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The University of Oklahoma, Ph.D., 1975
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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

COMPARISON OF ECOLOGY AND SEDIMENTATION IN PENNSYLVANIAN (MORROWAN) BIOHERMS OF NORTHEASTERN OKLAHOMA WITH MODERN PATCH REEFS IN JAMAICA AND THE FLORIDA KEYS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

RENA MAE BONEM

Norman, Oklahoma

1975

COMPARISON OF ECOLOGY AND SEDIMENTATION IN PENNSYLVANIAN (MORROWAN) BIOHERMS OF NORTHEASTERN OKLAHOMA WITH MODERN PATCH REEFS IN JAMAICA AND THE FLORIDA KEYS

APPROVED BY:

Patrick K. Sutherland

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DISSERTATION COMMITTEE

COMPARISON OF ECOLOGY AND SEDIMENTATION IN PENNSYLVANIAN (MORROWAN) BIOHERMS OF NORTHEASTERN OKLAHOMA WITH MODERN PATCH REEFS IN JAMAICA AND THE FLORIDA KEYS

by

Rena Mae Bonem

ABSTRACT

Examination of small bioherms developed within two intervals of the Lower Pennsylvanian (Morrowan) Sausbee Formation in northeastern Oklahoma and comparison with modern patch reefs reveals several features of mound development, biotic distribution, and association of different trophic groups.

Three phases of mound development were recognized: initiation, diversification, and termination. Associated with these three phases are four distinct associations of fossil biota that have recognizable vertical succession and horizontal distribution. These associations include 1) stromatolitic blue-green algae dominating the core and outer mound layers, 2) pelmatozoans and pediculate brachiopods developing on topographically higher areas of the mound surface, 3) fenestrate and arborescent bryozoans restricted to depressions on intermediate mound layers, and 4) a cryptic or cavity biota of michelinid and rugose corals that dominate the fauna of local cavities.

The initiation of mound growth requires stabilization of the carbonate substrate by stromatolitic blue-green algae. Once stabilization has occurred, the diversification phase is represented by the accumulation of a variety of organisms in the remaining three associations. The trophic relation within these associations described by position, nutrients preferred, and feeding mode, helps further explain the distribution and relationships of organisms within the Morrowan bioherms. Cavities form a significant portion of the total volume of modern reefs and provide greater area for attachment increasing the total biomass of the reef. In addition, cavities provide a unique habitat for secretive reef organisms that is subjected to intensified sediment-organism interaction. These features, as well as evidence of boring activity by sponges and bivalves, have been observed in the Morrowan bioherms.

Termination of biohermal growth is the result of two different causes in the two mounding intervals. In the lower interval, deepening water with a large amount of argillaceous material is supported by the biota and nature of the surrounding shales. However, in the higher interval, shallowing water and subaerial exposure is supported by ooliths, dolomite rhombs, mud cracks, and dessication features in the outer stromatolitic algal mound layers and the biota of the adjacent shales.

The character of the bioherms and adjacent strata suggests that the environment of deposition was a shallow marine shelf that was at least occasionally within the intertidal zone. Comparison of the Morrowan bioherms with other geologic occurrences reveals that the mounds appear most similar in development to early Paleozoic bioherms, particularly those of the Devonian and Ordovician. However, the faunal elements are most similar to those of later Pennsylvanian phylloid algal banks. No other such Morrowan developments have been described in the geologic literature.

Many Paleozoic communities developed on a lime mud substrate rather than on clean carbonate sand areas that are generally studied as modern analogs to ancient biohermal developments. Increased suspended material within a carbonate mud environment may result in development of different trophic groups and permit deeper water biota to occur at shallow depths because of decreased light penetration. These factors were recognized in the Jamaican reefs and should be considered when examining ancient communities developed in a carbonate mud environment.

ACKNOWLEDGEMENTS

I am greatly indebted to Dr. Patrick K. Sutherland who directed this dissertation and who, with Thomas W. Henry, suggested the problem. I realize that he has provided encouragement and advice many times when his schedule was so crowded that he really did not have the time to give. The assistance of Dr. R.N. Ginsburg of the University of Miami, who suggested the comparison with modern reefs in Florida and emphasis on reef cavities, is also appreciated.

Dr. Clyde H. Moore, the external advisor on the dissertation committee, provided direction on carbonate sedimentation in Jamaican reefs during the later stages of my work. His relentless search for sponge "chips" resulted in discovery and recognition of sponge borings in the Morrowan bioherms, and I also wish to express my gratitude to him for numerous suggestions and criticisms of my work.

Drs. Charles W. Harper, David B. Kitts, and Charles J. Mankin served on the dissertation committee and offered guidance and suggestions during the writing of this dissertation.

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INTRODUCTION

Significance of Investigation

The paleoecology and stratigraphic relations of small bioherms occurring in the Lower Morrow Series in northeastern Oklahoma are described and compared with modern patch reef environments in Jamaica and the Florida Keys. This investigation is part of a broad study of the lithostratigraphy, biostratigraphy, depositional history, and paleoecology of the Morrow Series in northeastern Oklahoma under the supervision of Patrick K. Sutherland.

The Morrow sequence in this area is of importance because it is located near the type Morrow section in Washington County, Arkansas, which is the standard sequence of reference for the Early Pennsylvanian of western North America and the midcontinent. The northeastern Oklahoma sequence includes marine limestones, shales, and sandstones with a well-preserved, diverse fauna and flora. Because the abundance and diversity of the preserved biota in the Morrowan of northeastern Oklahoma is greater than that recognized in Arkansas, Sutherland and Henry (in press) have proposed the reference area for the type Morrow Series, designated originally as being in the central and western part of Washington County, Arkansas, be extended forty miles westward into Oklahoma. Detailed biostratigraphy including over 100 measured sections permits Sutherland and Henry to correlate the more clastic and more poorly fossiliferous Morrowan strata of Arkansas with those in Oklahoma.

The abundance of the marine biota in northeastern Oklahoma is especially significant since the Lower Pennsylvanian Pottsville Formation, on which the Pennsylvanian System is based, consists primarily of thick, nonmarine deposits with only a few marine fossils (Dutcher and others, 1959). Although marine fossils have been described from the Morrowan of western Pennsylvania, Ohio, and eastern Kentucky (Dutcher and others, 1959; Williams, 1960; Morningstar, 1922; Sturgeon and Hoare, 1968), these occur primarily in the upper portion of the Morrowan Series.

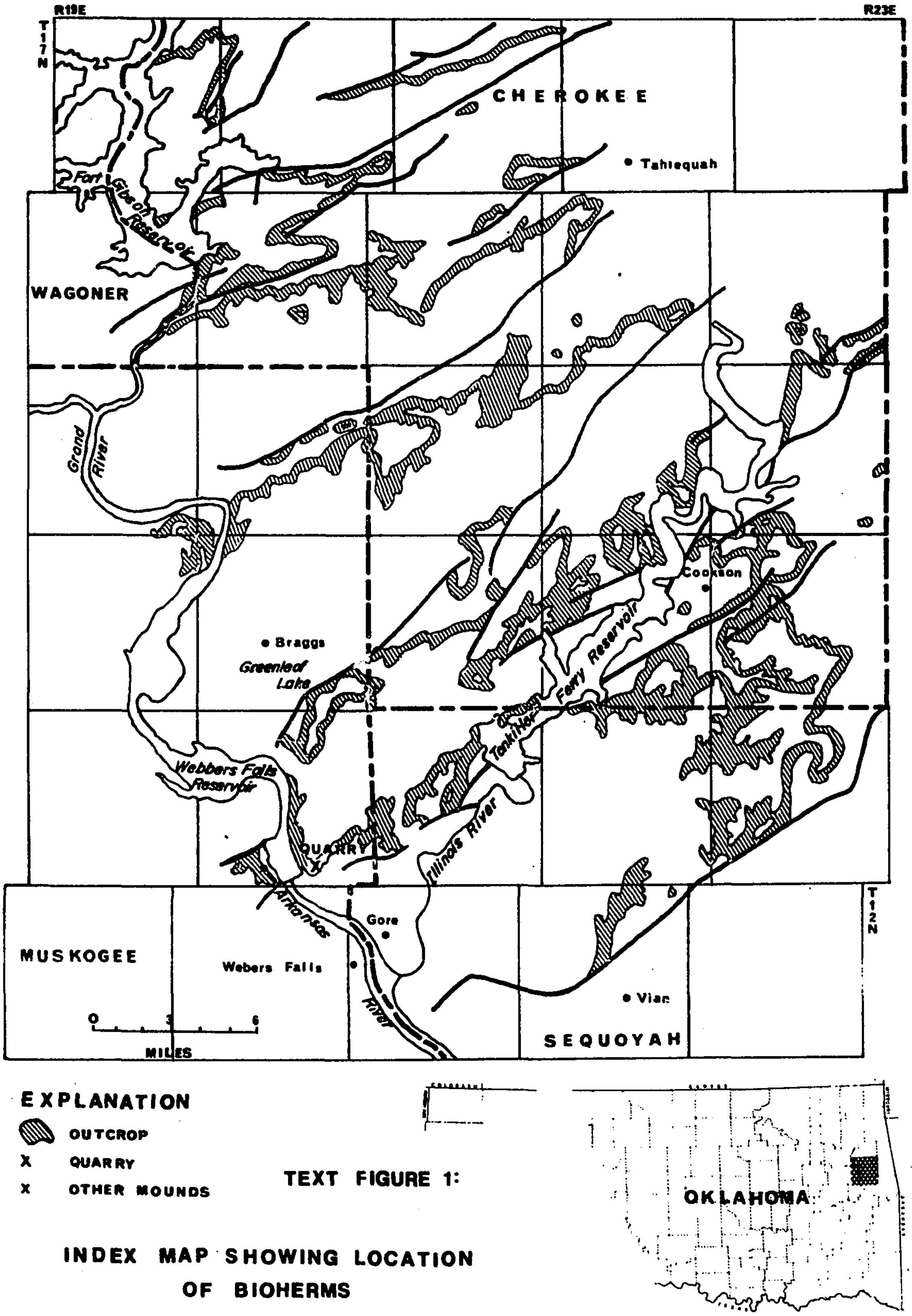
Nature of Investigation

This study includes a description of both Morrowan bioherms and selected modern patch reefs. The paleoecology of these unique small scale bioherms, exposed within the Lower Morrow sequence near Gore, Oklahoma (see figures 1 and 2), is interpreted in light of observations of the environment and ecology of the modern patch reefs studied.

Modern Reefs

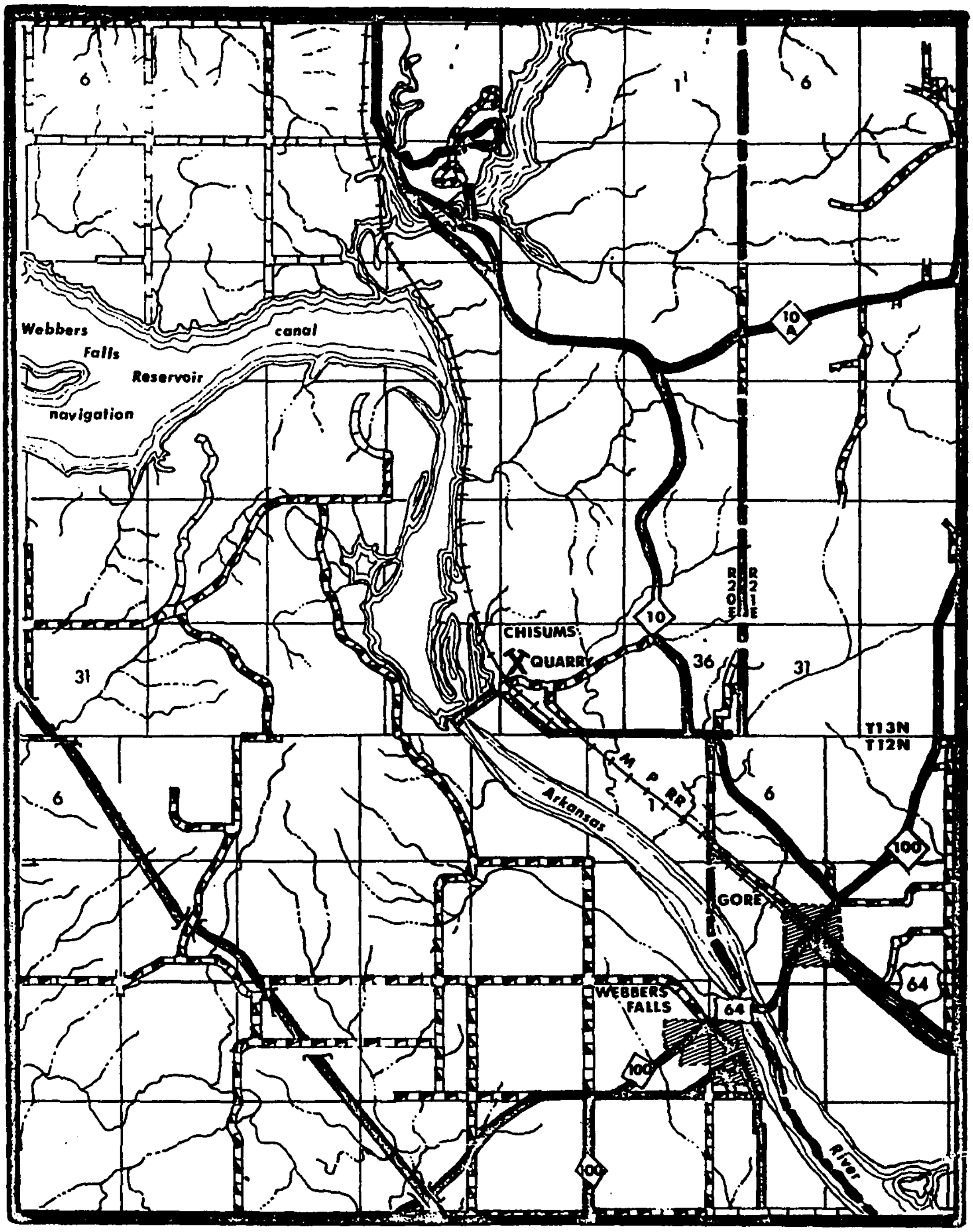
Living coral reefs reflect one of the most distinctive examples of a community. They are essentially isolated from sharply contrasting biotic associations on all sides, and reefs of varying composition have a geologic record that begins in the Precambrian. Although reefs have been the subject of many studies, geologists have, until recently, been concerned primarily with physical aspects such as lithic texture and distribution, while biologists have been concerned with coral physiology and growth. Few studies have been made of living organisms representing phyla important in Upper Paleozoic reefs. However, the significance of calcareous red and green algae, blue-green algae, sponges, and bryozoans in modern reef communities is becoming more and more apparent. With the discovery of the Sclerospongia and their significance in framework construction in modern reefs, Hartman and Goreau (1970) established a basis for new interpretation of several organisms. Sclerosponges possess an internal aragonitic skeleton with siliceous spicules, which in section appears similar to many stromatoporoids and chaetetids. Sclerosponges are, according to Lang (1974), the dominant framework constructor below the photic zone in modern reefs. The interpretation of environments based on stromatoporoids as hydroids or algae should be reconsidered if the relationship of these organisms were proven to be correct.

In addition, a preliminary examination of reef cavities, including their inhabitants and sediments, undertaken by me in Florida during June



TEXT FIGURE 1:

INDEX MAP SHOWING LOCATION OF BIOHERMS AND MORROWAN OUTCROPS



INDEX MAP SHOWING LOCATION OF QUARRY

1 inch = 1 mile

TEXT FIGURE 2

1972, and May 1973, suggests that cavities and irregular surfaces, which can make up 40 to 70 percent of the reef volume, may be of major importance in understanding the nature of sediment-organism interrelationships. Cavities provide a specialized habitat for reef organisms and serve as a trap for suspended and reef-derived sediments. Overhangs and caves, or any cavity in modern reefs, provide areas of low illumination, allowing deeper water inhabitants to be found at shallower depths. In addition, the presence of coelobites, or cavity-dwelling organisms, may profoundly alter the resistance of the substrate to mechanical and biochemical destruction. Ecologically, cavities enlarge the surface area available for colonization resulting in an overall increase in a biomass that is strongly dependent on light, water circulation, and sediment supply. A cyclic development of these communities has also been observed, comparable to that described by Zankl (1968, 1969) in his studies of the Triassic reefs of the northern Alps.

Although cavities appear to play a significant role in the ecology of modern reefs, as indicated by my preliminary investigations, cavities and coelobites have been essentially ignored in studies of both living and fossil reefs. Investigation of large cavities in modern reefs is mentioned by Wiens (1962) and Storr (1964) and is described by Ginsburg and Schroeder (1969), Garrett (1969), Scoffin (1972), Garrett and others (1971), Jackson and others (1971), and Scoffin and Garrett (1974).

Morrowan Bioherms

The recognition of cavities and their inhabitants provides insight into the nature and presence of framework in both modern and ancient biohermal and reef material. Thus, I have attempted to recognize and describe cavities in the Morrowan bioherms of northeastern Oklahoma, as well as to describe the organisms preserved, obvious associations of organisms that might represent fossil "communities," and in some cases, successions of these organisms.

Another aspect examined was the nature of the initiation of mound development: why and how were these bioherms formed? Also, what were the conditions that caused termination of mound development? Many modern reefs are found on a carbonate sand substrate, yet most Paleozoic bioherms, including those in the Morrow, appear to have formed in a carbonate mud environment. At Discovery Bay, in Jamaica, I had the opportunity to study a modern patch reef developed in a carbonate mud environment. This habitat is much more poorly illuminated than more typical reef areas because of the large amount of suspended mud. Therefore, it has a biota more characteristic of deeper water environments. But, it differs in other aspects also. Organisms more tolerant of fine, suspended material, but not necessarily coarser, sand-sized sediment, dominate the communities present. These characteristics should be considered when examining fossil bioherms developed on a micritic substrate and attempting to make comparisons with modern environments.

Finally, it is necessary to relate the mounds to the paleogeography of the Morrowan of northeastern Oklahoma and surrounding areas in an attempt to make broad environmental interpretations and relate these features to other bioherms and reef occurrences described in the geologic literature.

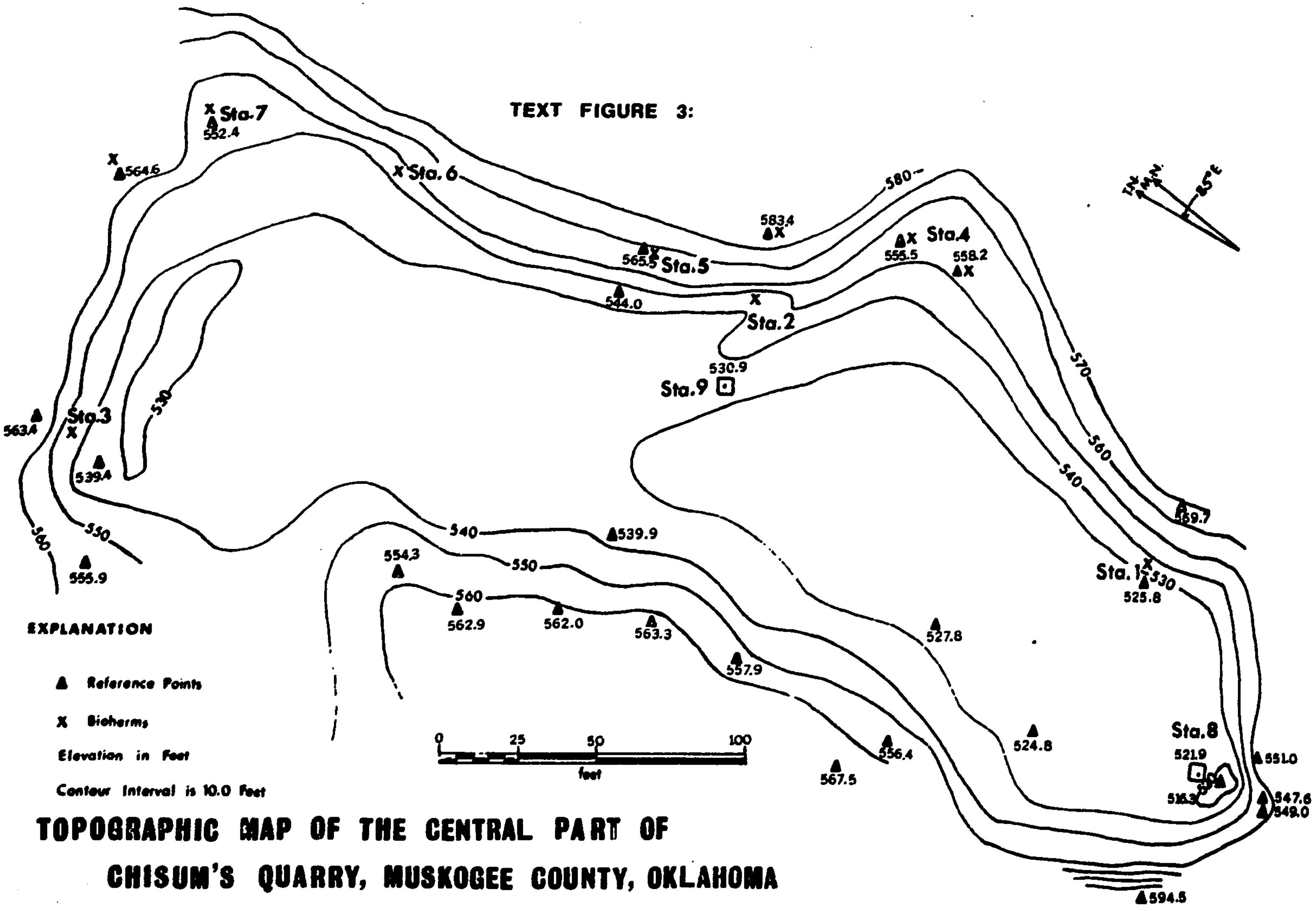
Methods of Investigation

Morrowan Bioherms

In order to describe the distribution and lateral relationships of the Morrowan mounds, it was first necessary to prepare a topographic base map of the quarry in which they are located. This was done using rod, alidade, and standard plane table techniques. The pool elevation of the Arkansas River Navigation Canal adjacent to the quarry was used as a bench mark for elevation. During preparation of the topographic base, major mounds were located within two mounding intervals and were noted on the map (text figure 3).

Oriented rock samples and shales were collected from a variety of mound surfaces including both horizontal and vertical sections through the mounds and within shales and limestone sequences adjacent to the mounds. Serial slabs were cut from each lithic sample and then polished

TEXT FIGURE 3:



TOPOGRAPHIC MAP OF THE CENTRAL PART OF CHISUM'S QUARRY, MUSKOGEE COUNTY, OKLAHOMA and varnished in order to examine successive biotic and textural components. Point counts were made on a 5 mm grid over several slabs from each sample. If possible, at least 200 points were counted in order to obtain a statistically significant sample. Thin-sections were made from slabs that appeared either unusual or interesting for more detailed examination.

Washed shale samples collected over gridded surfaces or within mounding sequences were processed by standard techniques. The shales are first dried and then covered with a light weight oil such as kerosene, varsol, or solvent. The shale is left in the oil for a period of time that varies with the nature of the shale sample. An extremely friable shale requires an hour or less to become saturated with oil, while more compact shales may require more than six hours. After the shale is thoroughly impregnated with oil, the remaining oil is decanted, and the sample is covered with hot water and allowed to stand for at least an hour, again depending on the nature of the sample. At the end of this period, the disaggregated shale sample is washed through a 120 mesh screen to remove the mud and retain coarse skeletal material. This method is effective on noncalcareous shales, but often calcareous shales will disaggregate only in part, leaving much nonskeletal material to be picked through. The residue from the shale sample is then dried, resieved, and then skeletal material is sorted and counted. From the point count data and shale samples, percentages of the total biotic composition were calculated for each biotic component and plotted on diagrams of each mound (appendix A). In order to facilitate description, the percentages were divided into groups by the first and third quartiles. The mean and standard deviation were not used because of the extreme variability of the percentages. Also, shale samples are considered separately from slabs since the percentages of nonbiotic components could not be determined in a similar manner for both lithologies. Examination of data from mound samples numbered VB (see appendix A, table 12), will reveal the variation between point counts on horizontal surfaces, vertical slabs, and shale samples. The diagrams of each mound are described qualitatively, and any trends of association or succession of biotic components are noted.

Modern Reefs

Living reefs in the Florida Keys were examined, photographed, and biotic elements described. Since cavities for a significant aspect of modern reefs, a part of this investigation was devoted to collection of reef biolithite and recognition and description of cavities and similar features in the reef material, as well as in the Morrowan bioherms.

In addition, a patch reef association in a carbonate mud environment at Discovery Bay, Jamaica, was studied and described for comparison with ancient biotic accumulations.

Finally, the Pennsylvanian bioherms were compared with modern patch reefs and other bioherms and reefs described in the geologic literature.

Previous Investigations

Detailed investigation of the paleoecology of the Morrowan bioherms in northeastern Oklahoma would not be possible if it were not for the intensive studies of these strata that had been done previously by Patrick K. Sutherland and several graduate students at the University of Oklahoma.

Initial examination of Morrowan lithostratigraphy in the Lake Tenkiller area was made by David C. Bowley (M.S., 1968) with Bruce N. Haugh (M.S., 1968) describing the biostratigraphy. Tommy Lee Rowland (Ph.D., 1970) described the carbonate petrology in part of the Morrowan outcrop area, and David Kotila (Ph.D., 1973) investigated the nature and paleoecology of the algal interval in the upper part of the Sausbee Formation. Thomas W. Henry made substantial contributions to the biostratigraphy of the Morrowan interval in northeastern Oklahoma and northwestern Arkansas in his thesis (M.S., 1970) and dissertation (Ph.D., 1973). The compilation of these studies and additional investigations of the Morrowan biostratigraphy of northeastern Oklahoma is now in preparation (Sutherland and Henry, in press).

Morrowan Biotic Investigations

A complete description of previous work may be found in Sutherland and Henry (in press); however, I will list some of the more significant biotic investigations here.

The most extensive investigation of the Morrowan megafauna was done by Mather (1915). This remains as an important reference on the Morrowan fauna because many of the biotic elements described have never been restudied. Detailed specific descriptions of the faunal elements of the Morrow Series began in the years that followed. The crinoid faunas of Oklahoma, Arkansas, and Texas have been described from isolated localities by Moore and Plummer (1937), Moore (1940), Moore and Plummer (1940), Moore and Laudon (1942), Strimple (1951), Moore and Strimple (1969), and more recently by Moore and Strimple (1973). Preliminary study of the coelenterate faunas was done by Moore and Jeffords (1945). The goniatite cephalopod fauna of the Morrow has been studied by a number of authors including Unklesby (1962), Gordon (1964, 1965, 1969), and McCaleb (1968). Henry (1973) has described the brachiopod faunas. A few published references may be found to other elements of the Morrowan marine biota.

LITHOSTRATIGRAPHY

Morrowan Depositional History and Formational Units

Morrowan strata unconformably overlie Mississippian formations in northeastern Oklahoma. The unconformity decreases in magnetude eastward into Arkansas as a result of tilting and differential Premorrowan erosion. There is indication of up to 80 feet of relief on the erosional surface. This occurs north of Gore on the Gore-Braggs Mountain High with a shallow basin lying to the northeast (Sutherland and Henry, in press). To the south lies the Arkoma Basin whose axis is approximately along the Choctaw Fault running eastward from Hartshorne, Oklahoma.

Sutherland and Henry (in press) have revised and proposed new formational terms for the Morrow Group in northeastern Oklahoma (text figure 4). Earlier workers (C.A. Moore, 1940, 1947; Huffman and others, 1958) had merely extended the Arkansas formational units into northeastern Oklahoma based on the distribution of quartz sand and shale. This criterion does not seem reliable according to Sutherland and Henry (in press), and they have proposed the terms Sausbee and McCully Formations for the lower and upper Morrowan strata, respectively, in northeastern Oklahoma. The basis for division of the formations is a major regional unconformity that allows correlation with the Morrow strata of Arkansas.

The lowest member of the Sausbee Formation is the Braggs Member, which includes limestone with minor sandstone, siltstone, and shale with a thin, locally developed, basal conglomerate. The Braggs Member appears to have been deposited on a shallow carbonate platform extending southward or southwestward from the Ozark Dome during Early Morrowan time. The platform falls rapidly off into the Arkoma Basin a few miles south of Webbers Falls (Sutherland and Henry, in press).

Morrowan strata are now exposed in a series of bands associated with elongated fault blocks that form a radial pattern around the southern part

PENNSYLVANIAN	ATOKAN	ATOKA FORMATION	
	MORROWAN	McCULLY FORMATION	shale "B" member
			Greenleaf Lake Member
			shale "A" member
			Chisum Quarry Member
		SAUSBEE FORMATION	Brewer Bend Limestone
			Braggs Member
MISSISSIPPIAN	CHESTERIAN	PITKIN FORMATION	
		FAYETTEVILLE FORMATION	
		HINDSVILLE FORMATION	

TABLE OF FORMATIONS IN

NORTHEASTERN OKLAHOMA

TEXT FIGURE 4

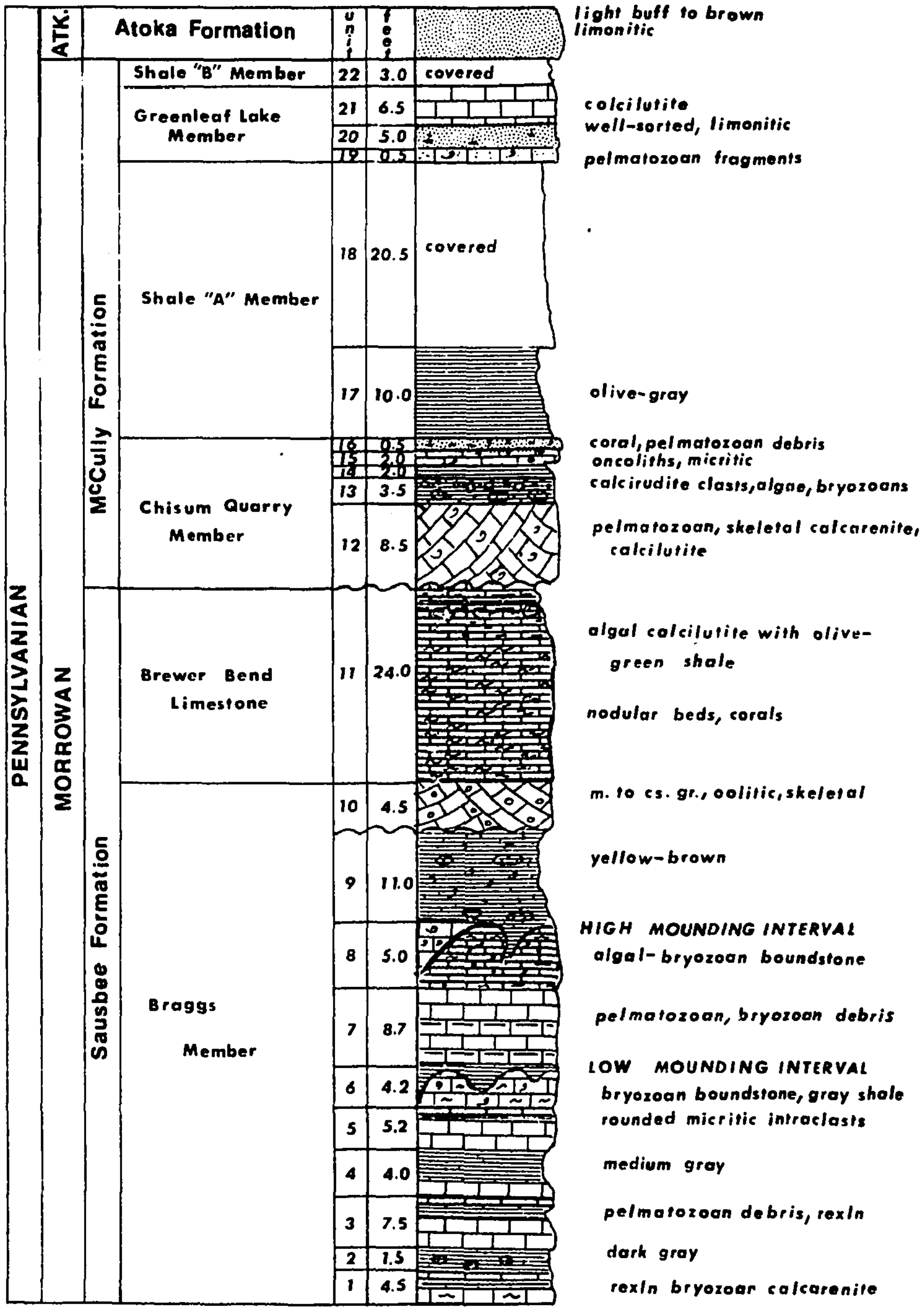
of the Ozark Dome (text figure 1) These strata are generally flat lying or dip gently south and southwest with dips exceeding three degrees only near radiating faults. Exposures are commonly capped by overlying, resistant Atoka sandstones.

Location and Nature of Bioherms

The Morrowan biohermal mounds selected for investigation are included in sections described by Sutherland and Henry (in press), designated "section 97: Chisum's Quarry Central." The section is located in the central quarry on the Chisum property that was leased by Jeffrey's Sand Company to provide material for the Webbers Falls Lock and Dam on the Arkansas River Navigation Canal (text figure 2). It is now used as a source for road material. The quarry is located in SW¼, NW¼, NW¼, Sec. 35, T. 13 N., R. 20 E., Muskogee County, Oklahoma. To reach the quarry:

> drive northward on Oklahoma State Highway 10 from the intersection of State Highway 10 and State Highway 100 at Gore for a distance of 1.8 miles to the junction of State Highway 10 and the paved road leading west to the Resident's Office of the U.S. Army Corps of Engineers and the east end of the dam. Continue westward on the latter road for a distance of 0.9 mile and turn northward on the gravel road that intersects the highway immediately east of the Missouri Pacific Railroad tracks. Continue due north for 0.5 mile to the point where the gravel road intersects another gravel road running due east-west. Turn to the west and follow this road for a distance of 0.5 mile to the gate that guards the entrance to the quarry. Continue on this road a short distance into the quarry and proceed to the east wall of the central quarry (Sutherland and Henry, in press).

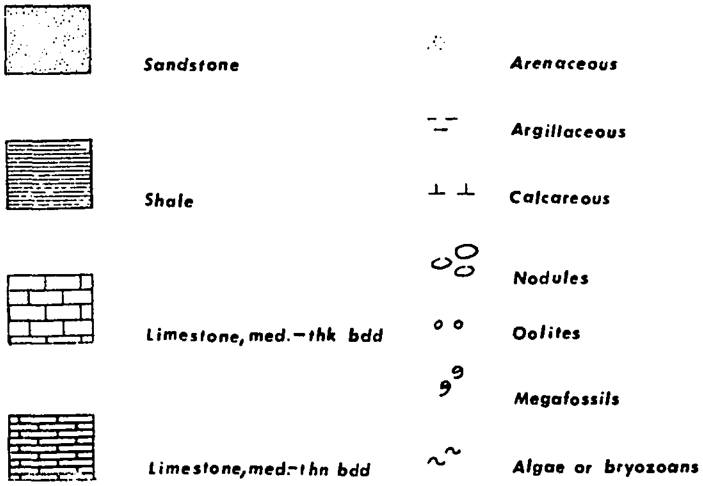
The section measured by Sutherland and Henry during May 1971, begins in the lower part of the Morrow Group near the southern end of the central quarry and includes two mounding intervals designated units 6 and 8. Both intervals occur in the Lower Morrow Group within the Braggs Member of the Sausbee Formation (plate I). At this location, the Braggs Member includes a variety of limestone and shale lithic types: calcareous and noncalcareous and arenaceous shales interbedded with limestones varying from algal-bryozoan boundstones (in which grains appear to be held together by biotic components) to lime grainstones (text figures 5 and 6).



COLUMNAR SECTION OF MORROWAN STRATA
IN CENTRAL CHISUM QUARRY
TEXT FIGURE 5

LEGEND

TEXT FIGURE 5A



Lithologies illustrated in text figure 5

The lower 0.8 to 4.0 feet of the lower mounding interval (unit 6) consists of skeletal lime wackestone containing fragments of pelmatozoan columnals and bryozoans (plate II, figures 1 and 2). This is overlain by irregularly developed pelmatozoan-bryozoan-algal boundstone mounds that contain local developments of Garwoodia (codiacean) algal boundstone. The individual mounds reach a maximum height of 2.5 feet and a width of 9.0 feet on the north wall of the central quarry. Medium gray, slightly silty shale occurs over, adjacent to, and within the boundstone mounds. The thickness of the shale varies from 0.7 to 1.3 feet on top of the mounds and to over 2.0 feet adjacent to the series of boundstone lobes occurring on the north wall. This interval varies greatly in thickness due to differential compaction of the shale around the mounds, and the otherwise parallel bedding of the shales becomes disturbed immediately adjacent to the mounds.

Eight to 9 feet of interbedded limestones and shales separate the upper mounding interval (unit 8) from the lower interval. The higher interval also contains bryozoan-algal boundstone mounds, but these mounds are generally larger and structurally more complex. They reach a maximum height of 6 feet and width of 10 feet (plate III, figure 1; plate IV, figure 1). The mounds commonly appear to be oriented, having a steep bryozoan-algal roll that faces into dark gray calcareous and noncalcareous shales and an elongated "back side" that gradually thins against lime grainstone channel deposits (plate III, figure 2). The grainstone includes fragments of pelmatozoans, bryozoans, and coelenterates including michelinid corals. The highest mounds occur in argillaceous, calcareous siltstones and shales that are buff-green to gray in color and weather rust brown. The only fossils found in this shale include a few abraded pelmatozoan columnals and plant fragments.

Carbonate Lithofacies

Lower Mounding Interval

Lithic types represented in the lower mounding interval of the central quarry include lime grainstones and bryozoan and algal boundstones and lime wackestones. Silicification of pelmatozoan, bryozoan, and tabulate coral debris is common, as is recrystallization of large skeletal clasts to spar. Dolomitization occurs only in the coarse-grained Garwoodia lime grainstones.

Grainstones occur in association with mounding structures in lower mound layers that extend away from the core of the mound at the base (plate IX, figure 1), while boundstones and lime wackestones form mound cores (plate VIII), but the outer layers of bioherms in the lower mounding interval consist of bryozoan boundstones to mudstones and lime wackestones.

Upper Mounding Interval

Lithic types represented in the upper mounding interval are more diverse than those of the lower interval and include lime grainstones, packstones, wackestones, mudstones, and boundstones. All exhibit partial silicification of pelmatozoan and bryozoan debris and partial recrystallization of large skeletal clasts to spar.

Pelmatozoan-dasycladacean algal lime grainstones are common in channel deposits adjacent to the lobed mounds in the central and north quarries (plate IX, figures 3 and 4). In contrast to the lower interval, stromatolitic boundstones and lime wackestones are found in both the mound core and outer layers of the mounds (where bryozoan boundstones were common in unit 97-6). These lithologies are illustrated in plates X through XIV (plate X, figure 1; plate XII, figures 1-6; plate XIII, figures 3 and 4; plate XIV, figures 2-4).

Stromatolitic boundstones occur with and intergrading to bryozoan-coral boundstones and lime wackestones in the intermediate layers of the bioherms (plate XI, figures 2-4; plate XIII, figure 2; plate XIV, figures 1, 4-6). Also associated with the middle layers of the mounds are red algal (Archaeolithophyllum)-tabulate coral-stromatolitic boundstone and lime wackestone (plate XIII, figure 1) and goniatite lime wackestone (plate XIC, figure 5) from two localities in the north quarry. Lime packstones and lime mudstones occur with these lithologies in the intermediate layers of mounds in the central quarry.

Nodules occurring in the shales between mounds in the upper mounding interval consist of dolomitized skeletal (pelmatozoan-spicule) lime mudstones or biomicrite (plate IX, figure 2).

Compaction Features

Vertical micro- and mega-fractures and stylolites are found in lithofacies in both upper and lower mounding intervals. These features are most common in the stromatolitic and bryozoan boundstones and, when occurring with dolomitization, fractures through grains only indicate that compaction preceded dolomitization.

Evidence for Exposure

Associated with the stromatolitic boundstones in the outer layers of the bioherms in the upper mounding interval are bird's-eye structures and dessication cracks that may have formed as mud cracks on the stromatolitic surface. The cracks are filled with coated grains or ooliths and are associated with anhydrite pseudomorphs and dolomite rhombahedrons (see thin section descriptions, appendix A). The outer surfaces of the mounds have an irregular "weathered" appearance, stained by iron oxide, while the adjacent and overlying shales contain a nonmarine biota.

DIAGRAMMATIC SECTION OF EAST WALL OF CENTRAL

CHISUM'S QUARRY

TEXT FIGURE 6

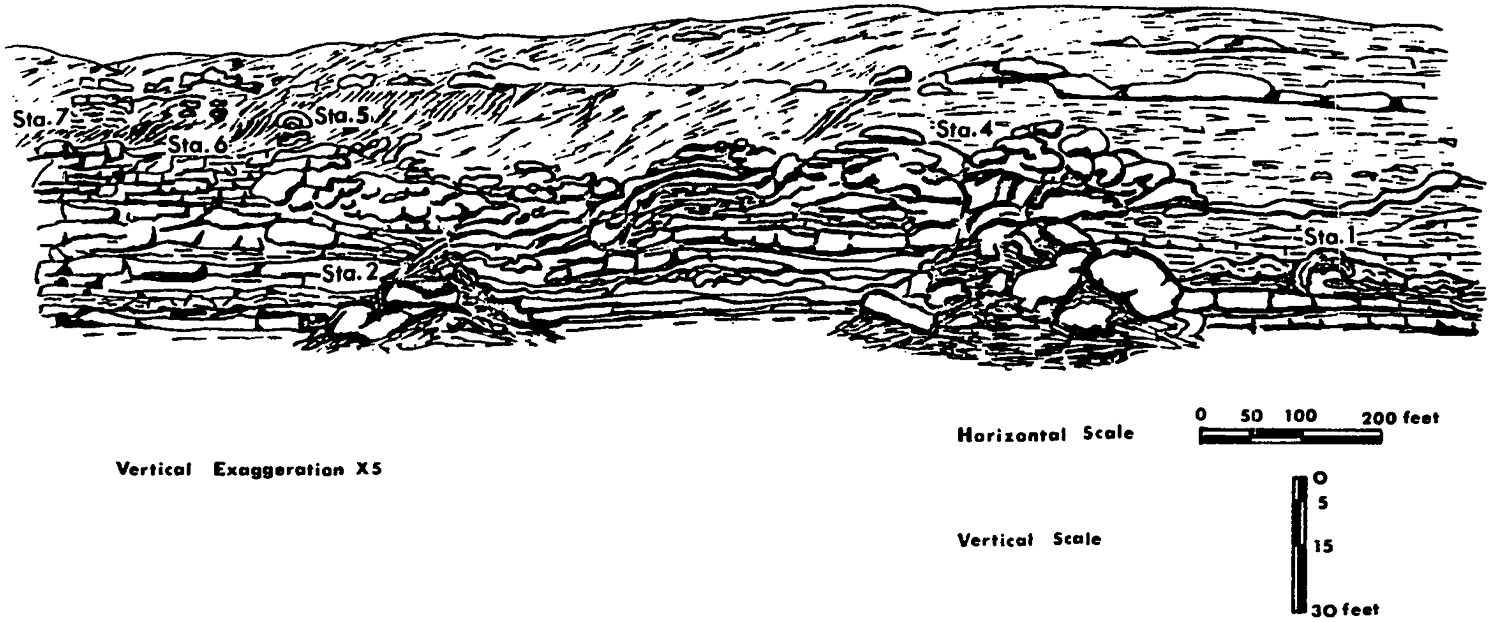


PLATE I

East wall of central Chisum's Quarry showing mounds 97-6 (station 1) and 97-8 (station 4) where Sutherland and Henry (in press) measured their original section.

PLATE I

PLATE II

Figure 1: Mound 97-6, station 1 at south end of the lower mounding interval exposed in central Chisum's Quarry. Detailed description in appendix A ....page 92.

Figure 2: Mound 97-6 WB, station 3, largest mounding complex developed in the lower interval at the north end of the central Chisum's Quarry. Detailed description in appendix A ....page 111.

PLATE II

1

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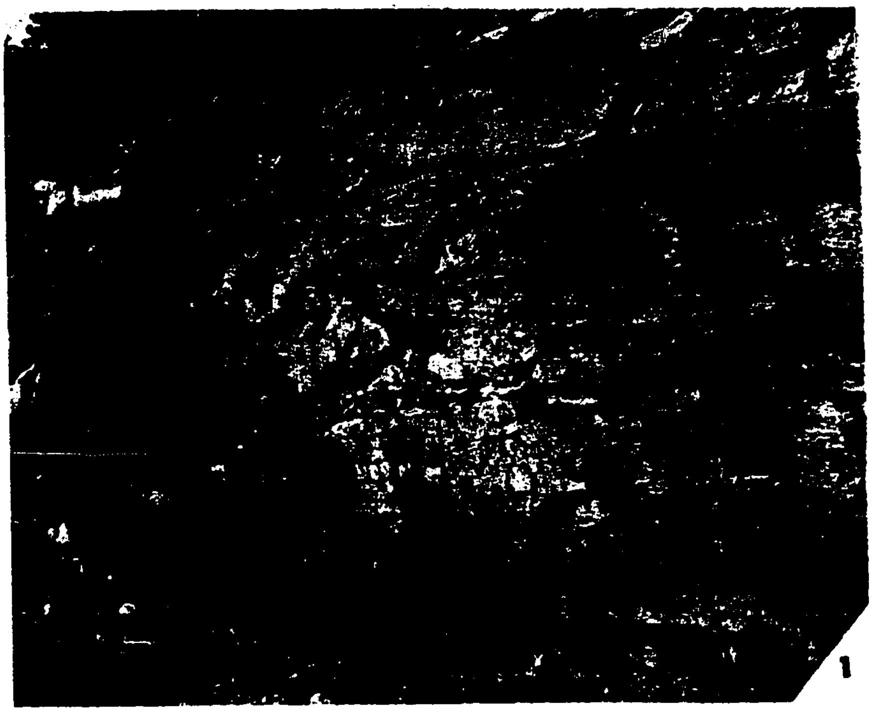
PLATE III

Figure 1: Mound 97-8, station 4 from the south end of the quarry. This mound is the largest mounding complex exposed in the upper interval of the quarry. Detailed description in appendix A ....page 117.

Figure 2: Detail of lobes of mound 97-8 showing the bryozoan roll that faces into shale while the back thins against lime grainstone channel deposits (A).

PLATE III



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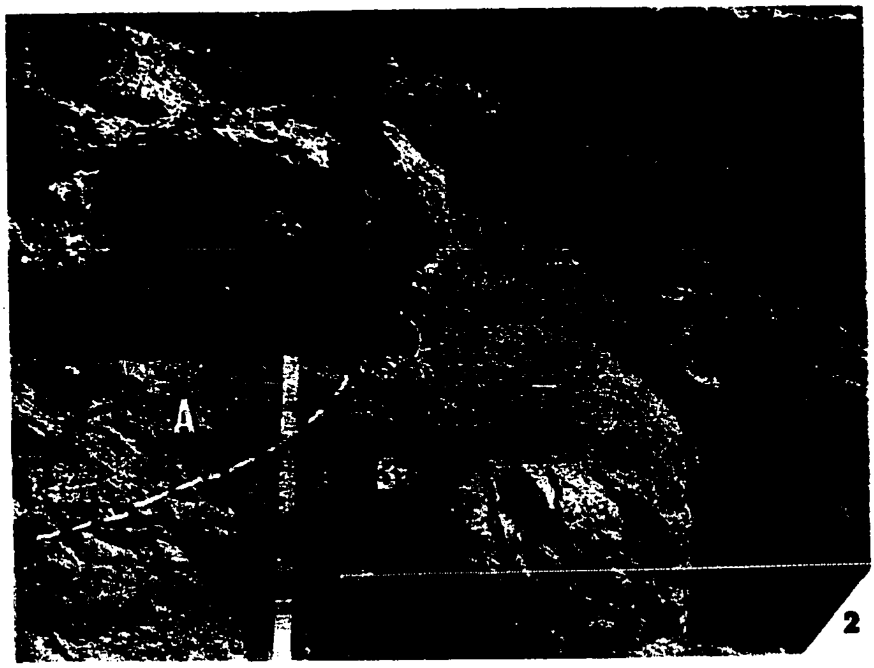

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PLATE IV

Figure 1: Northern development of mound 97-8, station 4. Samples were not collected from this section because it was inaccessible.

Figure 2: Mound 97-8 XB, station 8, loose block from upper mounding interval lying on the quarry floor. The weathered surface was used to make surface collections to establish biotic associations. Detailed description in appendix A .....page 165.

PLATE IV

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2

PLATE V

Figure 1: Mound 97-8 BN, station 9, loose block on quarry floor used for surface collections. Material collected from the surface differed from that of mound 97-8 XB in the large amount of goniatite material present. Detailed description in appendix A ....page 174.

Figure 2: Mound 97-8 YB, station 5, single roll or lobe occurring in the shales that lie high in the interval. Detailed description in appendix A ....page 134.

PLATE V

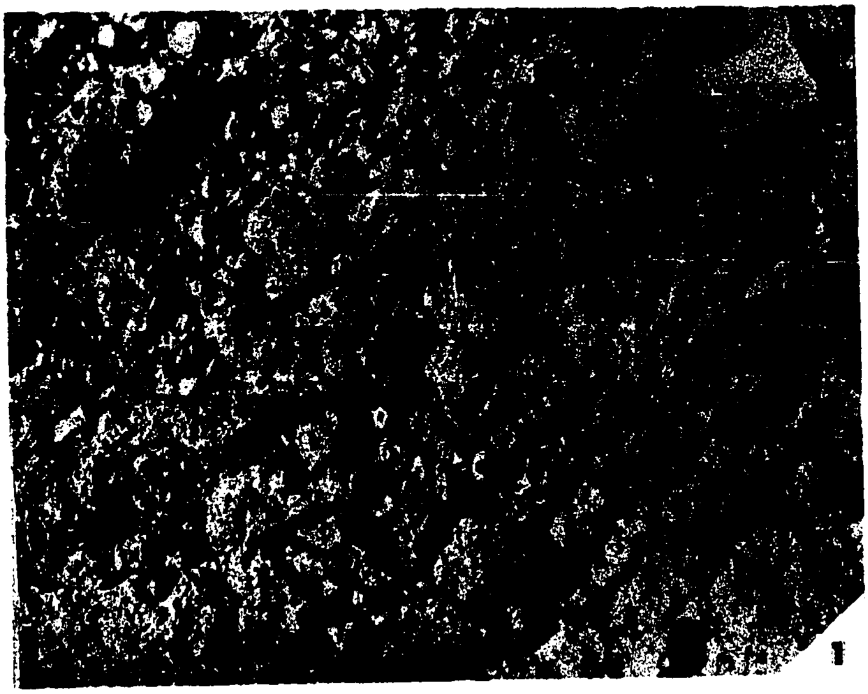

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PLATE VI

Figure 1: Mound 97-8 UB, station 6, interval of small, algal-bryozoan bioherms and shale exposed northward from 97-8 YB in the shales of the upper interval. Detailed description in appendix A ....page 146.

