southwest trending strike belts bounded by thrust faults which dip to the southeast in the Valley and Ridge Province of the Southern Appalachians. The westernmost strike belts contain a complex array of admixed carbonate and terrigenous clastic rocks which comprise the Chickamauga Group. The inhomogeneity of these rocks reflects the complex facies pattern of the shallow water carbonate depositional environments in which this ancient sediment was deposited. Lithologic complexity, coupled with poor exposure due to intense weathering, renders stratigraphic subdivision difficult and ambiguous (Rodgers, 1953). However, recent work by students at the University of Tennessee, Knoxville, provides a sedimentologic framework on which the stratigraphic subdivision is based.

The present study concerns the paleoecology of the rich biota which existed within a Medial Ordovician carbonate shelf which occupied what is now East Tennessee. While previous studies have recognized localized fossil assemblages and inferred paleoecological processes (see Sickafoose, 1978; Weiss, 1981; Ashworth, 1982; Ewing, 1985), this study focuses on the broad environmental regimes, and the taphonomic processes which occurred in this ancient shelf environment.

Purpose

The purposes of this study were to: (1) provide a complete, detailed stratigraphy and petrology of the middle Chickamauga Group near Thorn Hill, Tennessee, (2) construct an environmental framework for these shallow water, shelf deposited limestones and the indigenous biota, (3) determine the environmental distribution of bryozoans on a Middle Ordovician shelf, (4) demonstrate how syndepositional biotic and abiotic processes affected carbonate sediment and its associated biota, and (5) integrate this study with previous Middle Ordovician paleoenvironmental work at the University of Tennessee.

First, this study provides a comparison of problematic stratigraphic units of the Chickamauga west of the Saltville Fault. A detailed stratigraphic description of the middle Chickamauga at the Thorn Hill locality is provided. Although the stratigraphy of this locality was recently studied by Ruppel (1979), the middle Chickamauga was poorly exposed along old U.S. 25E. A recent re-routing of the highway around the town of Thorn Hill, provides better exposure which is the focus of this study.

Bryozoans, which are a major biotic constituent of the Chickamauga Group, have not previously been studied quantitatively in the shelf deposited lithologies. Earlier studies in the near shelf edge portions of the Chickamauga, however, have dealt with this group in some detail (Ferrigno, 1973; Cristil, 1985). This study includes the identification and distribution of this taxon within the various

on-shelf facies of the middle Chickamauga.

Finally, this study explores the interplay of physical and biotic factors which result in the preserved fossil assemblage. Since the distribution of invertebrate faunas is often a function of the substrate in or on which they lived, changes in substrate consistency may be reflected in the fossil assemblage. However, sediment reworking by current energy or infaunal burrowers removes much of the paleoecologic information. Certain sedimentary processes, such as marine cementation, rapid fine grained deposition, and early compaction through water loss, enhances the probability of fossil preservation.

Location of Study Area

The primary study area is located along the recently re-routed highway U.S. 25E in Clinch Valley, approximately 1km southwest of the town of Thorn Hill, Tennessee (Figure 1.1). Roughly 3300m of Paleozoic sedimentary rocks, including the entire Middle Ordovician sequence, are well exposed along the "new" U.S.25E roadcut (Walker, 1985). Approximately 1km to the northeast of the study area the "old" U.S.25E exposure, now highly weathered and poorly exposed, was studied by Hall and Amick (1934) and Ruppel (1979).

Figure 1.2 shows the position of the three outcrops where the Middle Chickamauga section was measured and sampled. Some good exposures of the Chickamauga are found in nearby fields along Tennessee Highway 131 both north and south of the study area. These field exposures prove useful in tracing units laterally along strike, as well

Figure 1.1 Location of study area within Clinch Valley, Grainger County, Tennessee. Inset in upper left corner shows location of map area (in black) in East Tennessee. Lower left inset shows detail of Thorn Hill area and the relative position of the middle Chickamauga.

Figure 1.1

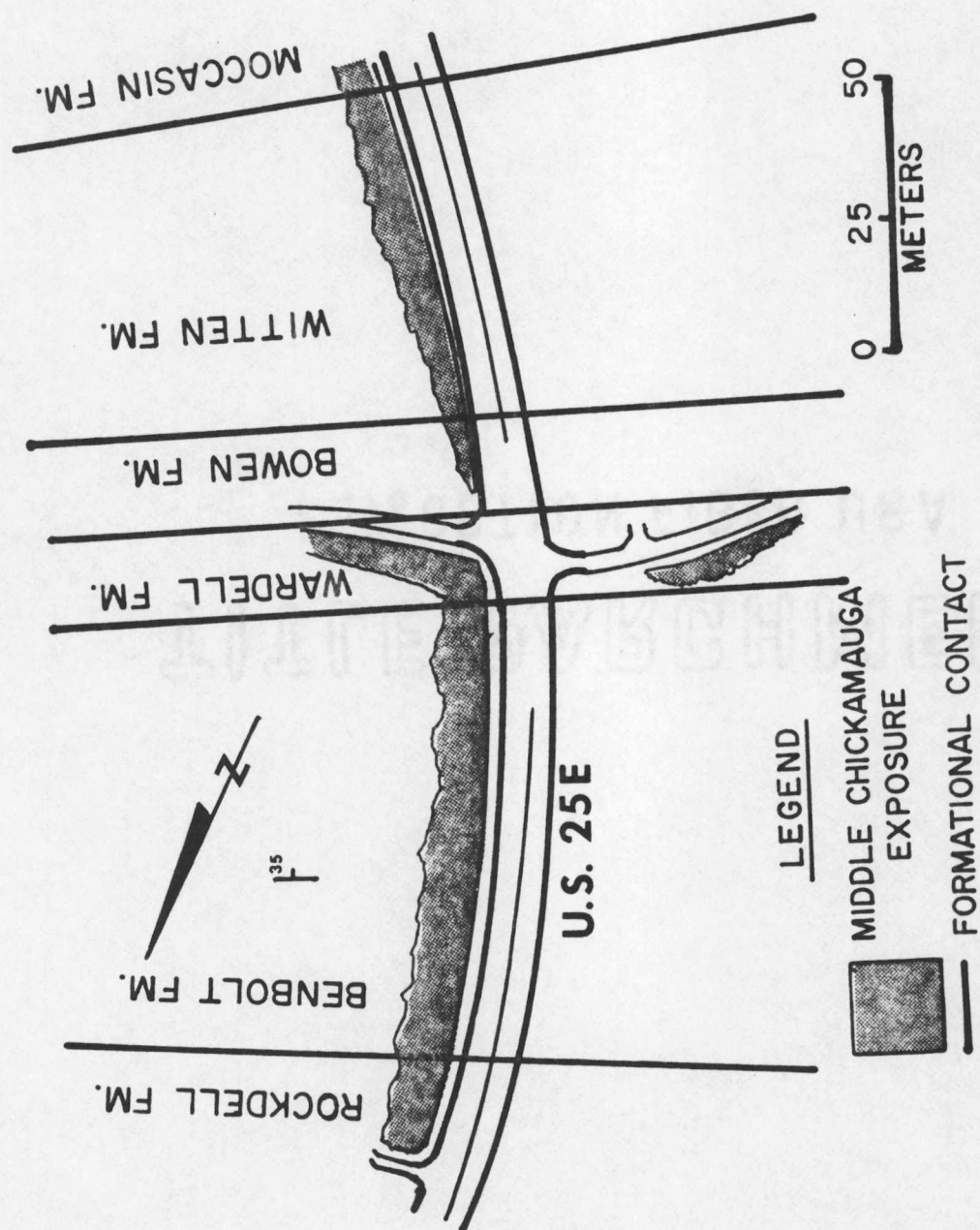


Figure 1.2. Location of middle Chickamauga exposure along U.S. 25E near Thorn Hill. Section was measured and described primarily along the east side of the highway.

as providing a useful check on the roadcut which is in part poorly exposed.

Paleodepositional Setting

Sediment which now comprises the Chickamauga Group initially was deposited upon the eroded, karstic surface of the Cambro-Ordovician Knox Group during the early Middle Ordovician (Marmor Stage). The lower units of the Chickamauga (Blackford, Five Oaks, Tumbez Formations and Mosheim member of the Lenoir Formation) are generally sparsely fossiliferous, desiccated lime mudstone which reflect shallow subtidal to supratidal deposition. This early phase of shallow water deposition was ended by major subsidence of the easternmost shelf, probably the result of early Taconic (Blountian Phase of Rodgers, 1953; 1971) deformation (Shanmugan and Walker, 1978; 1982). The newly formed basin was the locus of deposition of hemipelagite, turbidite (Blockhouse and Sevier formations) and shelf edge patch reef and associated skeletal sands, in addition to oolite shoals, and siliciclastic-rich muds (Holston and Chapman Ridge formations). The westward, shelf environments were the site of continued shallow water deposition in depths usually no greater than 30 or 40 meters (Ruppel, 1978). Shelf environments contained a variety of subfacies which are recognized in the Chickamauga. Skeletal sand banks, subtidal mud "ponds", biogenic mud mounds, patch reefs, and tidal flats are represented in the lithologies of the Lincolnshire, Hogskin, Rockdell, Benbolt, Wardell, Bowen, Witten, and Moccasin formations. Figure 1.3 shows the

Figure 1.3 Stratigraphic cross section of Middle Ordovician strata in upper East Tennessee west of the Saltville Fault. Section is roughly parallel to depositional strike. Note that the Wardell Formation thins markedly at the Thorn Hill (TH) locality. In addition, the Bowen Formation thickens slightly at this location. Other sections depicted here: IS = Idol Section; CS = Cedar Springs; LV = Lee Valley. Modified slightly from Ruppel and Walker (1984).

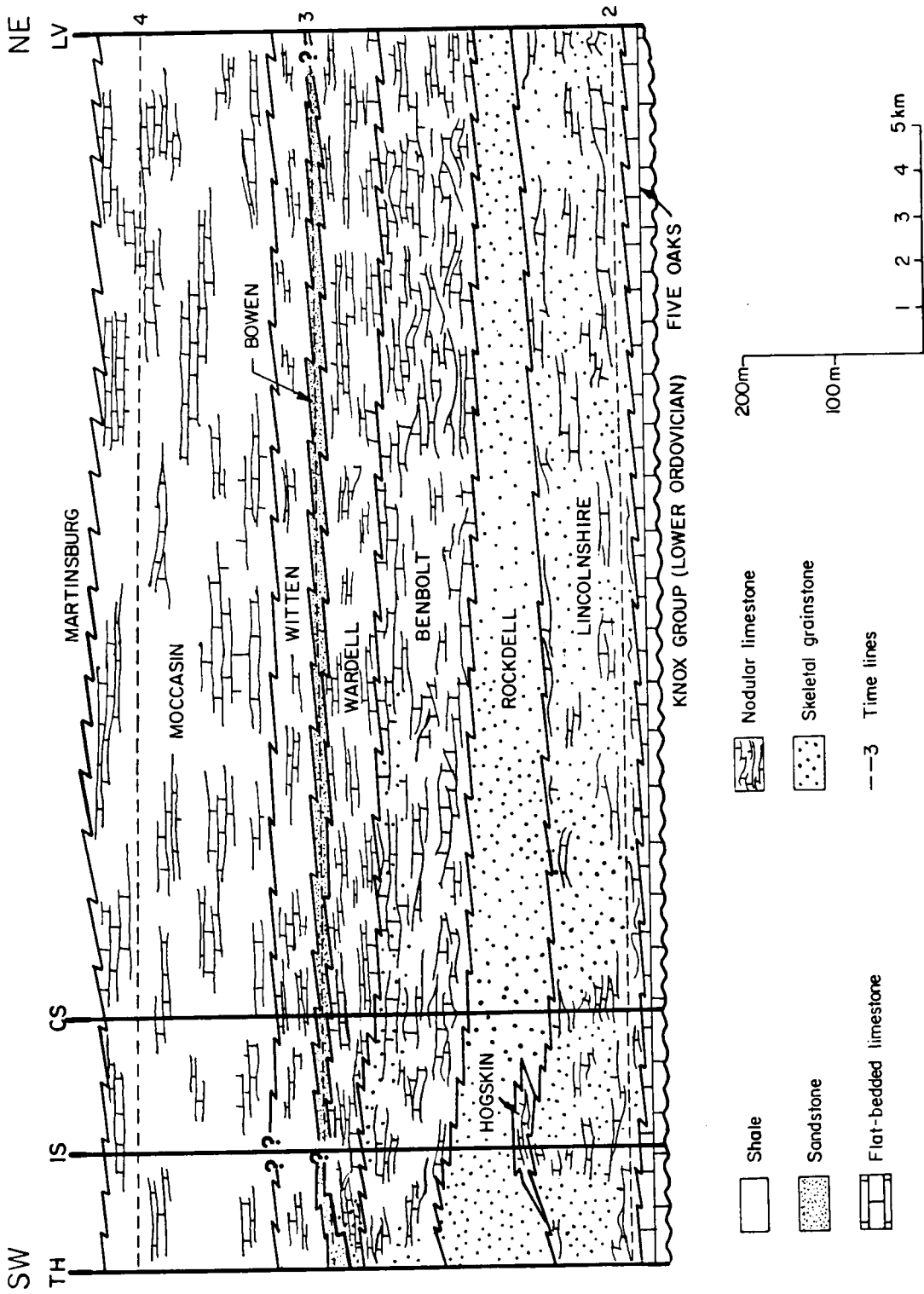


Figure 1.3.

distribution of the shelf deposited formations in a stratigraphic cross section trending roughly parallel to strike.

The lithologies of the middle Chickamauga were deposited as the eastward basin filled with sediment. Quartz silt, derived from a source to the southeast, is common in these rocks. Its appearance in the Benbolt Formation reflects the point at which the basin had largely filled with sediment (Walker et al., 1983; Ruppel and Walker, 1984). Each of the formations above the Benbolt contain trace amounts of sand, silt, and finer grained terrigenous clastics. By "Bowen time" the basin was completely filled and a bathymetric reversal ensued. Terrigenous and mixed carbonate-terrigenous clastic tidal flats developed to the east (Bays and Moccasin formations), while intertidal and shallow subtidal environments continued to the west (Simonson, 1985).

Stratigraphy

The stratigraphy of the Chickamauga Group remains controversial. The myriad of stratigraphic names proposed have largely been due to localized differences in the rocks. East of the Saltville Fault Middle Ordovician rocks display lithologic inhomogeneity due to large bathymetric variation within their environment of deposition (Benedict and Walker, 1978). The Chickamauga west of the fault represents a complex array of lithologies reflecting the variety of shallow water subenvironments found on carbonate shelves (Ruppel, 1979).

In his reappraisal of the Chickamauga in the northwestern strike

belts of the Valley and Ridge Province of East Tennessee, Ruppel (1979) adopted much of the classification used by Cooper and Prouty (1943) for Middle Ordovician strata in Tazewell County, Virginia. Ruppel identified (in ascending stratigraphic order) the Five Oaks, Lincolnshire, Rockdell, Benbolt, Wardell, Bowen, Witten, and Moccasin formations for exposures at three localities in Clinch Valley, TN. One of these localities, the "old" Thorn Hill section is less than one kilometer from the present study area. Subsequently, other workers have adopted much of Ruppel's classification for Chickamauga sections in the Copper Creek and Hunter Valley allochthons reaching as far as 100km southwest of the study area (see Sickafoose, 1979; Breland, 1980; Weiss, 1981; Ashworth, 1982; Ewing, 1985). Despite some minor discrepancies in thickness and lithology, the nomenclature of Ruppel (1979) has been applied to the "new" Thorn Hill section (Wedekind, 1985).

Controversy has surrounded biostratigraphic correlation in the Chickamauga as well. G.A. Cooper's (1956) study of brachiopods included extensive collections in East Tennessee which aided his development of the Whiterock, Marmor, Ashby, Porterfield, Wilderness, and Trenton stages of the Ordovician. However, McLaughlin (1973) observed that most fossil groups are facies controlled and, therefore, care must be taken when using Middle Ordovician fossils to correlate rocks across strike belts in East Tennessee. He established two biostratigraphic provinces for the lower units of the Chickamauga (his Phase IV): the Chickamaugan Province for fossils west of the Saltville Fault, and the Blountian Province for fauna east of the fault.

Conodont studies indicate that these faunal elements are similarly facies controlled. Carnes (1975) examined the conodont fauna near the study area and concluded that the middle Chickamauga (Tazewell Confacies Belt) is within the Prioniodus gerdae subzone of the Amorphognathus tvaerensis zone which reflects a Midcontinent fauna of Porterfieldian age (Bergstrom, 1973; Bergstrom and Carnes, 1985). Bentonites from coeval strata in Middle Tennessee which yield a similar conodont fauna give an absolute age of about 454 Ma. for the Chickamauga (Kunk and Sutter, 1984). Figure 1.4 shows the general chronostratigraphic and biostratigraphic relationships for the Middle Ordovician in East Tennessee.

Methods of Study

The stratigraphic units of the middle Chickamauga were measured and described and the section was divided into field units which were sampled at an average vertical spacing of 2 meters depending on lithologic dissimilarity, degree of exposure, and the presence of particularly unusual or interesting strata. The shaly nature of much of the middle Chickamauga necessitated coating many samples with polyester boat resin. This practice insures that the sample remains intact during transportation and initial preparation. This also allows for less biased sampling of the more coherent lithologies. A description of the detailed stratigraphy and sample locations is provided in Appendix A.

Each sample was slabbed with a standard rock saw and those slabs

NORTH AMERICAN SERIES	NORTH AMERICAN STAGES	BRITISH SERIES	CONODONT ZONES Sweet & Bergstrom 1976	MIDDLE ORDOVICIAN OF E. TENNESSEE		
CHAMPLAINIAN	TRENTONIAN	CARADOCIAN	<u>Amorphognathus superbus</u>	MARTINSBURG		
			<u>Amorphognathus tvaerensis</u> (P. gerdae) ----- (P. variabilis)	CHICKAMAUGA GROUP		
	BLACKRIVERIAN			<u>Pygodus anserinus</u>	MOCCASIN	
				CHAZYAN	<u>Pygodus serra</u>	WITTEN
					WHITEROCKIAN	
			WARDELL			
			BENBOLT			
			ROCKDELL	SEVIER		
				HOLSTON		
				LINCOLNSHIRE		
			FIVE OAKS			
			BLACKFORD			
				BLOCK-HOUSE		
				WHITESBURG		
				LENOIR		
				?		

Figure 1.4. Stratigraphic relationships of the Chickamauga Group. Note that the middle Chickamauga is predominately Blackriverian in age, and lies within the Amorphognathus tvaerensis conodont zone. From Ruppel and Walker (1984).

deemed lithologically diagnostic were either polished for acetate peels and/or prepared as thin sections. In all, 119 two by three inch thin sections were made for detailed petrography. Of these thin sections, 57 were point counted at an average of 300 points per slide using a Swift Automatic Point Counter. Point count data for all thin sections is given in Appendix C. All thin sections are permanently housed at the Department of Geological Sciences, University of Tennessee, Knoxville.

CHAPTER 2

PETROGRAPHY AND DEPOSITIONAL ENVIRONMENTS

Introduction

This chapter discusses the petrology of the middle Chickamauga at the "new" Thorn Hill exposure along U.S. 25E. Each unit is described based on macroscopic description and thin section analysis (see Figure 2.1). A paleoenvironmental interpretation of each unit follows the petrographic analysis. These petrographic and paleoenvironmental data, in providing an understanding of the subenvironment in which sediment was deposited, also serve as a framework for the paleoecologic analyses discussed in chapters 2 and 3.

Rockdell Formation

The Rockdell Formation is the uppermost unit in the lower Chickamauga. Previous workers have established criteria which distinguish the formation from the lithologically similar, and partly coeval, Holston Formation (see Ruppel and Walker, 1982; 1984). Although the Rockdell is not included in this study, a brief discussion is necessary for it provides a better understanding of the depositional environment of the lower middle Chickamauga.

At Thorn Hill, the Rockdell is about 120m thick and is composed of two distinct lithologies: (1) a brick red, medium to coarse grained

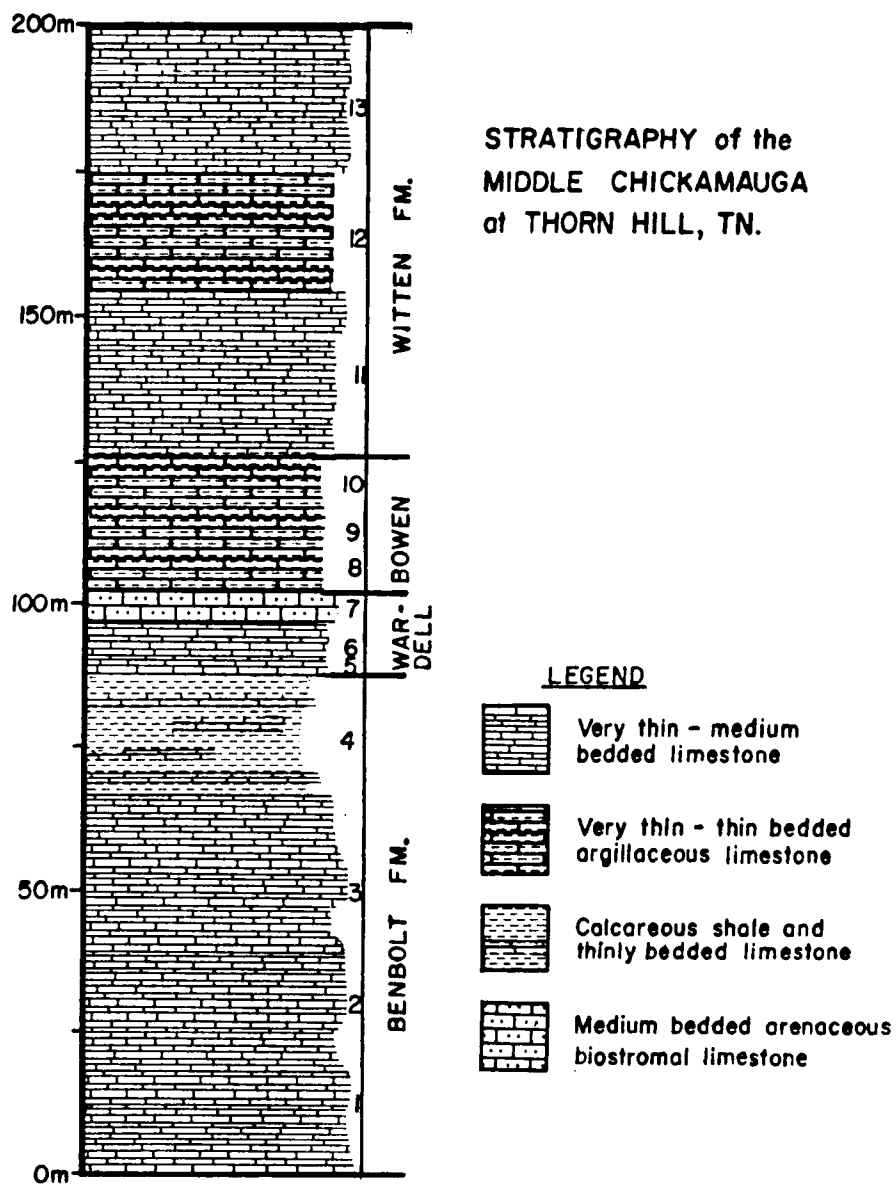


Figure 2.1. Columnar section showing stratigraphy of middle Chickamauga near Thorn Hill. Numbers to the right of column indicate relative position of field units.

fossiliferous wackestone and packstone and (2) a grey or reddish grey, fine grained, somewhat less fossiliferous, lime wackestone and mudstone, which forms lensoid bodies within the coarser grained lithology. The fauna is predominated by echinoderms and bryozoans with lesser amounts of algae (including Solenopora), trilobites, brachiopods, and ostracodes (Johnson, 1985).

At most localities, the Rockdell consists of pink to light grey echinoderm-rich packstone and grainstone which represent shelf deposited skeletal sand banks and biogenic mud mounds (Ruppel and Walker, 1982; 1984). The distinctive reddish coloration of much of the Rockdell at Thorn Hill, however, is strikingly similar to the shelf edge deposited Holston Formation (see Walker and Ferrigno, 1973, for a description of the Holston). The Rockdell at Thorn Hill contains bryozoan-rich bioherms associated with flanking skeletal grainstones. However, the presence of algae distinguishes the buildups found at Thorn Hill from those found in the Holston. Breland (1980) interpreted similar algae-bearing structures as patch reefs in Rockdell exposures approximately 50km southwest of the study area.

The uppermost part of the Rockdell at Thorn Hill consists of pinkish grey, stylolitic wackestone which contains abundant echinoderm debris including ossicles, stems, and holdfasts, in addition to a rich fauna of encrusting and ramose bryozoans. The contact with the overlying Benbolt Formation is distinctive because of the contrasting grey color of the latter unit. At the contact, the two formations are petrologically similar, therefore the occurrence of the last bed of pink wackestone was chosen as the top of the Rockdell.

Benbolt Formation

The Benbolt Formation is fairly well exposed along U.S. 25E and some good exposures may also be found in nearby fields northeast and southwest of the highway along Tennessee Route 131. The formation is divided into four units based on lithologic change. Unit 1 is 22.7m of irregularly bedded, light grey wackestone and rare thin beds of packstone. Unit 2 consists of 9.6m of cobbly bedded, grey lime mudstone and wackestone with locally abundant sponges. Unit 3 comprises 32.9m of a highly fossiliferous wackestone and packstone. Unit 4 is 19.4m of poorly fossiliferous, brown weathering shale and lime mudstone. All percentages given in the following descriptions represent volume percent of the total rock volume.

Unit 1

Description. The lowermost eight meters of this unit consist of medium bedded, light grey, fine to medium grained biomicrite with common, irregular stylolites. The fauna is predominately represented by echinoderm plates (including Cleiocrinus), pelmatozoan ossicles and in situ holdfasts, and bryozoans as shown in Figure 2.2A. Bryozoans are chiefly thinly walled, encrusting cystoporates (e.g. Ceramoporella, Crepipora), small fenestrates ("Phylloporina"), and arthrostylids (Osbornostylus, Ulrichostylus). Other bryozoans include small ramose bifoliate (Pachydictya, Stictoporella) and rare, robust colonies

Figure 2.2. Photomicrographs, field photos, and photonegatives of thin sections from the Benbolt Formation. Stratigraphic up is towards the top of the page unless indicated otherwise.

A. Photomicrograph from unit 1 showing well preserved bryozoans (Stictoporella? and Eridotrypa) and echinoderm plates in thoroughly bioturbated micrite matrix. Bar scale is 1.2mm in length. Sample TH1.

B. Photonegative of thin section showing three hollow, cylindrical sponge fossils in cross section. Note small size of other fossils. Bar scale is 8.0mm in length. Sample TH2b.

C. Field photo of wavy bedded, fossiliferous wackestone and intercalated calcareous shale from lithology B of unit 3. Ruler near left corner is 15mm wide.

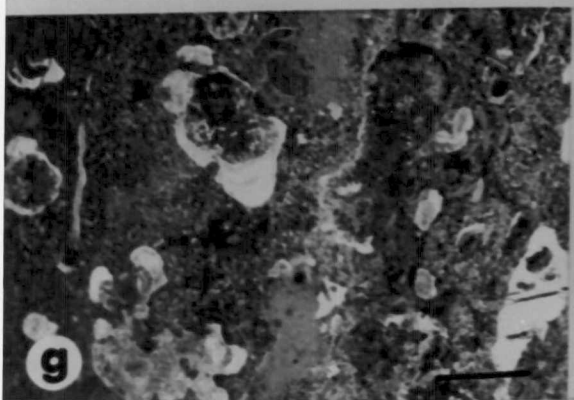
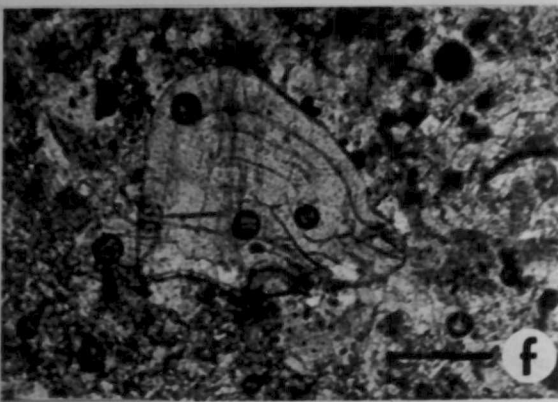
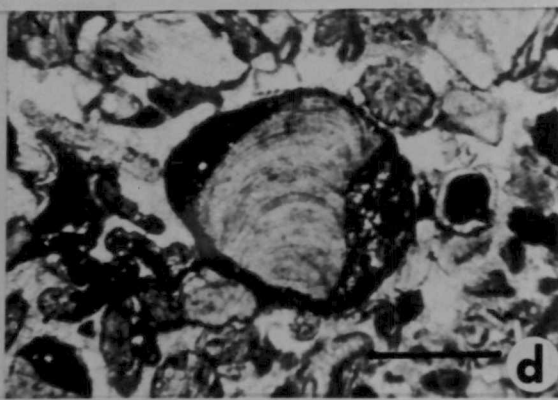
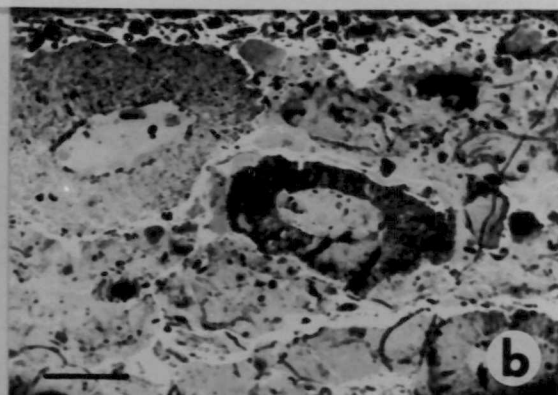
D. Partially neomorphosed (note dolomite rhombs) oncoid nucleated on a Nuia fragment. Note that many fossils contain thin micrite rims and allochems are poorly preserved. Photomicrograph from lithology A of unit 3. Bar scale is 1.3mm in length. Sample TH17.

E. Photonegative of thin section of fossiliferous packstone from unit 3. Large encrusting bryozoan (Xenotrypa) is encrusting an algal ball consisting of neomorphosed, organic-rich micrite and Girvanella. Smaller oncoids can be seen in the upper left corner (appear white in photonegative). Bar scale is 8.5mm in length. Sample TH17'.

F. Photomicrograph of well preserved, phosphatic inarticulate brachiopod valve in peloidal packstone of unit 3. Note incremental growth lines. Bar scale is 0.32mm in length. Sample TH11.

G. Photonegative of thin section showing many lobate oncoids and algally coated bryozoans in neomorphosed pelmicrite. Organic-rich algal coatings appear white in photonegative. Bar scale is 5.5mm in length. Sample TH11.

H. Field photo of strophomenid brachiopods on top of slab surface found in unit 4 of Benbolt. Scale is 15mm wide.



(Constellaria, Diplotrypa). Sponge fossils are somewhat hard to recognize, but can be identified by irregular spar filled voids that are circular or subcircular in cross section, and by the presence of spicules. Other fossil allochems include impunctate articulate and inarticulate brachiopods, ostracodes, trilobites, gastropods, and molluscan fragments. Algae are generally absent except within a thin bed of poorly washed packstone where Girvanella occurs.

Micrite is the predominant constituent of this unit (Figure 2.3), forming about half the total volume in most of the rocks. The percentage of micrite ranges widely, however, from a low of 33% to as much as 88%. Calcite spar (30%) is found only as void fillings or as blocky cement between allochems. Rare microspar occurs both as neomorphosed micrite and fine cement. Neomorphism appears to have been enhanced by weathering associated with clay laminae and stylolites. Peloids and intraclasts are found only in one sample, a poorly washed packstone. The peloids range in size from quite small (less than 0.01mm) to large (0.8mm), consist of featureless micrite, and are well rounded. These are presumed to be invertebrate fecal pellets.

Most fossils are very well preserved including many small forms, such as arthrostyloid bryozoans. The fossils show little evidence of physical abrasion although a few fossil allochems show evidence of biogenic borings. Few fossils show evidence of encrustation, yet ceramoporid bryozoans are frequently found within a muddy matrix and appear to have lived directly on the mud substratum. Pelmatozoan holdfasts are also found within the micrite and appear to be in situ. The jumbled appearance of the fossil assemblage without evidence of any

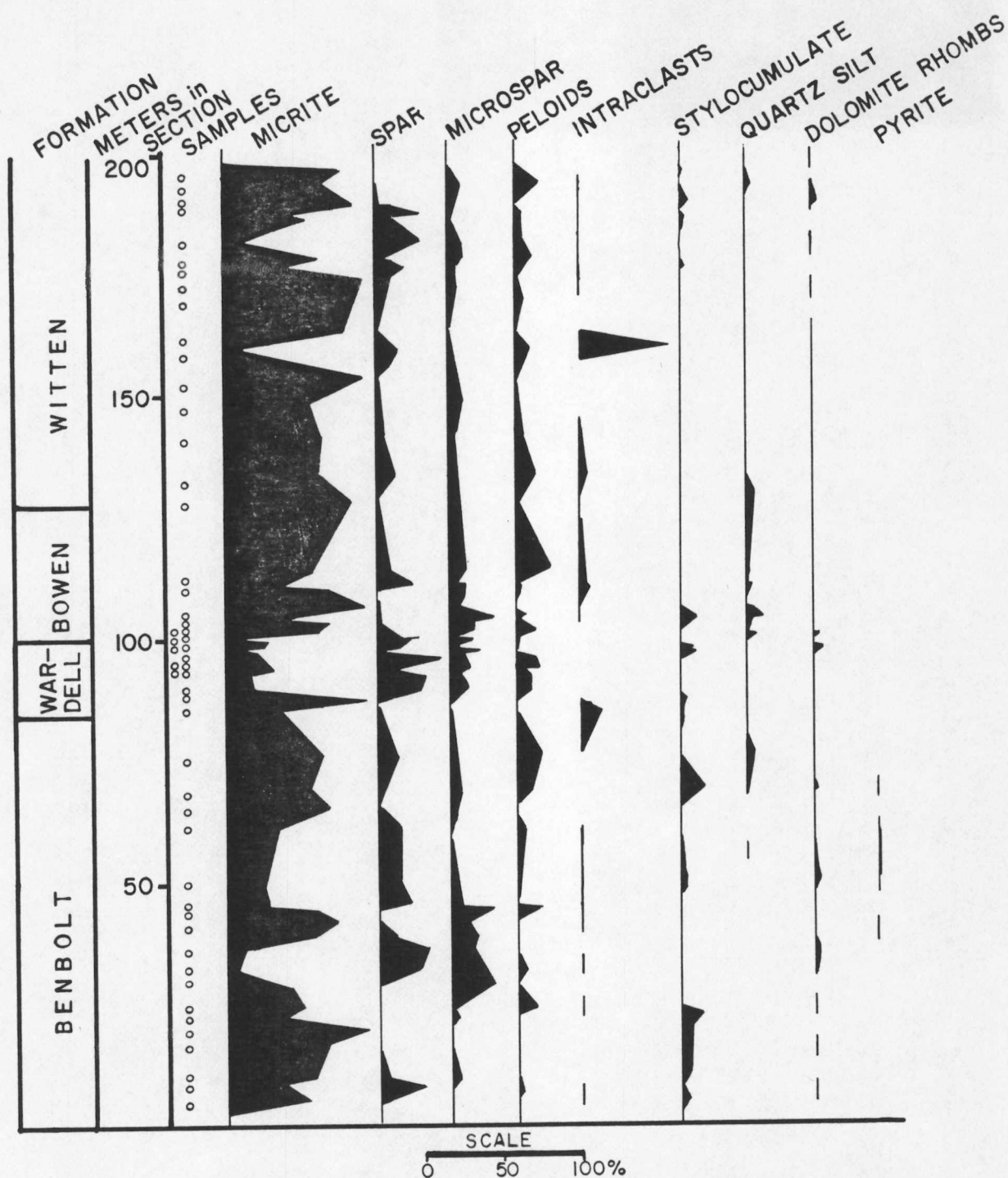


Figure 2.3. Stratigraphic distribution and abundance of non-fossil allochems in the Thorn Hill section. Scale is in volume percent.

physical reworking, suggests that bioturbation, not transport, has modified the fossil assemblage (Fursich, 1978; 1982).

Paleoenvironmental interpretation. The well preserved fossils, and abundance of fine grained matrix (micrite) in unit 1 is evidence of deposition in quiet water, below normal wave base. Lack of evidence of physical transportation of allochems implies that the sediment was deposited in an environment little affected by current energy, except for higher energy events such as severe storms. Storm events could rework sediment due to increased wave or tidal energy associated with storm surge.

The paucity of algal fossils in this unit reflects deposition below the base of the euphotic zone, or in an environment unsuited for algal growth. The depth limit of the euphotic zone is generally 100-150m in clear water, yet varies widely due to turbidity (Riding, 1975; Benedict and Walker, 1978). Ruppel (1979) attributes the lack of an algal flora in the Benbolt to turbidity generated by current agitation and influx of terrigenous clays. Based on occurrence of the trilobite Lonchodomas, which generally marks deeper water environments (Maitland, 1980), and the lack of algae, Ruppel and Walker (1984) believe the Benbolt was deposited in rather deep (up to 50m) water.

The biota of unit 1 is a fairly diverse assemblage, which indicates deposition under normal marine conditions. The abundance of fine grained material, and absence of preserved burrows, indicates that the substrate for these invertebrates was probably soupy or soft. Synsedimentary bioturbation by infaunal burrowers may exclude sedentary

invertebrates by rapidly overturning the sediment, causing the epifauna to be entombed in the substrate (Thayer, 1979; 1983). This favors those taxa which feed above the sediment water interface (e.g. stalked echinoderms and small arborescent bryozoans) and excludes the shelled epifauna. The holdfast systems of the stalked echinoderms may have served as a suitable base which inhibited their burial by the burrowing infauna. The bryozoan fauna of unit 1 consists primarily of small, arborescent and lace-like colonies which possibly avoided toppling due to their very small size and virtually negligible weight. Alternatively, they may have employed rapid upward growth after toppling, similar to the strategy used by the shallow water coral Porites in modern environments. The rocks of unit 1 are composed of sediment deposited in rather deep, turbid water, below storm wave base, perhaps below the euphotic zone. The environment was characterized by abundant lime mud inhabited by a moderately diverse, while somewhat diminutive, biota. The few shelly concentrations are the result of winnowing of the fine matrix during the most intense storm events, as evidenced by abundant perched sediment on fossil allochems (Kreisa, 1980).

