ENVIRONMENTAL ANALYSIS OF A VIRGILIAN (PENNSYLVANIAN) CARBONATE SEQUENCE WITHIN RHODES CANYON, SAN ANDRES MOUNTAINS, NEW MEXICO

by

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7 September 1983

Date

To my parents

Larry and Elaine

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ABSTRACT

The lowermost Virgilian (Pennsylvanian) limestone sequence exposed in Rhodes Canyon (San Andres Mountains) represents a period of carbonate deposition which occurred during cessation of clastic sedimentation responsible for thick carbonaceous shale accumulations. The carbonates consist of four stratigraphically layered, adjacent facies: 1) bryozoan-crinoidal wackestones and packstones, 2) phylloid algal wackestones and packstones, 3) grainstones, and 4) wackestones to in part packstones.

The bryozoan-crinoidal wackestones and packstones occupy the lower 2 meters of the carbonate sequence. The lowermost carbonate beds within this lithofacies exhibit grain-supported bioclasts, claystone clasts, and phosphate nodules. Above these basal beds mud-supported and non-abraded skeletal grains occur.

Phylloid algal wackestones and packstones, located stratigraphically above the previously discussed lithofacies, are several meters thick. The most diagnostic feature of this interval involves the dominance of phylloid algae which account for 70 percent of the total biotic fraction.

The grainstones extend 2-3 meters above the phylloid algal wackestones and packstones. Microscopic examination reveals intragranular and intergranular regions are filled with sparry calcite cement. In addition, non-skeletal grains such as ooids, peloids, and aggregate grains are abundant. These grainstones exhibit low-angle cross-beds and silicified burrows in the field.

The wackestones to in part packstones occupy the upper 18 meters of the carbonate sequence. This interval contains the greatest variation of environmentally significant fossils, sedimentary structures, and rock types.

Deposition of the carbonate sequence took place in shallow-marine waters. The bryozoan-crinoidal and phylloid algal wackestones and packstones were deposited within the photic zone, below normal wave base, and in normal or near-normal marine waters. The grainstones are associated with a barrier-shoaling sequence where deposition occurred above normal wave base. The carbonates within the wackestones to in part packstones were deposited in a restricted, back-barrier lagoonal environment which was located landward from the prograding shoal sequence.

This investigation suggests that major accumulations of oil and gas are unlikely, but the possibility does exist for extraction of hydrocarbons (from the carbonate sequence) within the subsurface of the Tularosa Basin. Carbonaceous shales, located above and below the carbonate sequence, could serve as source and cap rocks.

INTRODUCTION

Location

The San Andres Mountains, located in south-central New Mexico (Figure 1), are bound on the east and west by the Tularosa Valley and Jornada del Muerto plains, respectively. The range extends 85 miles north-south and is 6-17 miles wide, lying within the restricted area known as White Sands Missile Range. Although many canyons offer access for geologic investigation, only outcrops in Rhodes Canyon are of particular interest to this study. Rhodes Canyon, traversed by former New Mexico Highway 52, is located approximately 35 miles east of Truth or Consequences, New Mexico.

Purpose

This research attempts to achieve an interpretation of depositional environments based on examination of stratigraphy, sedimentation, paleontology, and petrography. Important aspects under investigation include: examining several detailed vertical sequences and their contained biotic successions, lateral relationships exhibited by the biota, sedimentary textures including microfacies criteria (all paleontologic and sedimentologic criteria which can be classified in thin-sections, acetate peels, and polished slabs), and diagenesis.

Methods of Investigation

Field Work

Prerequisites for any dependable microfacies analysis require geologic field studies. Special consideration was given to facies criteria, such as: lithology, fossil content, sedimentary textures and structures, stratigraphic relationships, and geometry of the rocks. A

FIGURE 1

INDEX MAP OF STUDY AREA

X = STUDY AREA

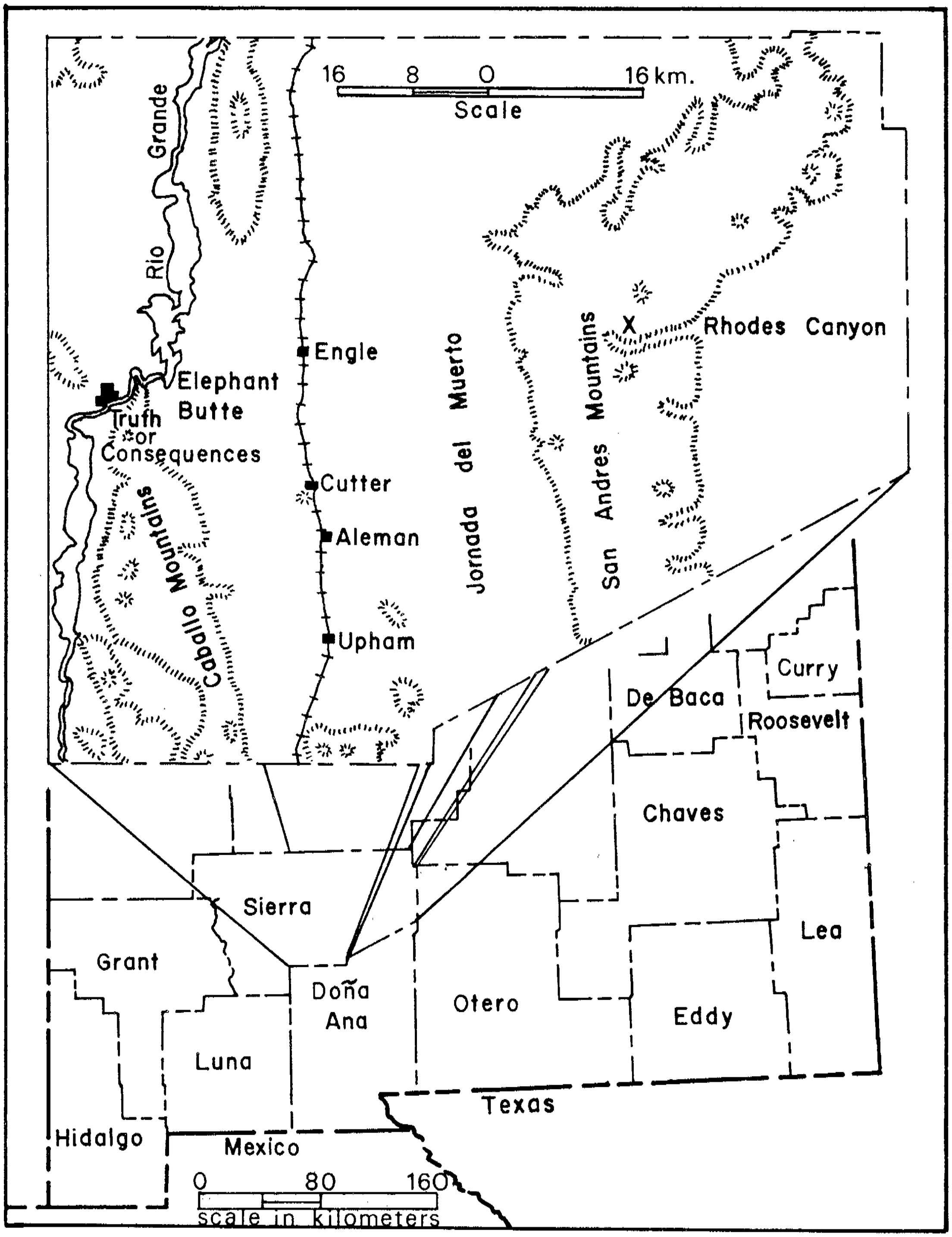
16 8 0 16 km.
Scale
Rio Grande
Elephant Butte
Truth or Consequences
Engle
Cutter
Aleman
Upham
Caballo Mountains
Jornada del Muerto
San Andres Mountains
Rhodes Canyon
X
Curry
De Baca
Roosevelt
Chaves
Sierra
Lea
Grant
Doña Ana
Otero
Eddy
Luna
Texas
Hidalgo
Mexico
0 80 160
scale in kilometers

Figure 1

Jacob's staff, pocket transit, and steel tape were employed to accurately measure the strata. Field work concluded after measuring and describing three stratigraphic sections.