Figure 2: Mound 97-8 VB, station 7, northernmost "mounding" structure in the upper interval of the central quarry. This structure is composed of algal-bryozoan boundstone nodules in shale. Detailed description in appendix A ....page 155.

PLATE VI

1

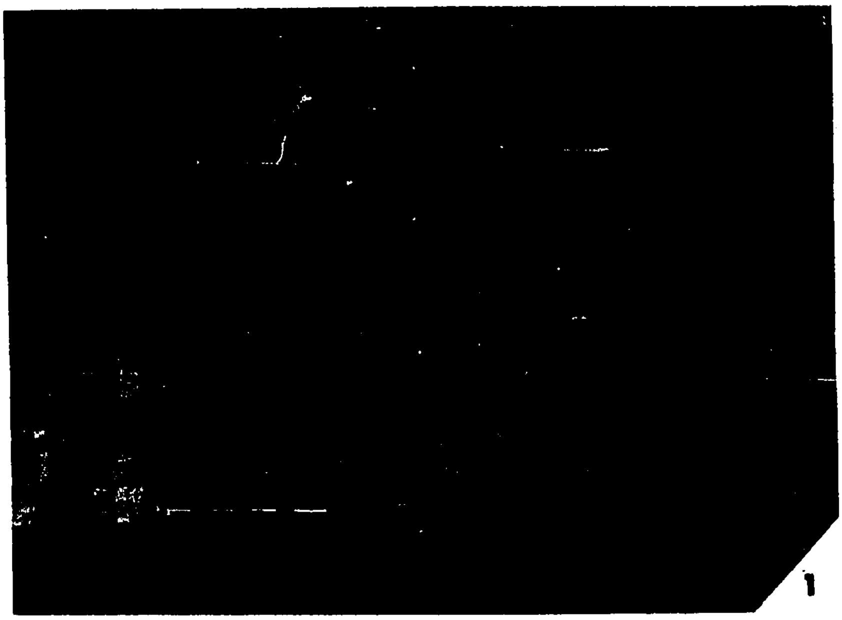
2

PLATE VII

Figure 1: View of mounding interval in the North Chisum's Quarry. In place mounds like these were inaccessible in the north quarry, but small talus mounds like the one pictured below were collected and sectioned as Mounds 97-8? ZB. Detailed descriptions of several mounds in appendix A ....page 158.

Figure 2: Surface of one of the "jelly-roll" mounds from the talus in the north quarry.

PLATE VII



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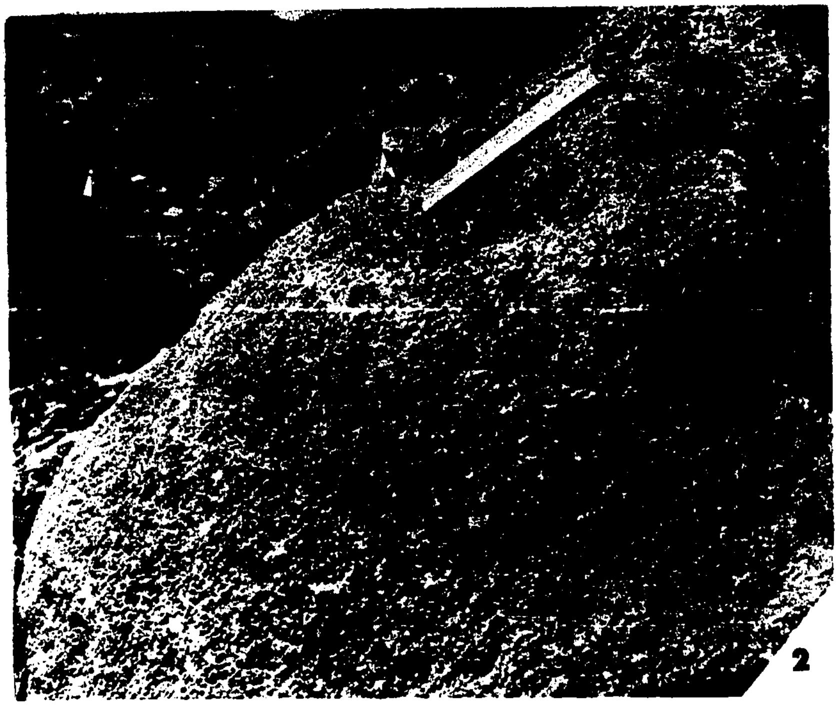

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BIOHERMAL PALEOECOLOGY

Problems in Paleoecology

Paleoecology borrowed the concept of the "community" from ecology as a basic unit. The term "community" in paleoecology has been used to refer to any association of organisms that can be recognized as recurrent and has a mappable distribution (Speden, 1965). The assumption is that the criterion of recurrence will eliminate chance associations and mappability will insure that the association is discrete, a requirement for modern communities. In modern communities, as defined by Petersen and Ekman (Hedgepeth, 1957; Thorson, 1957), the similarity of the association must be greater than its similarity to any surrounding associations. The question then becomes whether we can assume that these criteria will result in a fossil "community" bearing any similarity to a living community. Does recurrence necessarily rule out associations of organisms that did not live together, especially in light of the effects of transportation in some marine environments? Will the criterion of mappability of associations eliminate description of transported associations as communities?

In paleontology, we examine death associations of organisms and must remember that the evidence we view need not clearly represent the organisms that comprised the living communities. The fossil record consists of either the remains of organisms that died or those that left a record of their presence, and mortality need not reflect the living population (Odum, 1971). For example, a high infant mortality may produce a surprisingly large number of small individuals compared to adults, though adults may have dominated the living population (Boucot, 1953). We must also remember that these associations are biased by preservation — that some organisms are more likely to be preserved than others. Soft tissues are more susceptible to decay, but hard skeletal material must also survive the mechanical and chemical processes at work and be buried in a favorable environment that is later exposed to study. An association of fossil organisms is likely to include not just a single community, but material from the entire water column, which has filtered down over a period of time (Hedgepeth, 1957). If sedimentation is relatively slow, it may be possible to include individuals from a series of communities on a single substratum. The record is even further complicated by the number of fossil fragments that represent a single substratum. A trilobite will undergo a series of molts that may later be interpreted as different individuals (Harrington, 1959); a single blastoid or crinoid may produce scores of pelmatozoan fragments. These factors and others must be remembered if we are to look critically at any association of fossil organisms and attempt to make valuable paleoecologic interpretations.

Morrowan Bioherms

The Morrowan mounds appear to represent a life assemblage that has accumulated in place. Although adjacent pelmatozoan lime grainstones show definite indications of transport, including abrasion of fragments, sorting, current orientation, and absence of fragile skeletal material; the mound material itself does not appear to have been substantially transported. Studies by Chave (1962) indicate that calcareous red algae and fenestrate bryozoans, common in the Morrowan bioherms, are highly susceptible to mechanical destruction in a short time. Further, the organisms do not appear to have been current oriented or deposited as particulate material influenced by currents or waves. Instead, the bioherms have a boundstone framework that is formed by a variety of encrusting and cementing organisms and opportunistic accessory organisms such as brachiopods, rugose and tabulate corals who found a stable substrate in the mounds. The remains of vagrant organisms including trilobites, gastropods, nautiloids and goniatites, may have been transported into the mounds after death, but it is equally possible that they were a part of the normal fauna associated either with the mounds or the adjacent strata as they show little evidence of transport. Many cavities within the bioherms contain transported debris, but there are also instances where organisms appear to have grown in place within cavities that were present during biohermal growth. There appears to be no accurate method to estimate the number of organisms that is not represented within bioherms. However, it is important to recognize that many of the original inhabitants may not be preserved when attempting to interpret paleoecology of the bioherms.

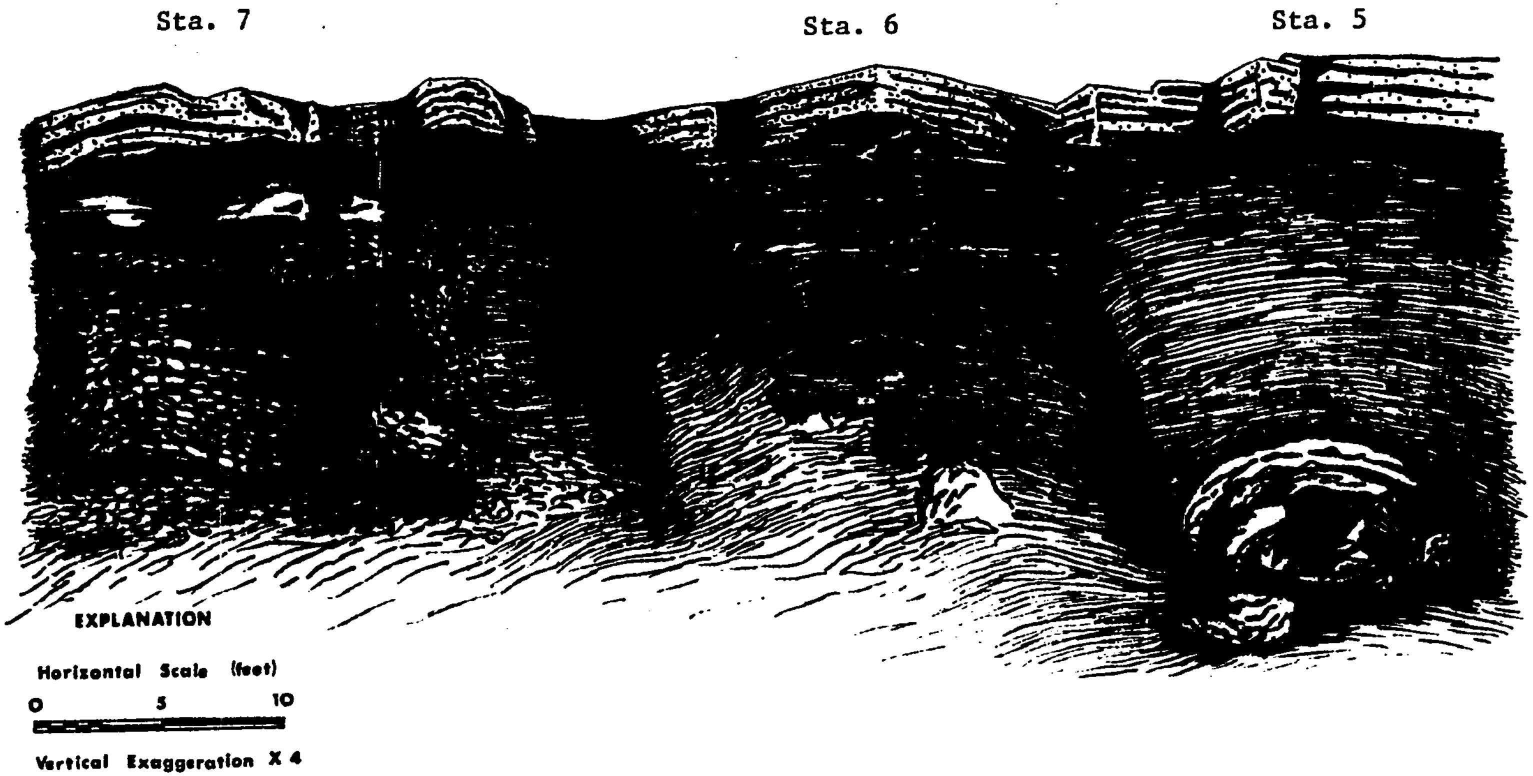
Mound Development

Initiation

The mounds usually seem to begin development above skeletal lime wackestone, which may or may not have a relatively thin layer of shale between it and the mound. The first problem then becomes one of sediment stabilization that can be followed by accumulation of more diverse organisms. Raup and Stanley (1971) state that organisms commonly occur in groups or clusters of individuals either because of inhomogeneities in the physical environment or reproductive and social behavior of the species. The first factor may be important when there is nonuniform distribution of nutrients, salinity, temperature, oxygen, or water circulation or an uneven substrate of varying composition that may include areas of ideal slope or composition. The reproductive and social behavior are presumably a major influence since organisms must be within a certain distance in order to produce offspring. Marine grass beds commonly develop as patches with asexual reproduction through runners. Planktonic larvae of other individuals tend to be transported together and may eventually settle together or with an adult population. In addition, vagrant adults commonly group together for protection and reproduction. Once a cluster or patch of organisms is established, other organisms tend to settle and form a more diverse community.

The Morrowan bioherms have a core or lowermost layer that consists primarily of algal material (text figure 9). This generalization is well supported by examination of three exposures in the higher mounding interval (text figure 7) that illustrate three successive stages in mound development. The northernmost exposure (plate II, figure 2) is a rubblely accumulation of stromatolitic algal-boundstone nodules in shale containing scattered pelmatozoan fragments, bryozoans, brachiopods, corals and goniatites. The second exposure (plate VI, figure 1) includes the first small biohermal accumulations in an interval of shales and skeletal lime grainstones, while the southern exposure (plate V, figure 2) contains a well-developed bioherm surrounded by shale. The presence of these three stages of mound development in the uppermost part of the highest mounding interval is probably the result of successive differences in the environment from the north to the south, perhaps from agitated intertidal water to slightly deeper water. Careful examination of the second exposure where bioherms first appear, therefore, should be useful in determining the conditions that resulted in mound development. There are three small mounds present in the sequence and each is underlain by a boundstone formed of stromatolitic blue-green algae and micrite. The algae have been tentatively referred to the form-genus Ottonosia, although recrystallization has destroyed much of the original structure. Studies of modern environments (Ginsburg and Lowenstam, 1958; Laporte, 1968) reveal that algal mats can form a tough, leathery coating that stabilizes the sediment surface. In addition, stromatolitic algae are actually sediment binders, growing upward and incorporating surface sediments into the mat (Neuman and others, 1970). In such a manner, stromatolitic algae, like those at the base of the Morrowan bioherms, can not only form a mat that is resistant to erosion, but can also forms a stable substrate that is free of shifting sediments, even on a carbonate mud base. Once such a mat has formed, it becomes a favorable habitat for other organisms requiring a stable surface. Thus, above the stromatolitic algae in the Morrowan bioherms, a diverse assemblage of accessory organisms appears including forms such as rugose and michelinid corals, fenestrate, arborescent, and encrusting bryozoans, and pediculate brachiopods. In a favorable environment, it appears that accumulations of algae and bryozoans with accessory organisms may flourish and develop relatively large bioherms that may have had little relief above the sediment surface. However, the southernmost exposure in the upper interval indicates at least 3.5 feet

TEXT FIGURE 7:



DETAILED DIAGRAM OF UPPER MOUNDING INTERVAL of relief since successive layers are wrapped around the central core in a "jelly-roll" fashion (plate V, figure 2). This would not be possible if the structure were only exposed a few inches above the surrounding substrate.

Succession in Bioherms

The first step in mound initiation is stabilization of the substrate by blue-green algae (text figure 9). The composition of the algal core may be simple, consisting of only one alga, or it may be quite complex as in the mound sampled on the northern wall of the central quarry in the lower mounding interval (plate II, figure 2). This mound begins with *Hedraites-Girvanella* (plate XVI, figure 3), followed by a green alga (*Garwoodia*), and then *Ottonosia*. However, most of the mounds in the quarry have a core of *Ottonosia* and minor amounts of the red calcareous alga, *Archaeolithophyllum missouriensis*.

The mound core is generally overlain by a crust-like layer of bryozoans, probably encrusting or fenestrate forms, or encrusting red algae like *Archaeolithophyllum lamellosum* (plate XV, figure 1; plate XVI, figure 1; plate XV, figure 2). These organisms further stabilize and prepare the substrate for habitation by other organisms including rugose and tabulate corals. The corals require a firm base for initial attachment, but as the colonies or individuals grow, they can obtain support by sinking into the soft algal mud. Debris of bivalves, bravhiopods, and pelmatozoans commonly seems to accumulate in irregularities on the algal or bryozoan crust.

Many of the mounds exhibit a cyclic repetition of *Ottonosia* and *Archaeolithophyllum lamellosum* growth. This may be a reflection of seasonal growth, sea level fluctuations, or periodic influences such as tides. Other organisms associated with the algal layers vary within individual mounds, but a few general relationships are summarized below from the biohermal description in appendix A.

Individual Biotic Components

Framework:

1. *Ottonosia*. This blue-green alga occurs in the cores of all mounds

examined within the quarry. It is also found throughout mounds in the higher mounding interval, although it is commonly recrystallized in the outermost layers of the mound (plate XV, figures 3 and 4).

2. Archaeolithophyllum lamellosum*. This red, clacareous, encrusting alga commonly occurs as a crust on the outer core layer above Ottonosia and often alternates with that alga in higher mound layers (plate XV, figure 2). It appears to encrust rugose and tabulate corals, although this may in reality be a case of the corals sinking into the algal substrate with growth (plate XIII, figure 2). In the oriented mound complex of the higher mounding interval, 97-8, station 4; this alga seems to prefer the gently sloping back of the complex that abutts against grainstone channel deposits.
3. Archaeolithophyllum missouriensis*. The other red, encrusting, calcareous alga associated with the Morrowan mounds has been compared to Lithophyllum and Goniolithon life habits in modern reefs. Thus, it is believed by Wray (1971) to prefer areas at or near wave base. It is found in large numbers near the tops of the mounds, perhaps areas of maximum wave action. It is also found in the complex adjacent to lime grainstone channel deposits (97-8, station 4), again suggesting preference for higher energy conditions (plate XV, figure 1; plate XVI, figure 1).
4. An undescribed dasycladacean alga, referred to by Kotila (1973) as a new genus, usually occurs in the middle part of the mound core where it is associated with A. missouriensis. However, its occurrence is relatively limited since it is only found in the southernmost mounds in both rhe upper and lower mounding intervals and in blocks from the north quarry (mound ZB), illustrated in plate XV, figures 5 and 6 and plate VII, figure 1.
5. Garwoodia. The other important green alga in the mounds belongs to the genus Garwoodia (plate XVI, figure 2). It is found primarily on the tops of mounds, and, as a green alga, might indicate shallowing water depths. However, this should be regarded cautiously, as I have

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*Identified by Wray for Kotila (1973)

observed modern codiaceans (Halimeda) at depths greater than 100 feet.

Cement:

6. Encrusting bryozoans. Bryozoans are habitat specific. Encrusting forms require a stable base for attachment and are confined primarily to mound tops, overhangs, and roofs of cavities. They are usually associated only with the mound, being very rare in the shales away from the mound itself. As noted previously, a few are associated with a crust over the core of the mound, but encrusting forms on the outside surface seem to prefer open water conditions adjacent to shales in most mounds (plate XVII, figures 26 and 27).

Sediments:

7. Fenestrate bryozoans. These bryozoans seem to prefer habitats that are protected, but have agitated water. They are most common in pockets and cavities within the mounds, with a few individuals living on the upper mound surfaces. However, in contrast to the encrusting forms, these bryozoans prefer to inhabit the channel side of mounds facing the lime grainstone channel deposits (plate XVII, figures 27 and 28). The advantage of living next to a channel may have been increased oxygen or nutrients near moving water.
8. Arborescent bryozoans. The third group of bryozoans prefer to live away from the mound itself, in shales either above or below the mound, or adjacent to it on the north, again near more agitated channel water. A few of these "stick" forms accumlated as debris in open cavities within the mounds (plate XVII, figures 34 and 35).
9. Lophotichium. Rugose corals appear to inhabit only the top, middle of mound surfaces and not the sides, which would not form a stable substrate. The corals occur most commonly adjacent to shales on the open water side of the mounds, perhaps indicating perference for open marine waters that are clear and oxygen and nutrient rich. These corals commonly occur in growth position on the floors and sides of cavities that were apparently dark or roofed-over. This may

indicate that these Morrowan forms were ahermatypic and not associated with photosynthesizing zooxanthellae found in many modern scleractinian corals. Bryozoans, Ottonosia, Archaeolithophyllum lamellosum often form a base for attachment of the rugose corals (plate XVII, figures 13 and 14).

10. Michelinid corals. Tabulate corals have a similar distribution pattern. They are also found on the tops, middle surfaces of mounds and within central and intermound shale cavities. Again, they are most abundant on the open marine side of the mounds and may be attached to an algal or bryozoan substrate (plate XVII, figures 17 and 18).
11. Pelmatozoan fragments. All pelmatozoan fossils consist of disarticulated fragments that commonly show abrasion or evidence for transport. They are most abundant on the tops of mounds or cavity roofs where they are entrapped by encrusting bryozoans and are the most common components of the debris that may accumulate in shale pockets and cavities within the mounds (plate XVII, figures 19-23).
12. Brachiopods. Hustedia and Composita brachiopods, as well as Punctospirifer, Anthracospirifer, and productids, are commonly found on the tops of mounds, under overhangs, on cavity roofs, and in intermound shales (plate XVIII). Each has its own special preferences: Composita is most abundant in intermound shales, while Hustedia prefers the tops of lobes of mounds. Chonetid brachiopods seem to prefer open marine conditions and are found most abundantly in the shales above and away from the lower mounds (plate XVIII, figures 1-5, 9 and 10).
13. Pelecypods. Pelecypods are rare but increase in number higher in the shales of the upper mounding interval.
14. Miscellaneous. Auloporid corals (Cladochonus) are also uncommon and are found associated with the mounds in shales above and within the mounds (plate XVII, figure 16). Goniatite cephalopods are most common in the core and outer layers of the mound, but some occur with shales

between mounds. Generally, their distribution is erratic and sparse, but definitely associated with mound development (plate XVII, figures 10 and 15). Gastropods seem to be associated with algae, particularly Ottonosia, A. lamellosum, and the new genus of dasycladacean, on which they may have grazed. They increase in abundance near the top of the mound and in the more "terrestrial" lagoonal shales (97-9). Trilobites are found in shales on the channel side near the top of mound 97-8, station 4 (plate XVII, figure 1-2 and 6). Foraminifera are rare and are associated with blue-green algae in the mound cores.

Thus, the organisms described appear to show a similar distribution in all mounds examined in both upper and lower mounding intervals. There appears to be a phase of mound initiation by blue-green algae, followed by habitation of the mounds by a variety of organisms during a "diversification" phase of mound growth, which is terminated by domination by bryozoans or algae (text figure 9).

Association of Organisms on Mound Surfaces

Two horizontal surfaces through the diversification phase of mound development were examined for possible biotic associations that might represent communities. Since the material was described from shale samples, algal components are not considered. In the first section examined, Mound XB (station 8), it was possible to recognize three associations using modified factor analysis (appendix A, table 16). These are:

1. The Hill or Highland Dwellers: pelmatozoans, spiriferid, Composita, and Hustedia brachiopods whether grouped together by life habit or hydrodynamic properties.
2. The Lowlanders: Fenestrate and arborescent bryozoans and goniatite cephalopods that appear to be more restricted in distribution than the first association. Perhaps, bryozoans formed a baffle, entrapping the goniatites.
3. Cavity Dwellers: Michelinid and rugose corals and encrusting bryozoans that dominate the cavity fauna of the bioherms.

The associations observed on the surface of the second mound (mound BN, station 9) differ only slightly from those in the first example (appendix A, table 18). However, the differences may be explained by the more ubiquitous nature of pelmatozoan fragments in the second mound, perhaps a factor of current distribution.

In both instances, the cavity association appears to be the only association that might clearly represent a "true" community possessing the necessary criteria. This association not only occurs in all mounds examined, it forms a discrete or mappable occurrence that may be readily recognized.

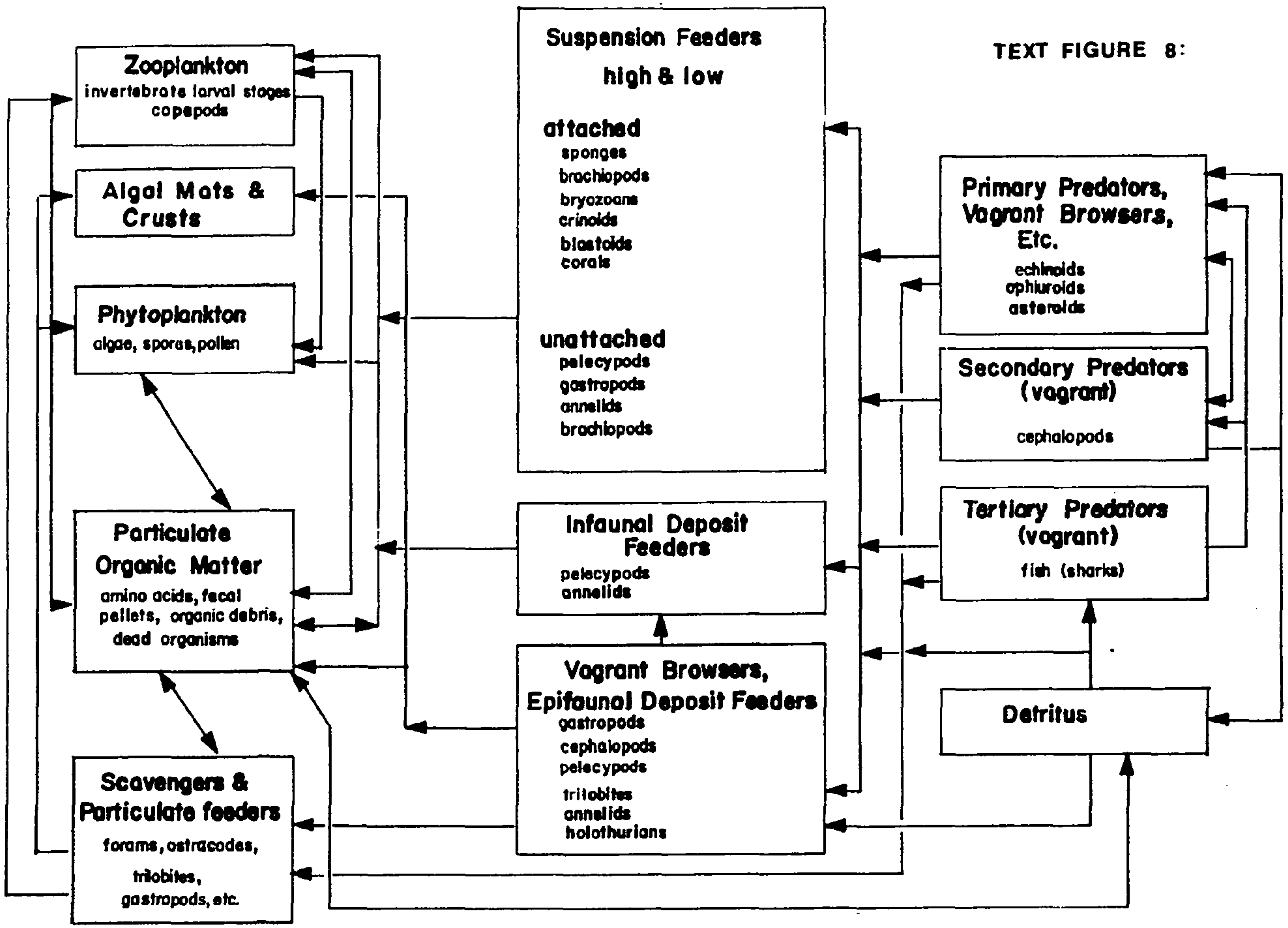
Trophic Structure Interpretation

More and more emphasis has been placed on the trophic relationships of organisms within their environment. Until recently, this relation was interpreted as a food chain or pyramid modified from the work of Lindeman (1942). According to this scheme, each ecosystem is divisible into a series of distinct trophic levels that have a constant flow of energy from one link to the next in a chain. This interpretation has presented a problem to paleontologists who often find organisms representing a few links, but generally those from higher levels (predators) are missing because of the relatively low number of individuals in the original environment.

Russian workers led by Zerkevich (1963) and Turpaeva (1957) evolved a scheme for recognition of trophic relationships of organisms on the same or adjacent levels. The key to these studies is the mode of feeding and type and availability of nutrients preferred. Much of the recent work has centered particularly on benthic invertebrates commonly encountered in paleontology.

Combining the investigations of Yonge (1954) in which organisms are classified by mode of feeding and type of food utilized with the classification schemes based on feeding habits and mechanisms (Turpaeva, 1957); Savilov, 1957: Newell, 1970), Walker and Bambach (1974) derived a classifi-

TEXT FIGURE 8:



Simplified FOOD WEB for Marine Communities cation of trophic structures that will be used in a modified form here (text figure 8). Feeding habit is the basis of separation into trophic groups, including suspension feeders, deposit feeders, browsers, carnivores, scavengers, and parasites. These are subdivided by position of the organisms: epifaunal, infaunal, or nektonic. The final subdivision depends on the location of food acquisition: high or low within the water mass, shallow or deep within the sediment, or at the sediment-water interface. Additional tools are the type of food preferred and specific feeding mechanisms.

The Morrowan bioherms appear to generally represent concentrations of primary production. Mound initiation begins with a patch of photosynthesizing algae, capable of forming their own nutrients. Once the primary producers have become established, other organisms form higher trophic levels classified into various trophic groups appear. However, at the same time, primary production remains high.

The first faunal elements occurring in the bioherms are usually encrusting bryozoans and tabulate and rugose corals. As epifaunal suspension feeders, these organisms feed on swimming and floating biota as well as suspended, colloidal, or dissolved organic matter. However, corals and bryozoans differ in the food utilized and the method of feeding. Bryozoans have a ciliated lophophore that moves very fine particles to the digestive system, while corals utilize tentacles with nematocysts and swallow larger particles (up to 5 mm in diameter). The position of encrusting bryozoans on the roof of cavities while corals inhabit the more stable areas of the cavity floors and walls may in part be influenced by the nature of the nutrients preferred.

Pelmatozoan fragments commonly accumulate in pockets adjacent to and within bioherms. Living crinoids are also classified as epifaunal suspension feeders, but use ambulacral grooves to move small particles to the mouth. In studies described by Macurda (1972), it was discovered that many living crinoids position themselves in such a manner that they can optimally utilize nutrient flow around the reef. It seems possible that Paleozoic forms may also have inhabited tops, steep walls, and lower sides of ledges in order to efficiently intercept nutrients in the lower portion of the water mass.

Brachiopods form another important element of the Morrowan mounds. Like bryozoans, they utilize a ciliated lophophore to transport small particles to the mouth. They also seem to occupy similar areas: on the tops of mounds, roofs of cavities, and below overhanging structures. It is possible for the two phyla to occur together with similar feeding characteristics since encrusting bryozoans commonly tap nutrients found near the sediment-water interface, while the brachiopods that occur commonly in the Morrowan bioherms are pediculate forms that would feed slightly higher in the water mass. Fenestrate and arborescent bryozoans who would be sampling levels in the water column similar to pediculate brachiopods, usually do not occur with the brachiopods. Rather, such forms are found in more open areas adjacent to the mound.

Other faunal elements increase with further mound development. Bivalved molluscs appear to become much more abundant near upper layers of the bioherms. There are usually infaunal suspension feeders who may be sampling the same water mass as the bryozoans. Thus, bivalves like nuculid pelecypods generally occur in areas with few encrusting bryozoans. Cephalopods are particularly common in later stages of mound development and represent an active predator, capable of chewing large pieces of organic material. Browsers are represented in the bioherms by gastropods, which are associated with large quantities of blue-green and red algae. In the mounds, they found an ideal habitat with abundant food to be scraped and rasped. Rare occurrences of trilobites, ostracodes, and foraminifera represent groups that were epifaunal deposit feeders, tentacular and setous low suspension feeders, and benthic suspension feeders capable of utilizing extremely small particles and fluids for nutrition.

All biotic elements, thus, interacted to develop the biohermal "community," with toleration, competition, and symbiosis among the individual trophic groups.

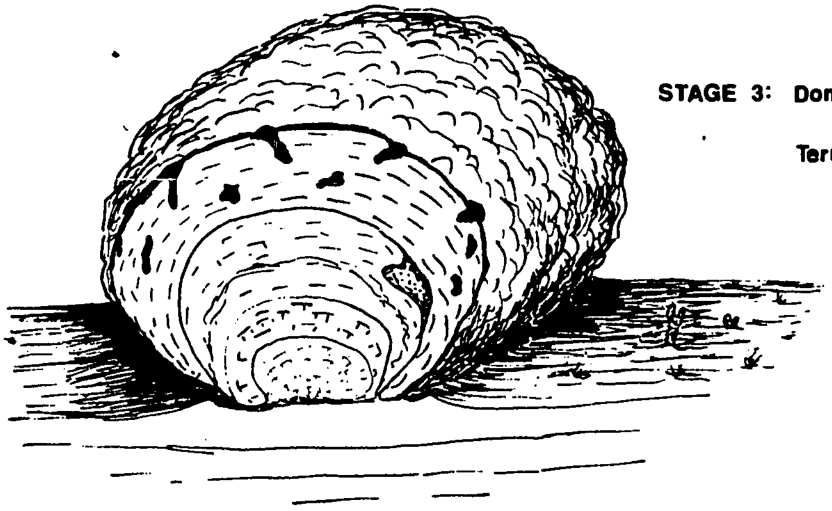
Cessation of Mound Development

The termination of mound development (text figure 9) occurred when conditions no longer favored growth of organisms associated with the mound. This could occur for a variety of reasons. Examination of the lithic succession suggests that sudden influx of clastic sediments, change in water depth and upward growth of mounds are the plausible explanations. Encrustation around the sides as well as the tops of the mounds indicates that shales encasing the biohermal developments were deposited after mound growth ceased.

Faunas associated with the shales of the upper and lower mounding intervals indicate two different causes of death of the mound biota. Gradual shallowing during mound development is indicated by ooids and dessication cracks in the outer layers of the bioherms in the upper mounding interval. The shales surrounding these mounds contain scattered, abraded marine fossils with fragments of leaves and stems. These factors indicate a shallowing pattern that could result either from upgrowth of the mounds to sea level or fluctuations in water depth. According to Wilson (1974), this is the more common cause of termination of carbonate growth. He states that rapid subsidence, drowning the bioherms, is much less likely since subsidence is generally so gradual that biohermal developments are able to maintain upward growth at a rate equal to subsidence. There are examples, however, where carbonate developments have been buried by terrigenous sediments following rapid subsidence, and I feel that the lower mounding interval could be indicative of such conditions. The dark shales surrounding the bioherms of the lower interval contain a rich, apparently untransported, fenestrate and arborescent bryozoan fauna with occasional chonetid brachiopods. In addition, there is no evidence for shallowing during mound development as is the case in the mounds of the upper mounding interval. A great change in water depth is not necessary, nor is it indicated by the bryozoan fauna. In order to inhibit mound growth, it might be necessary only to increase the influx of clastic sediments. This could be possible in a shallow platform area by merely increasing the seasonal rainfall in the sediment source area or by removing restrictive bathytopographic high areas through burial under sediment accumulation.

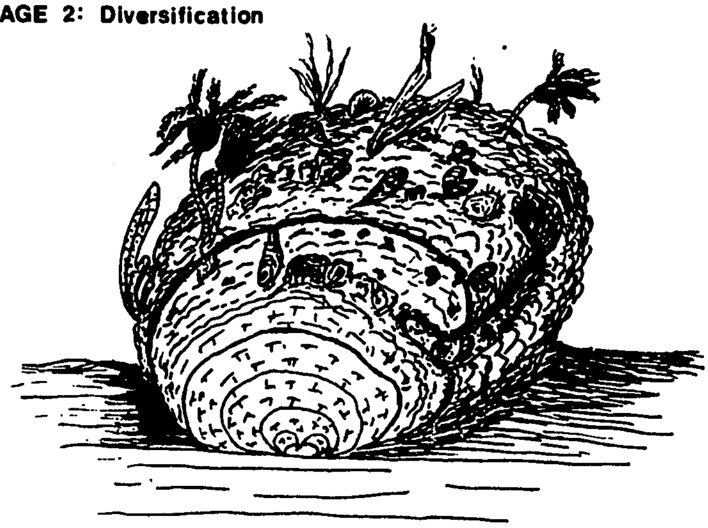
TEXT FIGURE 9

GENERALIZED MOUND DEVELOPMENT

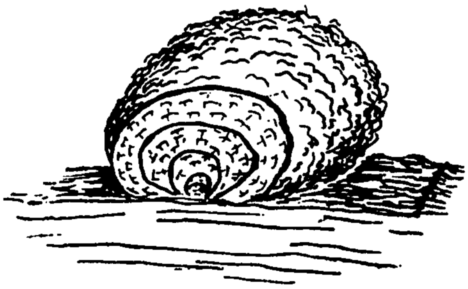


STAGE 3: Domination &
Termination

STAGE 2: Diversification



STAGE 1: Initiation &
Stabilization



REGIONAL MORROWAN PALEOGEOGRAPHY

The mounds occurring in Chisum's Quarry are part of a band of carbonate buildups that trend north-northwest for at least five miles along the edge of the Morrowan shelf (Sutherland and Henry, in press). Features similar to the bioherms examined in the quarry occur within the Braggs Member of the Sausbee Formation in at least three other sections. However, only those from Sutherland and Henry's section 42 are comparable in size and development to those from the quarry. Unfortunately, this exposure is located immediately south of the spillway of Greenleaf Lake Dam and has been covered by water following the construction of the Arkansas River Navigation Canal. Therefore, comparison with mounds from the quarry must be based on samples and descriptions made by others prior to the completion of the canal.

Point counts of biotic components were made on slabs cut from the mounding unit at Greenleaf Lake Dam (appendix A, table 19). The biotic composition of the mounds is very similar to that observed within Chisum's Quarry mounds. The core is composed of over 50 percent micrite that probably represents sediments stabilized by blue-green algae, while the dasycladacean alga is next in abundance (15 %). Pelmatozoans, bivalves, brachiopods, bryozoans, and michelinid corals form the accessory organisms. Minor percentages of both Archaeolithophyllum species, rugose corals, gastropods, and foraminifera also occur in the core. Higher layers are dominated by 80 to 90 percent micrite with sponge spicules and Cuneiphycus alga. Shallowing conditions are indicated by ooliths and bird's-eye structures similar to those observed in the highest mounding interval in the quarry.

Small mound-like features were also observed at Sutherland and Henry's Betsy Lee Creek section 5b. These structures are approximately 1.5 to 2.0 feet high and are composed of bioturbated micritic boundstone similar to that observed in the third lobe of the large mound complex in the lower mounding interval (mound WB). Debris in the micrite includes pelmatozoan fragments, Archaeolithophyllum missouriensis, bivalves, brachiopods, ostracodes, michelinid corals coated with Archaeolithophyllum lamellosum and ooliths. Again, the presence of unabraded ooliths suggests deposition in very shallow water. However, these mounds do differ from the mounds in the quarry in exhibiting vertical growth only. Algal and bryozoan components do not wrap around a core, indicating that these mounds probably had little or no relief above the surrounding surface.

An irregular surface with small mound-like features was also observed by Sutherland and Henry in the type section of the Sausbee Formation near Webbers Falls Lock and Dam on the Arkansas River Navigation Canal. These mounds occur in stratigraphic position similar to the lower mounding interval in Chisum's Quarry. Local bryozoan mounds with algal boundstone cores occur in fossiliferous dark gray shale and are two to three feet in diameter.

The Morrowan bioherms formed along the edge of the carbonate platform in an area possibly somewhat protected by the presence of the Gore-Braggs Mountain High, approximately six miles east-northeast of the quarry in T. 13 N., R. 21 E. Even though this feature was being buried, it possibly had sbfficient relief to influence currents during Early Morrowan time. Shallow lagoonal and tidal flat deposition occurred to the east and large tidal channels locally deposited coarse pelmatozoan lime grainstones adjacent to the mounds in the quarry. To the west and south are open marine and geosynclinal deposits of the Arkoma Basin.

INTERPRETATION OF BIOHERMAL FORMATION

Wilson (1974) describes three recurring groups of carbonate buildups on carbonate shelf margins. These are down-slope lime mud accumulations, knoll reef ramps, and frame-built reef rims. The Morrowan bioherms should fall into one of these groups.

Downslope lime mud accumulations form linear trending bioclastic micrite or mounds accumulating on the foreslope with locally steep angles up to 30 degrees. Calcarenite beaches and islands are found upslope while sessile organisms accumulate downslope. Mounds may develop in depths from 2000 feet upward into the zone of wave action and grade into knoll reef ramps.

Knoll reef ramps form at the outer edge of the shelf margin on gentle slopes. The lack of strong waves or currents permitted flourishing sessile and massive encrusting forms to develop above a minor framework component of branching and fasciculate colonies. Thus, such mounds result largely from primary production with binding, trapping, and encrusting of local debris. Mud accumulates in voids within the reefs, while sand and coarser material accumulate around cores. The slope of the substrate is less than five degrees and tidal flats with lime sands commonly form behind the reefs.

The third type of carbonate body described by Wilson (1974) includes linear belts of organic reef frame that build up to sea level similar to modern barrier or fringing reefs. Such reefs are common in post-Paleozoic deposits and commonly exhibit vertical zonation on slopes that may reach 90 degrees.

The Morrowan bioherms appear to be most similar to the knoll ramp reef model of Wilson (1974). They possess low depositional slopes of three degrees or less and are dominated by encrusting and massive biota. The mound cores are comprised almost exclusively of stromatolitic blue-green algae, while other organisms occur higher in the bioherms. Although many of the mounds contain large amounts of carbonate mud, I feel that this should not prevent their classification as knoll reef ramps. The presence of mud within the mounds does not require their accumulation below wave base, as mud can easily accumulate within cavities and interstices in shallow water.

Comparison with Other Paleozoic Carbonate Deposits

Organic buildups of Precambrian and early Paleozoic age are primarily composed of stromatolitic blue-green algae in platform environments throughout most of the world. Sponges, stromatoporoids, bryozoans, tabulate corals, and pelmatozoan grainstone deposits are associated with these buildups beginning in the Ordovician Period. Also present for the first time in Middle Ordovician time were Stromatactis spar structures that may provide the earliest evidence of boring organisms like the sponges.

The Morrowan bioherms resemble early Paleozoic buildups in that they possess an algal core. In addition, vertical zonation similar to that in the Morrowan mounds has been described in the Middle Ordovician stromatoporoid, coral, algal, bryozoan boundstones of Tennessee by Alberstadt and others (1974). Stages described include stabilization, colonization, diversification, and domination of organisms.

Silurian and Devonian carbonate buildups illustrate the peak development of the stromatolite-stromatoporoid bioherms. Stromatolitic algae seem to develop in calm, shallow water with more diverse assemblages in rougher water (Lowenstam, 1950; Nicol, 1962). Devonian deposits are characterized by domination of colonial tetracorals over tabulates. The Middle and Upper Devonian reefs of western Alberta, Canada, include large fringing and barrier reef structures, as well as smaller pinnacle and patch reefs. These structures are composed of massive, encrusting, and branching stromatoporoids, Renalcis, blue-green algae, crustose red coralline algae, solenoporoid red algae, and tabulate corals with tetracorals (Fischbuch, 1968; Jamieson, 1971). Again, initiation and stabilization, diversification, and domination developmental stages are recognized and are similar to those observed in the Morrowan bioherms. However, many of the organisms belong to different genera. Algal types, bryozoans, molluscs, brachiopods, rugose and tabulate corals, and pelmatozoans all appear to have similar habitats. The major element missing from the Morrowan bioherms is the stromatoporoids. Similar carbonate buildups have also been described by Laporte (1963, 1967) with stromatolitic facies developed in the intertidal zone and a more diverse assemblage including the codiacean alga, Garwoodia, (also found in the Morrowan) in the subtidal facies.

Many forms of reef-dwelling corals and stromatoporoids apparently became extinct at the close of the Devonian Period. Most Mississippian reefs are Walsortian-type assemblages. The core is formed of massive calcilutite with Stromatactis structures and fronds of fenestellid bryozoans. Flanking deposits consist of pelmatozoan lime grainstones, while minor debris of pelmatozoans and other invertebrates is scattered through the core and collected in small pockets within the buildups (Heckel, 1974).

The large Permian carbonate buildups consist of diverse faunal elements usually dominated by hydrocoralline algae and bryozoans. Smaller scale features, much more comparable in size and development to the Morrowan bioherms have been described as mud bank associations or patch reefs in central and western Texas. Algae and bryozoans combine with productid brachiopods to form the framework of these smaller structures.

Comparison with Other Pennsylvanian Features

Although various compositional similarities appear between the Morrowan mounds and those from other periods, not surprisingly, these features resemble other Pennsylvanian structures much more in actual composition and development. Beginning in Early Pennsylvanian, phylloid algae including ancestral coralline crustose algae, such as Archaeolithophyllum, and green codiacean algae become major contributors to carbonate developments in western and central United States, Canada, and Russia. However, most of those described are from Middle and Upper Pennsylvanian strata.

Upper Pennsylvanian phylloid algal mounds in eastern Kansas have been extensively studied by Heckel (1974; 1972) and Heckel and Cocke (1969). These features range from a few miles to 60 miles long and 10 to 80 feet in height, again much larger features than the Morrowan bioherms. The Stanton Limestone includes two facies. The first is a mound core developed on a carbonate platform. The facies consists of lime mud and phylloid algae with scattered bryozoans and pelmatozoan debris. Large sponges occur locally. A skeletal calcarenite facies is associated with mounds. rimming and capping them. Local occurrences of laminar stromatoporoids are noted with abraded algal and pelmatozoan grainstones that probably developed in channels. The mounds occur as basinal calcilutite with shale partings and a fauna of fenestrate bryozoans, calcisponges, brachiopods, and pelmatozoans. Open marine conditions are indicated to the north while thin limestones and terrigenous clastics occur in the south. Wilson (1974) describes these structures as downslope lime mud accumulations, probably because of the 15 degree slopes found in biohermal deposits and lime mud composition of the core. However, he does state that the mud accumulations are transitional to knoll reef ramps with accessory organisms resembling those found in the Morrowan bioherms.

Middle Pennsylvanian (Desmoinesian) buildups in Texas, although much larger than the Morrowan mounds (100 to 1000 feet thick), appear to be similar in composition and distribution of biota to the Morrowan (Toomey and Winland, 1973). A blue-green algal core is surrounded by pelmatozoan lime grainstone with fragments of brachiopods and bryozoans found in front of and on top of the mounds.

The Scurry Reef is a horseshoe atoll-shaped feature in west Texas within Upper Pennsylvanian and Lower Permian strata. This is a large feature with 1550 feet of relief and a dip greater than 8 degrees and may be classified as a downslope mud accumulation by Wilson (1974). The core is composed of phylloid algae in micrite surrounded by a grainstone talus deposit of pelmatozoans, brachiopods, fenestrate bryozoans, rugose corals, fusulinids, and rare chaetetids. Other large buildups of similar composition and size have been described in the Canadian arctic and Russian Urals.

A number of small carbonate buildups lacking phylloid algae occur in southeastern Kansas and are several feet high, consisting of *Tubiphytes*, horn and tabulate corals. Other non-algal carbonate buildups include molluscan accumulations in east-central Kansas, serpulid worm accumulations in Europe, and chaetetid-tabulate bioherms in southeastern Kansas and Utah.

The Morrowan mounds are small, only 2.5 to 6.0 feet in height and 9.0 to 10.0 feet in diameter, accumulating on an almost level platform. Because of their small size, similar features may have been overlooked in investigations of carbonate buildups. Perhaps the small size of these mounds is also related to the relatively small percentage of phylloid algae present in the core of the Morrowan mounds. No other carbonate buildups of Early Pennsylvanian age appear to have been described, so it is not possible to test this hypothesis at this time. However, other Pennsylvanian accumulations lacking phylloid algae do appear to be relatively small. Therefore, study of these bioherms forms a significant transition between stromatolitic mounds of earlier Paleozoic periods and the phylloid algal mounds occurring later in the Pennsylvanian Period.

Comparison with Modern Reefs

In order to interpret the environment of deposition of ancient carbonate buildups, it is useful to examine modern carbonate developments. In addition to the problems discussed earlier, comparison of ancient bioherms with modern reefs presents some special problems for paleontologic interpretation. The scleractinian corals that form a significant portion of the framework of modern reefs are absent from Paleozoic bioherms, but the niches they occupy may have been inhabited by other elements. In fact, most of the biotic elements in modern reefs are represented, at best in the Morrowan bioherms, by organisms with similar functions and interpreted life habits. These do not take into account the large proportion of the reef biota that we could not expect to find preserved except under the most unusual circumstances. This includes organisms such as sponges and noncalcareous algae and bryozoans that make up the bulk of modern reef biota.

Other problems in direct comparison include scale and patchiness of distribution of biota in modern reefs. The area that must be examined in order to obtain a meaningful sample of organisms distributed within living reefs is commonly so large that it is difficult to compare with small features like the Morrowan bioherms, Structures that resemble the mounds most in size are individual coral heads. Algal cup reefs in the Virgin Islands and Bermuda are comparable in composition and development, but are found in clear water with high energy conditions that were unlikely in the Morrowan example because of the nature of the carbonate and argillaceous mud substrate (Shinn, 1971; Scoffin and Garrett, 1974; Adey and McIntyre, 1973).

By adding the dimension of time to tha ancient bioherms, we must also consider the problems of varying tectonic movement. Unfortunately, the effects of uplift and downwarp can only be indirectly inferred in living reefs. Further, all living reefs are, to some degree, affected by human interference that may be difficult to evaluate and separate from other factors prior to comparison with ancient carbonate buildups.

Thus, although no precise analog to the Morrowan bioherms may be found in living reefs, it is possible to make some inferences that could apply to ancient carbonate buildups.

Investigation of Modern Reef Communities

Reefs in the inner and outer reef tracts of the Florida Keys and Jamaica were examined in a variety of environments (appendix B). Generally these organisms are zoned by depth or light penetration with varying effects by individual adaptations to conditions such as high edimentation, varying salinity, or turbulence.

Because many carbonate buildups are developed on a carbonate mud substrate, zonation was examined in a patch reef within Discovery Bay, Jamaica, where carbonate mud forms the bottom (appendix B, text figure 40). Within the lagoon, zonation is the product of sediment and light penetration in addition to depth and topography acted upon by currents and salinity. Sediments limit the forms present and reduce light penetration, so that the six biotic zones recognized were characterized by biota characteristic of much deeper water on the forereef.