Unit 2

Description. Unit 2 is distinguished from the preceding unit by the prevalence of macroscopic sponges. The rock is predominately micrite (38%) which is commonly neomorphosed (11%) with localized, blocky calcite cement (5.3%) surrounding many of the allochems. The

lithology is thinly bedded and undulatory, cobbly weathering lime mudstone and fossiliferous wackestone (biomicrite) with interbedded packstone. Exposures are grey, weathering to tan or brown. Limestone cobbles range widely in size from small ellipsoidal forms (2cm diameter), to larger (5cm) flattened cobbles. The interbedded lime mudstone is sparsely fossiliferous, and more deeply weathered than the wackestone cobbles. Diffuse, horizontal burrows are rarely preserved on some bedding surfaces.

Large sponges comprise up to 36% (Figure 2.4) of the lithology in some beds in this unit. The sponges appear as cylindrical bodies (up to 5cm long), usually with long axis parallel to bedding, with micrite filled atria and calcite replacement of the original organic wall material. The spongocoel (or atrium) of the sponges is filled with micrite and small fossil debris. Figure 2.2B shows how these fossils appear in cross section. Other faunal elements include echinoderms (12%), bryozoans (9%), and trace occurrences of articulated brachiopods, gastropods, trilobites, ostracodes, and pelecypod fragments. Algae are absent in unit 2.

Most fossils are well preserved. Articulated ostracodes, complete gastropod shells with geopetal fillings, and pelmatozoan columnals and holdfasts are found in the unit. Bryozoans are most commonly mud encrusting ceramoporids and lace-like phylloporinids. Ramose bifoliate (Pachydictya, Graptodictya) and trepostomes (Parvohallopora, Nicholsonella) are present in trace amounts. Arthrostylids are present but less abundant than in unit 1. Although unit 2 is more fossiliferous than unit 1, most fossils are quite small.

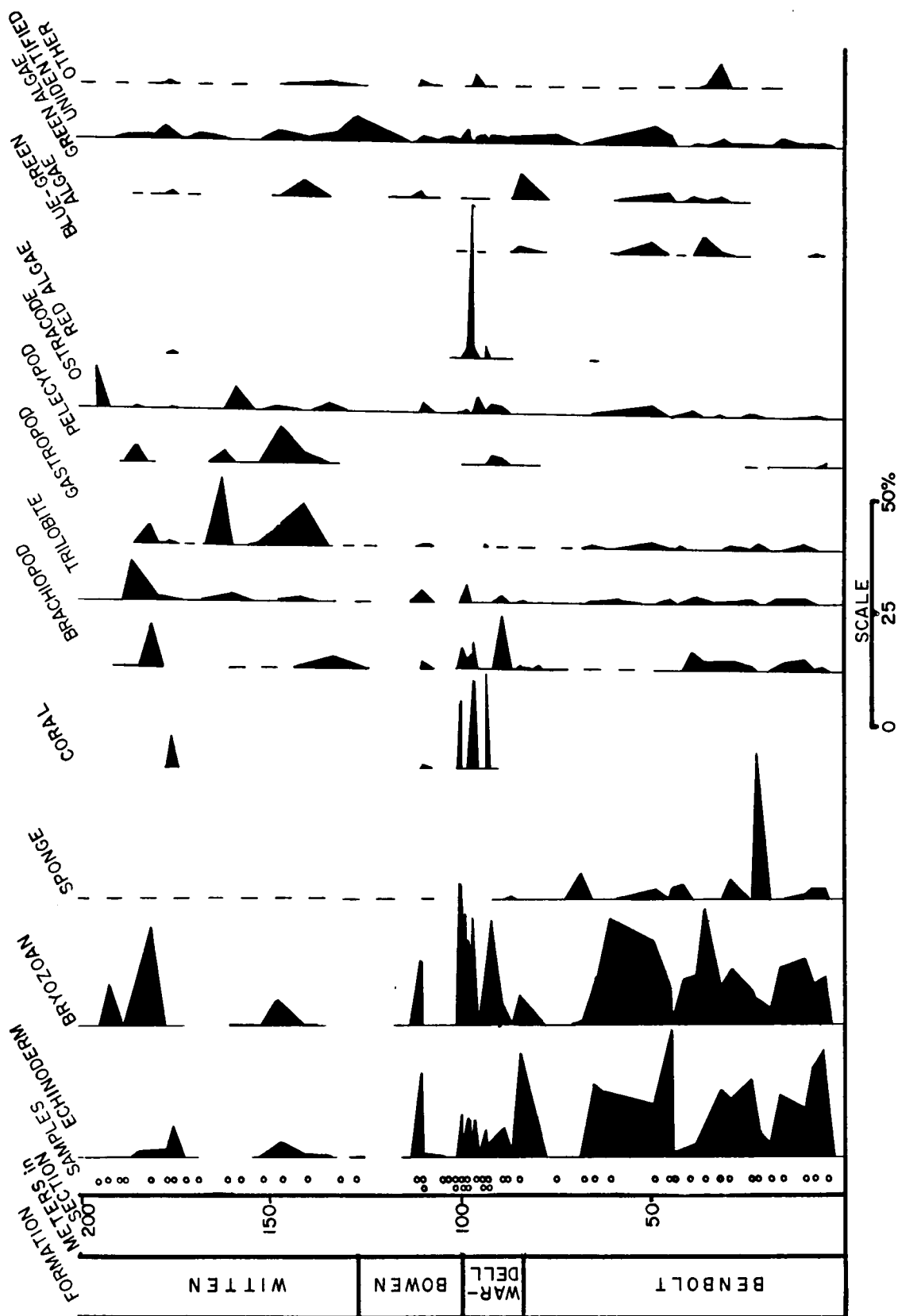


Figure 2.4. Stratigraphic distribution and abundance of fossil allochems in the Thorn Hill section. Scale is in volume percent.

Peloids and intraclasts occur in the rare, very thin beds of packstone. The peloids are angular to round and poorly sorted, ranging from 0.01mm to over 1.5mm in diameter. Irregular and horsetail stylolites, present in most samples, appear to be associated with intercalated shales. Neomorphosed micrite is abundant in some samples, especially around stylolites. Secondary dolomite rhombs are commonly found within the reactate of stylolites. Pyrite, sparsely disseminated throughout the unit, is commonly found replacing fossils.

Paleoenvironmental interpretation. The lithology of unit 2 depicts sediment deposited in a muddy subtidal environment. The abundance of upright fauna, especially sponges, which acted as current baffles to fine sediment, may have enhanced deposition around the patches of organisms. In modern environments, seagrasses such as Thalassia testudinum passively trap fine sediment, thus aiding the development carbonate mudbanks. Similarly, Walker (1972) observed the effects of wave baffling by Tetradium in the Black River Group of New York. The substrate appears to have been very soft or soupy when deposited, based on the swirled appearance of the mud and the lack of preserved burrows, which may reflect intense biogenic reworking (Rhoads, 1975). The abundance of sponges in certain beds may indicate the patchy formation of firmer substrates due to water loss and compaction. The "firmground" could then be colonized by invertebrates, in this case, sponges, pelmatozoans, and bryozoans.

The small size of much of the biota may suggest a stressful environment. Pyrite indicates either periodic reducing conditions or

early diagenesis due to organic decomposition. Oxygen depleted episodes could inhibit biotic diversification or at least favor smaller organisms (Raff and Raff, 1970). Alternatively, the lack of primary producers (algae) could account for the small-sized, locally sparse fauna due to lack of food, which is scarce in deeper environments (Thayer, 1975). Moreover, a smaller fauna could more easily cope with a soft substratum. Obviously, singly or in combination, reducing conditions and limited substrate make for a deleterious environment.

Nodular bedded, argillaceous mudstone, wackstone and localized fossiliferous packstone indicate deposition within deeper water of the middle shelf environment (Wilson and Jordan, 1983). The sediment appears to have been soft, argillaceous lime mud due to the complete absence of preserved burrows and "jumbled" appearance of the allochems. The environment supported a diverse, yet somewhat diminutive biota. An increase in fossils and decrease in carbonate mud at the top of the unit reflect a gradual shallowing trend.

Unit 3

Description. Unit 3 comprises the middle 33m of the Benbolt Formation. The base of the unit is 32.3m above the contact with the Rockdell Formation and is gradational with the underlying unit. The lithology is highly varied, consisting of light to dark grey, tan weathering, thickly bedded fossiliferous wackestone and packstone (biosparite), intercalated with poorly exposed, dark grey, medium wavy and cobbly bedded (Figure 2.2C), poorly fossiliferous mudstone and

wackestone. The lithologies are intimately associated; however they are described here separately as two distinct units. Lithology A represents the thinly bedded biosparite and lithology B the wavy and cobbly bedded mudstone and wackestone.

Lithology A. The cement in the biosparite of unit 3 consists primarily of sparry calcite (22.1%) which usually occurs as blocky spar. Syntaxial overgrowths on echinoderm grains, radiaxial and bladed fringing cement morphologies occur rarely. Micrite (16.7%) is commonly found interstitially, adhered to the surface of allochems, or as micrite envelopes produced by endolithic algae or fungi (Swinchatt, 1965; Logan, 1974; Hook et al., 1984; see however Friedman et al., 1971). Microspar (11.7%) is most commonly neomorphosed micrite (8.5%) and pseudospar. Longman (1977) attributed neomorphism in the Ordovician Bromide Formation of Oklahoma to high porosity and fluid migration associated with stylolites. The packstone of unit 3 lacks porosity, it is stylolitic and extensively fractured. Chafetz (1972) suggests that microspar formation and silicification are important weathering phenomena, as well. Peloids (2.5%) and intraclasts are locally abundant, and varied in size and shape. Peloids are mostly dark grey, almost opaque, and range widely in size from 0.01mm to over 1.0 mm grading to small intraclasts.

Girvanella coatings are common in most of the packstone, and oncoids are present in some samples. The oncoids are typically randomly stacked hemispheroids (Logan et al., 1964), some reaching 0.5cm in thickness. The algal coatings are dark grey, almost opaque, and many are neomorphosed to microspar and dolomite rhombs. One sample

contains abundant, well rounded oncoids (5 mm in diameter) and occasional large (3.5 mm) "algal balls" that are encrusted by bryozoans (see Figs. 2.2D and 2.2E). The oncoids either contain a nucleus of heavily micritized skeletal grains (commonly echinoderms or other algae) or simply a completely micritized interior.

Algae are present in all the packstones of unit 3, yet usually in trace amounts. In addition to Girvanella, the probable cyanophytic alga Spongiostroma is also present. Chlorophycophytes include the codiacean genus Hedstroemia, and dasyclads Kazakhstanelia and Vermiporella. Contexta and Solenopora represent the Rhodophycophyta, and the problematical genus Nuia is present, yet rare. The algal diversity is quite high, algae comprise only an average of 2.2% of the packstone, and preservation is generally poor.

Fossil allochems comprise about 36% of the packstone in unit 3 and are mostly broken, abraded and micritized. However, there is evidence that some of the biota represented was indigenous, or at least derived from nearby environments. The packstone shows the greatest diversity, although echinoderm debris (15.8%) and bryozoans (15.6%) comprise most of the fauna. Brachiopods (1.5%) are commonly partially silicified and usually disarticulated, except for some very small specimens. Ostracodes are locally abundant and occurring predominately as well preserved, but disarticulated valves. Trilobite fragments are common and often have algal coatings. Sponges, sponge spicules, and molluscan shells are present in trace amounts. A variety of less common taxa is found within the packstone. Well preserved, chitinophosphatic inarticulate brachiopod valves often retain external structure (Figure

2.2F). A tentaculid, a cone shaped, deposit feeder (Thayer, 1975) is present in one sample. Serpulid worm tubes, although very rare, are found attached to skeletal grains.

Lithology B. The presence of algae and well developed "sedimentary boudinage" distinguishes lithology B from the muddy lower units of the Benbolt. Lithology B is primarily composed of micrite (52.5%) and fossils (19%). Sparry calcite (4.9%) is localized in occurrence as small patches with micrite matrix, although bladed and fibrous fringing cement, possibly of marine origin, is present within some well washed wackestone. Microspar is present as neomorphosed micrite (5.8%) and fine cement (6.9%). The fine cement portion is found within laminated pelmicrite which may have been incompletely compacted, allowing for precipitation of fine grained, blocky calcite. Non-fossil allochems include peloids (4.6%) and (rarely) intraclasts.

Biotic components are less abundant in lithology B, yet most fossils are very well preserved. Bryozoans (6.9%) and echinoderm debris (6.8%) are essentially coequal in abundance, as was true of the packstone, however the remaining fauna has a rather low diversity. Brachiopods, algae, ostracodes, trilobites and fossil fragments are present in trace amounts. Unlike the packstone lithology of unit 3, lithology B contains no oncoids; however, Girvanella encrustations are found on some fossils, and as sparse clumps within the matrix. Moore (1977, 1978) attributes sparse clumps of Girvanella to sub-wave base, lagoonal deposition. Other algae include rare, poorly preserved specimens of the dasyclads Vermiporella and Kazakhstanella.

Bryozoan abundance and diversity is variable, with some samples

containing up to fourteen genera, others contain as few as seven genera, or no bryozoans at all. Some rather large globose trepostome colonies (up to 8cm in diameter) are found in the wackestone, seemingly little affected by the muddy conditions in which the colony thrived. The most common genera include robust trepostomes (Nicholsonella, Monotrypa), "Phylloporina", and ceramoporids. Ramose bifoliate (Pachydictya, Stictopora), and smaller ramose trepostomes (Parvohallopora, Batostoma) are other common taxa.

Limestone "boudins" or cobbles appear to have been produced by post-depositional loading of the semi-lithified sediment. Although the interstitial mud around the cobbles is poorly fossiliferous, the cobbles often contain fossils in addition to diffuse and well defined burrows. Wanless (1979) attributes such nodular bedding to selective weathering associated with stylolitization. However, the evidence here suggests the boudins are early diagenetic in origin, for the interstitial mud indicates flowage around the limestone boudin. The "chippy" shale found around the limestone boudins shows no preserved burrows, indicating homogenized sediment.

Terrigenous clastics, in the form of silt-sized quartz, appear first in the sequence within lithology B. Although possibly aeolian in origin, Ruppel (1979) attributes this occurrence to the overfilling of the basin to the east. Pyrite is sparsely disseminated throughout unit 3, and some rocks smell of hydrogen sulfide when struck. Pyrite may be associated with periodic anoxic conditions due to either very high organic production or rapid sedimentation, the latter inhibiting oxygenation of the sediment by the infauna.

Paleoenvironmental interpretation. Topographic highs in the Arabian Homocline within the Persian Gulf produce biogenic sand shoals flanked by finer grained sediments (Purser, 1973). The closely associated packstone and wackestone may indicate a similar environment of deposition for the middle Benbolt Formation. The well washed, algal-rich, oncolitic biosparite indicates deposition above fair weather wave base. Conversely, the poorly washed wackestone and biopelmicrite lithologies depict deposition in quieter, perhaps somewhat deeper water.

Algally coated grains indicate very shallow water deposition in depths of no more than 10m in modern seas (Ginsburg, 1960, p.26; Logan et al., 1964). The digitate nature of many of the oncoids indicate that agitation of these oncoids was only periodically sufficient to roll them over. An excellent example of this can be seen in Figure 2.2G. Therefore, only occasional periods of higher current energies moved these irregular oncoids. However, the presence of well rounded oncoids and "algal balls" indicate that in some very shallow areas of this environment wave and tidal currents constantly rotated these allochems. Cooper and Prouty (1943), Sickafoose (1979), Ruppel (1979), and Ashworth (1982) report the occurrence of thick bedded sequences of cross bedded skeletal grainstone deposits in the Benbolt, thought to have been derived from migrating skeletal sand banks. Although such deposits are absent at the Thorn Hill locality, the well washed packstone represents a similar depositional feature of lesser dimensions, or, possibly, the flanks of the migrating sand banks.

The lime mudstone and wackestone contain features which indicate sub-wave base deposition of argillaceous lime mud. The irregular nature of the bedding suggests slow, mixed carbonate/terrigenous deposition followed by more rapid accumulation of pure carbonate. Sedimentary boudinage is a common feature of quiet water shelf environments. This diagenetic feature is the result of differential compaction and solution of interbedded unlithified shales and semi-lithified carbonates (Wilson, 1974; Wilson and Jordan, 1983).

Fine grained sediment interspersed with skeletal sands is possibly related to bathymetric variation. The Florida shelf margin consists of a similar, modern depositional environment. Swinchatt (1965) relates abrupt changes in sediment type with variation in relief from the shallow water skeletal sands to deeper water muds. This seaward environment, of somewhat subdued relief, develops leeward mudbanks associated with seaward skeletal sand buildups such as those at Rodriquez Key Bank (Turmel and Swanson, 1976).

In the Persian Gulf, the transition from deep water muds to grain supported muddy sand occurs abruptly at a depth of 36m. At depths of 10 to 20m muddy sand gives way to well washed skeletal sand due to winnowing by current and wave action (Wagner and van der Togt, 1973). Importantly, however, small (as little as 5m) topographic variation, associated with the Umm Shaif High, results in sand and mud deposition within the same general area (Purser, 1973). Perhaps the interbedded wackestone and packstone of unit 3 represents a similar, subtidal depositional environment with slight variations in bathymetric relief at or near normal wave base.

Unit 4

Description. Unit 4 conformably overlies highly fossiliferous wackestone of unit 3 and is easily distinguished from the underlying lithology. Unit 4 consists of 19.4m of brownish-grey to tan weathered, argillaceous lime mudstone, wackestone, and shale. The unit is typically finely laminated internally, and sometimes cross laminated. Strophomenid brachiopods and trilobites are common in the shaly float and on bedding surfaces.

Unit 4 consists largely of argillaceous micrite (58%), which is often neomorphosed, and small (0.08 mm) peloids (13%). Fine grained blocky calcite (12%) is interstitial to peloids and fossil fragments (4.6%) which are badly broken and abraded. Identifiable bioclasts consist mostly of sponge spicules (3%) and trace amounts of ostracode valves, echinoderm pieces, fragmentary bryozoans (incl. Stictopora and Parvohallopora), articulate and inarticulate brachiopod pieces, molluscan debris, and serpulid worm tubes. Quartz silt (2%) is sparsely disseminated throughout the matrix. Stylocumulate (7.5%) and neomorphic dolomite is found associated with with irregular and anastomosing sets of stylolites (terminology of Logan and Semeniuk, 1976).

Horizontal burrows are conspicuous in the muddier lithologies of unit 4 and are well preserved on bedding surfaces. Dendritic, Chondrites and Planolites are common forms. Burrows are commonly spar filled and contain peloids and fossil fragments. Burrow walls are well

defined, which suggests that the substratum was firm or hard when burrowed (Rhoads, 1975).

Very thin beds of finely laminated pelsparite form conspicuous ledges in the upper portion of unit 4. Some laminae contain low angle, bidirectional cross sets, and are micrograded, commonly with fine fossil debris as a basal lag. Fossil fragments (particularly ostracode valves) are oriented parallel to bedding and often oriented convex-up. Pelsparite beds show no evidence of bioturbation, possibly reflecting low organic content of the original sediment.

Paleoenvironmental interpretation. The thinly interbedded shales and limestones of Unit 4 reflect deposition in a gradually shallowing muddy subtidal environment. The dramatic increase of terrigenous mud into this environment greatly diminished the abundance of suspension feeding epifauna in favor of deposit feeding taxa. During periods of decreased terrigenous influx, organisms such as the thin, flat brachiopod Strophomena could colonize the soupy mud substrate in a way similar to those occurrences described by Walker and Parker (1976). Subsequent influx of additional sediment, however, kept this environment relatively depauperate of filter feeders. Deposit feeders, however, flourished in the organic-rich muds, as indicated by the numerous preserved burrows, and the occasional gastropod and trilobite fossils.

The origin of nodular bedded, argillaceous limestones is rather controversial. Eder (1982) suggests that nodular bedding results from early diagenetic modification of the substrate rather than variable

influx of sediment. He cites geochemical evidence which demonstrates the isotopic similarity of the carbonate and shale sequences within Devonian strata in Germany. Additionally, Flugel et al. (1971) demonstrate that bedding in marly lithologies is often a result of diagenetic processes, and not the result of compositional differences. Unit 4 at Thorn Hill is a similar "marl" lithology but in this sequence, many bedding planes are indeed separated by compositional differences. Some beds contain a pavement of Strophomena shells on their upper or lower surfaces. Others are composed of thinly laminated pelsparite and argillaceous limestone. Bedding in these examples appears to be the result of invertebrate colonization or periodic high energy events, not diagenesis.

Unit 4 may represent a unique type of "restriction" on a carbonate shelf, where turbidity and lack of suitable substrates, rather than salinity or temperature, may have been the predominant limiting factor. The extreme areal extent of this shelf environment (more than 70,000km²; Walker, 1977) effectively inhibited water movement thereby producing a shelf lagoon, where mud could accumulate (Wilson and Jordan, 1983). The southern shelf lagoon in Belize represents a similar environment, where turbid water inhibits primary production by the calcareous alga Halimeda in addition to inhibiting a diverse macrofauna (Purdy, et al., 1975). Perhaps the activity of the abundant infaunal deposit feeders excluded the epifauna as in terrigenous muddy environments. Woodin (1983) describes how burrowing infauna can indirectly inhibit epifaunal colonization by destabilizing the substrate. However, Thayer (1979; 1983) indicates that although a

major diversification of infaunal burrowers occurred during the Ordovician, overall sediment turnover rates were lower than those observed today.

The thinly bedded, cross laminated peloidal wackestone lithology indicates occasional periods of enhanced current energy either by storm waves, or tidal currents. The low angle cross-sets suggest that current energies in either case were probably slight, for no cross-set is greater than a few millimeters in amplitude and the maximum grain size is that of fine sand. Ostracode valves and other skeletal grains form a distinctive shell gravel lag deposit which forms an erosive contact over peloidal muddy sand. Occasional accumulations of jumbled Strophomena brachiopods with shelter voids filled with sparry calcite resemble "unreworked coquinas" described by Jeffery and Aigner (1982). Such deposits indicate storm deposition followed by a return to quiet water conditions and minimal bioturbation.

Stratigraphic note. Unit 4 of the Benbolt Formation is strikingly similar to the description of the Gratton Limestone provided by Cooper and Prouty (1943). They used this 20m thick "calclutite" formation to separate the Benbolt and Wardell formations. Unit 4 differs from the Gratton in that the former contains abundant Strophomena and lacks chert, while the Gratton lacks brachiopods, contains Tetradium, with whitish chert occurring in its lowermost strata. Unit 4 may be the southwesterly equivalent of the Gratton Limestone as indicated by lithologic similarity and comparable stratigraphic position of the two units. However, in keeping with the present stratigraphic scheme for

East Tennessee, this 19.4m thick interval is considered here to be the uppermost unit of the Benbolt Formation.

Wardell Formation

The 15.1m thick Wardell Formation is lithologically distinct from the underlying Benbolt and the contact between the two is sharp and well exposed. The Wardell contains three distinctive units. Unit 5 is a thin (0.4m) interval composed of arenaceous, algal-rich, intraclastic wackestone. Unit 6 is 8.5m of interbedded, horizontally burrowed, poorly fossiliferous lime mudstone and fossiliferous, peloidal packstone. This unit contains well preserved fossil assemblages, including large ramose bryozoans and small, domate tabulate corals (Lichenaria?). Unit 7 is composed of 6.2m of silty, highly fossiliferous, thick bedded packstone and thin beds of pelsparite. This uppermost unit represents a biostromal accumulation of coral, red algae (Solenopora), and numerous bryozoans. Much of the Wardell was microstratigraphically sampled due to its diverse invertebrate assemblages and lithologic complexity. All percentages are given as volume percent of the entire sample.

Unit 5

Description. The 20cm thick beds of unit 5 form an obvious ledge on outcrop which sharply defines the lowermost beds of the Wardell from the thinly bedded calcareous shale of the underlying upper Benbolt.

The lithology is grey or dark grey, coarse grained, and weathers to a crumbly brown limestone along numerous stylolitic partings. Large (up to 5cm long) intraclasts (see Figure 2.5A) are conspicuous on weathered slabs, as are numerous fossils. Small brachiopods, ramose bryozoans, trilobite cephalons, tabulate corals, and echinoderm columnals are all visible on outcrop and are well preserved.

Petrographically, the faunal and floral diversity of unit 5 is most apparent. Up to twenty bryozoan genera and six algal genera are represented, as well as brachiopod valves, trilobite fragments, echinoderm debris, ostracodes, serpulid worm tubes, gastropods, pelecypods, and sponge spicules. Fossil preservation is highly varied; while many "delicate" fossils are perfectly preserved, others are broken and extensively micritized. Echinoderm debris comprises one quarter of the rock volume, followed by bryozoans (7.7%) and green algae (6.3%). Girvanella (2%) is common in encrustations around intraclasts, sometimes encompassing the entire grain, producing a rather large oncoid. Unidentifiable fossil fragments (2%), molluscan debris (1.2%), brachiopods (1%), trilobites and sponge spicules are minor fossil constituents.

Micrite (33%) is largely neomorphosed and contains traces of quartz silt, and other silt-sized terrigenous clastics. Calcite spar (4.2%) occurs largely as cement and void fillings, yet some interparticle bladed spar, presumably of marine origin, is present. Intraclasts (13%) average around 3cm in length, and consist of thinly laminated pelmicrite containing abundant terrigenous clastics, are highly abraded, and biogenically bored. Many intraclasts are encrusted

Figure 2.5. Petrographic features and field photos of Wardell Formation. Stratigraphic up is towards the top of the page unless indicated otherwise.

A. Photonegative of thin section from unit 5. Large intraclast is internally laminated and contains small, interlaminar fenestrae (appear black in photonegative). Note algal and bryozoan encrustation around the intraclast. Very small, circular fossils in matrix are dasycladacean algae. Bryozoans and echinoderms are conspicuous allochems in the left corner. Bar scale is 4.0mm in length. Sample TH24'.

B. Photomicrograph of lithology in unit 5. Vermiporella is large fossil in center. Note elongate echinoderm plates at top left and abraded pieces throughout matrix. Kazakhstanella can be seen in left corner. Bar scale is 1.4mm in length. Sample TH24'.

C. Photonegative of thin section from unit 6 showing storm deposited fossil assemblage of articulated brachiopods, bryozoans, and fossil debris. Sequence fines upward into cross laminated pelsparite. Note escape burrow with spreite. Bar scale is 8.0mm in length. Sample TH29.

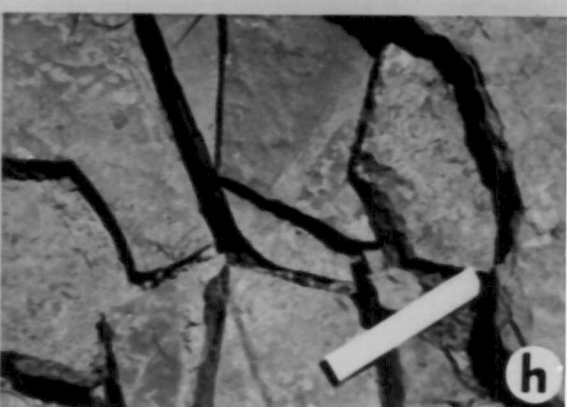
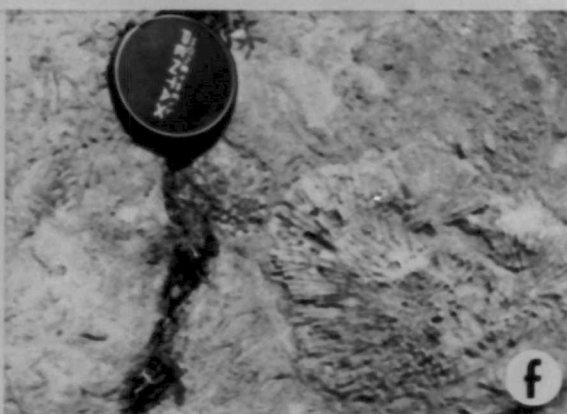
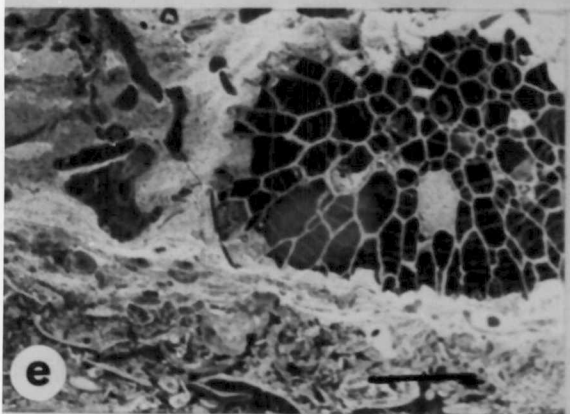
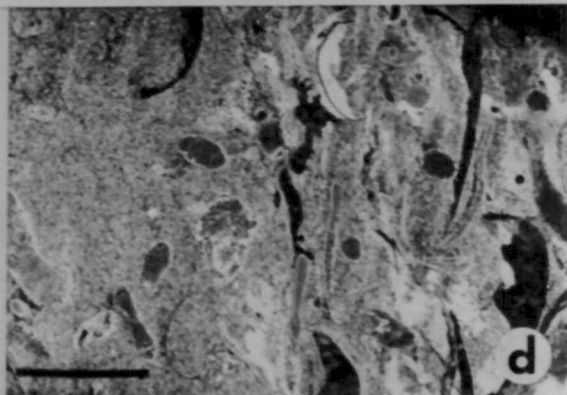
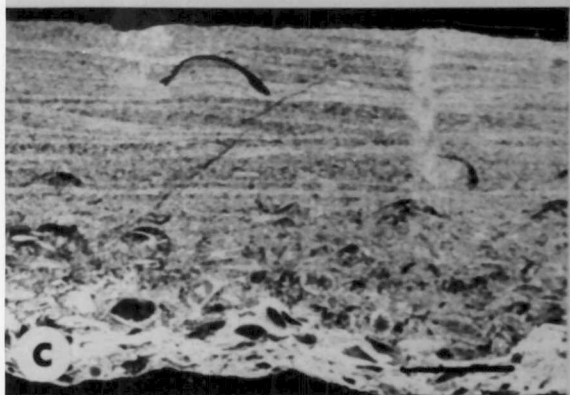
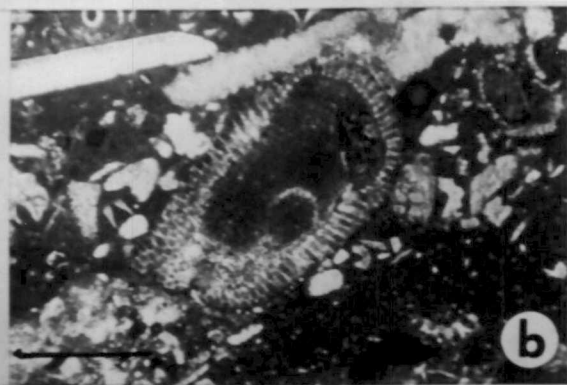
D. Photonegative of thin section showing well preserved fossil assemblage oriented parallel to bedding. Pelecypod valves, oriented concave-down, appear black in photonegative. Note excellently preserved, very thin cryptostome bryozoans. Also notice perched silt in concave-up trilobite moult. Actual size. Sample TH32.

E. Photonegative of thin section showing overturned(?) tabulate coral and numerous bryozoans overlying fossiliferous pelsparite from unit 6. Bar scale is 10mm. Sample TH39

F. Field photo of large tabulate coral (Saffordophyllum) and Solenopora in biostromal accumulation in unit 7. Note nested brachiopod shells around the coral "head". Lens cap is 5.7mm in diameter.

G. Photonegative of thin section showing in situ Amplexopora zooaria within arenaceous pelsparite near top of unit 7. Bar scale is 10mm in length. Sample TH48b.

H. Field photo showing flaggy bedded peloidal packstone interbedded with fossiliferous packstone in unit 7. Ruler is 15cm in length.



by ceramoporid bryozoans and the blue-green alga Girvanella. Peloids (2%) are of various sizes and shapes, yet average 0.7mm in diameter and are presumably fecal pellets.

The well preserved algal flora of unit 5 is the most diverse and abundant assemblage in the Middle Chickamauga at Thorn Hill. The dasyclad algae are most abundant, and include Kazakhstanelia (4%) and Vermiporella (1.6%; Figure 2.5B). Cross sections through the thalli of these algae are common as are a few longitudinal sections, which exhibit their upright cylindrical growth habit. The blue-green alga Girvanella occurs in an encrusting habit around intraclasts and in one instance is found encrusting a hardground surface. Algally coated grains, which commonly contain Girvanella tubules, are found throughout the unit. Representatives of the Rhodophycophyta (red algae) include Contexta, a ramose form, and a lone example of Solenopora (type P of Moore, 1978). Hedstroemia, a codiacean chlorophyte, is found as small, encrusting thalli.

Bryozoans in unit 5 show a high diversity, yet only a few colonies of each of the twenty genera were observed. Ceramoporids are common, and are found encrusting intraclasts and other allochems. Constellaria and Batostoma are the only other encrusters. Ramose bifoliate (Pachydictya, Stictopora, Stictoporella, and Athrophragma) represent the most common growth form. Ramose trepostomes include Nicholsonella, Batostoma, Eridotrypa, and Parvohallopora.

Paleoenvironmental interpretation. Moore (1978) associated the algal assemblage Contexta, Kazakhstanelia, Vermiporella, Hedstroemia,

and Girvanella with highly fossiliferous, subtidal mudbanks found in the Wardell Formation, which were stabilized by encrusting bryozoans and algae. The abundant and diverse fauna clearly indicates a normal marine environment, and the abundant algal flora suggests deposition well within the photic zone. The presence of algal coated grains, however, indicates deposition in less than 10m as found in Holocene sediments (Ginsburg, 1960; Logan et al., 1964). The presence of large abraded and encrusted intraclasts attests to reworking by tidal currents or by surface waves. Planar lamination and large amounts of quartz silt indicate that the intraclasts were derived from other environments for those structures are absent from the host lithology. Perhaps, alternatively, the intraclasts represent a layer of episodically deposited sediment that was semi-lithified, then physically reworked. The arenaceous intraclasts evidently were exposed on the seafloor for a long time as encrustation, abrasion, and endolithic boring suggests.

Unit 5 represents a nearshore, subtidal deposit which occurred adjacent to a terrigenous source. Muddy sediment was largely removed from the environment by tide or wave induced currents. The otherwise clear water supported a diverse assemblage of epifaunal filter feeders and a proliferation of calcareous algae.

Unit 6

Description. Overlying the fossiliferous arenaceous limestone of unit 5 is the poorly fossiliferous lime mudstone of lowermost unit 6.

The lithology consists of grey, thin, flaggy bedded, poorly fossiliferous, horizontally burrowed mudstone, very thin interbedded shale and occasional very thin beds of fossiliferous peloid packstone. On outcrop, Solenopora and small ramose bryozoans are observed in the packstone. Horizontal burrows are sparse but well defined in the lower few meters, yet prevalent in the uppermost portion where Chondrites is common. The peloidal packstone (pelsparite) beds are usually very thinly bedded, but are somewhat thicker near the top of the unit. Typically, the pelsparite is in sharp contact with the underlying mudstone, but there is no evidence of an erosive contact. Pelsparite beds fine upwards from a shelly gravel lag of whole fossils, to peloids and small fossil fragments. The tops of these thin beds often contain small scale, low angle cross lamination. Figure 2.5C shows a typical example of these deposits.

The beds of burrowed mudstone generally consist almost exclusively of micrite (87%) with calcite spar (3%) usually occurring as void fillings in burrows. Fossils are a rare constituent (4.3%) and consist of well worn fragments of ostracodes, echinoderms, sponge spicules, inarticulate brachiopods, and molluscs. Fossil fragments and peloids (1.7%) are found concentrated within the well defined burrows. The rock has inconspicuous, irregular lamination that is only occasionally obscured by burrowing. Silt-sized terrigenous material is found sparsely disseminated throughout the matrix.

The layers of thinly and very thinly bedded fossiliferous peloidal packstone are composed of well preserved fossils (31.4%) and broken, unidentifiable fragments (2.1%) in a matrix of peloids (10%), sparry

calcite cement (28.3%), and microspar (10%). Calcite cement occurs predominately as fine grained blocky spar between allochems, and as coarse grained equant spar in geopetal fillings. Some fibrous and bladed cement occurs internally in some allochems, especially articulated brachiopods. Micrite (16.5%) occurs interstitially among allochems, especially among the larger fossils.

Bryozoans (14%) constitute the most abundant bioclast group, and are most commonly cryptostomes of explanate form such as Pachydictya and Athrophragma plus, ramose trepostomes including Nicholsonella, Parvohallopora, and Eridotrypa. Brachiopods (7%), predominately small (4.2mm), impunctate robust forms, are common within whole fossil shell lags. They are found articulated, but in random orientation. Echinoderm debris (4.6%) is made up mostly of pieces of plates and columnals. Pelecypod valves (2.5%) are present in most pelsparite beds, but only as single valves oriented parallel to bedding (Figure 2.5D). Ostracode valves (2.1%) are found disarticulated within the finer fraction of the pelsparite. Other fossil allochems present include trilobite pieces, inarticulate brachiopods, and sponge spicules. Algae are restricted to large Solenopora "biscuits" (up to 1cm in diameter) which are conspicuous in outcrop.

The uppermost beds of carbonate mudstone and wackestone become increasingly fossiliferous. Moderately bioturbated pelmicrites contain well preserved horizontal burrows and in situ assemblages of Lichenaria, ramose hemispheric, and toppled reticulate bryozoans. Other bedding plane exposures have a current-winnowed fossil assemblage of abundant Sowerbyella valves, trilobite cephalons, and lanceolate and

strap-shaped bryozoans. The lithology changes in the upper 2m of unit 6 into thicker bedded (4cm) packstone and intercalated, very thinly bedded, chippy weathering shale. The shales contain a well preserved, but diminutive fauna of phylloporinids, strap-like ramose bryozoans and trilobite cephalons (Bumastus?).

Petrographic analysis reveals approximately coequal amounts of micrite (29.3%) and spar (28%). Peloids (15%) are abundant, rather small (average size 0.08mm), well rounded, and well sorted. The biota is predominately bryozoans (15%) which, for the most part, consist of ramose forms (Nicholsonella), upright cryptostomes (Athrophragma, Pachydictya, Stictopora), and phylloporinids. Echinoderm debris (6%) is the only other bioclast of volumetric importance. Also present are impunctate and pseudopunctate brachiopods, green algae (Hedstroemia), trilobites, ostracode valves, pelecypod valves, gastropods, inarticulate brachiopods, and serpulid worm tubes. Within this unit, planar laminated, burrowed pelsparite, grades upwards into poorly washed pelsparite with large, well preserved ramose trepostome bryozoans.