Sampling

The number and type of samples collected depend upon several variables. These variables include outcrop conditions, the amount of time to be invested in sample processing, and the amount of data to be integrated in subdividing depositional environments. Thus, with this in mind a "sampling plan" was devised in terms of the objectives of this project; a combination of search and stratified sampling methods were employed. Search sampling is simply the collection of hand specimens from conspicuous carbonate beds because of their texture and fossil content (Flugel, 1978). Stratified sampling is a statistical sampling method where at least one sample is taken from each carbonate unit. The number of samples were in most cases proportional to bedding thickness. According to McCammon (1975), stratified sampling is advantageous for the study of stratigraphic sections or vertical profiles.

Sample densities or sampling intervals tend to be very important when studying carbonate rocks. Their influence upon microfacies analysis cannot be underestimated. The calculated sample interval for shelf carbonates usually lies between 0.10 and 0.30 meters as based on studies by Nowak and Carozzi (1973), and applying this principle to the San Andres study, a sample interval (S.I.) of 0.22 meters is obtained.

Laboratory Work

In facies analysis paleontologic, sedimentologic, and other geologic data provide basic information about sedimentary environments, but to determine depositional environments of carbonate rocks, microfacies criteria (Flügel, 1978) and diagenesis must also be established.

Point Count Analysis

Quantification of recognizable features in thin-section is important when characterizing limestones. Determining percent composition of carbonate constituents enabled: 1) the arrangement of samples in limestone classifications, 2) the determination of skeletal material produced at a certain time (Flügel, 1978), and 3) recognition of facies development over time and space.

The number of "points" counted is statistically important and depends upon the size and distribution of particles. For the purpose of this study, a minimum of 300 point-counts per thin-section was conducted, and according to van der Plas and Tobi (1965), 300 point-counts will result in a 95 percent confidence level with a precision of ± 6 percent. In addition, to guarantee comparability of data, it is necessary to specify the method of measurement. In most studies (this one included) the grain-solid method is used (Flügel, 1978) (i.e., voids within skeletal grains are not regarded as skeletal).

Assumptions

Identification of biotic types during point-count analysis of thin-sections provided a measure of biotic diversity and an estimate of taxonomic abundance, but measurements of maximum size (by taxon) were conducted in the field. The basic assumption in the use of relative size, diversity, and abundance data is that these criteria vary in direct response to environmental factors (particularly salinity, but including temperature, turbidity, water depth, and substrate firmness) and environmental stability. Recent studies in Florida Bay and the Reef Tract demonstrate the predictability and utility of these factors. A comprehensive review relating faunal distributions to environmental conditions can be found in Heckel (1972).

Growing interest in stratigraphic facies relations has resulted in the proposal of numerous terms intended to distinguish lithologic facies. Instead of promoting accuracy in thinking and expression, this proliferation of terminology has created some confusion. One such term warranting discussion was proposed by Cumings in 1932. He defined "biostrome" as purely bedded structures (such as crinoid beds) consisting of or built by sedentary organisms in which beds did not mound nor swell. The major controversy centers around "sedentary organisms" and their origins. Many limestone beds consist largely of disarticulated and abraded skeletal fragments. Thus, what degree of fragmentation is allowable? If no limit is set, most marine limestone beds are biostromes because they consist of organic calcium carbonate. If a limit is determined, it would be arbitrary and would vary by author. In light of this discussion, I feel the term "biostrome" serves little purpose and I shall not employ the term herein.

Acknowledgements

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Thanks is extended to Mrs. Joan Burris whose typing expertise was second to none.

Finally, I would like to thank my wife, Teri, for her continual support "throughout it all".

GEOLOGIC SETTING

Virgilian strata in the San Andres Mountains differ lithologically from nearby synchronous deposits of the Holder and Bar B Formations within the Sacramento and Caballo Mountains respectively (Kottlowski and others, 1956). This distinction in lithology enabled Kottlowski and others (1956) to map Virgilian strata from Mockingbird Gap to the southern boundary of the San Andres Mountains as Panther Seep Formation.

Two resistant limestone units within the Panther Seep Formation are exposed in Rhodes Canyon. The focus of this study involves the lowermost of these two units (Figure 2). Grayish-black carbonaceous shale along with several interbedded light brown, fine to coarse-grained sandstones outcrop beneath the prominent limestone under investigation (Figures 3 and 4). Above this limestone grayish-black carbonaceous shale and argillaceous limestone can be observed.

FIGURE 2

VIRGILIAN LIMESTONE SEQUENCE UNDER INVESTIGATION

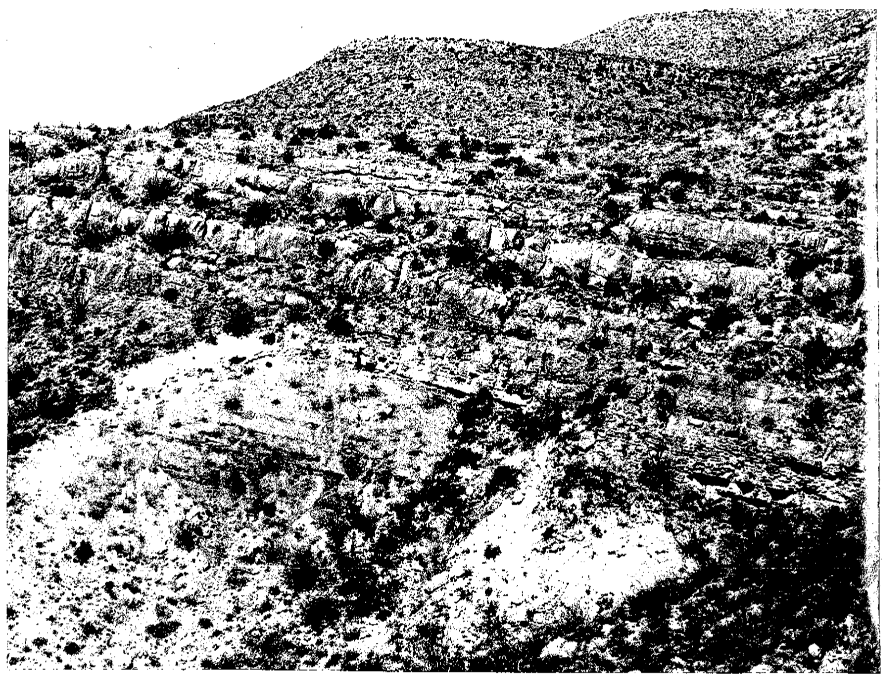


Figure 2

FIGURE 3

CARBONACEOUS SHALE JUST BENEATH THE CARBONATES UNDER INVESTIGATION
(knife for scale is 9 centimeters long)

Figure 3

FIGURE 4

SANDSTONE BENEATH THE CARBONATES UNDER INVESTIGATION
(knife for scale is 9 centimeters long)

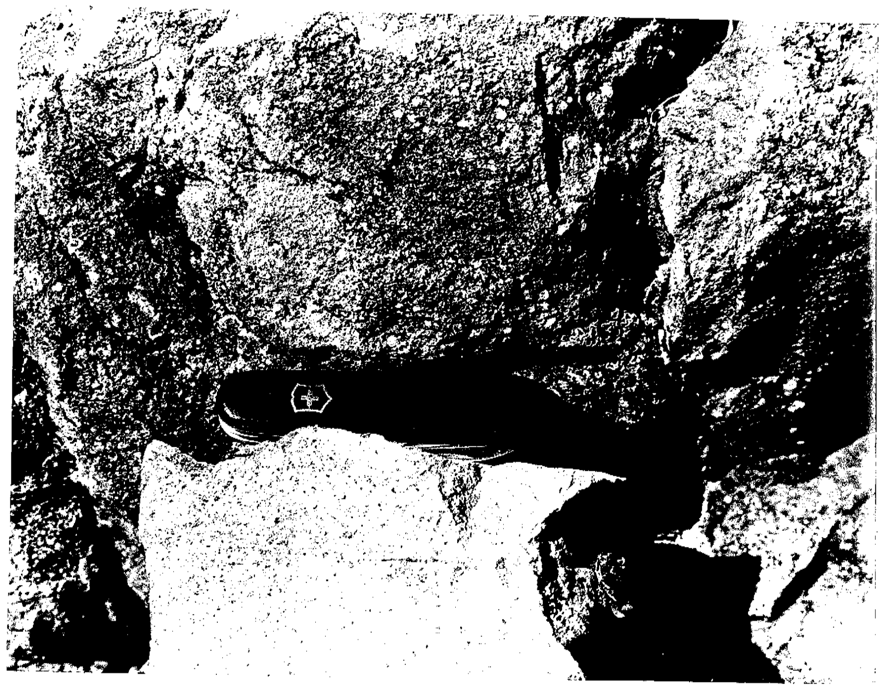


Figure 4

PREVIOUS WORK

Many authors have made observations and published significant articles on strata exposed in the San Andres Mountains. The interested reader should consult Kottlowski and others (1956), and Seager (1981) for a comprehensive list of previous workers. Most articles, to date, contain generalized data describing geologic sections from Precambrian to Tertiary, whereas, this study incorporates data collected from a localized area and single stratigraphic unit, allowing detailed interpretations concerning depositional environments.