Depth must also have exerted some effect on the development of the Morrowan bioherms. The algae, abundant in the mounds, are photosynthetic and thus, cannot be separated from their dependence on light. As noted, the blue-green stromatolitic algae are generally confined to depths of less than 30 feet in the clearest ocean water. In a carbonate mud environment, such as that found in the Morrowan bioherms, light penetration is much reduced and stromatolitic algae may have been confined to the upper 5 to 10 feet. Thus, it seems reasonable to speculate that the bioherms were initiated on shallow areas of the Morrowan platform, perhaps on areas of slight mud buildup or current shadows of a feature such as the Gore-Braggs Mountain High. There is no basis to assume that the rugose and tabulate corals of the Morrowan were hermatypic as are many modern scleractinian corals. In fact, the occurrence of *Lophotichium* and *Michelinia* within cavities and restricted voids in the bioherms would suggest that these organisms were *not* light dependent. Rather, they seem to occur in areas of the bioherms where they are protected from heavy sedimentation and turbulence on a stable substrate.

Cavities and Cryptic Biota in Modern Reefs

Modern reefs have been subjected to a generallized tripartate division into framework organisms, "cementing" organisms, and sediments (Ginsburg and Lowenstam, 1958). Most studies have dealt primarily with the first division — framework, treating other elements as merely accessory factors. Up to 50 percent of the reef, however, consists of cement and internal sediments that fill cavities and voids (Shinn, 1971). As geologists, we are too likely to visualize a reef as a solid mass of organisms. The typical modern reef framework consists of irregular masses of hermatypic coral and coralline algae overgrown and encrusted by hydrozoans, more coralline algae, bryozoans, and sponges. Void spaces resulting from this nonuniform development are termed growth cavities. Other cavities result from internal body spaces or skeletal voids, deterioration of organic material, and action of boring or burrowing organisms,

The significance of rock boring organisms in reefs was the subject of one of the early Great Barrier Reef reports (Otter, 1937; Yonge, 1963). In that investigation, Otter related life habits to morphology of organisms. He described many of the skeletal and muscular modifications as well as development of chemical secretions to enable boring within the cryptic biota. Boring serves in many instances, not only as a means of protection from predation and environmental parameters, but also as a source of food and living space.

During June 1972, cavities and the organisms associated with them (coelobites) were examined at five localities near Miami, Florida. Samples were collected at depths ranging from intertidal to 12 meters deep in the sublittoral zone. Lithic and coral material was broken and examined under binocular microscope. A complete description of these samples is found in appendix B.

These preliminary observations were supplemented with detailed investigation of cavities and coelobites in deeper reefs in the Florida Keys during May 1973. Much time was spent examining and photographing areas within Pennekamp Coral Reef Park while samples were collected in areas to the north and south of the park. Areas outside the park seem to have much less vigorous scleractinian coral growth. Whether this is the result of extensive removal of organisms in unprotected areas as has been suggested by several individuals, or whether this area was in fact more favorable prior to the location of the park, I do not know. However, I suspect that high sedimentation observed in areas outside the park may be a factor. The samples were collected from depths of 8 and 17 meters and are described in appendix B.

Finally, observations of living coral reefs in Jamaica were made during July and August 1974. Although few samples were collected, visual notes add to evaluation of the cavity environment.

Discussion

Cavities have been observed in substrates of varying composition. Granite blocks are one of the most unfavorable lithic substances, and only red and green filamentous algae are capable of growth on this resistant material. Also, sand and shifting sediments are unsuitable for habitation until they are stabilized by grass or blue-green algae, although burrowing can occur in some of the more consolidated sediments. Dead or dying coral forms one of the best materials for development of boring or encrusting organisms. However, living corals are generally one of the least favorable sites, perhaps because of toxic reaction to mesenterial filaments or nematocysts. At depths, however, a varied biotic assemblage develops under ledges or plates of shingle-shaped corals such as <u>Agaricia</u> or <u>Montastrea</u>. Sponges crinoids, ahermatypic corals, and cheilostome and cyclostome bryozoans attach themselves to the lower sides of such "shingles." In this position, these organisms exist in a protected environment above the sediment floor of sand and mud. In addition, calcareous rocks or biolithites form excellent substrates as long as they remain stable and do not shift about. In fact, irregular rocks within the intertidal zone shelter one of the most diverse cavity faunas observed. In the intertidal zone, such interspaces not only increase the substrate available for colonization, but also provide a new habitat within the environment. Cavities form areas that provide shelter from the force of waves and evaporation of moisture during low tides — a darker, yet less variable niche, that can support a unique biota. In general, cavities in the reef seem to permit deeper water organisms to inhabit shallower depths in shade and protection.

Large reef cavities have been classified by Garrett (1969) according to position, size, shape, and illumination. These do not include body cavities and borings that are also considered in this investigation. The first group includes "open" cavities between framework elements with about 5 to 50 percent of the surface illumination (plate XX , figure 1). The second group consists of dimly lit or "gloomy" cavities (plate XX , figure 2) at the base of coral knobs, while cavities within the reef face are classified as "gloomy" or dark (plate XX , figure 3). Each area is inhabited by a characteristic biota.

Open cavities have a biota similar to many of the open regions of the reef. The dominant element here, as in any coral rubble area, is red algae (50 to 90 percent surface coverage). Several genera of coralline red algae were identified in Jamaica, including Neogoniolithon, Leptolithon, Hydrolithon, and Porolithon, and Lithothamnion. Galaxaura is a common red filamentous alga on the coralline surfaces with the green alga, Cladophora, comprising a maximum of 40 percent of the coverage (W. Adey, 1974, personal communication). Other common elements include a variety of desmosponges dominated by encrusting and tubular forms (5 to 15 percent). Less abundant elements of the open cavity system include other algae, the encrusting foraminifera,Homotrema rubrum, branching and encrusting ectoproct bryozoans, Agaricia fragilis, antipatherians, encrusting species of Millepora, and crinoids. Initial encrustation may be accompanied by boring of clionid sponges, endolithic red and green algae, polychaete worms, bivalves such as Lithophaga nigra and Spengleria rostrata and grazing by sea urchins including Diadema antillarium and fish, notably the genus Sparisoma, the parrot fish.

Gloomy or dimly lit cavities at the base of coral knobs or on the reef face are commonly covered by nearly 100 percent red crustose coralline algae. Desmosponges and ectoproct bryozoans are other important elements. Homotrema rubrum, serpulid worms, ahermatypic corals, Agaricia *fragilis*, crinoids, and antipatherians were commonly noted in Jamaica. In Bermuda, several investigators (Garrett, 1969; Garrett and others, 1971; Ginsburg and Schroeder, 1969; and Scoffin, 1972) have noted several right valves of the bivalves *Spondylus americanus*, *Pseudochama* sp., and *Chama macerophylla*, though no living bivalves were found. I observed only a few of these right molluscan valves in my study of cavities in Florida and Jamaica; however, several living individuals of *Spondylus* were noted in a carbonate mud environment of the lagoonal patch reef studied in Jamaica. These individuals were not living in a protected habitat, but were in an area of decreased light intensity resulting from suspended carbonate mud. It should again be noted that conditions similar in many respects to cavities may be found in areas of low illumination due to light filtration or depth. Thus, biotic assemblages characteristic of deeper waters, caves and cavities, and murky water or low illumination environments may be quite similar.

The darkest growth cavities observed lack algal inhabitants and are dominated by bryozoans, ahermatypic corals, desmosponges, and sclerosponges with small percentages of encrusting foraminifera and serpulid worms. Detailed studies of light effects on settlement and zonation of cryptic biotas in artificial cavities are now being conducted by Jeromy B.C. Jackson of Johns Hopkins University at Discovery Bay Marine Laboratory in Jamaica. These investigations indicate that light, water flow, and size and shape of the "cavity" affect the zonation and succession of organisms over a period of time. During the first six months of the study, bivalves and serpulids dominated the environment; however, colonial organisms such as sponges and bryozoans expanded after that time, and began encrusting each other (Jackson and others, 1971).

The remainder of the cavities studied by me may be classified as body cavities or skeletal interspaces and those resulting from boring activity.

Julia A.E.B. Hubbard (1972) examined the micro-environmental communities developed within living scleractinian coral skeletons. She noted that areas not covered by living polyps are equally as subject to boring and encrustation as is any other calcareous material. The earliest inhabitants of the micro-environments must be those that can tolerate low pH conditions resulting from decay of organic material. These include encrusting serpulid worms and red algae. This pattern is similar to that noted within larger cavities.

Particular interest was directed to cavities resulting from the activity of boring organisms, since it is possible for such void spaces to be preserved and recognized in lithified material. At least three different types of cavity could be recognized by the type of organism that created the boring. Perhaps the most common cavities by volume and number are those created by the boring sponges. Neumann (1966) estimates that approximately 20 kilograms of carbonate material per year is excavated from the reefs by the chemical "chipping" activity of these sponges. The characteristically "chipped" sediments are common in the silt-size fraction of reef material (Futterer, 1974; Rutzler and Rieger, 1973). Borings attributed to clionid sponges may be recognized easily in Miocene reef material (plate XIV, figure 4).

Polychaete worms also create characteristically shaped borings that are readily recognized. In fact, such worms are generally the only faunal element observed in samples collected from one meter below the reef rock surface.

Bivalved molluscs are the third major element boring into reef biolithites. _Lithophaga_ sp. and _Spengleria_ are particularly abundant in samples taken from the outer 1/3 meter of the reef surface in Florida. Several irregular void spaces could not be associated with any particular biotic element, and these may be the result of multiple factors and organisms.

Coelobite Community Succession

From the cavities observed (appendix B), some general statements may be made concerning the development of coelobite communities.

1. Red and green filamentous algae encrust the surface of rocks in all zones of the reef. Cavities may be created by bivalves,

sponges, and boring worms and may be enlarged by grazing or rasping by organisms such as sea urchins or gastropods.

2. Serpulid worms inhabit vacated borings, while enlargement of cavities in the intertidal zone is largely mechanical, the result of higher wave energy and transport of sediments than found in deeper areas. Limited development of filter feeding organisms in the shallower environments may also reflect this increase in sediment load.
3. Red algae commonly encrust the reef surfaces and cavities to the depth of light penetration. Bryozoans are found in deeper parts of the cavities.
4. Clionid sponges invade pre-existing cavities as well as boring their own cavities. Areas of red algal encrustation that are covered by sponges die, perhaps from lack of light.
5. The surface of encrusting red algae is covered by a variable biota including encrusting foraminifera, desmosponges, other algae, bryozoans, and worm tubes.
6. The coelomic cavity of sponges also provides a soft cavity that is often inhabited by brittel stars (Ophiothrix) and polychaete worms. Although such "soft" cavities would not be expected to be preserved within the biolithite, sediments that accumulate within the openings commonly are preserved.
7. Many of the above stages do not occur within a single rock or coral, but some of the substrates demonstrate repetition of cycles such as alternation of red and green calcareous algae with encrusting bryozoans.

Variation in depth and energy of environments as well as communities within an environment allow some preliminary interpretation of development of cavities and coelobite assemblages. Encrusting of rock surfaces by filamentous red and green algae occurs relatively early. However, in order for a coelobite community to form, a cavity must exist. Those cavities observed in modern reefs seem to be generally initiated by boring bivalves, worms, and sponges. Depending on the energy of the zone, enlargement of the cavity may occur by physical as well as biological processes with or without habitation by organisms. Development of encrusting or cryptic biotas thus, depends on the interplay of several factors.

Cavity Sediments

Several of the cavities observed were partially or completely filled with sediments. Generally, some sediments were found in cavities that opened to the surface of the substrate. Only large open cavities and those with a steep floor lacked sediments near the surface of the substrate.

Fine mud usually lines the cavities and the interiors are filled by poorly sorted clastics that become finer grained toward the top of the cavity. The fine-grained initial lining may have originated through filter feeding of the original inhabitants or subsequent decay of the coelobites after death. Coarser material consists primarily of debris that could be dumped into cavities by the physical action of currents and boring organisms. Fine sediments entrapped by red algae, such as *Galaxaura* and mud carried into cavities in suspension may help explain the presence of the finer fraction. Most sediment-filled cavities generally occur near the surface of the substrate; however, several sediment-filled cavities do occur scattered throughout the biolithite.

Submarine Cement

Microcrystalline magnesium calcite and aragonitic cement is widespread in the Jamaican reefs, particularly in the reef crest and forereef framework and interreef sediments (Land and Goreau, 1970). This cementation appears to take place immediately below the reef-water interface and extends to depths in excess of 200 meters (Moore, 1975, personal communication). Several of the samples examined in Florida show evidence of initial excavation by bivalves or clionid sponges, sediment fill and submarine cementation, followed by reboring by the same or other organisms. In this manner, once the framework elements of a reef have died, it is possible to fill void spaces with sediment that may be lithified and bored and encrusted with the framework in such a manner that all semblance of the original texture may be lost.

Recognition of Marine Cavities as Compared to Those of Subaerial Origin

What distinguishes a marine cavity from one that is formed subaerially? This question, like the debate over marine versus subaerial formation of caves, has no simple answer. In Florida, I examined relatively large (up to several centimeters in diameter), subaerially-formed cavities in the Key Largo Limestone at Harry Harris Park near Tavernier. From that study, a series of observations are compiled that may not be indicative of large subaerial cavity formation when considered singlely, but combined with other factors might indicate that the cavities being observed may not have been occupied by marine organisms.

1. A dark brown to black weathering rind or crust forms on the surface of the subaerially exposed limestone, perhaps resulting from organic decay and secondary mineralization. This crust is darker than the crusts found in the intertidal zone and lacks the color sequence of black, yellow and gray described in the intertidal zone by Stephanson and Stephanson (1957) and Multer and Hoffmeister (1968).
2. Surfaces and edges are even and smooth as in many marine cavities. However, well-rounded fragments of Key Largo Pleistocene Limestone are associated with recent beach sands in the cavities.
3. A significant criterion is the presence of land fauna mixed with open marine organisms. The fauna includes the false limpet (_Siphonaria_), chiton (_Acanthopleura_), and gastropods (_Nerita_, _Phragmatopoma_, and _Batillaria_).
4. The size and shape of subaerially formed cavities are similar to those formed in the marine environment. They may be connected by more tunnels than normally observed in marine cavities, but this is variable. Potholes on the upper surfaces of the Key Largo

Limestone are abundant and similar features have not yet been noted in marine substrates. Often tops of Pleistocene corals, such as Diplora sp., are weathered with differential relief that corresponds to walls between corallites. Although differential erosion occurs within the marine environment, thus far none has appeared to be as pronounced as the sharp ridges developing on the Key Largo surface. This may be the result of encrustation in the former environment by bryozoans and algae.

5. Cavities in the subaerial environment at Harry Harris Park tend to form levels controlled by the depth of brackish water pools. This would not be expected under normal marine cavity development. Further, the bottoms of such cavities and tunnels are generally fairly flat as contrasted to those of the marine substrate.
6. Some characteristics should not be relied upon. The subaerial cavities commonly show sediments and broken pieces of coral from the marine environment located adjacent to the exposures. Although solution collapse breccias seem to be more characteristic of the Key Largo Limestone, they could also form under certain conditions in the marine environment during burial.

It is also necessary to consider the origin of smaller cavities that might be borings or skeletal voids of marine organisms. Vadose or subaerial cavities commonly contain crystal silt (Dunham, 1969) that may superficially resemble marine sediments. However, Dunham distinguishes these voids as containing silt of uniform texture, lacking both sand-sized material and clay-sized lime muds as well as skeletal material. In addition, the wall of vadose cavities is generally smooth, a marked contrast to the "sculptured" appearance of sponge borings (Moore, 1975, personal communication).

Cavities in Pennsylvanian Bioherms

Both large and small cavities have been observed in the Morrowan bioherms of northeastern Oklahoma. The larger features are formed by irregular biohermal growth and are commonly filled by shale deposited either during or after mound development (plate II,figure 2). Although such features are more pronounced in the complex mounding developments, they are observed in every mound studied.

Many of the large cavities were apparently fairly open, as in the growth cavities described by Garrett (1969). The most obvious open cavities are areas located adjacent to and between individual bioherms or lobes of bioherms. The biohermal walls of the cavities are generally encrusted by a dense development of encrusting bryozoans on a stromatolitic algal "framework." Shales within the cavities may include merely debris of such organisms as blastoids, crinoids, bryozoans, and brachiopods, or they may contain a more characteristic fuana of arborescent and fenestrate bryozoans. In the first instance, sediments probably prevented the development of a true cryptic fauna as the walls seldom show any evidence for actively growing surfaces. Open cavities are generally relatively large features from four inches high to several feet, depending on the height of surrounding bioherms (plate II, figure 2).

Other large shale-filled cavities occur within the bioherms. The "roll" structure in many of the mounds forms a central cavity that is slightly more restricted than areas between mounds (plate III, figure 2). These cavities are "roofed" and thus, probably represent an environment similar to the "gloomy" cavities within the reef and under the basal coral knobs in Bermuda (Garrett, 1969). The walls and ceiling of the cavity are encrusted by bryozoans over the algal framework of the mound core. The floor and lower part of the walls are frequently lined by michelinid and rugose corals growing outward into the cavity. A minor amount of debris is commonly found in the shale that generally fills these cavities. The skeletal material includes scattered pelmatozoan fragments, disarticulated brachiopods, and bryozoan fragments. Of the cavities in this class, a few are more restricted and inhabited only by encrusting bryozoans without coral inhabitants. Most of the interior or central cavities range from several inches to a foot in length and are several inches high (plate II, figure 1).

Several small, irregular cavities and borings are also observed within the Morrowan bioherms. In fact, these features seem to comprise up to 50 percent of the biohermal mass. The smaller cavities fall into three general categories: 1) borings, 2) shelter voids or cavities formed by irregular encrustation or imbricate pattern of large skeletal fragments, and 3) internal skeletal voids. In addition, a number of small void spaces were formed by dessication or gas formation from organic decay.

Borings are perhaps the most variable of biohermal cavities. They range in size from 50 mm to less than 1 mm in diameter. In many cases, the origin of the borings is unknown, but a few may be attributed to specific organisms. One example is a large boring (7.62 cm long) of a siphonate bivalve. Although the original skeletal material is no longer present, the outline of the bivalve and its siphon are clearly defined. Many of the irregular borings (plate XII, figures 1-6; plate XIII, figure 4; plate XIV, figure 2) resemble clionid sponge borings with serrated cavity walls. These borings occur scattered throughout the mounds, but are particularly abundant adjacent to the large interval cavities and outer surfaces of the mound layers where cavities comprise over 50 percent of the biohermal mass. In addition, sediments within some of these borings contain sediments that have been identified as characteristic sponge "chips" (Moore, 1975, personal communication).

A few of the larger borings have been inhabited by encrusting bryozoans, but many of the smaller borings appear to have been uninhabited after they were vacated. Whether encrusted or not, the larger cavities are frequently lined with a fine layer of mud and filled by coarse, unsorted sediments in the lower part of the cavity. The upper part of the void is then filled with finer material forming geopetal structures. Then fine mud may fill the cavity or leave a space at the top, now partially or completely filled with spar (plate XIV, figure 2).

Smaller borings are frequently filled with micrite or left unfilled, particularly if deep within the interior of the bioherm. Those cavities that were apparently open during mound growth are commonly lined by microcrystalline spar — possibly submarine cement (Land, 1974, personal communication), and are generally partially or completely filled with spar that is probably the result of secondary cementation during diagenesis.

Voids resulting from irregular encrustation by algae and bryozoans and sheltered areas under large skeletal grains are particularly common in the outer mound layers and within walls and ceilings of large internal cavities. These are generally a few millimeters in diameter and are filled with micrite or spar (plate X, figure 5).

Skeletal voids are fairly common. Perhaps the most obvious biotic internal cavities are those of brachiopods that are commonly filled with fine sediments and micrite exhibiting graded bedding and overlain bu spar. Again, the spar probably represents cement cavity fill (plate X, figure 3). Michelinid corals, bryozoans, rugose corals, and blastoid calyxes are all commonly filled partially or completely with micrite and spar (plate X, figures 2-4).

Finally, particularly in the outer layers of mounds in the upper mounding interval, there is evidence of dessication cracks that are filled by oolith sediments and spar (plate XII, figures 3 and 4; plate XIV, figure 3), as well as bird's-eye structures. Bird's-eye structures apparently result from the escape of gas produced by decaying organic matter. These small features, commonly a millimeter or less in diameter, complete the variety of cavities in the Morrowan bioherms.

SUMMARY AND CONCLUSIONS

Examination of the small bioherms developed within two intervals of the Lower Pennsylvanian (Morrow) Sausbee Formation in northeastern Oklahoma led to the recognition of several features of mound development, biotic distribution, and association of different trophic groups.

1. Mound development: In order for mound growth to occur, it is first necessary to stabilize the carbonate mud substrate by growth of blue-green algae, followed by encrusting bryozoans and/or coralline red algae. The phase of diversification then begins, in which a variety of organisms begin to inhabit the bioherm. These include other bryozoans, corals, brachiopods, pelmatozoans, trilobites, molluscs, and others. During this phase, cyclic development of blue-green and red calcareous algae occurs, perhaps corresponding to seasonal or periodic growth. The final phase of mound growth is domination by a single group of organisms. In the upper mounding interval, this group is again the blue-green algae that favored the shallowing conditions that would eventually terminate mound growth. However, in the lower interval, bryozoans became successful in deeper waters until the influx of clastic material overwhelms the biohermal association.

2. Biotic distribution: Many of the individual biotic components exhibit pronounced distributional patterns. Crustose coralline red algae appear to prefer higher energy conditions at or near wave base and are most abundant at or near the mound tops and sides. Bryozoans are habitat specific according to growth form groups. The encrusting forms are common on the tops and sides of mounds as well as under overhangs and on cavity ceilings, while fenestrate bryozoans prefer protected, agitated water in posckets and cavities near lime grainstone channel deposits. Arborescent bryozoans are particularly common in shales away from the mounds in the more restricted areas to the north (in the lower mounding

interval, station 1). Both rugose and tabulate corals prefer stable areas toward the middle of the tops of layers within the mounds and on the floors and sides of cavities. They often appear to provide a substrate for encrusting bryozoans and red algae. Gastropods are associated with blue-green and red algae, while each taxon of brachiopod appears to have its own distributional preferences. Composita and Hustedia are very common in intermound shale pockets and on tops of mound lobes. Pelmatozoans are invariably disarticulated and are distributed as current accumulations within the mounds. A number of other organisms are merely associated with the mounds including goniatite cepahlopods, pelecypods, trilobites, and others.

3. Biotic associations: Three characteristic, repetitive associations are found within the mounds as recognized by modified factor analysis of abundance. These include associations of pelmatozoans and spiriferid, Composita, and Hustedia brachiopods that accumulate on small topographic highs on individual mound layers, perhaps because of hydrodynamic properties. Fenestrate and arborescent bryozoans and goniatite cephalopods occur in lower areas on the individual mound layers, while an association of rugose and tabulate corals and encrusting bryozoans occurs in cavities within the mounds.

4. Cavities and cryptic biota: Up to 50 percent of the volume of living reefs consists of cavities and irregular surfaces, and that amount may increase after death of the reef so that the original framework may be completely obliterated. In addition, these factors increase the area available for colonization in a protected (from evaporation in shallow areas and from water turbulence in both shallow and deeper areas) environment with low light penetration. Hence, the cryptic biota is commonly an association normally found in much deeper water. Development of this association depends on a stable substrate that is easily bored. In modern environments, a succession of coelobite (cavity-dwelling) organisms has been observed, beginning with stabilizing red and green filamentous algae and followed by a variety of worms, crustose coralline red algae (in light areas), bryozoans, sponges, benthic foraminifera, and

opportunistic vagrant benthos. Cavities have been classified according to size, morphology, and position within living reefs. Open interreef areas, gloomy reef face cavities, and dark coral knob basal cavities are all relatively large. Smaller cavities include borings by organisms such as molluscs, worms, and sponges, as well as voids or spaces within the skeleton or body cavities of individual biotic elements. All types of cavities have been recognized in the Morrowan bioherms. While larger scale features may have been inhabited by a variety of organisms, smaller cavities are generally inhabited by bryozoans, although desmosponges may have been a significant, but not preserved, component. Boring sponges are now recognized as early as the Morrowan by the presence of characteristic borings and silt-sized chips.

5. Trophic analysis: Several different trophic groups are represented in the Morrowan bioherms. Division into high and low filter feeders, as well as other groups helps explain the nature and distribution of biotic associations.

6. Comparison with other geologic occurrences: As far as is known, no other Morrowan bioherms have been described in the geologic literature. The mounds appear to be similar in development and structure to many of the early Paleozoic bioherms, particularly of the Ordovician and Devonian. However, the faunal elements, as would be expected, are more similar to those of the later Pennsylvanian reefs. Other described Pennsylvanian occurrences, in contrast, are much larger accumulations with abundant phylloid algae. Thus, the Morrowan bioherms are a significant transition between the Lower Paleozoic stromatolitic developments and later Pennsylvanian phylloid algal banks.

7. Comparison with modern reefs: Examination of living reefs enables recognition of controlling factors that may have exerted an influence on the Morrowan biohermal associations. Depth, light penetration, and sedimentation effect the distribution and zonation of organisms in both modern and ancient reef-like accumulations. Further, in a manner similar to that used for modern reefs, the biota of the Morrowan bioherms may be divided into

framework organisms, encrusting and cementing organisms, and sediment contributors. A fourth group of bioherm destroyers is suggested to include the boring and burrowing organisms.

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THIN SECTIONS

PLATE VIII

figure 1: M97-6D, vertical fractures cutting skeletal *Archaeolithophyllum* lime boundstone, foraminifera and spines, X3.5.

figure 2: M97-6a, skeletal *Archaeolithophyllum* boundstone to lime wackestone, one foot above base of 97-6, X3.5.

figure 3: M97-6b, *Archaeolithophyllum* boundstone to lime wackestone, two feet above base of 97-6, finer grained than 6a, X3.5.

figure 4: M97-6D, skeletal *Archaeolithophyllum* boundstone with extensive compaction, X3.5.

figure 5: M97-6F, recrystallized *Archaeolithophyllum* boundstone to lime packstone, both *A. lamellosum* and *A. missouriensis*, some stylitization, X3.5.

figure 6: M97-6b, skeletal *Archaeolithophyllum* boundstone to lime wackestone, large vertical fractures with some borings, ooliths, anb dolomitic rhombs, X3.5.

PLATE IX

figure 1: M97-6, *Garwoodia* lime grainstone, intraclasts of *Garwoodia*, *Archaeolithophyllum missouriensis* and *Michelinia* in a recrystallized dolomitic matrix, X3.5.

figure 2: M97-8a, nodule 2.5 feet above the base of unit 97-8. Recrystallized dolomitic skeletal (pelmatozoan-spicule) lime mudstone, replacement of clasts to spar in a pelleted micritic matrix, X3.5.

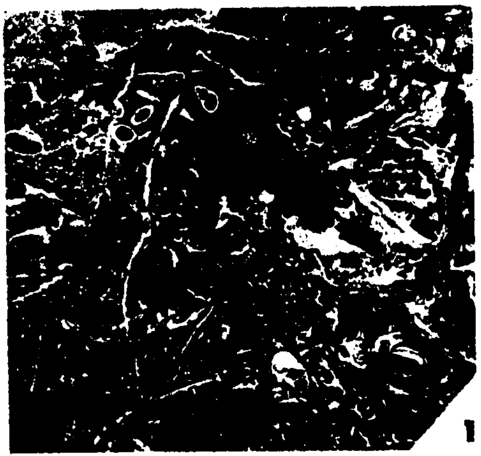
figure 3: M97-8 AE, Recrystallized pelmatozoan-dasyclad like packstone, moderately well-sorted, recrystallized grains of pelmatozoans and dasycladacean algae. Pelmatozoan material is silicified, X3.5.

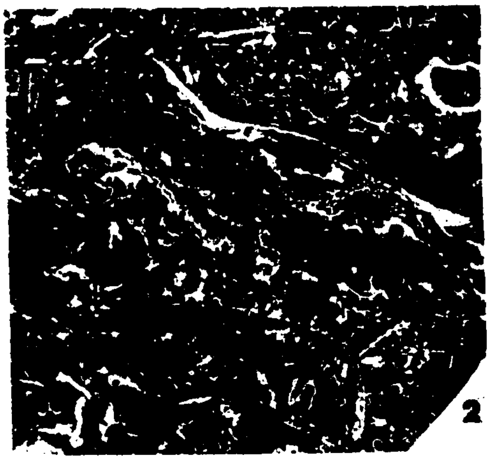
figure 4: M97-8 XB-7, skeletal (bryozoan, brachiopod, pelmatozoan) lime wackestone to mudstone with large, irregular micritic clast, X3.5.

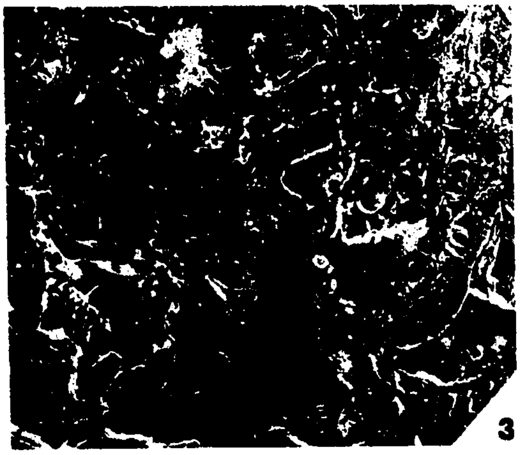
figure 5: M97-8 AG, recrystallized dasyclad-pelmatozoan lime packstone with rugose corals and bivalve and brachiopod clasts, X1.75.

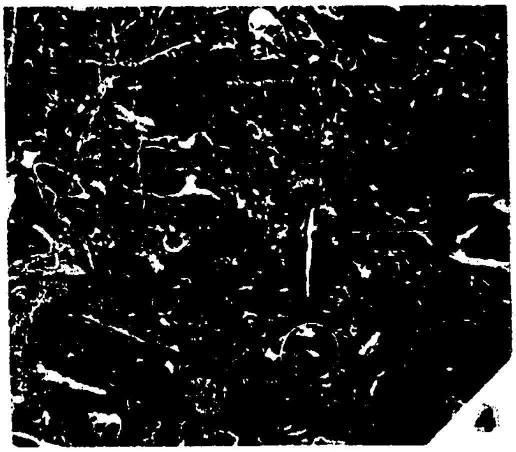
figure 6: M97-8 EA, stromatolitic (*Ottonosia*) boundstone with fine pelmatozoan and brachiopod debris, ooliths, quartz silt, X1.75.

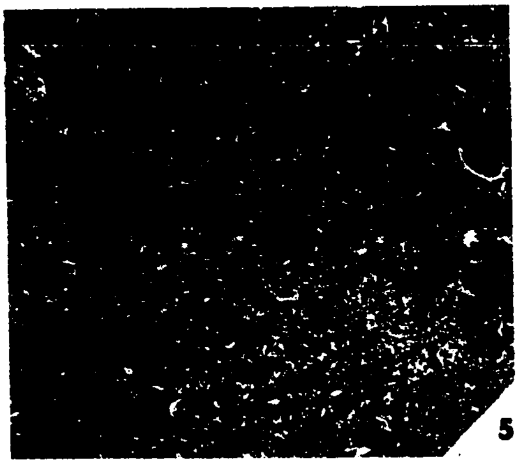
PLATE VIII

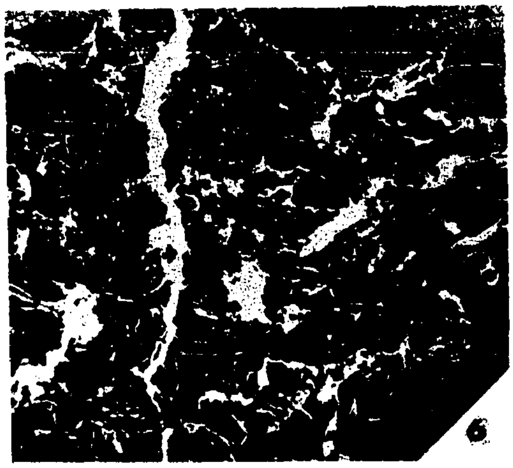












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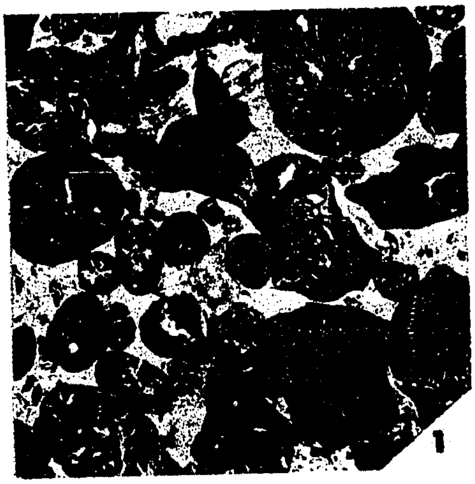

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PLATE X

figure 1: M97-8Dc, stromatolitic (*Ottonosia*) boundstone, numerous sponge borings with fine sediment fill, X3.5.

figure 2: M97-8Db, *Archaeolithophyllum* boundstone surrounding tabulate coral (*Michelinia*), closer to core than figure 1, X3.5.

figure 3: M97-8Da, skeletal (*Archaeolithophyllum*-*Michelinia*-brachiopod) lime wackestone to boundstone, *Archaeolithophyllum* surrounding tabulate corals with brachiopods showing geopetal cavity filling, X3.5.

figure 4: M97-8Ba, *Archaeolithophyllum*-bryozoan boundstone, with algal coated rugose corals (*Lophotichium*), and large cavities filled with spar, X3.5.

figure 5: M97-8, XB-7, skeletal limewackestone to packstone showing shelter cavity structures filled with micrite and spar, X3.5.

figure 6: M97-8 EB, skeletal (pelmatozoan-dasyclad-goniatite) lime mudstone, sponge borings with fine sediment fill and spar, X3.5.

PLATE XI

figure 1: M97-9d, brachiopod-goniatite skeletal lime wackestone, showing sections of goniatites that form skeletal voids, filled with fine sediments and spar, X3.5.

figure 2: M97-8 YB-18, skeletal (brachiopod,bryozoan, *Archaeolithophyllum*) lime mudstone and sponge borings and skeletal cavities, X3.5.

figure 3: M97-8 YB-18, as above showing recrystallized clasts and spines, X3.5.

figure 4: M97-8 YB-38, pelmatozoan lime mudstone with silicified pelmatozoan fragments, *Garwoodia* alga (just above center), micro-spar lined voids, X3.5.

PLATE X

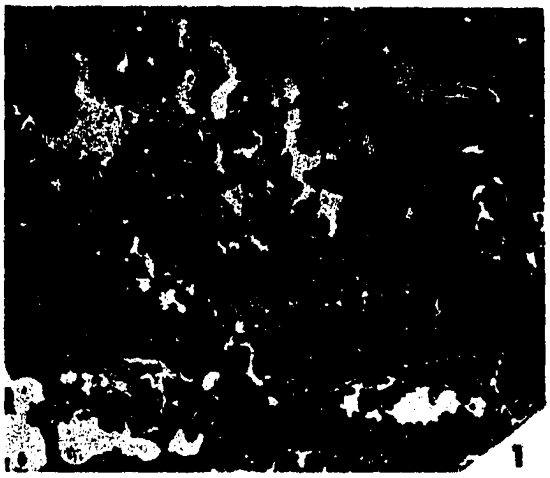
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PLATE XI


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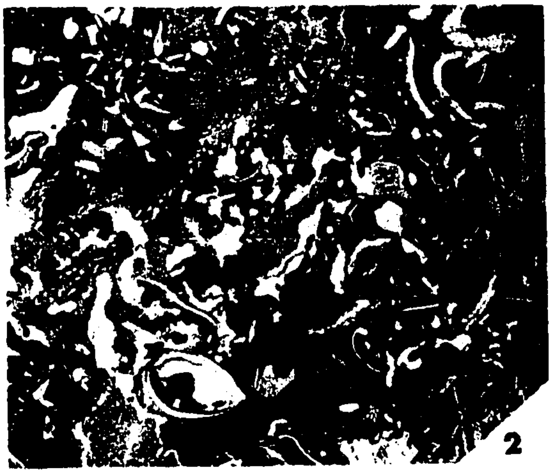
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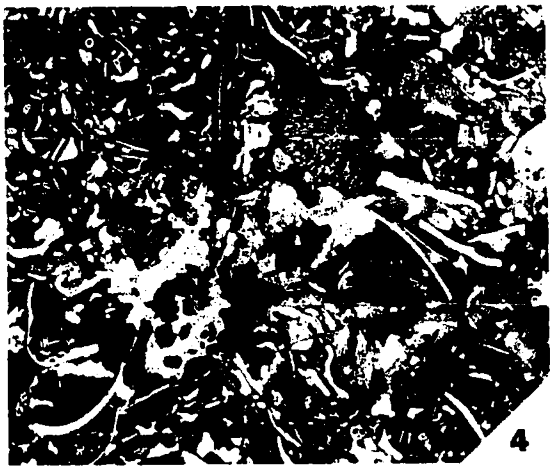
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PLATE XII

figure 1: M97-8 YB-3, *Ottonosia* boundstone with minor sponge borings, X3.5.

figure 2: M97-8 YB-13, *Ottonosia* boundstone with fine to medium-grained pelmatozoan, brachiopod, and bryozoan debris, larger sponge borings filled with spar and micro-spar, X3.5.

figures 3, 4: M97-8 YB-2, upper layer of mound, showing fractures or dessication cracks in algal boundstone, filled with fine debris and ooliths, with minor pyrite, X3.5.

figures 5, 6: M97-8 YB-22, mound core, similar to outer crust, bioturbated *Ottonosia* boundstone with sponge borings partially filled with dolomitic silitstone, X3.5.

PLATE XIII

figures 1, 2: M97-8 ZB-4, bryozoan-*Archaeolithophyllum* boundstone with sponge borings filled with spar and micro-spar and coated grains, X3.5.

figures 3, 4: M97-8 ZB-3, *Ottonosia*-*Girvanella* boundstone, extensive sponge borings filled with spar and lined by micro-spar, ooliths, anhydrite pseudomorphs, X3.5.

PLATE XIV

figure 1: M97-8 YB-17, *Ottonosia*-*Archaeolithophyllum* boundstone with *Michelinia* and illustrating trap for sediments formed by brachiopod, X1.75.

figure 2: M97-8 YB-38, *Ottonosia* boundstone with lage sponge boring filled with micro-spar and spar, X3.5.

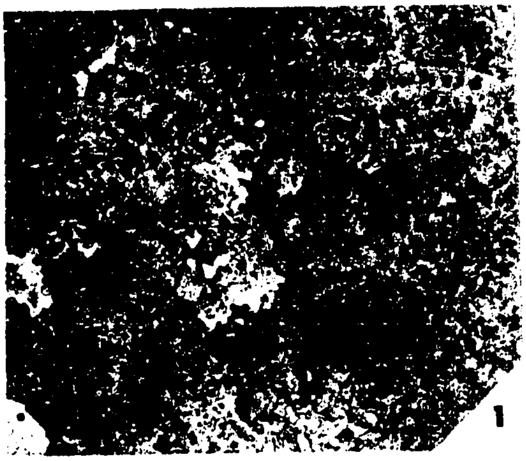
figure 3: M97-8 AG, recrystallized *Ottonosia* boundstone showing dessication fractures and pyrite accumulating along the algal crusts, X1.75.

figure 4: M97-8 ZB-14, bryozoan-*Archaeolithophyllum*-*Ottonosia* boundstone showing succession of algal and bryozoan types with bryozoans at core, then alternation of red and blue-green algae, X1.75.

figure 5: M97-8a-North Quarry, recrystallized goniatite lime wackestone with skeletal voids and shelter structures providing porosity, X1.75.

figure 6: M97-8 YB-19, bryozoan-*Archaeolithophyllum* boundstone just above core of mound with *Ottonosia* boundstone, fractures, and sponge borings, X1.75.

PLATE XII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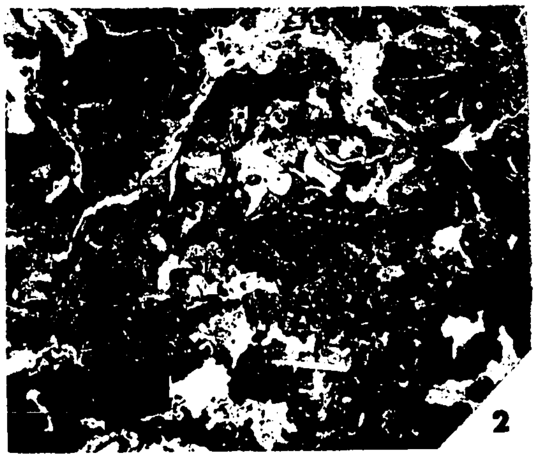
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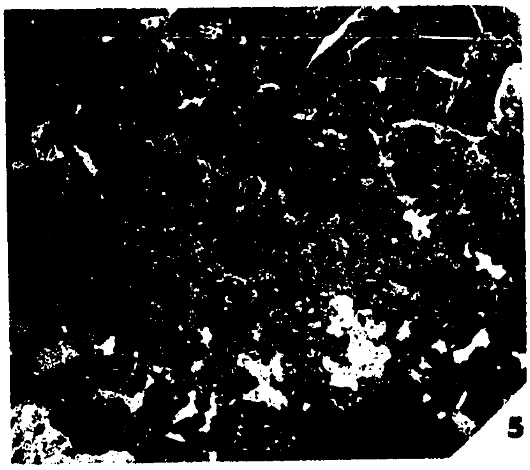
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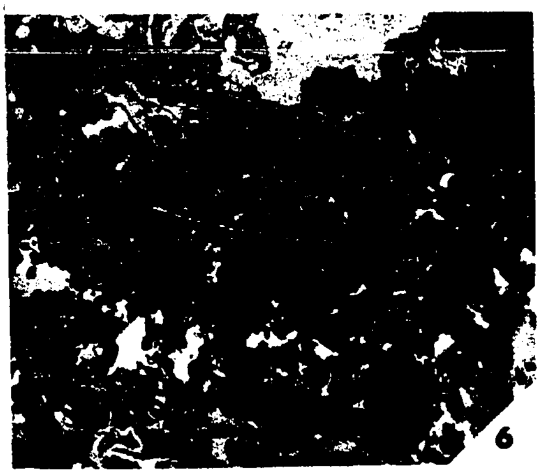
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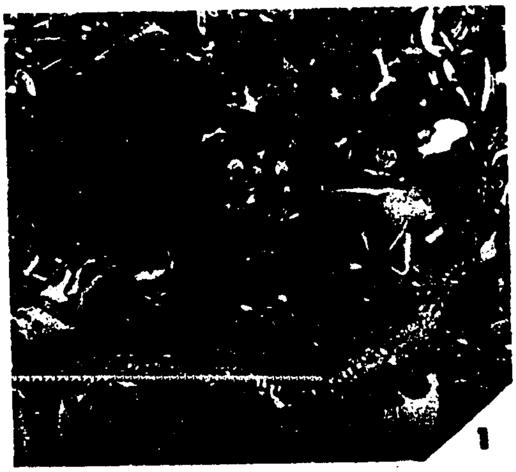
PLATE XIII



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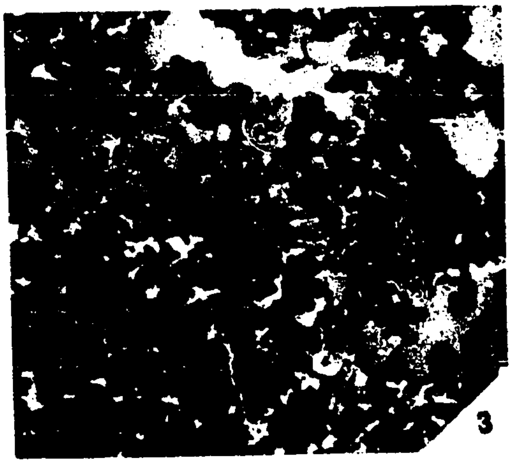

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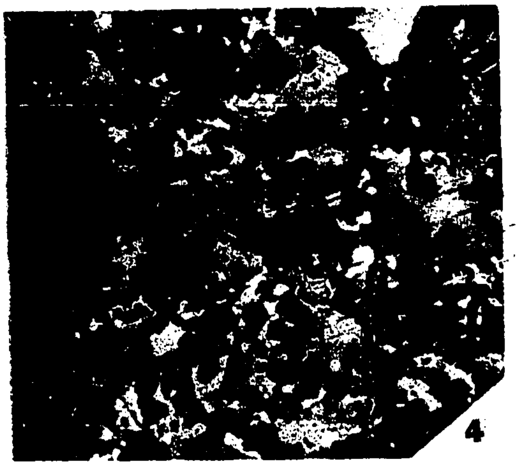

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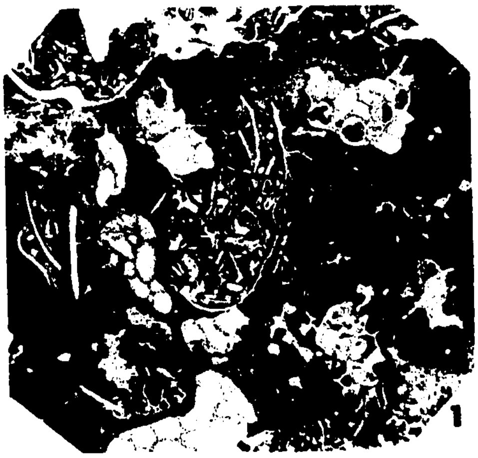
PLATE XIV



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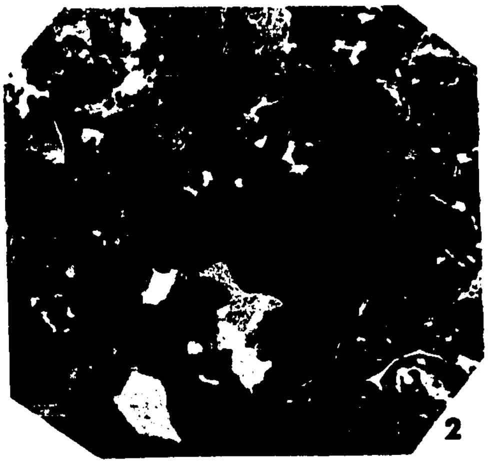

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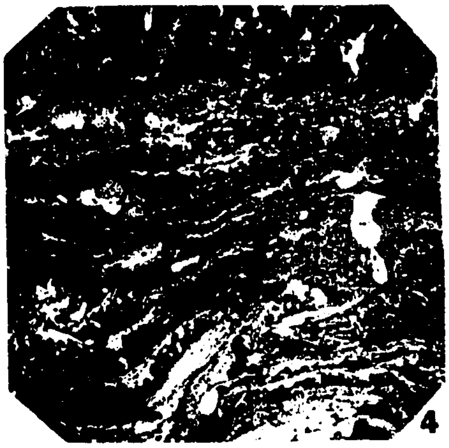

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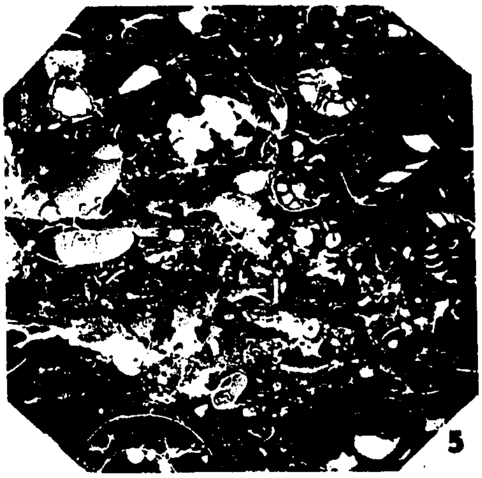

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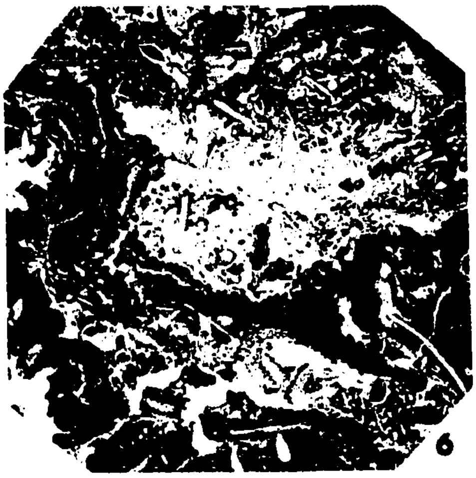

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ALGAL COMPONENTS

PLATE XV

figure 1: *Archaeolithophyllum missouriensis*, M97-6a, detail showing internal structure, X25.

figure 2: *Archaeolithophyllum lamellosum*, M97-8Da, detail of slightly recrystallized internal structure, X25.

figure 3: *Ottonosia laminata* crust from M97-8AG, detail showing pyrite on crusts (black), X25.

figure 4: *Ottonosia laminata* crust from M97-8 AG, detail of dessication crack with coated grains or ooliths, X25.

figure 5, 6: Dasycladacean alga, partailly recrystallized, but showing evidence of internal structure, section from mounding interval at Greenleaf Lake, X25.

PLATE XVI

figure 1: *Archaeolithophyllum missouriensis*, M97-6a, lower magnification of internal structure, X11.2.

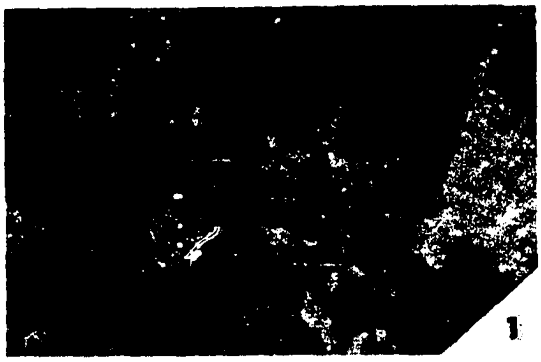
figure 2: *Garwoodia gregaria*,M97-6B, detail of internal structure, X25.

figure 3: *Girvanella moorei*, M97-8 YB-22, detail in *Ottonosia* boundstone, X25.

figure 4: Sediment fill of a clionid sponge boring in Miocene coral (internal mold), Jamaica, X1.75.

figure 5, 6: Sponge borings with internal sediments, M97-8 YB-38, X25.