Paleoenvironmental interpretation. The lower few meters of unit 6 represent deposition in a shallow subtidal setting which was punctuated by periodic storm deposition. The upper few meters indicate a similar environment except it appears to have been less muddy and supported a more abundant and diverse biota. The mudstone portion of unit 6 appears to have been somewhat restricted for it contains little or no biota except for burrowers. Burrows are abundant in some beds and

essentially absent from others. This feature may be an indication of sedimentation rate, mobility restrictions of the infauna or sediment consistency (Rhoads, 1967; 1975). The horizontal morphology (Planolites) of these borrows suggests they may have been deposit feeders (see Walker and Laporte, 1970). McCall and Tevesz (1983) note that numbers and diversity of infaunal deposit feeders increases offshore because nutrients are winnowed from the sediment in nearshore environments. The network of mudbanks and subtidal pools in Florida Bay restrict circulation which results in widely ranging salinities and water temperatures and an impoverished fauna (Enos and Perkins, 1979). Perhaps the skeletal-poor lithologies of Unit 6 were deposited in a similar restricted, shallow subtidal environment.

The upward fining, skeletal peloidal packstone indicates deposition during periodic high energy events such as storms. These deposits are characterized by a basal lag of larger fossils, many very well preserved, consisting predominately of orthid brachiopods and ramose bryozoans. This is overlain by a planar laminated pelsparite, which often contains escape structures (Figure 2.5C). The uppermost layers contain evidence of wave ripple lamination, and occasionally, pelitic mud caps the sequence. This sequence is identical to that described by Aigner (1982) for "proximal tempestites" deposited near shore on marine shelf platforms. Moreover, the presence of shelter porosity, and micrograded sediment perched on bioclasts (Figure 2.5D) in many of the thicker pelsparite beds is an indication of an episodic high energy event in a normally quiet water environment (Kreisa, 1981; Kreisa and Bambach, 1982).

Appearance of in situ fossil assemblages indicates a return to a less restricted environment. The occurrence of Lichenaria? and large ramose bryozoans directly on a surface of burrowed pelmicrite indicates that the substrate was rather firm when colonized. Well defined burrow morphologies in conjunction with diffuse burrows substantiate a progressive firming of the substratum allowing for colonization by epifaunal invertebrates. This phenomenon is one of several termed synsedimentary sediment modification by Walker and Diehl (1986) and will be discussed in more detail in Chapter 4.

Unit 6 depicts a restricted, muddy environment occasionally influenced by storms which blanketed the muds with a deposit of shell material from adjacent, open marine environments. Gradually, facies migration resulted in an increasingly less restricted environment, a more prolific invertebrate fauna, and increased carbonate production.

Unit 7

Description. Unit 7 is 7.5m of grey, tan weathering, medium bedded (up to 35cm), very fossiliferous packstone interbedded with dark grey, thin to medium bedded peloidal packstone. Macrofossils include large (average size 8cm, up to 15cm), discoid and hemispheric tabulate coral colonies (Saffordophyllum), algal biscuits of extensively bored Solenopora (3 to 4cm in diameter), ramose and encrusting bryozoans, nested strophomenid brachiopods, echinoderm debris and trilobite cephalons (Figure 2.5E). Unit 7 is locally severely weathered, with extensive caliche development and some evidence of solution channels.

The unit grades upward into bryozoan-rich peloidal skeletal sands, then abruptly changes into brown, argillaceous lime mudstone of the Bowen Formation.

Bioclasts (51%) make up the majority of rock volume in unit 7. Many fossils are in life position and excellently preserved, however neomorphism and stylolitization have altered what is an otherwise a marvelously preserved fossil assemblage. Bryozoans (22.2%) are the most abundant biotic component (see Figure 2.4, page 27); at least 23 genera are represented and most growth forms are exhibited. Encrusting forms are prevalent and sometimes are the dominant morphology, some representatives include: ceramoporids, Constellaria, and Batostoma. Robust ramose, lanceolate, and explanate forms are present in all samples. The more common genera include Parvohallopora, Nicholsonella, Athrophragma, Amplexopora, and Diplotrypa. Amplexopora completely dominates a bed of siliciclastic-rich pelsparite, comprising about 50% of the lithology (Figure 2.5G). Tabulate corals (Saffordophyllum, Foerstephyllum?, 8.6%) are locally dominant in some beds along with Solenopora (6.9%). Bedding plane exposure reveals in place assemblages composed almost entirely of bryozoans, coral heads and Solenopora, with fossil fragments and nested strophomenid brachiopods filling the interstices (Figure 2.5F). Echinoderms (6.8%) are generally pieces of pelmatozoan columnals. However, a complete specimen of Ristocrinus altobasalis was found, in addition to plates of the paracrinoid Batherocystis appressa. Brachiopods (3.8%), and trilobite debris (1%), are locally abundant, especially where they have accumulated around coral heads and Solenopora. Ostracodes are ubiquitous and often still

articulated. However, they are generally sparsely distributed. Molluscan debris, inarticulate brachiopods, and serpulid worm tubes are other invertebrate fossils found in unit 7. Other calcareous algal genera include Hedstroemia and Sphaerocodium(?), which are often found encrusting fossil fragments. Algal coatings (Girvanella and Spongiostroma) and micrite envelopes are common, especially in the upper 2.5m of unit 7, where much of the lithology appears to have been physically reworked.

The matrix surrounding the bioclasts is either micrite (24%), which is often neomorphosed to microspar (6.8%), or blocky calcite cement (15.4%). Small (approximately 0.05mm) well rounded peloids (1.8%) are common in the well washed sparry areas. Intraclasts are found in some samples but are volumetrically a minor constituent. The intraclasts are mostly well rounded, organic-rich micrite, and average about 4mm in size. Stylolitization is locally extensive. Most stylolites are irregular, anastomosing sets (Logan and Semeniuk, 1976) that are often associated with micritic areas of the rock. It appears that neomorphism is associated with the stylolitized portions of the lithology, resulting in thin laminations of dark brown, neospar-rich reactate (3.8%) that contains partially dissolved fossils and dolomite rhombs (2.1%). Quartz silt (1.3%) is present in all samples and is locally abundant, forming 5.3% of the lithology near the Wardell-Bowen contact.

Thin beds of pelsparite are often interbedded with the highly fossiliferous wackestone and packstone of unit 7. The lithology is dark grey, poorly fossiliferous, horizontally laminated, sometimes

cross laminated, and often contains escape structures. In outcrop, these beds appear as flaggy beds of dark grey packstone with circular depressions representing the tops of the escape burrows (see Figure 2.5H). Fine grained blocky calcite cement (37%) and microspar (11%) make up most of the matrix except in the upper portions of fining upwards sequences where micrite (23%) is found interstitially to peloids (14%). Some fibrous, presumably marine fringing cement (5.3%) surrounds coarser grained fossil debris which is mostly ostracode valves (4.3%) and unidentifiable fragments (2.3%). Identifiable fragments include trilobites, bryozoans, echinoderms, and sponge spicules. Many of the pelsparite beds contain low angle, ripple cross lamination in their upper parts.

Paleoenvironmental interpretation. Unit 7 was deposited in a nearshore, shallow subtidal environment. The presence of a rich, varied biota and a significant algal flora indicates a shallow, normal marine environment. Evidence of ripple cross-laminations and nested brachiopods among coral and algal heads indicates deposition above normal wave base, which can be rather shallow on broad carbonate shelves. Additionally, the stratigraphic proximity to the supratidal environments of the Bowen Formation makes a shallow water interpretation the most plausible.

The skeletal limestone of unit 7 represents a biostromal bank. The term biostrome refers to any "purely bedded structure . . . consisting of and built mainly by sedentary organisms, and not swelling into moundlike or lenslike forms, . . . which means layer or bed"

(Cummings, 1932). The bedded nature of the skeletal limestone of unit 7 clearly defines such a structure. Nelson et al. (1962) define a reef as "a skeletal limestone deposit formed by organisms possessing the ecologic potential to erect a rigid, wave-resistant, topographic structure." While the biogenic limestone of the unit does not form such a topographic structure, bryozoans, tabulate corals, and red algae are found in reefs throughout the Middle Ordovician (Walker and Ferrigno, 1973; Alberstadt et al., 1974; Copper and Morrison, 1978; James, 1983). Thus, although these organisms definitely had the "ecologic potential" to form a resistant structure, the shallow water depth inhibited upwards growth of the skeletal accumulation. Heckel (1974) defines such low relief structures as biostromal banks.

Among the biostromal accumulations, patches of peloidal and skeletal sands accumulated as sand blankets or sheets. Small scale, current influenced, asymmetric ripple marks are found on some bedding surfaces with their steep sides dipping very gently to the southwest. The internal structure of these ancient sand sheet deposits are somewhat similar to the modern oolitic sands described by Ball (1967) and Hine (1977). Both authors conclude that the surface sands are constantly reworked by tidal currents and wave energy, the larger scale bedforms move episodically in higher energy events such as currents associated with major cyclonic storms. Escape traces found within the pelsparite beds attest to rapid deposition, which buried some mobile invertebrates.

While the majority of carbonate sand is composed of broken and abraded allochthonous fossils and peloids, the occurrence of many well

preserved fossils of sedentary organisms may indicate invertebrate colonization of the peloidal sands. Modern carbonate sand is regarded as being generally devoid of sessile invertebrate faunas except in highly specialized taxa (Shepherd, 1983) or where organisms such as seagrass provide protection and stabilize the substrate (Davies, 1970; Young and Young, 1982). Actively burrowing faunas, however, thrive in mobile sediment and effectively increase the competency of the sediment by removing pore water (Rhoads and Boyer, 1982). During periods of non-deposition (or non-migration of the sand sheets) sessile suspension feeders could inhabit the unstable substrate, with the aid of the "colonizing" mobile infauna.

The association of biostromes and skeletal sand in unit 7 depicts a patchwork environment of low relief biostromes surrounded by carbonate sands. Similar modern environments can be found fringing back-reef slopes such as at Carrie Bow Cay, Belize (Burke, 1982), and Allacran Reef, Yucatan (Logan, 1969), or as nearshore accumulations found off Abu Dhabi in the Persian Gulf (Evans et al., 1973). Copper and Morrison (1978) describe a similar shallow water biostrome in the Middle Ordovician of Manitoulin Island, Canada. They observed Tetradium colonies which appear to have initiated growth on bioclastic debris and subsequently were encrusted by bryozoans and stromatoporoids. Upward shoaling in Unit 7 appears to have limited the development of the biostromal accumulations. Read (1980) attributes the small size of Ordovician biostromes in the Wassam Formation of Virginia to static or falling sea level and restricted conditions.

Bowen Formation

Thinly bedded, brown and tan weathering argillaceous limestone of the Bowen Formation forms a sharp contact with the underlying, medium bedded, grey fossiliferous limestones of the Wardell. The Bowen is 26m thick at Thorn Hill and is composed of three units. Unit 8 consists of 8.6m of brownish grey and reddish lime mudstone which contains birdseyes, and is vertically burrowed and mudcracked. Unit 9 is 5.7m of tan and cream colored finely laminated, desiccated lime mudstone and contains a single bed of skeletal packstone. Unit 10, similar to Unit 8, is predominantly medium bedded, red and maroon, internally laminated, argillaceous lime mudstone. The Bowen is impoverished in fossils, containing mostly vertical and horizontal traces, ostracodes, serpulid worms, and molluscs.

Unit 8

Description. The rocks immediately above the Wardell-Bowen contact are very thinly bedded, internally cross laminated, shaly brown pelmicrite. The lamination is micrograded, with a basal lag of comminuted ostracode valves and fossil fragments grading upward to small peloids (less than 0.05mm) and quartz silt and ultimately argillaceous micrite. The brownish, chippy weathering shaly lithology at the contact is gradational with tan to reddish brown mudstone which is characteristic of the unit.

The most dominant lithology of unit 8 consists of tan and reddish

brown, thinly laminated, argillaceous, very sparsely fossiliferous pelmicrite and dismicrite. Individual laminae are planar or slightly undulatory, often micrograded, occasionally cross stratified, and usually disrupted by burrows or desiccation features (Figures 2.6A, B, and C). Argillaceous micrite comprises two thirds of the rock volume with up to 12% (average 5%) subangular to rounded grains of quartz silt, disseminated throughout the matrix. Some thin laminae of pelsparite show very low angle cross beds (less than 1cm in amplitude) that have erosive contacts with the underlying planar lamination. Fossil fragments (1.5%), most commonly disarticulated ostracode valves or sponge spicules, are found oriented parallel to bedding or filling burrows.

Interlaminar and irregular birdseyes or fenestrae are common throughout the Bowen Formation. Interlaminar birdseyes are typically less than a millimeter high and a few millimeters long. Irregular birdseyes in unit 8 are larger, oblong and branched voids a few millimeters in size. Shinn (1968a) found that desiccation of Recent lime mudstones in the Florida Keys produce similar types of birdseyes through shrinkage due to dewatering and gas bubble formation. Birdseyes are most commonly found preserved in high intertidal or supratidal environments on modern carbonate tidal flats including Florida, the Bahamas, and the Persian Gulf (Shinn, 1983).

Vertical, subvertical, and horizontal burrows are conspicuous throughout unit 8. Typically, they are filled with blocky calcite spar, peloids, fossil debris, micrite and quartz silt. Burrows vary in diameter, and generally are found in three sizes: 1) small (less than

Figure 2.6. Petrographic features and field photo of Bowen Formation. Stratigraphic up is towards top of page in all photos.

A. Photomicrograph of lithology from unit 8. Finely laminated fabric is cut by diffuse vertical burrow. Lithology consists of peloids, few fossil fragments, very fine grained sparry calcite, and argillaceous micrite. Scale bar is 1.5mm. Sample TH54.

B. Photomicrograph of well defined vertical burrow and interlaminar birdseyes from unit 8. Notice that peloids and fossil fragments fill the upper portion of the burrow. Scale bar is 1.2mm in length. Sample TH51.

C. Field photo of top surface of float block in unit 8. Notice the well preserved desiccation mudcracks, enhanced by weathering. Ruler is 15cm long.

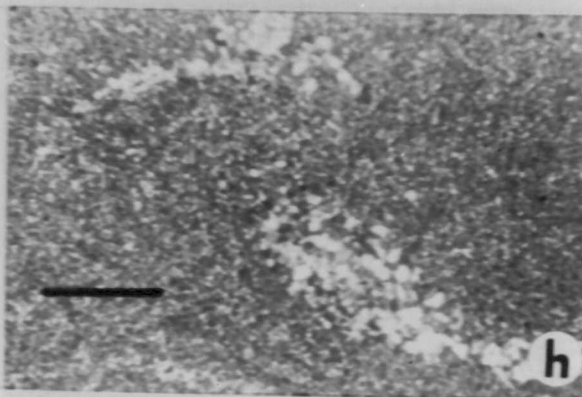
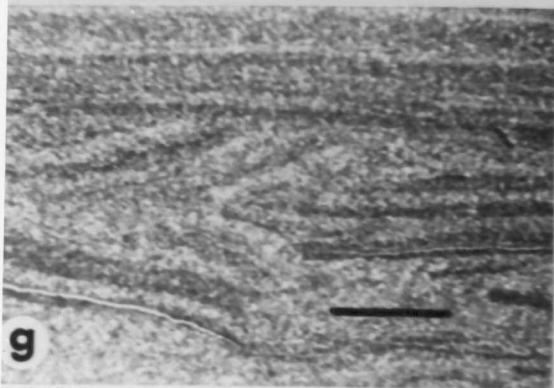
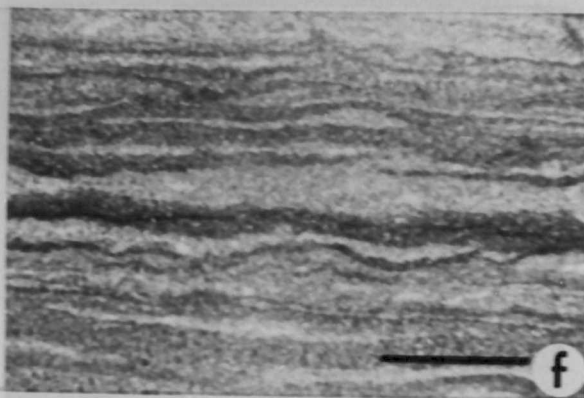
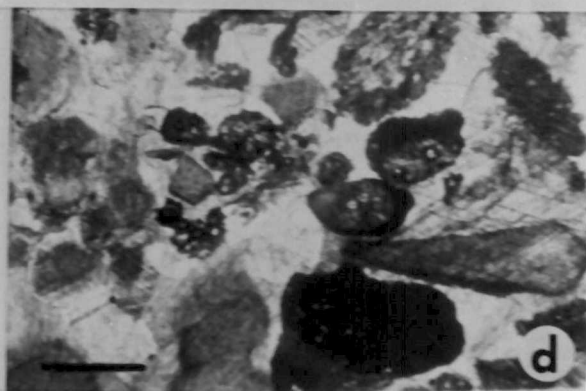
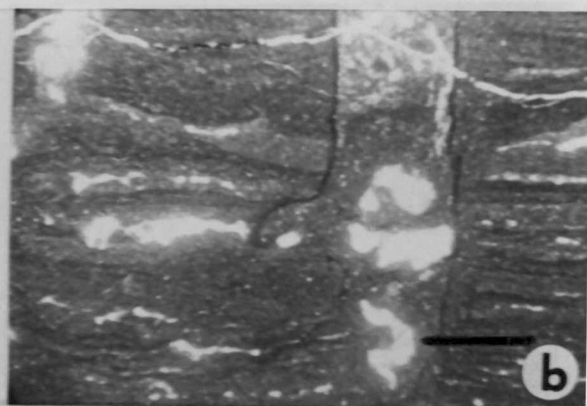
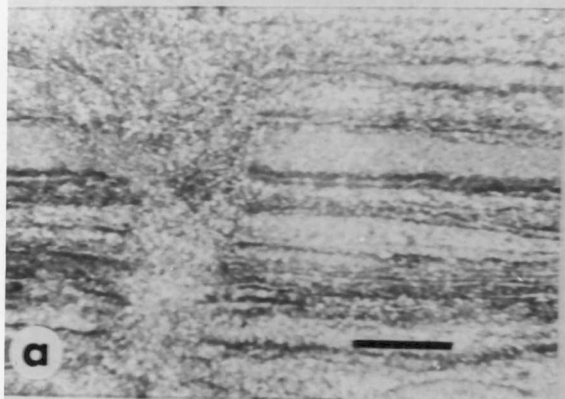
D. Photomicrograph of packstone bed from unit 9. Note poor preservation of echinoderm pieces, adhered micrite on bryozoans, and organic-rich intraclast. Bar is 1.5mm in length. Sample TH57.

E. Photomicrograph of well preserved, "restricted" fossil assemblage from unit 9. Notice the large ostracode valve, Solenopora, and cross section of coiled serpulid worm tube (Spirorbis?). Scale bar is 1.4mm in length. Sample TH58.

F. Crenulated (algal?) laminae in photomicrograph from unit 10. Notice the micrograded nature of the laminae. Scale bar is 1.5mm. Sample TH60.

G. Photomicrograph of finely cross laminated fabric from unit 10. Notice that the planar laminae cut across the upper set of cross laminae. Scale bar is 1.0mm in length. Sample TH60.

H. Photomicrograph of subvertical burrow filled with quartz sand. Note homogenized character of sediment which surrounds the burrows. Plane light. Scale bar is 1.3mm in length. Sample TH61.



0.1mm), 2) medium (approximately 0.4mm), and 3) large (greater than 1.0mm). The small vertical burrows generally extend no more than a few centimeters into the substratum, while the medium and large burrows attain lengths of over 10cm. An example of a small sized burrow is seen in Figure 2.6B. Most vertical burrows are well defined, and many exhibit "deformation halos." Deformation features around burrows may suggest burrowing occurred in firm substrates (Rhoads, 1970; Walker, 1974; Howard, 1975; Walker and Diehl, 1986). Horizontal burrows, as well, are usually very well preserved, however localized burrow mottling indicates areas where softer substrate allowed complete reworking by grazers and deposit feeders.

Mudcrack polygons are a conspicuous feature of unit 8 (Figure 2.6C). They are typically rather wide (up to 15cm) and extend over 4cm into the sediment, cutting many generations of laminae. Large mudcracks are typical of sediments that have been subaerially exposed for extended periods (Ginsburg, et al., 1977). Although mudcracked carbonates commonly are dolomitized (Shinn, 1968b), no evidence of primary dolomite is present.

Paleoenvironmental interpretation. Fenestral fabric, thinly laminated sediment, abundant vertical burrows, mudcrack polygons, and a sparse, restricted biota indicate a supratidal to high intertidal environment of deposition for unit 8. The lowermost, argillaceous beds of the unit lack mudcracks and birdeyes and were probably deposited on a very shallow subtidal or low intertidal mudbank. This sequence shoals upward into reddish brown, desiccated mudstone which, except for

the color, resembles sediment deposited on Holocene carbonate tidal flats.

The thinly laminated nature of supratidal deposits on carbonate tidal flats is attributed to spring and storm tide deposition (Ball, et al., 1967; Shinn, et al. 1969). Such events flood the flats with sediment laden water, leaving a thin layer sediment derived from adjacent environments. Additionally, blue-green algal mats aid in trapping fine grained sediment, resulting in a laminated fabric that may be organic rich (Davies, 1970). Subsequent drying of the sediment results in mudcracks, birdeyes, and possibly dolomite formation.

Unit 8 contains no evidence of penecontemporaneous dolomite or evaporites which are found on many modern carbonate tidal flats. Dolomite formation has been documented by different processes, yet generally involves the mixing of Mg-rich brines with underlying sediment [seepage refluxion model of Adams and Rhodes (1960) and Deffeyes, et al. (1965)] or with overlying sediment [capillary concentration model of Shinn, et al. (1965)], producing very fine grained, dolomitic laminae. Simonson and Walker (1984) and Simonson (1985) indicate that mixed carbonate-siliciclastic tidal flats may not form dolomite due to: 1) abundance of clay minerals which could capture magnesium ions and 2) humid environmental conditions which inhibit formation of Mg-rich brines. Unit 8 is argillaceous lime mudstone with no evidence of evaporites, which suggests tidal flat deposition in a muddy, humid environment, similar to the interpretation for the New Market Limestone by Grover and Read (1978) and for the Moccasin Formation described at length by Simonson (1985).

Unit 9

Description. Unit 9 is 5.7m of blue grey to cream colored, thin to medium bedded lime mudstone, fossiliferous wackestone and a solitary, 10cm thick bed of fossiliferous, peloidal packstone/wackestone. The lithology is finely laminated or massive, extensively burrowed (vertical and horizontal morphologies), and contains polygonal mudcracks averaging 6cm in width. Fenestral voids are abundant in addition to pseudo-birdseye structures described by Shinn (1983a; 1983b) as calcite filled burrows or root tubes.

An abrupt color change demarcates the contact of the reddish mudrock of unit 8 with the cream colored unit 9. Petrologically, however, the units are not as easily distinguished. Unit 9, while occasionally laminated, is heavily bioturbated and more fossiliferous. Fossil fragments, commonly disarticulated ostracode valves (1.5%), trilobite fragments (3%), and pieces of serpulid worm tubes (0.7%), are found as fossil lags in micrograded sequences. The single bed of fossiliferous packstone/wackestone grades upward from poorly washed to well washed peloidal packstone within the bed. Fossils are oriented parallel to bedding, poorly preserved, show evidence of physical abrasion and bioerosion by endolithic algae or fungi, and often have micrite adhered to their outer surfaces. Adhered micrite results from fossils exhumed and reworked from their original burial site (Kreisa, 1981). Although adhered micrite resembles algal coatings or micrite rims, it is distinguished by its irregular distribution around the

allochem, and generally structureless appearance (Ewing, 1985). Echinoderms (20%) and bryozoans (15%) are the most common fossils. Calcareous algae (Hedstroemia, Solenopora, Spongiostroma) are commonly found encrusting fossil allochems. Shelter voids are common beneath larger fossil fragments and are filled with coarse grained blocky calcite.

Well preserved fossils of ostracodes, molluscs, trilobites, and serpulid worms are found in beds of heavily bioturbated wackestone of unit 9 (Figure 2.6E). The wackestone (biomicrite) is irregularly bedded, probably due to multiple generations of burrowing. Burrows range widely in size, preservation, and morphology. Intraclasts (4.3%) are unfossiliferous dismicrite and contain distinct burrows and no fossils.

Paleoenvironmental interpretation. Unit 9 suggests deposition in a subtidal to low intertidal and supratidal environment. The unlaminated sediment reflects intense bioturbation, indicated by the churned appearance of the fine grained sediment. The muddy sediment contains randomly oriented, yet well preserved fossils. Although irregular lamination is found, it is commonly intensely burrowed. Deposition of (algally?) laminated sediment was followed by extended periods of high water that allowed deposit feeders to invade the sediment. Tidal ponds in the Bahamas described by Shinn et al. (1969) display a similar burrow-homogenized, fine grained sediment. The tidal ponds could have periodically been abandoned by channel migration, only to be reactivated by subsequent channel migration or storm tides.

The coarse grained, bioclastic packstone/wackestone represents a temporary return to subtidal, skeletal sand deposition like that of the Wardell. Preferred orientation and abundant shelter voids suggest an episodic, high energy event within a lower energy regime (Kreisa and Bambach, 1982). Because the fossil biota is inconsistent with the harsh conditions associated with tidal flats, it is concluded that the source of this deposit was a contiguous marine environment, strongly reminiscent of the upper Wardell. The packstone, which lacks desiccation features and ripple cross lamination, must have been deposited subtidally and subsequently reworked.

Unit 9 exhibits a complex facies pattern reflecting a transitional environment on an ancient tidal flat. Though parts of the flat were exposed for long periods, adjacent tidal ponds and subtidal banks supported an indigenous biota. Lateral migration of these facies resulted in the present stratigraphy.

Unit 10

Description. The brick red, thin to medium bedded, conspicuously vertically burrowed, fenestral lime mudstone of unit 10 is almost identical to unit 8. However, the former is: 1) generally more fossiliferous, 2) contains evidence of cryptalgal lamination and 3) is occasionally interbedded with cream colored lime mudstone.

Unit 10 is predominantly finely laminated micrite (52%), and micrograded intrapelmicrite and rarely cross laminated pelsparite containing abundant peloids (23%) and angular intraclasts (3%), with

some fine grained sparry calcite matrix (14%). While most laminae are generally planar, some exhibit the crenulated texture associated with sediment binding by blue-green algal mats. Logan et al. (1974) describe similar laminoid cryptalgal structures forming in the lower intertidal zone of Hamelin Pool, Australia, associated with smooth algal mats. Some laminae, however, are finely cross laminated as shown in Figure 2.6G.

Vertical burrows are sometimes quite long (8cm) and are typically filled with peloids, fossil fragments, quartz silt, and blocky calcite. Interestingly, some horizontal burrows contain sand-sized quartz grains which are generally absent from the matrix. This feature is seen in Figure 2.6H. Many deposit feeders are size selective, thus leaving size segregated grains within their burrows (Byers, 1982). Additionally, Tudhope and Scoffin (1984) report size selectivity by the burrowing shrimp Callianassa in Davies Reef Lagoon, Australia, which results in an inhomogeneous sediment.

Paleoenvironmental interpretation. Unit 10 was deposited within the intertidal and supratidal zone of a mixed carbonate-terrigenous clastic tidal flat. Episodic flooding of the tidal flat resulted in deposition of micrograded and cross laminated pelsparite laminae which subsequently were dried or colonized by blue-green algal mats. The seaward, intertidal zone was reworked by burrowing deposit feeders during periods of high water, resulting in a homogenized sediment. Infaunal suspension feeders dominated the landward intertidal regime because they could escape drying by constructing deeper burrows.

The abundance of sand and silt sized quartz (2.3%) and argillaceous material in unit 10 suggests a distant terrigenous source areas. The silt-sized quartz could represent wind-blown sediment derived from terrigenous environments to the southeast. The intertidal sediment of the northern Persian Gulf contain a significant amount of eolian silt derived from dust storms. Such storms are capable of transporting silt and sand sized grains up to 5000m (Kukal and Saadallah, 1973). In exposures of the Bowen in southwest Virginia, however, a thin basal deposit of terrigenous sandstone (Cooper and Prouty, 1943; Prouty, 1946) indicates fluvial or deltaic sedimentation (Read, 1980; Ruppel and Walker, 1984). Unit 10 was deposited within seaward intertidal and supratidal environments of this short lived deltaic system.

The Bowen is very similar to the Moccasin Formation which overlies the middle Chickamauga. Both lithologies contain many features indicative of subaerial exposure (e.g. mudcracks and fenestral fabric). However, both formations lack penecontemporaneous dolomite, evaporites, and have only sparse evidence of cryptalgal lamination; all of which are commonly associated with carbonate tidal flats. The similarities between the Bowen and Moccasin formations suggests they were deposited in similar depositional environments. Simonson (1985) interpreted the depositional environment of the Moccasin as an extremely broad mixed carbonate-terrigenous clastic tidal flat deposited within a humid climate. The Bowen represents a similar depositional environment; however, the tidal flat was not as extensive nor as persistent as the Moccasin environment. The Bowen tidal deposit either indicates a

short-lived regression or temporary end to subsidence, which allowed the westward progradation of shoreward environments.

Witten Formation

The Witten Formation at Thorn Hill comprises about 73m of blue grey, locally fossiliferous wackestone with rare cream colored and reddish brown sparsely fossiliferous lime mudstone units. The formation is divided into three units. Unit 11 is 27m of gently folded, thinly bedded, light grey, locally fossiliferous mudstone, wackestone, and packstone. Unit 12 is 19.8m of laminated, thinly bedded, light grey to reddish brown and buff, intraclastic, fenestral lime mudstone. Unit 13 is 26m of light to dark grey, thin to medium bedded, locally very fossiliferous wackestone and packstone with rare intercalated shale.

Unit 11

Description. The lower 14m of unit 11 consists of poorly exposed, thin, flaggy bedded fossiliferous blue-grey limestone with numerous well-defined horizontal burrows. The rock is conspicuously fractured and gently folded, resulting in repetition of 1.5m of section. The remainder of the unit is essentially undeformed, better exposed, and lithologically similar. Fossils are most numerous on bedding planes, consisting mainly of gastropods (Figure 2.7A) (3%), bivalves (1.3%), and other molluscan debris (2.2%). Bryozoans, brachiopods, ostracodes,

Figure 2.7. Field photos and petrographic features of Witten Formation. Stratigraphic up is towards top of page unless indicated otherwise.

A. Field photo of bedding plane exposure of unit 11. Note the low spired gastropods which are conspicuous on the weathered surface. Scale at bottom of photo is in millimeters.

B. Photonegative of thin section from unit 11. Note the three depositional events recorded in this bed. The lowermost portion is lime mudstone in erosive contact with climbing ripple cross laminated pelmicrite, which is overlain by a well preserved fossil assemblage consisting mostly of geopetally-filled gastropods (pore filling calcite appears black in photonegative). Bar is 1.0mm in length. Sample TH76.

C. Photonegative of thin section from unit 11 showing well preserved molluscan assemblage in wackestone in erosive contact with upward-fining (storm deposited) assemblage. Notice the well preserved trepostome bryozoans in the uppermost stratum. Scale bar is 10mm in length. Sample TH69.

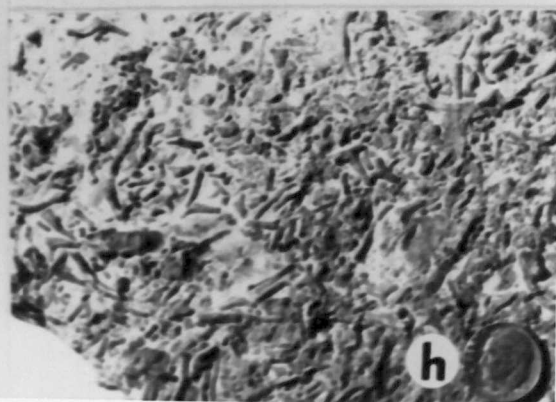
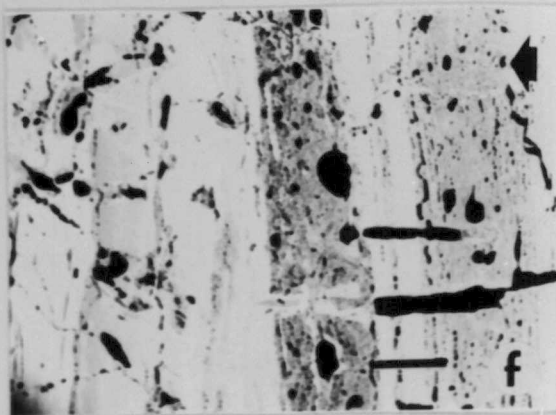
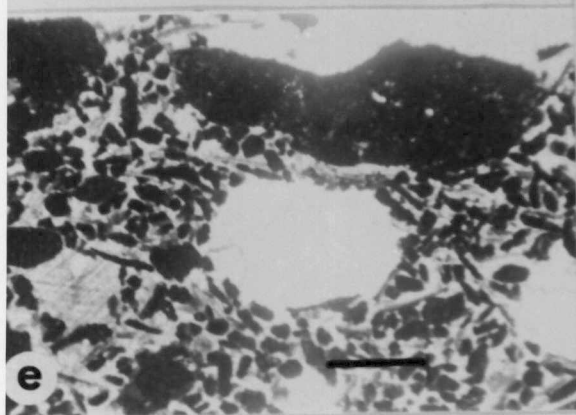
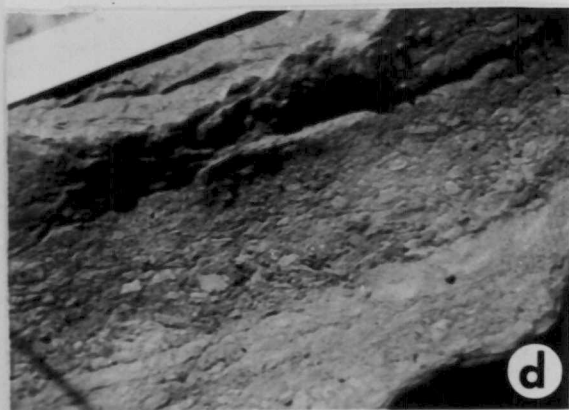
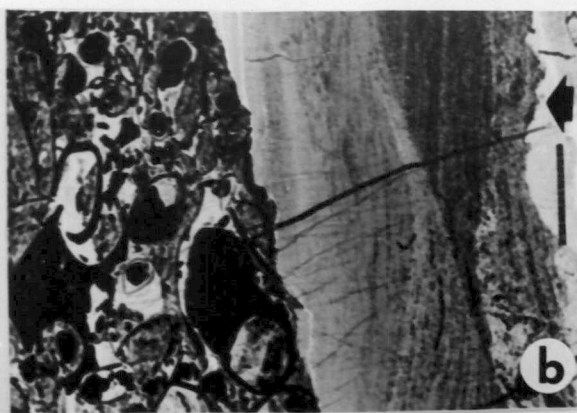
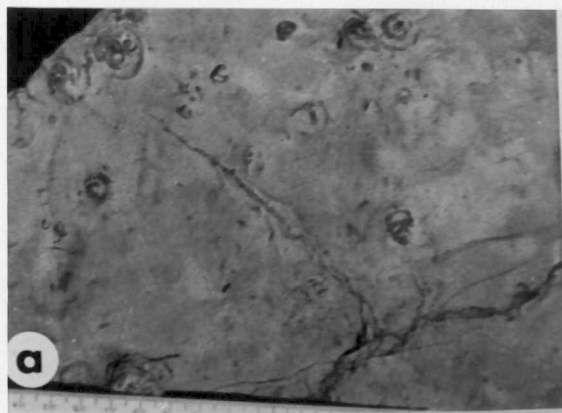
D. Field photo of intraclastic packstone bed in unit 12. Note the sharp upper contact, and poor sorting. Ruler is 15mm in width.

E. Photomicrograph of intraclastic packstone lithology from unit 12. Note that the intraclasts vary in size and shape and grade into peloid-sized allochems. Subcircular voids are keystone vugs. Fossil fragments are mostly ostracode valves. Scale bar is 1.0mm in length. Sample TH74.

F. Photonegative of thin section from unit 12. Lithology is heavily bioturbated dismicrite and illustrating "true" fenestrae (interlaminar voids) produced by desiccation, and pseudo-birdseyes produced by burrowing. Both appear black in photonegative. Scale bar is 5.0mm in length. Sample TH79.

G. Photonegative of thin section illustrating three depositional episodes. Note low angle cross lamination in the two lower beds, which contain basal lag deposits of small intraclasts and fossil fragments. The upper left bed consists of a well preserved bryozoan assemblage at its base (black in photonegative) overlain by argillaceous lime mudstone. Scale bar is 11mm in length. Sample TH82.

H. Float slab from unit 13 showing a weathered surface of a well preserved ramose bryozoan (Homotrypa) assemblage. Other fossils are trilobite pieces and small orthid brachiopods. Dime for scale.



and small orthoconic cephalopods are commonly articulated or well preserved, yet in trace amounts. Fragments of echinoderms, trilobites, and serpulid worms are common matrix constituents. Quartz silt, which is abundant in most of the underlying lithologies is noticeably scarce in unit 11.

Many bedding surfaces show evidence of scour and hardground formation indicating episodic sedimentation. Several episodes of deposition and subsequent removal are preserved. Scoured contacts are identified by truncated skeletal grains and knife sharp textural changes from burrowed biomicrite to size graded biosparite composed of bioclastic debris and intraclasts. Figure 2.7B shows an example of this feature. The resulting storm deposit often superficially resembles a Bouma sequence (Aigner, 1982). The lower contact is erosional and often quite distinct. A basal deposit of bioclasts fines upward into planar laminated bioclastic wackestone, and finally into bioturbated lime mudstone or wackestone. Commonly, mixtures of well preserved, probably autochthonous, fossils are found with obviously reworked, broken and abraded skeletal grains. This may be evidence of repeated storm and biogenic reworking after colonization of a previous storm layer. Such deposits are termed parautochthonous accumulations by Fursich (1982).