PALEOGEOGRAPHIC/TECTONIC SETTING

Wedge-shaped bodies of arkosic sandstones, siltstones, and shales associated within Pennsylvanian strata of New Mexico support evidence that source areas were located near depositional basins. Throughout the late Paleozoic, ancient landmasses (Ancestral Rocky Mountains) existed in what is known today as the southern Rocky Mountain region (Thompson, 1942).

According to Bachman (1975), Middle Pennsylvanian marks the earliest orogenic pulse responsible for the Ancestral Rocky Mountains in New Mexico, when conglomeratic sandstones were deposited within the Rowe-Mora basin in response to vertical movements of the Uncompahgre region (Figure 5). During Missourian deposition, mountain building activity intensified and migrated southward to include the Pedernal Mountains (Figure 5). Seas became more restricted as continental sediments encroached marine margins. By late Missourian, seas regressed as a result of regional uplift and basinal infilling (Bachman, 1975).

Local orogenic movements provided sediments throughout the state during Late Pennsylvanian (Virgilian). With major faulting and uplift of Pedernal landmass, the Orogrande basin (Figure 5) became an important negative tectonic element. As stated by Pray (1961), marine shelf sediments interfingered with fluvial deposits within the Orogrande basin. The Orogrande basin received sediments from the Pedernal landmass until Middle Permian when both structures began accumulating fluvial sediments (Kottlowski, 1963).

During Late Pennsylvanian the study area was located on the northwest margin of the Orogrande basin (Figure 5) and was probably associated with a shallow marine shelf. The shelf extended between the

FIGURE 5

PENNSYLVANIAN PALEOGEOGRAPHIC MAP OF NEW MEXICO
(after Kottlowski, 1960)

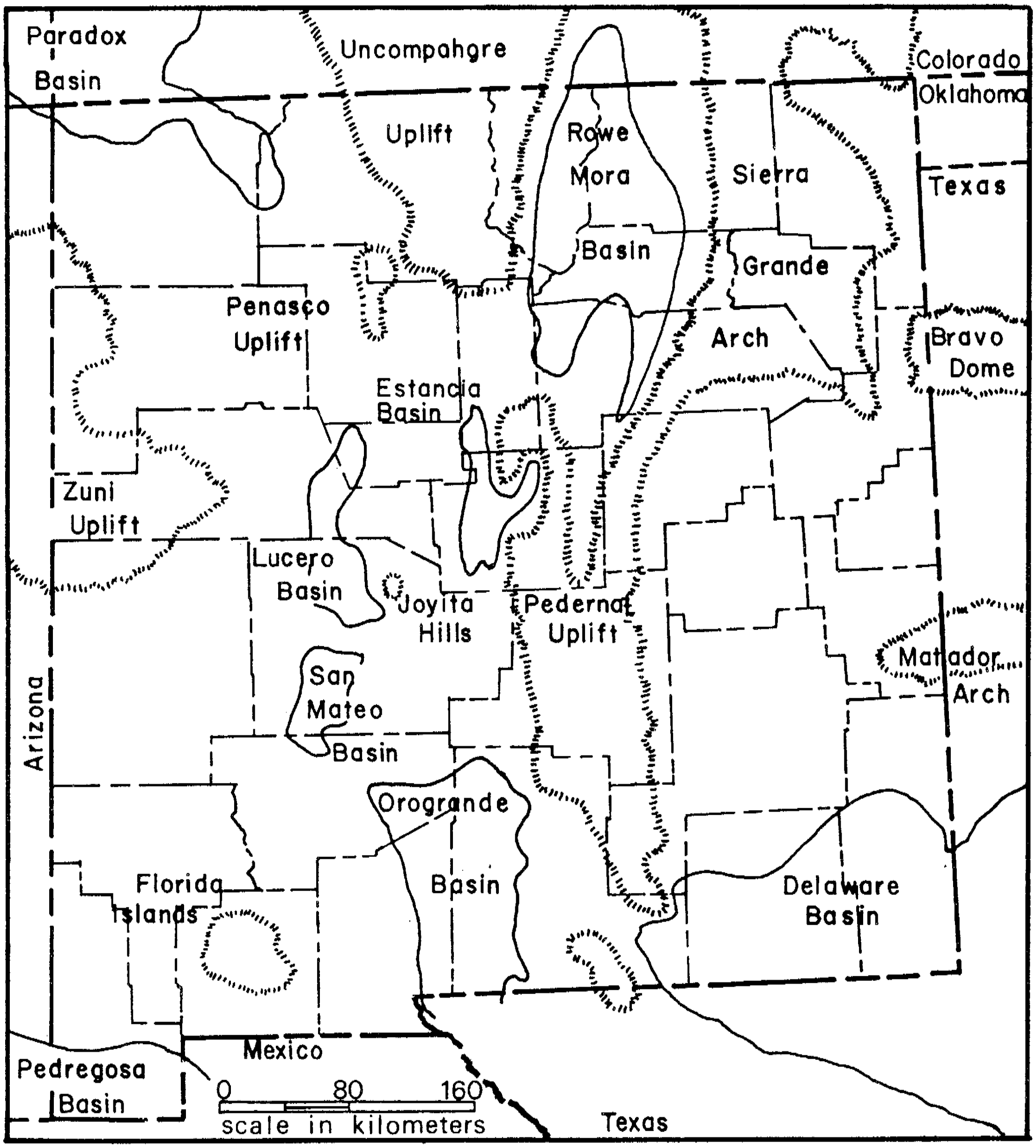

Paradox
Basin
Uncompahgre
Uplift
Rowe
Mora
Basin
Sierra
Grande
Arch
Colorado
Oklahoma
Texas
Bravo
Dome
Penasco
Uplift
Estancia
Basin
Zuni
Uplift
Lucero
Basin
Joyita
Hills
Pedernal
Uplift
Matador
Arch
Arizona
San
Mateo
Basin
Orogrande
Basin
Florida
Islands
Delaware
Basin
Mexico
Pedregosa
Basin
0
80
160
scale in kilometers
Texas

Figure 5

San Mateo and Orogrande basins and was related to a northwest trending seaway connecting the Pedregosa and Delaware basins to the south with the Paradox basin to the north (Kottlowski, 1960). This seaway was bound on the east and west by two uplifts, the Pedernal and Zuni, respectively.

STRATIGRAPHY

Introduction

Three stratigraphic sections (columns) were measured and described to characterize the lower carbonate sequence within Virgilian strata of Rhodes Canyon. Section locations, as shown in Figure 6, have resulted in a chevron-shaped outcrop trend of approximately 1.9 kilometers. Each stratigraphic column has been subdivided into six units based on facies criteria.

The thickness of the lower carbonate sequence averages 26 meters with interbedded, calcareous shales (covered intervals) constituting 16 percent of the total sequence. Interestingly, Section 2 (the northernmost section) contains the least limestone (81 percent) while calcareous shales contribute 19 percent to the total sequence. The inverse is true in the vicinity of Section 3, where shales (covered intervals) comprise 13 percent of a total thickness of 28 meters. Section 1 statistics correspond with average values previously described.

Dunham's (1962) carbonate rock names are used for hand specimen descriptions.