PLATE XV



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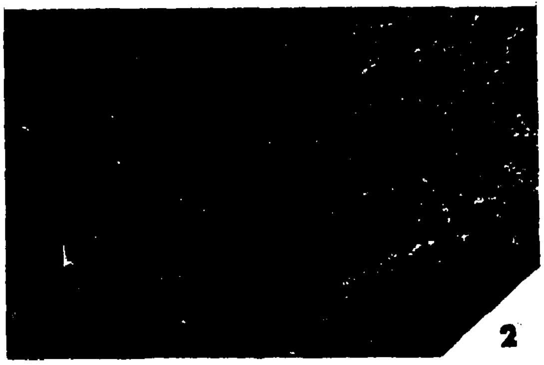

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PLATE XVI

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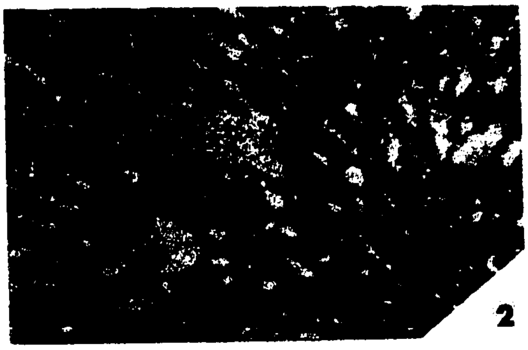

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PLATE XVII: MISCELLANEOUS MORROWAN BIOTA

Figure:

1 Trilobite: *Paladin morrowensis* Mather, enrolled complete specimen, loc. BN-BJ, X2.

2 Trilobite: *Kaskia* sp.,enrolled complete specimen, loc. 97-8L, X2.

3 Leaf?, impression, loc. 97-9A, X1.

4 Nautiloid: *Pseudoorthoceras knoxense* McChesney, cross-section, loc. BN-ND, X1.

5 Nautiloid, *P. knoxense* McChesney, lateral view, loc XB-7, X1.

6 Trilobite: *P. morrowensis* Mather, pygidium, loc. 97-9V, X2.

7 Goniatite: *Branneroceras branneri* (Smith), lateral view, loc. BN-BF, X2.

8 Goniatite: *Syngastrioceras oblatum* (Miller and Moore), lateral view, loc. BN-BB, X2.

9 Goniatite: *S. oblatum* (Miller and Moore), showing sutures, loc. BN-BL, X2.

10 Gastropod: *Naticopsis*? sp., loc. BN-BM, X2.

11 Goniatite: *B. branneri* (Smith), oblique-lateral view, loc. BN-NA, X1.

12 Wood fragment?, loc. 97-9A, X1.

13 Coral: *Lophotichium amoenum* Moore and Jeffords, oral-lateral view, loc. XB-7, X2.

14 Coral: *L. amoenum* Moore and Jeffords, showing juvenile attachment surface, loc. XB-7, X2.

15 Gastropod: *Soleniscus*? sp., lateral view, loc. XB-7, X2.

16 Coral: *Cladochonus fragilis* Mather, oral view, loc. UB-4t, X2.

17 Coral: *Michelinia eugeneae* White, loc. UB-2a, X1.

18 Coral: *M. eugeneae* White, loc. UB-2a, X1.

19 Blastoid: *Pentremites rusticus* Hambach, lateral view, loc. XB-2, X1.

20 Blastoid: *P. angustus* Hambach, oral view, loc. XB-2, X1.

21 crinoid plate, loc. XB-3, X2.

22 crinoid cup, loc. ZB-North Quarry, X2.

23 echinoid spine, loc. XB-2, X1.

24 Arborescent bryozoan: *Rhombopora* sp., loc. XB-2, X2.

25 Arborescent bryozoan: *Rhombopora* sp., loc. XB-2, X2

PLATE XVII


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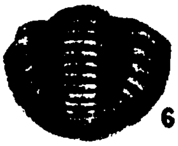
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Figure:

26 Bryozoan: *Prismopora* sp. on pelmatozoan stem, loc. UB-2t, X1.

27 Encrusting bryozoan on fenestrate bryozoan, loc. XB-7, X1.

28 Fenestrate bryozoan: *Polypora*? sp., loc. XB-7, X1.

PLATE XVIII: BRACHIOPODA

Figure:

1-4 *Plicochonetes? arkansanus* Mather, 1: pedicle valve exterior, 2: brachial valve interior, 3: brachial valve exterior, 4: pedicle valve interior; loc. 97-6 talus, X2.

5 *Neochonetes* sp., brachial valve exterior, loc. 97-6 talus, X2.

6 *Krotovia? globosa* (Mather), pedicle valve exterior, front view, loc. 97-6 talus, X2.

7 *K.? globosa* (Mather), pedicle exterior, loc. 97-6E-B, X2.

8 *Anthracospirifer matheri* (Dunbar and Condra), pedicle valve exterior, 97-6 talus, X2.

9-10 *Neochonetes?* sp., 9: pedicle valve exterior, 10: pedicle valve interior, loc. 97-5 talus, X2.

11-12 *Punctospirifer morrowensis* Sutherland and Harlow, 11: pedicle front, 12: pedicle valve exterior, loc. UB-2a, XB-7, X2.

13-14 *Hustedia miseri* Mather, 13: brachial valve, 14: pedicle valve
18 18: lateral view, loc. XB-14, X2.

15 *Desmoinesia* sp., pedicle exterior, loc. BN-BJ, X1.

16 *D. nambeensis* Sutherland and Harlow, pedicle exterior, loc. 97-9 talus, X1.

17 *Composita gibbosa* Mather, pedicle exterior, loc. BN-ND, X2.

19 *Composita?* sp., pedicle exterior, loc. XB-14, X2.

20 *Composita gibbosa* Mather, lateral, loc. BN-ND, X2.

21 *Rhipidomella* sp., crushed specimen, loc. 97-8L, X2.

22 *Composita gibbosa* Mather, pedicle interior, loc. XB-2, X1.

23 *Tesuquea morrowensis* (Mather), pedicle lateral view, loc. 97-9U, X1.

24 *Derbya* sp., brachial view, loc. 97-6 talus, X1.

25 *Desmoinesia nambeensis* Sutherland and Harlow, pedicle exterior, crushed specimen, loc. 97-6 talus, X2.

26 *Linoproductus* sp., pedicle exterior, loc. 97-9 talus, X1.

27 *Schizophoria altirostris* Mather, pedicle interior, loc. 97-9, X1.

28 *Derbya* sp., pedicle exterior, loc. XB-11, X1.

29-30 *Spirifer goreii* Mather, 29: front, 30: pedicle exterior, loc. 97-6 talus, X1.

31 *Sandia* cf. *S. welleri* Mather, pedicle exterior, loc. 97-6 or 8 talus, X1.

PLATE XVIII


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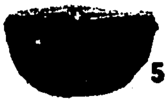
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PLATE XIX

figure 1: Bioherm from North Quarry showing shale-filled central cavity in a small "jelly-roll" mound.

figure 2: Slab from Bermuda reefs illustrating bryozoan encrusting irregular cavity surface.

figure 3: Internal or skeletal void of bivalve from Bermuda reef material of R. N. Ginsburg.

PLATE XX

figure 1: Open "cavity" between coral heads at Chalet Carib reef front, Jamaica.

figure 2: Dark "basal cavity" under plate of *Agaricia lamarcki* at Dancing Lady Reef, Discovery Bay, Jamaica.

figure 3: Gloomy reef face cavity area from Pear Tree Bottom, Jamaica.

PLATE XIX

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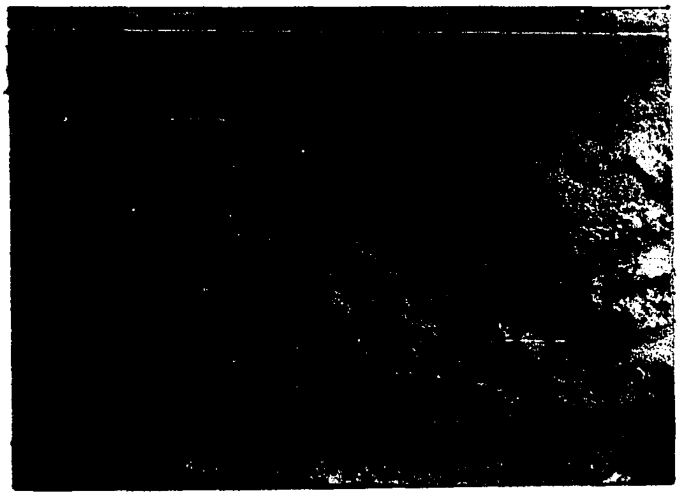

PLATE XX

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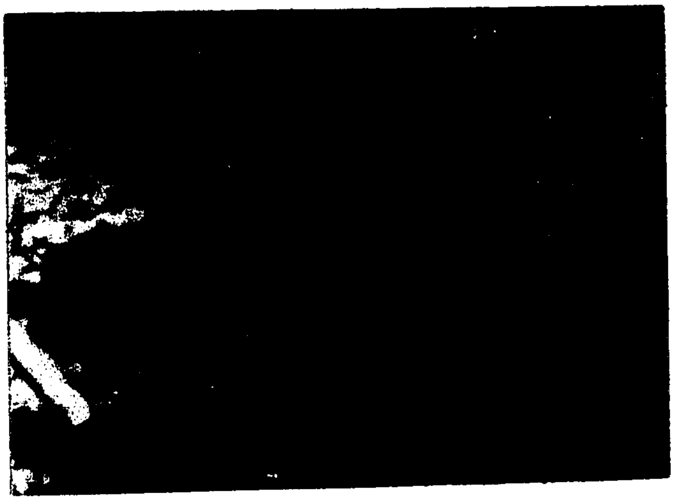

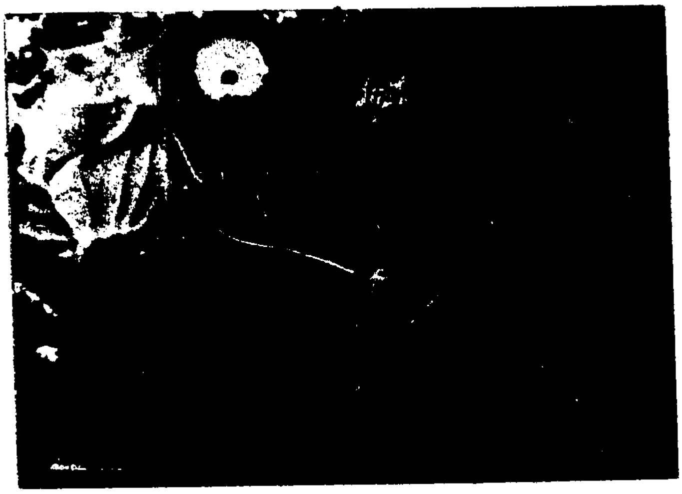

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APPENDIX A

DESCRIPTION OF MORROWAN BIOHERMS

General Description of Mound Composition

Ten sets of samples were taken from vertical and horizontal exposures of mounds and mounding intervals within the quarry. Where possible, samples include not only limestone blocks that have been serially slabbed, but also washed shale samples. Point counts were made on a 5 mm grid on several slabs from each block in order to obtain statistically significant samples. The number of points required varies with the lithic sample and may be tested by plotting a graph of number of points versus new species encountered at each count. Such a graph will have a high slope at first where new species are found at almost every point, and then fall rapidly and level off as no new species are found. All of the point counts were made well beyound the number of points required for the curve to level off.

Percentages of the total composition for each sample are calculated for each component of the individual mounds and are also found in this appendix. These percentages are separated by approximately the first and third quartiles and are plotted on diagrams of the mounds for each component found after a general description of each mound in the sections that follow. The mean and standard deviations were not used to separate biotic percentages because of the extreme variability of the percentages. A brief description of each mound or mounding interval gives the general location and nature of the mound. Table 1 lists the combined biotic composition of mounds within each interval. No major differences in framework biota exist, though some minor accessory organisms are found in different areas: trilobites, foraminifera, _Neospirifer_, _Anthracospirifer_, and _Cleiothyridina_ brachiopods, nuculid pelecypods, nautiloid cephalopods are found only in the higher interval. However, this probably reflects the larger sample available from that interval.

TABLE i

MORROWAN BIOTIC ELEMENTS

Biotic Element	Occurrence			
	97-6	97-8	N.Quarry	97-9
ALGAE				
Girvanella moorei Johnson	X	X	X	
Ottonosia laminata Twenhofel	X	X	X	
Cuneiphycus texana Johnson	X			
Garwoodia gregaria (Nicholson)	X	X		
dasycladacean alga	X	X	X	
Archaeolithophyllum missouriensis Johnson	X	X	X	
A. laminata Wray	X	X	X	
FORAMINIFERA				
Hedraites sp.	X	X	X	
millerellid foraminifera	X	X		
ANTHOZOA				
Lophotichium amoenum Moore and Jeffords	X	X	X	
Michelinia eugeneae White	X	X	X	
Cladochonus fragilis (aulopoid) Mather	X	X		
BRYOZOA				
Encrusting:	X	X	X	
Anisotrypa sp.				
Stenopora sp.				
Fistulipora sp.				
Fenestrate:	X	X	X	
Polypora sp.				
Fenestrella sp.				
Arborescent:	X	X	X	
Rhombopora sp.				
Cystodictia sp.				
Dictyocladia sp.				
Prismopora concava Mather	X	X		
BRACHIOPODA				
Schizophora altirostris Mather	X	X		
Derbyia sp.	X	X		
Plicochonetes? arkansanus (Mather)	X			
Neochonetes sp.	X			
Krotovia? globosa (Mather)	X	X		
Desmoinesia nambeensis Sutherland and Harlow	X	X		
Sandia cf. *S. welleri* (Mather)	X			
Tesuquea morrowensis (Mather)	X			
Linoproductus sp.		X		
Hustedia miseri Mather	X	X	X	X
Composita gibbosa Mather	X	X	X	X

Biotic Element	97-6	97-8	N.Quarry	97-9
Cleiothyridina milleri Sutherland and Harlow		X		
Spirifer goreii Mather	X	X		
Anthracospirifer matheri Dunbar & Condra		X		
Punctospirifer morrowensis Sutherland and Harlow	X	X		
P. curvilateralis (Easton)	X	X		
Phricodothyris perplexa (McChesney)		X		
MOLLUSCA				
Gastropods:				
Naticopsis sp.	X	X	X	
Soleniscus? sp.	X	X		
Goniasma sp.	X	X		
Bivalves:	X	X	X	
nuculid bivalve		X		
Cephalopods:				
Pseudoorthoceras knoxense McChesney		X		
Branneroceras branneri (Smith)		X		
Syngastrioceras oblatum (Miller & Moore)		X		
ARTHROPODA				
Trilobites:				
Paladin morrowensis Mather		X		
Kaskia sp.		X		X
Ostracodes	X			
ECHINODERMATA				
Pentremites angustus Hambach		X		
P. rusticus Hambach	X	X	X	
Delocrinus sp.		X		
pelmatozoan fragments	X	X	X	X
MISCELLANEOUS				
plant material				X

MOUND 97-6, Station 1

This mound is located on the south end of the east wall of the central quarry and was included in the original section measured by Sutherland and Henry (in press) (plate II, figure 1). It occurs within the 4.0 to 4.5-foot thick lower mounding interval (unit 6). The mound itself is nearly circular in outline with a diameter of 2.0 to 2.5 feet and is exposed in only two-dimensions. Two algal-bryozoan boundstone layers wrap around forming a smooth roll on the north and a central shale-filled cavity on the south (sample index, text figure 11). The mound is overlain and interbedded with medium gray shale and bryozoan boundstone. Following the description of the fossil biota are text figures illustrating the biotic components (text figures 10-13). Tables listing percentage composition (tables 2 and 3), and thin-section descriptions.

The fauna associated with the north side of the mound indicates that this area may have been more restricted as in a lagoonal area, while the south side faced open marine conditions with a diverse fauna.

General Description of Biota in Slabs

The lower extension of the core rock in this mound to the south includes almost 50 percent Garwoodia, a green codiacean alga, in a micritic matrix (text figure 11). Relatively high percentages of the rugose coral, Lophotichium amoenum, are found with pelmatozoan fragments (over 28%), brachiopods, gastropods, and minor percentages of michelinid corals, bryozoans, Archaeolithophyllum missouriensis, the "corn-flake" shaped red calcareous alga (text figure 10-11). In the lower part of the mound, the core rock is primarily micrite (81.0%) that -ay have originally been stabilized by algae (text figure 10). However, recrystallization and compaction has obliterated any algal structures that may have been present with the exception of a relatively large percentage of Archaeolithophyllum missouriensis (text figure 11). As a red calcareous alga, this species would be more likely to be preserved than the stromatolitic blue-green algae. In contrast to the same layer away from the mound, there is no Garwoodia in the lower core. Relatively large percentages of pelmatozoan fragments, goniatites, and an undescribed genus of dasycladacean alga are found with bryozoans and rugose corals. Minor gastropods and michelinid corals occur.

The upper part of the mound core is again dominated by micrite (41.6 to 91.2%) with large amounts of A. missouriensis (up to 37.14%) and relatively large numbers of bryozoans. Minor components include pelmatozoan fragments, michelinid corals, rugose corals, brachiopods like Hustedia and Composita, goniatites, blue-green algae such as Ottonosia, the red encrusting alga A. lamellosum, and a green dasycladacean alga (text figure 10, 11).

The outer limestone roll that covers the core rock is again dominated by the green alga, Garwoodia (53.2%) with 41.6 percent micrite. Minor components include bryozoans , michelinid corals, rugose corals, brachiopods, and A. missouriensis (table 2).

A bryozoan boundstone layer extends laterally southward from the central core rock. The layer is primarily micrite (76.8%) with approximately 15 percent bryozoans and 8 percent michelinid corals. Minor numbers of rugose corals and pelmatozoan fragments also occur.

Distribution of Individual Components in Slabs

Bryozoans are found in greatest percentages on the lateral limestone layer that extends into the adjacent shales to the south of the mounds (text figure 10). They are also abundant lining the central shale cavity. The lowest percentage of bryozoans occurs in the core rock and in the outer limestone layer. The latter distribution is in contrast to the pattern normally developed in the Morrowan bioherms studied, where bryozoans commonly dominate the outer surface of the mound. However, none of the other mounds show a dominant Garwoodia flora in the outer layer and this may reflect slightly different conditions locally. Bryozoans are abundant in the shale above the mound.

Michelinid corals are most abundant on the lateral bryozoan boundstone layer that may have provided a stable substrate (text figure 10). They are least abundant in the lower core and outermost layer where they would also have had to compete with Garwoodia for attachment. The rugose coral Lophotichium is abundant in this position with lesser percentages around the steep sides of the core (text figure 10). This distribution may be one of stability for attachment as the steep sides would form an unstable surface.

Micrite is most abundant in the mound core and least abundant in the areas dominated by Garwoodia, the southern extension of the mound core and outer boundstone layer (text figure 10). As mentioned earlier, micrite may represent the muds stabilized by blue-green stomatolitic algae whose structure has been destroyed by recrystallization and compaction after decay.

When compared to the shale samples, pelmatozoan fragments comprise a minor fraction of the limestone slabs (text figure 10, table 2). The only relatively high percentage of these fragments is found in the Garwoodia boundstone extension of the lower core where they form 28.29 percent of the slab. Perhaps this was an area of more agitated water that could deposit coarse material and remove carbonate muds that dominate other parts of the mound. This is especially true in the upper part of the core where pelmatozoan fragments are completely absent in two slabs above the central shale cavity.

Goniatites are relatively rare in the mounds and are found only in the core rock with greatest numbers at the base and top sides of the core (text figure 10). Brachiopods such as Composita and Hustedia (identified in shale samples) are also a minor component (less than 2.6%, text figure 11). They are found in greatest percentages near the top of the shale cavity, which probably provided a protected habitat. Lowest numbers are found in the limestones below the central cavity, which may have been a muddy environment unsuitable for filter feeding forms and in the bryozoan boundstone layer.

Archaeolithophyllum missouriensis is most abundant in the core rock over and below the central shale cavity where it forms a substantial part of the cemented frame of the mound (text figure 11). It is least abundant in areas dominated by the green alga Garwoodia that is found in the extension of the core rock away from the mound and above the core in the outer Garwoodia boundstone layer. This may indicate some competition between genera. Garwoodia seems to prefer habitats that are relatively open to agitation or water movement and illumination, while these do not seem to be absolute restrictions for the red alga. Gastropods are also a minor component that occurs most commonly associated with the green alga Garwoodia or A. lamellosum on which they may have grazed.

Distribution of Biota in Shales

Encrusting bryozoans are found in greatest numbers (up to 27%) in the shales immediately above the upper mound surface and within the central shale cavity (text figure 12). The lowest percentages are found outside the mound and in shale pockets within the mound. Other fairly high concentrations (8 to 10%) are found at the topmost roll of the mound and immediately below the mound and in the shales below the mounding interval(unit 5).

Howver, arborescent bryozoans are most abundant (up to 85%) outside the mound itself in the shales to the north and are least common in the shales immediately above the inner mound surface to the south (26-36%) where encrusting bryozoans are most abundant (text figure 12). This may be a reflection of competition or environmental restriction since encrusting forms may thrive in higher energy conditions than fragile arborescent bryozoans.

Fenestrate bryozoans are relatively uncommon except within the mound itself (text figure 12). There are a few scattered individuals outside the mound, but fenestrate bryozoans are most common in the intermound shale pockets (13.5%) and in the shale in the upper part of the central shale cavity. They occur in lesser numbers in the shale belwo the mound and to the wouth above the mound proper.

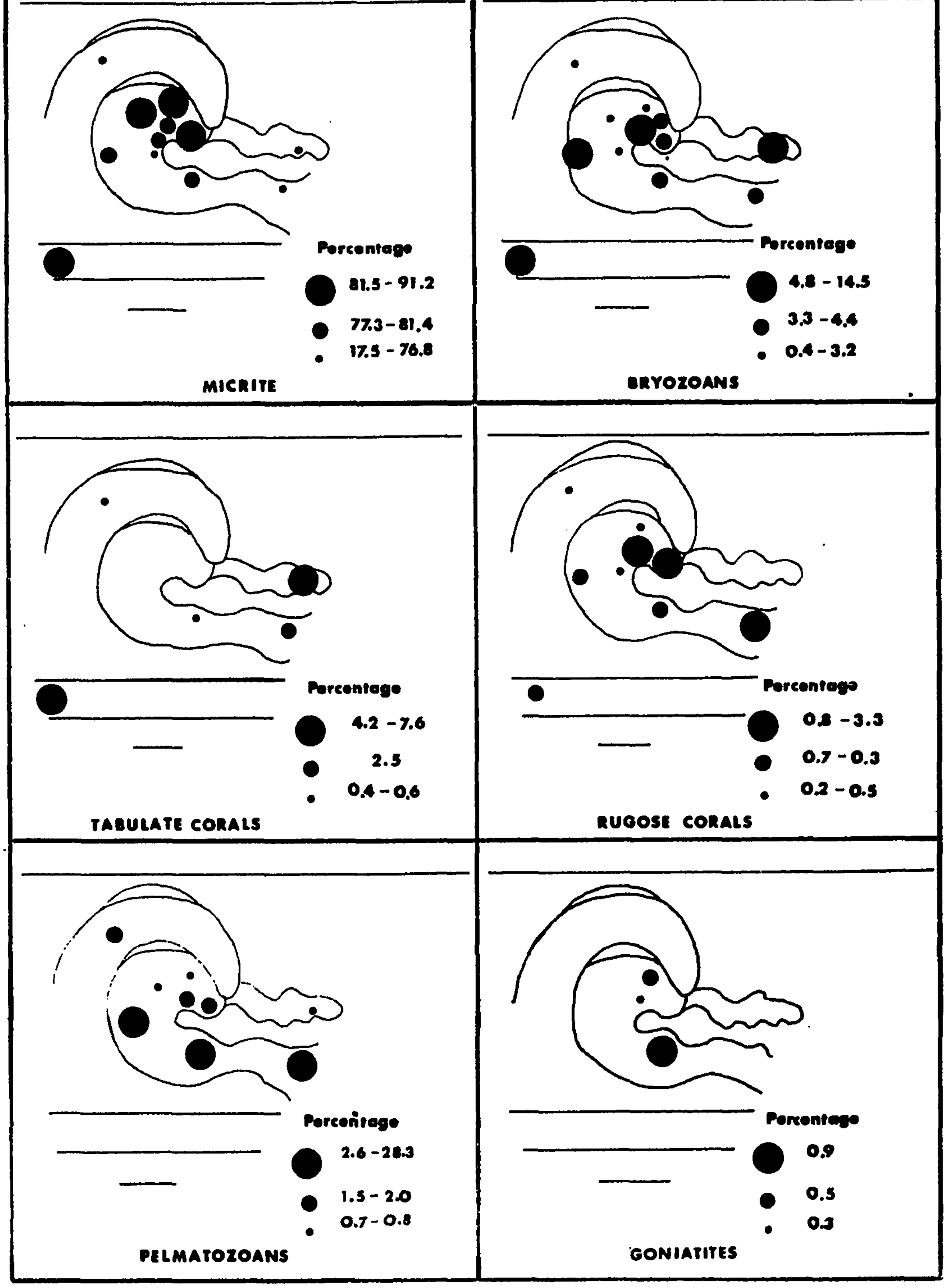
Michelinid corals are most common in the shales below the mounding interval and then above the interval to the south (text figure 12). Lesser numbers are found in the central shale cavity and northward outside the mound. These tabulate corals are not found in the shales below the mounds or in the intermound shale pockets that probably did not persist as open cavities.

Lophotichium is most abundant in the shales immediately above and to the south of the mound, but is always present in numbers less than one percent (text figure 12). The coral is absent elsewhere except as a minor component adjacent to the mound on the north and in the top intermound shale.

Pelmatozoan fragments are found above and below the mound in quantities up to 44 percent of the total composition and in the shales above the mound to the south (text figure 12). Fragments are least abundant outside the mound to the north and in the central shale cavity. This may indicate that low energy prevented normal current deposition of pelmatozoan fragments in these areas.

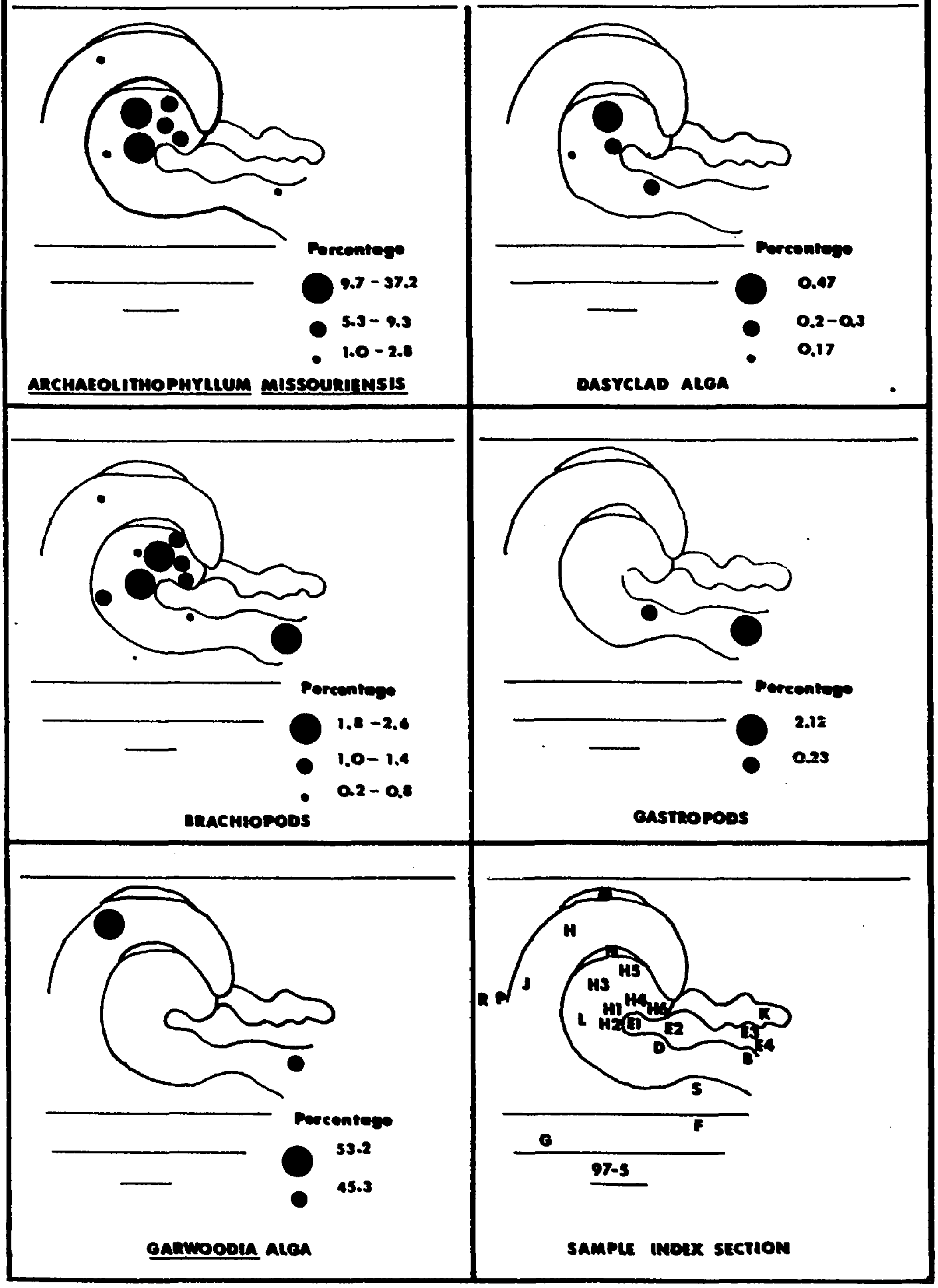
Gastropods are relatively rare (less than 1%) and are restricted to the upper part of the shale cavity and above the inner core and above the inner core and above the mound proper (text figure 13).

Brachiopods are found primarily in the protected habitat of the central shale cavity and above the mound to the south and in shales below the mound. Composita is most abundant (9.5%) within the central shale cavity with scattered individuals on the south side of the mound. However, productid brachiopods are found in shales below the mound in greatest numbers (up to 6%) with percentages less than one percent seaward and leeward of the mound. Hustedia, like Composita, is most common within the central shale cavity (8.5%), then in shales to the south, below the mound and to the north. Spiriferid brachiopods can be found in quantities up to 2 percent to the north (lagoonward?) and above and below the mound proper, while chonetids are most abundant (up to 2%) away from the mound to the north with scattered individuals in the central shale cavity (text figure 13).

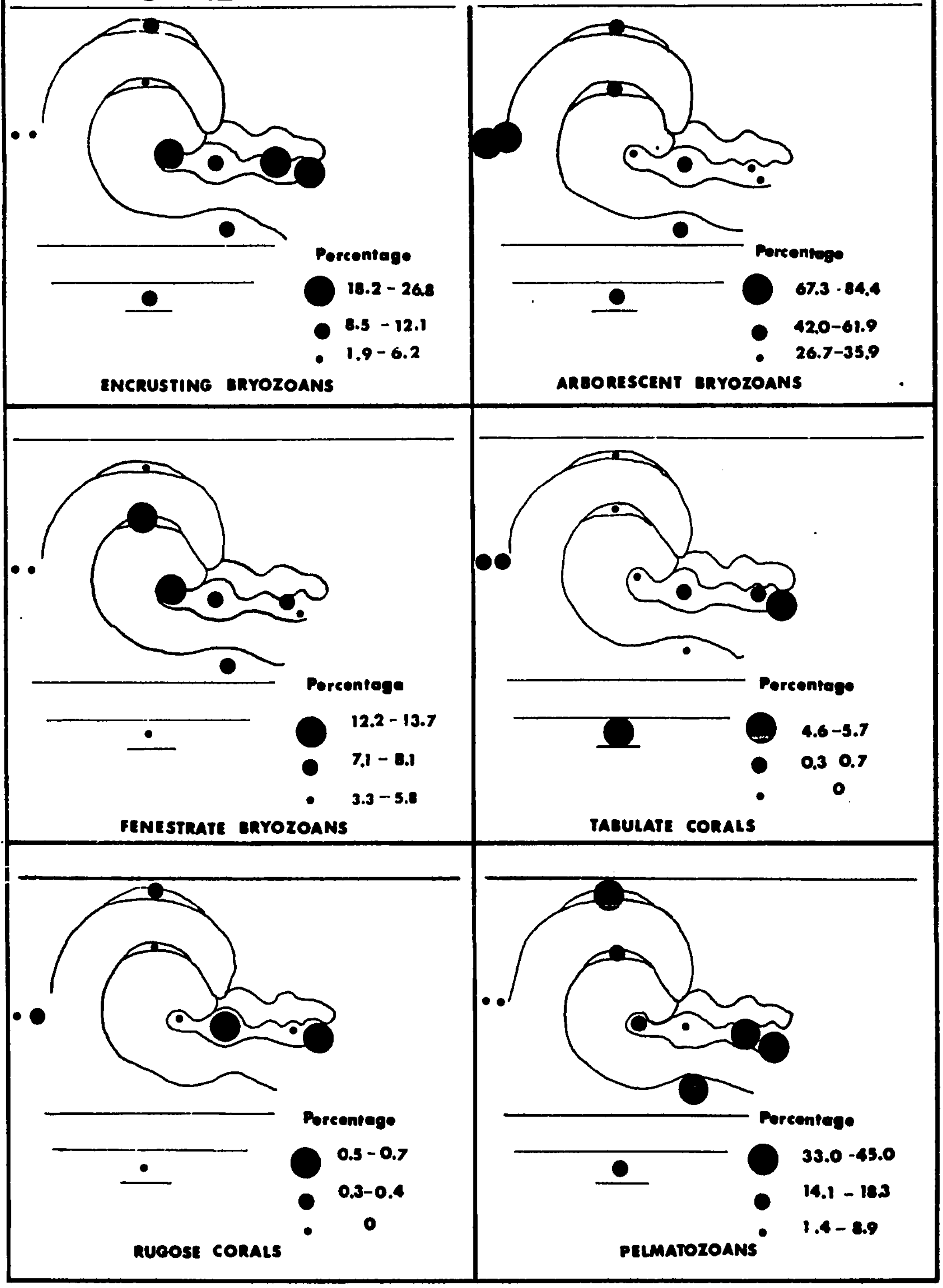


Text Figure 10 : 97-6 CARBONATE BIOTA

Text Figure 11: 97-6 CARBONATE BIOTA



Text Figure 12 : 97-6 SHALE BIOTA



Text Figure 13 : 97-6 SHALE BIOTA

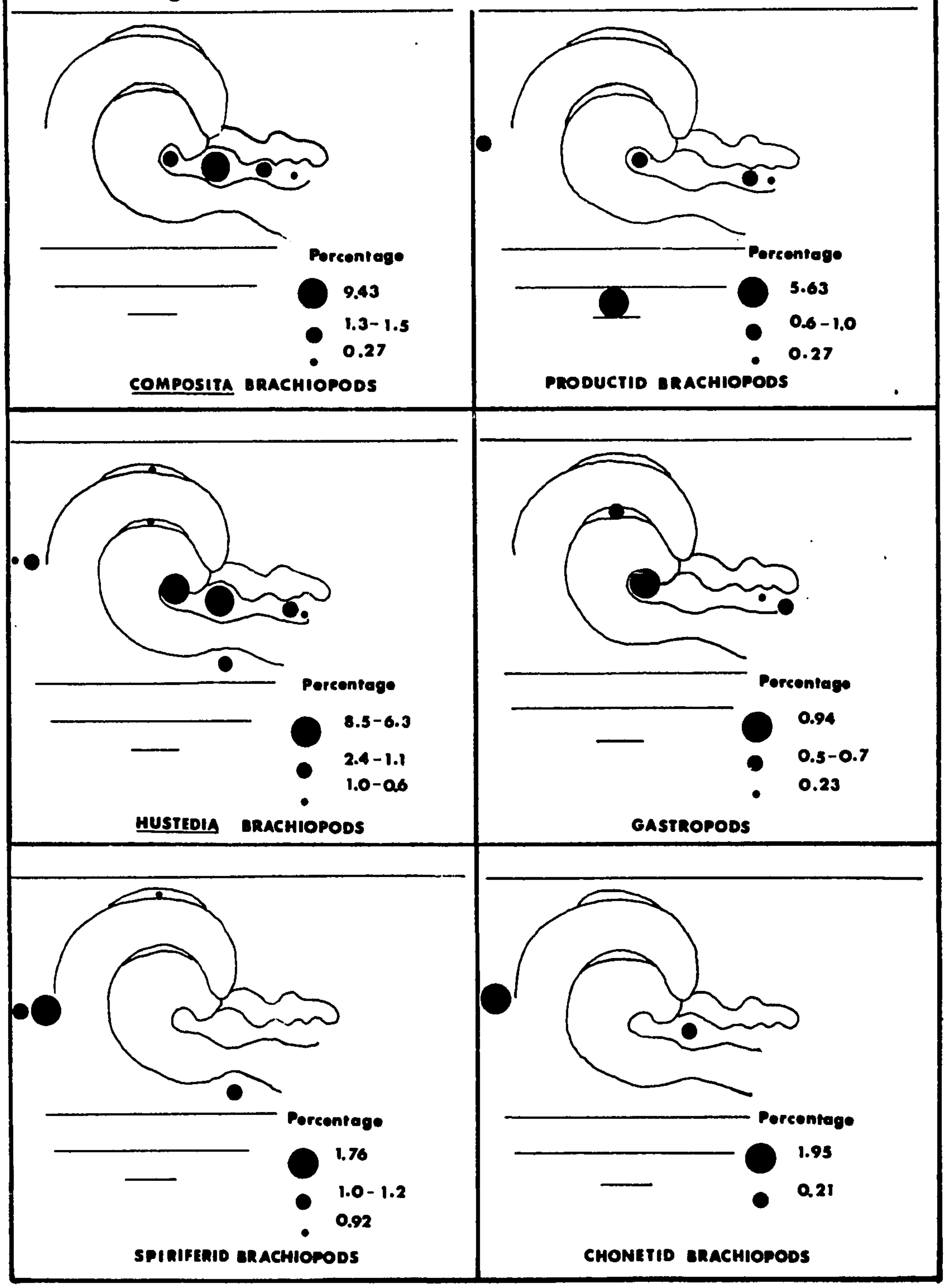


TABLE 2

97-6 CARBONATE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	MICRITE	BRYOZOA	TABULATE CORAL	RUGOSE CORAL	PELMATO.	OTTONOS.	ARCHAEO. MISSOUR.	ARCHAEO. LAMELL.	BRACHIO.	OTHER	OTHER
97-6B	17.54	3.38	2.53	0.84	28.29	---	1.90	---	2.12	2.12ga	45.43gw
97-6D	81.0	3.55	0.47	0.47	2.60	0.23	9.71	---	0.71	0.23ng	0.92gn
97-6G	85.2	8.17	4.28	0.38	1.94	---	---	---	---	---	---
97-6H	41.6	1.55	0.51	0.25	1.55	---	1.03	---	0.25	---	53.2gw
97-6H1	81.58	0.47	---	---	0.79	---	16.19	---	0.31	0.47ng	---
97-6H2	57.42	3.13	---	0.28	---	---	37.14	0.28	1.70	0.28gn	---
97-6H3	81.08	4.11	---	1.73	1.51	---	9.30	---	2.59	---	---
97-6H4	81.35	5.91	---	---	1.77	---	7.69	---	1.77	---	---
97-6H5	90.1	1.77	---	0.25	0.75	0.50	5.31	---	1.25	---	---
97-6H6	91.2	4.39	---	3.29	---	---	---	---	1.09	---	---
97-6K	76.8	14.44	7.60	0.41	0.76	---	---	---	---	---	---
97-6L	77.3	4.83	0.0	0.69	12.43	0.34	2.76	0.17	1.38	---	---

ga: gastropod, gw: <u>Garwoodia</u>, ng: dasyclad alga, gn: goniatite

TABLE 3

97-6 SHALE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	ENCR. BRYO.	ARBOR. BRYO.	TABULATE CORAL	RUGOSE CORAL	PELM.	FENES. BRYO.	HUSTED.	COMPO.	GAST.	OTHER	OTHER
9706E	29.74	7.75	2.32	1.55	50.00	0.51	4.65	---	---	2.84au	---
97-6,2'	11.45	15.62	1.04	6.25	37.50	2.08	3.12	---	---	7.29pr	15.62db
97-6M	8.58	42.6	---	0.30	44.1	3.37	0.92	---	---	---	---
97-6N	6.15	67.3	---	---	10.76	13.53	0.61	---	0.61	0.92sp	---
97-6P	5.92	84.4	0.32	0.32	1.44	3.37	2.40	---	---	1.76sp	---
97-6R	1.95	81.0	0.39	---	6.38	5.60	0.78	---	1.95ch	1.04sp	0.78pr
97.6S	9.19	44.82	---	---	35.63	8.04	1.14	---	---	1.14sp	---
97-5	9.85	54.92	5.63	---	18.30	5.63	---	---	---	5.63pr	---
97-6E1	21.69	33.01	---	---	14.15	12.26	8.49	9.43	0.94	---	---
97-6E2	12.04	61.9	0.43	0.64	8.81	7.52	6.23	1.50	---	0.64pr	0.21ch
97-6E3	18.20	35.9	0.69	---	34.1	7.14	1.38	1.38	0.23	0.92pr	---
97-6E4	26.72	26.72	4.68	0.55	33.0	5.78	0.82	0.27	0.55	0.27pr	---

au: auloporid coral, pr: productid brachiopod, db: Derbyia sp., sp: spiriferid brachiopod, ch: chonetid brachiopod

Thin-Section Descriptions

Unit No.	Description
97-6a, basal 1'	SKELETAL *ARCHAEOLITHOPHYLLUM* BOUNDSTONE TO LIME WACKESTONE (very micritic algal-bryozoan biolithite); medium to coarse grained, poorly sorted, floating to tangential contacts, minor overgrowths and solution, slight silicification of pelmatozoan and bryozoan debris, recrystallization of clasts to spar; compaction features absent; maximum of 50 % micritic matrix, minor iron oxides; porosity less than 15 % consisting of skeletal voids and sponge borings filled with spar; grains include *Archaelolithophyllum missouriensis*, *Cunsiphycus*, *Lophotichium amoenum*, and millerellid foraminifera (plate VIII, figure 2)
97-6B, 2' above base	SKELETAL *ARCHAEOLITHOPHYLLUM* BOUNDSTONE TO LIME WACKESTONE (algal-bryozoan biolithite); fine to medium grained, moderate to poor sorting, grains floating, minor overgrowths and solution, slight silicification of pelmatozoan and bryozoan debris, recrystallization of fossil clasts to spar; extensive compaction features: micro and mega-fractures, grain brecciation and stylolites; bird's-eye structures, maximum of 50 to 60 % micritic matrix, 5 % ooliths, 10 % dolomite; porosity 20 to 30 % consisting of spar-filled fractures; fossil clasts include tabulate corals, *Archaeolithophyllum missouriensis* and *A. lamellosum* (plate VIII, figure 3, 6)
97-6B	*GARWOODIA* LIME GRAINSTONE (intraclast-bearing rounded biosparite); very coarse rounded intraclasts of *Garwoodia*, *Michelinia*, and *Archaeolithophyllum*, well sorted, tangential to sutured grain contacts with pressure solution; replacement of matrix by sucrosic dolomite, recrystallization of many fossil clasts to spar; minor compaction with micro-fractures cutting grains; matrix/cement a maximum of 30 %, no accessory minerals; porosity less than 5 % fractures and skeletal voids filled by spar; 80 % *Garwoodia*, 15 % *Michelinia* fossil clasts (plate IX , figure 1)
97-6D	SKELETAL *ARCHAEOLITHOPHYLLUM* BOUNDSTONE (algal biolithite); medium to coarse grains of *Archaeolithophyllum lamellosum* (20-30 %), minor foraminifera, bryozoans, and spines;moderate sorting, floating grains, armored grains, minor solution, recrystallization of fossil clasts to spar (extensive); extensive compaction, including mega- and microfractures and stylolites; 50 to 60 % micirtic matrix; 10 to 15 % porosity consisting of skeletal voids filled by spar (plate VIII, figure 1)

Unit No.	Description
97-6F	RECRYSTALLIZED *ARCHAEOLITHOPHYLLUM* BOUNDSTONE TO LIME PACKSTONE (bryozoan-algal biolithite); fine-grained in *Archaeolithophyllum lamellosum* with some *A. missouriensis*, very well sorted, contacts tangential to convexo-concave, armored grains, solution common, moderate silicification of pelmatozoans and bryozoans, extensive recrystallization of clasts to spar; minor compaction represented by stylolites; 35 to 40 % micritic matrix, less than 5 % iron oxides, porosity 15 % (plate VIII, figure 5)
97-6G	RECRYSTALLIZED *ARCHAEOLITHOPHYLLUM* BOUNDSTONE TO LIME MUDSTONE (algal biolithite); fine-grained, well sorted pelmatozoan and dasyclad algal debris in *A. lamellosum*; floating grains, overgrowths and solution very common; 40 to 50 % recrystallized micritic matrix, minor pyrite and iron oxides; compaction minor with micro-fractures; bird's-eye structures; 10 % porosity consisting of sponge borings up to 2 mm in diameter filled with spar and a lining of micro-spar or submarine cement.

MOUND 97-6E, Station 2

This small structure is also located within the lower mounding interval (unit 6). It is located above the northern base line (see text figure 3, topographic base) in the central part of the east wall of the central quarry, approximately 850 feet northward of Mound 97-6, station 1. This interval is 6.4 feet thick and consists of algal-bryozoan boundstone interbedded with medium gray shales above a thin skeletal lime wackestone (calcilutite). Although it does not include a mound-like structure, the exposure occurs within the lower interval and includes irregularly thickened limestone layers (sample index, text figure 15).

Distribution of Biota in Shale Samples

Encrusting bryozoans comprise a maximum of 21 percent of the fossil components of the shale immediately above the small structure. Lesser amounts of these bryozoans are found within shale pockets in the mound, while no encrusting forms are found higher in the shales above the mound or in contact with the mound itself (text figure 14).

Fenestrate bryozoans have a similar distribution in that they are not found in contact with the upper surface of the mound, but are found in a maximum number of 14 percent in the shales within the mound (text figure 14). These bryozoans number almost 5 percent just above the mound. Both encrusting and fenestrate forms seem to require a stable base for attachment and are not generally found outside the mound itself. However, encrusting forms are dominant on the upper surfaces of the mound, while fenestrate forms are most common within the intermound shales and more protected niches.

Another pattern is apparent in the "stick" bryozoans or arborescent forms as the shales above the mound are comprised almost entirely (99.5%) of the forms (text figure 14). None of the arborescent bryozoans are intact, but none of the fragments is abraded or worn as should be the case if they were transported. Relatively high abundances of these forms are also found within the mound itself. Even the lowest percentage (22%) is high compared to other components.

Michelinid corals are uncommon in the shales and are present in less than one percent within the shales just above the mound and within the intermound shales. The rugose coral, Lophotichium,has a similar distribution, but comprises up to 3 percent of the shale fauna on top of the mound (text figure 14). This may be an indication of stability as noted in other mound surfaces.

Pelmatozoans, strangely, have a distribution similar to that of the corals, but in much greater percentages (from 0.3 to 41.0%) shown in text figure 14. Pelmatozoan fragments are most abundant at the top of the mound where they could be trapped by encrusting bryozoans. They are least abundant away from the mound itself where there is nothing to trap the columnals and there is no stable substrate on which a crinoid or blastoid could attach.

Hustedia shows a similar distribution (text figure 14). As pediculate brachiopods, they require a stable substrate on which attachment is possible. They are found in greatest numbers in the shales on the upper surface of the mound (up to 5%) and decrease to less than 2 percent in the intermound shales where they may have been washed in. Away from the mounds, Hustedia is rare and scattered individuals form a maximum of 0.06 percent of the total fauna.

Composita and productid brachiopods are found in greatest numbers near the outside of the intermound shales and immediately above the upper mound surface, similar to the distribution of Hustedia (text figure 14). The lowest numbers are found away from the mound in the adjacent shales and within the mound itself (1.3%) perhaps reflecting need for attachment and nutrient supply.

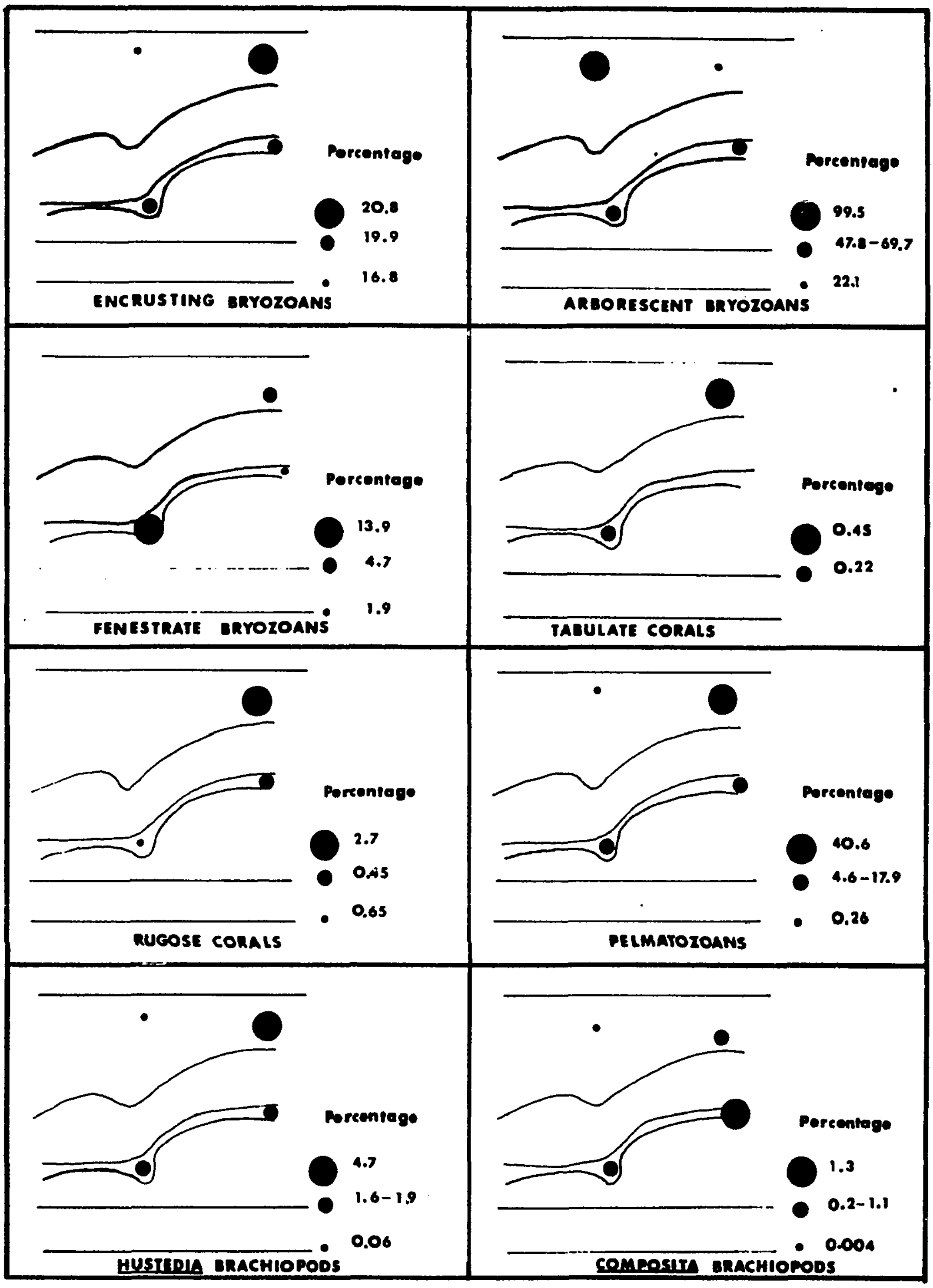
Chonetid brachiopods are generally regarded as a form that prefers open marine conditions and is found above and away from the mound proper; spiriferid brachiopods are found just above the mound surface and could have been attached to the upper surface of the mound (text figure 15). Likewise Cladochonus, a small colonial tabulate coral, is found in intermound shales and on the upper surface of the mound.