The fauna of unit 11 is indicative of partially restricted conditions, and generally firm substrates. Gastropods are commonly very well preserved and dominate many fossil assemblages. Low spired forms are most common, although some high spired shells are also present. Pelecypod casts and replaced shells are present on some

bedding planes. Ostracodes, trilobites, inarticulate brachiopods, and serpulid worm tubes are present in most samples. The ostracodes are commonly articulated and well preserved. Bryozoans are locally abundant, yet diversity is low. Ceramophylla, a ceramoporid, is common, as is Homotrypa, which is often found associated with arthrostylids. Bifoliate, such as Stictopora, are small, lanceolate in construction, and rare. The most common bryozoans are thin, ramose trepostomes, usually Amplexopora or Nicholsonella. Algae are rare in the lower few meters of unit 11, but are common in overlying beds. Hedstroemia is found as sparse thalli and encrustations on skeletal grains. Spongiostroma is commonly an encruster, often forming algal coatings on bioclasts. Many allochems have micrite coatings, presumably the result of microborings by algae or fungi. While microborings are found at essentially all depths and environments, they are most prolific within quiet, shallow water (Golubic et al., 1975). The scarcity of extensively micritized grains in unit 11 suggests that fossils were exposed on the seafloor only a short time before burial.

Paleoenvironmental interpretation. Unit 11 indicates a return to shallow subtidal conditions. This interpretation is based on: 1) presence of a diverse marine fauna, 2) absence of vertical burrows, birdseyes, mudcracks, and cryptalgal lamination, 3) marked reduction in terrigenous material concomitant with pure carbonate deposition, and 4) lack of thinly laminated fabric. Although the sediment implies subtidal deposition, the fauna of unit 11 indicated a restricted environment. Gastropods, pelecypods, trilobites, and ostracodes are

the most common taxa observed in unit 11 (Figure 2.7C). The groups generally are considered eurytopic. Additionally, brachiopods, bryozoans, and echinoderms, generally considered stenotopic taxa, are considerably less common in unit 11, while being more numerous in other subtidal units.

The nonlaminated nature of the fine grained sediment indicates an active burrowing infauna. Burrows show numerous generations of burrowing in soft and firm substrates. Presumably, the sediment was initially soft and burrowing was easily accomplished and extensive. With time, however, the sediment lost water, was compacted, partially cemented, and colonized by sediment stabilizing invertebrates. The resulting sediment is generally homogenized, and often contains distinct horizontal burrows.

Unit 11 was deposited under wholly subtidal conditions that were somewhat restricted. Current activity was probably minimal except during storms which were of sufficient force to remove material and deposit it elsewhere on the shelf. Restricted conditions may have occurred due to the extensive breadth of the shelf which would have inhibited water exchange and promoted elevated temperatures and/or salinities (Wilson and Jordan, 1983). Walker (1977) believes this Ordovician shelf was about 70,000 km² in area.

Unit 12

Description. Unit 12 is light grey to buff or cream colored, sometimes reddish, thinly bedded, occasionally internally laminated,

lime mudstone and poorly fossiliferous wackestone. Large mudcrack polygons (approximately 12cm across), spar-filled vertical burrows, irregular and interlaminar birdseyes, and fine, irregular (algal?) lamination attest to periodic subaerial exposure. Desiccation features are increasingly common upwards in the unit. A thin bed of reddish lime mudstone occurs near the top of unit 12, which grades rather sharply upwards to blue grey, fossiliferous wackestone of unit 13. Generally, argillaceous mud and quartz silt are rare in unit 12.

Intraclasts are a common feature in unit 12. Typically, they are light grey, occasionally desiccated lime mudstone, somewhat angular, and vary widely in size up to 2cm long, and 0.5cm wide (Figure 2.7C). Some very thinly bedded lithologies contain up to 58% intraclasts in a sparry matrix in which keystone vugs and abundant (5.6%) ostracode valves are found. Keystone vugs are formed by spherical gas bubbles trapped within coarse grained intertidal lithologies by flood tides (Inden and Moore, 1983), an example is seen in Figure 2.7D. The intraclastic beds form knife sharp contacts with overlying and underlying lithologies, indicating these beds were formed by rapid, short-term, high energy events. The resemblance of the intraclasts to the surrounding sediment, and their angular appearance, indicates these clasts were essentially autochthonous accumulations. Shinn, et al. (1969) report that redeposition of mud chips is common on beach ridges in intertidal and supratidal environments in the modern tidal flat complex off Andros Island, Bahamas.

Vertical, subvertical, and horizontal burrows indicate a dense population of soft bodied burrowers inhabited this environment. Most

burrow walls are very well defined, and are filled with spar, peloids, and fossil fragments. Sediments are often burrow homogenized, but occasionally contain continuous laminae and thin interlaminar birdseyes. Figures 2.7F and 2.7G show comparison between sediment burrowed while soft (Figure 2.7F) and sediment burrowed after some water loss and compaction (Figure 2.7G). Shelly fauna is patchy in distribution. Gastropods comprise as much as 16% of some samples, and pelecypods an additional 3%. However, most samples are essentially unfossiliferous, except for an occasional trilobite moult, ostracode valve, sponge spicule, serpulid worm tube, or bryozoan fragment. Rarely, very thin beds of fossiliferous packstone, consisting of "fossil hash," show some diversity of bioclasts. These fossil assemblages appear to have been largely transported from nearby, less restricted environments. Thinly laminated fabric suggests trapping and binding of sediment by cyanophytic algae, however antigravitational sedimentation, a common cryptalgal structure, is absent in unit 12.

Paleoenvironmental interpretation. Unit 12 contains abundant evidence of intertidal and supratidal deposition. Large mudcracks and mudcrack polygons indicate prolonged subaerial exposure (Ginsburg, et al., 1977). Additionally, birdseye structure, keystone vugs, intraclasts, and finely laminated sediment are features commonly observed within the intertidal zone on modern carbonate tidal flats. The well preserved nature of the intraclasts, some containing laminar fenestrae, indicates partial lithification of the sediment soon after deposition. Abundant sharp contacts indicate periodic scouring (storm)

events followed by rapid deposition of skeletal packstone and subsequent fine grained (micrite) deposition in the waning stages of the storm.

The scarcity of biota in unit 12 also suggests tidal flat deposition. Molluscs and arthropods are the only indigenous faunal element in most of the samples, however, rare occurrences of small, articulated orthid brachiopods and ramose bryozoans indicate occasional episodes of normal marine waters. Generally, the fauna of the lower portion of the unit may reflect shallowest subtidal to lower intertidal conditions, based on the co-occurrence of horizontal and vertical burrows and presence of some stenohaline taxa. Horizontal burrowers are normally indicative of lower intertidal and subtidal conditions (Rhoads, 1967). The upper few meters of unit 12 indicate wholly supratidal deposition. The shelly fauna consists of very rare, disarticulated, abraded fragments. Horizontal burrows are somewhat diffuse, while vertical burrows have distinct walls and are filled with sparry calcite and small peloids. The sediment may have been burrowed extensively by deposit feeders during periods of high water, only to be subsequently exposed, partially lithified, and inhabited by vertical burrowers.

Unit 12 represents a gradual shallowing trend from very shallow subtidal or intertidal to supratidal conditions. The numerous upward-fining, coarser grained deposits indicate occasional storm events, which deposited seaward-derived sediment into the tidal flat regime. The relatively pure carbonate composition of unit 12 contrasts with the siliciclastic-rich tidal flat sediments of the Bowen or the

overlying Moccasin Formation. Therefore, unit 12 may represent a migrating mudbank or shoal similar to those found today in Florida Bay (Enos and Perkins, 1979). The presence of such migrating features could have led to restriction of the shelf environment by: 1) creating small basins or subtidal ponds cut off from normal marine waters or 2) dissipating wave and tidal currents.

Unit 13

Description. Unit 13 caps the Middle Chickamauga at Thorn Hill and is in gradational contact with the overlying Moccasin Formation. The most striking characteristic of unit 13 is the variety of lithologies represented within the flaggy bedded wackestone and packstone. Generally, the unit comprises 26m of grey and dark grey, thin to very thinly bedded, locally very fossiliferous wackestone, packstone, and intercalated shale or horizontally burrowed lime mudstone. The lower 2.2m is very poorly exposed, sparsely fossiliferous, shale and current-rippled pelmicrite. The remainder of the unit consists of interbedded biomicrite and biopelsparite which commonly are found in erosive contact with each other. The unit becomes increasingly argillaceous near the top of the unit and grades into reddish brown, chippy weathering, shale and muddy limestone where it is in conformable contact with the Moccasin Formation.

The biotic diversity of unit 13 is the highest in the Witten Formation. Although much of the fauna appears to have been transported and of little paleoecologic importance (using the criteria of Johnson,

1960), some of the fossil assemblages are excellently preserved and probably indigeneous to their host sediment. Bryozoans are a common taxon (average 7.6%), locally abundant (up to 23%), and diverse. At least ten genera are represented; most are arborescent trepostomes (Amplexopora, Homotrypa, Eridotrypa) and ramose bifoliate (Stictopora, Stictoporella, Escharopora). Encrusters are generally rare, while arthrostylids are common. Brachiopods, most commonly very small (about 3mm), articulated orthids, are locally abundant (up to 10%), but average only 3% of the rock volume throughout the unit. Trilobite pieces (3.2%) are sometimes excellently preserved in unit 13 where they comprise over 10% of some samples. Other taxa (in descending order of abundance) include ostracodes, molluscs, serpulid worm tubes, echinoderms, and inarticulate brachiopods. Algae, most commonly Hedstroemia, and rarely Solenopora, are present in most samples. Micrite coatings and adhered micrite are found on many fossil allochems, yet no cortoids, oncolitic coatings, or Girvanella are present. Hedstroemia occurs as small encrustations on allochems or an isolated thalli. Moore (1978) suggests that Hedstroemia was a eurytopic Ordovician alga.

As with much of the Witten, unit 13 contains abundant evidence of periodic high energy events resulting in scour of hardened sediment and deposition of an upwards fining bed of bioclasts, well-rounded intraclasts, and peloids with shelter voids and perched sediment (see Kreisa, 1981; Aigner, 1982a; Kreisa and Bambach, 1982). Unique to unit 13, however, is the occasional arcuate scour surface, commonly with a bioclastic and intraclastic base, that is often filled with fine

grained sediment. This feature can be observed in Figure 2.7H, which shows three separate depositional events within one bed. Additionally, continuous thin beds of climbing current rippled peloid packstone are found only in unit 13. These slightly asymmetrical ripples, up to 3.5cm in amplitude, consist of micrograded peloids and micrite.

Paleoenvironmental interpretation. A return to semi-restricted, subtidal conditions is indicated in the sediment and fauna of unit 13. Evidence supporting this includes: 1) a moderately diverse, indigenous invertebrate fauna, 2) lack of desiccation features, 3) presence of well developed, generally symmetrical ripple cross-lamination, and 4) abundance of horizontal burrows.

The fauna consist of in situ and exotic elements. In nearshore environments, accumulations of allochthonous shell material is high (Kidwell and Jablonski, 1983), while destructive forces such as biogenic and physical abrasion tend to render such exotic fossils unidentifiable. Thus, most well preserved fossils in nearshore environments such as this are probably at or near their place of origin. The biota of unit 13 contains a moderate diversity of filter feeding invertebrates in addition to mobile deposit feeders/scavengers, and some "eurytopic" groups (e.g. ostracodes, inarticulate brachiopods, and serpulid worm tubes), yet no single taxon overwhelmingly dominates the fossil assemblages, except in individual beds.

Beds of swaley cross laminated strata and mud filled, trough-shaped scour surfaces with basal lags of bioclasts and intraclasts represent migrating tidal gulleys or creeks within this

shallow subtidal environment. Climbing ripple cross lamination is believed to be the result of deposition mainly in unidirectional flow of mainly the suspended sediment load (see however Kreisa, 1981). Hardie and Garrett (1977) report that tidal channel migration may be the result of vertical accretion of channel bars, which eventually cut off the old channel that is subsequently "silted in." Davies (1970), however, shows evidence of channels breaching their levees and abandoning their former channels. Tidal channels typically extend for short distances into the subtidal zone where they may shallow and form submarine fans such as those at Shark Bay, Australia (Davies, 1970).

The shallow subtidal regime of unit 13 represents a nearshore marine environment proximal to mixed carbonate-siliciclastic tidal flat environments such as those described in detail by Simonson (1985) for the Moccasin Formation. The encroaching tidal flat environment is indicated by an increase in argillaceous material and a concomitant decrease in well preserved fossils in the upper few meters of the unit.

Depositional Summary

The middle Chickamauga represents a regressive sequence of subtidal, intertidal and supratidal environments deposited on an ancient carbonate shelf. The major features of this depositional environment are summarized in Figures 2.8 and 2.9. The Benbolt Formation depicts wholly subtidal deposition generally below fairweather wave base. Bioclastic lime muds accumulated in areas of subdued relief, while skeletal sands formed subtidal shoals on

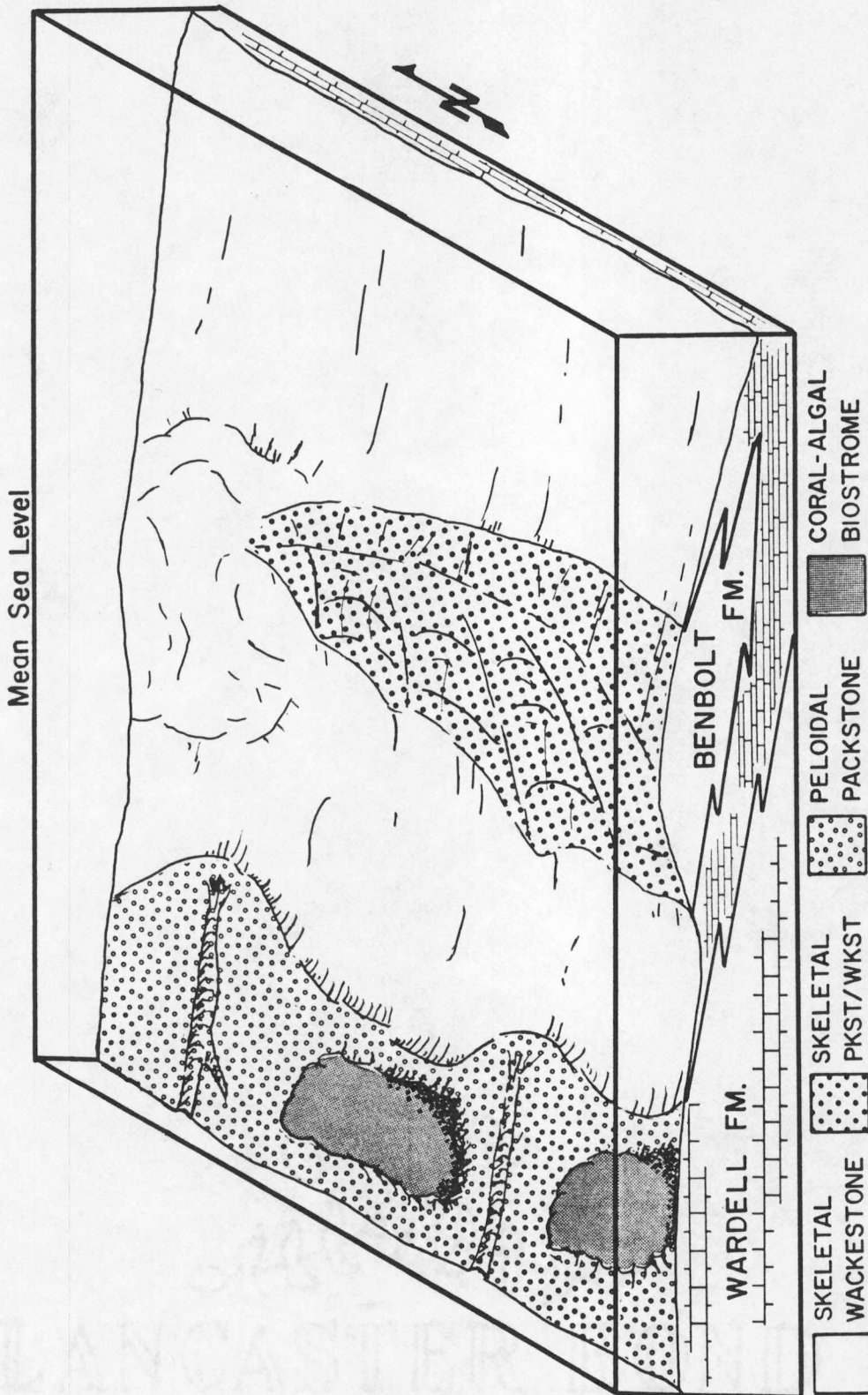


Figure 2.8. Block diagram representation of depositional environments inferred for the Benbolt and Wardell formations at the Thorn Hill locality. Note that deposition occurred in shallow subtidal and deeper subtidal environments. Also note that deeper water environments are to the east.

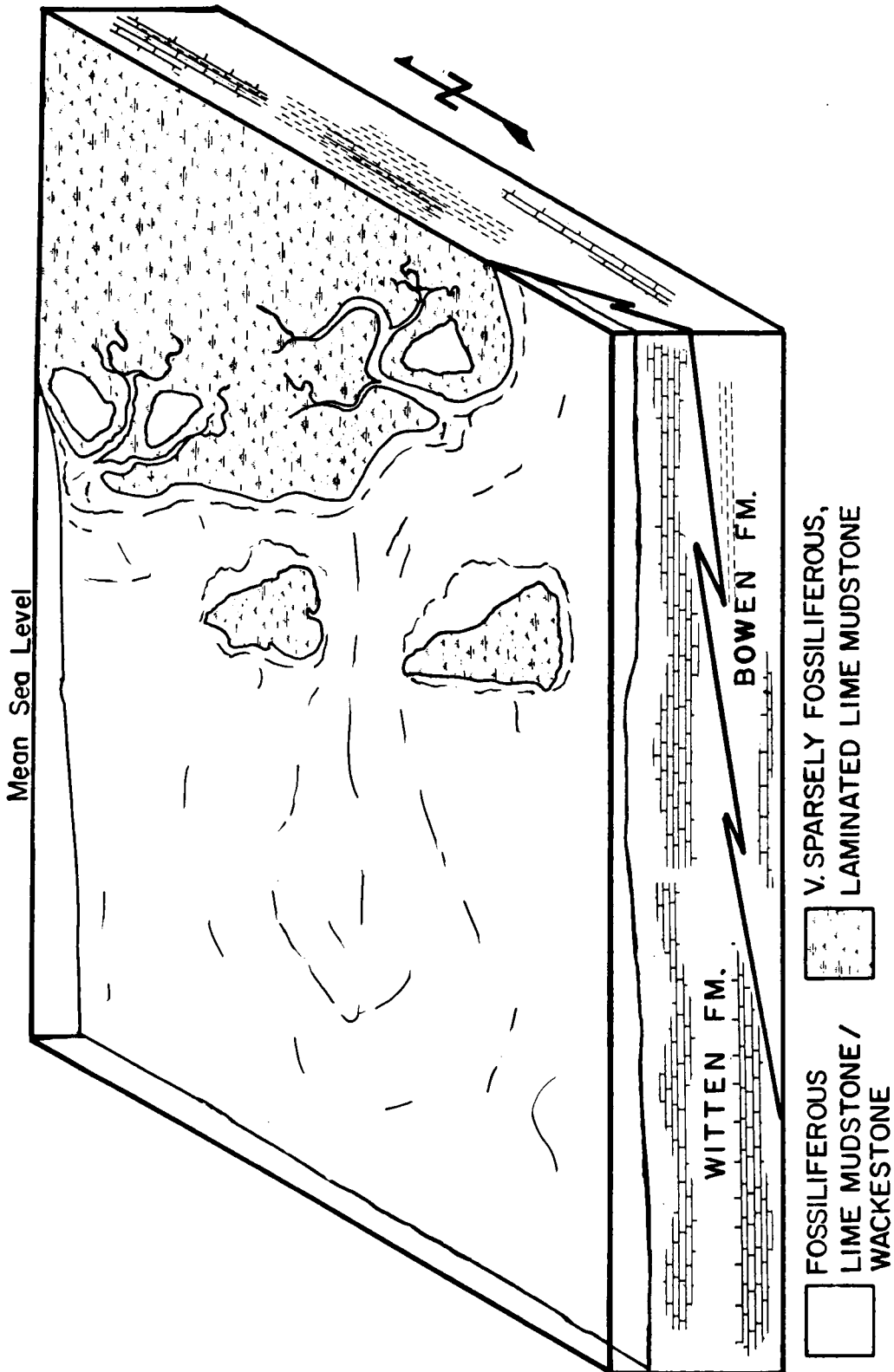


Figure 2.9. Block diagram representation of depositional environments inferred for the Bowen and Witten formations at the Thorn Hill locality. Note that deposition occurred within shallow subtidal and peritidal environments.

bathymetric highs. The Wardell Formation consists primarily of coarse grained (bio)pelsparite and thin biostromal units. The Wardell was deposited nearshore, within normal wave base, and contains evidence of periodic storm deposition and proliferation of marine invertebrates and calcareous algae. The sequence shoals upwards into finely laminated, maroon, argillaceous lime mudstone containing desiccation mudcracks, vertical burrows, and birdseyes. This intertidal and supratidal deposit represents tidal flat deposition characteristic of the Bowen Formation. The Witten Formation consists of fossiliferous lime mudstone, intercalated shale, and some unfossiliferous reddish mudstone. The Witten represents shallow subtidal, intertidal, and supratidal deposition on a broad shallow shelf.

The middle Chickamauga typifies a shallowing middle shelf environment. Deeper water, fine grained lithologies of the Benbolt give way upsection to coarser grained deposits associated with shallower water, and ultimately to tidal flat deposition. Shallowing on the shelf was facilitated either by regression of sea level or a temporary end to subsidence, which allowed for western progradation of landward environments. This upwards shoaling sequence coincides with the filling of the eastward basin, allowing the introduction of terrigenous fines onto the carbonate shelf as predicted for carbonate to terrigenous sequences by Walker et al. (1983).

CHAPTER 3

DISTRIBUTION AND PALEOECOLOGY OF ECTOPROCT BRYOZOANS
IN THE MIDDLE CHICKAMAUGA GROUP

Introduction

Remains of ectoproct bryozoans constitute a major component of the strata comprising the Middle Chickamauga Group. Bryozoans form over 20% of the rock volume in many samples as shown in Figure 2.3 (p.19). Previous study of the bryozoan fauna in the Chickamauga dates to pioneering work by Ulrich (1882). Recent studies by Ferrigno (1973), Ruppel (1979), and Cristil (1985) stress the distribution of bryozoans within on-shelf and shelf-edge reef and patch reef environments. This chapter explores the distribution of bryozoans within the various subenvironments of the middle and inner shelf facies of the Middle Chickamauga at the Thorn Hill locality. In addition, observations concerning the paleoecology of the abundant and diverse representatives of this phylum are discussed.

Extant species of bryozoans may change morphology in response to environmental constraints. Schopf (1969) showed that zooarial growth form changes in response to water turbulence. He found that delicate branching forms were more commonly encountered in quiet water, and robust and encrusting forms are found in high energy environments near shore. Ferrigno (1973) found "reef core" facies of the Ordovician Holston Formation contain mostly encrusting zooarial forms, while the

flank facies contain more ramose forms. He interpreted this to represent an environmental response to turbulence as well. The present study examines similar environmental controls of zooarial growth form that occur in the shelf environments of the Chickamauga Group. Figure 3.1 illustrates some of the zooarial growth forms observed in Paleozoic stenolaemate bryozoans. The abundance of encrusting growth forms in shallow water environments and numerous thinly calcified bryozoans in muddy environments suggests that substrate availability and consistency, as well as water turbulence, effect zooarial growth form.

Although modern bryozoans are found in most marine environments and many freshwater ones, they are most abundant and diverse on shallow marine shelves (Cuffey, 1970). This appears to be true for Middle Ordovician ectoprocts in the Southern Appalachians as well. The deeper water, shelf-edge reef deposits contain about 20 genera (Ferrigno, 1973; Walker and Ferrigno, 1973; Cristil, 1985). In contrast, the shallow shelf environments presented in this study supported over thirty identifiable genera. The generic diversity of Family Arthrostylidae in the Benbolt Formation alone, exceeds the total number of presently described arthrostylid genera (F.K. McKinney, 1985, pers. comm.). In the numerous subenvironments described in Chapter 2, some bryozoan genera appear most often in specific facies. Ross (1984) believes that bryozoan diversification during the Ordovician resulted in increased niche specialization. By the end of the Middle Ordovician, ectoprocts were found in most tropical shallow water shelf environments. This study identifies some examples of environmental preference by bryozoans in the Chickamauga Group.

Environmental Distribution of Bryozoans
in the Middle Chickamauga Group

In the discussion of bryozoan distribution, the thirteen units discussed in Chapter 2 have been simplified into three general environments: 1) Middle Shelf (comprising units 1-4 of the Benbolt Formation), 2) Nearshore Shoal/Shoreface (comprising units 5-7 of the Wardell Formation) and 3) Restricted Inner Shelf (comprising units 7-13 of the Bowen and Witten formations). This chapter examines the most common bryozoan assemblages found in each of the environments.

Procedure

Assemblages were discerned by volume percent obtained through point count data. Volume percent data may be a poor indication of abundance of a taxon, for a few very large, yet scarce individuals may bias the data from single samples. However, this technique does provide a quantitative measure of the occurrence of a particular allochem. In all, thirty-nine thin section slides were used in the analysis, with a total of 1326 bryozoan points counted.

Middle Shelf Environment

The middle shelf-deposited Benbolt Formation typifies wholly subtidal, quiet water deposition, typically below normal wave base. Occasional lenses of coarser grained lithologies indicate shallower

water deposition on current-winnowed, carbonate sand shoals. In general, fossils are better preserved, but less abundant in the muddier lithologies, but overall the environment supported an abundant and diverse biota. Bryozoans are a common constituent in much of the Benbolt. However, there is a distinct difference between the ectoproct genera found in the mudstone and wackestone and those in the packstone.

Table 3.1 lists the bryozoan genera identified in the middle shelf environment (Benbolt Formation) lithologies and their volume percentage compared to all middle shelf bryozoans. Despite the taxonomic variability found in the formation, "Phylloporina" (Figure 3.2A; 16.75%) and ceramoporids (15%) clearly comprise the predominate portion of the bryozoan fauna. Batostoma, Pachydictya (Figure 3.2B), Nicholsonella (Figure 3.2C), and Xenotrypa (Figure 3.2D) are present in nearly coequal amounts, each comprising slightly over 7% of the middle shelf environment's bryozoan fauna. Batostoma and Xenotrypa, however, are principally found in the packstone. Monotrypa (5.4%) is absent in the packstone, but dominates one sample of wackestone because of its large, slightly bulbous zooarial form. In all, twenty-one genera are identified from the middle shelf facies.

Zooarial growth forms are also quite varied in the middle shelf environment. While phylloporinids are ramose or reticulate, ceramoporids in the muddy lithologies are found as thin encrusting sheets, only a few zooecia thick. Ramose bifoliate (cryptostomes) form strap-shaped (Stictopora, Pachydictya) or lanceolate (Escharopora) zooaria and are usually very small. Ramose trepostomes (Nicholsonella, Parvohallopora) are typically branched and form large zooaria. Robust

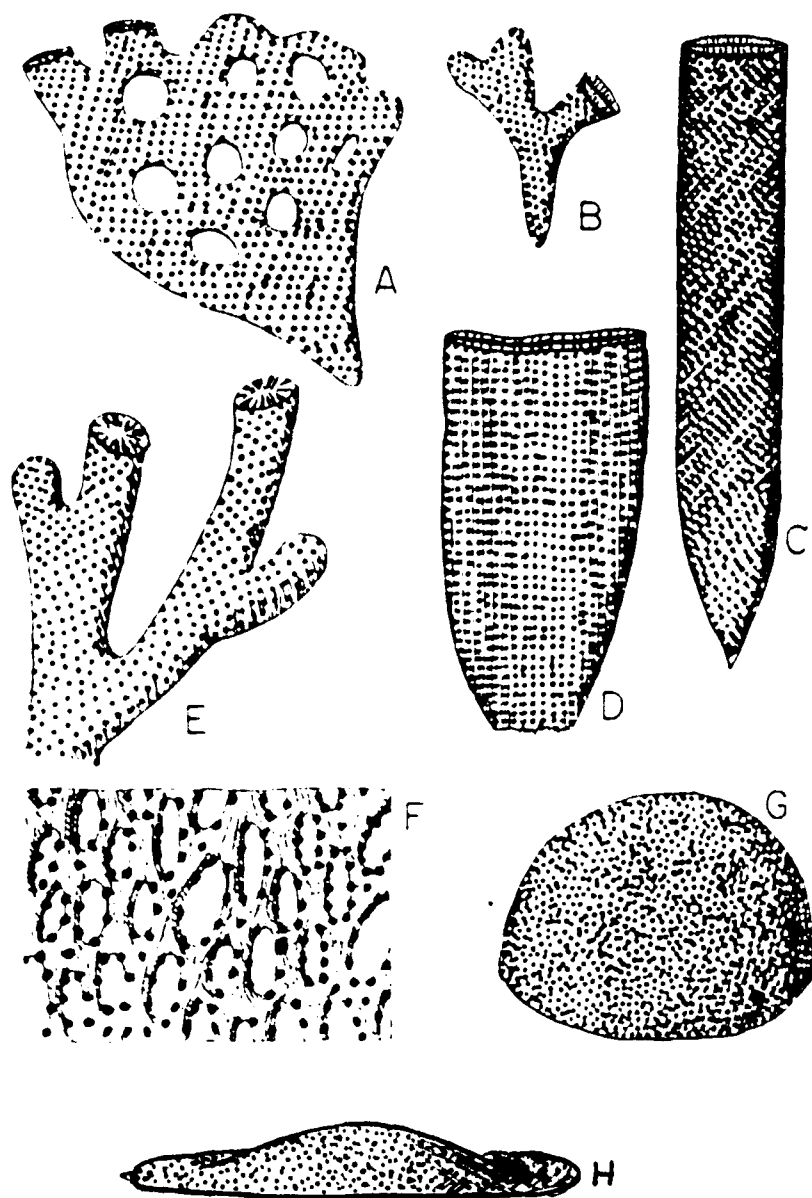


Figure 3.1. Generalized bryozoan zooarial growth forms. An Ordovician genera which exhibits each growth form is given as an example. Slightly modified from Ross (1982). (A) Cribrate, Graptodictya x4. (B) Strap-shaped, Stictopora x4. (C) Lanceolate, Escharopora x6. (D) Explanate, Athrophragma x6. (E) Ramose, Amplexopora x3. (F) Reticulate, "Phylloporina" x20. (G) Hemispheric, Prasopora x4. (H) Discoid, Monotrypa x0.75.

TABLE 3.1

BRYOZOANS OF THE MIDDLE SHELF ENVIRONMENT

BRYOZOANS	ZOOARIAL GROWTH FORM	TOTAL VOL. %	BRYOZ. VOL. %
<u>Athrophragma</u>	Explanate bifoliate	0.15	1.00
Arthrostylidae	Ramose radial	0.17	1.17
<u>Batostoma</u>	Encrusting	1.15	8.71
<u>Bythopora</u>	Ramose	trace	trace
Ceramoporina	Encrusting, semi-ramose	2.23	15.24
<u>Constellaria</u>	Encrusting	0.12	1.00
<u>Diplotrypa</u>	Hemispheric, semi-ramose	0.66	4.52
<u>Eridotrypa</u>	Ramose	trace	trace
<u>Escharopora</u>	Lanceolate bifoliate	trace	trace
<u>Graptodictya</u>	Strap-shape bifoliate	trace	trace
<u>Hemiphragma</u>	Ramose	0.17	1.17
<u>Monotrypa</u>	Hemispheric	0.78	5.36
<u>Nicholsonella</u>	Ramose	1.10	7.54
<u>Ottoseetaxis</u>	Ramose radial	trace	trace
<u>Pachydictya</u>	Lanceolate bifoliate	1.57	7.70
<u>Parvohallopora</u>	Ramose	0.42	2.85
<u>"Phylloporina"</u>	Anastomosing	2.45	16.75
<u>Prasopora</u>	Ramose or hemispheric	trace	trace
<u>Stictopora</u>	Strap-shaped bifoliate	0.49	3.35
<u>Stictoporella</u>	Strap-shaped bifoliate	0.37	2.51
<u>Xenotrypa</u>	Encrusting, semi-ramose	1.08	7.37
Unidentified		1.94	13.23

Figure 3.2. Bryozoans of the middle shelf environment (Benbolt Formation). Stratigraphic up direction is towards the top of the page in all photos.

A. Photomicrograph shows a shallow longitudinal section of "Phylloporina" which exhibits linearly arranged acanthostyles and an anastomosing growth form. Bar is 0.25mm. Sample TH1.

B. Photomicrograph of deep tangential section through Pachydictya, a ramose bifoliate with a lanceolate growth form. Note perforate mesotheca and elliptical zooecia. Bar is 1.0mm. Sample TH3.

C. Photomicrograph illustrates a tangential section through Nicholsonella showing irregularly shaped zooecia. Note algal and ectoproct encrustation of zooarium. Bar is 1.0mm. Sample TH24.

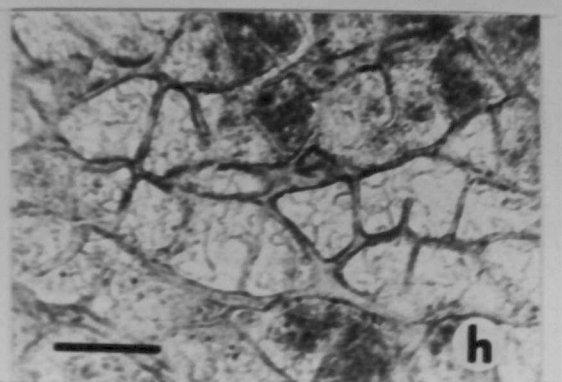
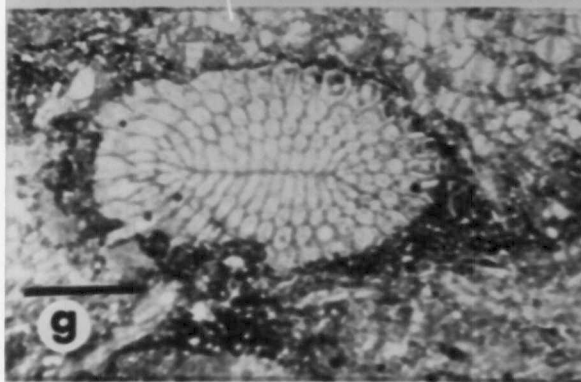
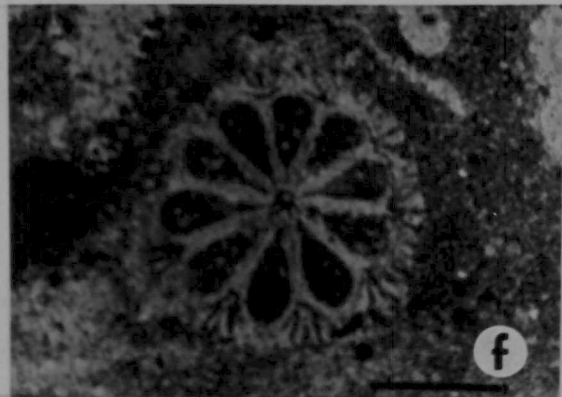
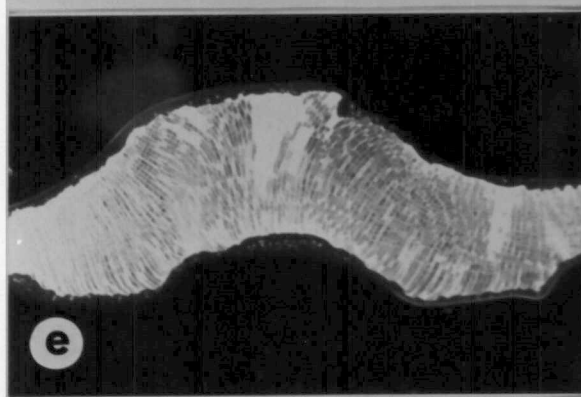
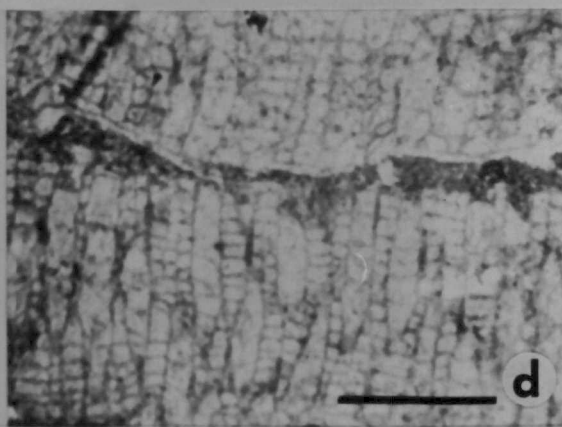
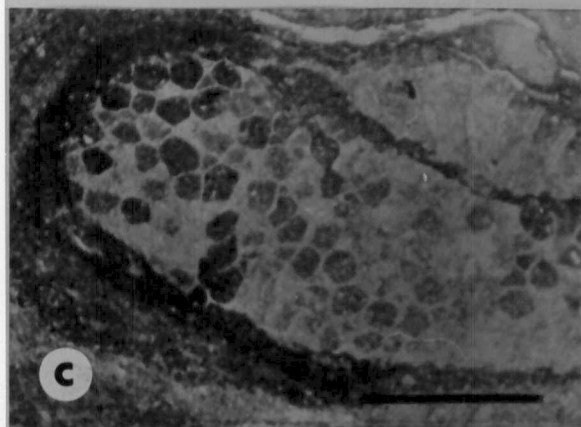
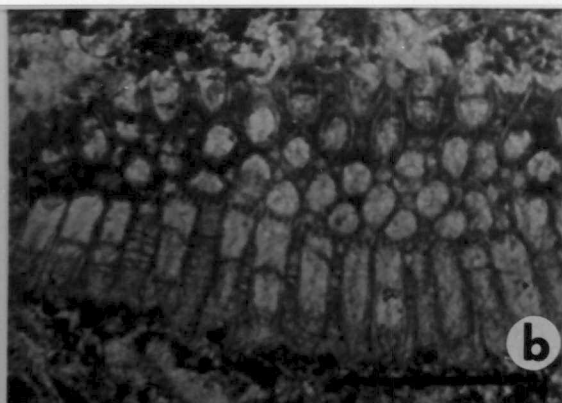
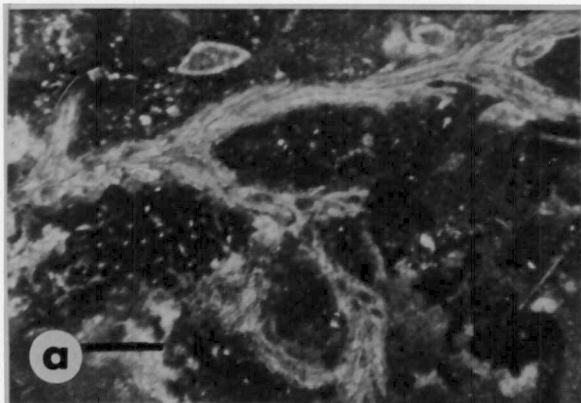
D. A longitudinal section of Xenotrypa seen in this photomicrograph shows numerous vesicles, and indistinct microstructure characteristic of this genera. Bar is 1.0mm. Sample TH17'.