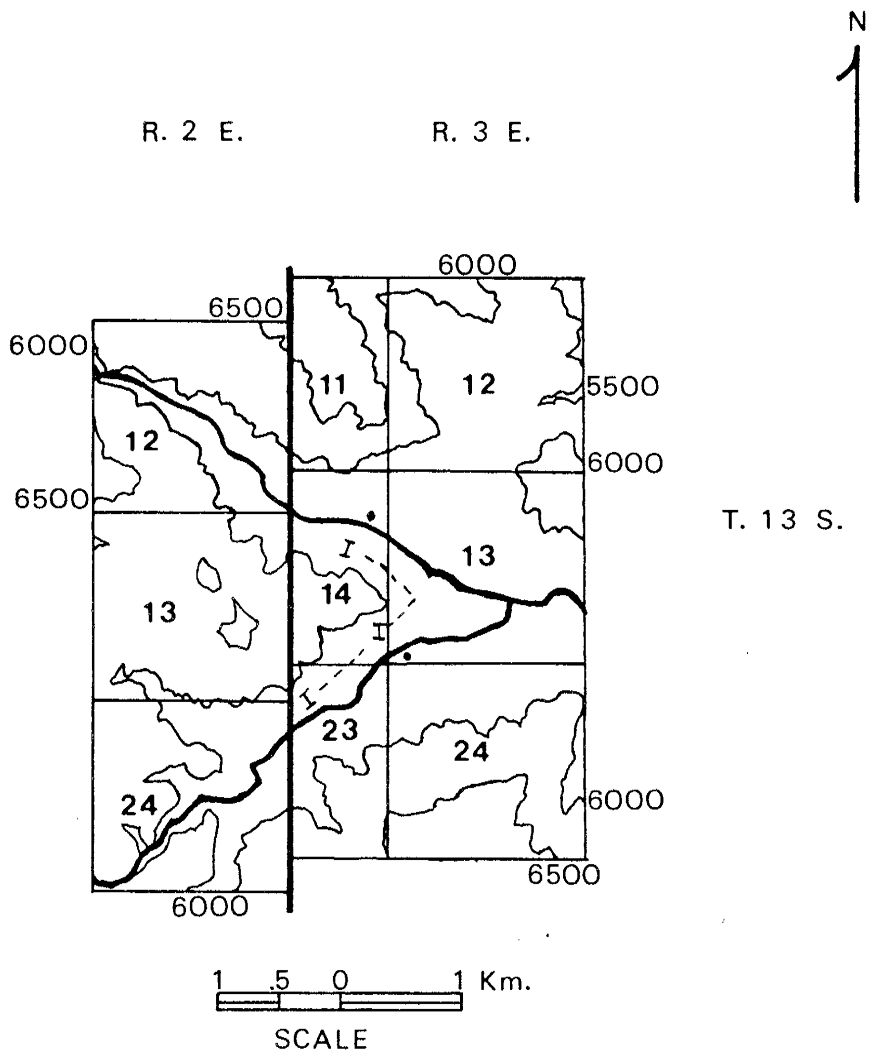
Megascopic Abundance Study

Several beds, located within Units 2, 3, and 6, were the focus of abundance studies. Biota (greater than 5 millimeters in longest dimension) contained in a circular grid were identified and recorded. The purpose of this study was to determine vertical and lateral variations in megascopic biotic abundance, and to compare these results with abundance data obtained from thin-sections. Collation of megascopic biotic abundance revealed some problems, mainly the lack of

FIGURE 6

LOCATION OF MEASURED SECTIONS IN RHODES CANYON

Figure 6



LEGEND

Section **1** = SE **1/4** SE **1/4** Sec. **14** T. **13** S. R. **3** E.
Section **2** = SW **1/4** NE **1/4** Sec. **14** T. **13** S. R. **3** E.
Section **3** = NW **1/4** NW **1/4** Sec. **23** T. **13** S. R. **3** E.

Road

Potter Ranch/Housing

Measured Section

Outcrop Pattern

Contour Line

sufficient data. Perhaps if more beds were sampled, this type of investigation could have produced positive results. This investigation is not pursued further herein.

Descriptive Lithology

Carbonaceous Shales

Field observations suggest grayish-black carbonaceous shales are conformable with the overlying carbonates under investigation. The shales gradually become more calcareous until limestones and argillaceous limestones dominate. The shales lack observable biota, but are pellet-rich. The pellets are generally rod-shaped, usually less than 0.5 millimeters in their longest dimension. Beneath Section 2, these carbonaceous shales interbed with poorly exposed, fine to very coarse-grained sandstones. The sandstones are approximately 3.3 meters thick. At the base, these sandstones are fine-grained, subrounded to subangular, well-sorted, and micaceous grading upward into coarse sandstones. The uppermost sandstone bed is located 1.8 meters below the basal carbonates of Unit 1.

Grayish-black carbonaceous shales are also located above the carbonate sequence, but due to poor exposures they were not examined in detail.

Unit 1 Lithology

The dominant lithology in Unit 1 is a skeletal wackestone to mudstone, although packstones are locally important. Unit 1 carbonates are dark gray; their dark appearance probably results from greater than average abundance of clay, pyrite, and organic material. Clays were observed on weathered surfaces (a result of weathering from thin shale beds and partings), whereas, fresh surfaces exposed small, cubic, pyrite crystals and fetid odors.

Basal carbonates of Unit 1 are best described as disarticulated crinoid wackestones/mudstones. Interbedded with these carbonates are discontinuous, green to greenish-gray shales (Figure 7) from 5 to 13 centimeters thick, which occupy the lowermost 0.9 meters above a thick carbonaceous black shale sequence.

The associated carbonates exhibit nodular-wavy beds 8 to 30 centimeters thick, possibly resulting from load casting. Other notable characteristics of the limestones are their contained chert nodules and fossils, which include: phylloid algae, bryozoans (fenestrate and stony varieties), foraminifers (mainly fusulinids), and several molluscs. The interval overlying the basal carbonates becomes increasingly fossiliferous while interbedded fine clastics decrease from thin beds to partings less than 1.3 centimeters. Phylloid algae increase in abundance upward to become the major biotic constituents. Other skeletals such as fenestrate bryozoans, fusulinids, and crinoids are much less important. The remainder of Unit 1 is dominated by phylloid algal mudstones. Although lithologically similar to underlying carbonate beds, this interval is devoid of shale partings. In Section 2 (within the upper portion of Unit 1) some horizons show unbranched, circular, horizontal burrows. The cross-sections of these burrows are parallel to bedding, and burrow fillings have a slightly different color and texture than the surrounding rock. Where sufficient bioturbation has occurred, the rocks display a peculiar "swirled" or mottled texture, resembling feeding structures of the trace fossil _Zoophycos_.

FIGURE 7

SHALE BEDS (S) NEAR THE BASE OF THE CARBONATE SEQUENCE
(knife for scale is 9 centimeters long)

Figure 7

Unit 2 Lithology

Conformably overlying Unit 1 are thinly-bedded phylloid algal wackestones and packstones of Unit 2. These beds exhibit three distinct differences when compared to Unit 1: 1) phylloid algae account for 70 to 90 percent of all skeletal components, 2) fresh surfaces are light gray, and 3) nodular-wavy beds are generally absent. Approximately 0.3 meters above the base of Unit 2 within Section 1, large growths of the colonial, tabulate coral Syringopora sp. are encountered (Figure 8). Syringopora sp. does not represent a laterally continuous buildup; the largest colony measures 9.0 meters long and 0.7 meters thick. Sediment infilling around this organism's structural framework consists of skeletal packstones containing (fragments of) crinoids, gastropods, bryozoans, fusulinids, horn corals, and brachiopods. Above these isolated Syringopora sp. boundstones, skeletal grains decrease in abundance resulting in wackestones and mudstones, which grade conformably into Unit 3.

Unit 3 Lithology

The lowermost 2.4 to 2.7 meters of Unit 3 are fine-grained wackestones/mudstones to in part packstones which contain phylloid algae, molluscs (mainly gastropods), and brachiopods. The only noteworthy exceptions are isolated occurrences of Syringopora sp. boundstones. The weathered limestone of this interval displays a tan-brown surface extensively pitted by dissolution, whereas, fresh surfaces appear light to drab gray. Bedding surfaces are not distinct and are usually discontinuous. Where discontinuous bedding planes occur, subrounded to elongate, black, chert nodules seem to be abundant.

FIGURE 8

GROWTH FORM OF THE TABULATE CORAL *SYRINGOPORA* sp.
(knife for scale is 9 centimeters long)

Figure 8

The remaining 1 or 2 meters of Unit 3 are bioclastic packstones and grainstones, which begin as fine-grained packstones and grade vertically into coarse grainstones, exposing discontinuous beds. Section 1 contains low-angle cross-bedding (Figure 9) with good to excellent sorting in this part of Unit 3. In addition, bioturbation is a common feature. Most burrows are small, with diameters between 3 and 6 millimeters. Maximum length of these silicified vertical and horizontal burrows is difficult to determine, but some have been traced for 3 centimeters (Figure 10). Directly beneath the contact with Unit 4, a debris bed is present at each of the three localities. The bed contains a restricted biota of coiled cephalopods with perhaps a few gastropods, brachiopods, fusulinids, and straight-shelled cephalopods.