Distribution of Biota in Limestone Slabs

Data obtained from the slabs cut from limestone blocks complements the shale data (table 4). Two samples were collected: "D", a brachiopod-*Archaeolithophyllum missouriensis* boundstone with a large amount of carbonate mud, occurring near the top of the irregular algal limestone mound and "E" having a similar composition of brachiopods and *A. missouriensis* with numerous fragments of the undescribed dasycladacean alga genus. The second samplewas taken from the same limestone layer approximately 1.5 feet laterally from the first sample where the limestone is thin and overlain by a thick shale (text figure 15).

The limestone includes 1.35 to 1.0 percent bryozoans, a low figure when compared to other mound (text figure 15). These bryozoans are most abundant where the limestone thickens into the buildup "D". Micrite and brachiopod percentages also increase in this position with scattered goniatites and ostracodes. The new genus of alga and gastropods are associated with higher percentages of *A. missouriensis* in the thin lower areas ("E"). Pelmatozoan fragments are relatively rare (0.66 to 0.16%) but are also common in the thinner limestones where the rugose coral *Lophotichium* is found in less than one percent abundance (text figure 15).

Text Figure 14 :97-6E SHALE FAUNA



Text Figure 15 :97-6E BIOTA

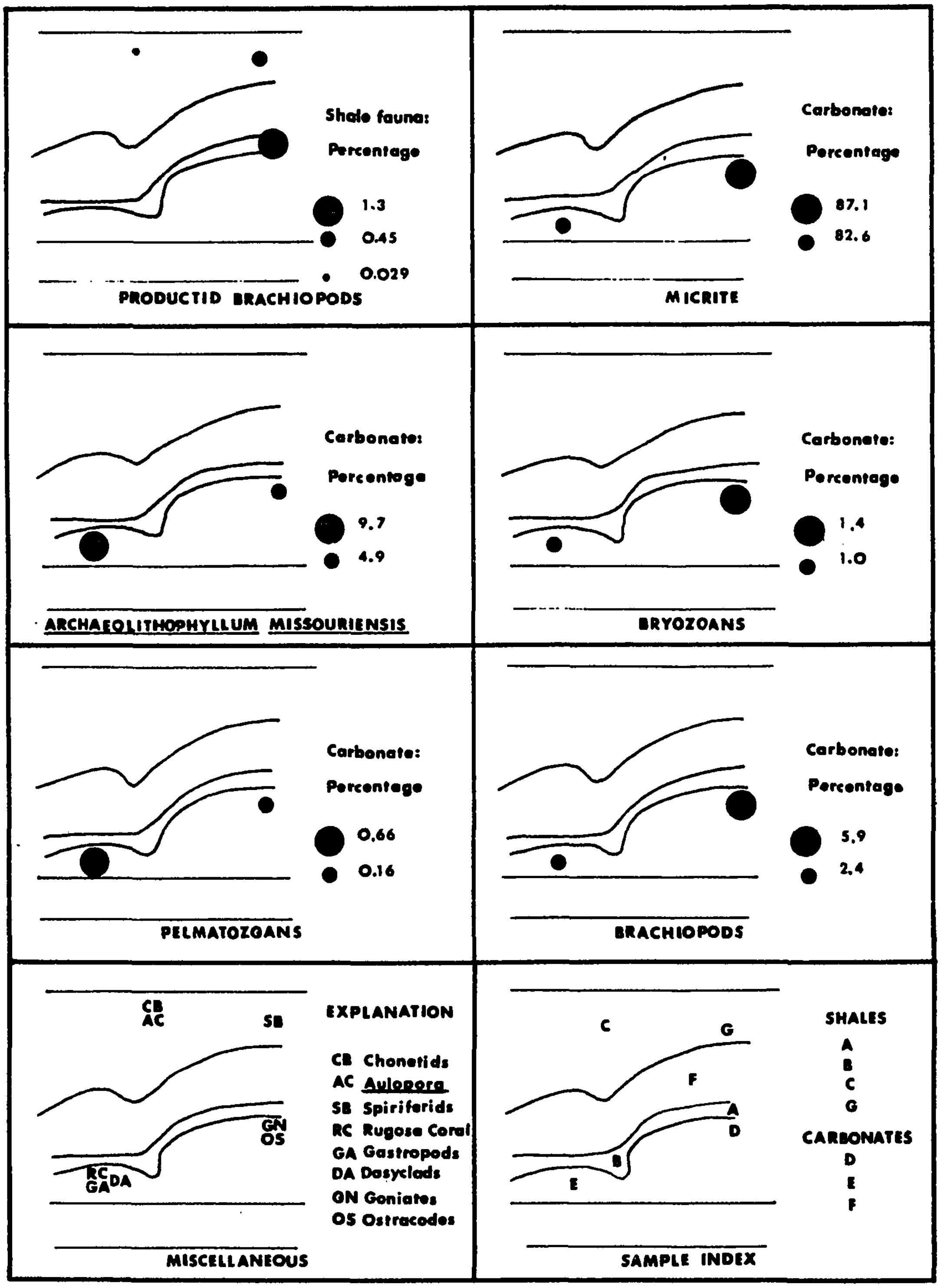


TABLE 4

97-6E CARBONATE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	MICRITE	BRYOZ.	TABULATE CORAL	RUGOSE CORAL	PELM.	OTTO.	ARCH. MISS.	ARCH. LAMEL.	BRACH.	OTHER	OTHER
97-6Ed	87.11	1.35	---	---	0.16	---	4.90	---	5.93	0.50gn	0.16os
97-6Ee	82.63	0.99	---	0.88	0.66	---	9.71	---	2.42	2.20ng	0.11ga

gn: goniatite, ga: gastropod, ng: dasyclad alga, os: ostracode

97-6E SHALE SAMPLE COMPOSTIION

SAMPLE	ENC. BRYO.	ARBOR. BRYO.	TABULATE CORAL	RUGOSE CORAL	PELM.	FENES. BRYO.	HUSTED.	COMPO.	GAST.	OTHER	OTHER
97-6Ea	19.86	69.7	---	0.65	4.56	1.95	1.95	1.30	---	1.30pr	---
97-6Eb	16.85	47.8	0.22	0.45	17.99	13.89	1.59	0.22	0.45	0.45au	---
97-6Ec	---	99.5	---	---	0.26	---	0.006	0.004	0.004ch	0.029pr	0.11au
97-6Eg	20.76	22.12	0.45	2.70	40.6	4.74	4.74	1.12	0.90	0.90sp	0.67pr

pr: productid brachiopod, au: auloporid coral, sp: spiriferid brachiopod, ch: chonetid brachiopod

MOUND WB, 97-6 Station 3

This mound also occurs in the lower mounding interval (unit 6) and is located on the north wall of the central quarry (plate II, figure 2). It is different from other mounds that occur in the lower interval in that it is composed of a series of boundstone lobes similar to mounds in the upper interval (unit 8), but no definite orientation of lobes within the complex was observed. Six distinct mounding layers or lobes occur in the complex and reach a maximum total height of 4.5 feet. The width of the complex is approximately nine feet, the largest development in the lower mounding interval. Each of the lobes appears to have a characteristic composition, although all can be described as boundstones. Unfortunately, the large lobes were not oriented before they were broken free of the complex; however, growth attitude and geopetal structures made orientation of individual samples possible.

General Composition of the Complex

The innermost part of the mound complex has a great amount of micrite that is primarily included in a *Hedraites* (foram)-*Girvanella* (stromatolitic blue-green alga) boundstone that has minor percentages of bryozoans and pelmatozoan fragments associated (text figure 16 and 17). Goniatites, brachiopods, and michelinid corals become common near the outer surface of the innermost lobes. The second lobe is again formed of *Hedraites*-*Girvanella* boundstone with pelmatozoan and bryozoan fragments more common. Significant growth of the green alga *Garwoodia* becomes apparent near the top of the lobe. Minor percentages of *Archaeolithophyllum missouriensis*, michelinid and rugose corals, and brachiopods occur near the top.

In the third lobe of the complex, the entire lower portion of the slabs is dominated by *Garwoodia* with a pronounced absence of *Heteractis*-*Girvanella* that formed the innermost lobes. Michelinid corals are the only faunal elements that are frequently associated with *Garwoodia* in this layer. Minor components include pelmatozoan fragments, bryozoans, *A. missouriensis*, the blue-green algal form genus *Ottonosia*, with very minor amounts of brachiopods. The fourth lobe of the complex has a similar composition.

However, the fifth lobe again illustrates a complete change in compositional structure. The blue-green form genus Ottonosia comprises the major portion of the lobe, but is overlain by the red encrusting alga, A. lamellosum.

The sixth lobe is of yet another character and is best described as a bryozoan-micrite boundstone.

Distribution of Biota

Pelmatozoans are found in relatively low percentages (1-5%) throughout the mound complex. The highest percentages occur in shale cavities in the main part of the complex (13-21%) with the lowest percentages found in the boundstone slabs from the upper lobes of the mound (text figure 16).

The rugose coral Lophotichium varies from absent to 1.3 percent of the boundstone fauna and flora (text figure 16). It is absent in the shale cavities of the main complex, which may indicate that these shales were deposited in cavities that were restricted or almost closed so that they lacked sufficient light or nutrients and clear water circulation. Rugose corals are most abundant in the outer layers associated with bryozoans. However, they are also abundant in the second and third layers, but are present in only minor percentages in the innermost (first) and fourth lobes.

Michelinid corals reach a maximum abundance of 9 percent (text figure 16). Again, michelinid corals like rugose corals are absent from the shale filled cavities that are filled with bryozoan and pelmatozoan fragments. They are found in greatest numbers toward the center of lobes in the complex, with lower numbers toward the tops and bottoms of the mounds. This may reflect the nature of the samples or might indicate an approach to a climax succession followed by a change in environment.

Brachiopods also are found in greatest numbers toward the center of individual lobes (1-2%) and are lowest near the bottom or core lobe (text figure 16). Cavities filled with shales contain large numbers of Composita (upto 8.7%) and Hustedia (6.8%) with lesser amounts of Punctospirifer

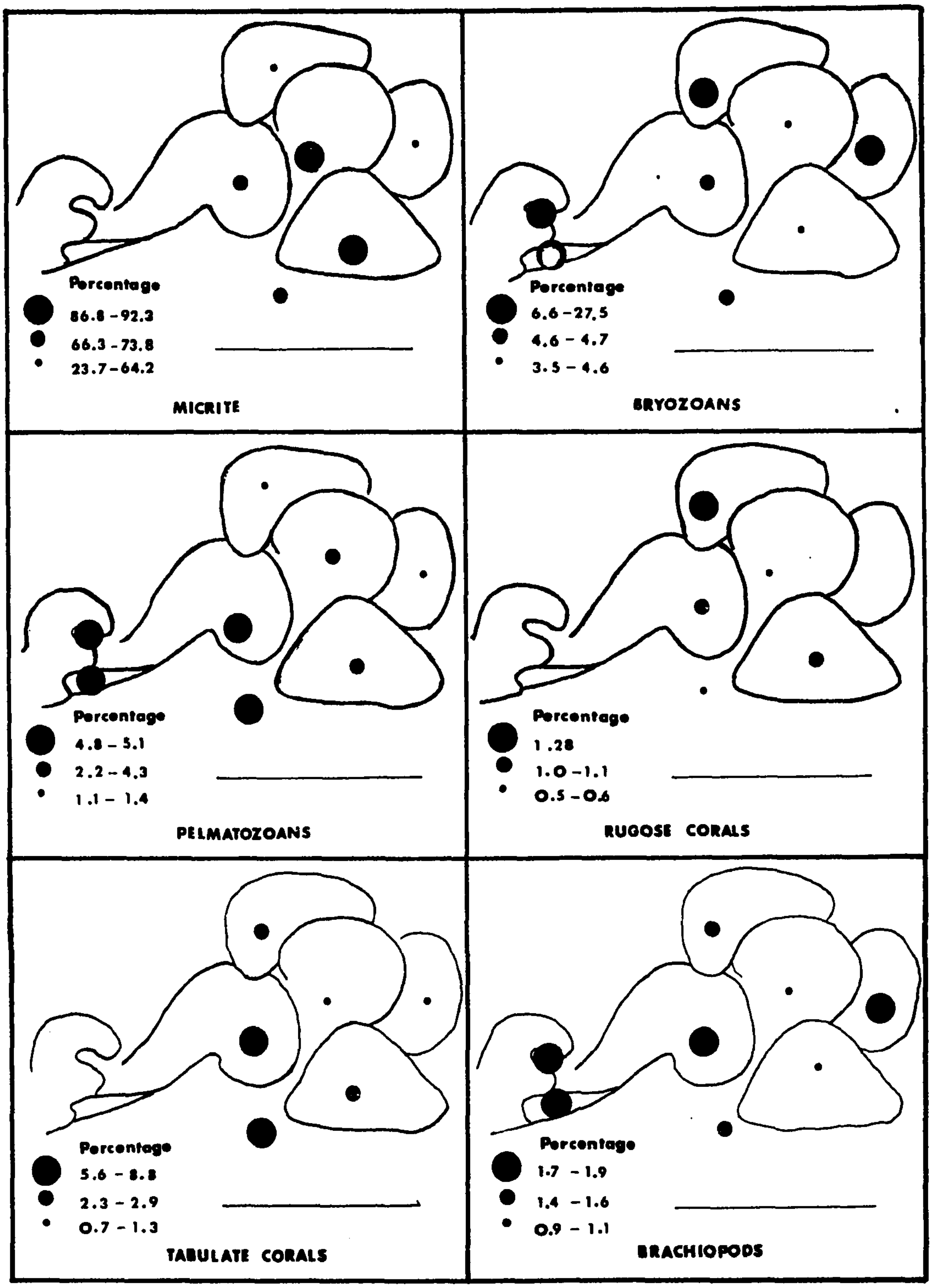
(1.58%) and shell fragments that probably belong to *Derbyia* (6.9%) as shown in text figure 16. The lower shale cavity even contained an ostracode valve.

Goniatite cephalopods are found in the innermost core lobe and central lobes, while gastropods occur primarily in the central lobes. It is possible that the gastropods are associated with the abundant occurrence of the blue-green alga *Ottonosia* on which they could graze. Also, the encrusting red alga *Archaeolithophyllum lamellosum* has the same distribution and relative abundance as the gastropods (text figure 17).

A. missouriensis, also a red calcareous encrusting alga, is found in concentrations up to 1.4 percent (text figure 17). It is absent from shale cavities as would be expected and is most abundant near the outer layer of the mound complex. This is in contrast to its presence primarily near the core of mounds in the upper mounding interval and may indicate a different history for mounds in the lower interval. *Garwoodia*, as mentioned previously, is the dominant element of the middle lobes of the complex, while *Girvanella-Heteractis* boundstone forms the innermost lobes.

Bryozoans are most abundant in the outermost layers of the complex and often encrust the outer surfaces and sides. Encrusting forms are most abundant on the outer surfaces of the highest lobe and in the area lining the lower shale cavity; however, large amounts of arborescent bryozoans (up to 53.2%) are found in the higher shale cavity. Shale cavities are dominated by the bryozoan fauna that comprises nearly 72 percent of the lower cavity and 61 percent of the higher cavity (text figure 16).

Text Figure 16 : 97-6 WB BIOTA



Text Figure 17 : 97-6WB BIOTA

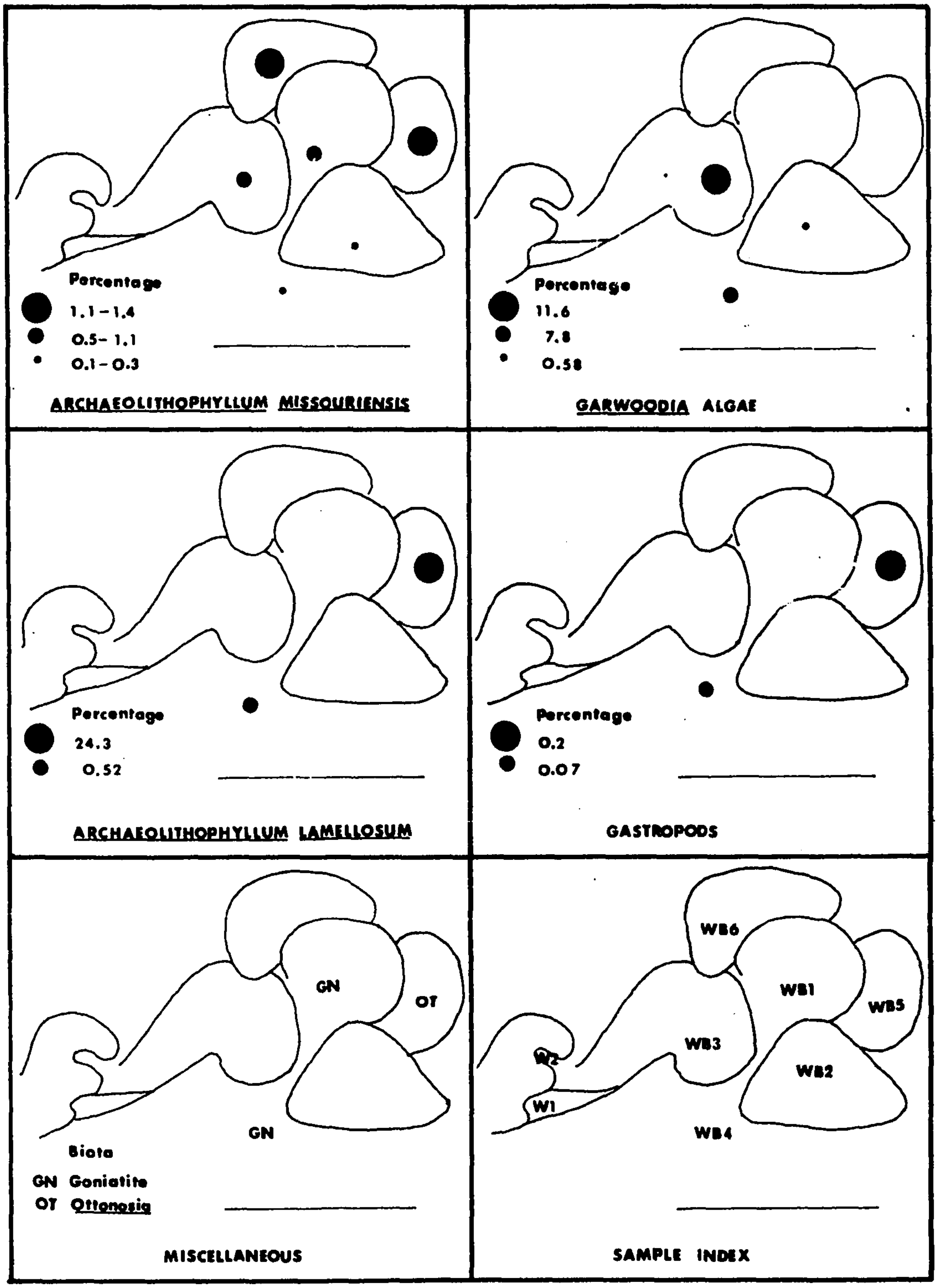


TABLE 5

97-6 WB CARBONATE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	MICRITE	BRYOZOA	TABULATE CORAL	RUGOSE CORAL	PELM.	OTTO.	ARCH. MISS.	ARCH. LAMEL.	BRACH.	OTHER	OTHER
WB-1	86.8	4.61	1.24	0.53	4.26	---	10.6	---	1.05	0.35gn	---
WB-2	90.29	3.57	2.32	1.06	2.22	---	0.29	---	0.96	0.58gw	---
WB-3	66.3	4.67	8.77	1.10	4.85	0.12	0.55	---	1.72	11.65gw	---
WB-4	73.8	4.64	5.61	0.52	5.01	---	0.14	0.52	1.42	0.07ng	7.8gw 0.29gn
WB-5	23.33	6.67	0.78	---	1.37	39.8	1.37	24.31	1.96	0.20ga	---
WB-6	64.2	27.5	2.91	1.28	1.19	---	1.19	---	1.54	---	---

gn: goniatite, gw: *Garwoodia*, ng: dasyclad alga, ga: gastropod

97-6 WB SHALE SAMPLE PERCENTAGE COMPOSTIION

SAMPLE	ENCR. BRYO.	ARBOR. BRYO.	TABULATE CORAL	RUGOSE CORAL	PELM.	FENES. BRYO.	HUSTED.	COMPO.	GAST.	OTHER	OTHER
W-1	28.57	34.39	---	---	12.69	8.99	3.70	2.11	6.87db	1.58ps	1.05os
W-2	7.12	53.2	---	---	20.74	0.61	6.81	8.66	---	0.61ps	2.16db

db: *Derbyia* sp., ps: *Puncotospirifer* sp., os: ostracode

MOUND 97-8, Station 4

This mound consists of a complex series of algal-bryozoan boundstone lobes similar to those described in the previous mound. The lobes, however, appear to be oriented with a steep bryozoan-algal roll that faces into gray shale and with a backside that thins gradually against lime grainstone channel deposits (plate III, figures 1 and 2; plate IV, figure 1). The mound complex is six feet high and ten feet across and is exposed at the south end of the deep art of the central quarry on the east wall. This complex was also included in the original section measured by Sutherland and Henry (in press) in this quarry.

Following the mound descriptions are text figures illustrating biotic compostion (text figures 18-23), tables of percentage composition (tables 6 and 7), and thin-section descriptions.

Distribution of Components in Slabs

There is no obvious pattern to the distribution of micrite that may have been stabilized by stromatolitic blue-green algae. Micrite seems to be most abundant near the shales where lobes curl and in lowest percentages adjacent to lime grainstones and in the upper part of the lithified cavity sediments (text figure 18).

Bryozoans are most common in the rolls of lobes adjacent to shales and on the upper part of the sloping back sides of lobes (text figure 18). They are least common near the core, but the pattern of distribution is extremely variable. This may be the result of lumping all habits of bryozoans together in the shale samples. Encrusting forms are more common on the back side that abutts the grainstone channel deposits. In this position, fenestrate forms could take maximum advantage of agitated waters of the channel for nutrients and oxygen as do many modern crinoids.

Pelmatozoans are most abundant in cavities and on the outside of lobes (text figure 18). All are fragments, as no complete blastoids or crinoids have been found associated with the mounds of the quarry, and probably represent transported debris accumulating adjacent to and within open spaces in the mounds. Lowest percentages of pelmatozoan fragments are found within the mound itself.

Michelinid and rugose corals have a similar distribution within the mound complex (text figure 18 and 19). They are most abundant on the shale side of lobes away from channel conditions where the water was probably calmer, more oxygenated and nutrient-rich. These forms also appear to inhabit the bottoms of lithified cavities where the corals appear to be in growth position. This is noted in other areas within the upper mounding interval and may indicate that Morrowan rugose and tabulate corals were ahermatypic, inhabiting enclosed, protected areas within the mound complex. Lowest abundances of rugose and tabulate corals were found in the lime grainstone channel deposits, an agitated area unfavorable to coral development.

Brachiopods, probably including both Hustedia and Composita, are most abundant in the outer rolls near the center of the complex and on the steep front side of the lobe at the top of the complex (text figure 19). Perhaps these brachiopods preferred more open marine conditions as well as more protected habitats found in the upper part of the lithified cavity. Although goniatites are found primarily low in the mound complex, gastropods are most abundant in the highest lobe of the complex. The colonial coral Cladochonus is found primarily on the channel side of the highest lobe where it may reflect the approach of cessation of channel deposition (text figure 20).

The encrusting red calcareous alga Archaeolithophyllum is again represented by two species (text figure 19 and 20). A. lamellosum is found only in the lowest parts or the core of the mound complex. However, A. missouriensis is most abundant on the top of the highest and lowest (core) lobes and adjacent to the lime grainstone channel deposits. This is also common in modern marine environments where calcareous red algae thrive at shallow depths with maximum wave agitation (W. Adey, 1974, oral communication). This alga is also common in the upper part of the lithified cavity. Areas of low occurrence of the red alga are especially pronounced down the shale face of the mound complex where there may have been insufficient turbulence. However, the distribution is not clearly defined as this alga is not generally abundant.

The green alga Garwoodia has a more limited, but also more obvious distribution (text figure 19). The most abundant occurrences are found on the front side of the highest lobe with another maximum abundance occurring near the middle of the lobes in the channel deposits. Lowest abundances seem to occur where the mound abutts against channel grainstones.

The undescribed dasycladacean genus shows a complex distribution with greatest abundances near the center or core lobe of the mound complex as in the red alga A. lamellosum, but also in a lobe just above and to the center of the core (text figure 20). The lowest abundances are found in layers between lobes and on both sides of upper lobes and in areas away from the mound complex.

Biotic Distribution in Shale Samples

Encrusting bryozoans are found primarily on the tops of mounds with a maximum abundance of up to 11 percent (text figure 21). Lesser percentages of encrusters are found in the shales within and above or below the lobes of the mound complex. No encrusting forms are found in the shales away from the mound proper, which may indicate that these shales are later in age than the mound itself and merely filled in around the complex.

Arborescent bryozoans are found in percentages up to 58 percent in the shale sequence below the mounding interval and in the shales above this mound complex, as well as on the backsides of lobes in shales disassociated with the mound complex (text figure 21). These shales may have been deposited in an environment near agitated channel waters that were well oxygenated and nutrient rich. These shales are a striking contrast to those found in the "equivalent" shales farther northward and associated with the next mound development (Mound YB) and buff-green arenaceous shales high on the front side of this mound that contain leaf and stem fragments in "mudballs" with transported marine material.

Fenestrate bryozoans comprise up to 18 percent of the components of the shales above the mound lobes on the front or seaward side of the complex, although they are present in lesser amounts toward the channel. Scattered individuals are found in shales within the mound itself.

Rugose corals comprise up to 5 percent of the faunal components of the shales between lobes and are associated with algal nodules on the channel side (text figure 22). They occur as rare inhabitants of intermound shales. Michelinid corals exhibit a similar distribution, but reach a maximum of only 3.4 percent (text figure 22).

Pelmatozoan fragments, as usual, form a substantial percentage of the shale fauna with a maximum abundance of 87.7 percent occurring in the grainstone channel deposits on the backside of the mound complex (text figure 21). Other large amounts occur in the intermound shales with lesser percentages occurring above and below lobes of the complex. Abraded fragments occur in the "equivalent" buff-green shales toward the steep side and associated with the next mound toward the north. There is a surprising lock of pelmatozoan fragments in the shale that occurs at the top of the outer roll. This absence may be explained by the lack of a trapping or current shadow to allow deposition of fragments as was noted in Mound 97-6, station 1.

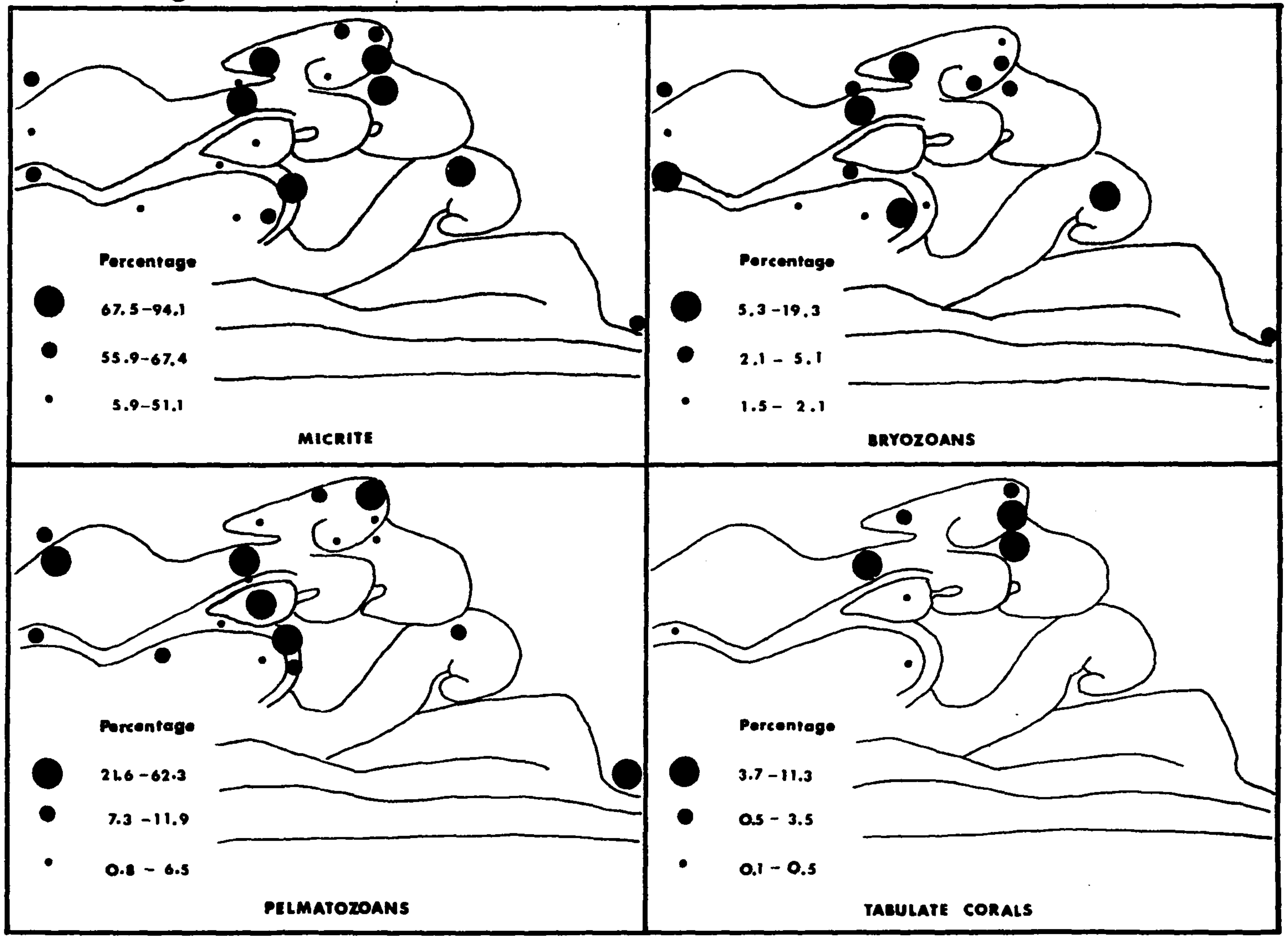
Composita brachiopods are very abundant and may comprise 71.5% of the shale fauna in shales located within the mound complex and above the lime grainstone channel deposits (text figure 22). They also form a substantial part of the fauna in shales over the tops of mounds and are transported into the "equivalent" shales. They are least abundant on the backside or channel side of the complex.

Hustedia brachiopods exhibit a similar distribution forming up to 11 percent of the fana in internal shales, but is least abundant in the innermost shales where Composita is most abundant, perhaps a reflection of competition (text figure 22). Hustedia is also abundant on the tops of lobes and is associated with nodules in the shales on the channel side.

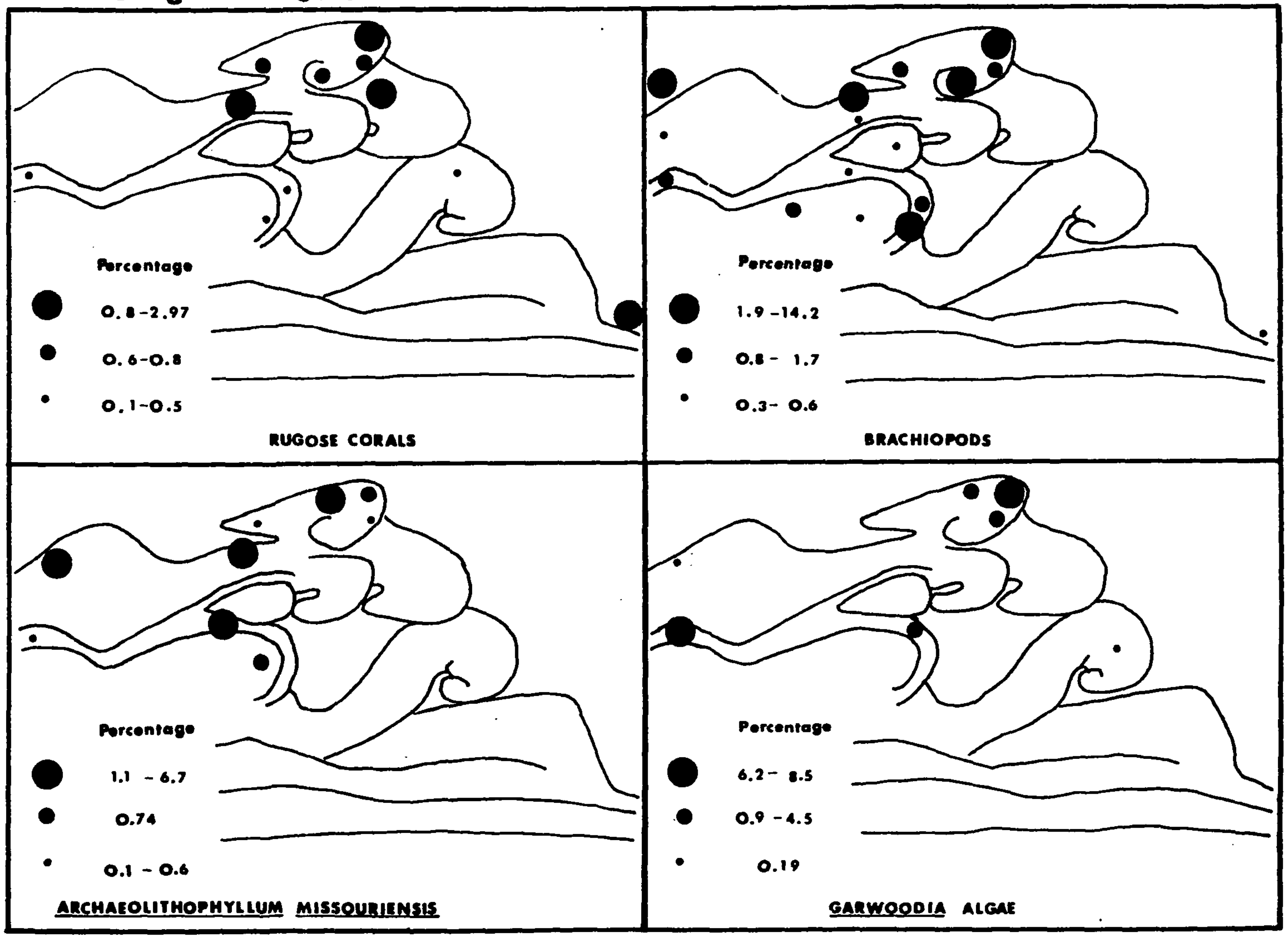
Other elements are distributed as follows: spiriferid brachiopods are associated with internal cavities and tops of the mound complex, but never exceed 2 percent of the total composition. Productid brachiopods are found primarily with shales above lobes as are the pelecypods. Trilobites are found associated with the upper shales on the channel side while gastropods and encrusting forams are generally associated with lagoonal shales ("equivalent" shales) and shales above and within the mound complex. Cladochonus corals are associated with the upper shales and and intermound shales to the channel side. Goniatites appear to be restricted to the intermound shales (text figure 23).

The buff-green calcareous, arenaceous shales (unit 9) that occur laterally adjacent to the mound complex toward the south and associated with the next mound toward the north are comprised of 47.5 percent abraded and worn pelmatozoan fragments, 8.4 percent abraded *Composita* valves, 2.0 percent abraded *Hustedia* valves, associated with 2.6 percent siliceous mudballs that do not disaggregate in the shale wash, 35.5 percent stem and leaf fragments (text figure 23), and 4.0 percent gastropods that do not appear to be of the normal marine type. This shale is interpreted as being a lagoonal or terrestrial deposit into which reworked marine fossils were transported. The nature of the relations of the 10 to 12 foot thick shale with the mounds it surrounds in the uppermost interval, leads to the speculation that the shale was deposited after mound development, a subject discussed more fully in the text.

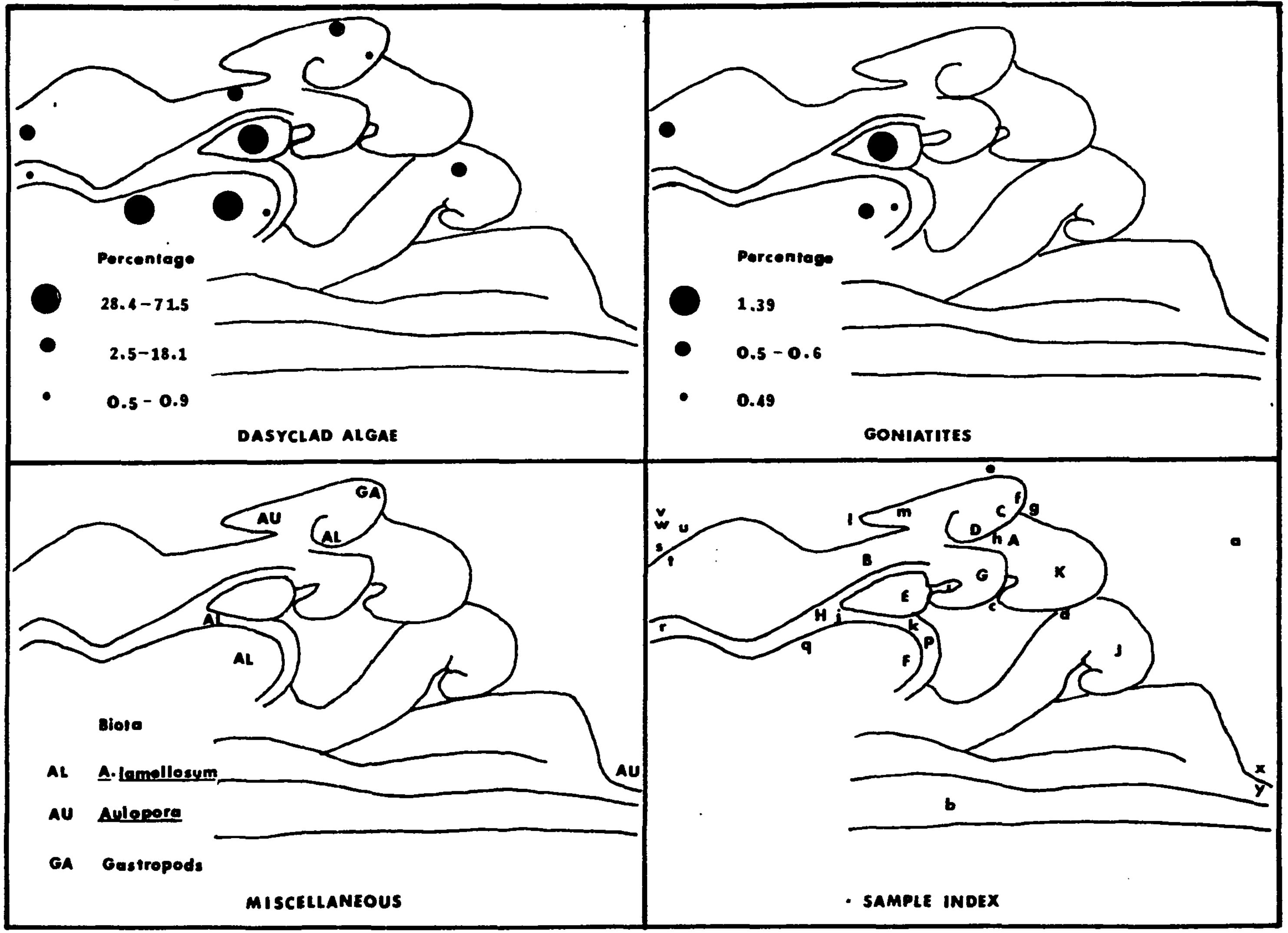
Text Figure 18: 97-8 CARBONATE BIOTA



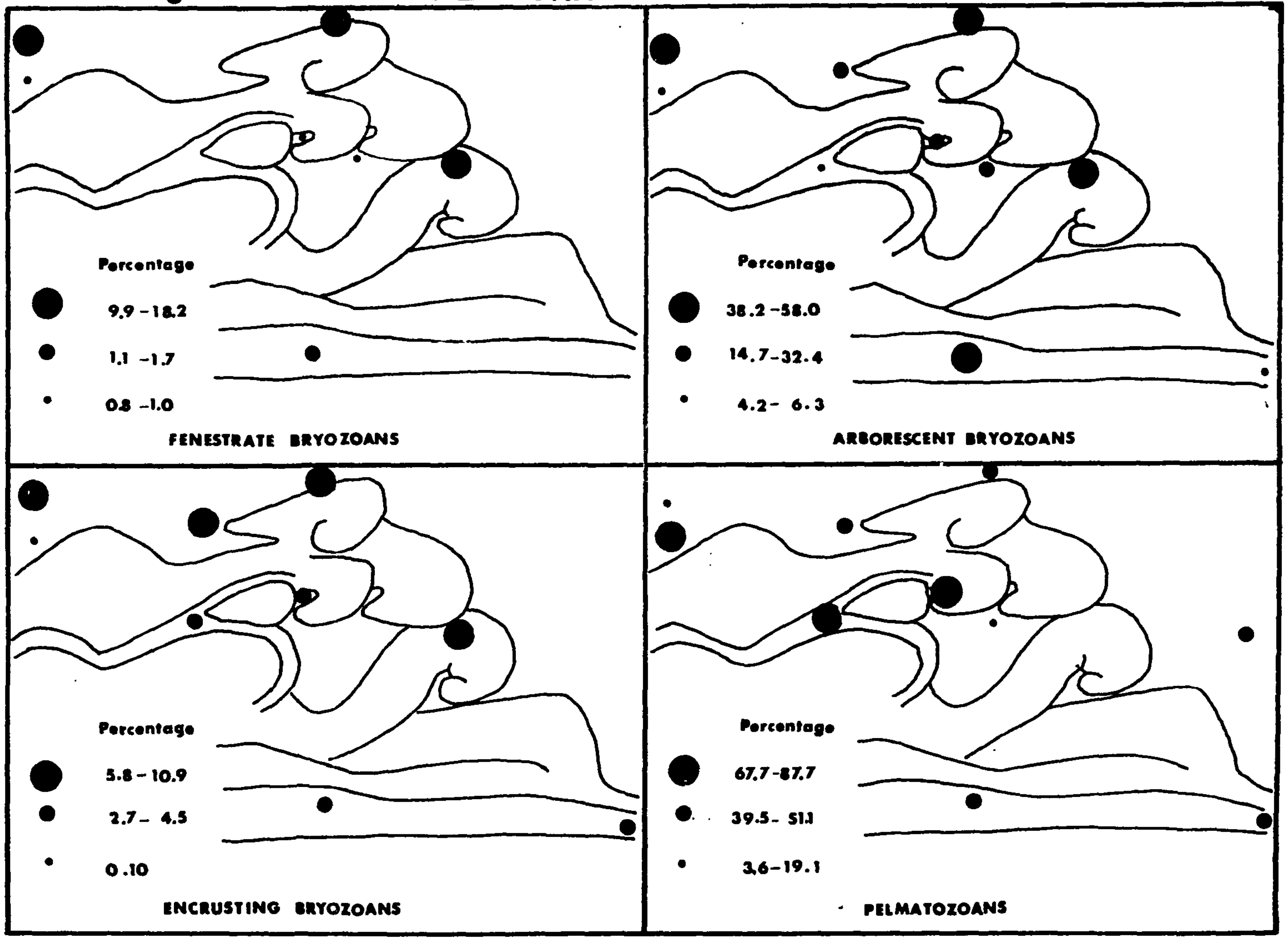
Text Figure 19 : 97-8 CARBONATE BIOTA



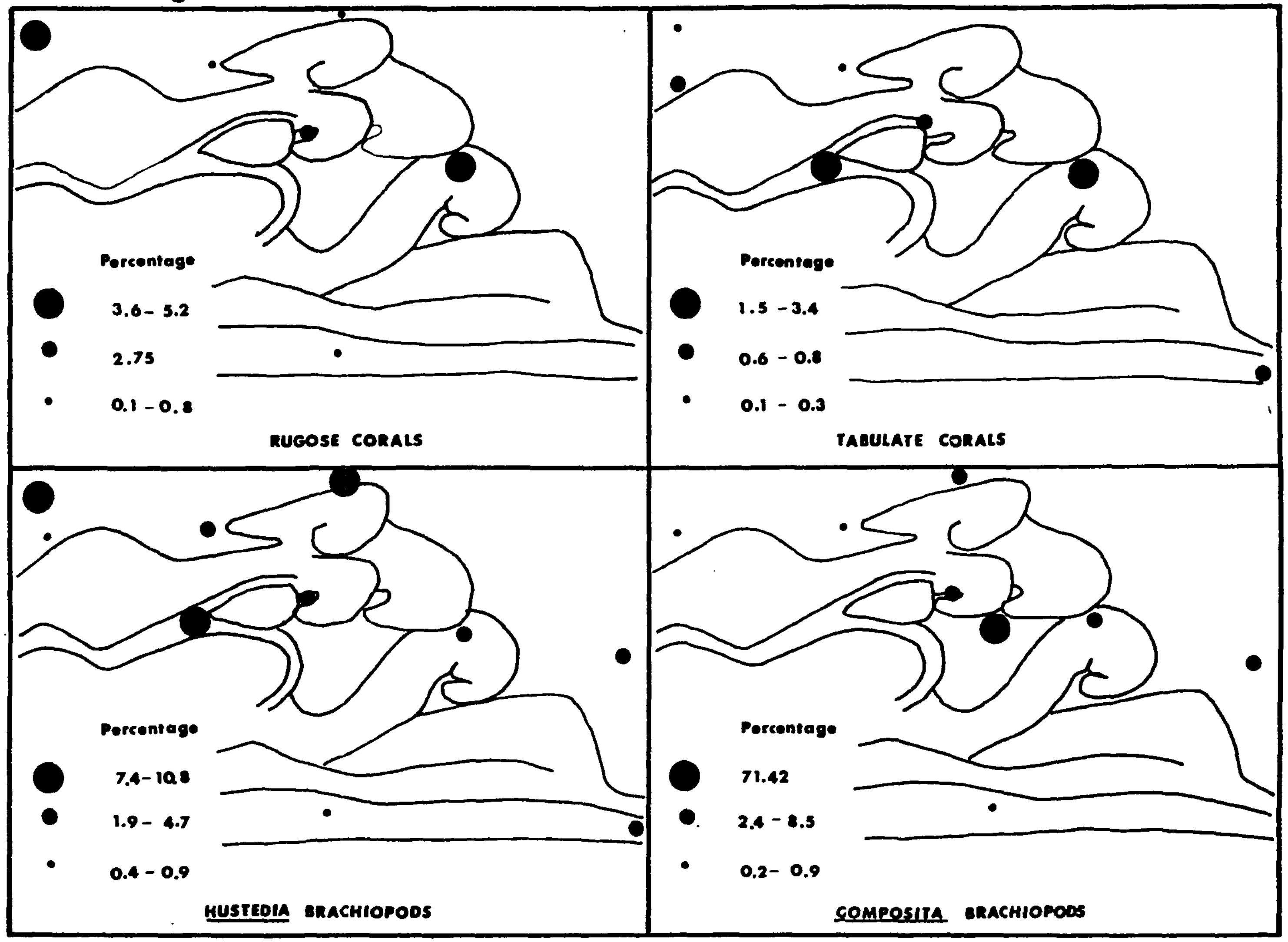
Text Figure 20: 97-8 CARBONATE BIOTA



Text Figure 21 : 97-8 SHALE FAUNA



Text Figure 22 : 97-8 SHALE FAUNA



Text Figure 23: 97-8 SHALE FAUNA

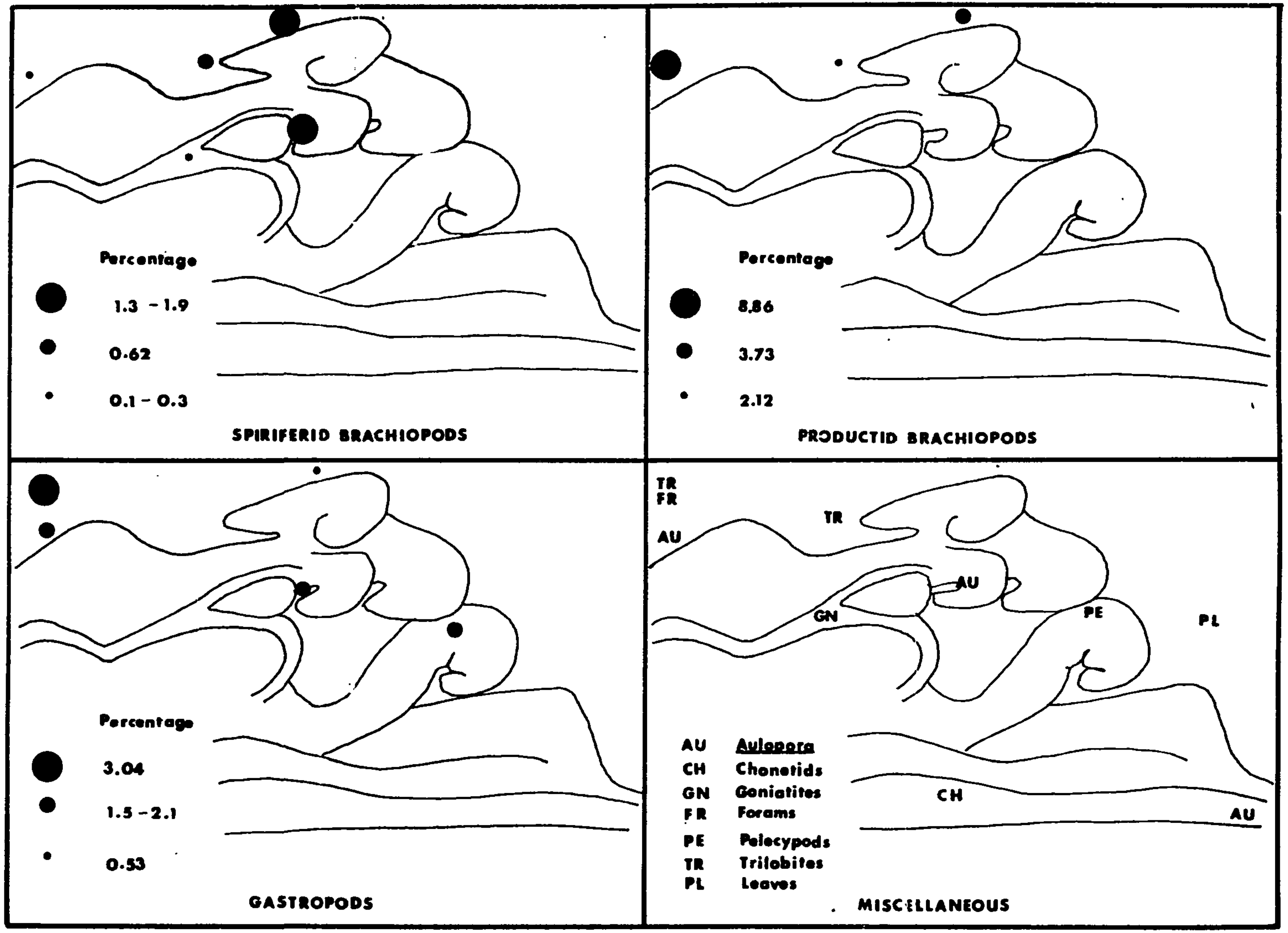


TABLE 6

97-8 CARBONATE SAMPLE PERCENTAGE COMPOSTION

SAMPLE	MICRITE	BRYOZOA	PELM.	TABULATE CORAL	RUGOSE CORAL	OTTO.	ARCH. MISS.	GARW.	BRACH.	OTHER	OTHER
97-8F	61.79	2.05	21.07	1.02	1.28	---	1.02	8.48	2.05	0.51ng	0.51ga
97-8G	83.2	2.78	2.78	7.73	0.61	---	0.30	0.92	1.54	---	---
97-8J	94.0	2.12	0.85	---	2.97	---	---	---	---	---	---
97-8K	70.7	1.73	23.8	0.52	0.17	---	---	2.08	0.86	---	---
97-8M	72.35	17.55	2.76	3.55	0.78	---	0.59	---	1.18	0.78au	---
97-8N	57.0	---	11.86	---	---	---	6.77	4.51	1.69	18.07ng	---
97-8P	67.4	19.25	7.65	0.49	0.49	---	0.74	---	2.71	0.74ng	0.49gn
97-8Q	51.11	1.55	7.31	---	---	---	---	---	0.88	39.99ng	---
97-8R	56.0	24.4	8.94	0.36	0.18	1.82	0.18	6.20	0.91	0.91ng	---
97-8T	30.75	1.89	62.3	---	---	---	1.13	0.19	0.38	2.65ng	0.56gn
97-8U	62.22	4.42	19.46	---	---	---	---	---	14.15	---	---
97-8X	64.6	2.55	31.06	---	0.85	---	---	---	0.42	0.42au	---
97-8b1	82.7	5.37	1.61	3.76	5.91	---	---	---	0.54	---	---
97-8b2	50.60	2.44	34.54	---	---	---	1.22	---	4.88	5.50ng	---
97-8d	34.25	5.01	3.75	11.27	0.75	37.75	5.01al	---	2.00	---	---
97-8e	17.56	---	52.00	0.39	---	---	---	---	0.39	28.4ng	1.39gn
97-8f	6.01	1.63	6.55	---	---	---	13.1al	---	0.54	17.5ng	0.54gn
97-8j	67.5	17.51	11.67	---	0.50	---	---	0.25	---	2.53ng	---

ng: dasyclad alga, ga: gastropod, au: auloporid coral, gn: goniatite, al: <u>Archaeolithophyllum lamellosum</u>