E. Photonegative of thin section illustrates simplistic internal skeletal architecture of flattened hemispheric growth form in Monotrypa. Note the thin the zooecial walls and absence of mesopores. Actual size. Sample THM.

F. A tranverse section of Ulrichostylus? is depicted in this photomicrograph. Note the radiating zooecia. Zooarium is 0.6mm in diameter. Sample TH8.

G. Photomicrograph of transverse section through Ottoseetaxis, a rhabdomesid ectoproct possibly related to the arthrostylids, exhibiting ramose growth form. Bar is 1.0mm. Sample TH13.

H. A longitudinal section of Hemiphragma illustrates characteristic hemiphragms, which protrude into the irregularly shaped zooecia. Bar is 0.5mm. Sample TH19.



encrusters (Xenotrypa, Batostoma) are mainly found in the higher-energy shoal subfacies, while Monotrypa, a discoid or hemispheric form (Figure 3.2E) is only found in muddy lithologies. Arthrostylids, common especially in the finer grained lithologies, are very small (rarely over 0.5mm in diameter), erect, and usually jointed (Blake, 1983).

Discussion

Since most of the middle shelf facies in this section consist of mudstone and wackestone, it is difficult to draw statistical comparisons between the coarse grained shallow shoal subfacies and the deeper water, muddy subtidal environment. In general, the bryozoan fauna of the deeper water facies consists of very small ramose forms (see Figure 3.3) such as "Phylloporina," arthrostylids, and various smaller bifoliate (e.g. Pachydictya). Encrusters, large flattened hemispheroids and bulbous forms are also present.

The encrusters of the middle shelf are mostly ceramoporoids (Ceramoporella?) which form sheet-like zooaria (terminology of Jackson, 1979). They are usually found within the micrite matrix; rarely are they found encrusting other organisms. The substrate appears to have been fairly soft and inhabited by sediment destabilizing burrowers (see Chapter 2). Such an environment is generally considered unsuitable for encrusting epifauna; however, this obviously is not the case. It is important to note that the zooaria of the ceramoporids in this environment are usually only a few zooecia thick, resulting in a high surface-to-volume ratio. Apparently, the ceramoporids could use this strategy to encrust soft, muddy substrates. As shown in Figure 3.4,

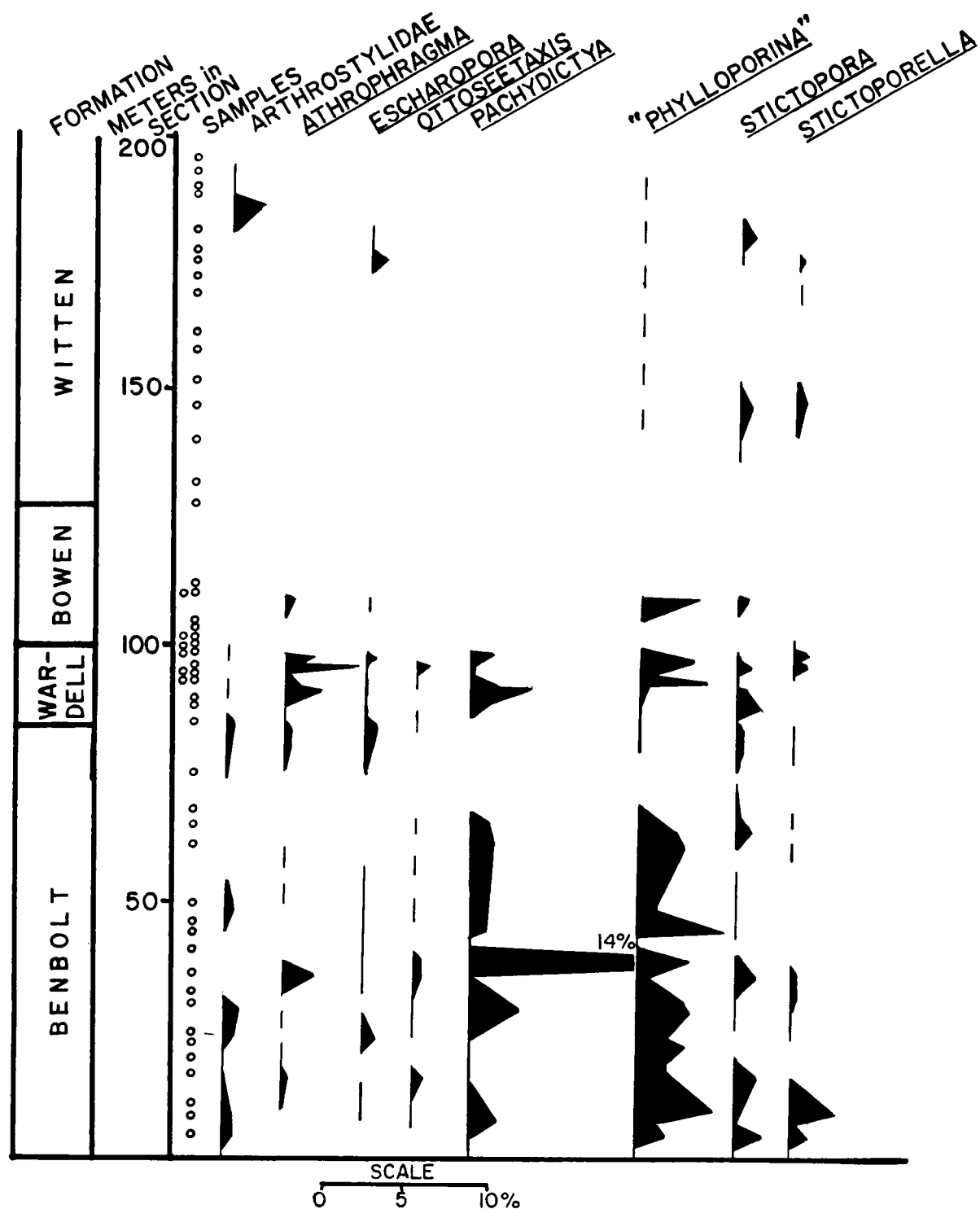


Figure 3.3. Distribution and abundance of cryptostome bryozoans in the middle Chickamauga Group at the Thorn Hill locality. Note the abundance of cryptostomes in the Benbolt Formation.

Figure 3.4 Distribution and abundance of trepostome bryozoans in the middle Chickamauga Group at the Thorn Hill locality. Notice that many genera found primarily within a certain stratigraphic interval while others are rather widespread in occurrence. Scale is percentage of total rock volume.

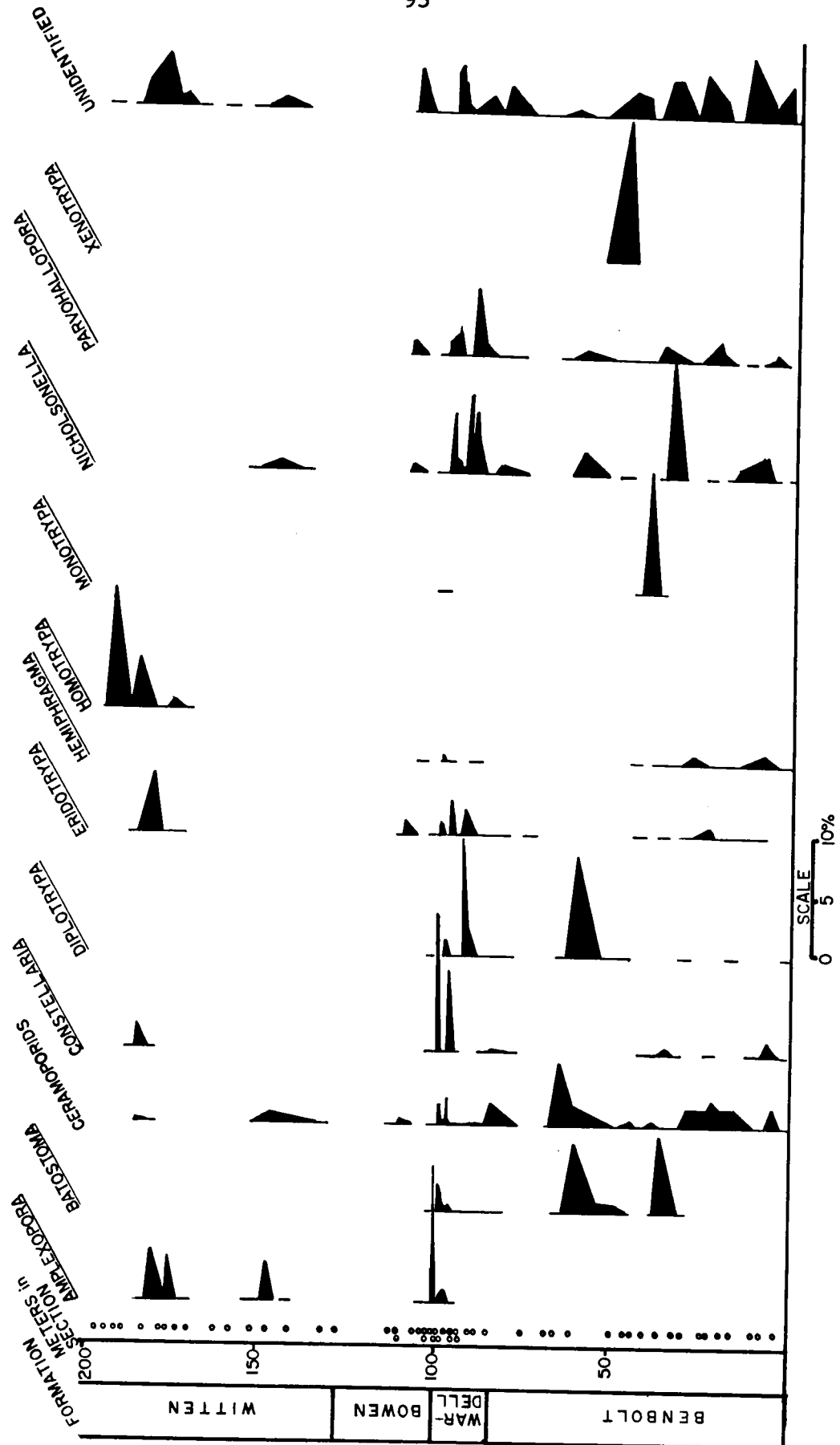


Figure 3.4

ceramoporids are quite common. Although the author found no modern examples of bryozoans inhabiting soft, muddy seafloors in the literature, Boardman (1960) believes certain ramose trepostomes favored a muddy substratum. Ross (1964b) believes Ceramoporella encrusted "new areas" of previously uninhabited substrate. Perhaps the ceramoporids were able to encrust muddy surfaces, expending energy for more rapid growth rather than building an elaborate skeleton. Jackson and Hughes (1985) have observed similar behavior on the undersurfaces of coral heads in modern gymnolaemate bryozoans.

The small ramose cryptostomes are predominately ptilodictyines excepting the rhabdomesid arthrostylids and Ottoseetaxis (Figures 3.2F, 3.2G). Ptilodictyines are typically small and delicate erect forms (see however Ross, 1963b; and Walker and Ferrigno, 1973) that are anchored to the substrate by an encrusting basal attachment. They occur in most carbonate facies, but are often abundant in shale and argillaceous limestone (Karklins, 1983). Arthrostylids are superficially similar to the ptilodictyines and even smaller in size. Like the ptilodictyines, the arthrostylids rested on an encrusting basal structure which may have required a firm substratum for attachment (Blake, 1983), however, Brood (1975a) describes arthrostylids as inhabiting soft sediment. Perhaps the firm substratum could have been provided by a shell fragment in an otherwise soft sediment.

The fragile ptilodictyines and arthrostylids thrived in the quiet water and muddy subtrata found in the middle shelf environment. The small size and almost negligible weight of these cryptostomes allowed

them to inhabit this muddy environment. Concentrations of small ramose ectoprocts such as these may have trapped fine sediment, similar to thickets of seagrass and algae in modern environments. The ceramoporids, ptilodictyines and arthrostylids are associated with the echinoderm-sponge wackestone characteristic of muddy middle shelf deposits.

Large colonies of discoid or mound-shaped bryozoans are also found in the muddy shelf environment often associated with brachiopods and sponges. As shown in Figure 3.1 (page 92), certain bryozoan genera are capable of producing mound or discoid shaped zooaria and are commonly found in muddy subtidal deposits. Specimens are exclusively the trepostomate genera Monotrypa and rarely Diplotrypa. These bryozoa appear to have initiated growth on a skeletal grain or other hard substratum and subsequently spread out onto the surrounding sediment. This adaptation is apparently environmentally controlled, for Monotrypa is also found as a massive, bulbous form in similar lithologies. Perhaps higher rates of sedimentation favor a mound-like morphology over a discoid or platy one as predicted by Jackson (1979). The skeleton of both Monotrypa and Diplotrypa is very thin, although the zooecia are quite large. Thin skeletons are often found in fast growing, R-selected, modern bryozoans (Jackson, 1983; Jackson and Hughes, 1985). Monotrypa, then could represent a fast growing genus that inhabited soft sediment by rapidly expanding its zooarium when sedimentation rates were low, forming a thin plate-like morphology which kept it from sinking into the soft sediment. If sedimentation rate was higher, Monotrypa could form an upright, bulbous mound which

could actually aid the colony in maintaining itself upright in the soft sediment. Jablonski and Bottjer (1984) have identified a similar adaptive strategy in other soft bottom inhabitants, especially pelecypods. They found that soft sediment dwellers are often enlarged at their base, which is buried in the substrate. This provides a "keel" to support the organism above the sediment-water interface. They aptly termed this adaptation an "iceberg strategy." The two morphologies exhibited by Monotrypa may, however, represent different species but this is unlikely for their microstructures are similar.

Ramose trepostomes are more common in the higher energy facies of the middle shelf environment. Nicholsonella and Batostoma are common ramose forms, and rarely Hemiphragma (Figure 3.2H), is found in the algal-rich packstone of the Benbolt. As an encruster and sediment stabilizer, Batostoma is a common constituent in the reef core facies of the Holston Formation (Walker and Ferrigno, 1973; Ruppel, 1979; Cristil, 1985) and in bioherms of the Chazy of New York (Ross, 1964). Reduced current energies, or limited food supply may favor a ramose habit in the middle shelf environment.

Although ceramoporids are less abundant in the packstone than the finer grained sediment, another cystoporate, Xenotrypa is common. Interestingly, this taxon is found forming extensive, hemispheric encrustations around algal balls and is absent elsewhere. This is the first reported occurrence of Xenotrypa in the Middle Ordovician of East Tennessee.

Bryozoan assemblages differ in the various subenvironments comprising the middle shelf environment. The quiet-water, muddy

environment is characterized by thin sheet-like encrusting ceramoporids, "Phylloporina," small ramose cryptostomes and occasional large hemispheric trepostome colonies. Associated fossils consist mainly of echinoderms, sponges, brachiopods, and trilobites. In the higher energy environment the bryozoans are ramose trepostomes, large encrusters and smaller bifoliate and phylloporinids, associated with echinoderms, algae, and ostracodes.

Nearshore Shoal/Shoreface Environment

Bioclastic peloidal sands and biostromal deposits of the nearshore shoal and shoreface environment (Wardell Formation) occurred landward of the middle shelf environment. Excepting a few minor beds of poorly fossiliferous mudstone, this environment supported a variety of invertebrate fossils. Tabulate corals, solenopodid algae, brachiopods, echinoderms, trilobites, and twenty-one genera of bryozoans were present in this nearshore, high energy environment.

The nearshore shoal environment is characterized by an abundance of the genus Amplexopora (Figure 3.5A, 3.5B), a branched ramose trepostome, which comprises about 16% of the bryozoan fauna (3% of the rock volume; Table 3.2). Importantly, Amplexopora is absent from all but a few samples, however, it is very abundant in those samples which it does occur. Constellaria (Figure 3.5C), a ramose and encrusting cystoporate, has a distribution similar to that of Amplexopora in the nearshore environment. Constellaria ranks second in volume percentage (12.5% of bryozoans), however, it also is most abundant in only a few

Figure 3.5. Bryozoans of the Nearshore and Restricted Shelf Environments. Stratigraphic up direction is towards the top of the page in all photos.

A. Photomicrograph of a longitudinal section of Amplexopora exhibiting thickly calcified exozone and numerous mesopores in a ramose growth habit. Bar scale is 1.0mm. Sample TH48.

B. Photomicrograph shows a shallow tangential section of Amplexopora exhibiting thickly calcified exozone and numerous acanthostyles. Bar scale 0.2 mm. Sample TH48.

C. A longitudinal section of Constellaria in this photomicrograph shows numerous cystopores. Note geopetal sediment in hollow portion of pseudo-encrusting zooarium. Bar scale is 1.0mm. Sample TH42.

D. This photomicrograph illustrates a longitudinal section through Ceramophyllum? in an encrusting growth form. Bar scale is 0.3mm. Sample TH41.

E. Photomicrograph of a transverse section of Diplotrypa with a pseudo-encrusting zooarial growth form. Bar scale is 3.0mm. Sample TH34.

F. A transverse section of Parvohallopora shows varied sizes of autozoecia and mesopores in this photomicrograph. Bar scale is 1.0mm. Sample TH44.

G. Photomicrograph of Escharopora in transverse section, illustrating thickly calcified exozone and bifoliate morphology. Bar scale is 0.3mm. Sample TH41.

H. Photomicrograph of two genera of ceramoporids encrusting Solenopora. Note encrusting alga (Girvanella?) which is encrusted by Batostoma (center, with larger zooecia) Bar scale is 1.0mm. Sample TH42.

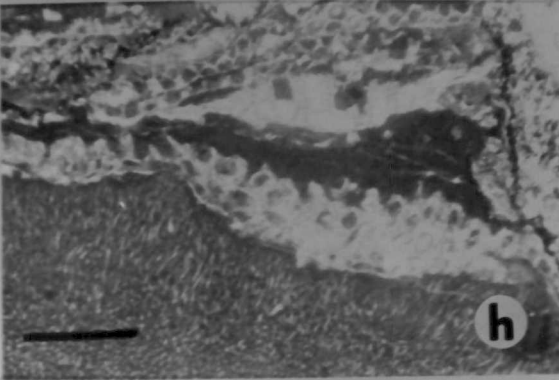
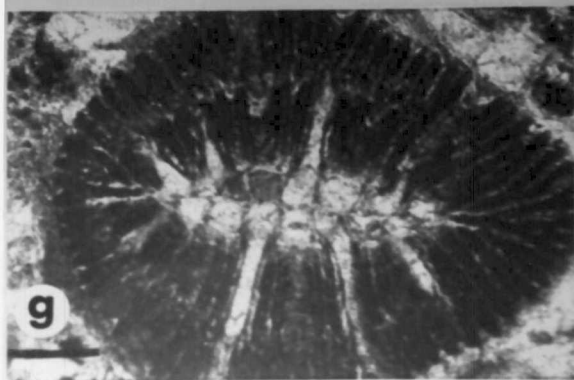
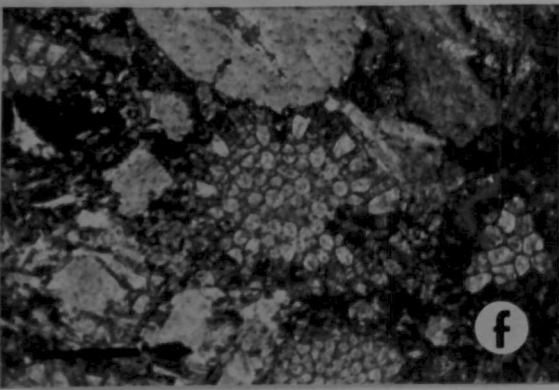
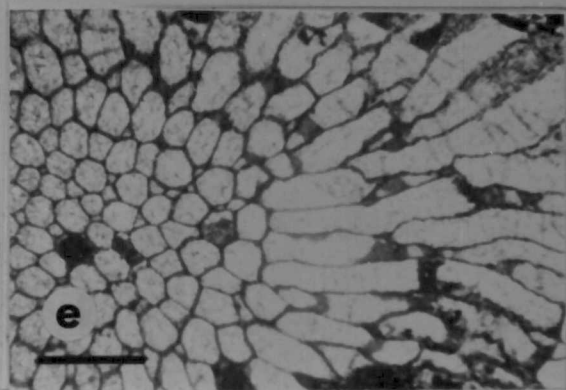
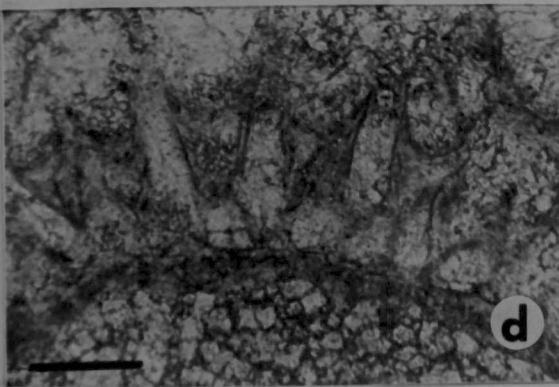
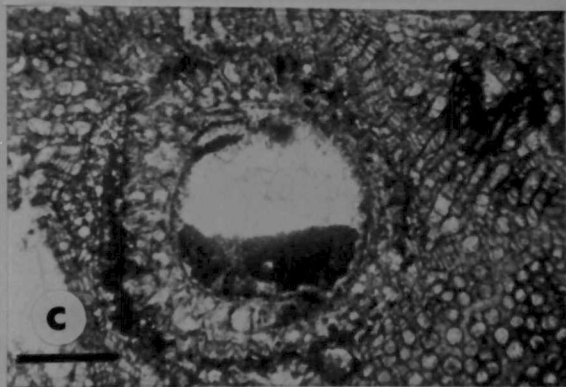
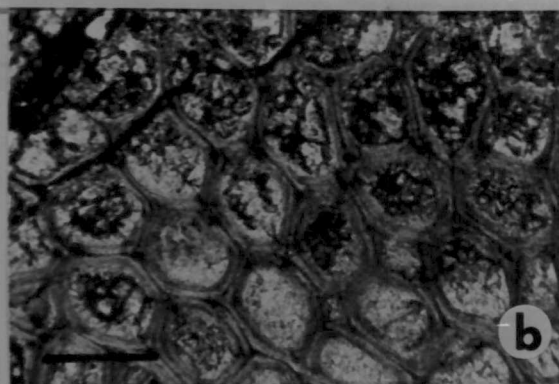
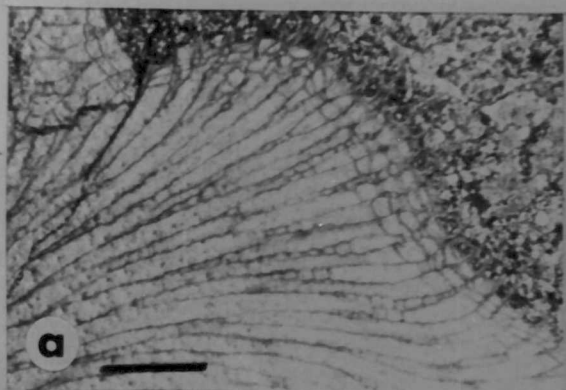


TABLE 3.2

BRYOZOANS OF THE NEARSHORE SHOAL ENVIRONMENT

BRYOZOANS	ZOOARIAL GROWTH FORM	TOTAL VOL. %	BRYOZ. VOL. %
<u>Amplexopora</u>	Ramose	3.00	16.09
<u>Athrophragma</u>	Explanate bifoliate	1.00	5.36
Arthrostylidae	Ramose radial	trace	trace
<u>Batostoma</u>	Encrusting	0.61	3.28
<u>Bythopora</u>	Ramose	trace	trace
Ceramoporina	Encrusting, semi-ramose	1.42	7.60
<u>Constellaria</u>	Encrusting	2.30	12.52
<u>Diplotrypa</u>	Hemispheric, semi-ramose	1.10	5.96
<u>Eridotrypa</u>	Ramose	0.53	2.83
<u>Escharopora</u>	Lanceolate bifoliate	0.11	0.59
<u>Graptodictya</u>	Cribrate, strap-shaped	0.22	1.20
<u>Hemiphragma</u>	Ramose	trace	trace
<u>Nicholsonella</u>	Ramose	1.86	9.98
<u>Ottoseetaxis</u>	Ramose radial	trace	trace
<u>Pachydictya</u>	Lanceolate bifoliate	0.69	3.73
<u>Parvohallopora</u>	Ramose	1.31	7.00
<u>"Phylloporina"</u>	Anastomosing	1.53	8.20
<u>Prasopora</u>	Ramose or hemispheric	0.22	1.20
<u>Stictopora</u>	Strap-shaped bifoliate	0.50	2.68
<u>Stictoporella</u>	Strap-shaped bifoliate	0.25	1.34
<u>Trigonodictya</u>	Explanate bifoliate	trace	trace
Unidentifiable		1.58	8.49

samples. Conversely, "Phylloporina" is found in almost every sample, but is never the most abundant genera present. Note that unlike the forementioned taxa, "Phylloporina" ranks highly in volume percent due to its more ubiquitous distribution. This may reflect the pervasive nature of "Phylloporina," which is present in all samples, but due to its small size, makes up a small percentage of the total volume.

Nicholsonella, a ramose or subramose trepostome which may have been originally aragonitic and fragile (Ross, 1964; McKinney, 1985, pers. comm.), is found in many samples from the nearshore environments, and comprises about 10% of the bryozoan fauna. Ceramoporids are common as encrusters and as hollow ramose forms (Ceramophylla; Figure 3.5D). Diplotrypa (Figure 3.5E), a thinly-walled ramose trepostome and (more commonly here) encruster, is most common in the biostromal lithology. Figure 3.5F illustrates Parvohallopore (formerly Calopora), a ramose trepostome which forms 7% of the bryozoan fauna. Athrophragma, an explanate cryptostome is the most common ramose bifoliate. Other important cryptostomes are Stictopora and Pachydictya, while Graptodictya, Escharopora (Figure 3.5G), and Trigonodictya, are present but rare.

Discussion

The abundant and diverse fauna in the nearshore environment suggests that the environment was equitable for most Middle Ordovician epifauna, including bryozoans. Hard substrates were readily available from bioclastic debris and possibly from early marine cementation of the coarse grained sediment. Importantly, current energy removed the

fine grained sediment which can be deleterious to filter feeding organisms. With soft sediment no longer a limiting factor, ramose bryozoans, with access to higher levels in the water column, flourished in the nearshore environment.

Branched, ramose trepostomes are the dominant growth form displayed in the nearshore environment. In sessile organisms, arborescent growth forms are favored in areas frequently disturbed by high rates of sedimentation or where food is a limiting factor (Jackson, 1979). Both factors may have been important in the nearshore environment. Amplexopora overwhelmingly dominates one bed of peloid packstone, forming 30% of the rock volume. The irregularly branched zooaria of Amplexopora occur in situ in the deposit, forming "clumps" of colonies (see Figure 2.5G, p.45). It appears the colonies of Amplexopora were periodically toppled, with subsequent renewed upward growth. The coarse grained matrix indicates episodic sedimentation of peloids and bioclasts which would easily smother low level attached epifauna or encrusters (see Walker, 1977).

Abundance of ramose growth forms may indicate avoidance of competition for food by trophic-level tiering of suspension feeders. Turpaeva (1957) observed tiering among modern invertebrates, and this has been inferred from fossil assemblages as well (Walker, 1972; Ausich, 1980). In the nearshore environment, bryozoans may have been in competition with the high-medium level filter feeding tabulate corals, high level filter feeding crinoids, and various epibenthic organisms such as brachiopods. A ramose growth habit surely minimized competition with the abundant filter feeding fauna.

Ceramoporids also show adaptations to the more agitated, nearshore environment. In the biostromal units, Ceramoporella, which encrusted soft muds in the middle shelf environment, forms small buildups or "microbioherms" (see Fritz, 1979). In the nearshore environment, Ceramoporella is found encrusting Solenopora, Batostoma, another genera of ceramoporid (Crepipora?), and an encrusting alga (Girvanella?) (Figure 3.5H). This association suggests that under conditions of more readily available substrata, Ceramoporella will compete for growth space, and is not restricted to inhabiting muddy substrata. Ceramophylla, which can form a hollow ramose zooarium, occurs frequently in the nearshore environment. As an encruster, Ceramophylla is almost indistinguishable from other ceramoporids. However, in the nearshore environment the distinctive hollow ramose zooaria is common. This may be further indication of an adaptation to increased competition for food in this environment.

The relative scarcity of ramose bifoliate and the decrease in importance of phylloporinids and arthrostylids may indicate the deleterious effects of increased current energy on more delicate ramose bryozoans. Although the bifoliate are found in most samples, and Athrophragma occurs in some abundance, they played a subordinate role as sediment producers. Perhaps the smaller ramose zooarial forms were so easily broken by wave and current energy they were unable to proliferate as they did in quiet water.

Figure 3.6 illustrates the bryozoan diversity found within the middle Chickamauga at Thorn Hill. The nearshore environment supported a more abundant and slightly more diverse bryozoan fauna than the

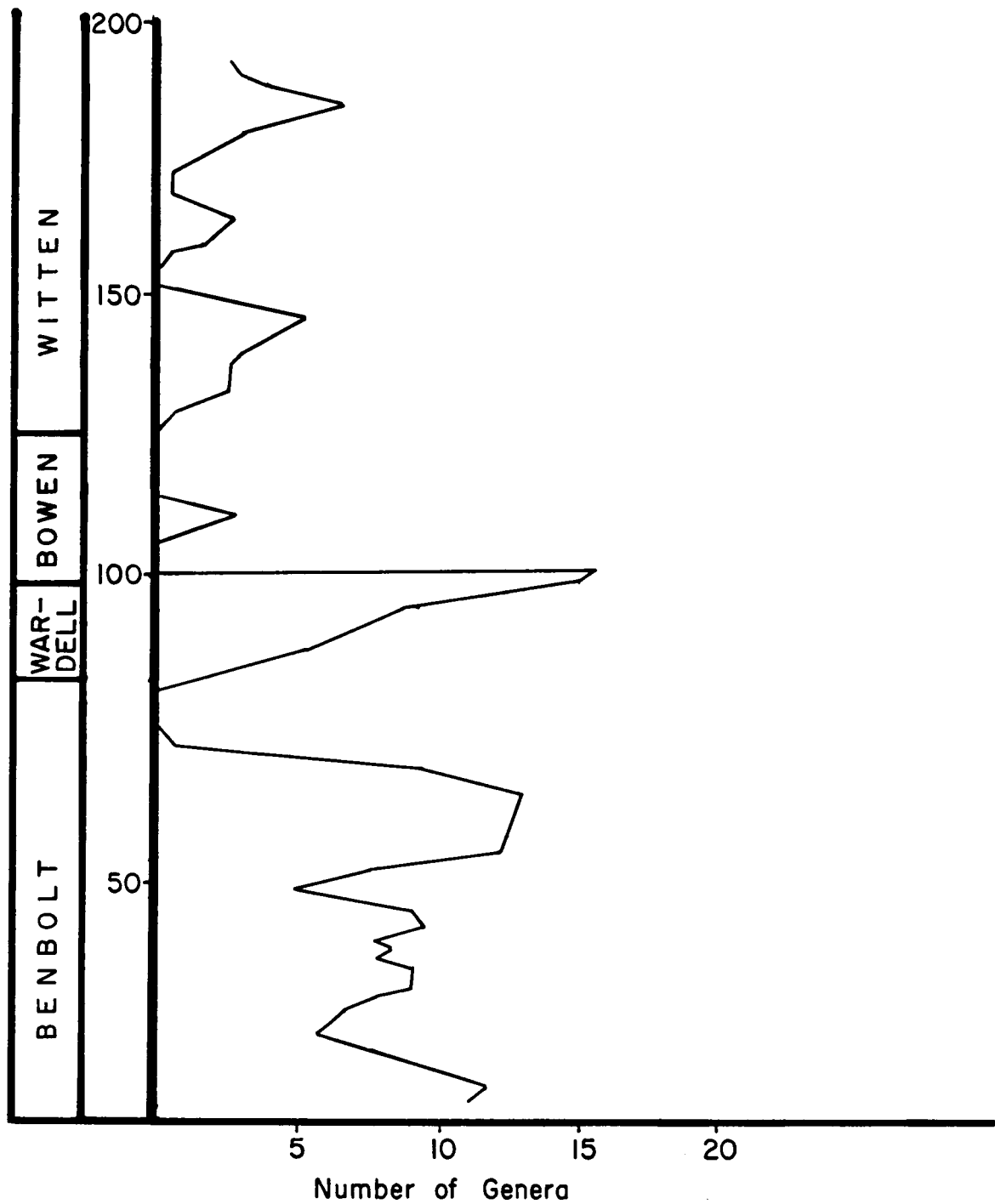


Figure 3.6. Bryozoan generic diversity in the middle Chickamauga at the Thorn Hill locality. Notice the particularly high diversity in the Wardell Formation. 3 by 3 moving average curve of all samples.

middle shelf. The availability of hard substrate and reduced amounts of fine grained sediment clearly were advantageous to most bryozoans. More frequent physical disturbances in the nearshore environment (e.g. storm sedimentation) may have aided in an increase in diversity as observed in modern coral reefs (Connell, 1978; Woodley, et al., 1981). The abundance of robust ramose ectoprocts (particularly trepostomes) suggests that high epifaunal diversity may have promoted competition, favoring the arborescent bryozoans. Fragile ramose bryozoans are less abundant in the nearshore environment, possibly reflecting an increase in breakage by wave energy and tidal currents. The dominant ectoproct fauna includes: Amplexopora, Constellaria, and Nicholsonella. These bryozoans are associated with tabulate corals, Solenopora, echinoderms, and brachiopods in the nearshore shoal/shoreface environment.

Restricted Inner Shelf Environment

The inner shelf environment is represented by a complex mosaic of supratidal, intertidal, and shallow subtidal facies. The lithology is an array of unfossiliferous, desiccated lime mudstone, fossiliferous wackestone composed primarily of molluscs, arthropods, and bryozoans, among storm-deposited fossil packstone. The bryozoan fauna (Table 3.3) is sparsely distributed except in some beds where Homotrypa and Amplexopora are abundant. The limited occurrence and low diversity of bryozoans, and dominance by only a few taxa suggest a bryozoan fauna adapted to restricted conditions of variable temperatures and salinities.

TABLE 3.3

BRYOZOANS OF THE RESTRICTED INNER SHELF ENVIRONMENT

BRYOZOANS	ZOOARIAL GROWTH FORM	TOTAL VOL. %	BRYOZ. VOL. %
<u>Amplexopora</u>	Ramose	1.10	14.52
<u>Athrophragma</u>	Explanate bifoliate	trace	trace
Arthrostylidae	Ramose radial	0.27	3.63
Ceramoporina	Encrusting, semi-ramose	0.24	3.23
<u>Constellaria</u>	Encrusting	0.24	3.23
<u>Eridotrypa</u>	Ramose	0.61	8.06
<u>Escharopora</u>	Lanceolate bifoliate	trace	trace
<u>Homotrypa</u>	Ramose	2.58	34.27
<u>Nicholsonella</u>	Ramose	0.12	1.61
<u>Pachydictya</u>	Lanceolate bifoliate	trace	trace
<u>Parvohallopora</u>	Ramose	0.12	1.61
<u>"Phylloporina"</u>	Anastomosing	0.33	4.43
<u>Prasopora?</u>	Ramose	0.15	2.02
<u>Stictopora</u>	Strap-shaped	0.18	2.42
<u>Stictoporella</u>	Strap-shaped	trace	trace
Unidentified		1.27	16.93

Note: Trace occurrence is less than 0.10%.

Although fifteen ectoproct genera were identified from the inner shelf lithologies, individual samples rarely contain more than five genera (see Figure 3.6). Homotrypa, a small-diameter, ramose trepostome, dominates the inner shelf sediment, as illustrated in Figure 2.7H (page 75). Homotrypa occurs in over half the samples which contain bryozoans and comprises over 2.5% of the total rock volume. Amplexopora, also a small-diameter, ramose trepostome, is subordinate, and it constitutes 1.1% of the rock and 14.5% of the bryozoan volume. The remaining bryozoans are present in minor amount (less than 0.5%) excepting a third ramose trepostome, Eridotrypa, which makes up 0.6% of the rock volume. Phylloporinids, arthrostylids, ceramoporids, and Stictopora are some of the associated taxa.

Discussion

The obvious dominance of Homotrypa in the restricted inner shelf environment suggests that this taxon was well adapted to variable environmental conditions. As discussed in Chapter 2, the inner shelf sediment contains a fauna composed chiefly of molluscs, ostracodes, trilobites, and bryozoans. Such assemblages are often referred to as a "restricted" fauna which implies an abundance of eurytopic organisms. The absence of Homotrypa in the open marine facies, and its abundance in the restricted environment suggests that Homotrypa was stenotopic, however well adapted to a stressful environment. Amplexopora, which was common in the restricted environment also appears to have a limited distribution. Although Amplexopora was the dominant bryozoan in the nearshore environment, it is also the most abundant genus in many

samples in the inner shelf. Like Homotrypa, Amplexopora was not found in the samples of sediment from the middle shelf environment.

Although Homotrypa and Amplexopora are superficially similar in zooarial form and external ornamentation (both contain numerous acanthostyles and thick exozones), any inference of these similarities as adaptations to a stressful environment is purely conjectural. However, the thickly calcified exozones surely added strength to the zooarium. This may have been important to taxa in high energy nearshore regimes, such as Amplexopora, or those often restricted to tidal channels within an inner shelf setting, such as Homotrypa.

The inner shelf sediments contain a locally abundant bryozoan fauna of low diversity. Most of the bryozoans are small ramose trepostomes although a few cryptostomes, most notably *Stictopora*, are present. Encrusters are rare, although some encrusting ceramoporids are present. Poor circulation on the shelf probably resulted in variable water temperatures and salinities which kept bryozoan diversity low. Apparently, the trepostomes Homotrypa and Amplexopora were well adapted to this stressful environment.

Summary

Ross (1970) published one of the few paleoecological studies of Middle Ordovician bryozoans. She suggested that the distribution of bryozoans in the Champlainian sequence in New York State exhibited facies control. Although Ross describes many genera that were not identified in this study, some of her conclusions are similar to those

proposed here. Most notably, Ross identifies Amplexopora, Stictopora, and Escharopora as occupying the most landward environment, which she characterized by "protected bays on broad shallow shelves." Although Escharopora was not a dominant element in the inner shelf environment in the present study, it did occur in many samples. More importantly, however, while Ross did not list Homotrypa as an abundant taxon, she shows it as being associated with Escharopora, Stictopora, and Amplexopora.