Unit 4 Lithology

Unit 4, although conformable, appears to be quite different from previously described units. It can be divided into lower and upper shales separated by skeletal wackestones and packstones. These light green to white, very friable, fine-grained calcareous shales vary in total thickness from 3.0 meters in the northern portion of the study area (Section 2) to approximately 1.8 meters in the south (Section 3). The friable nature and lack of observable biota distinguishes these calcareous shales from fossiliferous, argillaceous limestones within Unit 1. Thin-bedded skeletal wackestones and packstones ranging from 0.6 meters near Sections 1 and 2 to greater than 1.2 meters within Section 3 are located between (upper and lower) calcareous shales. Thus, limestone and shale thicknesses show inverse relationships when traversing north or south through the study area.

FIGURE 9

CROSS-BEDDING WITHIN THE UPPER PORTION OF UNIT 3
(knife for scale is 9 centimeters long)

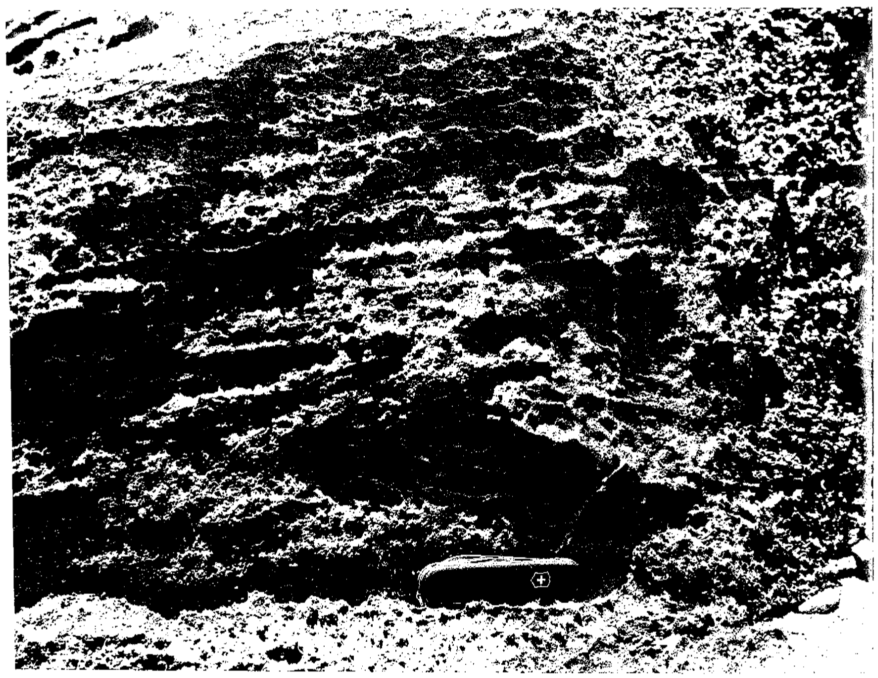


Figure 9

FIGURE 10

VERTICAL BURROWS WITHIN THE UPPER PORTION OF UNIT 3

Figure 10

Unit 5 Lithology

Unit 5 has been divided into a lower and upper carbonate sequence due to distinctive lithologic variations. The lower carbonates vary in thickness from 2.1 to 2.7 meters and are non-bedded, whereas, the thick-bedded upper sequence is 2.5 to 3.6 meters; their combined thicknesses are thinnest in the vicinity of Section 2. These limestones are separated by a thin (0.3 to 0.8 meters) covered interval.

The lowest 0.9 meters of Unit 5 (lower carbonate sequence) are wackestones containing a diverse assemblage of phylloid algae, small gastropods, fusulinids, crinoids, brachiopods, and ostracodes. Above this horizon invertebrate organisms decline in diversity, and phylloid algal mudstones prevail. Lithographic limestones, displaying conchoidal fracture, occur in interbeds where phylloid algae are absent. Re-establishment of skeletal grains in the upper 1.1 meters (of the lower carbonate sequence) produced wackestones/packstones containing straight-shelled cephalopods, phylloid algae, and gastropods, nearly 7.0 centimeters in diameter (Figure 11).

Skeletal wackestones/boundstones and peloidal packstones/grainstones comprise the upper carbonate sequence of Unit 5. The wackestones/boundstones contain phylloid algae, bryozoans, fusulinids, crinoids, small gastropods, small brachiopods, and *Syringopora* sp. In addition, this interval includes nodular cherts, which increase in abundance vertically and grade into several 10-13 millimeter chert beds. Most bedded cherts are fairly continuous, some traceable for 18.0 meters. Packstones and grainstones make up the remaining portion of Unit 5. Non-skeletal grains consist of peloids, ooids, and intraclasts, whereas skeletal constituents include encrusting forams, phylloid algae, brachiopods, fusulinids, gastropods, and crinoids.

FIGURE 11

LARGE GASTROPOD WITHIN UNIT 5

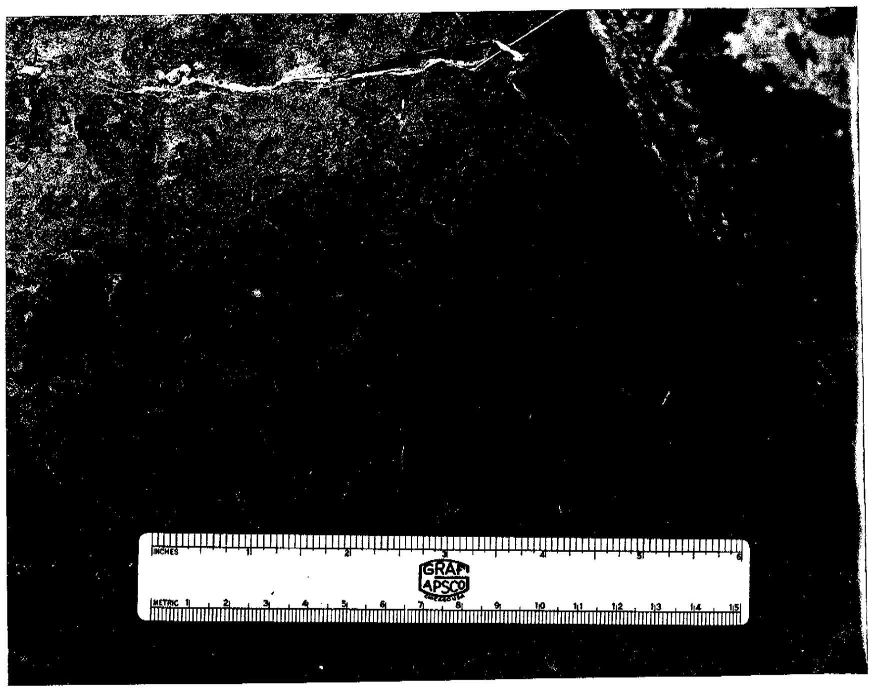


Figure 11

Unit 6 Lithology

Peloidal grainstones of Unit 5 are conformably overlain by light gray, thin-bedded, skeletal carbonates of Unit 6 which vary from 8.1 to 8.5 meters (covered intervals account for approximately 10 percent). Except for some flat-laminated horizons, virtually all fine-grained carbonates in Unit 6 exhibit bioturbation which has homogenized the sediment. Subsequent weathering has produced a pronounced mottled texture (Figure 12).

The lowermost 2.7 meters can be described as a cyclic carbonate sequence. Generally, cycles begin as skeletal wackestones and grade vertically into packstones and grainstones. Thin, micritic beds overlie the packstones and grainstones. Above this interval, black, fine-grained, stromatolitic carbonates occur (Figure 13). Mudstones and wackestones dominate, but relative size, diversity, and abundance of observable biota decrease markedly from below. A noteworthy exception exists within the same interval in Section 2 where continuous flat-laminations are absent. The upper 3.0 meters are wackestones with interbedded packstone debris beds. These debris beds exhibit low diversity and high abundance, and fusulinids, large molluscs (gastropods and pelecypods), and brachiopods (<u>Composita</u> sp.) are major contributors. The uppermost bedding surface is a <u>Composita</u> sp. packstone, and it represents one of the final contributions made by calcareous organisms to the entire carbonate sequence.