TABLE 7

97-8 SHALE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	ENCR.	ARBOR.	FENES.	RUGOSE	TABULATE	RUGOSE	HUSTED.	COMPOS.	GAST.	OTHER	OTHER
97-9A	---	---	---	---	2.57mb	47.5	1.92	8.36	4.18	14.79st	20.57lv
97-8B	4.44	51.0	1.63	0.70	---	39.5	0.93	0.23	---	1.40ch	---
97-8C	---	15.17	0.89	---	---	3.57	---	71.42	---	8.92	---
97-8D	10.88	58.0	12.95	5.18	1.55	---	4.66	3.63	1.55	1.55pe	---
97-8E	5.86	40.0	18.13	0.80	---	14.66	7.46	2.40	0.53	0.26pe 4.26fm	1.86sp 3.73pr
97-8I	2.75	14.75	1.0	2.75	0.75	67.75	4.50	2.75	1.50	0.25au	1.25sp
97-8J	3.68	6.23	---	---	3.39	74.5	10.76	---	---	1.13gn	0.28sp
97-8L	8.23	32.4	1.62	0.12	0.12	51.1	2.49	0.87	0.12tr	2.12pr	0.62sp
97-8S	0.10	6.29	1.65	---	0.61	87.7	0.41	0.72	2.06	0.30au	0.10sp
97-9V	6.37	38.2	9.97	3.60	0.28	19.11	7.47	0.83	3.04	8.86pr	1.94fm 0.28tr
97-8Y	3.49	4.68	1.16	---	0.78	43.7	1.94	0.78	---	1.16au	---

mb: mud ball, st: stem, lv: leaf, ch: chonetid brachiopod, pe: pelecypod, sp: spiriferid brachiopod, fm: foraminifera, au: auloporid coral, gn: goniatite, pr: productid brachiopod, tr: trilobite

Thin-Section Descriptions

Unit No.	Description
97-8a, Nodule 2.5 feet above base	RECRYSTALLIZED SKELETAL (PELMATOZOAN-SPICULE) DOLOMITIC LIME MUDSTONE (packed biomicrite); medium to coarse-grained,well sorted including pelmatozoan fragments(10%) and spicules (25 to 30%), floating grains with minor overgrowths and moderate to extensive solution, replacement by dolomite and recrystallization of fossil clasts to spar; moderate compaction prior to dolomitization with micro- and mega-fractures; pelleted micrite matrix (55 to 60%), minor pyrite (2%) and iron oxides (1%); primary porosity obscured (plate IX, figure 2)
97-8E	DASYCLAD-PELMATOZOAN LIME PACKSTONE(packed biomicrite); medium to very coarse-grained, moderately well sorted grains of dasycladacean alga (10 to 25%), pelmatozoan fragments (25 to 50%) with minor rugose coral, foraminifera, and *Archaeolithophyllum lamellosum* debris, floating grains to tangential contacts, minor to moderate solution and overgrowth, minor dolomitic replacement and recrystallization of clasts to spar (also matrix); moderate post recrystallization compaction with fractures cutting clasts; recrystallized micritic matrix (25 to 40%); no accessory minerals ; 15 to 25 % porosity including spar-filled shelter structures lined by micro-spar or submarine cement
97-8a, North Quarry	RECRYSTALLIZED GONIATITE LIME WACKESTONE (sparse biomicrite); fine to very coarse-grained, poorly sorted grains of pelmatozoans (20%), *A. missouriensis* (5%), dasyclad alga (1%), goniatite cephalopods (25-30%), and *Girvanella* alga (5%); contacts floating, minor overgrowths and solution, silicification of pelmatozoan debris, extensive replacement of fossil clasts to spar; moderate compaction with mega-fractures; micritic matrix partially pelleted (50 to 60%), pyrite (5%), 20 to 25 % porosity including skeletal voids, shelter structures, and sponge borings filled with several generations of spar and micro-spar
97-8 AG	RECRYSTALLIZED DASYCLAD-PELMATOZOAN LIME PACKSTONE (sparse to packed biomicrite); medium to very coarse-grained, moderately to well sorted grains of pelmatozoan fragments (20%), dasycladacean alga (50%), foraminifera (5%), *Archaeolithophyllum missouriensis* (5%), and rugose corals (5%), floating to tangential contacts, minor solution and overgrowths, slight silicification of pelmatozoan clasts and recrystallization of clasts to spar; compaction minor with a few micro-fractures; recrystallized micritic matrix (25 to 45%); original porosity less than 5 % spar-filled shelter structures and skeletal voids (plate XIV, figure 3; plate IX, figure 5)

Unit No.	Description
97-8 AE	RECRYSTALLIZED PELMATOZOAN-DASYCLAD LIME PACKSTONE (sparse to packed biomicrite); medium to very coarse-grained, moderately to well sorted grains of pelmatozoans (55%), dasyclad alga (35%), foraminifera (5%), and rugose corals and *A. missouriensis* (5%), floating to tangential contacts, minor solution and overgrowths, silicification of pelmatozoan debris, recrystallization of skeletal clasts to spar; minor compaction with micro-fractures; recrystallized micritic matrix (25 to 40%); less than 5 % porosity consisting of spar-filled skeletal voids and shelter structures (plate IX, figure 3)
97-8 AD	SKELETAL (PELMATOZOAN-DASYCLAD) LIME WACKESTONE (sparse biomicrite); fine to very coarse-grained, moderately to poorly sorted grains of up to 20 % pelmatozoan debris, bryozoans (10%), 50 to 70 % dasyclad alga, and 5 % brachiopods, floating grains, minor to moderate solution and overgrowths, silicification of pelmatozoan and bryozoan material and recrystallization of clasts to spar; no compaction observed; micritic matrix (50 to 65%), 5 to 10 % pyrite; 10 to 15 % porosity as skeletal voids and shelter structures with a few sponge borings filled by very fine sediments and spar
97-8 EA	STROMATOLITIC (*OTTONOSIA*) BOUNDSTONE (biolithite); very fine grains of pelmatozoan, foraminifera, and dasyclad alga debris floating in *Ottonnosia* boundstone, very well sorted, silicification of pelmatozoan fragments; extensive compaction with mega- and micro-fractures and mudcracks; minor micritic matrix, quartz silt (5%), and anhydrite pseudomorphs replaced by calcite (1%); 15 to 20 % porosity as mudcracks and bird's-eye structures with spar filling (plate IX, figure 6)
97-8 Da, center	SKELETAL (*ARCHAEOLITHOPHYLLUM*-MICHELINID) LIME WACKESTONE TO BOUNDSTONE (biolithite); fine to very coarse grains of *A. lamellosum* (10-50%), michelinid coral (10-50%), pelmatozoans (5%), and brachiopods (10-25%), floating to tangential contacts, moderate to minor solution and overgrowths, silicification of pelmatozoan debris, no recrytallization of clasts; only minor compaction with a few micro-fractures; micritic matrix (40-45%); 15 to 30 % porosity including skeletal voids and sponge borings filled with fine sediments and spar, lined by micro-spar (plate X, figure 3)

Unit No.	Description
97-8 Db, middle	*ARCHAEOLITHOPHYLLUM* BOUNDSTONE (biolithite); fine to very coarse grains in *Ottonosia* and *Archaeolithophyllum lamellosum* with michelinid corals, floating grains, minor solution and overgrowths, silicification of very minor pelmatozoan debris, no recrystallization; extensive compaction with mega- and micro-fractures cutting clasts and matrix; minor micritic matrix, ooliths (5%), pyrite (5%), dolomite rhombs (5%), and anhydrite pseudomorphs (1%); 14 to 40 percent porosity in bioturbated matrix includes fractures and sponge borings filled with fine sediments and spar and lined with micro-spar (plate X, figure 2)
97-8 Dc, outer	STROMATOLITIC (*OTTONOSIA*) BOUNDSTONE (biolithite); fine to medium grains of bryozoan fra-ments, brachiopods, and mollucs (5%) in *Ottonosia* boundstone, moderately corted, floating to tangential contacts, no overgrowths, moderate solution, silicification of bryozoan fragments, no recrystallization of clasts; extensive compaction with large fractures and brecciation of clasts; minor (5%) micritic matrix, ferroan dolomite ooliths (5%), pyrite (5%), and organic material (less than 1%); 15 to 20 percent porosity consisting of fractures and sponge borings filled with fine sediments, ooliths, and spar with micro-spar lining (plate X, figure 1)
97-8 Ba-d, "core"	PELMATOZOAN LIME GRAINSTONE (packed biomicrite); fine to medium grains of pelmatozoans (80 to 90%) and 20% algal and brachiopod debris, well sorted with minor graded bedding, tangential to sutured grain contacts, with minor overgrowths and moderate to extensive solution, silicification of pelmatozoan grains, but no recrystallization noted; compaction illustrated by two directions: vertical micro-fractures and horizontal stylolites near edge; micritic matrix (5 to 10%), ooliths (10%), glauconite pebbles (5%), ferroan dolomite in ooliths, and quartz silt (5%); less than 5 percent porosity consisting of shelter structures, skeletal voids filled with fine sediments and spar
97-8 Ba-d "outer"	BRYOZOAN BOUNDSTONE TO *LOPHOTICHIUM* LIME MUDSTONE (biolithite to sparse biomicrite); medium to very coarse grains of *Lophotichium* rugose corals (20%) and brachiopods (5%) in 50 % bryozoan boundstone, moderately sorted, floating grains, minor overgrowth and solution, silicification of bryozoan material, no recrystallization; moderate compaction with vertical micro-fractures; micritic matrix (30 to 50%), ooliths (5%), glauconite (less than 1%), pyrite (5%) with no quartz silt in outer layers; 30 to 40 percent porosity as sponge borings filled with fine sediments and spar and lined by micro-spar (plate X, figure 4)

Unit No.	Description
97-9d North Quarry	BRACHIOPOD-GONIATITE SKELETAL LIME WACKESTONE (sparse biomicrite); fine to very coarse grains of goniatite cephalopods (20%), brachiopods (20%), gastropods (5%), dasyclad alga (5%), *Archaeolithophyllum missouriensis* (10%), and pelmatozoans (5%), poorly sorted, floating grains, minor to moderate overgrowths and solution, silicification of pelmatozoan material, recrystallization of clasts to spar; no compaction; over 50 % micritic matrix with less than 5% pyrite; 20 % porosity consists primarily of skeletal voids with a few sponge borings filled with very fine sediments and spar and lined by micro-spar (plate XI, figure 1)

MOUND YB, 97-8, Station 5

This mound occurs within the siltstone and calcareous shales of unit 9 as described by Sutherland and Henry (in press). The unit is laminated to thinly and irregularly bedded with up to 5 ffet of relief at the top due to compaction. Locally, calcilutite nodules or layers are developed near the top of the unit, while algal nodules patches and mounds are developed near the base of the unit to the north of the large mound complex in unit 8. This mound is located at station 5 (see topographic base, text figure 3), and it occurs above the level "terrace" bulldozed during quarry operation on the east wall of the central quarry. This permits relatively easy access to the mound, which resulted in more detailed investigation. Before sampling the mound itself, approximately three days were spent attempting to remove shale that surrounded the mound (plate V, figure 2). Although it was hoped that this would expose the eastern surface of the mound, this was not accomplished as the mound appears to extend backward into a large volume of shale. The mound itself is approximately 3.5 feet high and 8.3 feet across the face and is overlain by 6.5 feet of siltstone and shale that are truncated at the top by oolitic-pelmatozoan lime grainstone with small-scale cross-bedding (unit 10).

The internal structure of this mound is particularly interesting. The mound and others similar to it but occurring as talus blocks in the north quarry were described by Sutherland and Henry (in press) as having a "jelly-roll" structure. The mound consists of a series of boundstone layers that wrap around each successive layer on at least three sides resulting in a "jelly-roll" appearance. When compared to the lobed mounds, the major distinction appears to be that these mounds do not abutt against grainstone channel deposits, but are surrounded on all visible sides by shale. In order for the layers to wrap around each other in this manner, however, it was necessary for the shale to have been deposited after mound formation since shale would have prevented development of growing surfaces on the sides and front of the mound. Therefore, the buff-green siltstone and shales of unit 9 must have necessarily been deposited after mound development.

Distribution of Biota in Slabs

At first glance, the distribution of the bryozoans appears to be erratic with low percentages near the center of the mound (text figure 24). These percentages range up to 39 percent (table 8), a substantial contribution for an organism that was though to make a negligible contribution to modern reefs with at most, only a baffeling effect on the surrounding sediments. Closer examination of the bryozoan types present reveals that fenestrate forms occur only in the inner two limestone layers, while encrusting forms occur in greatest numbers at higher levels in the mound on tops of layers and lining small cavities. Examination of modern bryozoans, reveals that most fenestrate forms are found in areas of lower energy. Thus, increased numbers of encrusting forms with lack of fenestrate forms may be indicative of shallowing water during mound development.

A single species of rugose coral, Lophotichium amoenum, is found in the mounds (text figure 24). The lowest percentage of this coral occurs on the outside and top layers of the mound, while peak percentages that are less than 2 percent occur toward the center of layers. This distribution might be explained by the need for initial attachment of rugose corals in the post larval stage (plate XVII, figure 14). As the coral grows and becomes heavier, it may break loose and sink into the soft algal mud. The sides of the mound formed an unsuitable substrate because of the instability of the high angle of the algal muds. Numerous bird's-eye structures, scattered oolites, and dolomite rhombs in the outer layer of the "jelly-roll" indicate shallow water that may have prevented rugose coral growth.

The largest percentage of michelinid corals is also found near the center of layers in the mound - again suggesting a need for stability - a base for attachment where the enlarging colony could be supported by sinking into lime mud (text figure 24). However, michelinid corals may be more tolerant of shallow water than Lophotichium, since michelinid forms are found in higher layers of the mound.

Disarticulated pelmatozoan fragments are found in small percentages throughout the mound with highest numbers near the top (text figure 24). All fragments are abraded, suggesting transport or deposition in the surge.

Again, two form-species of *Archaeolithophyllum*, an alga that is interpreted to have a habitat similar to modern red algae like *Goniolithon* or *Lithothamnion*, are found in the mound (text figure 25). *A.missouriensis* is found concentrated near the mound core and in lesser amounts at the top outer edge of the mound. It is interpreted by Kotila (1973) to occur *below* the maximum surge level. However, *A. lamellosum*, the second form-species, occurs encrusting rugose and michelinid corals *at* the surge or wave break zone. The encrusting of rugose and michelinid corals by the alga may be indicative of cyclic seasonal or periodic shallowing within each boundstone layer of the mound. *Archaeolithophyllum* is considered by Wray (1971) to be a binding and framework element capable of forming organic buildups or banks with a semi-rigid crust of potential wave resistance.

Ottonosia, a blue-green form genus, forms a crust-like laminated algal mass on the tops and sides of algal colonies of *A. lamellosum*. Thus, its distribution coincides closely with that of *Archaeolithophyllum* (text figure 25). The lack of algal growth over the bottom of the colonies may indicate that the area was protected by a barrier or deeper water from the force of breaking waves that could roll the colonies around. Since there is no evidence for an intermittant barrier, periodic deepening of water seems more likely as an explanation for *Ottonosia* encrustation of *Archaeolithophyllum*. Also, cyclicity may be explained readily by seasonal growth patterns.

Brachiopods occur later in mound history. Most are probably *Composita* and *Hustedia*, which occur in shales within the mounds (text figure 24, 26). The presence of some siphonate pelecypods is indicated by borings. All of the valves of brachiopods and bivalves are disarticulated, with the exception of specimens that occur in shales and below overhangs where brachiopods could attach in a protected environment.

Minor constituents include goniatites, gastropods, and nautiloids that could represent endemic or transient predators (text figure 25). The green alga, *Garwoodia*, is found only in the topmost layer of the mound, perhaps another indication of shallowing water.

In the slabs, any unidentifiable carbonates are loosely classified as lime mud since it is difficult to determine lime mud or micro-spar in slabs. This comprises up to 92 percent of mound layers. In many cases, as discussed earlier, one may suspect an original algal composition, particularly when the mud resembles Ottonosia except in fine detail, but bioturbation is obvious in many of the slabs and has obliterated much of the original texture.

Distribution of Shale Fauna

Washed shale sampled in general support the data gathered from polished slabs.

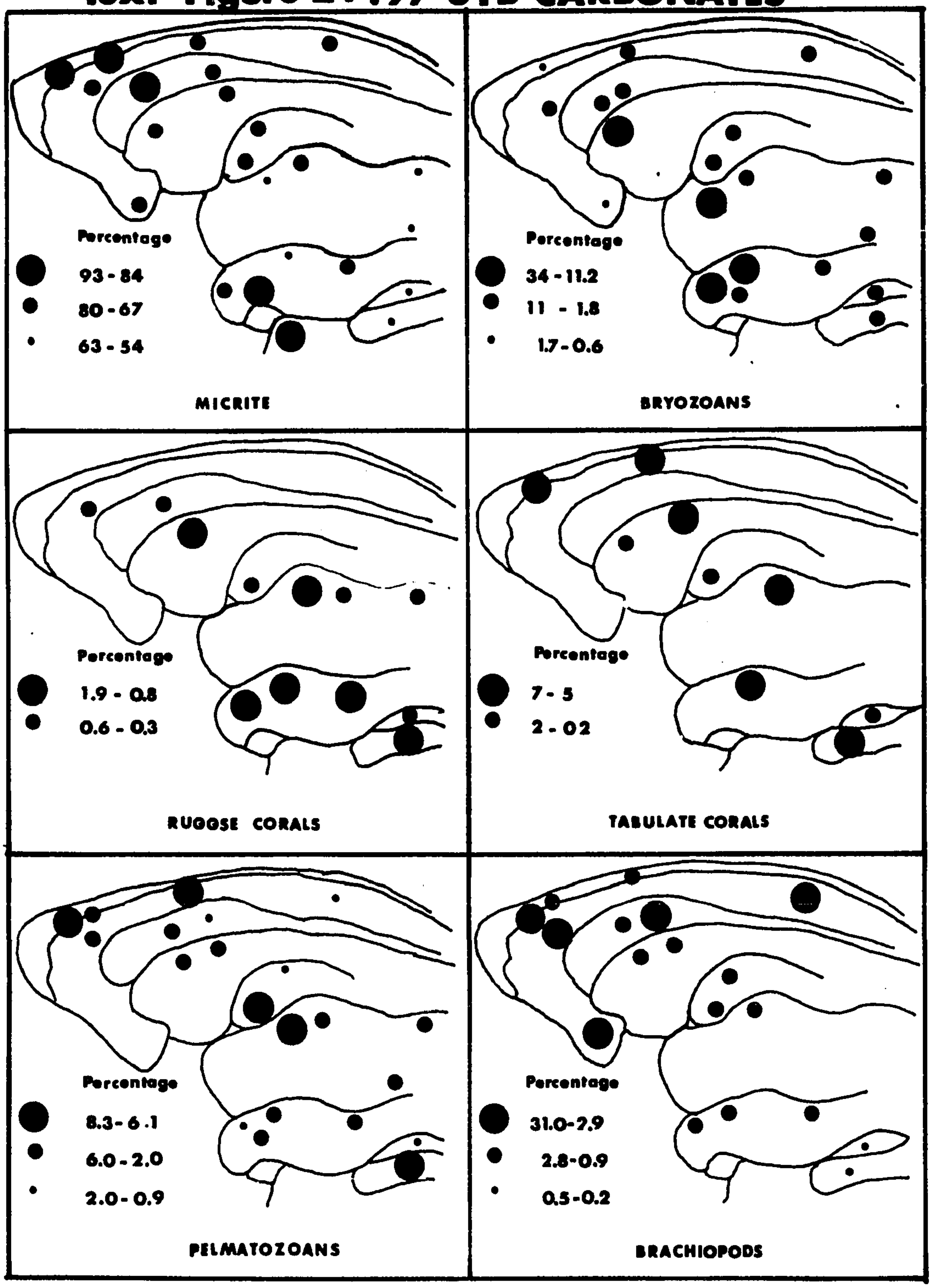
Bryozoans in the shales are dominated by fenestrate forms, except under overhangs where encrusting forms are abundant. The highest percentage of branching or arborescent forms again occurs near the core of the mound (table 9, text figure 25).

Lophotichium and michelinid corals, as well as algal components, are not found in the closed, shale-filled cavities within the mound. However, pelmatozoan fragments (up to 75%) are found, particularly in shales close to the outside of the mound (text figures 25, 26).

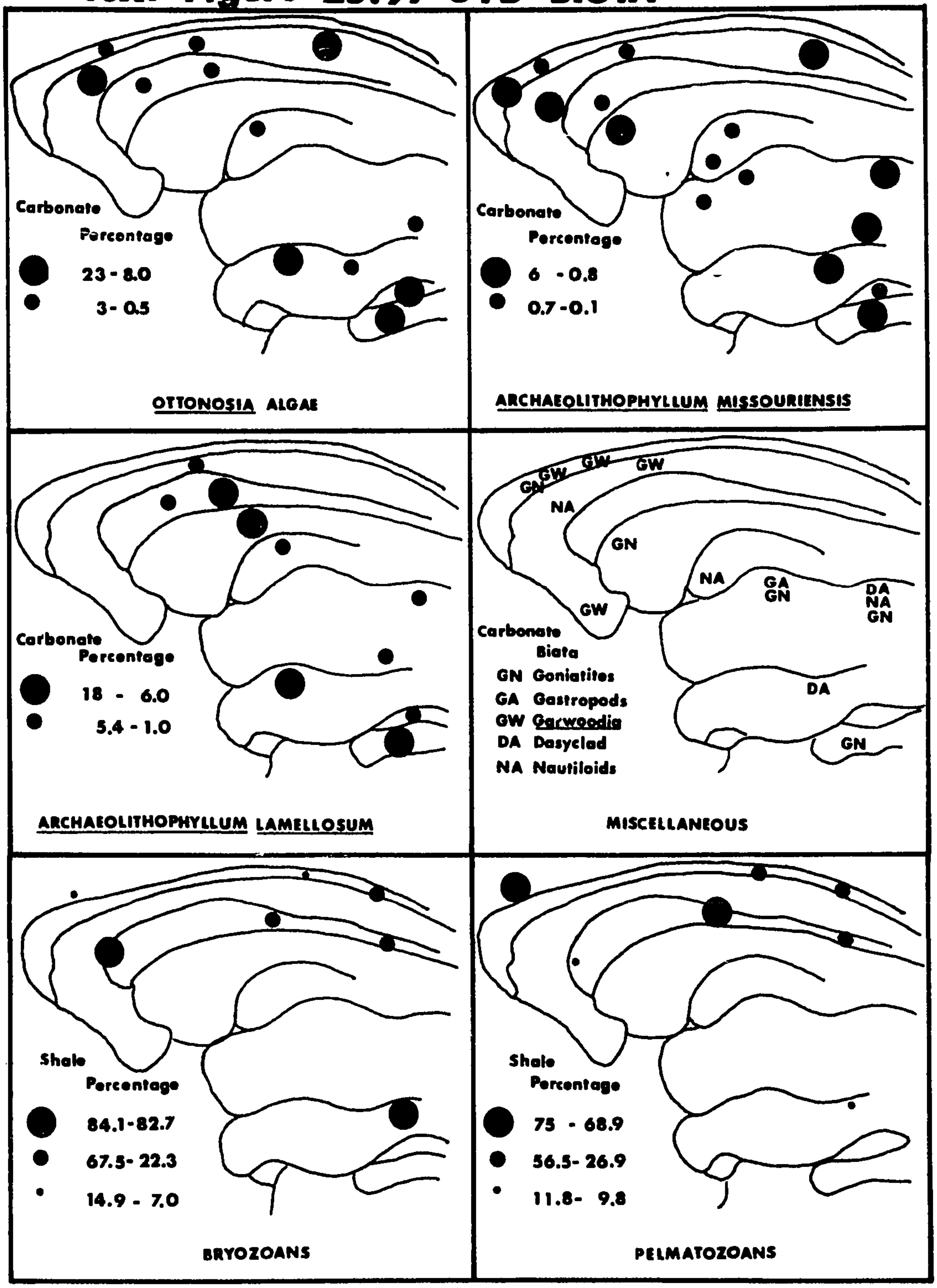
Thin-section Data

Complete thin-section descriptions of the lithic samples in this mound may be found in the following pages. Sections from the lower part of the mound reveal primarily Ottonosia boundstone with some Girvanella algal boundstone. Borings are filled by several generations of spar. Near the middle of the mound, some coated grains occur in the Ottonosia boundstone, an indication of shallowing water. A few scattered crystals appear to be anhydrite pseudomorphs, but they have been etched and identification is not positive. This would offer even greater evidence of shallow water deposition. Some bryozoans appear to be thickened by submarine cement (Land, 1974, oral communication). The limestones of the upper layers show some stylitization, an indication of compaction of the Ottonosia boundstone. The outermost layer of the mound appears to be a bioturbated micrite developed from a stromatolitic boundstone. Numerous vertical cracks are present and may be dessication features. These cracks contain ooliths, fine skeletal material and grains that must have washed into open cracks prior ro deposition of the nanmarine shale surrounding the mounds. These data suggest development in later stages in very shallow water.

Text Figure 24 :97-8YB CARBONATES



Text Figure 25:97-8YB BIOTA



Text Figure 26:97-8YB SHALES & INDEX

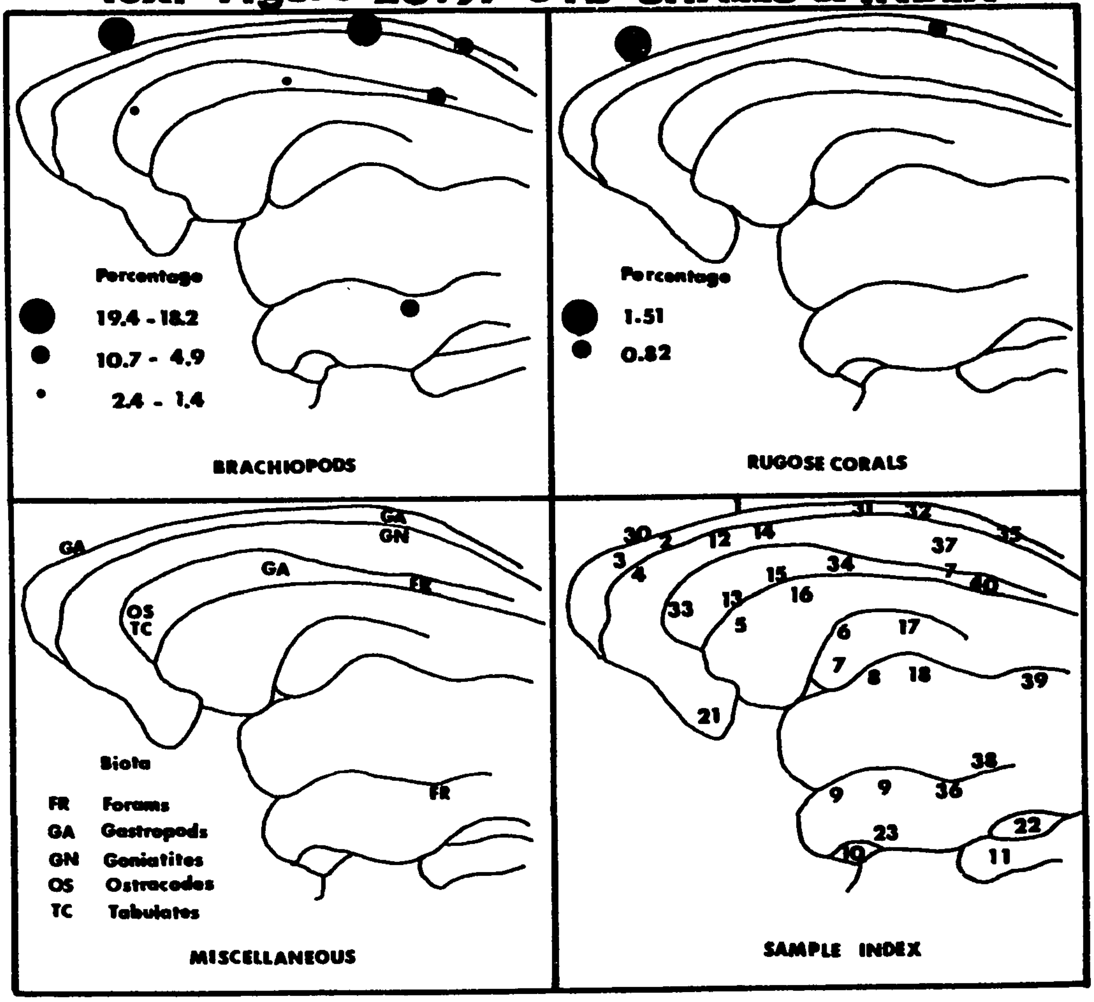


TABLE 8

97-8 YB CARBONATE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	MICRITE	BRYOZOA	TABULATE CORAL	RUGOSE CORAL	PELM.	OTTO.	ARCH. MISS.	ARCH. LAMEL.	BRACH.	OTHER	OTHER
YB11	54.4	6.05	6.35	1.16	6.92	11.56	5.77	7.79	0.29	0.86gn	---
YB22	67.6	1.86	0.37	0.64	1.19	22.43	0.09	5.41	0.34	---	---
YB23	92.1	5.80	---	---	2.10	---	---	---	---	---	---
YB19	60.0	11.25	6.95	0.89	3.49	8.34	---	6.95	2.68	---	---
YB9	62.7	33.33	---	0.98	1.96	---	---	---	0.98	---	---
YB8	55.0	38.76	---	---	6.14	---	---	---	---	---	---
YB18	79.2	11.01	---	0.58	5.21	---	0.58	---	2.61	0.87gn+ga	---
YB7	77.0	10.91	0.45	0.56	8.28	---	0.45	---	2.09	0.12na	---
YB17	76.6	4.00	5.35	1.85	1.95	2.35	0.06	5.10	0.95	0.40gn	---
YB16	69.9	---	5.07	1.26	5.07	---	---	17.74	1.26	---	---
YB5	80.4	14.11	1.04	---	3.13	---	---	---	1.56	0.52gn	---
YB20	62.2	1.86	---	---	5.88	---	---	---	30.22	---	---
YB13	85.1	1.82	---	0.33	3.14	1.41	0.25	2.81	2.50	2.50gw	---
YB15	75.5	6.34	---	---	0.98	0.50	0.98	6.86	10.43	---	---
YB4	72.7	4.95	---	0.55	4.40	13.15	0.82	---	3.05	1.38gw+na	---
YB14	78.4	2.40	4.80	---	6.69	1.80	0.60	2.40	1.80	1.20gw	---
YB2	90.3	0.63	---	---	5.6	0.63	0.63	---	2.18	---	---
YB3	84.7	---	0.29	---	6.17	---	1.77	---	2.94	4.0gn+gw	---

gn: goniatite, ga: gastropod, na: nautiloid, gw: Garwoodia sp.

TABLE 9

97-8 YB SHALE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	BRYOZOA	TABULATE CORAL	RUGOSE CORAL	PELM.	OTTO.	ARCH. MISS.	ARCH. LAMEL.	BRACH.	OTHER	OTHER	OTHER
YB40	67.47	---	---	26.9	---	---	---	4.9	0.82fm	---	---
YB1	---	---	---	---	---	---	---	---	---	---	---
YB36	84.03	---	---	9.84	---	---	---	5.58	0.66fm	---	---
YB35	48.00	---	---	40.0	---	---	---	10.66	---	---	---
YB34	22.34	---	---	75.0	---	---	---	2.35	0.47ga	---	---
YB33	82.72	2.15	---	11.8	---	---	---	0.44	2.15os	---	---
YB32	14.85	---	0.82	56.5	---	---	---	19.39	8.45gn+ga	---	---
YB-30	7.05	---	1.51	68.9	---	---	---	18.2	5.30ga	---	---

fm: foraminifera, ga: gastropod, os: ostracode, gn: goniatite

Thin-Section Descriptions

Unit No.	Description
YB-11 core	BIOTURBATED *OTTONOSIA* BOUNDSTONE (biolithite); very fine to coarse-grained *Archaeolithophyllum* (20%), bryozoans (10%), brachiopods (10%), *Lophotichium* corals (5%) in *Ottonosia-Girvanella* boundstone (25 to 50%), poorly sorted, floating to tangential grain contacts, moderate solution and overgrowths, silicification of bryozoan material with recrystallization of large clasts to spar, stylolites rare; micritic matrix (30%), pyrite (5%); 30 percent porosity consisting of skeletal voids and sponge borings filled with equal amounts of spar and micro-spar lining voids
YB-22	BIOTURBATED *OTTONOSIA* BOUNDSTONE (biolithite); very fine-grained bryozoan and miscellaneous debris in *Ottonosia-Girvanella* boundstone, well sorted, floating grains, with moderate solution and overgrowths, silicification of bryozoan material and extensive recrystallization of clasts to spar; very extensive compaction with micro-fractures, bird's-eye structures and stylolites; up to 50 percent micritic matrix with pyrite (5%), feroan dolomite (5%), and iron oxides (5%), 20 % porosity consisting of sponge borings with micro-spar lining (plate XII, figures 5, 6)
YB-19	*OTTONOSIA* BOUNDSTONE (biolithite); very fine to very coarse-grained pelmatozoan fragments (5%), bryozoans (5%), *Archaeolithophyllum* (10%), brachiopods (5%), and dasyclad alga (5%), in *Ottonosia* boundstone (55%), poorly sorted, floating grains, moderate solution and overgrowths, silicification of bryozoan and pelmatozoan material, recrystallization of clasts to spar; moderate compaction with stylolites; 20 % bioturbated micritic matrix with ooliths (1%), quartz silt (5%), and iron oxides (1%); 30 to 40 percent porosity with burrows, skeletal voids, and sponge borings filled with micro-spar and spar
YB-18	SKELETAL (BRACHIOPOD-*ARCHAEOLITHOPHYLLUM*-BRYOZOAN) LIME MUDSTONE (sparse to packed skeletal biomicrite); very fine to very coarse-grained pelmatozoan fragments (5%), bryozoans (15%), *Archaeolithophyllum missouriensis* (10%), dasyclad alga (5%), brachiopods (15%), goniatites (5%); poorly sorted, floating to convexo-concave grain contacts, moderate to extensive overgrowths and solution, silicification of bryozoan and pelmatozoan material, extensive recrystallization of clasts to spar, post cementation compaction with microfractures and stylolites cutting matrix; micritic matrix (30 to 60%) with no accessory minerals; porosity (20%) includes burrows, internal skeletal voids, shelter structures, and sponge borings filled with spar and lined with micro-spar (plate XI, figure 2, 3)

Unit No.	Description
YB-17	*OTTONOSIA-ARCHAEOLITHOPHYLLUM* BOUNDSTONE (biolithite); very fine to very coarse-grained pelmatozoan fragments (5%), bryozoans (5%), rugose corals (5%), *Michelinia* (10%), *Ottonosia* (60-75%), *Givanella* (5%) and *Archaeolithophyllum lamellosum* (10%) boundstone; poorly sorted with floating to convexo-concave grain contacts, moderate to extensive solution and overgrowths, silicification of pelmatozoan and bryozoan material and extensive recrystallization of fossil material to spar; moderate compaction with stylolites; bioturbation of micritic matrix (10%), 15-20 percent porosity including shelter structures filled with spar and lined by micro-spar or submarine cement (plate XIV, figure 1)
YB-38	SKELETAL (PELMATOZOAN) LIME MUDSTONE (sparse to packed biomicrite); fine to coarse grains of pelmatozoan fragments (15%), bryozoans (5%), *Garwoodia* alga (5%), *Ottonosia* (5%), *Archaeolithophyllum missouriensis* (5%), and brachiopods (5%), poorly sorted, floating to sutured grain contacts, extensive overgrowths and solution, silicification of pelmatozoan and bryozoan material, recrystallization of clasts to spar with no apparent compaction; 55 percent micritic matrix with 1 % anhydrite pseudomorphs; 20 % porosity consisting of skeletal voids and sponge borings filled by micro-spar (plate XIV, figure 3; plate XI, figure 4)
YB-13	*OTTONOSIA* BOUNDSTONE (biolithite); fine to medium-grained pelmatozoan fragments (5%), bryozoans (1%), and brachiopods (5%) floating in an *Ottonosia* boundstone; moderately sorted with armored grains and moderate solution; calcification of dolomite rhombs and silicification of pelmatozoan and bryozoan debris, recrystallization of large fossil clasts to spar; extensive compaction with micro-fractures and stylolites; bird's-eye features; bioturbated micritic matrix (10%) with ooliths (5%) and pyrite (5%); porosity consisting of sponge borings filled with spar and micro-spar lining voids (75 to 90%)(plate XII, figure 2)
YB-3	*OTTONOSIA* BOUNDSTONE (biolithite) very fine to fine-grained, pelmatozoan fragments (5%), bryozoans (5%), and *Girvanella* alga (5%) in *Ottonosia* boundstone (90%); well sorted, foating to straight grain contacts, moderate overgrowths and armoring with extensive solution, silicification of bryozoan and pelmatozoan debris, recrystallization of large fossil clasts to spar; extensive compaction including micro-fractures and stylolites; bird's-eye features; 15 percent bioturbated micritic matrix with 5 to 10 percent transported ooliths, pyrite (5%), and anhydrite pseudomorphs (1%); low porosity (5-10%) consisting of sponge borings filled by spar and lined with micro-spar (75-80%) (plate XII, figure 1)

Unit No.	Description
YB-2 crsut	SKELETAL (PELMATOZOAN-DASYCLAD-BRACHIOPOD) LIME MUDSTONE (dismicrite to sparse biomicrite); very fine to fine grains of pelmatozoans (5%), brachiopods (5%), dasyclad alga (5%), ostracodes (1%), goniatite cephalopods (1%), and bryozoans (1%) floating in a micritic matrix; well sorted, extensive overgrowths and solution; silicification of pelmatozoan and bryozoan material, recrystallization of coarse clasts to spar; extensive compaction with micro- and mega-fractures, bird's-eye structures; stylolites, mud cracks and grain brecciation; bioturbated micritic matrix (75%) with pyrite (5%), ooliths (5%), dolomite (5%), etched quartz silt (5%), anhydrite pseudomorphs replaced by calcite (1%), and limonite after pyrite (5%); porosity of 20 to 25 percent with spar-filled fractures and sponge borings lined by micro-spar or submarine cement

UB MOUND INTERVAL 97-8 & 9, STA. 6

This interval presents a different type of data from the mounds examined previously. The section is exposed 56.8 feet northward from the mound described at station 5. but is within the same interval (plate VI, figure 1). However, the interval consists of a vertical succession of boundstones and calcareous shales and siltstones that have poorly developed mounds near the base of the section (sample index, text figure 37). These mounds were mentioned in the text under mound initiation, and are found only in the lower 2.8 feet of the unit. They are overlain by approximately 3 feet of calcareous shale and siltstone that contains skeletal calicilutite nodules near the top of the unit. The unit is overlain unconformably by 3 feet of oolitic pelmatozoan lime grainstone with small-scale cross-bedding (unit 10 of Sutherland and Henry, in press). Each of the mounds in the lower part of the interval is developed on an irregular stromatolitic boundstone base and is separated from succeeding mounds by buff-green shale and calcareous siltstone that is locally fossiliferous adjacent to the mounds.

Biotic Components

Pelmatozoans are found in increasing numbers higher in the section and are most abundant just below the lime grainstone channel deposits of the unit (text figure 33 and 35). However, Lophotichium and michelinid corals, Composita and Hustedia are found in greatest abundances in the thin boundstones and shales of the lower sequence (text figures 34, 36). The relatively low percentage of pelmatozoan fragments in these beds indicates that pelmatozoans probably were not a substantial component of the adjacent substrate and the area lacked currents sufficient to move large amounts of pelmatozoan debris into the region of the mounds. Hustedia and rugose and tabulate corals differ from Composita in that Composita has another high area of abundance near a limestone nodular layer in the middle of the shale interval, while the others decrease in the upper part of the section.

Bryozoan distributions are very similar for encrusting, arborescent, and fenestrate forms (text figure 33). All become abundant in the third (highest) small limestone "mound", and fenestrate and arborescent forms are both abundant in the shales above this boundstone and in the middle limestone nodular layer and shales occurring above that layer. All bryozoans are abundant in the shales below the lime grainstone channel deposits of unit 10. The locallized nature of the bryozoan occurrences may indicate periods of relatively little sedimentation when a bryozoan cover could develop.

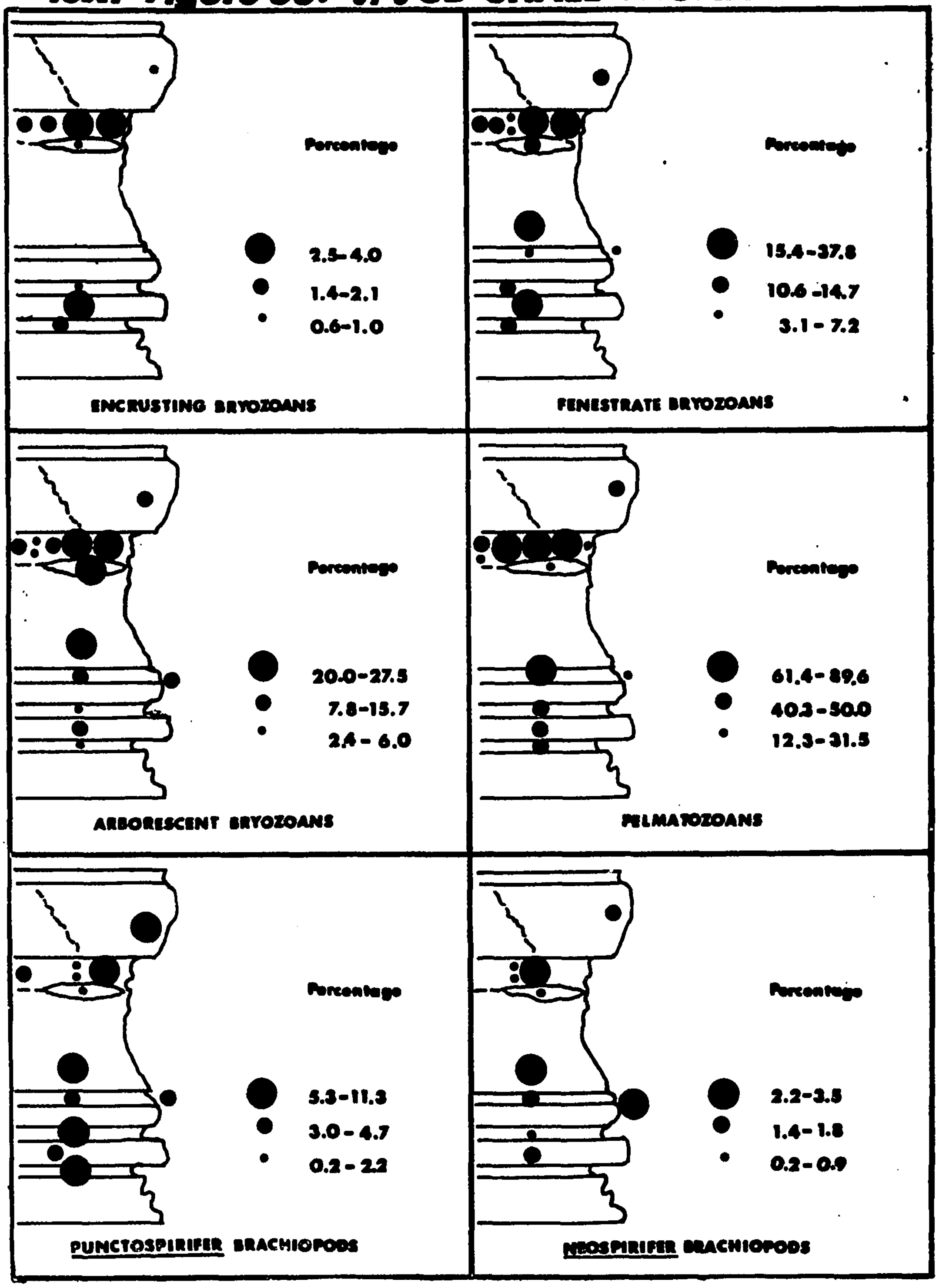
Punctospiriferid brachiopods are found abundantly in the shales above and below the mounds and in shales above the middle nodular layer, as well as within limestones below the lime grainstone. Anthracospirifers are much less common and have a slightly different distribution (text figure 37). They occur in greatest numbers below the grainstone and just above the third mound in the shale. Distribution of these forms probably is a reflection for the need for a stable mud substrate for attachment.

In contrast to the well-developed mound to the south (text figure 3), gastropods and goniatites do not become more abundant upward in the section (text figure 35). They are most abundant in the shales below the second mound and within the third mound. In addition, a few goniatites occur above the nodular layer in the middle of the shale section.

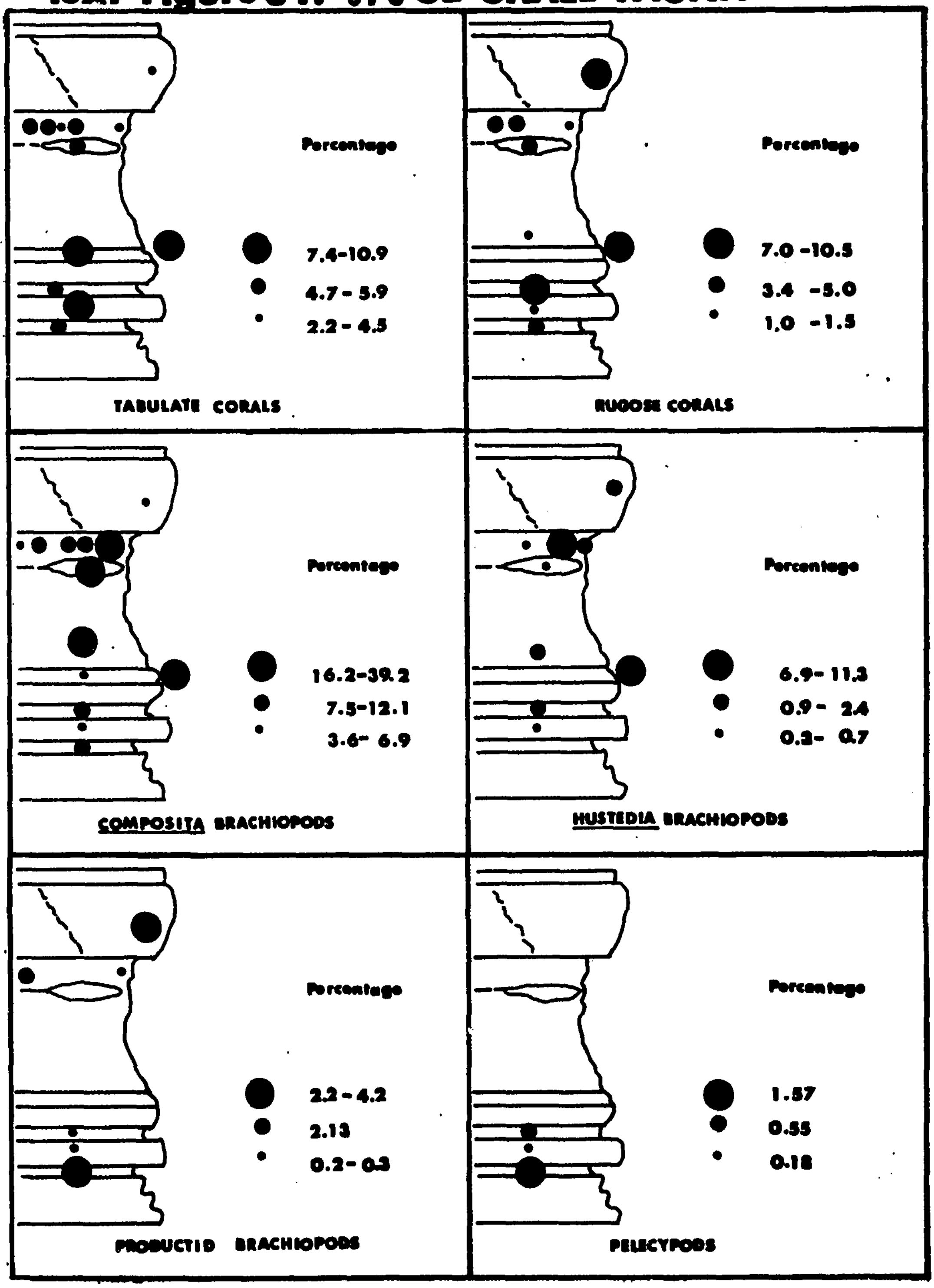
Cladochonus auloporid corals have no obvious pattern of distribution and are present only in relatively small, scattered occurrences (text figure 35). They are most abundant in the second mound and above the third mound in shales and within shale approximately three-quarters of the way up the sequence. Productid brachiopods are also found in scattered small occurrences and are most abundant in shales just below the second mound and just below the grainstone at the top of the interval (text figure 34).