Unfortunately, for purposes of comparison, Ross' faunal list includes many important genera not found in this study. However, she includes Pachydictya, Bythopora, Prasopora, Eridotrypa, and Graptodictya in the deeper, quieter water environments of the Champlainian sequence. The presence of these taxa, particularly Pachydictya, in her offshore assemblage agrees with the findings of the present study.

Previous bryozoan studies in East Tennessee focused on open shelf or shelf edge environments, particularly the Holston Formation. Ferrigno (1973) found Amplexopora, Bythopora, and Stictopora dominated the reef core facies of the Holston, while Bythopora, Hemiphragma, Ottoseetaxis, and Stictopora dominated the flanking grainstone. Ruppel (1979) found Constellaria antheloides and Bythopora dominated the reef core of the Holston at other localities, while Batostoma, Bythopora, Constellaria, Diplotrypa, and Ottoseetaxis dominated the flank deposits. Ruppel also studied the bryozoans of the on-shelf deposited Rockdell Formation which he found to consist mostly of Ceramophylla (his Coeloclema), Constellaria, arthrostylids,

Nicholsonella, Ottoseetaxis, and Stictopora. More recently, Cristil (1985) found the Holston reef core facies in a third area, consisted mainly of Batostoma, Nicholsonella, and Stictopora, and the flank facies of Hemiphragma, Nicholsonella, and Stictopora.

Figure 3.7 summarizes the facies distribution of the more common bryozoans present in this study. Generally, the bryozoan fauna of the middle shelf facies consisted of ceramoporids and phylloporinids with isolated occurrences of Batostoma and Nicholsonella associated with offshore shoals. In nearshore, higher energy environments, Constellaria and Amplexopora were abundant. Stictopora and arthrostylids were ubiquitous while Pachydictya was common to open shelf facies only. Ottoseetaxis and Bythopora were present, yet rare, throughout the middle shelf. The inner shelf environment was characterized by low diversity, but Homotrypa and Amplexopora were locally abundant.

The facies distribution of some of the bryozoans covered in this study is consistent with the ectoproct distribution noted by previous workers in Middle Ordovician sediments of East Tennessee. However, the abundance of Amplexopora in the open shelf as reported by Ferrigno (1973) is problematical. The principle bryozoans responsible for producing buildups are found in the open marine, middle shelf environment of this study, and that of Ross (1970). As in the skeletal buildups, Batostoma was an important encrusting taxon in the high energy environments of the shelf. Nicholsonella was an important ramose trepostome associated with on-shelf deposited skeletal accumulations. Stictopora appeared in the shelf-edge patch reefs,

Figure 3.7 Facies distribution of bryozoans in the middle Chickamauga at the Thorn Hill locality. Note that many genera are most abundant in the near-shore shoal facies and higher energy environment of the middle shelf. Also note the somewhat widespread abundance of phylloporinid and ceramoporid taxa in the open marine facies.

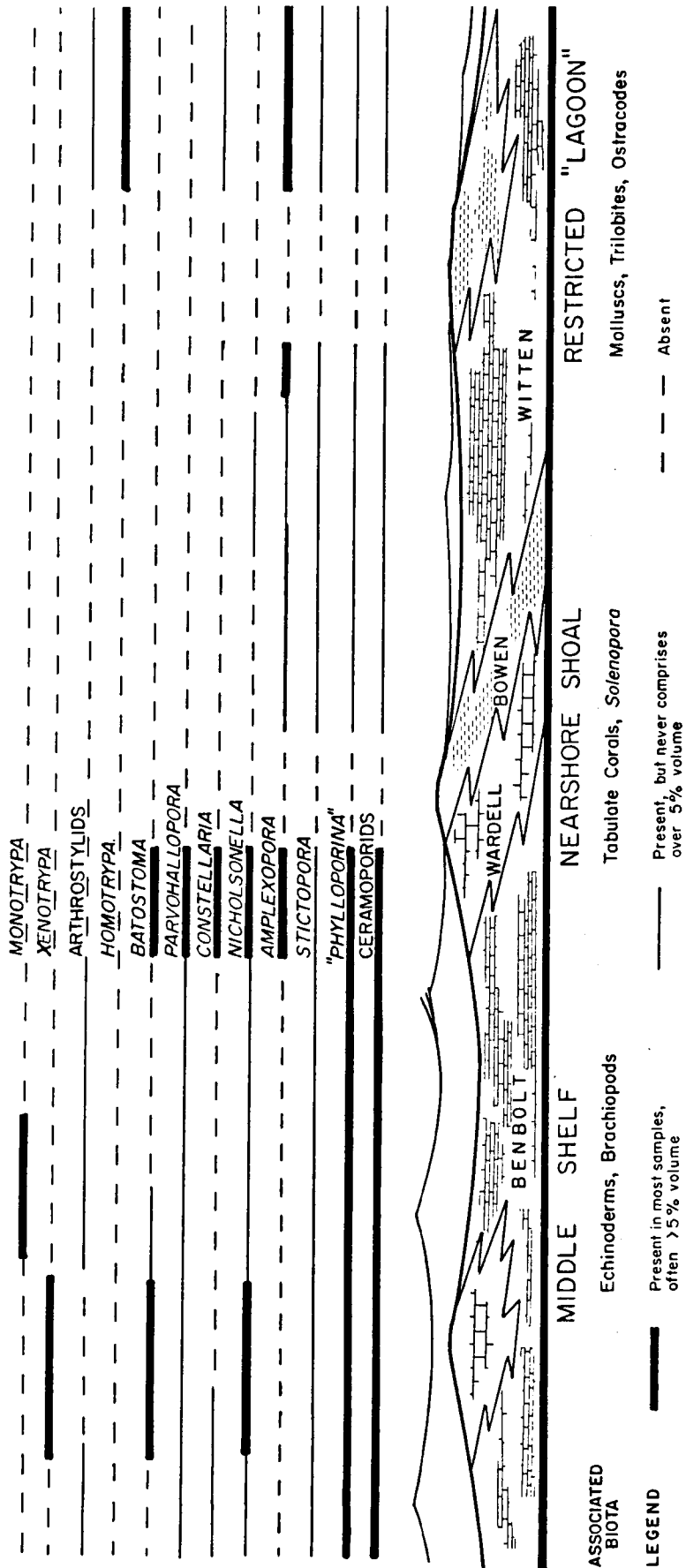


Figure 3.7.

throughout the middle shelf, and into the inner shelf environment. However, Stictopora did not dominate any of the on-shelf environments as it did in reef and patch reef environments. Constellaria, which Ross (1964b) believed to occupy "a very restrictive ecological niche," is found predominately in high energy on-shelf skeletal accumulations. Amplexopora and Homotrypa are found in open shelf facies by other workers (i.e. Ratliff, 1974; Sitterly, 1976), however, the present study demonstrates that their greatest abundance was in the restricted inner shelf environment.

The disjunct facies distribution of bryozoans, as presented here, suggests that Middle Ordovician ectoprocts of East Tennessee exhibit some degree of facies specificity. A more in depth study, encompassing many localities and including shelf, shelf edge and slope environments could shed much needed light on the environmental distribution of Middle Ordovician Bryozoa. Such a study would have obvious paleontologic and paleoenvironmental value. This thesis recognizes the need for a comprehensive study of the bryozoans of the Chickamauga Group.

CHAPTER 4

TAPHONOMIC CONSIDERATIONS OF CARBONATE

SHELF FOSSIL ASSEMBLAGES

Introduction

Before an invertebrate assemblage enters the fossil record, biotic and abiotic taphonomic processes effect the preservability of the original assemblage. In numerous studies during the last twenty years, invertebrate skeletal assemblages have been used as approximations of original organic communities. Many of these paleoecologic studies suggest further that compositional changes in fossil assemblages are manifestations of faunal succession (Bretsky and Bretsky, 1975; Walker and Alberstadt, 1975; Walker and Parker, 1976; Rollins, et al., 1979; Harris and Martin, 1979; Walker and Diehl, 1986). However, recent studies have questioned the viability of skeletal accumulations as accurate portrayals of ancient communities.

Obviously, syndepositional and post mortem sedimentologic processes can obscure short-term events such as faunal succession. Succession may be confused with environmental change and community replacement (Hurst, 1979; McCall and Tevesz, 1983). Moreover, faunal mixing by bioturbation and condensation of shell layers by compaction may obscure the detail necessary to discern successional events (Fursich, 1978, 1982; Schindel, 1980). Faunal mixing is also facilitated by physical reworking or winnowing by tidal and

storm-induced currents (Specht and Brenner, 1979; Kreisa and Bambach, 1982; Kidwell and Jablonski, 1983). However, not all taphonomic processes involve removal or condensation of the original community information.

Certain taphonomic processes may actually enhance preservation of fossil assemblages in carbonate shelf environments. Synsedimentary compaction, water loss, and early marine cementation may, in fact, have aided in preserving fossil communities in the Ordovician (Walker and Diehl, 1985). In the Middle Ordovician of East Tennessee, short term depositional events, such as rapid deposition or "obtrusion" (see Seilacher et al. 1985), have preserved biotic responses to changes in sediment consistency (Wedekind and Walker, 1985). This chapter identifies some early taphonomic processes and discusses how they may have aided in the preservation of fossil assemblages in the Middle Ordovician.

Taphonomic Processes

Marine Cementation

Early marine cementation, an important diagenetic process in carbonate depositional environments, has been identified in various facies on modern carbonate shelves (MacIntyre, 1977; Mullins, et al., 1981). Marine cementation is most commonly associated with higher energy shelf edge environments such as reefs and skeletal shoals where flushing by wave action forces water into the sediment (Cantrell and Walker, 1985). Submarine cementation in shallow water, muddy

carbonates is not as well understood, but has been observed in Recent sediments of the Persian Gulf (Shinn, 1969). Although early cementation is absent in most modern on-shelf lagoonal and back reef environments (see, for example, James et al., 1976), hardgrounds attributed to early submarine lithification are common in ancient carbonate shelf deposits (e.g. Zankle, 1969; Hagdorn, 1982; Seilacher, 1982).

Although marine cementation has a rather limited distribution in modern environments, this may not have always been the case. Sandberg (1983) believes that at certain times during the Phanerozoic, changes in oceanic chemistry (particularly the Mg:Ca ratio and partial pressure of carbon dioxide) favored the physiochemical precipitation of calcite over aragonite. Since most Ordovician faunas were originally calcitic, marine cementation may have been favored during this time, especially in fossiliferous sediments (Walker and Diehl, 1985). While early cements are not common in the middle Chickamauga, they indeed occur in many of the coarse grained lithologies (Figure 4.1A). Since submarine cements are absent in most mid-shelf environments today, their presence in these Ordovician deposits suggests marine cementation was more widespread during this time.

Walker (1985) and Walker and Diehl (1985) hypothesize that marine cementation was more common in middle shelf environments during the Ordovician, hence the preservation of in situ fossil assemblages may be common in these rocks. In addition, enhanced cementation may have aided in consolidating marine muds, allowing initially soft sediment to become a firm substratum. Walker and Diehl (1986) believe mixed

Figure 4.1. Photos illustrating various taphonomic features found in the middle Chickamauga. Stratigraphic up is towards top of page unless indicated otherwise. Samples are from Thorn Hill locality unless stated otherwise.

A. Photomicrograph with crossed nichols of marine cement fringing an articulated brachiopod, a brachiopod fragment, and a trepostomaceous bryozoan. Notice how the marine fringe connects the grains, suggesting they were cemented together subaqueously. Bar scale is 0.66mm in length. Sample TH36, Wardell Formation.

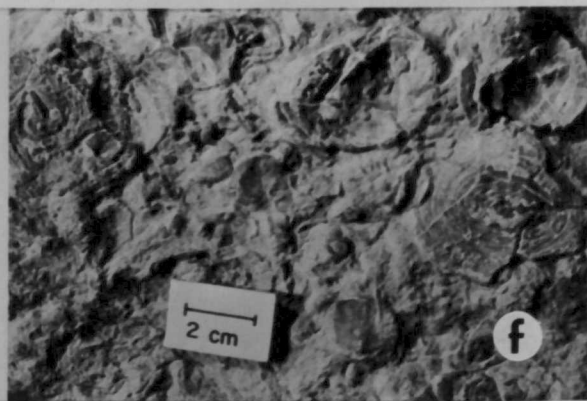
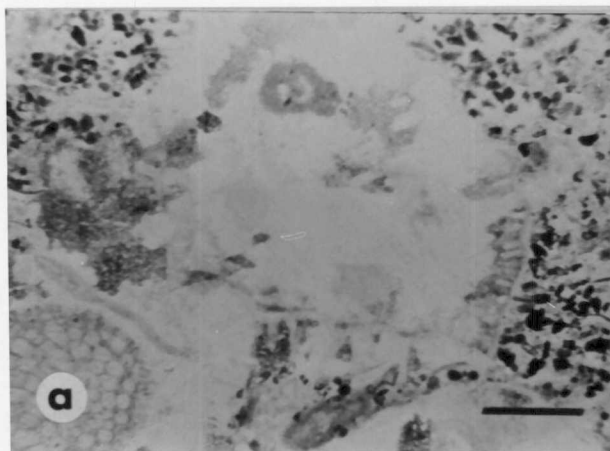
B. Photomicrograph with crossed nichols showing infiltration fabric in storm deposited lithology. Note perched peloidal sediment and shelter porosity under skeletal grains. Allochems are trilobite pieces, molluscan fragments, intraclasts, and bryozoans. Bar scale is 0.5mm in length. Sample TH80, Witten Formation.

C. Bottom of slab showing bryozoan encrustation of strophomenid brachiopods. Note how the encrustation extends beyond the shell margin. Dime for scale. Sample Fb 23-Fb 24; Benbolt Formation, Hogskin Valley locality.

D. Top of slab showing pelmatozoan holdfast encrusting top of "microbioherm". Note margin of microbioherm and small brachiopod valves within adjacent sediment. Bar scale is 10mm. Sample Fb 15; Benbolt Formation, Hogskin Valley locality.

E. Basal surface of microbioherm showing strophomenid valve serving as attachment site for bryozoan growth. Notice the small brachiopod which was also overgrown by the bryozoan. Penny for scale. Float sample from unit 4 of Benbolt Formation.

F. Bottom surface of slab showing numerous bryozoan microbioherms on a single bedding surface. Note that the basal attachments are absent in some instances. Also note small nest of brachiopods in lower right corner. Sample Fb 23-24; Benbolt Formation, Hogskin Valley locality.



assemblages of hard and soft sediment-adapted taxa from the Middle and Upper Ordovician reflect a gradual hardening of the substratum in response to syndepositional cementation, compaction and dewatering.

Biogenic Reworking

Deposit feeding organisms thrive in oxygenated muddy environments and tend to obliterate primary sedimentary features (Byers, 1982). Under optimal conditions, a single species of deposit feeder can rework all of the annually deposited sediment in a subtidal environment in a single day (Rhoads, 1963). Where deposit feeders are abundant, sediment at the sediment-water interface typically contains greater than 60% water due to burrowing and pelletization of the surface sediment (Rhoads and Boyer, 1982; Levinton, 1982). Such water-charged sediment is unsuitable for sessile suspension feeders because it is easily resuspended and forms a thin layer of turbid water above the sediment-water interface. This layer of turbid water may clog the delicate suspension feeding apparatus of the sessile epifauna (Rhoads and Young, 1970). Although most of the studies mentioned above were conducted in temperate muddy environments, trophic amensalism has been documented in tropical carbonate environments as well (Wade, 1972; Aller and Dodge, 1974). Additionally, a mobile infauna can cause epifaunal organisms to be advected into the sediment, in a process termed "bulldozing" by Thayer (1979; 1983).

Clearly, it is problematical for sessile invertebrates to attempt colonization of a muddy substratum inhabited by a diverse, deposit feeding infauna. For invertebrate colonization to occur, infaunal

diversification must be precluded, allowing the sediment to lose water and compact. Gray (1981) found that while trophic amensalism does occur between benthic faunas, mixed communities of both suspension and deposit feeders are most common. He views modern soft bottom environments as a temporal mosaic composed of patches locally dominated by either suspension feeders or deposit feeders. It appears that suspension feeders have developed opportunistic colonization strategies which allow them to occupy areas of substrate which have low infaunal diversity (Probert, 1984).

Biogenic Stabilization

Sediment stability in physically unstable muddy environments is primarily dependent on the type of organisms inhabiting the substrate. Levinton and Bambach (1970) found that the suspension feeding bivalve Mulinia is most abundant in sediment deposited above storm wave base. They believe that Mulinia is an opportunist capable of inhabiting disturbed seafloors since it usually occurs in great numbers in frequently disturbed sediments. Pioneer communities of infaunal burrowers have little effect on primary sedimentary fabrics (Larson and Rhoads, 1983), for they feed only at the sediment surface and do not actively overturn sediment (Rhoads and Boyer, 1982). Additionally, small scale reworking results in an increase in benthic and interstitial microorganisms, which are important sediment stabilizers (Probert, 1984). Meiobenthic organisms are rapid colonizers of freshly disturbed muds (Sherman and Coull, 1980) which they bind by mucoid exudates, increasing the sediment shear strength. Probert (1984) has

presented a post-disturbance model for soft bottom colonization. He hypothesizes that suspension feeders may colonize the firm sediment provided by the activities of the meiofauna before infaunal deposit feeders render it flocculent. Thus, in muddy environments, often beset by physical disturbance, suspension feeders may colonize soft sediment.

More stable muddy environments, which are rarely affected by physical disturbance, develop an equilibrium community of active burrowers. An infaunal community dominated by equilibrists actively overturns the sediment, resulting in higher surface water content, smaller grain size at the surface, and a generally smooth substratum (Rhoads and Boyer, 1982). Although active burrowers oxygenate the sediment, causing an increase in microbenthotic organisms (Byers, 1982), bioturbation serves to destroy the sediment-binding mucilagenous films produced by the meiofauna (Probert, 1984). Thus, in protected lagoonal environments or during prolonged periods of fair weather, muddy environments result in thixotrophic sediment and a smooth substratum, which is unsuitable for invertebrate colonization.

In carbonate depositional environments, the abundance of skeletal material and frequency of disturbance aids in the colonization of suspension feeders. This would explain why muddy carbonates, such as those found in the lower Benbolt Formation at Thorn Hill, often contain a diverse macrofauna though the sediment appears to have been extensively bioturbated (see Chapter 2). However, in environments where storm effects are diminished or an influx of terrigenous mud has inhibited the proliferation of suspension feeders, only soft-sediment adapted taxa are common. Similarly, the calcareous shale of the upper

Physical Reworking

Sediment deposited within fairweather wave base is subject to more or less constant abrasion, erosion and redeposition by wave energy. Nearshore and shallow shoal environments are typically subject to such intense reworking. Although many organisms certainly live in shoal environments, preservation potential is generally low. Rapid burial by large amounts of sediment may preserve a fossil assemblage relatively intact (Jeffery and Aigner, 1982), but often the assemblage will be subsequently reworked by wave-induced currents. However, current agitated environments often contain organisms which can stabilize the substratum by trapping or binding the sediment. This greatly increases the possibility of preservation, for the community essentially entombs itself in sediment.

Fossil assemblages may also be reworked by current energy produced during storms. During a storm, increased wave energy removes loose sediment and may even erode the semi-lithified seafloor below the layer of uncompacted sediment. As the storm wanes, the suspended load settles out and accumulates on the tops of larger clasts as perched sediment (Kreisa, 1981). The rain of sediment is shielded from accumulating below the larger clasts, leaving shelter voids beneath them (Figure 4.1B). Storm-generated infiltration fabrics, as described above, are indicative of periodic high energy events which have reworked the original fossil assemblage, thereby destroying fine-scale paleoecologic information.

Physical Factors which Enhance Preservation

While certain events serve to remove and redeposit shell material, they may also provide an excellent mechanism for fossil preservation. A fossil assemblage deposited below fairweather wave base but well above storm wave base may actually have a better than average chance of being preserved. If a community of sessile organisms is well established on a substratum, they can resist erosion by storm currents. Thus, as the storm passes, the assemblage will be buried as the finer grained material falls out of suspension.

Storm events may also be important in providing firm substrata for sessile invertebrates. A storm event may remove only the soft sediment, depositing it elsewhere, thereby exposing semi-lithified compacted sediment. The exposed "firmground" may serve as an available substratum for invertebrates (Aigner, 1982b), providing muds deposited in the storm waning stage do not form a substantial thickness of fine sediment. If a large amount of mud is deposited, soft-bottom succession as described by Walker and Parker (1976) could ensue. However, if post-storm reworking winnows away the mud of a storm deposit, a shell horizon is produced (Aigner, 1982b; Kidwell and Jablonski, 1983). A bioclastic storm deposit provides abundant hard substrata for invertebrate colonization. Therefore, although storm deposits are often cited for their information destroying capabilities, storm episodes are also important in providing new areas for the establishment of invertebrate communities.

Examples from the Middle Ordovician

In the upper Benbolt Formation of Hogskin Valley, Tennessee, Ewing (1985) found an excellent example of biotic-mediated response to soft sediment. He found a bedding surface inhabited by ceramoporid bryozoans and strophomenid brachiopods which served as an attachment site for large encrusting bryozoan (Monotrypa) colonies (Figure 4.1C). In this example, it appears that the large surface area of the strophomenid valves served to float the brachiopod on the soft sediment. This floating strategy is termed a "snowshoe" strategy by Jablonski and Bottjer (1983) and is a common adaptation in bivalves. Monotrypa encrusted the hard substrate provided by the brachiopod shell, and expanded out over the surrounding mud, resulting in a flattened hemispheric shape (see Chapter 3). The large surface area exhibited by the Monotrypa zooarium served as a suitable substrate for other taxa including other brachiopods and pelmatozoans (Figure 4.1D). Flattened and encrusting macrofaunal organisms may have a stabilizing effect on sediments similar to the role played by seagrasses in modern environments. Therefore, in addition to providing a source of hard substratum by their shells, soft sediment adapted taxa may also serve to stabilize the sediment surface.

Unit 4 of the Benbolt at Thorn Hill contains biogenic structures similar to those found in Hogskin Valley (Figure 4.1E), but they do not extend over such an extensive area as the ones found at the Hogskin Valley locality (Figure 4.1F). In the Thorn Hill example, the "microbioherms" did not facilitate short term succession as predicted by

Walker and Alberstadt (1975). In this case, the surrounding sediment did not accumulate the skeletal debris to provide additional hard substrates for later taxa. Instead, the substrate remained fluid and unsuitable for additional macrofauna because of the amensalistic effect of resident infauna (Rhoads and Young, 1970). Only patches of organisms adapted to life on soft substrates are present, along with epibionts encrusting their hardparts. They occurred as "island faunas" in a rather inhospitable environment for suspension feeders. Figure 4.2 diagrams the sequential process of substrate modification by purely epifaunal colonization. In this example, the epifauna had no observable effect on the surrounding sediment.

In lime mudstones of the Wardell Formation at Thorn Hill, originally soft sediment became stabilized, compacted, and possibly syndepositionally cemented, allowing a diverse assemblage of invertebrates to become established. Figure 4.3A shows the well preserved invertebrate assemblage composed of a large tabulate coral (Lichenaria?), numerous robust ramose bryozoans, and trilobite pieces. The assemblage is excellently preserved and most fossils (except trilobites) are essentially in life position. Importantly, the assemblage is not continuous across the top of the slab.

Figure 4.3B shows the homogenized fabric of the sediment immediately below the aforementioned fossil assemblage. Although the sedimentary fabric is thoroughly bioturbated, several generations of burrows are recognized. The initially soft sediment was obviously thoroughly reworked as evidenced by the lack of preserved burrows and mottled fabric. Later generations of burrows contain well defined

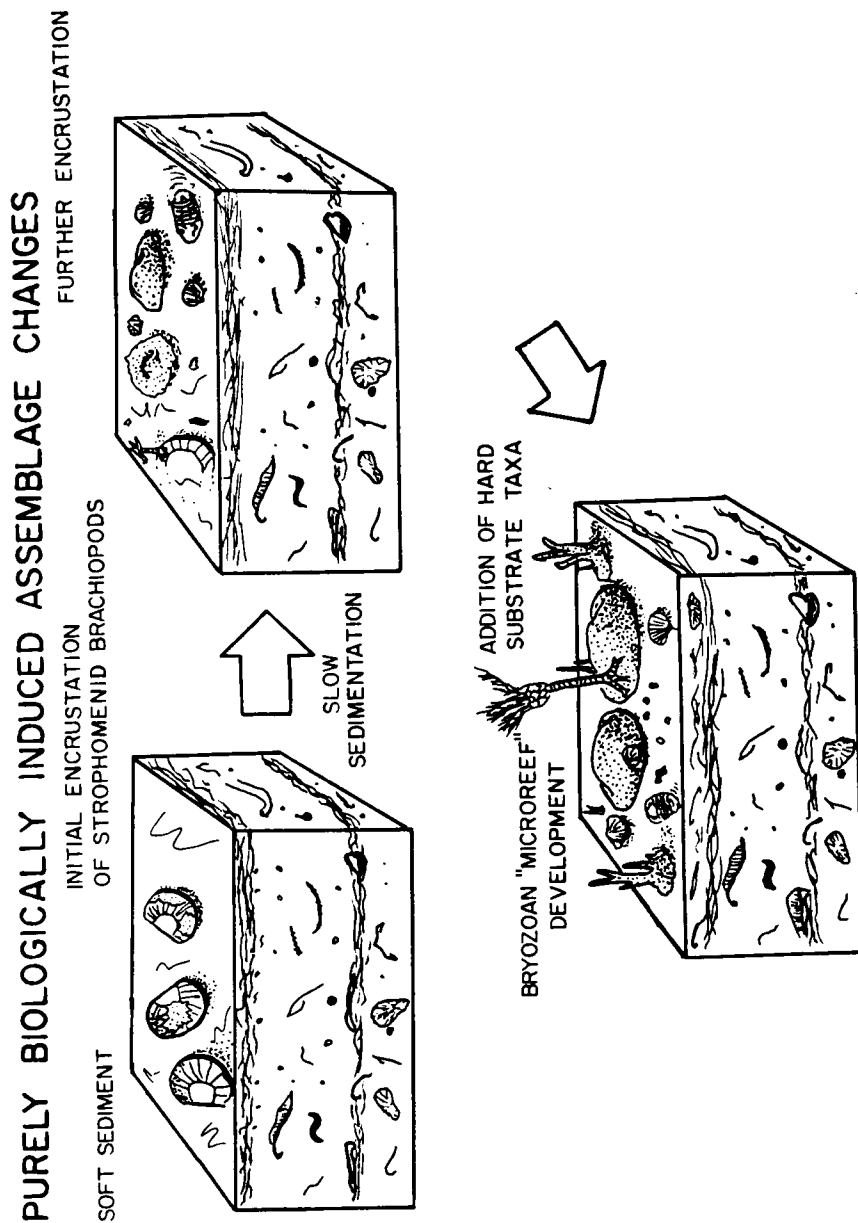


Figure 4.2. Schematic representation of biologically induced assemblage changes. Block diagrams outline how soft sediment adapted taxa facilitate addition of hard substrate taxa to assemblage.

Figure 4.3. Photographic examples of soft sediment modification resulting in invertebrate colonization from Wardell Formation at Thorn Hill locality. Stratigraphic up is towards top of page unless stated otherwise.

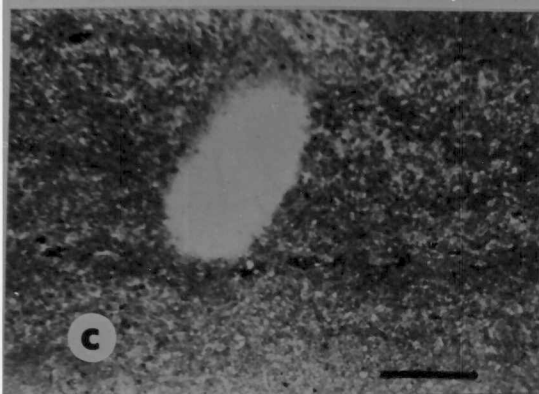
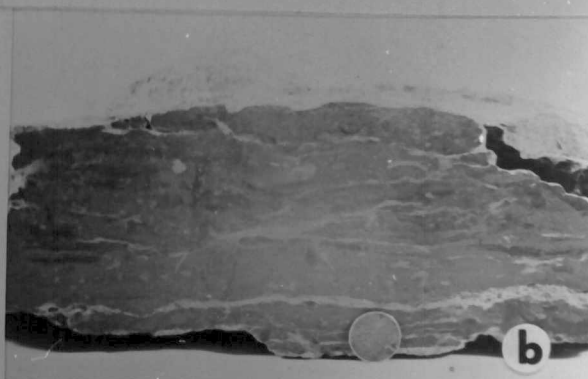
A. Lichenaria occurring in situ on bedding surface which includes phylloporinid bryozoans (center of photo), lanceolate bryozoans (top center), and trilobite cephalon (bottom right). Dime for scale. Sample TH34b.

B. Polished slab photo illustrating generally homogenized fabric of lime mudstone in lower Wardell Formation. Note some well defined burrows which appear lighter colored due to neomorphism. Also note coral head on top surface of slab. Penny for scale. Sample TH34.

C. Well defined, spar-filled burrow from above sample. Note slight sediment deformation associated with burrow walls, indicating that burrowing occurred while the sediment was somewhat firm. Scale bar is 0.6mm in length. Sample TH34.

D. Top of slab depicted in figure 4.3B. Coral head and ramose bryozoans dominate the assemblage, and are essentially in life position. Note the abrupt boundary between fossiliferous area (center) and unfossiliferous region (bottom). Penny for scale. Sample TH34.

E. Slab showing in situ coral head (Saffordophyllum), Solenopora, nested brachiopods, bryozoans, and echinoderm debris. Note that although bryozoans are nested, they are usually still articulated. Unit 7 of Wardell Formation.



walls suggesting a gradual firming of the substrate (Figure 4.3C). Walker and Diehl (1986) discuss how progressive changes in sediment consistency may be manifested by successive changes in biogenic structures.

Walker and Diehl (1986) suggest that early marine cementation not only enhances the preservation of paleocommunities, but also serves as a control on the spatial distribution of faunal succession. They believe the patchy distribution of submarine cement results in a substratum with areas of varying hardness, depending on the degree of cementation. The previously discussed coral-bryozoan assemblage may be a reflection of a patchy firmground and neighboring softer sediment. Close inspection of the slab surface shows the fossil assemblage tightly clustered in one area (Figure 4.3D). Adjacent to the fossil assemblage is burrowed lime mud, devoid of a skeletonized fauna. Alternatively, the sediment may have developed an abundant meiofauna which served to add cohesion to the sediment, and possibly prompted macrofaunal colonization, as suggested by Probert (1984). Realistically, both processes may have occurred simultaneously. In either case, burrow analysis reveals a sequential hardening of initially soft sediment, followed by colonization by a benthic megafauna.

Figure 4.4 is a depiction of the development of a sessile invertebrate community by biotic and abiotic interaction. Clearly, this is an oversimplification, but the series of diagrams outlines the important physical processes associated with muddy carbonate sediments. These processes are: 1) dewatering, 2) initial compaction, and 3)

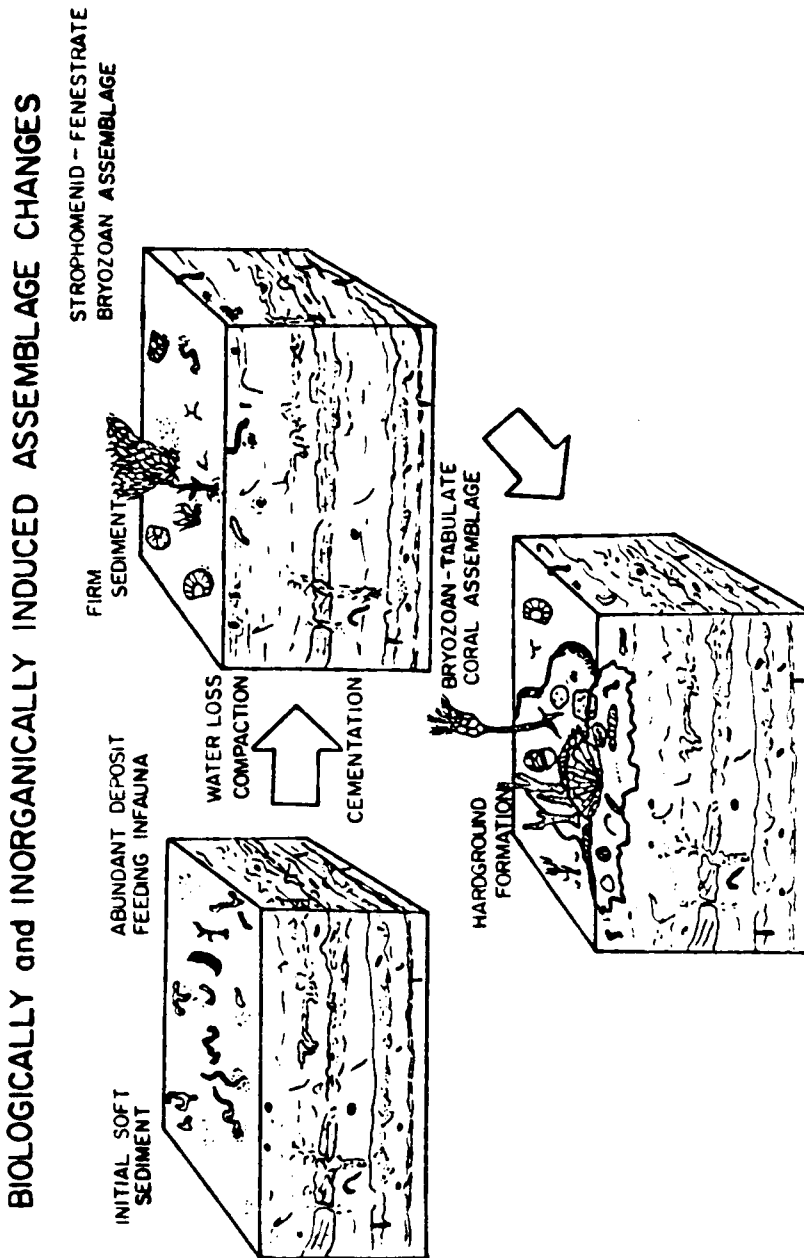


Figure 4.4. Schematic diagrams illustrating invertebrate assemblage which reflect changes in substrate consistency. Modified from Walker and Diehl (1986).

early cementation. If meiofaunal activity is added to these physical processes, the net result is the same. That is, preservation of a hard substrate assemblage on what was initially deposited as soft mud.

In nearshore carbonate environments, increased wave and current energy regularly winnows away mud, leaving behind coarser grained skeletal material. Skeletal grains provide readily available substrate for colonization by invertebrates. Periodic storms in the Wardell environment resulted in a coarse grained deposit composed mostly of peloids and bioclastic material. The storm-deposited sequence shows little evidence of biogenic reworking, due to rapid sedimentation. The storm-deposited beds served to add coarse grained sediment. Sand-sized sediment has high initial porosity, but tends to compact, rather than dilate when burrowed (Rhoads and Boyer, 1982). Therefore, coarse grained storm deposits provide an instantaneous hard substratum, well suited for colonization by an invertebrate megafauna.

In the Wardell Formation at Thorn Hill, the closely associated biostromal beds (Figure 4.3E) and bioclastic peloidal sands suggest the two lithologies represent originally contiguous environments. Horizontal lamination and escape traces found in most pelsparite beds suggests these peloidal sands moved episodically as observed in modern carbonate sands (Ball, 1967; Hine, 1977) and were not subsequently reworked. When the sand sheets moved, probably during severe storms, they sometimes blanketed invertebrate communities which occupied areas of stabilized sand. These events are recorded as thin beds of pelsparite, often underlain by a lag deposit of brachiopods, which cover biostromal deposits of coral and calcareous algae. Figure 4.5A

Figure 4.5. Photos exhibiting physical control on substrates as indicated by resident invertebrate assemblages. All samples from unit 7 of Wardell Formation, Thorn Hill locality.

A. Slab photograph showing the close association between biostromal assemblage and carbonate sand sheet (at left). Lens cap is 6cm in diameter.

B. Polished slab of carbonate sand lithology (pelsparite) showing colonization of sand sheet by Constellaria and tabulate coral. Both organisms were subsequently covered by later depositional event. Penny for scale. Sample TH48.

C. Well preserved crinoid (Ristacrinus altobasalis) preserved by rapid burial. Float slab. Crinoid is 30mm in length.

D. Cribrate, trepostomaceous bryozoan preserved in life position in outcrop of upper Wardell. Side view of bedding plane, note bedding parallel orientation of other fossils. Penny for scale.



illustrates the close association of these two distinctive lithologies.

Macrobiota, in this case corals, bryozoans and algae, re-colonized the coarse substratum provided by the bioclastic peloidal sand. Unlike the case of muddy environments, little substrate modification, either biogenic or physical, is necessary in a coarser grained substratum for invertebrate colonization. Water loss and compaction are easily facilitated as skeletal material accumulates and increasing numbers of invertebrates inhabit the sediment surface. Rapid sedimentation during storms entombed the original community, yet apparently could not exhume the fauna inhabiting the hardground. Figure 4.6 summarizes epifaunal community development in a storm-deposited nearshore bioclastic environment.

Summary and Discussion

Johnson (1960) summarized criteria, based primarily on physical characteristics of fossils, by which a fossil assemblage could be categorized as to its paleoecologic usefulness. However, fossils can be biogenically reworked or transported in suspension with minimal abrasion. In light of more recent sedimentologic and ichnologic work, reworked fossil assemblages can be discerned more readily. Obviously, well preserved paleocommunities which contain minimal time averaging are exceedingly rare. However, some taphonomic processes enhance, rather than destroy, community information. Lack of uniformity in oceanic chemistry and diversification in infaunal burrowers may have favored assemblage preservation at certain times in the past.