FIGURE 12

MOTTLED TEXTURE ON WEATHERED BEDDING SURFACES WITHIN UNIT 6
(knife for scale is 9 centimeters long)

Figure 12

FIGURE 13

FLAT-LAMINATED HORIZON WITHIN UNIT 6
(knife for scale is 9 centimeters long)

Figure 13

PETROGRAPHY

Introduction

Thin-section analysis (Figures 14, 15, and 16) along with previously discussed lithologic data reveal four broad facies and three subfacies (facies nomenclature from Dunham, 1962) (Table 1).

TABLE 1

STRATIGRAPHIC DISTRIBUTION OF FACIES AND SUBFACIES

1. Bryozoan-Crinoidal Wackestones/Packstones	Basal 1.6-1.9 meters of Unit 1
2. Phylloid Algal Wackestones/Packstones	Upper portion of Unit 1, all of Unit 2, and lower one-half of Unit 3
3. Grainstones and Poorly Washed Grainstones	Upper one-half of Unit 3
4. Wackestones and Packstones	All of Units 4, 5, and 6
4. a) *Apterrinella* sp. Packstones	Upper portion of Unit 5 and lower portion of Unit 6
4. b) *Tubiphytes* sp. Packstones/Boundstones	Located within Unit 6, 3 to 6 meters below uppermost bed of the carbonate sequence
4. c) Mudstones/Wackestones (Crystalline Carbonates)	Upper 1.4 - 2.0 meters of Unit 6

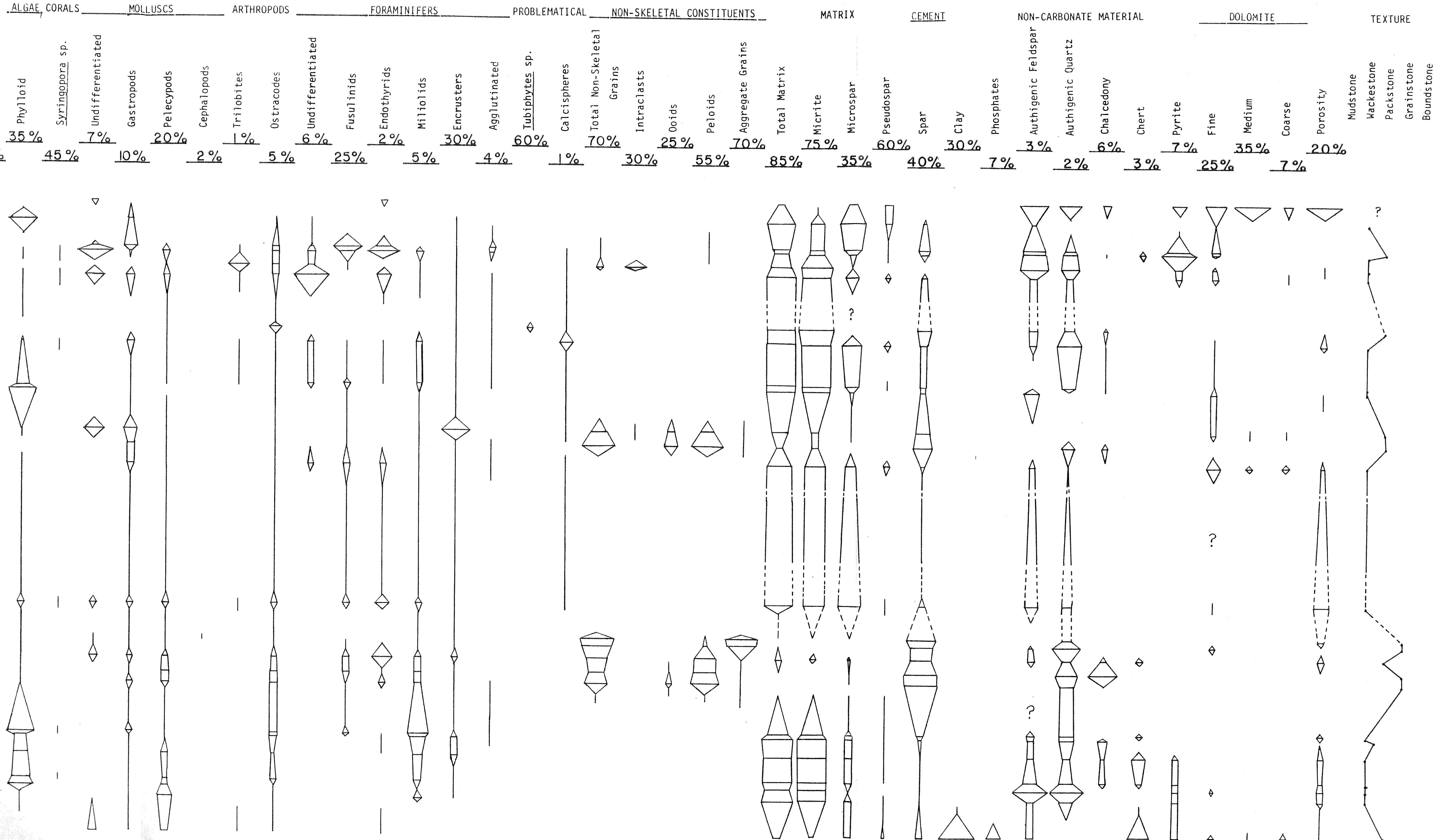
In addition, thin-section data permit more detailed subdivisions into 21 rock types which are named according to Folk's (1962, 1980) classification. A constituent analysis of the carbonate sequence (Table 2) contains abundance data which will be utilized throughout much of the forthcoming petrographic and diagenetic discussions.