A significant discovery is the nature of the boundstone that underlies the small mounds. Ottonosia comprised 62.9 percent of the boundstone with 30.0 percent stabilized micrite (table 11). Minor components include 4.52 percent bivalves, o.52 percent bryozoans, and 0.28 percent red calcareous alga, A. missouriensis. The mounds themselves are very thin and friable making examination of slabs impossible. Observation of the nature of the mounds is thus, based on surface examination. However, the small mounds appear to have a composition similar to that of larger features described.

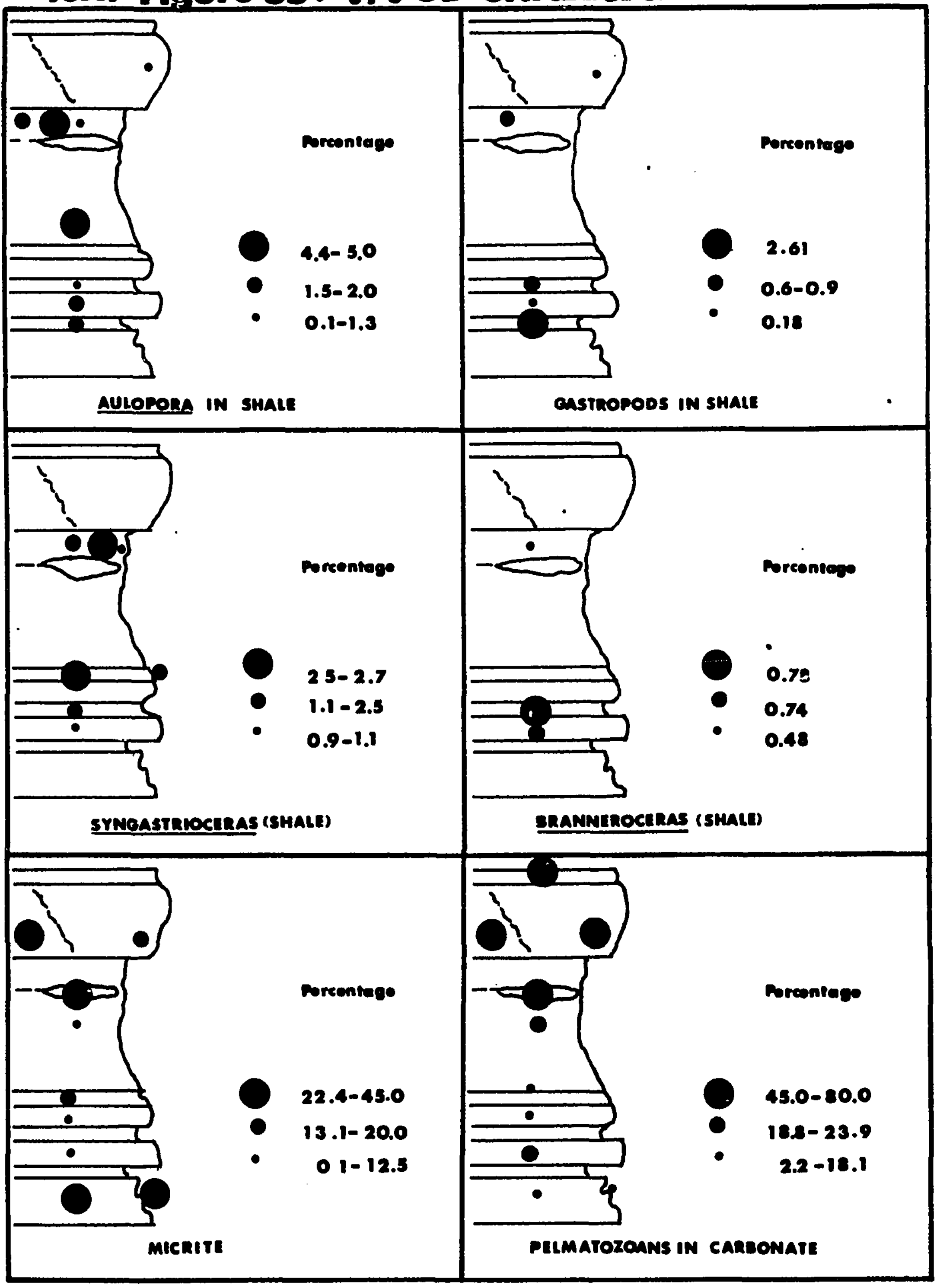
Text Figure 33: 97-8 UB SHALE FAUNA



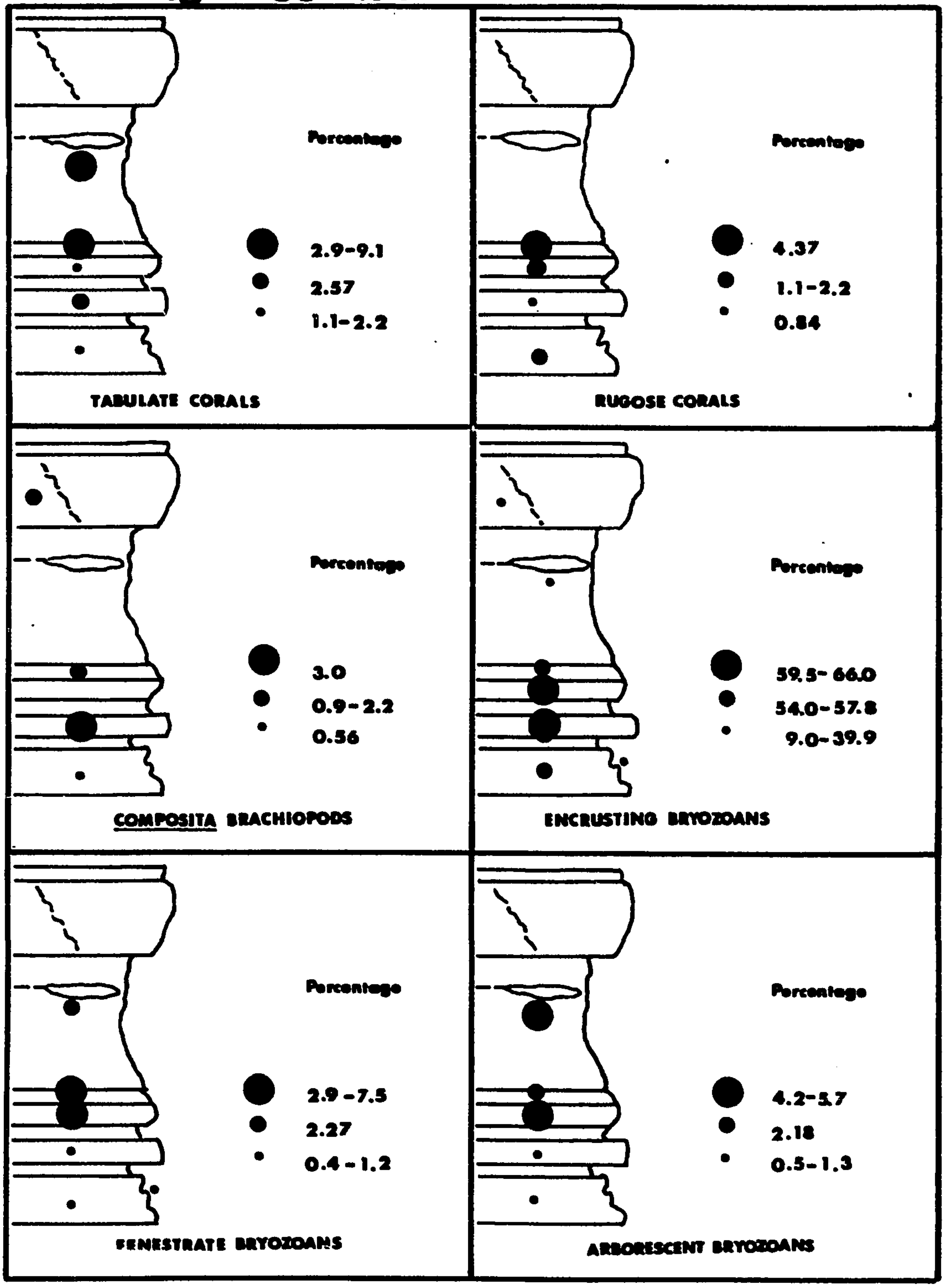
Text Figure 34: 97-8 UB SHALE FAUNA



Text Figure 35: 97-8 UB SHALE & CARBONATES



Text Figure 36: 97-8 UB CARBONATE BIOTA



Text Figure 37: 97-8 CARBONATE BIOTA (UB)

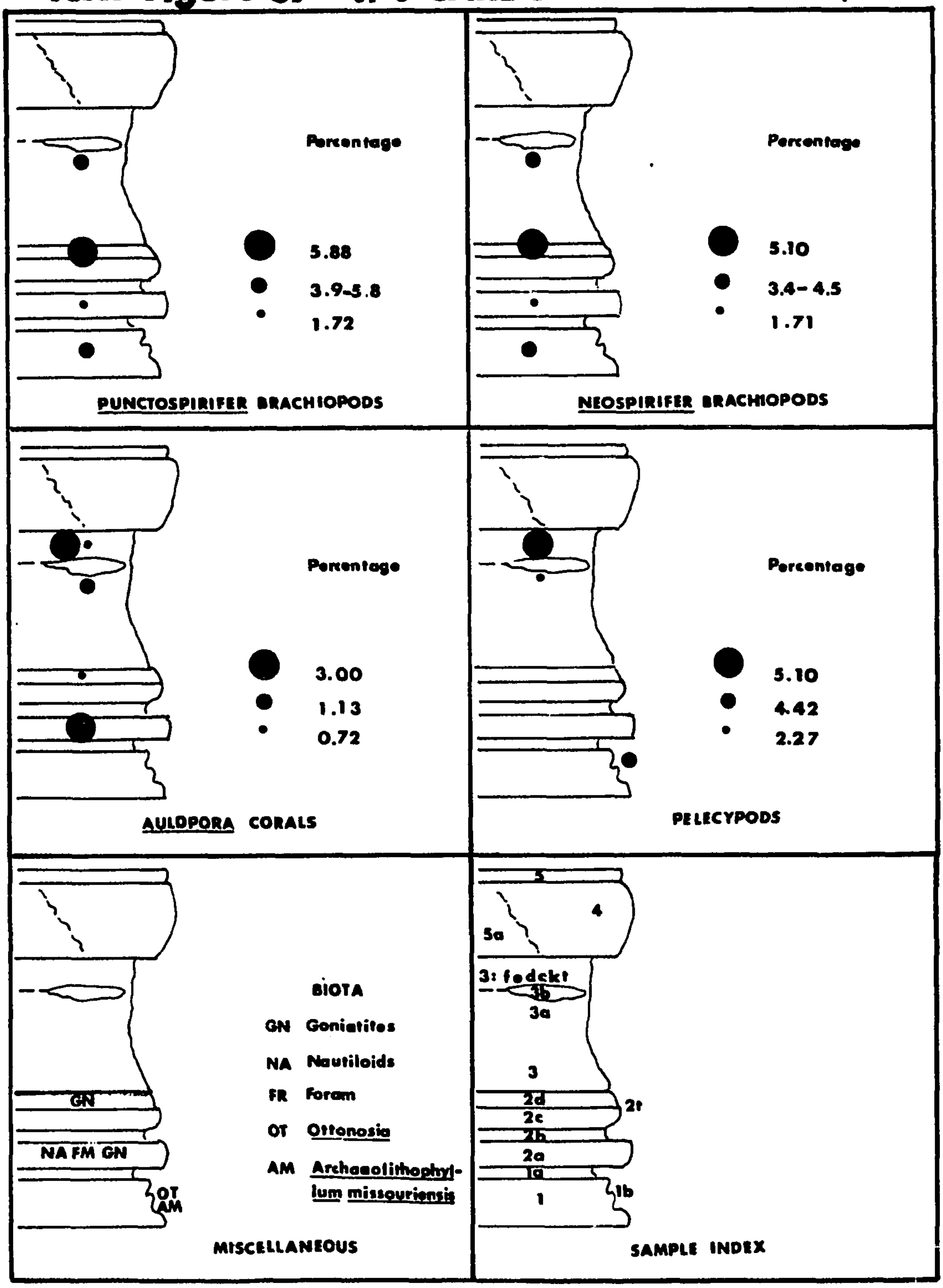


TABLE 10

97-8 UB SHALE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	PELM.	RUGOSE CORAL	TABULATE CORAL	PUNCTO. BRACH.	COMPO.	ENCR. BRYO.	FENES. BRYO.	ARBOR. BRYO.	HUSTED.	OTHER	OTHER
2	40.31	4.18	4.71	6.28	12.04	2.09	14.65	5.23	1.57pe	2.61ga	1.57au 4.18pr
2a	41.00	7.43	4.42	3.36	6.87 1.68ab	3.92 0.18pe	15.93 0.43prs	10.31 0.74br	0.31 1.94au	0.18na 0.99sy	0.12ga 0.31pr
2b	45.00	4.99	7.48	5.13	10.40	0.69	12.20 0.82ga	5.96 0.13pr	2.35 0.13au	0.55pe 2.35sy	0.97ab 0.78br
2d	61.40	7.01	---	3.50	5.26	1.74ab	7.01	10.52	2.50sy	---	---
2t	31.39	10.46	8.13	4.65	16.27	2.22ab	6.97	9.30	6.97	1.16pe	1.16sy
3	---	---	2.22	6.66	24.44	2.22ab	37.77	20.00	2.22	4.44au	---
3a-b	31.47	3.82	5.88	2.05	20.00	0.88	11.17	23.82	0.59	0.29ab	---
4	43.7	1.28	10.84	5.33	3.67	0.91	12.50	15.62	0.91	1.47ab 1.28au	2.20pr 0.18ga
3t	17.50	5.00	---	2.50ab	7.50	2.50	37.50	27.50	---	---	---
3f	89.6	---	---	---	---	---	3.17	5.55	---	5.00au	---
3k	61.42	1.42	5.33	2.13	9.96	1.42	7.11	7.82	0.71	0.71ab	2.13pr
3d	50.00	3.40	4.09	11.3	6.81	2.50	14.31	10.00	11.3 0.66ga	0.90prs 2.72sy	2.04au 0.22pr
3c	12.37	1.03	---	3.09	39.17	2.06	15.46	24.74	1.03	1.03sy	---
3e	62.00	2.91	5.82	1.45	10.15	1.45	10.67	2.42	0.48ab	o.48prs 0.48br	0.98au 2.42sy

ga: gastropod, au: auloporid coral, pr: productid brachiopod, na: nautiloid, ab: *Anthracospirifer* sp., prs: *Prismopora* sp., pe: pelecypod, br: *Branneroceras*, sy: *Syngastrioceras*

TABLE 11

97-8 UB CARBONATE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	MICRITE	ENCR. BRYO.	FENES. BRYO.	ARBOR. BRYO.	PELM.	RUGOSE CORAL	TABULATE CORAL	PUNCTO. BRACH.	COMPO.	AULO. CORAL	OTHER
2d	13.13	54.01	2.91	2.18	11.67	4.37	2.91	5.10	2.18	0.72	0.72gn
2a	0.42	66.0	0.42	1.28	18.88	0.84	2.57	1.71	3.00	3.00	0.84gn 0.84na
2c	5.31	59.57	7.44	4.25	18.08	2.12	2.12	---	---	---	1.06gn
3t	25.0	---	---	---	75.0	---	---	---	---	---	---
4	20.0	---	---	---	80.0	---	---	---	---	---	---
3a-b	12.50	39.7	2.27	5.68	23.86	---	9.09	3.40	---	1.13	2.27pe
5a	54.04	9.00	---	---	45.04	---	---	---	0.09	---	---
1	22.47	57.77	1.12	0.56	9.55	1.12	1.12	4.49	0.56	---	---
1b	30.00	0.56	---	---	---	4.52pe	0.28am	62.85ot	---	---	---

gn: goniatite, na: nautiloid, pe: pelecypod, am: Archaeolithophyllum missouriensis, ot: Ottonosia sp.

VB MOUND INTERVAL, 97-8 & 9, STA. 7

This interval consists of a loose aggregation of algal micrite nodules (boundstone) and shales typical of unit 9. The exposure is located 42.5 feet northward of the interval described in the previous section, station 6, and is again within unit 9 of Sutherland and Henry (in press). It is illustrated in plate VI, figure 2. The nodular interval is approximately 6 feet thick and is overlain by a 2.5 foot thick grainstone channel deposit typical of unit 10.

Composition of Algal Nodular Layer

The shales within the algal nodular layer are buff-gray and contain a fauna similar to many of the other shales described in the Morrowan bioherms (table 12). The most abundant elements are arborescent bryozoans, pelmatozoan fragments, and *Hustedia* brachiopods. *Composita* brachiopods, encrusting and fenestrate bryozoans are also common faunal elements that occur with minor michelinid corals, rugose corals, *Cladochonus*, *Syngastrioceras* goniates, punctospiriferid brachiopods, prismoporid bryozoans, and gastropods. The limestone nodules are composed of almost 50 percent micrite with substantial areas of surface covered by fenestrate bryozoans (44%). However, the interior of the nodules includes 5-18 percent bryozoans and 18 percent pelmatozoan fragments (only 3.6 percent of the surface composition). Other substantial components of the algal nodules include the undescribed dasycladacean alga, *A. missouriensis*, minor *Hustedia* and *Punctospirifer* brachiopods, *Syngastrioceras* goniatites, bivalves, and gastropods. Examination of the percentage data in table 12,suggests some of the difficulties encountered when trying to compare data from mound surfaces, polished slabs, and shale samples.

Composition of Algal Boundstone

The lowest part of the lithified boundstone is dominated by a blue-green alga that resembles either *Girvanella* or *Ottonosia*?, but lacks internal structure. A few scattered fragments of pelmatozoans, bryozoans, and disarticulated brachiopods occur within this "core." A thin layer of with similar debris follows and is overlain by another layer of stromatolitic algae with a few rugose corals. The outer layer consists of micrite that may have been initially stabilized by blue-green algae. Again, the micrite contains debris of bryozoans and pelmatozoans.

Examination of the entire boundstone layer reveals that approximately 68 percent of the lithified material is composed of blue-green algae. Next in abundance is micrite (just less than 20%), with 8 percent bryozoans, 6.3 percent pelmatozoan fragments, 5 percent brachiopods, and less than one percent rugose corals.

TABLE 12

97-8 VB SAMPLE PERCENTAGE COMPOSITION

SAMPLE	MICRITE	ENCR. BRYO.	FENES. BRYO.	ARBOR. BRYO.	PELM.	RUGOSE CORAL	TABULATE CORAL	COMPO.	HUSTED.	OTHER	OTHER
shale	---	6.22	6.08	13.64	50.81	1.21	1.75	4.46	12.58 1.08sy	0.54prs 0.27ga	1.21au 0.27ps
Surface Estim.	44.7	4.47	4.47	1.11	3.57	---	---	---	0.67	0.22ps	0.45sy
slab 1	31.42	53.0ab	4.08	---	7.34	---	---	---	2.04pe	0.40ga	1.63am
slab 2	46.89	---	18.64	---	18.64	---	---	---	1.69	10.16am	3.95ng
hi Ls.	18.50	---	7.98	---	6.26	---	---	---	---	4.76pe	67.75ot

prs: *Prismopora*, au: auloporid coral, sy: *Syngastrioceras*, gas: gastropod, ps: *Punctospirifer*, pe: pelecypod, am: *Archaeolithophyllum missouriensis*, ng: dasyclad alga

MOUNDS ZB, 97-8?

This set of samples includes a series of four mound blocks that occurred as unoriented talus within the north quarry on the Chisum property (text figure 38). Although several mounds occur in place in this quarry, the quarry floor is flooded below the steep shale that forms the quarry walls (plate VII) making examination of these mounds impossible. The mounds exposed in place occur within units 8 and 9, the upper mounding interval of the central quarry. The lower interval from the central quarry is not exposed in this quarry and it seems reasonable to suggest that the talus blocks examined in the north quarry are probably from the upper mounding interval. This is supported by the nature of the biota and thin-section data that follow.

Mound #0

Micrite is present in greatest percentages (up to 94%) in the outer layers near the top of the mound(table 13). This "micrite" retains enough of its primary stromatolitic character to be assigned to the form-genus Ottonosia, although the original texture has been a-tered through recrystallization and bioturbation. Brachiopods and the red alga, A. missouriensis, are associated with Ottonosia in the outermost layers.

Fenestrate bryozoans are most abundant (up to 66%), as might be expected, in the central shale cavity. They also occur as encrusters primarily on the uppermost surface of the mound, as well as above the shale on the "roof" of the cavity. The lowest part of the mound is poor in bryozoan composition.

Both tabulate and rugose corals are rare in the mound, however, they are abundant when compared to slabs from other mounds in the north quarry. Rugose corals appear to be associated with bryozoans and many individuals appear to use fronds of fenestrate bryozoans as a base for attachment. Although both groups of corals are present in percentages less than 1 percent, Lophotichium is found to occur more commonly in the lower part of the mound than michelinid forms. This is the same pattern observed in the mounds within unit 9 in the central quarry.

Pelmatozoan fragments are also most common in the central shale cavity and occur as abraded fragments, probably washed into the open area. The limestone immediately above the cavity also has a high percentage of pelmatozoan fragments incorporated into the loose bryozoan framework. The lowest percentage of pelmatozoan fragments occurs in the Ottonosia boundstone at the base of the mound.

Ottonosia is the major constituent (94%) of the lower part of the mound, but is not found in the central shales and is recorded as comprising only a small percentage of the upper part of the mound (16%). This may be explained by reworking and diagenesis of the stromatolitic micrite to a degree that the original texture is obliterated.

Minor amounts of red algae are found in the upper layers of the mound associated with the stromatolitic boundstone. Non-productid brachiopods such as Hustedia and Composita form over 10 percent of the shale fauna. These forms are most common in the shale cavity, as was true of the pelmatozoans, and are found in a lesser abundance within the boundstone of the mound (1.21%).

A single foraminifera was found in the lower part of the boundstone, perhaps associated with the larger mass of Ottonosia.

Mound #1

The outer layer of this mound, as is the case in the other mounds examined, is comprised largely of micrite, which is mottled with apparent algal texture. This outer layer constitutes approximately two-thirds of the outer part of the mound and includes several voids filled with red clay. The remaining third of the outer part of the mound is formed of encrusting bryozoans.

The lowermost slab from the mound is dominated by almost two-thirds pelmatozoan fragments with a relatively large percentage of brachiopods and rugose corals. In contrast, as is the case in many other mounds, michelinid corals are most abundant in the outer layers of the mound. This sample includes a basal cavity in the mound that is filled with pelmatozoan debris and rugose corals with brachiopods attached to the roof of the cavity.

The mound interior or core includes over 50 percent Ottonosia boundstone with relatively large numbers of both species of red algae, Archaeolithophyllum missouriensis or lamellosum. The persence of these algae reflect conditions that fluctuated from wave or surge base to just below that level during the major part of mound history. Also, there are large numbers of the undescribed dasycladacean alga and brachiopods such as Hustedia and Composita and accessory amounts of pelmatozoans and rugose corals. The core of the mound itself contains debris of brachiopods and A. missouriensis, which are also found in cavities in the upper part of the mound. The remainder of the mound has an Ottonosia "framework" in which michelinid corals seem to float. Just above a particularly well-developed level of michelinids is an irregular layer of A. lamellosum that is 3 to 5 mm thick with Ottonosia boundstone above. One particularly pronounced depression in the A. lamellosum layer is filled with brachiopod debris.

Mound #2A

Character is similar to other mounds observed in the north quarry. Micrite or bioturbated and recrystallized algal mud comprises up to 80 percent of the outer layer of the mound. Up to 10 percent of the biotic components of this outer layer is formed of encrusting bryozoans. However, there are unusually large numbers of pelmatozoan fragments and brachiopods in the outer layer as well as goniatites and gastropods. These are found in a hash of fossil debris near the base of the layer, which also includes fenestrate bryozoans. Red clay filling fractures and voids in the outer layer is also prominent.

The inner part of the mound consists of lesser amounts of micrite and encrusting bryozoans with up to 60 percent Ottonosia boundstone and small amounts of A. missouriensis, pelmatozoan fragments, brachiopods, goniatites,and shale. Greater percentages of solitary corals are found near the core, but these forms still comprise less than one percent of the total composition.

Mound #2B

This mound is circular in cross-section and is of uncertain orientation (text figure 38). However, the examination of samples indicates an outer growth surface. The core consists of mottled black and gray algal micrite with fragments of pelmatozoans, bryozoans, dasycladacean alga, goniatites, and brachiopods. A thick layer of bryozoans encrusts this core with zoaris facing outward. This is overlain by a stromatolitic boundstone 4 mm thick, overlain by A. lamellosum 3 mm thick, Ottonosia 2-3 mm thick, 1-2 mm of A. lamellosum, 3-10 mm of Ottonosia, and finally an outer crust of A. lamellosum 2-5 mm thick. Michelinid corals frequently occur immediately above the initial algal layers, perhaps during a period of slightly deeper water. This slab can be interpreted as indicating fluctuating water depths from at to just below wave base.

Mound #3

This mound is slightly different from the others examined in the north quarry in that the outer layer appears to consist of only 21.4 percent micrite with 39.0 percent Ottonosia, and 25 percent A. lamellosum. The lowest part of the outer layer consists of buff to gray mottled micrite with pelmatozoan debris encrusted by bryozoans that are overlain by Ottonosia, A. lamellosum, Ottonosia, and a final A. lamellosum layer. The core is formed of 93 percent A. lamellosum with minor amounts of Ottonosia, pelmatozoan fragments, bryozoans and micrite.

TEXT FIGURE 38
Sample Index for Mounds in North Chisum's Quarry (ZB)

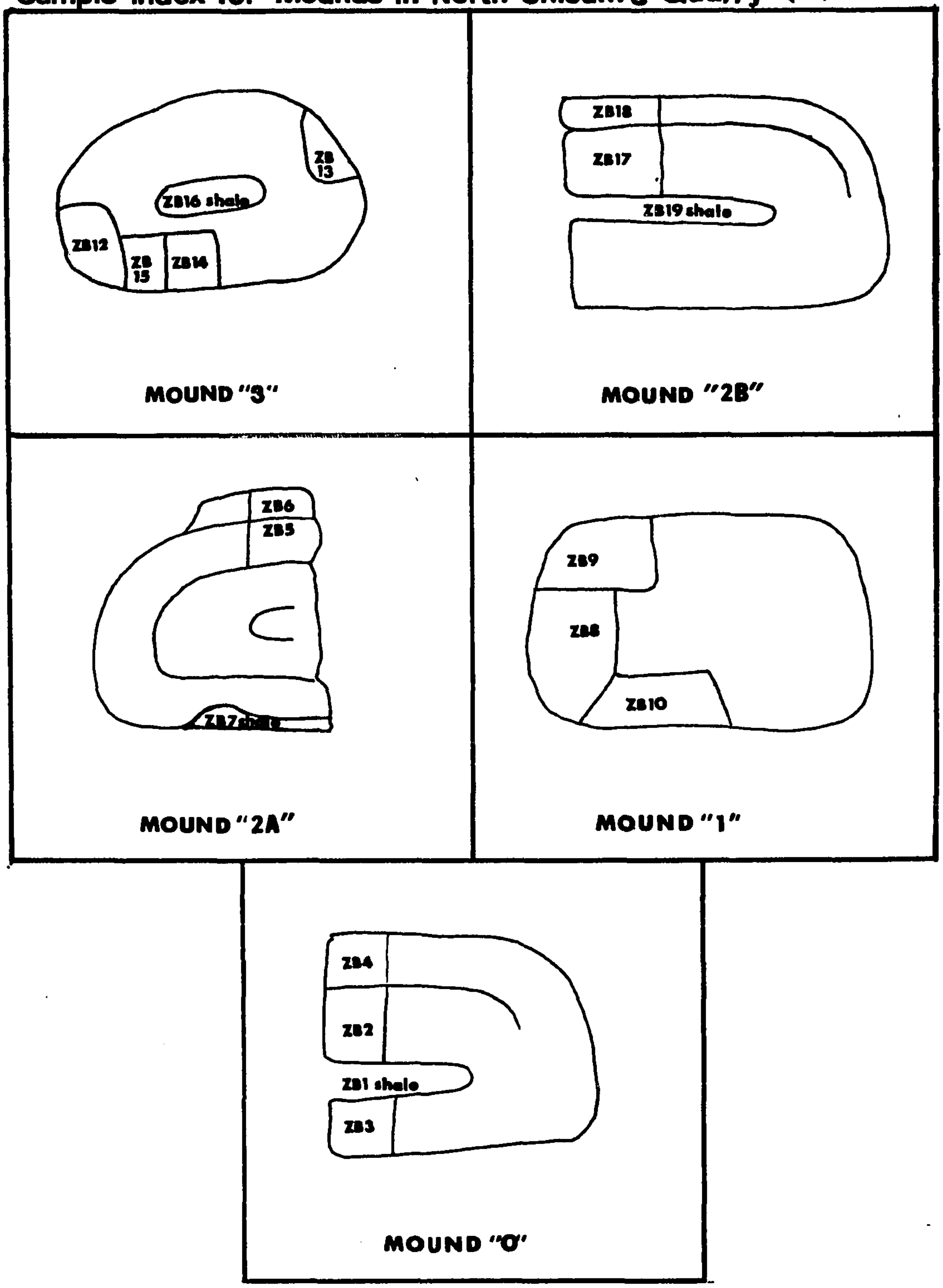


TABLE 13

NORTH QUARRY (ZB) PERCENTAGE COMPOSITION

SAMPLE	MICRITE	BRYOZOA	TABULATE CORAL	RUGOSE CORAL	PELM.	OTTO.	ARCH. MISS.	ARCH. LAMEL.	BRACH.	OTHER	OTHER
ZB-1	---	65.6	0.31	0.31	23.5	---	---	---	1.24	8.05hu	0.93co
ZB-2	60.9	16.5	0.13	0.13	19.1	---	1.75	---	1.21	---	---
ZB-3	---	2.59	---	1.53	1.53	93.8	---	---	0.46	0.15fm	---
ZB-4	55.6	19.4	0.82	0.16	4.89	15.8	1.31	---	0.20	---	---
ZB-5	62.1	31.1	---	---	5.26	---	1.05	---	0.53	---	---
ZB-6	0.60	5.13	11.5	0.43	4.19	57.9	4.36	6.41	2.99	2.48ng	5.04sh
ZB-7	8.93	---	---	3.57	4.3	13.0	---	---	3.13	2.23ng	4.91sh
ZB-8	24.4	6.14	---	0.70	1.32	59.7	0.35	---	0.70	0.09gn	6.58sh
ZB-9	71.9	9.19	0.62	0.10	5.58	1.45gn	3.20	---	7.23	0.21ga	1.55sh
ZB-11	87.1	5.66	0.38	0.94	3.01	0.47	---	---	1.04	2.36gn	---
ZB-12	37.6	18.5	2.73	0.46gi	4.55	19.0	3.04	4.70	2.12	0.15gn	2.73ng
ZB-13	84.6	10.3	---	0.26	3.33	---	---	---	0.26	1.28sh	---
ZB-14	43.2	10.7	---	0.11	1.58	44.0	---	---	0.11	---	0.11sh
ZB-15	45.2	9.50	0.62	---	3.17	13.4	0.68	25.6	1.80	0.06gn	---
ZB-17	1.45	1.45	---	---	2.41	1.45	---	93.2	---	---	---
ZB-18	21.4	7.17	0.29	---	5.42	39.1	---	25.5	1.17	---	---
ZB-20	75.2	2.94	---	0.28	16.4	---	1.02	---	2.30	1.38ng	0.18ga

hu: *Hustedia*, co: *Composita*, ng: dasyclad alga, sh: shale, gn: goniatite, ga: gastropod

Thin-Section Descriptions

Unit No.	Description
ZB-3	*OTTONOSIA-GIRVANELLA* BOUNDSTONE (biolithite); very fine to fine-grained auloporid coral, spicules, and micellaneous fine debris in an *Ottonosia* and *Girvanella*-foram boundstone; well sorted, extensive solution and overgrowths with silicification of pelmatozoan and bryozoan debris, recrystallization of clasts to spar; moderate compaction with small, iron oxide-coated fracture fill; bioturbated micritic matrix (10-15%), ooliths (5%), dolomite rhombs (1%), anhydrite pseudomorphs (1%), and less than 5% iron oxides; 25 to 30 percent porosity consisting of sponge borings filled with spar and micro-spar lining (50%) (plate XIII, figures 3, 4)
ZB-4	*ARCHAEOLITHOPHYLLUM* *BOUNDSTONE* (biolithite); very fine to coarse-grained pelmatozoan fragments (5%), bryozoans (5%), *Garwoodia* alga (5%), foraminiferas (5%0, brachiopods (20%), in *Archaeolithophyllum* *lamellosum* (25%), well sorted, floating grains, moderate to extensive overgrowths and solution, silicification of pelmatozoan and bryozoan debris, recrystallization of fossil clasts to spar; moderate compaction with micro-fractures; micritic matrix (30%) with ooliths and detrital quartz silt (5%); 10 % porosity including sponge borings filled with spar and lined by micro-spar (plate XIII, figures 1, 2)
ZB-14	BRYOZOAN-*ARCHAEOLITHOPHYLLUM-OTTONOSIA* BOUNDSTONE (biolithite); fine to medium-grained pelmatozoans (10%), bryozoans (30%), michelinid corals (5%), dasyclad alga (5%), *Archaeolithophyllum* *lamellosum* (10%), brachiopods (15%) in *Ottonosia-Girvanella* boundstone, boundstone alternates bryozoan, red algal and stromatolitic algal layers; well sorted, foating grains, extensive solution and overgrowths, silicification of pelmatozoan and bryozoan debris, recrystallization of fossil clasts to spar; moderate compaction with micro-fractures and mudcracks; micritic matrix (10%) with ooliths (5%) and pyrite (5%); 25 to 15 % porosity including fractures, skeletal voids, and sponge borings filled with spar and lined by micro-spar (plate XIV, figure 4)

Distribution of Organisms on Mound Surfaces

Mound XB, 97-8, Station 8

This mound block lies loose on the talus floor at the south end of the central quarry just below the cliff containing unit 4 in the section measured by Sutherland and Henry (in press) and is illustrated in plate IV, figure 2. The block is 9.5 feet long and approximately 4 feet wide and varies from 1 to 2.5 feet thick. It consists of an algal boundstone with an upper surface that is very irregular and appears to have over one foot of relief. Local areas are encrusted by bryozoans while pelmatozoans form scattered pockets of high relief. A long, narrow cavity runs below a roof of encrusting bryozoans and is filled with fossiliferous light gray noncalcareous shale.

Instead of collecting oriented blocks of limestone that form the mound, collections were made of loose material on the surface. The area of the collections was marked on a diagram of the mound (text figure 28). Each of the shale and other surface samples was washed and picked. Percentages (table 14) were plotted on diagrams of the mound as in previous samples (text figures 27-29). Then an attempt was made to note any patterns of distribution as well as establishing any associations of organisms. This was done by utilizing a simplified similarity matrix. The percentages for each component were divided again by the first and third quartiles into high, medium, and low with a fourth category of "not present," and these were assigned values from 1 to 4. The similarity of two components was calculated by comparing the percentage of the components at each occurrence and adding the absolute value of the differences between the assigned values. This resulted in a similarity matrix (table 16) that was used to describe association of biotic components. This method was selected in order to minimize the effects of actual percentages of components and maximize the relative differences.

Distribution of Biotic Components

This mound contains one of the best examples of a cavity that was present and inhabited during mound formation and filled in with shale either later in mound history or after cessation of mound development. As mentioned, encrusting bryozoans line the top of the cavity, which has been noted in other mounds within the quarry. Lophotichium, a rugose coral and michelinid tabulate corals appear to be in growth position, attached to the bottom of the cavity and growing upward. The remaining material includes minor productid brachiopod fragments, gastropods, spiriferid and Composita brachiopods with Hustedia, Prismopora bryozoans, and goniotites associated with relatively large masses of fenestrate and arborescent bryozoans. The pelmatozoan fragments that are found in the shale are worn and abraded small fragments comprising over 90 percent of the fauna. Even the limestone that roofs the cavity contains only 17.5 percent pelmatozoans with large amounts of brachiopods and gastropods. The dasycladacean alga seems to be a dominant algal component in the boundstone of the mound adjacent to the cavity, but not above it (see thin-section descriptions following).

Shale Distribution

Pelmatozoan fragment distribution compares closely with that of Composita and Hustedia (text figure 27). This material is found in local high areas on the mound surfaces that might have resulted from protection or stabilization by the holdfast of a blastoid or crinoid; or they may merely be current accumulations since although many of the columnals are articulated, they are not in growth position. The distribution of fenestrate bryozoans bears least similarity to that of the pelmatozoans as they prefer areas of lower topography and less micrite (see slab data, table 15),

The goniatite distribution is defined by a few scattered occurrences that correspond most to michelinid coral and spiriferid brachiopod distributions (text figures 27 and 28). These also are not represented by large numbers of individuals over the entire mound surface. Probably for this reason, the distribution is most different from that of the pelmatozoan fragments that occur in large numbers over the mound surface.

The distribution of Hustedia coincides most closely to that of pelmatozoan fragments and to Composita. The similarity of Hustedia distribution to pelmatozoan fragments may to a large degree be a reflection of similar size and shape resulting in transport to common areas. However, in the case of Composita it may also be a reflection of similar requirements and habitats. The distribution of Hustedia differs most from that of goniatites (see above) and then fenestrate bryozoans that seem to inhabit the lower areas. Similarly, the Composita distribution is closest to that of Hustedia and then pelmatozoans, and most different from that of the goniatites.

The spiriferid brachiopods show most similarity to the distribution of goniatites, (text figure 28), again probably because of the scattered, rare occurrences of these organisms. Where they do occur, the distribution seems to closely follow that of Composita, but again is most dissimilar in in distribution to the pelmatozoans that are much more ubiquitous.

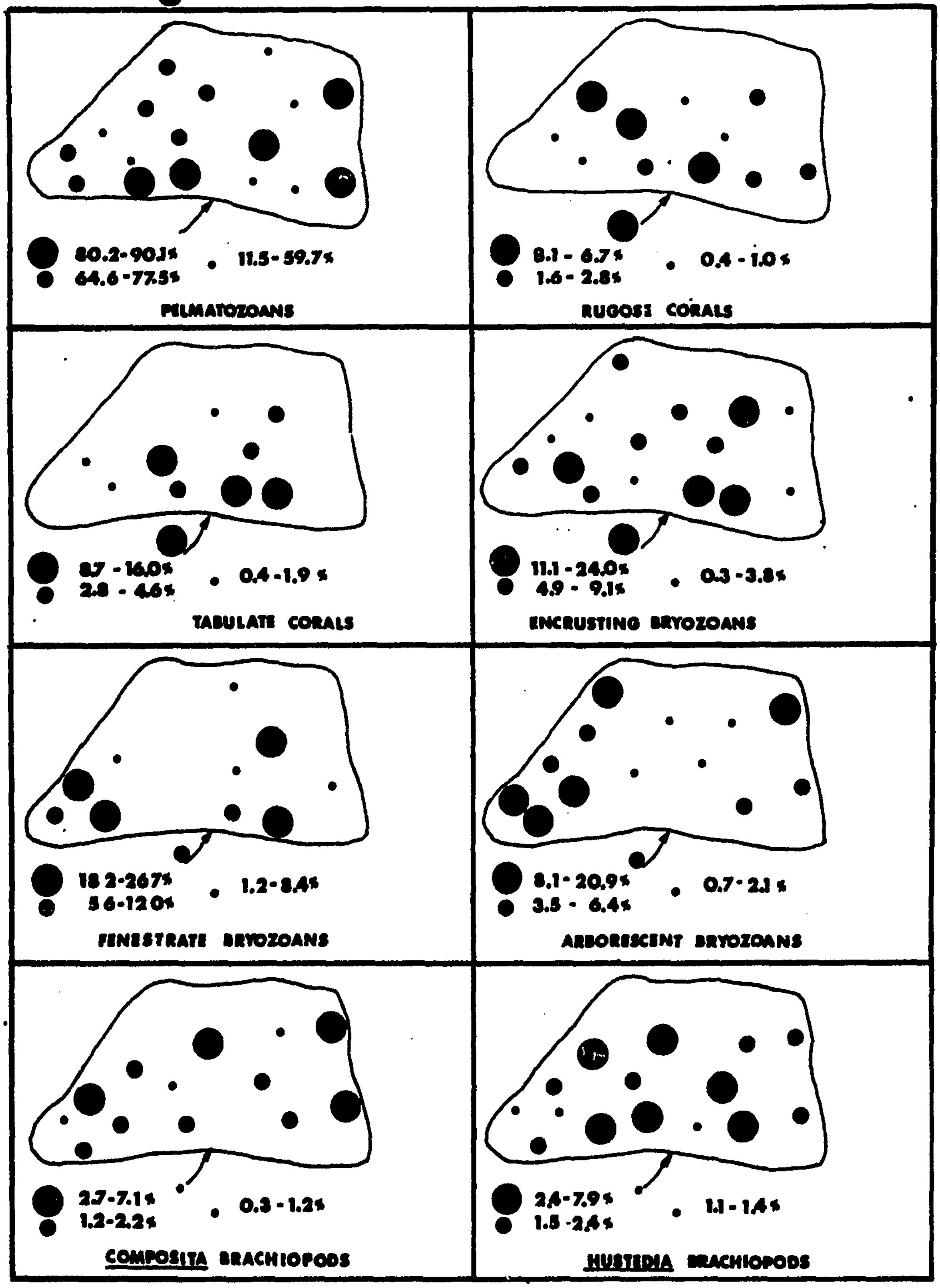
Michelinid and rugose corals have very similar distributions (differing by only 8 points) that coincide closely (12 points) with the distribution of encrusting bryozoans (text figure 27). This is a reflection of the utilization of such corals as a substrate by the encrusting bryozoans who even occur with the corals in the shale-filled cavity. Arborescent bryozoans and pelmatozoans are most different in their distribution.

The distribution of arborescent does not seem to be closely related to any other distribution, but is closest to that of the fenestrate bryozoans and Composita. Again, it is most different from the distribution of the goniatites (because of their sparsity) and michelinid corals that are found in topographically low areas.

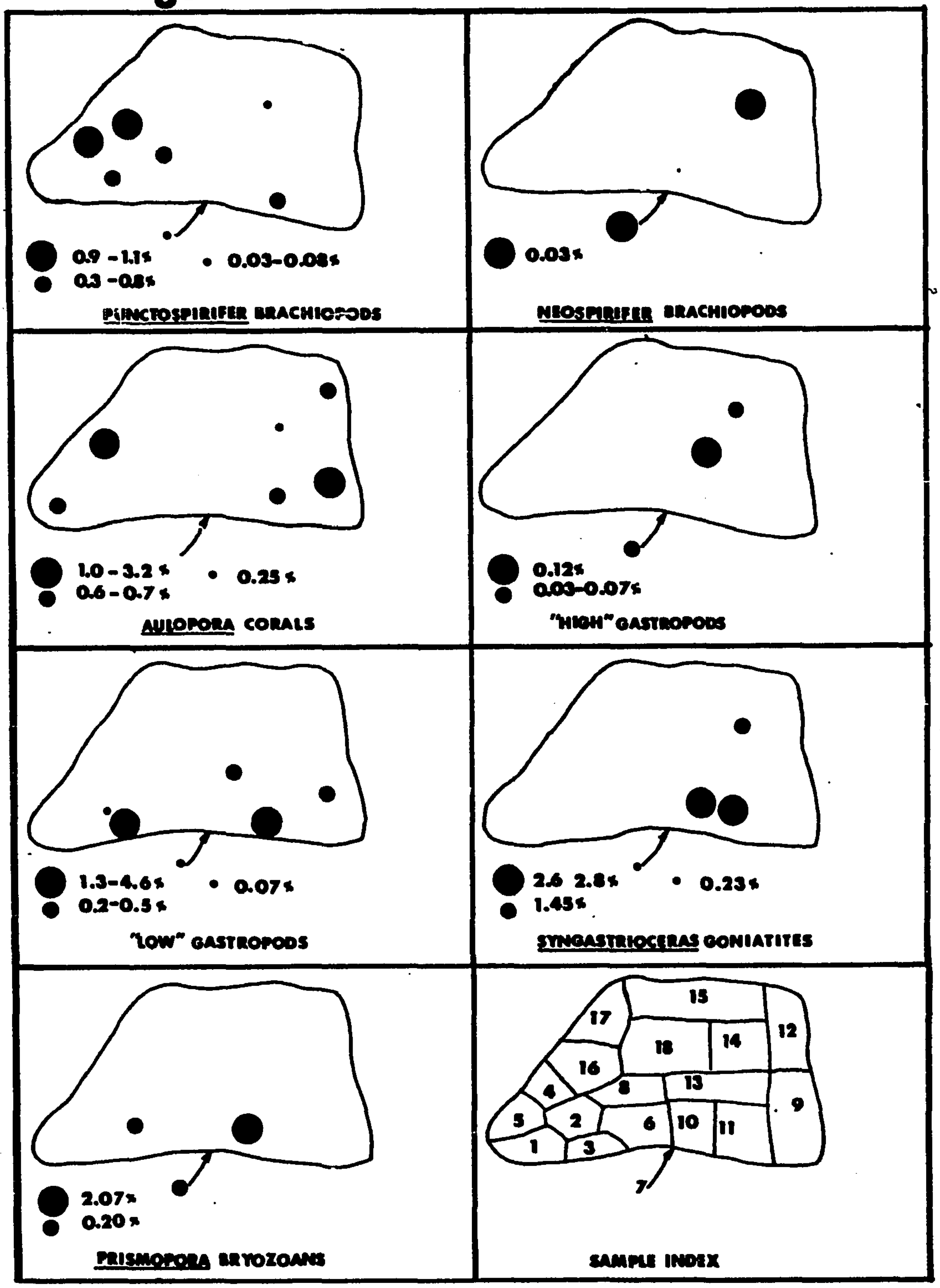
Fenestrate bryozoans are closest to other forms of bryozoans in their distribution, probably because of life habits. All bryozoans can tolerate some sand sized particles, but are unable to thrive in conditions of high mud composition and need an area with some water circulation. These bryozoans differ most in distribution from the "hill" dwellers, the pelmatozoans and Hustedia .

Encrusting bryozoans require a substrate to encrust and thus, their distribution coincides most closely with that of michelinid corals and fenestrate bryozoans. It differs most from that of Composita, spiriferid brachiopods, and arborescent bryozoans that form unsuitable substrates.