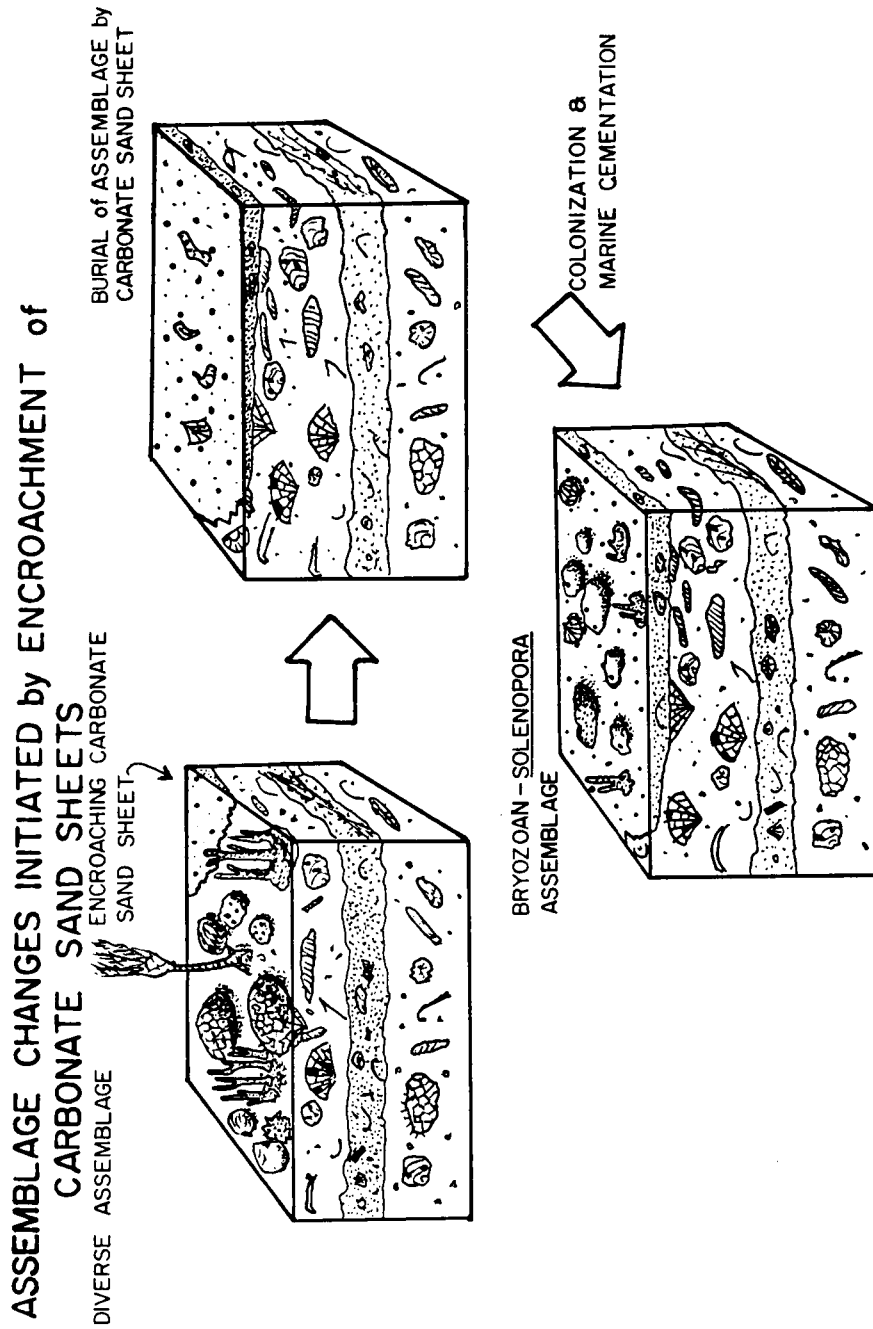


Figure 4.6. Schematic diagrams illustrating mechanism for assemblage preservation and re-colonization in a nearshore environment. Block diagrams based on field observation and thin section analysis.

Figure 4.7 summarizes the taphonomic processes which can be observed in the various facies of the middle Chickamauga at Thorn Hill. It may be noticed that the areas where constructive taphonomic processes are most prevalent and destructive processes are least effective are very small. Generally, assemblages which stand the best chance of preservation lie below fairweather wave base and above storm wave base. However, this zone of water depth, while appearing very narrow in this diagram may be quite extensive on broad shelves, easily on the order of kilometers.

Sediment deposited below storm wave base, as inferred for much of the Benbolt Formation, was apparently biogenically reworked as it was deposited. Low rates of physical disturbance, resulted in the establishment of an abundant deposit-feeding infauna capable of periodically excluding suspension feeders. The extensive reworking in this environment reflects slow rates of sedimentation which, according to Fursich (1978), should result in a condensed assemblage of fossils. The subtidal shoal deposits found in the Benbolt contain some evidence of marine cementation, and many encrusting bryozoans. However, a majority of these deposits show evidence of oscillatory currents which have thoroughly reworked the fossil assemblage.

The nearshore (Wardell) environment, however, has several constructive taphonomic processes which aid in preserving the fossil assemblages. The presence of marine cement, an abundant encrusting fauna, and frequent storm events all favor preservation in this environment. Since the substratum was colonized by hard substrate taxa between storms, and partially cemented, erosion by the storms was

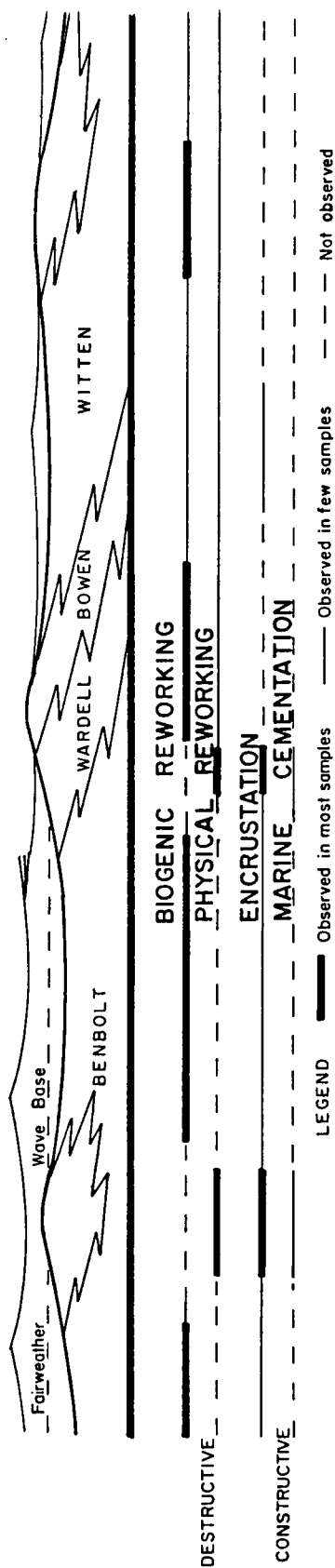


Figure 4.7. Schematic cross section of shelf environment illustrating the relative effect of various taphonomic processes. Notice that shallow water environments below fairweather wave base are most likely to contain preserved assemblages. Diagram based on petrographic analysis.

minimal. Finer grained sediment deposited in the waning stages of the storm preserved the original assemblage relatively intact (Figures 4.5C, D).

Very shallow subtidal, partially restricted environments also may contain well preserved fossil assemblages. McCall and Tevesz (1983) suggest that slow rates of sedimentation in restricted environments may limit food supplies for deposit feeders, allowing the substrate to become firm enough for invertebrate colonization. Subsequent storms cover the invertebrate assemblage with muddy sediment. A similar scenario might explain the well preserved bryozoan assemblage observed in Figure 2.7G (p.45)

Well preserved fossil assemblages interpreted to be paleocommunities have been identified in several middle Chickamauga localities. Interestingly, Walker and Parker (1976) and Weiss (1981) describe succession in the partially restricted Witten Formation, and the study by Sickafoose (1979) was made on a nearshore facies of the Benbolt Formation. Although these studies cite faunal succession as controlling sequential faunal changes within strata, they alternatively could represent small scale taphonomic changes as suggested by the present study.

CHAPTER 5

SUMMARY AND CONCLUSIONS

1. The Middle Ordovician middle Chickamauga Group is composed of four formations west of the Saltville Fault in northeastern Tennessee: the Benbolt, Wardell, Bowen, and Witten formations. The middle Chickamauga is conformably underlain by the Rockdell Formation and overlain by the Moccasin Formation. The middle Chickamauga was deposited as a regressive sequence of deep subtidal to intertidal and supratidal environments on a broad carbonate shelf.

2. The middle Chickamauga is 198.8m thick near Thorn Hill, Tennessee, the primary area of this study. Thirteen units are identified at this locality. The Benbolt Formation is 84.6m thick and is composed of four units. Unit 1 is 22.7m of stylolitic irregularly bedded, fossiliferous wackestone and intercalated shale. Unit 2 (9.6m) is thinly bedded, fossiliferous wackestone with numerous sponge fossils. Unit 3 (32.9m) is a mixed lithology composed of thin to medium bedded highly fossiliferous, oncolitic packstone and poorly fossiliferous, wavy bedded wackestone and mudstone. Unit 4 is 19.4m thick and consists of poorly fossiliferous, chippy weathering shales and argillaceous limestone. Unit 4 forms a sharp contact with the overlying fossiliferous limestone of the Wardell Formation. The Wardell is 15.1m thick and consists of units 5 through 7. Unit 5 is 0.4m of intraclastic, algal-rich, fossiliferous wackestone. Unit 6 (8.5m) consists of interbedded lime mudstone and fossiliferous peloid

packstone. Unit 7 (6.2m) is composed of interbedded peloid packstone and coral, algal and bryozoan-rich biostromal beds. Unit 7 forms a sharp contact with the overlying argillaceous mudstone of the Bowen Formation. The Bowen is about 26m thick and composed of units 8 through 10. Unit 8 (8.6m) is brown and reddish-brown thinly bedded lime mudstone with vertical burrows, birdseyes, and mudcracks. Unit 9 is 5.7m thick and composed of medium bedded, cream colored, burrowed lime mudstone and fossiliferous wackestone and packstone. Unit 10 is 11.8m of reddish brown, vertically burrowed, fenestral lime mudstone. Unit 10 forms a gradational contact with unit 11 of the Witten Formation. The Witten is 73m thick and composed of three units. Unit 11 is 27.3m of blue-grey fossiliferous wackestone and lime mudstone. Unit 12 is composed of 19.8m of poorly fossiliferous, intraclastic and fenestral lime mudstone. Unit 13 (26.0m) is flaggy bedded, fossiliferous limestone and thinly bedded shale. Unit 13 grades upwards into reddish-brown, argillaceous lime mudstone of the Moccasin Formation.

3. The four formations of the middle Chickamauga Group each represent a generalized environment of deposition. The Benbolt Formation was deposited in relatively deep water, below fairweather wave base. Skeletal shoals, however, developed in shallower depths, perhaps on areas of higher bathymetric relief. The Wardell Formation was deposited nearshore, in an agitated clear water environment. The Bowen Formation represents intertidal and supratidal deposition reflecting progradation of a mixed carbonate-siliciclastic tidal flat. The Witten Formation consists of shallow subtidal, intertidal, and supratidal

deposits, suggesting deposition in a restricted "lagoon". The middle Chickamauga is a regressive (offlap) sequence which reflects the filling of an eastward basin, resulting in a bathymetric reversal.

4. Bryozoans in the middle Chickamauga Group reflect facies control for some genera. The deeper subtidal environments of the mid-shelf (Benbolt Formation) contain an assemblage dominated by small erect forms such as "Phylloporina" and sheet-like encrusters (ceramoporids). Other common genera include: Nicholsonella, Xenotrypa, and Monotrypa. The nearshore and shoreface environment (Wardell Formation) contains a diverse assemblage and most zooarial growth forms are represented. The more common genera include: "Phylloporina", ceramoporids, Amplexopora, Parvohallopora, Athrophragma, and Nicholsonella. The inner shelf environments (Bowen and Witten formations) consists of a marked decrease in diversity, but bryozoans are locally abundant. The most common genera are Homotrypa and Amplexopora. The limited occurrence of these last two genera, and their abundance in the inner shelf suggests they were best adapted to restricted conditions.

5. Both constructive and destructive taphonomic processes occur in carbonate shelf environments. Destructive taphonomic processes involve paleoecologic information loss. Constructive processes enhance the preservability of an ancient community. Destructive processes involve condensation or mixing of fossil assemblages by biogenic or physical reworking. Constructive processes include marine cementation which concomittant with water loss and compaction, can facilitate colonization of hard substrate organisms in a soft bottom environment.

Colonization by soft bottom adapted taxa may also serve to stabilize the substratum, allowing other invertebrates to encrust the hardparts of the colonizers. Rapid sedimentation can serve to preserve assemblages intact or provide bioclastic sediment to substrate-starved environments.

6. The middle Chickamauga contains many examples of well preserved benthic assemblages. The preservation of these assemblages reflect synsedimentary changes in the substrate consistency caused by organic encrustation, meiobenthic binding, marine cementation, initial water loss and compaction. Storm deposition plays a key role in rapid burial or obrution and provides coarse grained skeletal material for later invertebrate colonization.

7. The present study provides a basis for alternative explanations of fossil assemblages previously inferred to represent paleocommunities. Most taphonomic studies in modern marine environments suggest that post mortem reworking of skeletal material obscures the fine scale biologic and sedimentologic information requisite for paleocommunity identification. Rarely, a paleocommunity may be identified due to extraordinary preservation, however, most fossil assemblages represent the sum of biologic, sedimentologic, and taphonomic processes.

8. Future work in the highly fossiliferous Middle Ordovician strata in East Tennessee could more completely discern the environmental distribution of bryozoans throughout the shelf and shelf edge environments. In addition, taphonomic effects on ancient fossil assemblages is poorly documented. Further work concerning the

preservation mechanisms for well preserved assemblages in the Chickamauga Group would further elucidate the depositional history of this well studied stratigraphic unit.

LIST OF REFERENCES

LIST OF REFERENCES

- Adams, J. E., and Rhodes, M. L., 1969, Dolomitization by seepage refluxion: Amer. Assoc. Petroleum Geologists Bull., v. 44, p. 1912-1920.
- Aigner, T., 1982a, Calcareous tempestites: Storm-dominated stratification in Upper Muschelkalk limestones (Middle Triassic, Southwest Germany) in Einsele, G., and Seilacher, A., eds., Cyclic and Event Stratification: Springer-Verlag, New York, p. 180-198.
- Aigner, T., 1982b, Event stratification in nummulite accumulations and in shell beds from the Eocene of Egypt, in Einsele, G., and Seilacher, A., eds., Cyclic and Event Stratification: Springer-Verlag, New York, p. 248-262.
- Alberstadt, L. P., Walker, K. R., and Zurawski, R., 1974, Patch reefs in the Carters Limestone (Middle Ordovician) in Tennessee and vertical zonation of Ordovician reefs: Geol. Soc. Amer. Bull., v. 85, p. 1171-1182.
- Aller, R. C., and Dodge, R. E., 1974, Animal-sediment relations in a tropical lagoon, Discovery Bay, Jamaica: J. Mar. Res., v. 32, p. 209-232.
- Ashworth, J. K., 1982, Depositional environments and paleoecology of Middle Ordovician rocks in Union County, Tennessee: Univ. of Tennessee, Knoxville, Unpub. Master's Thesis, 176 p.
- Ausich, W. I., 1980, A model for differentiation in Lower Mississippian crinoid communities: Jour. Paleontol., v. 54, p. 273-288.
- Ball, M. M., 1967, Carbonate sand bodies of Florida and the Bahamas: Jour. Sed. Petrology, v. 37, p. 556-591.
- Ball, M. M., Shinn, E. A., and Stockman, K. W., 1967, The geologic effects of Hurricane Donna: Jour. Geology, V. 75, p. 583-597.
- Bambach, R. K., Calef, C., and Wovician Chickamauga Group at Thorn Hill and Evans Ferry, in Walker, K. R., ed., The geologic history of the Thorn Hill Paleo zoic section (Cambrian - Mississippian), Eastern Tennessee: SE-GSA Field Trip 6, Univ. of Tennessee, Dept. of Geol. Sciences, Studies in Geology 10, p. 51 -59.
- Benedict, G. L., III, and Walker, K. R., 1978, Paleobathymetric analysis in Paleozoic sequences and its geodynamic significance: Amer. Jour. Science, v. 278, p. 579-607.
- Bergstrom, S. M., 1973, Biostratigraphy and facies relations in the lower Middle Ordovician of easternmost Tennessee: Amer. Jour. Science, v. 273-A, p. 261-293.

Bergstrom, S. M., and Carnes, J. B., 1985, Conodont biostratigraphy of the lower Middle Ordovician Chickamauga Group at Thorn Hill and Evan's Ferry, in Walker, K. R., ed., The geologic history of the Thorn Hill Paleozoic section (Cambrian-Mississippian), Eastern Tennessee: SE-GSA Field Trip 6, Univ. of Tennessee, Dept. of Geol. Sciences, Studies in Geology 10, p. 51-59.

Blake, D. B., 1983, The Order Cryptostomata, in Robinson, R. A., ed., Treatise on Invertebrate Paleontology: University of Kansas and the Geological Society of America, Inc., p. 440-452.

Boardman, R. S., 1960, Trepotomatous Bryozoa of the Hamilton Group of New York State: U. S. Geol. Surv. Prof. Paper 340, 87 p.

Breland, F. C., 1980, Stratigraphic, paleoenvironmental, and echinoderm distribution patterns in an unfaulted Middle Ordovician (Chickamauga Group) shelf-edge to on-shelf transect in East Tennessee: Univ. of Tennessee, Knoxville, Unpub. Ph.D. Dissertation, 217 p.

Bretsky, P. W., and Bretsky, S. S., 1975, Succession and repetition of Late Ordovician fossil assemblages from the Nicolet River Valley, Quebec: Paleobiology, v. 1, p. 225-238.

Broad, K., 1975, Paleocology of Silurian Bryozoan from Gotland (Sweden), in Pouyet, S., ed., Bryozoa: 1974, Doc. Lab. Geol. Fac. Sci. Lyon, hors-serie 3, fasc. 2, p. 401-414.

Burke, R. B., 1982, Reconnaissance study of the geomorphology and benthic communities of the Outer Barrier Reef Platform, Belize, in Rutzler, K., and Macintyre, I. G., eds., The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, I. Structure and Communities: Smithsonian Institution Press, City of Washington, p. 509-526.

Byers, C. W., 1974, Shale fissility: Relation to bioturbation: Sedimentology, v. 21, p. 479-484.

Byers, C. W., 1982, Geologic significance of marine biogenic sedimentary structures, in McCall, P. L., and Tevesz, M. J. S., eds., Animal-Sediment Relations, The Biogenic Alteration of Sediments, Topics in Geobiology, v. 2: Plenum Press, New York, p. 221-256.

Cantrell, D. L., and Walker, K. R., 1985, Depositional and diagenetic patterns, ancient oolite Middle Ordovician, Eastern Tennessee: Jour. Sed. Petrology, v. 55, n. 4, p. 518-531.

Carnes, J. B., 1975, Conodont biostratigraphy in the lower Middle Ordovician of the western Appalachian thrust belts in northeastern Tennessee: Ohio State University, Columbus, Unpub. Ph.D. Dissertation, 291 p.

- Chafetz, H. S., 1972, Surface diagenesis of limestone: Jour. Sed. Petrology, v. 42, no. 2, p. 325-329.
- Connell, J. H., 1978, Diversity in tropical rain forests and coral reefs: Science, v. 199, p. 1302-1310.
- Cooper, G. A., 1956, Chazy and Related Brachiopods, Part I, Text: Smithsonian Miscellaneous Collections, v. 127, Part I, Publ. no. 4253, Lord Baltimore Press, Inc., Baltimore, Md., 1024 p.
- Cooper, B. N., and Prouty, C. E., 1943, Stratigraphy of the Lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. Amer. Bull., v. 43, p. 819-886.
- Copper, P., and Morrison, R., 1978, Morphology and paleoecology of Ordovician tetradiid corals from the Manitoulin District northern Ontario: Canadian Jour. of Earth Sciences, v. 15, no. 12, p. 2006-2020.
- Cristil, A. I., 1985, Analysis of the Upper Lenoir and Holston formations deposited along a Middle Ordovician shelf re-entrant, Rutledge Pike locality, Knoxville, Tennessee: Univ. of Tennessee, Knoxville, Unpub. Master's Thesis, 151 p.
- Cuffey, R. J., 1970, Bryozoan-Environment interrelationships - An overview of Bryozoan paleoecology and ecology: Earth and Mineral Sciences, v. 39, no. 6, p. 41-45, and 48.
- Cummings, E. R., 1932, Reefs or Bioherms?: Geol. Soc. Amer. Bull., v. 43, no. 1, p. 331-352.
- Davies, G. R., 1970, Carbonate bank sedimentation, eastern Shark Bay, western Australia, in Logan, B. W., Davies, G. R., Read, J. F., and Cebulski, D. E., eds., Carbonate Sedimentation and Environments, Shark Bay, western Australia: Amer. Assoc. Petroleum Geologists, Mem. 13, p. 169-205.
- Deffeyes, K. S., Lucia, F. J., and Weyl, P. K., 1965, Dolomitization of Recent and Plio-Pleistocene sediments by marine evaporitic waters on Bonaire, Netherlands Antilles, in Pray, L. C., and Murray, R. C., eds., Dolomitization and limestone diagenesis, A symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Publ. 13, p. 89-111.
- Diehl, W. W., 1982, Depositional environments and paleoecology of the Middle and Upper Ordovician Martinsburg Formation of Grainger County, Tennessee: Univ. of Tennessee, Knoxville, Unpub. Master's Thesis, 242 p.
- Eder, W., 1982, Diagenetic redistribution of carbonate, a process in forming limestone-marl alternations (Devonian and Carboniferous, Rheinisches Schiefergebirge, West Germany), in Einsele, G., and Seilacher, A., eds., Cyclic and Event Stratification: Springer-Verlag, New York, p. 98-112.

- Enos, P., 1983, Shelf Environment, in Scholle, P. A., Bebout, D. G., and Moore, C. H., eds., Carbonate Depositional Environments: Amer. Assoc. Petroleum Geologists Mem 33, Tulsa, OK., p. 267-295.
- Enos, P., and Perkins, R. D., 1979, Evolution of Florida Bay from island stratigraphy: Geol. Soc. Am. Bull., v. 90, p. 59-83.
- Evans, G., Murray, J. W., Biggs, H. E. J., Bate, R., and Bush, P. R., 1973, The oceanography, ecology, sedimentology, and geomorphology of parts of the Trucial Coast Barrier Island Complex, Persian Gulf, in Purser, B. H., ed., The Persian Gulf, Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea: Springer-Verlag, New York, p. 233-237.
- Ewing, E. L., 1985, Environmental sedimentology of the Lower Middle Ordovician in the Lay School section Hogskin Valley, Grainger County, Tennessee: Univ. of Tennessee, Knoxville, Unpub. Master's Thesis, 333 p.
- Ferrigno, K. F., 1973, Paleoecology of the reefs of the Holston Formation: Univ. of Tennessee, Knoxville, Unpub. Ph.D. Dissertation, 142 p.
- Flügel, E., Homann, W., Tietz, G. F., 1971, Litho-und Biofazies eines Detailprofils in den Oberen Pseudoschwagerinen-Schichten (Unter-Perm) der Karnischen Alpen: -Verh. Geol. B.-Anst. p. 10-42.
- Frey, R. W., and Howard, J. D., 1970, Comparison of Upper Cretaceous ichnofaunas from siliceous sandstones and chalk, Western Interior Region, U. S. A., in Crimes, T. P., and Harper, J. C., eds., Trace Fossils: Geol. Jour., Spec. Issue 3, p. 141-166.
- Friedman, G. M., Gebelein, C. D., and Sanders, J. E., 1971, Micrite envelopes of carbonate grains are not exclusively of photosynthetic algal origin: Sedimentology, v. 16, p. 89-96.
- Fritz, M. A., 1977, A microbioherm, in Church, C. S., ed., Athlon, Essays on Paleontology in Honor of Loris Shano Russell: Life Sci. Misc. Publ. Royal Ontario Museum, p.18-25.
- Fursich, F. T., 1978, The influence of faunal condensation and mixing on the preservation of fossil benthic communities: Lethaia, v. 11, p. 243-250.
- Fursich, F. T., 1982, Rhythmic bedding and shell bed formation in the Upper Jurassic of East Greenland, in Einsele, G., and Seilacher, A., eds., Cyclic and Event Stratification: Springer-Verlag, New York, p. 208-222.

Ginsburg, R. N., 1956, Environmental relationships of grain size and constituent particles in some South Florida carbonate sediments: Amer. Assoc. Petroleum Geologists Bull., v. 40, p. 2384-2427.

Ginsburg, R. N., 1960, Ancient analogues of recent stromatolites: XXI Internat. Geol. Cong., pt. 22, p. 26-35.

Ginsburg, R. N., Hardie, L. A., Bricker, O. P., Garrett, P., and Wanless, H., 1977, Exposure index: A quantitative approach to defining position within the tidal zone, in Hardie, L. A., ed., Sedimentation on the modern carbonate tidal flats of northwest Andros Island, Bahamas: The Johns Hopkins University Press, Baltimore, Md., p. 7-11.

Golubic, S., Perkins, R. D., and Lukas, K. J., 1975, Boring micro-organisms and microborings in carbonate substrates, in Frey, R. W., ed., The Study of Trace Fossils: Springer-Verlag, New York, p. 147-160.

Gray, J. S., 1981, The Ecology of Marine Sediments, An Introduction to the Structure and Function of Benthic Communities: Cambridge Univ. Press, Cambridge, 185p.

Hall, G. M., and Amick, H. C., 1934, The section on the west side of Clinch Mountain, Tennessee: Jour. Tenn. Acad. Science, v. 9, p. 157-168, and p. 195-220.

Hardie, L. A., and Garrett, P., 1977, General environmental setting, in Hardie, L. A., ed., Sedimentation on the Modern Carbonate Tidal Flats of Northwest Andros Island, Bahamas: The Johns Hopkins University Press, Baltimore, Md., p. 12-49.

Harris, F. W., and Martin, W. D., 1979, Benthic community development in limestone beds of the Waynesville (Upper Dillsboro) Formation (Cincinnatian Series, Upper Ordovician) of Southeastern Indiana: Jour. Sed. Petrology, v. 49, n. 4, p. 1295-1305.

Heckel, P. H., 1974, Carbonate buildups in the geologic record: a review. in Laporte, L. F.(ed.), Reefs in Space and Time, Selected Examples from the Recent and Ancient: Soc. Econ. Paleontol. and Mineral. Spec. Pub. 18, p. 90-154.

Hine, A. C., 1977, Lily Bank, Bahamas: History of an active oolite sand shoal: Jour. Sed. Petrology, v. 47, p. 1554-1582.

Hook, J. E., Golubic, S., and Milliman, J. D., 1984, Micritic cement in microborings is not necessarily a shallow-water indicator: Jour. Sed. Petrology, v. 54, no. 2, p. 425-431.

Howard, J. D., 1975, The sedimentological significance of trace fossils, in Frey, R. W., ed., The Study of Trace Fossils: Springer-Verlag, New York, p. 147-160.

- Hurst, J. M., 1979, Evolution, Succession and replacement in the type Upper Caradoc (Ordovician) benthic faunas of England: *Paleogeogr. Paleoclimatol., Paleoecol.*, v. 27, p. 189-246.
- Inden, R. F., and Moore, C. H., 1983, Beach Environment, in Scholle, P. A., Bebout, D. G., and Moore, C. H., eds., *Carbonate Depositional Environments*: Amer. Assoc. Petroleum Geologists, Mem. 33, Tulsa, OK., p. 211-266.
- Ingram, R.L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: *Geol. Soc. Amer. Bull.*, v. 65, p. 937-938.
- Jablonski, D., and Bottjer, D. J., 1983, Soft-bottom epifaunal suspension feeding assemblages in the Late Cretaceous - implications for the evolution of benthic paleocommunities, in Tevesz, M. J. S., and McCall, P. L., eds., *Biotic Interactions in Recent and Fossil Benthic Communities*: Plenum Press, New York, p. 747-811.
- Jackson, J. B. C., 1979, Morphological strategies of sessile animals, in Larwood, G. P., and Rosen, B. R., eds., *Biology and Systematics of Colonial Organisms*: Academic Press, New York, p. 499-555.
- Jackson, J. B. C., 1983, Biological determinants of present and past sessile animal distributions, in Tevesz, M. J. S., and McCall, P. L., eds., *Biotic Interactions in Recent and Fossil Benthic Communities*: Plenum Press, New York, p. 39-120.
- Jackson, J. B. C., and Hughes, T. P., 1985, Adaptive strategies of coral-reef invertebrates: *American Scientist*, v. 73, p. 265-274.
- James, N. P., 1983, Reef Environment, in Scholle, P. A., Bebout, D. G., and Moore, C. H., eds., *Carbonate Depositional Environments*: Amer. Assoc. Petroleum Geologists, Mem. 33, Tulsa, OK., p. 345-440.
- Jeffery, D., and Aigner, T., 1982, Storm sedimentation in the Carboniferous limestones near Weston-Super-Mare (Dinantian, Southwest England), in Einsele, G., and Seilacher, A., eds., *Cyclic and Event Stratification*: Springer-Verlag, New York, p. 240-247.
- Johnson, R. E., 1985, The Lower Chickamauga Subgroup - peritidal and subtidal deposition on a stable carbonate platform, in Walker, K. R., ed., *The geologic history of the Thorn Hill Paleozoic section (Cambrian - Mississippian), eastern Tennessee*: University of Tennessee Studies in Geology 10, p. 60-69.
- Johnson, R. G., 1960, Models and methods for analysis of the mode of formation of fossil assemblages: *Geol. Soc. Amer. Bull.*, v. 71, p. 1075-1086.

- Karklins, O. L., 1983, Ptilodictyoid Cryptostomata Bryozoa from the Middle and Upper Ordovician rocks of central Kentucky: Jour. Paleontology, Mem. 14, 31 p.
- Kidwell, S. M., and Jablonski, D. J., 1983, Taphonomic feedback: ecological consequences of shell accumulation, in Tevesz, M. J. S., and McCall, P. L., eds., Biotic Interaction in Recent and Fossil Communities: Plenum Press, New York, p. 195-248.
- Kreisa, R. D., 1981, Storm-generated sedimentary structures in subtidal marine facies with examples from the Middle and Upper Ordovician of southwestern Virginia: Jour. Sed. Petrology, V. 51, p. 823-848.
- Kreisa, R. D., and Bambach, R. K., 1982, The role of storm processes in generating shell beds in Paleozoic shelf environments, in Einsele, G., and Seilacher, A., eds., Cyclic and Event Stratification: Springer-Verlag, New York, p. 200-207.
- Kukal, Z., and Saadallah, A., 1973, Aeolian admixtures in the sediments of the northern Persian Gulf, in Purser, B. H., ed., The Persian Gulf, Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea: Springer-Verlag, New York, p. 99-113.
- Kunk, M. J., and Sutter, J. F., 1984, 40 Ar/39 Ar age Spectrum dating of biotite from Middle Ordovician bentonites, Eastern North America, in Brunton, D. L., ed., Aspects of the Ordovician System: Palaeontological Contributions from the University of Oslo, n. 295, Universitetsforlaget, p. 11-22.
- Larson, D. W., and Rhoads, D. C., 1983, The evolution of infaunal communities and sedimentary fabrics, in Tevesz, M. J. S., and McCall, P. L., eds., Biotic Interactions in Recent and Fossil Benthic Communities: Plenum Press, New York, p. 627-648.
- Levinton, J. S., 1982, The subtidal benthos: sampling, substratum control, and community interactions, in Marine Ecology: Prentice Hall Publ., Englewood Cliffs, N. J., p. 352-378.
- Levinton, J. S., and Bambach, R. K., 1970, Some ecological aspects of bivalve mortality patterns: Amer. Jour. Sci., v. 268, p. 97-112.
- Logan, B. W., et al., 1969, Late Quarternary carbonate sediments of Yucatan Shelf, Mexico, in Carbonate Sediments and reefs, Yucatan Shelf, Mexico: Amer. Assoc. Petroleum Geologists, Mem. 11, p. 1-128.
- Logan, B. W., 1974, Inventory of diagenesis in Holocene-Recent carbonate sediments, Shark Bay, Western Australia, in Logan, B. W., Read, J. F., Hagan, G. M., Hoffman, P., Brown, R. G., Woods, P. J., and Gebelein, C. D., eds., Evolution and diagenesis of Quaternary carbonate sequences, Shark Bay, Western Australia: Amer. Assoc. Petroleum Geologists Mem. 22, p. 140-194.

- Logan, B. W., Hoffman P., and Gebelein, C. D., 1974, Algal mats, cryptalgal fabrics, and structures, Hamelin Pool, Western Australia, in Logan B. W., Read, J. F., Hagan, G. M., Hoffman, P., Brown, R. G., Woods, P. J., and Gebelein, C. D., Evolution and Diagenesis of Quaternary Carbonate Sequences, Shark Bay, Western Australia: Amer. Assoc. Petroleum Geologists Mem. 22, p. 140-194.
- Logan, B. W., Rezak, R., and Ginsburg, R. N., 1964, Classification and environmental significance of algal stromatolites: Jour. Geology, v. 72, p. 68-83.
- Logan, B. W., and Semeniuk, V., 1976, Dynamic metamorphism: Processes and products in Devonian carbonate rocks, Canning Basin, Western Australia: Geol. Soc. Australia Inc., Spec. Publ., no. 6, 138 p.
- Longman, M. W., 1977, Factors controlling the formation of microspar in the Bromide Formation: Jour. Sed. Petrology, v. 47, p. 347-350.
- Maitland, M. R., 1979, The paleobathymetric and paleogeographic distribution of Middle Ordovician trilobites within a portion of the Valley and Ridge of East Tennessee: University of Tennessee, Knoxville, Unpub. Master's Thesis, 140 p.
- MacIntyre, I. G., 1977, Distribution of submarine cements in a modern Caribbean fringing reef, Galeta Point, Panama: Jour. Sed. Petrology, v. 47, no. 2, p. 503-516.
- McCall, P. L., and Tevesz, M. J. S., 1983, Soft-bottom succession and the fossil record, in Tevesz, M. J. S., and McCall, P. L., eds., Biotic Interactions in Recent and Fossil Benthic Communities: Plenum Press, New York, p. 157-194.
- McKee, E.D., and Weir, G.W., 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Geol. Soc. Amer. Bull., v. 64, p. 381-390.
- McLaughlin, R. E., 1973, Observations on the biostratigraphy of Knox County, Tennessee and vicinity: The Geology of Knox County, Tennessee: Tenn. Div. Geol. Bull., v. 70, p. 25-62.
- Miller, M. F., and Byers, C. W., 1984, Abundant and diverse early Paleozoic infauna indicated by the stratigraphic record: Geology, v. 12, p. 40-43.
- Moore, N. K., 1977, Distribution of the benthic algal flora in Middle Ordovician carbonate environmental units of the Southern Appalachians in Ruppel, S. C., and Walker, K. R., eds., Ecostratigraphy of the Lower Middle Ordovician of the Southern Appalachians, U.S.A.: Univ. of Tennessee Studies in Geology, no. 77-1, p. 18-29.

Moore, N. K., 1978, Taxonomy and paleoenvironmental distribution of the benthic algal flora from Middle Ordovician carbonate rocks of East Tennessee: Univ. of Tennessee, Knoxville, Unpubl. Ph.D. Dissertation, 148 p.

Mullins, H. T., Newton, C. R., Heath, K., and van Buren, H. M., 1981, Modern deep-water coral mounds north of Little Bahama Bank: criteria for recognition of deep-water coral bioherms in the rock record: Jour. Sed. Petrology, v.51, p. 999-1014.

Nelson, H. F., Brown, C. W., and Brineman, J. H., 1962, Skeletal limestone classification, in Ham, W. E., ed., Classification of Carbonate Rocks: Amer. Assoc. Petroleum Geologists, Mem. 1, p. 224-253.

Probert, P. K., 1984, Disturbance, sediment stability, and trophic structure of soft bottom communities: J. Mar. Res., v. 42, p. 893-921.

Purdy, E. G., Pusey, W. C., and Wantland, K. F., 1975, Continental shelf of Belize - Regional shelf attributes, in Wantland, K. F., and Pusey, W. C., eds., Belize Shelf - Carbonate Sediments, Clastic Sediments, and Ecology: Amer. Assoc. Petroleum Geologists, Tulsa, OK., p. 1-52.

Purser, B. H., 1973, Sedimentation around bathymetric highs in the southern Persian Gulf, in Purser, B. H., ed., The Persian Gulf, Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea: Springer-Verlag, New York, p. 157-177.

Raff, R. A., and Raff, E. C., 1970, Respiratory mechanisms and the fossil record, Nature: v. 228, p. 1003-1005.

Ratliff, L. E., 1974, Environmental stratigraphy of the Middle Ordovician carbonates in the Luttrell Belt, Union and Grainger Counties, East Tennessee: Univ. of Tennessee, Knoxville, Unpubl. Ph.D. Dissertation, 148 p.

Read, J. F., 1980, Carbonate ramp-to-basin transitions and foreland basin evolution, Middle Ordovician, Virginia Appalachians: Amer. Assoc. Petroleum Geologists Bull., v. 64, no. 10, p. 1575-1612.

Rhoads, D. C., 1963, Rates of sediment reworking by Voldis limatula in Buzzards Bay, Massachusetts and Long Island Sound: Jour. Sed. Petrology, v. 33, p. 723-727.

Rhoads, D. C., 1967, Biogenic reworking of intertidal and subtidal sediments in Barnstable Harbor and Buzzards Bay, Massachusetts: Jour. Geology, v. 75, p. 461-476.

Rhoads, D. C., 1970, Mass properties, stability, and ecology of marine muds related to burrowing activity, in Crimes, T. P., and Harper, J. C., eds., Trace Fossils: Geol. Jour. Spec. Issue 3, p. 391-406.

Rhoads, D. C., 1975, The paleoecological and environmental significance of trace fossils, in Frey, R. W., ed., The Study of Trace Fossils: Springer-Verlag, New York, p. 147-160.

Rhoads, D. C., and Boyer, L. F., 1982, The effects of marine benthos on physical properties of sediments, a successional perspective, in McCall, P. L., and Tevesz, M. J. S., eds., Animal-Sediment Relations, The Biogenic Alteration of Sediments: Topics in Geobiology, v. 2, Plenum Press, New York, p. 3-52.

Rhoads, D. C., and Young, D. K., 1970, The influence of deposit-feeding benthos on bottom sediment stability and community trophic structure: Jour. Marine Res., v. 28, p. 150-178.

Riding, R., 1975, Girvanella and other algae as depth indicators: Lethaia, v. 8, p. 173-179.

Rodgers, J., 1953, Geologic map of East Tennessee with explanatory text: Tenn. Div. Geol. Bull. 58, part 2, p. 64-99.

Rollins, H. B., Carothers, M., and Donahue, H., 1979, Transgression, regression and the fossil community succession: Lethaia, v. 12, p. 89-104.