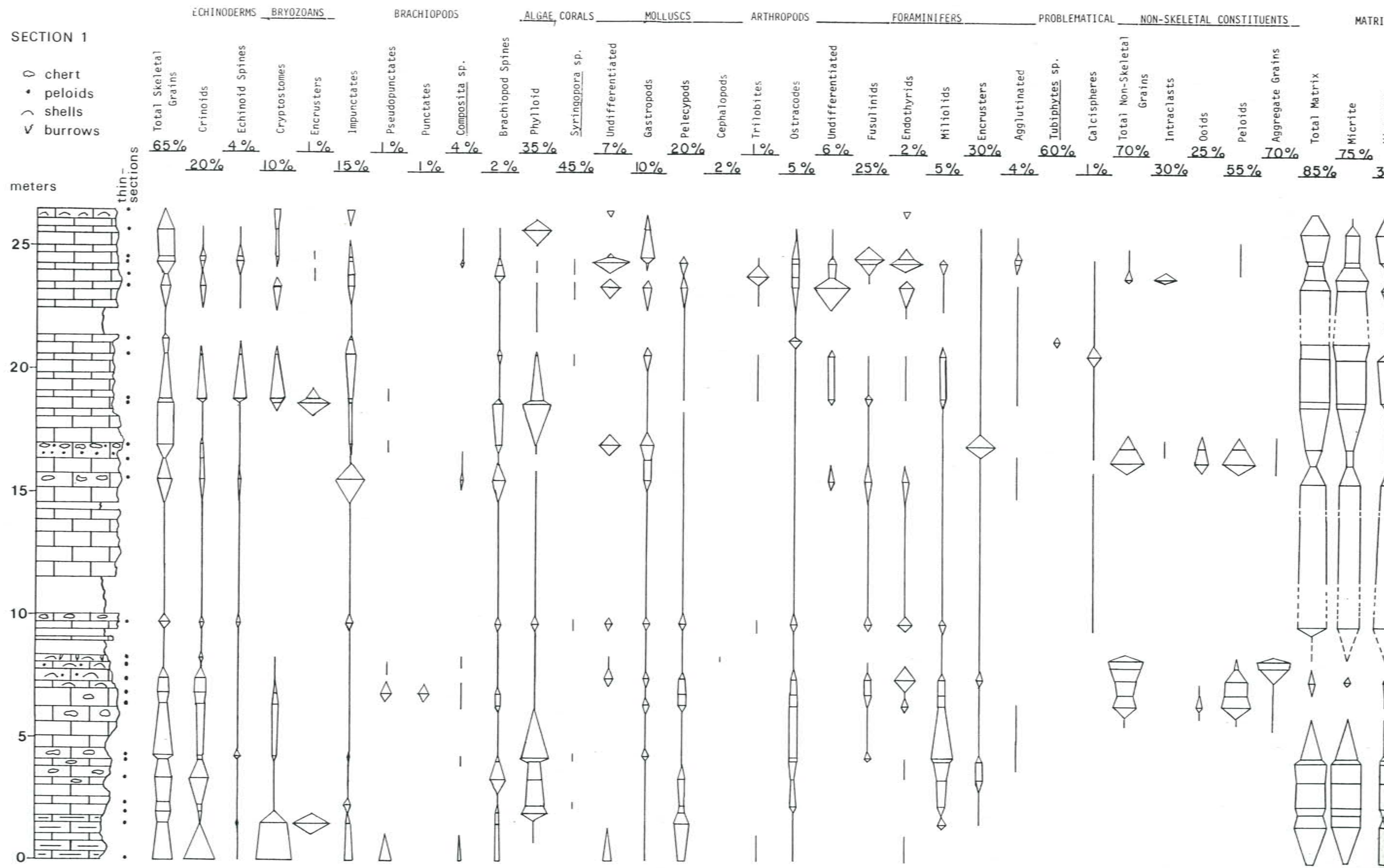
Procedure

Data presented herein and in subsequent discussions are based primarily on detailed studies of approximately 85 thin-sections. Also,

FIGURE 14

THIN-SECTION ANALYSIS OF SECTION 1

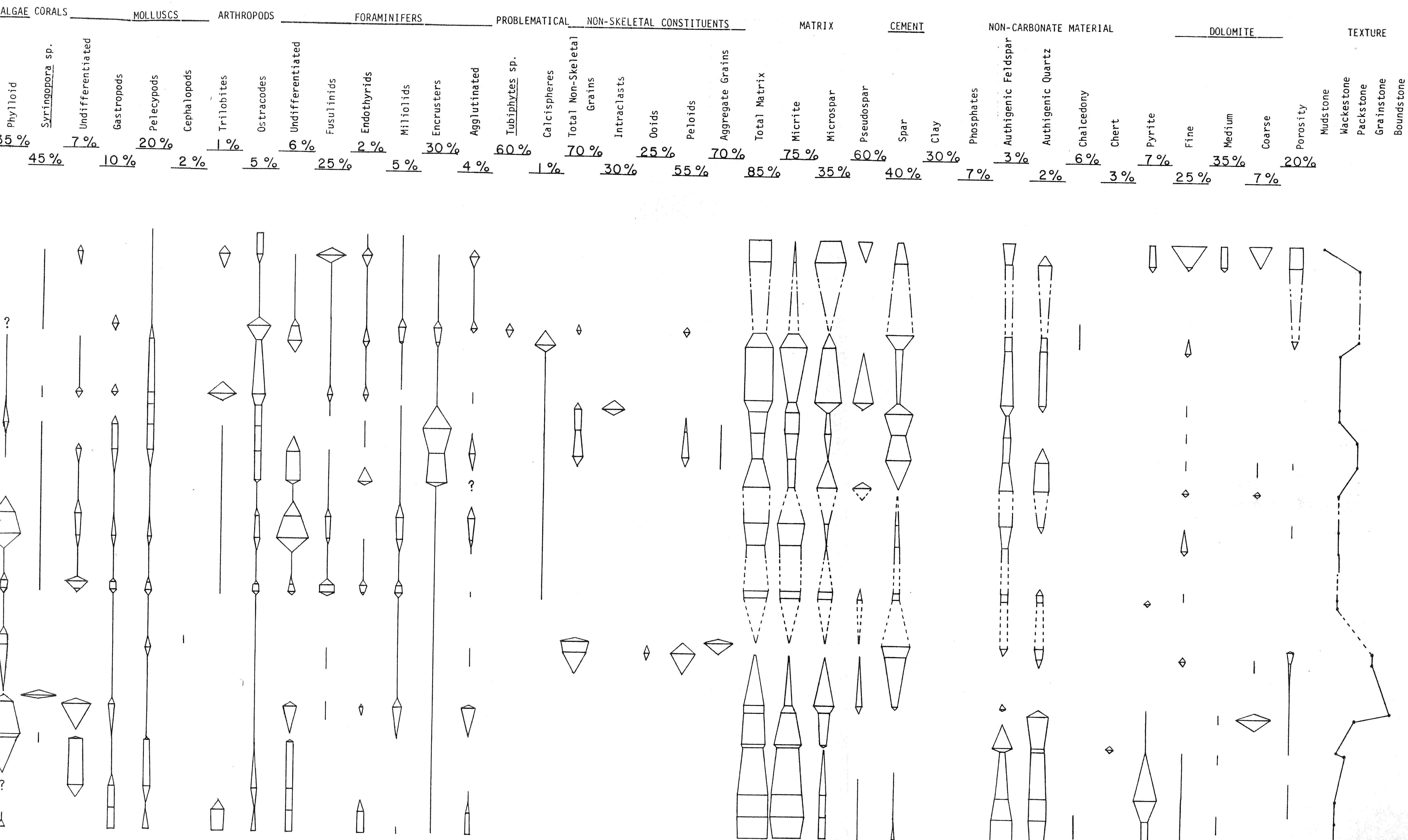

ALGAE, CORALS
MOLLUSCS
ARTHROPODS
FORAMINIFERS
PROBLEMATICAL
NON-SKELETAL CONSTITUENTS
MATRIX
CEMENT
NON-CARBONATE MATERIAL
DOLOMITE
TEXTURE
Phylloid 35%
Syringopora sp. 45%
Undifferentiated 7%
Gastropods 10%
Pelecypods 20%
Cephalopods 2%
Trilobites 1%
Ostracodes 5%
Undifferentiated 6%
Fusulinids 25%
Endothyrids 2%
Miliolids 5%
Encrusters 30%
Agglutinated 4%
Tubiphytes sp. 60%
Calcispheres 1%
Total Non-Skeletal Grains 70%
Intraclasts 30%
Ooids 25%
Peloids 55%
Aggregate Grains 70%
Total Matrix 85%
Micrite 75%
Microspar 35%
Pseudospar 60%
Spar 40%
Clay 30%
Phosphates 7%
Authigenic Feldspar 3%
Authigenic Quartz 2%
Chalcedony 6%
Chert 3%
Pyrite 7%
Fine 25%
Medium 35%
Coarse 7%
Porosity 20%
Mudstone
Wackestone
Packstone
Grainstone
Boundstone



SECTION 1
chert
peloids
shells
burrows
meters
thin-sections
0
5
10
15
20
25
ECHINODERMS
BRYOZOANS
BRACHIOPODS
ALGAE
CORALS
MOLLUSCS
ARTHROPODS
FORAMINIFERS
PROBLEMATICAL
NON-SKELETAL CONSTITUENTS
MATRIX
Total Skeletal Grains 65%
Crinoids 20%
Echinoid Spines 4%
Cryptostomes 10%
Encrusters 1%
Impunctates 15%
Pseudopunctates 1%
Punctates 1%
Composita sp. 4%
Brachiopod Spines 2%
Phylloid 35%
Syringopora sp. 45%
Undifferentiated 7%
Gastropods 10%
Pelecypods 20%
Cephalopods 2%
Trilobites 1%
Ostracodes 5%
Undifferentiated 6%
Fusulinids 25%
Endothyrids 2%
Miliolids 5%
Encrusters 30%
Agglutinated 4%
Tubiphytes sp. 60%
Calcispheres 1%
Total Non-Skeletal Grains 70%
Intraclasts 30%
Ooids 25%
Peloids 55%
Aggregate Grains 70%
Total Matrix 85%
Micrite 75%
Microspar
?

FIGURE 15

THIN-SECTION ANALYSIS OF SECTION 2


ALGAE
CORALS
MOLLUSCS
ARTHROPODS
FORAMINIFERS
PROBLEMATICAL
NON-SKELETAL CONSTITUENTS
MATRIX
CEMENT
NON-CARBONATE MATERIAL
DOLOMITE
TEXTURE
Phylloid
35%
Syringopora sp.
45%
Undifferentiated
7%
Gastropods
10%
Pelecypods
20%
Cephalopods
2%
Trilobites
1%
Ostracodes
5%
Undifferentiated
6%
Fusulinids
25%
Endothyrids
2%
Miliolids
5%
Encrusters
30%
Agglutinated
4%
Tubiphytes sp.
60%
Calcispheres
1%
Total Non-Skeletal Grains
70%
Intraclasts
30%
Ooids
25%
Peloids
55%
Aggregate Grains
70%
Total Matrix
85%
Micrite
75%
Microspar
35%
Pseudospar
60%
Spar
40%
Clay
30%
Phosphates
7%
Authigenic Feldspar
3%
Authigenic Quartz
2%
Chalcedony
6%
Chert
3%
Pyrite
7%
Fine
25%
Medium
35%
Coarse
7%
Porosity
20%
Mudstone
Wackestone
Packstone
Grainstone
Boundstone
?
?
?