Text Figure 27 :97-8 XB SURFACE SAMPLE



Text Figure 28 : 97-8 XB SURFACE SAMPLE



PUNCTOSPIRIFER BRACHIOPODS

NEOSPIRIFER BRACHIOPODS

AULOPORA CORALS

"HIGH" GASTROPODS

"LOW" GASTROPODS

SYNGASTRIOCERAS GONIATITES

PRISMOPORA BRYOZOANS

SAMPLE INDEX

Text Figure 29 :97-8XB SURFACE SAMPLE

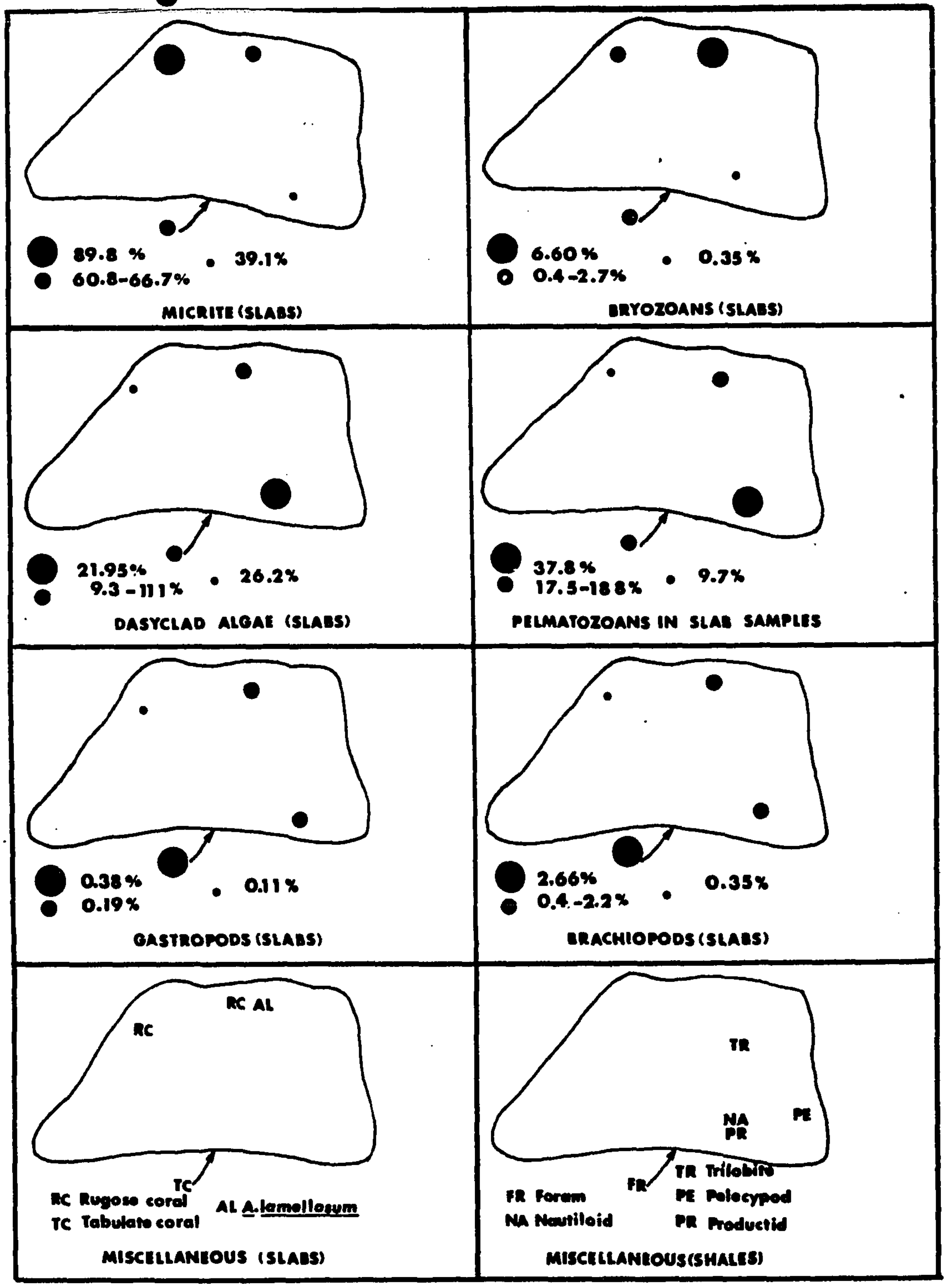


TABLE 14

97-8 XB SHALE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	PELM.	HUSTED.	COMPO.	SPIRIF.	TABULATE CORAL	RUGOSE CORAL	ENCR. BRYO.	ARBOR. BRYO.	FENES. BRYO.	OTHER	OTHER
XB-1	77.41	1.61	1.61	---	---	1.61	---	17.74	---	---	---
XB-2	59.7	1.20	1.40	0.80	0.80	0.60	11.87	9.85	13.27	0.20prs	0.20ga
XB-3	81.81	4.54	---	---	---	---	9.08	---	---	4.54ga	---
XB-5	69.1	1.05	1.05	---	---	---	4.91	11.22	11.92	0.70au	---
XB-6	90.10	2.46	1.23	---	3.69	2.46	1.23	---	---	---	---
XB-8	64.61	1.53	1.15	0.38	10.76	3.84	7.70	0.77	---	---	---
XB-9	32.70	1.89	2.70	0.27ga	1.89	1.62	1.89	3.51	2.16	1.08au	0.27pe
XB-10	42.66	1.33	---	2.66ga	16.00	6.66	24.00	---	6.66	---	---
XB-11	33.10	3.37	2.02	0.67	8.78	2.78	16.89	8.10	8.24 0.67au	2.78gn 0.67db	1.34ga 0.67na
XB-12	84.4	2.35	5.20	---	---	---	0.33	10.47	---	0.67au	---
XB-13	80.2	3.76	2.03	---	2.82	0.78	5.64	2.03	1.76	0.62ga	---
XB-16	72.34	5.31	2.12	1.06	---	3.18	2.12	6.36	4.24	3.18au	---
XB-17	70.83	---	---	---	---	---	---	20.83	8.33	---	---
XB-18	77.5	7.85	7.02	---	0.41	0.41	5.37	0.82	1.23	---	---
XB-14	11.50	1.51	0.91	0.04prs	4.59	2.10	55.1	0.91	18.3	0.03ab 0.1tr	0.1ga 0.13au
XB-4	57.14	1.90	2.85	0.95	1.90	0.95	3.80	3.80	26.66	---	---
XB-7	58.83	1.28	0.31	0.08prs	12.9	4.37	11.16 0.014.pr	4.28 0.014fm	5.66 0.021prs	0.35ga 0.25au	0.23gn 0.01tr

prs: *Prismopora*, ga: gastropod, au: auloporid coral, pe: pelecypod, gn: goniatite, db: *Derbyia*, na: natiloid, ab: *Anthracospirifer*, tr: trilobite, pr: productid brachiopod, fm: foraminifera

TABLE 15

97-8 XB CARBONATE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	MICRITE	BRYOZOA	TABULATE CORAL	RUGOSE CORAL	PELM.	ARCH. LAMEL.	OTTO.	BRACH.	OTHER	OTHER	OTHER
XB-7	66.7	2.66	0.76	---	17.49	---	---	2.66	9.31ng	0.38ga	---
XB-11	39.13	0.19	---	---	37.82	---	---	0.43	21.95ng	0.19ga	---
XB-15	60.8	6.60	---	0.10	18.8	0.21	---	2.16	11.1ng	---	---
XB-17	89.8	0.35	---	0.59	9.66	---	---	0.35	2.62ng	0.11ga	---

na: dasyclad alga, ga: gastropod

Thin-Section Description

Unit No.	Description
XB-7	SKELETAL (BRYOZOAN-BRACHIOPOD-PELMATOZOAN) LIME WACKESTONE TO LIME MUDSTONE (sparse to packed biomicrite); fine to very coarse-grained pelmatozoan fragments (10%), bryozoans (25%), brachiopods (20%), *Archaeolithophyllum missouriensis* (5%), and dasyclad alga (5%); poorly sorted, floating grains, moderate solution and overgrowth, silicification of pelmatozoan and bryozoan debris with recrystallization of fossil clasts to spar; moderate compaction with micro-fractures and stylolites; bird's-eye structures; 40 to 65 percent micritic matrix (bioturbated) with no accessory minerals; porosity (25 to 30%) including primarily shelter structures, internal skeletal cavities, and sponge borings filled with spar and fine sediments and lined by micor-spar or submarine cement (plate IX, figure 4)

TABLE 16

SIMILARITY MATRIX MOUND XB

BIOTA	PELM.	GONIA.	HUST.	COMPO.	SPIRI.	MICH.	LOPHO.	ARB.B.	FEN.B.	ENC.B.
PELM.		34	11	15	27	27	25	21	29	23
GONIA			29	29	15	14	20	29	17	21
HUST.				14	24	22	18	24	28	20
COMPO.					16	24	20	16	24	24
SPIRI.						20	18	21	18	24
MICH.							8	28	18	12
LOPHO.								23	22	18
ARB.BRY.									16	24
FEN.BRY.										14
ENC.BRY.										

Mound BN, 97-8, Station 9

This mound block is also found as a part of the talus on the floor of the central quarry (plate V, figure 1). It is located at station 9 (see topographic base, text figure 3), and is approximately 8 feet in diameter. The surface was covered with a diverse fauna of goniatites and bryozoans that were collected and described in a manner similar to that for the preceding mound (text figure 32). Percentage data is recorded in table 17.

Distribution of Components

The distribution of pelmatozoan fragments in contrast to the previous study, most closely resembles that of the arborescent bryozoans and the goniatite *Branneroceras branneri* (text figure 30). However, in neither case is there a strong similarity. It is possible that the bryozoan and pelmatozoan columnals have similar hydrodynamic characteristics and tended to accumulate together in death assemblages,or these forms may in fact exist together in similar habitats, and the goniatite is associated with them. Michelinid coral distribution is most dissimilar to that of the pelmatozoans, which might not be expected if this were merely transported debris.

The distribution of the two goniatite cephalopod genera found, *Syngastrioceras* and *Branneroceras*, closely coincides (text figure 30). This is not surprising since they should have similar life habits as well as similar hydrodynamic properties. The distribution of *Syngastrioceras* is and pelmatozoan fragments. It is most different from the distribution of *Composita* (text figure 31), which exhibits a sessile benthonic existance compared to that of a vagrant or nektonic goniatite.

As was true in the previous study, the similarity between the distributions of *Composita* and *Hustedia* are most striking with only 20 points of dissimilarity (table 18). Both forms are pediculate brachiopods that might inhabit similar habitats and both are most dissimilar in distribution to michelinid corals (58 and 53 points of dissimilarity).

Punctospiriferid brachiopods on the other hand, show no close similarity to any other distribution (text figure 31). The closest distribution is that of Prismopora bryozoans with 35 dissimilarity points, which it resembles primarily in scattered, sparse distribution. Fenestrate bryozoans are most dissimilar in distribution, probably due to their more ubiquitous nature.

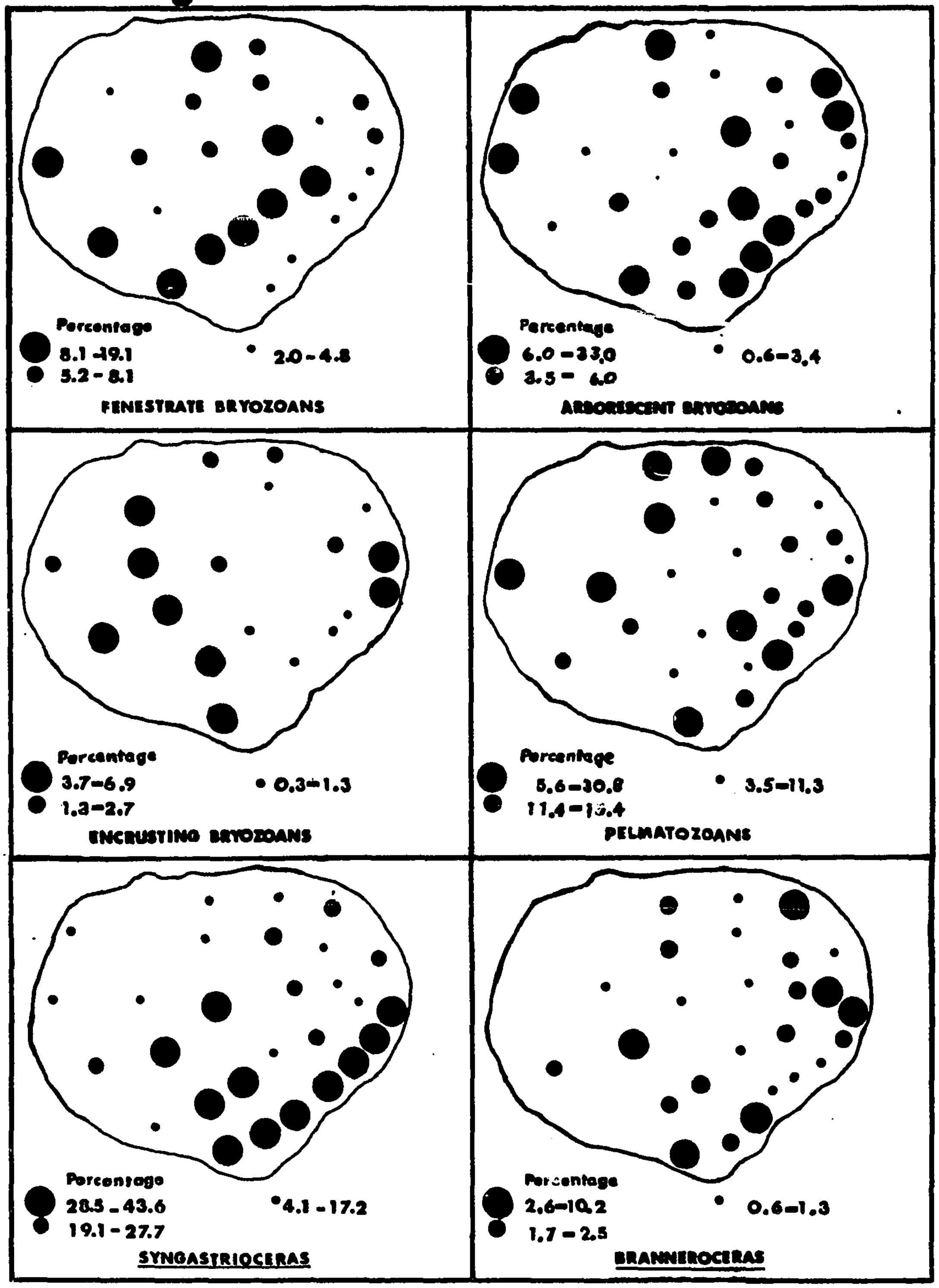
Fenestrate and arborescent bryozoans are more closely related in distribution, possibly as a result of niche. They are most dissimilar in distribution to Punctospirifer, which is more restricted on the mound surface (text figure 31). This may also be a reflection of difference in life habits between these organisms: difference in attachment, food preference, or sediment tolerance. The distribution of arborescent bryozoans is most different from that of encrusting forms (text figure 30), which might not be expected unless there is competition for nutrients or differences in substrate preferences.

Michelinid and rugose corals again appear very similar in distribution, but the occurrence of Lophotichium is extremely limited and michelinid corals (text figure 32) appear closest to the distribution of both Prismopora bryozoans and punctospiriferid brachiopods that have in common only their nonubiquitous nature. Michelinid corals differ most from the distribution of Hustedia that probably preferred a different type of sediment or food.

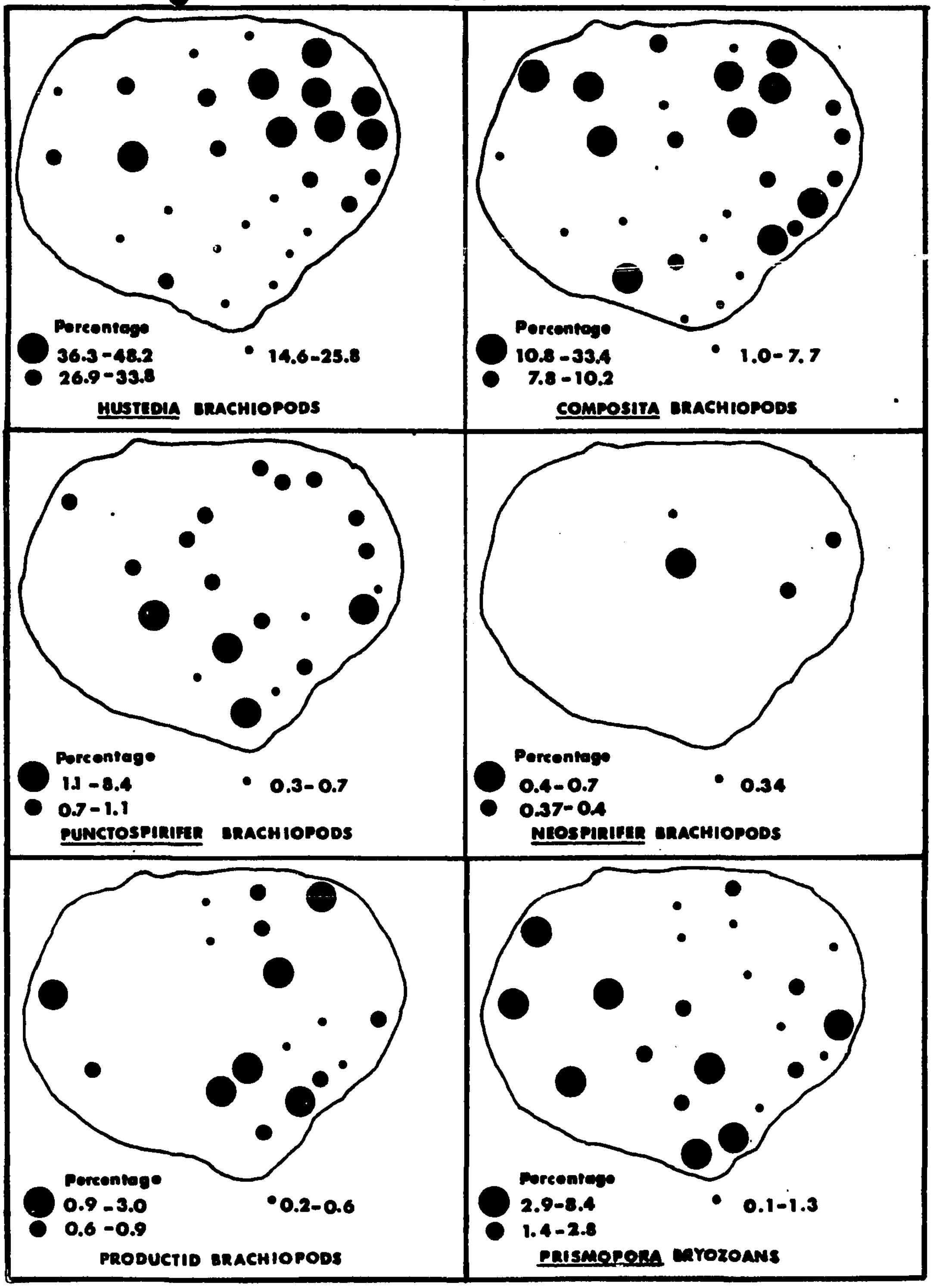
The distribution of encrusting bryozoans (text figure 30) is most similar to that of Prismopora, which might have inhabited similar niches. The distribution is most dissimilar to that of arborescent forms that again might have preferred a different type of habitat for attachment and growth as noted in modern bryozoans.

Likewise, the distribution of Prismopora is most closely related to that of encrusting forms illustrating a similar mode of life. It is most different from that of Composita, a pediculate brachiopod that would not have the same type of habitat preferences. In addition, the hydrodynamic character of the organisms is entirely different, and Composita might be expected to be moved slightly after death.

Text Figure 30: 97-8 SURFACE SAMPLE BN



Text Figure 31: 97-8 SURFACE SAMPLE BN



Text Figure 32: 97-8 SURFACE SAMPLE BN

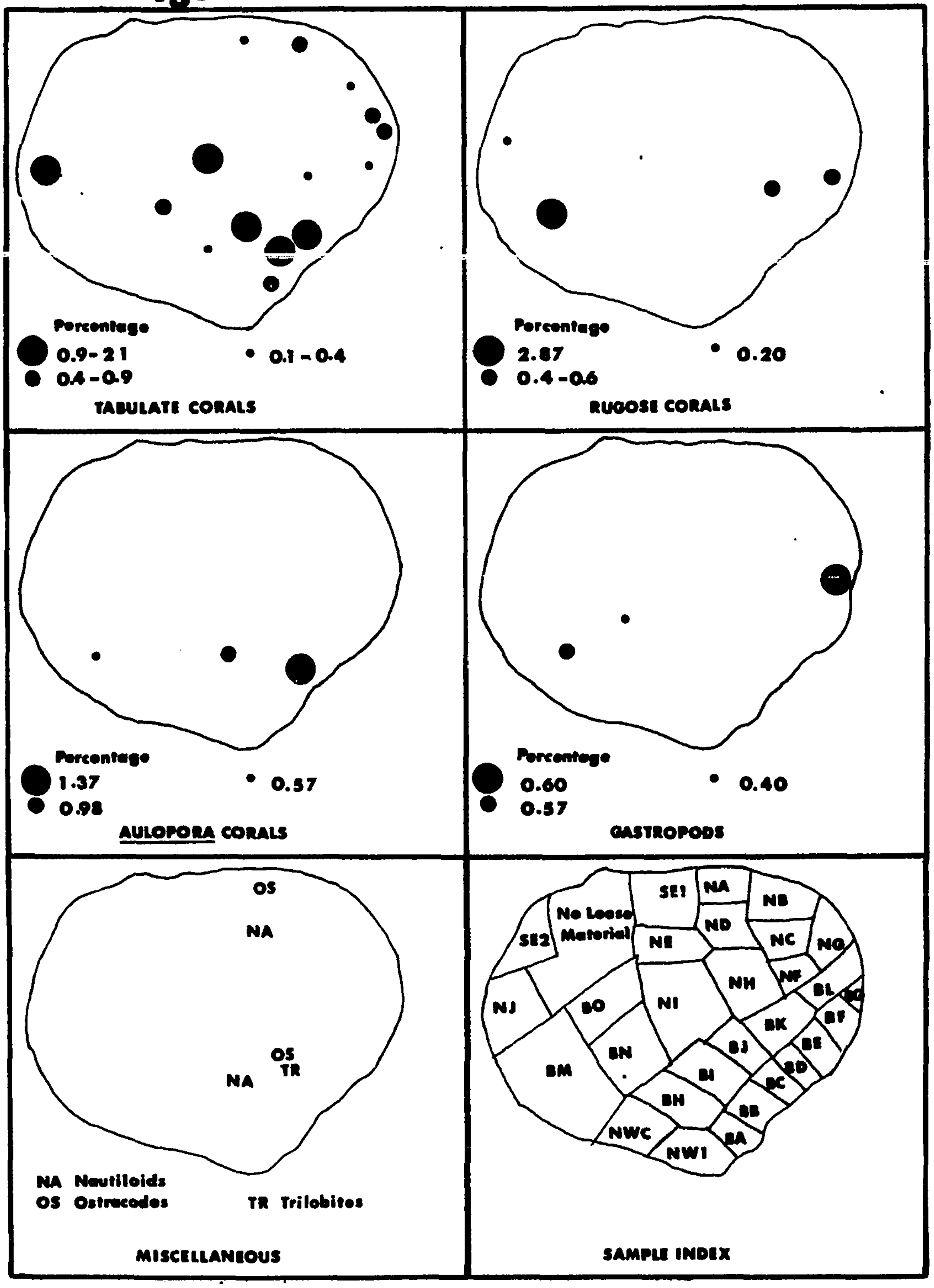


TABLE 17

97-8 BN SURFACE SAMPLE PERCENTAGE COMPOSITION

SAMPLE	PELM.	SYNGAS.	BRANNER.	HUSTED.	COMPO.	PUNCTO.	PRISMO. BRYO.	FENES. BRYO.	TABULATE CORAL	ARBOR. BRYO.	ENCR. BRYO.
BA	1.42	37.61	1.90	20.47	7.14	2.38	5.23	4.76	0.48	7.61	0.95pr
BB	9.90	43.56	2.97	20.29	5.94	0.49	0.99	3.46	0.99	8.91	0.99 0.99pr
BC	29.65	14.48	0.68	22.75	12.41	---	1.37au	0.68pr	2.06	14.48	1.37
BD	3.02	29.57	1.05	33.80	9.50	0.70	2.46	2.81	0.35pr	5.63	1.05
BE	13.54	32.81	1.04	32.29	12.50	---	1.04	2.08	---	3.64	1.04
BF	15.67	31.6	2.19	26.95	8.46	1.56	5.32	2.50	0.31	3.44	2.19 0.62pr
BG	9.90	31.2	2.70	28.22	7.80	0.36	1.80	5.40	0.90 0.62au	6.00 0.60ga	4.20 0.60na
BH	10.75	25.08	1.99	21.51	8.76	0.39	2.78	14.74	0.39	4.78 0.39ga	2.39 1.99na
BI	11.21	35.60	1.95	14.63	7.31	3.41	3.41	9.75 0.98au	0.98 0.98na	5.85 2.92pr	0.98
BJ	27.8	3.27	1.23	20.6	0.97	0.17	---	19.10	---	18.5	0.04tr
BK	14.33	27.62	2.44	2b.67	8.04	0.34	1.04 0.34ab	9.09 0.34rc	0.34 0.34na	4.19 0.34db	2.44 0.34ds
BL	12.01	17.16	3.43	36.90	9.01	0.85	0.42ab	8.15	0.42	7.29	4.29
BM	13.79	22.98	1.72	23.56	5.17	1.87rc	6.32	12.64	0.57au	2.29 0.57ga	6.89 0.57db
BN	12.09	36.29	4.83	22.17	4.43	1.20	2.82	4.43	0.80	3.62	6.85 0.40ga
BO	15.62	14.58	1.04	36.45	12.50	1.04	7.29	5.20	---	3.12	3.12
BP3	15.38	23.07	3.41	33.33	7.69	---	3.41	5.98	---	5.12	2.56

SAMPLE	PELM.	SYNGAS.	BRANNER.	HUSTED.	COMPO.	PUNCTO.	PRISMO. BRYO.	FENES. BRYO.	TABULATE CORAL	ARBOR. BRYO.	ENCR. BRYO.
BQ2	15.73	25.84	10.11	28.08	10.11	1.72	---	4.49	---	4.49	---
BR3	8.84	33.33	20.4	38.77	10.88	0.68	2.04	4.68	1.36	1.36	---
BS2	3.57	22.14	2.85	45.7	6.42	1.42ds	1.42	7.14	---	2.85	0.71
NA	30.8	8.92	0.78	25.8	6.57	0.46	0.62	15.49	0.15 0.31cl	6.57 0.15br	0.31os 0.15pr
NB	14.01	25.73	2.94	41.17	12.50	0.72	0.72cl	1.46ds	0.73	---	---
NC	14.70	17.64	2.45	42.64	12.74	---	---	6.86	---	4.90	---
ND	9.23	28.02	1.27	37.8	12.73	0.63ds	1.27	7.00	0.95na	0.63	0.31
NE	27.7	9.65	2.47	29.8	7.67	0.86	0.12	16.9	0.37ab	3.58	0.61pr
NF	15.65	19.13	2.60	46.08	---	---	2.13	5.21	---	3.47	6.08
NF2	13.84	16.92	2.30	40.76	10.00	1.53	1.53	4.61	---	3.07	5.38
NG	7.88	22.53	1.12	42.8	11.54	0.84	0.56	8.16	0.28	3.38	0.84
NH	9.09	24.91	1.01	36.3	9.76	---	1.01	8.08	1.01pr	6.06	2.69
NI	7.29	35.03	0.72	32.84	8.75	0.72	2.18	6.56	1.45	1.45	2.18 0.72ab
NJ	27.64	4.11	1.76pr	30.58	6.47	0.58rc	2.94	8.23	0.17	14.11	2.35
NK	12.36	15.72	0.20te	48.2	11.74	1.67	0.41ab	3.98	0.20	3.98	1.25 0.20rc
NWTi	22.61	28.57	4.76	17.85	4.76	1.19	4.76	7.14	---	2.38	5.95
NWT2	---	20.00	---	33.33	33.33	---	---	10.00	---	10.00	---
SETi	22.70	14.59	2.16	25.40	8.10	---	1.08	8.64	0.54pr	14.59	2.16
SET2	---	16.66	---	16.66	16.66	8.33	8.33	---	---	33.33	---
---	11.11	22.22	---	29.62	29.62	---	---	3.70	---	---	3.70

TABLE 18

SIMILARITY MATRIX MOUND BN

BIOTA	PLM.	SYN.	BRN.	HST.	CMP.	SPR.	FEN.	MCH.	ARB.	ENC.	PRM.
PELM.		44	32	38	42	44	34	48	30	37	40
SYNGAS.			32	36	38	43	40	43	42	42	36
BRANN.				38	48	41	43	45	40	35	36
HUST.					20	48	38	58	42	41	48
COMPOS.						43	43	53	38	45	50
SPIRIF.							53	38	45	48	35
FENES.BRY.								50	28	40	40
MICHEL.									47	44	38
ARB.BRYO.										50	49
ENC. BRYO.											31
PRISM.BRY.											

TABLE 19

PERCENTAGE COMPOSITION OF SLABS FROM GREENLEAF LAKE

SAMPLE	MICRITE	BRYOZOA	PELM.	ARCH. MISS.	ARCH. LAMEL.	DASY. ALGA	TABULATE CORAL	RUGOSE CORAL	BRACH.	GAST.	OTHER
1c-tp	57.66	8.75	4.37	2.91	1.45	10.21	10.21	---	4.37	---	---
1c-bs	56.79	3.08	10.49	1.85	---	19.13	---	1.85	4.93	1.23	0.33fm
1c-total	57.1	5.68	7.69	2.34	0.66	15.05	4.68	1.00	4.68	0.66	0.33fm
2c	89.2	1.71	5.15	0.42	---	---	---	---	1.28	---	2.14cp
3c	83.0	3.08	1.93	0.77	---	0.77	1.54	---	0.38	0.38	8.10fm

fm: foraminifera, cp: Cuneiphycus sp.

FROM TABLE 17: pr: productid brachiopod, au: auloporid coral, ga: gastropod, na: nautiloid, tr: trilobite, ab: Anthracospirifer, rc: rugose coral, db: Derbyia, ds: Desmoinesia, os: ostracode, cl: Cleithyridina, br: Branneroceras

APPENDIX B

DESCRIPTION OF MODERN REEFS

Florida

During June 1972, cavities and the organisms associated with them were examined and described at five localities near Miami, Florida. Samples were collected in depths ranging from intertidal to 12 meters in the sublittoral zone (text figure 39). Lithic and coral material was broken and examined under a binocular microscope.

Samples were collected in the upper intertidal zone, 12 cm below high tide (MHWM) in nonporous biomicrite. Several small cavities ranging from 1 to 10 cm in size occur and represent sipunculid worm, clionid sponge, and bivalve borings. The sponge and worm borings are actively inhabited by sponges and worms, however, the bivalve borings were usually vacated and coated with drusy calcite overlain by a thin red organic film that has been identified as the red alga Peysoneillia. Calcareous tubes from all sizes of serpulid worms are particularly dense near the top of the cavity.

A second series of samples was collected 12 cm below low tide (MLWM) in a material that resembled "swiss cheese." The original rock was probably Miami Oolite that has been excavated and is now encrusted by colonial tunicates, Zoanthus sociatus-Palythoa (algal-zoanthid consortum), bivalves, clionid sponges, feather duster and spirorbid worms, and the common short-spined sea urchin, Echinometra luncater.

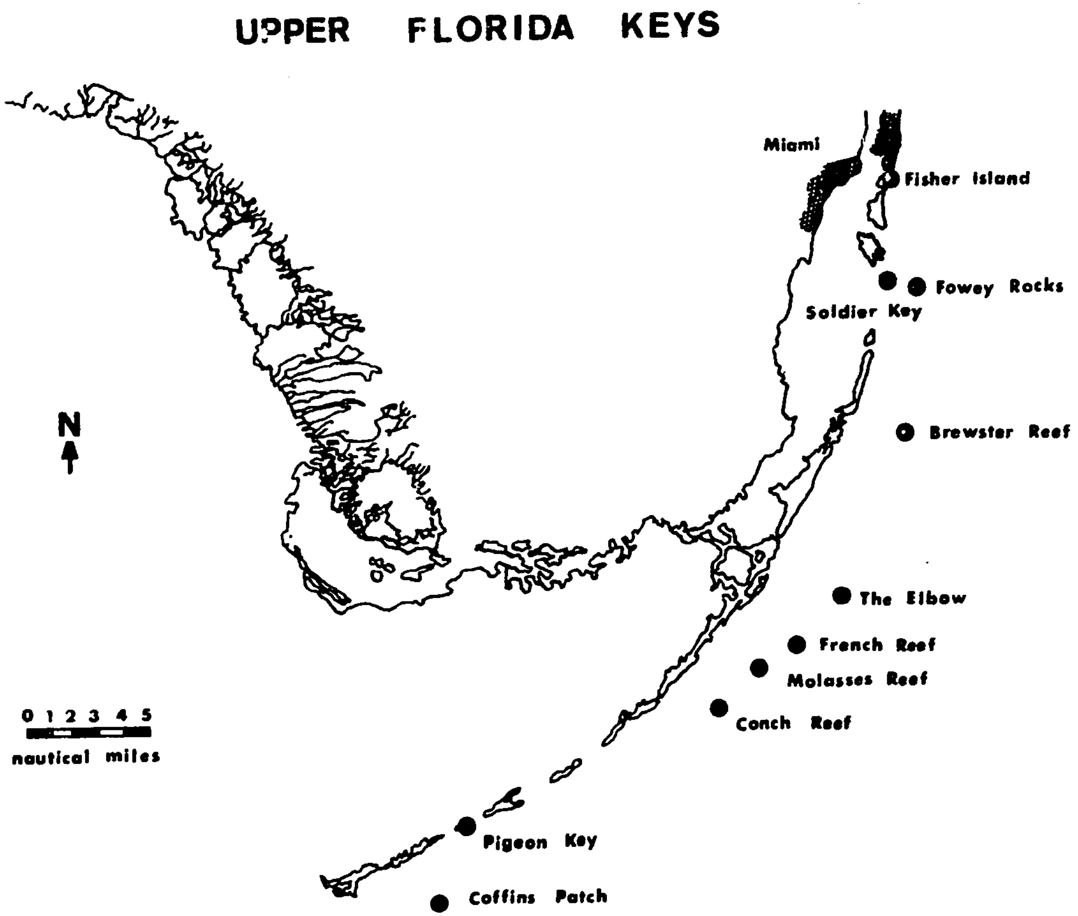
The subtidal zone was sampled in the next two sets of samples. Both samples were taken at 1.3 to 2.0 meters below low tide (MLWM). However, the first sample was taken in granite that was brought in to form the jetty at Government Cut. This sample had only a covering of filamentous green algae on the surface. The second sample was in Miami Oolite similar in nature to that collected just below low tide. This material contained abundant clionid sponge borings, tunicates, sipunculid worms with red and green filamentous algae and associated sediments.

The last sample was collected at a depth of 12 meters and consisted of biolithite and dead coral heads with a variety of cavities including worms, bivalves, sponges, and irregular coral growth. The upper surfaces are characteristically covered by coralline red algae that extends into old cavities to a depth of 3 mm where the algae may encrust old serpulid worm tubes. The lower part of the cavity contains filamentous bryozoans that help entrap fine debris. Clionid spong borings are common and appear to occur in cavities that the sponges initiated or rebored, killing areas occupied by red algae. Fleshy green and red algae commonly live on the top of the calcareous red algal crust on the surface. Other biotic elements occurring on the surface of the material include encrusting foraminifera and sponges as well as polychaete worms and gorgonians.

Detailed investigation of cavities and coelobites in deeper reefs in the Florida Keys was conducted during May 1973. Much time was spent examining and photographing areas within Pennekamp Coral Reef Park while samples were collected outside the park to the north and south. Areas outside the park seem to have much less vigorous scleractinian coral growth. Whether this is the result of extensive removal of organisms in unprotected areas as has been suggested, or whether this area was in fact more favorable prior to the location of the park, I do not know. However, I suspect that the high sedimentation observed in areas outside the park may be a factor.

Samples were collected at depths of 8 to 17 meters within four areas in the outer reef tract: near Pompano Beach, Brewster Reef, east of French Reef, and at Conch Reef (text figure 39). Most of the biolithite substrates examined were comprised of dead corals. The most common material was *Montastrea* and *Diploria* with some samples of *Porites*, *Acropora cervicornis*, and *A. palmata*.

The surface biota in all areas was similar. Typically, the upper surface is encrusted by filamentous red and green algae (*Galaxaura* and *Cladophora*) and serpulid worm tubes. Algae including *Dictyota*, *Udotea*, and *Halimeda opunta* commonly attach to free substrates on the upper surface along with *Siderastrea siderea*, alcynarians, encrusting gorgonians including *Erythropodium*, desmosponges, colonial bryozoans, and bivalves. Encrusting foraminifera, tunicates, and bryozoan colonies are much more common on the



TEXT FIGURE 39

lower surfaces. Clionid sponges and endolithic algae excavate small borings in the upper few millimeters. In addition, boring bivalves such as *Lithophaga* are common, as are sabellid and sipunculid worms. Vacated borings are commonly inhabited by red algae near the opening with serpulid worm tubes and ectoproct bryozoans deeper in the cavity.

TABLE 20

MODERN REEF BIOTA

SUBSTRATE	Clastic Sand	Calcareous Sand	Mud
DEPTH 0-5 Feet	red & green filamentous algae *Peysoneillia* sp.	*Thalassia* sp. *Cymodocia* sp. *Udotea* sp. *Penicillus* sp. *Siderastrea radians* *Diploria strigosa* *Porites astreoides* *Diadema antillarium*	*Thalassia* sp. *Halimeda optunta* *Penecillus* sp. *Meandrina mean.* *Siderastrea radi.* *Manicina areolat.* *Colpophyllia nat.* *Montastrea annul.* *Rhodactis* sp. *Zoanthus* sp. *Condylactis giga.* *Heteractis* sp. *Eunicea* sp. holothurians
20-25 Feet	*Millepora complanata* *Montastrea annularis* *Manicina areolata* *Schizothrix* sp. *Palythoa-Zoanthus* sponges *Pseudogorgonia* sp. serpulid worms	*Thalassia* sp. *Halimeda opunta* *Montastrea annularis* *Diploria clivosa* *D. strigosa* *D. labyrintheformis* *Eunicea* sp. *Millepora alcicornis* *Condylactis gigantus* *Heteractis* sp. *Gelloides astreodes* *Homotrema rubrum* *Haliclona rubens* *H. erina* *Neogoniolithon* sp. *Diadema antillarium*	calc. red alga *Manicina areolata* *Porites astreodes* *Porites porites*

SUBSTRATE	Clastic Sand	Calcareous Sand	Mud
30-50 Feet	*Montastrea cavernosa* *M. annularis* *Diploria strigosa* alcynarians gorgonians misc. sponges	*Montastrea annularis* *Diploria strigosa* *Agaricia agaricites* *Acropora cervicornis* *Millepora alcicornis* *M. complanata* *Eusmilia fastigiata* *Pseudogorgonia* sp. *Gorgonia flabellum* misc. sponges *Cliona* sp. bryozoans crinoids *Diadema antillarium*	*Dendrogyra cylin.* *Porites porites* *Colpophyllia nat.* *Montastrea caver.* *Gorgonia* sp. *Haliclona erina* *Gelloides astreo.* bryozoans
60-110 Ft.	*Halimeda cryptica* *Mycetophyllia alic.* *Mussa angulosa* *Agaricia agaricites* *Helioseris cuculata* *Millepora alcicornis* gorgonians zoanthids *Mycale laevis* *Mycale* sp. *Ianthella* sp. *Gelloides astreodes*	*Porites astreoides* *Mycetophyllia darana* *Montastrea cavernosa* *M. annularis* *Agarica lamarki* *Porites astreoides* *Madracis mirabilis* *Eusmilia fastigiata* antipatherians *Eunicea* sp. *Haliclona rubens* tube sponge *Diadema antillarium* crinoids	*Agaricia lamarkia.* *Montastrea cavern.* antipatherians *Haliclona rubens* misc.sponges

TABLE 21

DESCRIPTION OF MODERN CAVITY BIOTA

A. Brewster Reef Material (11 samples)

1. Compostion of Reef Rock: Pleistocene to Modern Coral: Diploria and Montastrea
2. Surface Fauna: Clionid sponge (18.9%), green filamentous alga (13.5%) red encrusting alga (13.5%), Erythropodium sp. (10.8%), encrusting sponge (8.1%), Dictyota alga (5.4%),serpulid worms (5.4%), sabellid worm tube (2.7%), filamentous red alga (2.7%), colonial bryozoans (2.7%), bivalves (2.7%), alcynarians (2.7%)
3. Cavity Fauna: clionid sponges (20.8%), red alga (calcareous: 16.6%), filamentous red alga (Jania: 16.6%), serpulid worms (12.5%), sipunculid worms (8.3%), siliceous sponge (8.3%), Homotrema rubrum (encrusting foram: 8.3%), sabellid worm (4.2%), coarse sediments (4.2%)
4. Types of Cavities: bivalves, clionid sponges, worms
   over 85% filled with medium to coarse sediments
5. Observations:
   a. green filamentous alga growning on red calcareous enc. alga
   b. Erythropodium growing over sediments and red enc. alga
   c. clionid sponge in top of cavity lined by red calc. alga with serpulid worm tubes in middle and filamentous bryozoan in bottom

B. Pompano Beach Reef Material (3 samples)

1. Composition: Pleistocene to modern coral: Montastrea and Porites
2. Surface Fauna: red encrusting calcareous alga (15.8%), filamentous green alga (15.8%), red filamentous alga (15.8%), Udotea alga (10.5%), clionid sponge (10.5%), colonial bryozoan (10.5%), polychaete worm (5.3%), Lithophaga bivalve (5.3%), Erythropodium (5.3%), Dictyota (5.3%)
3. Internal or Cavity Bio.:clionid sponges (60.0%), red encrusting calcareous alga (20.0%), sipunculid worm (20.0)
4. Types of cavities: clionid sponge borings, bivalve borings
   some are filled and rebored
5. Observations: red and green filamentous algae encrust red encrusting calcareous algae.

C. Conch Reef Material (10 samples) average depth 20-30 feet

1. Composition of Reef Rock: dead coral: Montastrea annularis, Diploria sp., Acropora cervicornis, A. palmata, and biomicrite

2. Surface fauna:

   a. Upper Surface: encrusting red calcareous algae (17.5%), filamentous green alga (15.0%), Siderastrea siderea (10.0%), serpulid worm tubes (10.0%), green endolithic alga (7.5%), Udotea (5.0%), Dictyota (7.5%), Amphiroa-Jania algae (7.5%), Halimeda opunta (5.0%), Homotrema rubrum (2.5%), red filamentous alga (2.5%), clionid sponge (2.5%), green coiled alga (2.5%), orange tunicate (2.5%), Vermicularia sessile gastropod (2.5%)

   b. Lateral surfaces: red-orange colonial bryozoans (17.6%), serpulid worm tubes (17.6%), Homotrema rubrum (17.6%), green filamentous bryozoan (5.9%), Ophiothrix brittle star (5.9%), Ascidea nigra black tunicate (5.9%), Udotea (5.9%), Jania and Amphiroa (5.9%)

   c. Bottom Surface: serpulid worm tubes (18.8%), colonial bryozoan (18.8%), Neogoniolithon alga (18.8%), Homotrema rubrum (12.5%), orange tunicate (12.5%), Jania-Amphiroa (6.25%), Siderastrea siderea (6.25%), Ophiothrix (6.25%)

3. Cavity Fauna: clionid sponges (46.7%), sipunculid worms (40.0%), Lithophaga (6.7%), Brachiodontes bivalves (6.7%)

4. Types of Cavities: open cavities lined with encrusting red calcareous algae covered with serpulid worm tubes near the top and bryozoans near bottom, bivalve borings and clionid sponge borings; many filled with coarse to very coarse calcareous sediments; Halimeda plates (91.5%) with bivalve fragments, fine coral fragments, foraminifera and echinoid spines in sediments

5. Observations: endolithic green alga in red calcareous encrusting alga (Neogoniolithon)

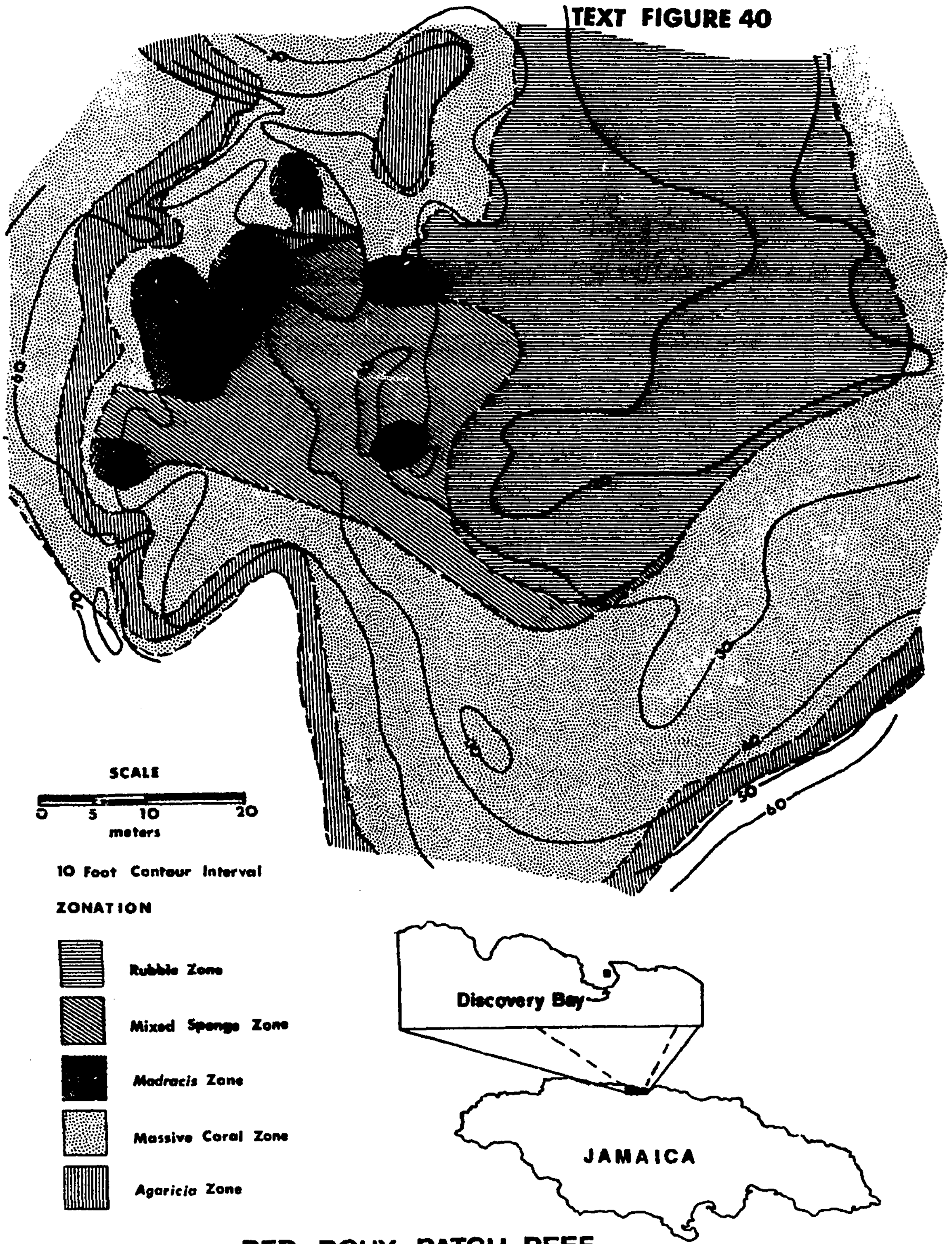
Jamaica

The biota and substrate of a patch reef in the lagoon at Discovery Bay, Jamaica, were studied in an attempt to relate these features to ancient environments.

The Red Bouy Patch Reef is located on a long, narrow bank that extends south and slightly west from the 20-foot contour in the northeastern part of Discovery Bay (text figure 40). The reef association extends approximately from 18 to 70 feet where the bottom becomes a predominately flat mud floor interrupted only by mounds of burrowing organisms and antipatherians.

The substrate of the Red Bouy Patch reef is composed of carbonate mud with varying amounts of skeletal debris - primarily Halimeda plates. The difference in size of sediments between the Red Bouy and the forereef areas that have a sand bottom may have a great influence on the organisms. Not only does the large amount of suspended sediment in the waters of the lagoon affect and limit the organisms present by their ability to cope with and rid themselves of sediments, but also the amount of suspended material greatly alters light penetration. The visibility during the period of study (July-August, 1974) ranged from a maximum of 15 feet to a minimum of 6 inches. Where the visibility is least, the fauna and flora is much less dense and deeper water corals are found at shallow depths. Fragile plates of Agaricia lamarcki and other corals normally found below 100 feet are found at depths from 50 to 60 feet at the Red Bouy Patch Reef. In fact, the entire association is dominated by forms common on the upper and lower forereef slope (Goreau and Goreau, 1973) instead of a 20 to 70 foot lagoonal area. The Jamaican hermatypic corals not represented are generally shallow, clear water forms. These include Dendrogyra cylindrus, Acropora palmata, A. prolifera, Isophyllia sinuosa, Isophyllastrea rigida, Siderastrea radians, and most of the Diploria species.

TEXT FIGURE 40



RED BOUY PATCH REEF

General Description of Faunal Zones

Porites-Rubble Zone

This zone covers over 25 percent of the map area on the shallow top and sides of the bank. Swimming over the zone gives the impression of a low, rubble-covered desert (text figure 40). The dominant species are *Haliclona rubens*, *Porites astreoides*, and *Diadema antillarium*. Percentage of organic cover based on transects of the zones are given below.

Haliclona rubens (sponge)	32.22%
Porites astreoides (coral)	22.22
Diadema antillarium (urchin)	15.56
Isognommon alatus (bivalve)	6.67
Colpophyllia natans (coral)	6.67
Neofibularia nolitangere (spg)	4.44
Agaricia agaricites (coral)	4.44
Porites porites (coral)	3.33
Eucidaris sp. (urchin)	2.22
Siderastrea siderea (coral)	2.22

Mixed Sponge Zone

The Mixed Sponge Zone covers approximately 10 percent of the patch reef. This is one of the most variable and diverse (if number of species are considered) zones with 27 species represented over two transects. The red alga, *Ceramium nitens*, is found in greatest abundance, followed by *Haliclona dora*.

Ceramium nitens (alga)	37.04%
Haliclona dora (sponge)	16.67
Isognommon alatus (bivalve)	11.11
Agaricia agaricites (coral)	10.49
Diadema antillarium (urchin)	4.94
Haliclona rubens (sponge)	4.32
Callyspongia pallida(sponge)	3.70
Speciospongia vesparia (spg)	3.09
red encrusting sponge	3.09

Siderastrea sidera(coral)	1.23
Verongia sp.(sponge)	1.23
Haliclona erina(sponge)	1.23
Mycale sp.(sponge)	1.23
Heteractis sp(anemone)	0.62

Madracis Zone

This zone is dominated by *Madracis mirabilis* with minor elements of the Sponge Zone occurring near zonal boundaries. The middle of the *Madracis* Zone forms a conspicuous hillock of nearly 100 percent *Madracis* that surrounds the low areas of the Sponge Zone.

Madracis mirabilis(coral)	84.78%
Haliclona rubens(sponge)	15.21

Massive Coral Zone

The Massive Coral Zone covers the greatest areal extent of the mapped area (text figure 40). In contrast to the *Madracis* Zone that covered less than 10 percent, the zone covers over 40 percent of the patch reef. It contains many elements of the Mixed Sponge Zone, but also adds several coral species as described below.

Speciospogia vesparia(spg)	19.74%
Haliclona dora(sponge)	17.76
Montastrea cavernosa(coral)	17.11
Agaricia agaricites(coral)	11.18
Erythropodium sp.(coral)	10.53
Gelliodes areolata(sponge)	9.21
Siderastrea siderea(coral)	5.26
Condylactis gigantea(anemone)	5.26
Scolymia cubensis(coral)	1.32
Haliclona rubens(sponge)	1.32
Callyspongia pallida(sponge)	0.66

Agaricia Zone

The *Agaricia* Zone forms a narrow belt in the Massive Coral Zone and covers less than 10 percent of the Red Bouy Patch Reef (text figure 40). It is distinguished by the presence of *Agaricia lamarcki* that is also a dominant faunal element.

Erythropodium sp.(coral)	27.0%
Montastrea cavernosa(coral)	23.0
Porites porites(coral)	12.0
Agaricia agaricites(coral)	10.0
A. lamarcki (coral)	8.0
Speciospongia vesparia(sponge)	8.0
Ceramium nitens(alga)	8.0
Haliclona dora(sponge)	2.0
Siderastrea siderea(coral)	2.0

Summary

The fauna developed at the Red Bouy Patch Reef forms a striking contrast to that of the fringing reef. Low light intensities result from the great amount of suspended particulate matter and sediments. Although this water may be nutrient rich, it is "saturated" with fine carbonate mud. The low light intensity added to the suspension of fine mud results in the sparsity of shallow water biota that cannot cope with fine sediments. The resulting faunal association, divided into five zones or associations with a mappable distribution, is one that would normally occur on the forereef slope.