Ross, J. R. P., 1963b, Ordovician Cryptostome Bryozoa, Standard Chazy Series, New York and Vermont: Geol. Soc. Amer. Bull., v. 74, p. 577-608.

Ross, J. R. P., 1964b, Champlainian Cryptostome Bryozoa from New York State: Jour. Paleontology, v. 38, no. 1, p. 1-32.

Ross, J. R. P., 1970, Distribution, paleoecology and correlation of Champlainian Ectoprocta (Bryozoa), New York State, pt. III: Jour. Paleontology, v. 44, no. 2, p. 346-382.

Ross, J. R. P., 1984, Paleoecology of Ordovician Bryozoa in Brunton, D. L., ed., Aspects of the Ordovician System: Palaeontological Contributions from the University of Oslo, N.295, Universitetsforlaget, p. 141-147.

Ruppel, S. C., 1979, Ecostratigraphy of the Chickamauga Group (Middle Ordovician) of northern Tennessee: Univ. of Tennessee, Knoxville, Unpub. Ph.D. Dissertation, 226 p.

Ruppel, S. C., and Walker, K. R., 1982, Sedimentology and distinction of carbonate buildups: Middle Ordovician, East Tennessee: Jour. Sed. Petrology, v. 52, no. 4, p. 1055-1071.

Ruppel, S. C., and Walker, K. R., 1984, Petrology and depositional history of a Middle Ordovician carbonate platform: Chickamauga Group, northeastern Tennessee: *Geol. Soc. Amer. Bull.*, v. 95, p. 568-583.

Schindel, D.E., 1980, Microstratigraphic sampling and the limit of paleontologic resolution: *Paleobiology*, v. 6, p. 408-426.

Schopf, T. J. M., 1969, Paleoeecology of Ectoprocts: *Jour. Paleontology*, v. 43, p. 234-244

Scoffin, T. P., 1970, The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini Lagoon, Bahamas: *Jour. Sed. Petrology*, v. 40, no. 1, p. 249-273.

Seilacher, A., Rief, W. E., and Westphal, F., 1985, Sedimentological, ecological and temporal patterns of fossil Lagerstätten, in Whittington, H. B., and Morris, S. C., eds., *Extraordinary Fossil Biotas: Their Ecological and Evolutionary Significances*: *Phil. Trans. R. Soc. Lond. B311*, p. 5-23.

Sepkowski, J. J., 1982, Flat-pebble conglomerates, storm deposits, and the Cambrian bottom fauna, in Einsele, G., and Seilacher, A., eds., *Cyclic and Event Stratification*: Springer-Verlag, New York, p. 371-385.

Sepkowski, J. J., and Sheehan, P. M., 1983, Diversification, faunal change, and community replacement during the Ordovician radiations, in Tevesz, M. J. S., and McCall, P. L., eds., *Biotic Interactions in Recent and Fossil Communities*: Plenum Press, New York, p. 673-717.

Shanmugan, G., and Walker, K. R., 1978, Tectonic significance of distal turbidites in the Middle Ordovician Blockhouse and Lower Sevier formations in East Tennessee: *Amer. Jour. Science*, v. 278, p. 551-578.

Shanmugan, G., and Walker, K. R., 1980, Sedimentation, subsidence and evolution of a foredeep basin in the Middle Ordovician, Southern Appalachians: *Amer. Jour. Science*, v. 280, p. 479-496.

Shanmugan, G., and Walker, K. R., 1983, Anatomy of the Middle Ordovician Sevier Shale basin, eastern Tennessee: *Sediment. Geol.*, v. 34, p. 315-337.

Shepherd, S. A., 1983, The epifauna of megaripples: A species' adaptations and population responses to disturbance: *Australian Jour. of Ecology*, v. 8, p. 3-8.

Sherman, K. M., and Coull, B. C., 1980, The response of meiofauna to sediment disturbance: *J. Exp. Mar. Biol., Ecol.*, v. 46, p. 59-71.

Shinn, E. A., 1968a, Practical significance of birdseye structures in carbonate rocks: *Jour. Sed. Petrology*, v. 38, p. 215-223.

- Shinn, E. A., 1968b, Selective dolomitization of Recent sedimentary structures: *Jour. Sed. Petrology*, v. 38, p. 612-616.
- Shinn, E. A., 1968c, Burrowing in Recent lime sediment of Florida and the Bahamas: *Jour. Paleontology*, v. 42, p. 879-894.
- Shinn, E. A., 1969, Submarine lithification of Holocene carbonate sediments in the Persian Gulf: *Sedimentology*, v. 12, p. 104-144.
- Shinn, E. A., 1983a, Birdseyes, fenestrae, shrinkage pores, and loferites - a reevaluation: *Jour. Sed. Petrology*, v. 53, p. 619-628.
- Shinn, E. A., 1983b, Tidal Flat Environment, in Scholle, P. A., Bebout, D. G., and Moore, C. H., eds., Carbonate Depositional Environments: Amer. Assoc. Petroleum Geologists, Mem. 33, Tulsa, OK., p. 171-210.
- Shinn, E. A., Ginsburg, R. N., and Lloyd, R. M., 1965, Recent supratidal dolomite from Andros Island, Bahamas, in Pray, L. C., and Murray, R. C., eds., Dolomitization and limestone diagenesis, a symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Publ. 13, p. 112-123.
- Shinn, E. A., Lloyd, R. M., and Ginsburg, R. N., 1969, Anatomy of a modern carbonate tidal flat, Andros Island, Bahamas: *Jour. Sed. Petrology*, v. 39, p. 1202-1228.
- Sickafoose, D. K., 1979, Ecostratigraphy of the Lower Middle Ordovician and paleoecology of Porterfieldian and Wilderness biotas at Evans Ferry, Tennessee: Univ. of Tennessee, Knoxville, Unpub. Master's Thesis, 184 p.
- Simonson, J. C. B., 1985, The stratigraphy, carbonate petrology, depositional environments, and paleoecology of the Middle Ordovician Moccasin Formation near Thorn Hill, Tennessee: Univ. of Tennessee, Knoxville, Unpub. Master's Thesis, 279 p.
- Simonson, J. C. B., and Walker, K. R., 1984, Distinctions between carbonate and mixed-carbonate-siliciclastic tidal flat deposits: An example from the Ordovician of the Southern Appalachians (abs.): *Geol. Soc. Amer. Abst. with Programs*, v. 16, p. 657.
- Sitterly, P. D., 1976, Paleoecological analysis of the Meadow Marble (Middle Ordovician) in Blount County, Tennessee: Univ. of Tennessee, Knoxville, Unpub. Master's Thesis, 162 p.
- Specht, R. W., and Brenner, R. L., 1979, Storm-wave genesis of bioclastic carbonates in Upper Jurassic epicontinental mudstones, East-Central Wyoming: *Jour. Sed. Petrology*, v. 49, n. 4, p. 1307-1321.

- Swinchatt, J. P., 1965, Significance of constituent composition, texture, and skeletal breakdown in some Recent carbonate sediments: *Jour. Sed. Petrology*, v. 35, p. 71-90.
- Thayer, C. W., 1974, Substrate specificity of Devonian epizoa: *Jour. Paleontology*, v. 48, p. 881-894.
- Thayer, C. W., 1975, Morphologic adaptations of benthic invertebrates to soft substrata: *Jour. Mar. Res.*, v. 33, p. 177-189.
- Thayer, C. W., 1979, Biological bulldozers and the evolution of marine benthic communities: *Science*, v. 203, p. 458-461.
- Thayer, C. W., 1983, Sediment-mediated biological disturbance and the evolution of marine benthos, in Tevesz, M. J. S., and McCall, P. L., eds., *Biotic Interactions in Recent and Fossil Benthic Communities*: Plenum Press, New York and London, p. 479-625.
- Tudhope, A. W., and Scoffin, T. P., 1984, The effects of Callianassa bioturbation on the preservation of carbonate grains in Davies Reef Lagoon, Great Barrier Reef, Australia: *Jour. Sed. Petrology*, v. 54, no. 4, p. 1091-1096.
- Turmel, R. J., and Swanson, R. G., 1976, The development of Rodriguez Bank, a Holocene mudbank in the Florida reef tract: *Jour. Sed. Petrology*, v. 46, p. 497-518.
- Turpaeva, Y. P., 1957, Food interrelationships in marine benthic biocoenoses, in *Marine Biology*: *Amer. Inst. Biol. Science*, v. 20, p. 137-148.
- Ulrich, E. O., 1882, American Paleozoic Bryozoa: *Cincinnati Society Natural History Journal*, v. 5, p. 121-175.
- Wagner, C. W., and van der Togt, C., 1973, Holocene sediment types and their distribution in the southern Persian Gulf, in *The Persian Gulf, Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea*, Springer-Verlag, New York, p. 115-121.
- Walker, K. R., 1972, Community ecology of the Middle Ordovician Black River Group of New York State: *Geol. Soc. Amer. Bull.*, v. 83, p. 2499-2524.
- Walker, K. R., 1974, Mud substrata, in Ziegler, A. M., Walker, K. R., Anderson, E. J., Kaufmann, E. G., Ginsburg, R. N., and James, N. P., *Principles of Benthic Community Analysis: Sedimenta IV*, Div. of Marine Geology and Geophysics, Rosentiel School of Marine and Atmospheric Sciences, Univ. of Miami, Miami, Florida, p. 5-11.
- Walker K. R., 1977, A brief introduction to the ecostratigraphy of the Middle Ordovician of eastern Tennessee, in Ruppel, S. C., and Walker,

K. R., eds., The ecostratigraphy of the Middle Ordovician of the Southern Appalachians: Univ. of Tennessee, Dept. of Geol. Sciences Studies in Geology, no. 1, p. 12-17.

Walker, K. R., 1985, Special factors in the preservation of lower Paleozoic communities (abs.), Geol. Soc. Amer. Abstracts with Programs, v. 17, n. 2, p. 140.

Walker, K. R., and Diehl, W. W., 1985, The role of marine cementation in the preservation of lower Early Palaeozoic communities: Phil. Trans. R. Soc. Lond. , ser. B, v. 311, no. 1148, p. 143-153.

Walker, K. R., and Diehl, W. W., 1986, The effect of synsediment substrate modification on the composition of paleocommunities: Paleoecologic succession revisited: Palaios, v. 1, p. 65-74.

Walker, K. R., and Ferrigno, K. F., 1973, Major Middle Ordovician reef tract in East Tennessee: Amer. Jour. Science, v. 273-A, p. 294-325.

Walker, K. R., and Laporte, L. F., 1970, Congruent fossil communities from Ordovician and Devonian carbonates of New York: Jour. Paleontology, v. 44, p. 928-944.

Walker, K. R., and Parker, W. C., 1976, Population structure of a pioneer and a late stage species in an Ordovician ecological succession: Paleobiology, v. 2, p. 191-201.

Walker, K. R., Shanmugan, G., and Ruppel, S. C., 1983, A model for carbonate to terrigenous clastic sequences: Geol. Soc. Amer. Bull., v. 94, p. 700-712.

Wanless, H. R., 1979, Limestone response to stress: pressure solution and dolomitization: Jour. Sed. Petrology, v. 49, no. 2, p. 437-462.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments, Jour. Geol., v. 30, p. 377-392.

Wedekind, J. E., 1985, Shelf facies of the Middle Chickamauga Group in The geologic history of the Thorn Hill Paleozoic section (Cambrian - Mississippian), Eastern Tennessee: SE-GSA Field Trip 6, Univ. of Tennessee, Dept. of Geol. Sciences, Studies in Geology 10, p. 70-75.

Wedekind, J. E., and Walker, K. R., 1985, The effects of short-term events in marine biotas on a Middle Ordovician carbonate shelf in East Tennessee (abs.), Geol. Soc. Amer. Abstracts with Programs, v. 17, n. 2, p. 142.

Weiss, E. A., 1981, Environmental sedimentology of the Middle Ordovician and paleoecology of a portion of the Witten Formation at Solway, Tennessee: Univ. of Tennessee, Knoxville, Unpub. Master's Thesis, 229 p.

Wilson, J. L., 1969, Microfacies and sedimentary structures in "deeper water" lime mudstones, in Friedman, G. M., ed., Depositional Environments in Carbonate Rocks, Soc. Economic Paleontologists and Mineralogists, Spec. Pub. 14, p. 4-17.

Wilson, J. L., and Jordan, C., 1983, Middle Shelf Environment, in Scholle, P. A., Bebout, D. G., and Moore, C. H., eds., Carbonate Depositional Environments: Amer. Assoc. Petroleum Geologists Mem. 33, Tulsa, OK., p. 297-344.

Woodin, S. A., 1983, Biotic interactions in recent marine sedimentary environments, in Tevesz, M. J. S., and McCall, P. L., eds., Biotic Interactions in Recent and Fossil Benthic Communities: Plenum Press, New York, p. 3-38.

Woodley, J. D., Chornesky, E. A., Clifford, P. A., Jackson, J. B. C., Kaufman, L. S., Knowlton, N., Lang, J. C., Pearson, M. P., Porter, J. W., Rooney, M. C., Rylaarsdam, K. W., Tunnicliffe, V. J., Wahle, C. M., Wulff, J. L., Curtis, A. S. G., Dallmeyer, M. D., Jupp, B. P., Koehl, M. A. R., Neigel, J., and Sides, E. M., 1981, Hurricane Allen's impact of Jamaican coral reefs: Science, v. 214, p. 749-755.

Young, D. K., and Young, M. W., 1982, Macrobenthic invertebrates in bare sand and seagrass (Thalassia testudinum) at Carrie Bow Cay, Belize in Rutzler, K., and Macintyre, I. G., eds., The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, Smithsonian Institution Press, Washington, D.C. p. 115-126.

APPENDIXES

APPENDIX A

DESCRIPTION OF MEASURED SECTION

Measurement Conventions

Bedding thickness conventions are based on the work of McKee and Weir (1953) as modified by Ingram (1954). Grain size descriptions are after the standardized Wentworth (1922) classification. Carbonate rock-type descriptions used in the following measured section follow the classification terminology of Dunham (1962).

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

Grain Size

Coarse grained	grains visible and easily identifiable to the unaided eye (approximately greater than 1.0 mm in size)
Medium grained	grains visible but not readily identifiable to the unaided eye (approximately 0.25 - 1.0 mm in size)
Fine grained	grains visible only with a hand lens (approximately 0.1 - 0.25 mm)
Very fine grained	grains not visible even with a hand lens (approximately less than 0.1 mm)

DESCRIPTION OF MEASURED SECTION

"New" Thorn Hill Section

The exposure of middle Chickamauga measured and described for this study occurs as a partially continuous roadcut along the eastern side of U.S. 25E near Thorn Hill, Grainger County, Tennessee. Exposure along a side road which intersects the highway was also used in the description. Lithologic descriptions, sample locations, unit thickness, cumulative thickness within each formation, and total thickness above the Knox Unconformity is given in the following measured section. Thin sections were prepared from all samples listed. Fossils are listed in approximate order of decreasing abundance.

Field Description of the Middle
Chickamauga Group Along U.S. 25E
West of Thorn Hill, Tennessee

The contact between the Rockdell and Benbolt formations occurs about 10 m south of a driveway intersection with the northbound lane of the highway. The contact is gradational and poorly exposed, however the pinkish colored Rockdell is easily distinguished from the grey colored Benbolt. The base of the middle Chickamauga is discerned as the first bed of grey, fossiliferous wackestone.

Unit Cum Thk Cum Thk
Thk(m)Form(m)Chick(m)

2.4	2.4	235.1	<u>Benbolt Formation.</u> Thin to medium bedded, light grey, fossiliferous medium grained, stylolitic wackestone and very thin beds of intercalated, greenish grey shale. Lithology weathers to small, light brown wackestone cobbles. Pelmatozoan holdfasts and columnals, small ramose and encrusting bryozoans and various sponge fossils are conspicuous on weathered slabs. Generally poorly exposed. Sample: TH1, 0.8 m.
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- 5.9 8.3 241.0 Benbolt Formation. Medium to thin bedded, light grey, stylolitic, fine to medium grained fossiliferous wackestone and unfossiliferous, very thin, greenish grey shale drapes. Rarely, thin beds of medium grained, fossiliferous packstone are found interbedded with wackestone. Fossils are locally abundant, usually small, and consist of echinoderms (incl. Clieocrinus), ramose bryozoans, sponges, and brachiopods. Samples: TH2, 5.0 m; TH2a, 8.3 m.
- 2.4 10.7 243.4 Benbolt Formation. Grey, thin bedded, light grey weathering, poorly fossiliferous wackestone and intercalated, brownish weathering calcareous shale. Fossils vary widely in size and include: echinoderm plates, cryptostome bryozoans, sponges, trilobite moults, gastropods, brachiopods, and ostracodes. Some large, anastomosing sponge fossils conspicuous on weathered outcrop surfaces. Sample: TH3, 10.1 m.
- 6.5 17.2 249.9 Benbolt Formation. Irregular bedded, grey, poorly fossiliferous, thin bedded wackestone and very thin greenish grey shale drapes. Beds range from 2 - 5 cm in thickness. Fossils are mostly fine to medium grained in a very fine grained matrix. Identifiable fossils include: bryozoans, echinoderm plates, and brachiopods. Samples: TH4, 14.0 m; TH5, 17.0 m.
- 5.5 22.7 255.4 Benbolt Formation. Dark grey, thin bedded, very fossiliferous, medium grained, packstone/wackestone, with very thin, grey calcareous shale drapes. Weathers to light brown or buff, especially around stylolitic, clay-rich lenses, producing small nodules. Fossils consist mostly of echinoderms (Meristochisma), ramose trepostome bryozoans, and sponges. Calcite-filled fractures prevalent in many beds. Generally well exposed along base of roadcut. Sample: TH6, 19.75 m.
- 6.2 28.9 261.6 Benbolt Formation. Wavy bedded, dark grey, weathering cobbly and light grey or brownish, sparsely fossiliferous lime mudstone and fossiliferous wackestone. Bedding ranges from 2 - 7 cm in thickness. Very thin beds of light grey calcareous shale or lime mudstone form sharp contacts between thin beds of wackestone. Wackestone cobbles reach over 5 cm in length

but vary in size. Fossils well preserved and include: cylindrical sponges, echinoderms, small ramose cryptostome, and much larger trepostome bryozoans, brachiopods, and trilobites. Some diffuse horizontal burrows preserved on bedding surfaces. Samples: TH6b, 22.8 m; TH7, 24.3 m; TH8, 27.0 m.

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| 10.3 | 39.2 | 271.9 | <p><u>Benbolt Formation</u>. Thin to medium bedded, grey to light grey, stylolitic, medium to coarse grained, very fossiliferous wackestone/packstone and dark grey, coarse grained, very fossiliferous packstone, containing small, irregular oncoids (about 0.3 cm in diameter) and algally coated grains. Ostracodes, brachiopods, and fossil fragments are common but poorly preserved. Near top of unit, lithology becomes wavy bedded, cobbly weathering, greyish brown wackestone with intercalated shale. Samples: TH9, 29.7; TH10, 32.3; TH11, 33.1; TH12, 34.7; TH13, 36.6.</p> |
| 5.8 | 45.0 | 276.1 | <p><u>Benbolt Formation</u>. Interbedded, wavy, thin to medium bedded, grey, fine grained, poorly fossiliferous wackestone, and medium bedded, dark grey, coarse grained, very fossiliferous packstone which emits a fetid odor when struck. Faint internal lamination observed in some beds of fine grained wackestone. In wackestone beds, fossils are generally very small phylloporinid bryozoans, ostracodes, and debris. The coarser grained packstone contains some large trepostome bryozoans (3 cm wide) strophomenid brachiopods, trilobite pieces, ostracodes, and oncoids. Some beds weather cobbly and brownish, especially near top of unit, where the lithology is deeply weathered. Exposure varies from fair to poor. Samples: TH14, 39.5; TH15, 42.0; TH15b, 44.7.</p> |
| 3.7 | 48.7 | 279.8 | <p><u>Benbolt Formation</u>. Medium to thin bedded, grey, medium grained, variably fossiliferous packstone and wackestone interbedded with very thin bedded chippy weathering, grey, calcareous shale. Some beds weather to cobbly, brown fossiliferous wackestone. Limestone cobbles range in length from 3 to 10 cm. Calcareous shale appears to have "flowed" around wackestone cobbles. Fossils generally abundant and well preserved, including: encrusting and ramose bryozoans, echinoderm plates, strophomenid brachiopods, and trilobite</p> |

pieces. Some fossils found weathering out of outcrop. Exposure varies from fair to poor. Samples: TH16, 45.2; TH16a, 47.5; TH17, 89.5; TH18, 50.9.

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| 8.5 | 59.5 | 290.6 | <p><u>Benbolt Formation</u>. Medium bedded, wavy, and irregularly bedded, grey or light grey, brown weathering, medium grained, very fossiliferous packstone, sparsely fossiliferous wackestone, and intercalated very thinly bedded calcareous shale. Fossils often well preserved and include: 7-8 cm long bifoliate bryozoans, cylindrical sponges (about 2 cm in diameter), large trepostome bryozoans, orthid brachiopods, echinoderm debris, and calcareous algae (<u>Solenopora</u>?). Exposure mostly obscured by chippy weathering shale, but improves towards top of unit. No samples.</p> |
| 5.1 | 64.6 | 295.7 | <p><u>Benbolt Formation</u>. Thick bedded, grey, fossiliferous wackestone and intercalated light grey calcareous shale. Fossils include abundant trepostome, cryptostome, and phylloporinid bryozoans, encrusting bryozoans (about 7 cm in length), echinoderm pieces, brachiopods, and <u>Solenopora</u>. Becomes less fossiliferous, more argillaceous towards top of unit. Contact gradational with overlying unit, but exposure quality diminishes. Sample: TH18b, 61.5.</p> |
| 3.6 | 68.2 | 299.3 | <p><u>Benbolt Formation</u>. Very thin to thin bedded, grey to brownish grey, brown and tan weathering, argillaceous lime mudstone and fossiliferous wackestone. Generally becomes less fossiliferous, more argillaceous towards top of unit. Horizontal (<u>Planolites</u>) burrows common on some bedding surfaces. Fossils in lower portion of unit include bryozoans and echinoderms, upper part contains a few <u>Strophomena</u> brachiopods, which can be found weathering out of outcrop. Becomes very poorly exposed. Samples: TH19, 65.2; TH19a, 65.6; TH20, 67.8.</p> |
| 9.3 | 77.5 | 308.6 | <p><u>Benbolt Formation</u>. Very thin to thin bedded, occasionally internally laminated light grey very fine grained, argillaceous lime mudstone and shale, weathering to brown or buff chippy shale and "chalky" calcareous nodules. Horizontal burrows and, very rarely, small vertical burrows are preserved on bedding</p> |

surfaces. Strophomena brachiopod fossils common in float and occasionally found concave down on bedding surfaces. Samples: TH21, 68.7; TH22, 69.5; TH23, 75.6.

- 7.1 84.6 315.7 Benbolt Formation. Light grey, thin bedded, poorly fossiliferous, very fine grained, brown weathering, interbedded, argillaceous lime mudstone and calcareous shale. Fossils occur mostly on bedding surfaces and include: brachiopods, gastropods, and trilobites. Some beds contain fine planar and low angle cross lamination, and small horizontal burrows. Exposure improves near top of unit, near contact with Wardell Formation. Benbolt - Wardell contact is easily determined as the lowermost stratum of Wardell forms a rather prominent ledge of medium to coarse grained rock which is readily distinguished from the fine grained shale brown shale of the Benbolt. Samples: TH23a, 80.5; TH23b, 83.1.

Total Benbolt thickness: 84.6 m.

- 0.4 0.4 316.1 Wardell Formation. Medium to thin bedded, dark grey, brown weathering, very fossiliferous, intraclastic, arenaceous, coarse grained wackestone. Fossils range in degree of preservation; many are fragmentary and algally coated. Identifiable fossils include: Solenopora, bryozoans, echinoderm debris, brachiopods, trilobite cephalons, and small tabulate corals. Intraclasts are well rounded, often algally coated, biogenically bored, and internally laminated. Upper and lower contacts are very sharp transitions from fossiliferous wackestone to calcareous shale. Samples: TH24, 84.8; TH 24b, 84.85; TH25, 84.9; TH26, 85.0.

- 5.0 5.4 321.1 Wardell Formation. Flaggy bedded, thin bedded, light grey, buff weathering lime mudstone and occasional very thin beds of dark grey, medium grained, bioclastic, peloidal packstone. Lime mudstone is poorly fossiliferous, but horizontal burrows are conspicuous on outcrop for they often are filled with sparry calcite. Packstone beds form distinct ledges in weathered exposures. Samples: TH27, 86.9; TH28, 87.8; TH29, 89.2; TH30, 89.7.

- 2.2 7.6 323.3 Wardell Formation. Interbedded, light grey, thin bedded, poorly fossiliferous, horizontally burrowed lime mudstone/wackestone, and less frequently, thin bedded, dark grey, fossiliferous peloidal packstone. Contacts between lithologies are very sharp, but not erosive. Packstone contains poorly developed, low-angle cross lamination and horizontal lamination. Many geopedal structures are filled with medium grained, sometimes pinkish-colored, sparry calcite. Fossils are well preserved and include: bryozoans, brachiopods, and pelecypods. Top of one prominent bed of packstone consists of an abundant and diverse bryozoan assemblage, consisting of many ramose and lanceolate growth forms. Samples: TH31, 91.4; TH32, 92.2.
- 1.3 8.9 324.6 Wardell Formation. Flaggy bedded, interbedded, light grey, weathering to whitish brown, thin bedded, horizontally burrowed, sparsely fossiliferous lime mudstone and thinly bedded, dark grey, fossiliferous peloidal packstone. Tabulate corals (Lichenaria ?), ramose bryozoans, and Sowerbyella brachiopods found very well preserved and often in life position on bedding planes on some bedding surfaces of lime mudstone. Roadcut changes due to intersection of secondary road and highway, affording lateral exposure. Exposure allows examination of well preserved fossil assemblages on slump blocks. Some bedding surfaces slightly undulatory. Samples: TH33, 93.2; TH34, 93.4; TH34b, 93.45; TH35, 93.5.
- 3.0 11.9 327.6 Wardell Formation. Interbedded, thick bedded, very fossiliferous, brownish grey, tan weathering, coarse grained packstone, and thin bedded, dark grey, poorly fossiliferous fine or medium grained, peloidal packstone. Thickly bedded units consist primarily of tabulate corals (Saffordophyllum), Solenopora, many bryozoans, crinoids (Ristacrinus), brachiopods, and trilobite pieces. Thin bedded peloidal packstone beds show crude grading, are horizontally laminated, sometimes cross-laminated, and often contain biogenic escape traces. Both lithologies occur in very sharp contact with the other. Outcrop is excellently exposed except where caliche development is pervasive. Samples: TH36, 93.8; TH37, 94.8; TH38, 95.2; TH40, 96.3.

- 0.4 12.3 328.0 Wardell Formation. Thin-medium bedded, grey, weathering brownish grey, very fossiliferous, biostromal packstone/wackestone. Fossils are mostly well preserved, often in life position. Most common fossils include: corals (Saffordophyllum) up to 20 cm in diameter, nested strophomenid brachiopods, ramose and encrusting bryozoans, biogenically bored Solenopora up to 8 cm in size, echinoderm pieces, and trilobite moults. Biostromal lithology forms sharp contact with overlying fossiliferous, peloidal packstone. Samples: TH39, 96.6; TH41a, 96.8.
- 2.8 15.1 330.8 Wardell Formation. Thin bedded, dark grey or grey, very fossiliferous to sparsely fossiliferous, arenaceous, peloidal packstone. Fossils abraded or well preserved, and consist almost entirely of ramose trepostome bryozoans (esp. Amplexopora). Bryozoan diversity decreases towards the top of the unit. Contact with overlying brown calcareous mudstone of the Bowen Formation is gradational over about 0.5 m and well exposed on the west side of the highway along the side road. Samples: TH41, 97.0; TH42, 97.3; TH43, 97.6; TH44, 98.1; TH45, 98.7; TH46, 99.1; TH47, 99.3; TH48b, 99.4; TH48, 99.6.
- Total Wardell thickness: 15.1 m.
- 2.9 2.9 333.7 Bowen Formation. Very thin bedded, dull grey or brownish, tan and buff weathering, finely cross laminated and horizontally laminated, poorly fossiliferous, fine grained, horizontally burrowed, argillaceous lime mudstone. Becomes mudcracked, vertically burrowed, and contains birdseye fenestrae about 2 m above the Wardell-Bowen contact. Burrows are generally well defined and partially filled with calcite spar and quartz silt. Birdseyes are spar filled, irregular in shape, and less than 5 mm in length. Samples: TH49, 100.0; TH50, 100.7; TH51, 101.9; TH52, 102.6.
- 5.7 8.6 339.4 Bowen Formation. Reddish brown, medium to thin bedded, thin laminated internally, very fine grained, mudcracked, vertically burrowed, unfossiliferous, argillaceous, lime mudstone with numerous irregular birdseyes. Vertical burrows range widely in length (1-5 cm) and

diameter (average 0.5 cm). Mudcracks large (>15 cm across) and disrupt several centimeters of laminated strata. Lamination is planar but gently undulatory. Occasional very thin beds of light grey, birdseye-rich lime mudstone. Samples: TH53, 102.9; TH54, 103.4; TH55, 105.6.

4.7 13.3 344.1 Bowen Formation. Cream or whitish grey, medium bedded, planar fine internal lamination, fine to medium grained, occasionally mudcracked, fenestral, very sparsely fossiliferous, vertically and horizontally burrowed lime mudstone/wackestone and a single thin bed of fossiliferous packstone near the base of the unit. Fossils are broken and abraded in packstone bed, but preservation is better elsewhere. Fossils include: echinoderm debris, bryozoans, and algae in packstone; ostracodes and trilobite moults in mudstone/wackestone. Burrows distinct, rarely diffuse, and some beds appear bioturbated. Samples: TH56, 108.4; TH57, 110.1; TH58, 109.9.

12.7 26.0 356.8 Bowen Formation. Thick-medium bedded, reddish brown, mudcracked, fenestral, internally laminated, vertically and horizontally burrowed, unfossiliferous, very fine grained, argillaceous, lime mudstone. Occasional thin beds of greyish-red or cream colored, fenestral, less argillaceous, lime mudstone. Some beds show burrow mottling which disrupts primary lamination. Reddish brown mudstone weathers to chippy shale, resulting in poor exposure. Contact gradational with overlying unit, which is thin bedded, blue-grey lime mudstone of Witten Formation. Samples: TH59, 113.2; TH60, 115.0; TH61, 121.1.

Total Bowen thickness: 26.0 m.

13.9 13.9 370.7 Witten Formation. Flaggy bedded, thin to medium bedded, blue-grey, stylolitic, horizontally burrowed, sparsely fossiliferous, very fine to medium grained, lime mudstone and wackestone. Lithology becomes more fossiliferous towards top of unit, however fossils are concentrated at the base of certain beds as shell lags, and are often broken and abraded. Well preserved fossils are most commonly brachiopods and gastropods. Unit is gently folded near base as seen in small

outcrop on west side of highway along a small creek. Calcite-filled fractures common throughout unit. Samples: TH62, 127.4; TH63, 128.0; TH64, 133.0; TH65, 138.9.

- | | | | |
|------|------|-------|--|
| 13.4 | 27.3 | 384.1 | <p><u>Witten Formation.</u> Thin to medium bedded, grey, medium to coarse grained, fossiliferous wackestone and packstone; and rare, very thin beds of very thinly bedded, fine grained lime mudstone. Numerous fining upwards sequences floored with bioclastic debris and capped with fine very fine grained, horizontally and gently cross laminated, peloidal(?) lime mudstone. Many fossils well preserved, including: gastropods, pelecypods, brachiopods, bryozoans, cephalopods, and echinoderm debris. Horizontal burrows are conspicuous in some beds. Lithology becomes finer grained, occasionally fenestral, and more intensely burrowed at top of unit. Samples: TH66, 140.3; TH67, 142.9; TH68, 144.6; TH69, 147.1; TH70, 150.0; TH71, 152.5.</p> |
| 7.4 | 34.7 | 391.5 | <p><u>Witten Formation.</u> Light grey and blue grey, whitish to buff weathering, thin to medium bedded, often internally laminated, generally poorly fossiliferous, fine-medium grained, occasionally mudcracked, intraclastic lime mudstone and packstone. Mudcracks poorly developed, but average 12 cm across and disrupt a few centimeters of primary lamination. Intraclasts are composed of featureless lime mudstone, are angular, average 0.75 cm, and range up to 2 cm in length. Vertical burrows locally abundant, attaining lengths up to 5 cm. Most identifiable fossils are gastropods, often with geopetal structures. Bioclastic debris common in upwards fining sequences. Contact gradational with tan weathering mudstone of overlying unit. Samples: TH72, 154.8; TH73, 156.0; TH74, 158.3.</p> |
| 12.4 | 47.1 | 403.9 | <p><u>Witten Formation.</u> Tan and buff weathering, thin to medium bedded, internally laminated, light grey and reddish, argillaceous, poorly fossiliferous, lime mudstone, with large (15-20 cm) mudcracks, spar-filled vertical burrows, birdseye fenestrae, and rounded intraclasts. Laminae are very thin, and often graded, with basal lags of fossil hash. Occasional well preserved gastropod fossils. Single bed of reddish brown mudstone near top of unit.</p> |

Samples: TH75, 161.7; TH76, 163.4; TH77, 165.1; TH79, 172.2; TH78, 168.7.

14.8 61.9 418.7 Witten Formation. Very thin to medium bedded, dark grey, weathering to light grey flaggy bedded, rarely rippled, fossiliferous wackestone and packstone and intercalated lime mudstone. Ripples show climbing ripple cross lamination in very fine grained (peloidal?) lithology. Well rounded intraclasts (up to 8 cm in length) often found in beds of coarse grained fossil packstone. Fossils in packstone are mostly fragmentary. Bryozoans (Homotrypa) are very abundant in the middle of the unit in some beds. Other well preserved fossils are predominately gastropods and very small orthid brachiopods. Planolites common on many bedding surfaces. Exposure very poor at base of unit, but improves higher in the unit. Samples: TH80, 174.9; TH81, 176.4; TH82, 178.4; TH83, 180.2; TH83b, 182.0; TH84, 183.7; TH85, 184.5; TH86, 185.3; TH87, 185.5.

11.2 73.1 429.9 Witten Formation. Thin to medium bedded, light grey, tan weathering, sparsely fossiliferous, horizontally burrowed, lime mudstone and wackestone. Becomes brownish, argillaceous and thin bedded, less fossiliferous towards top of unit. Contact with Moccasin Formation gradational over about 4 m. A very thin bed of ostracode-rich packstone serves as a useful marker bed for Witten-Moccasin contact. Samples: TH88, 187.7; TH89, 189.6; TH90, 189.9; TH91, 191.5; TH92, 194.3.

Total Witten thickness: 73.1m.

Total middle Chickamauga thickness: 198.8m.

APPENDIX B

PETROGRAPHIC CONSTITUENT ANALYSIS

Table B.1. Petrographic Constituent Analysis. Explanation of symbols: SMPL# = Sample number; STRAT = Stratigraphic position; MICR = Micrite; MICSP = Microspar; SPAR = Calcite spar; PELO = Peloid; INTRA = Intraclast; OSTR = Ostracode; TRIL = Trilobite; BRYO = Bryozoan; ECHIN = Echinoderm; SPONG = Sponge; BRACH = Brachiopod; CORAL = Tabulate Coral; PELE = Pelecypod; GAST = Gastropod; MOLL = Molluscan Fragments; RED = Red Algae; GREEN = Green Algae; BL-GRN = Blue-Green Algae; OTHR = Other Allochems; DOLO = Dolomite Rhombs; PYRI = Pyrite; STYL = Stylolites; UNID = Unidentifiable Allochems.

Table B.1. Petrographic Constituent Analysis

UNIT	STYL	PVRI	DOLLO	DTZ3	DTMR	BL-GR	RED	GREEN	MOLL	PELE	GAST	CORAL	BRACH	SPONG	ECHIN	BRYO	TRIL	OSTR	INTRA	PELO	SPAN	NICESP	RICK	STRAT
0.70	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.10	0.00	1.00	2.50	25.00	11.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
0.80	1.80	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.10	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
0.90	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.10	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.20	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.30	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.40	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.50	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.60	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.70	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.80	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
1.90	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.10	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.20	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.30	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.40	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.50	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.60	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.70	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.80	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
2.90	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.10	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.20	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.30	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.40	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.50	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.60	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.70	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.80	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
3.90	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.10	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.20	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.30	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.40	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.50	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.60	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.70	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.80	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
4.90	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.10	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.20	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.30	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.40	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.50	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.60	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.70	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.80	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0.00	0.70	30.00	8.00
5.90	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.30	0.00	2.70	20.00	9.00	0.10	0.60	0.30	1.30	0			

APPENDIX C

BRYOZOAN CONSTITUENT ANALYSIS

Table C.1. Bryozoan Constituent Analysis. Explanation of symbols: SMPL# = Sample number; STRAT = Stratigraphic Position; BRYO = Bryozoan; APLX = Amplexopora; ARTH = Arthrostylidae; ATFRG = Athrophragma; BATO = Batostoma; BYTH = Bythopora; CERA = Ceramoporina; CERF = Ceramophylla; CONS = Constellaria; DIPL = Diplotrypa; ERID = Eridotrypa; ESCH = Escharopora; GRAP = Graptodictya; HEMI = Hemiphragma; HOMO = Homotrypa; NICH = Nicholsonella; MONO = Monotrypa; OTTO = Ottoseetaxis; PACH = Pachydictya; PARV = Parvohallopora; PHYL = Phylloporina; PRAS = Prasopora; STIC = Stictopora; STCLA = Stictoporella; TRIG = Trigonodictya; XENO = Xenotrypa; UNID = Unidentified.

Table C.1.. Bryozoan

[illegible]

VITA

James Edward Wedekind was born in Knoxville, Tennessee on April 22, 1958. After attending public, private and parochial schools in the Knoxville area, he graduated from Bearden High School in June 1976. He enrolled in the University of Tennessee, Knoxville in September 1976, majoring in Liberal Arts. In March 1981 he graduated with honors from the University of Tennessee with a Bachelor of Arts degree in Biology. In May 1981 he began employment as a mudlogger with Continental Laboratories in Oklahoma City, Oklahoma. After spending the winter residing in Silver Plume, Colorado, he enrolled in University of Tennessee to study geology in April 1982. He entered the graduate program in the Department of Geological Sciences the following fall, and in April 1983 received a Teaching Assistantship. He received his Master of Science degree in June 1986. As of this writing, James is unemployed.