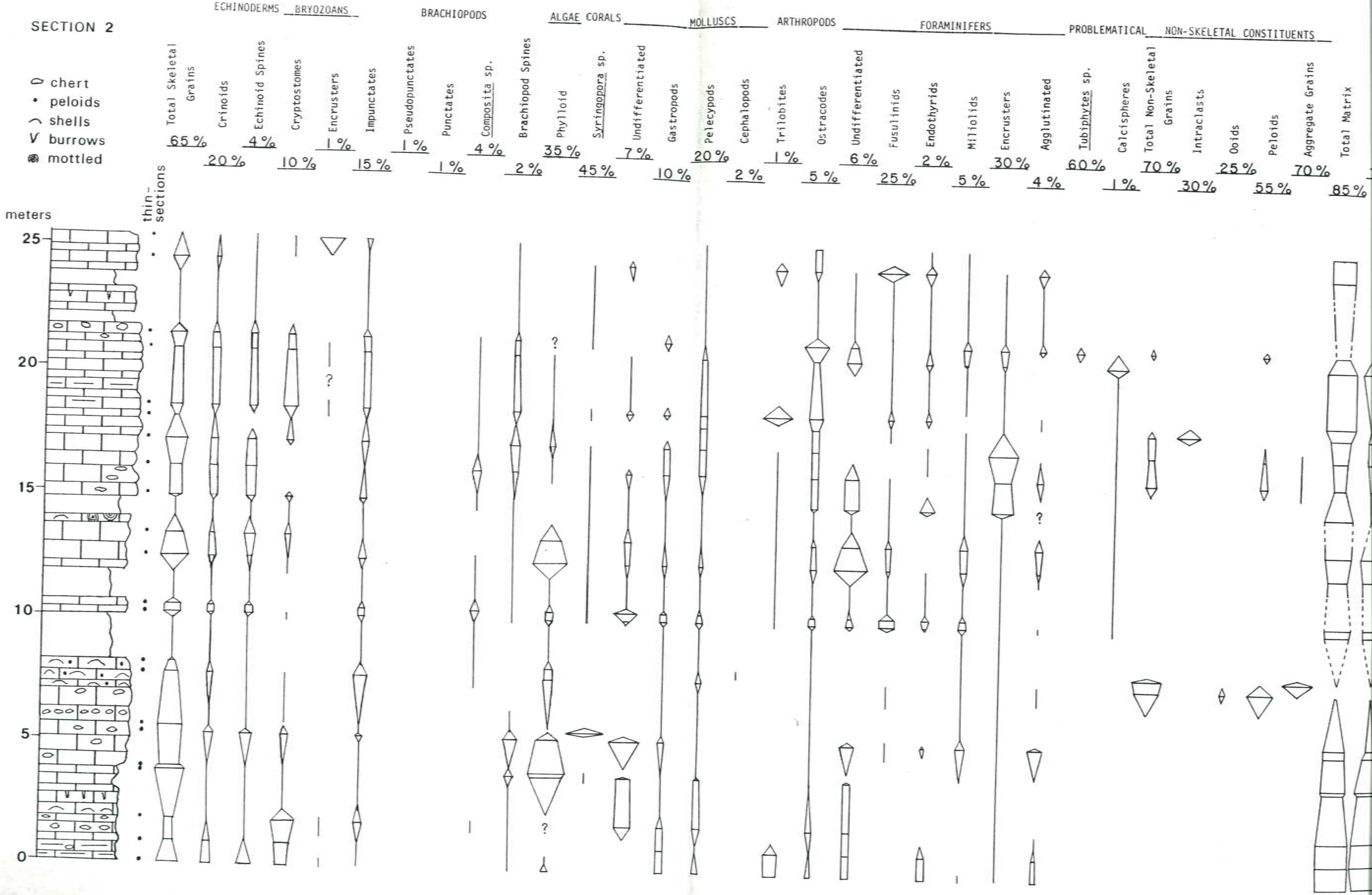
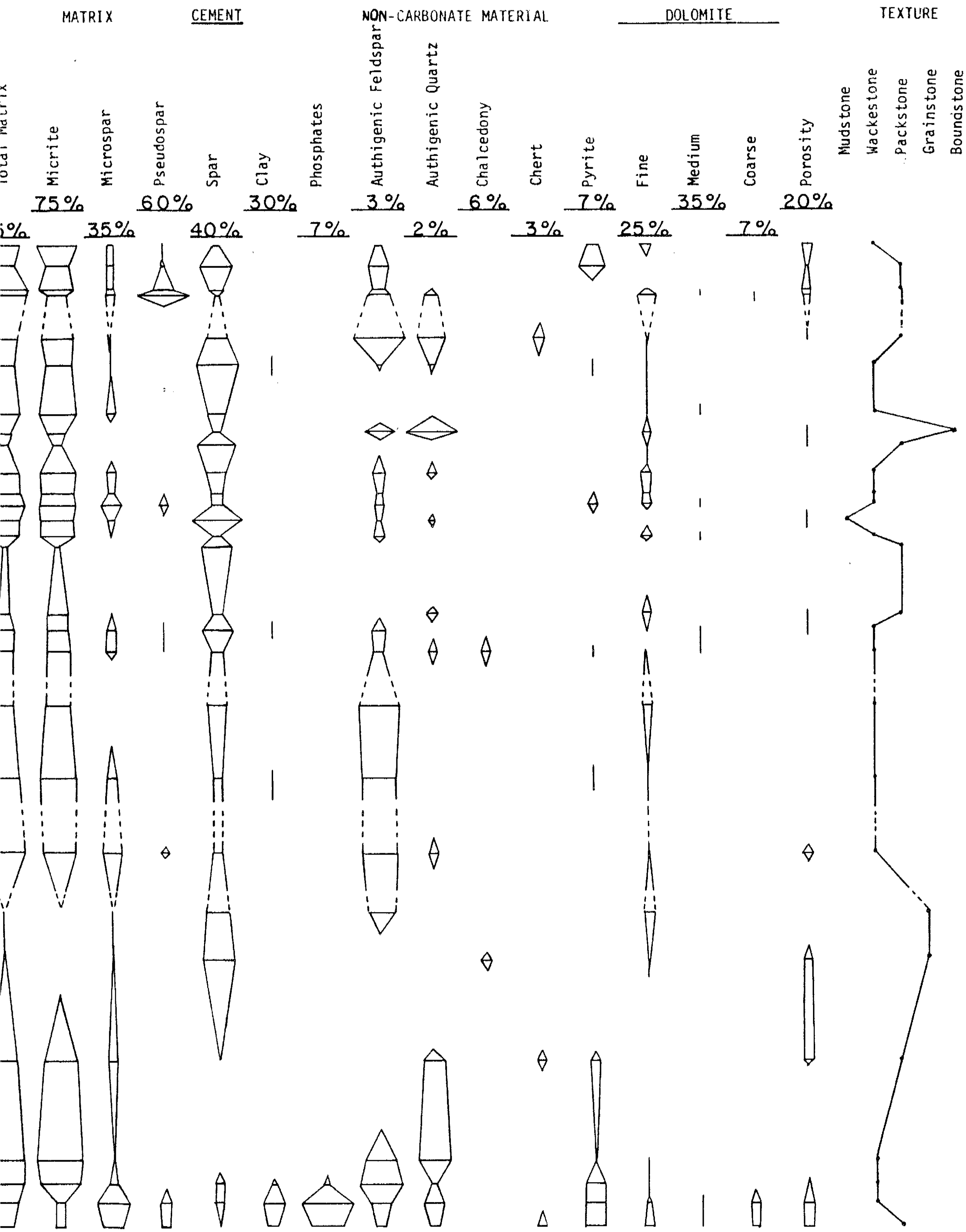
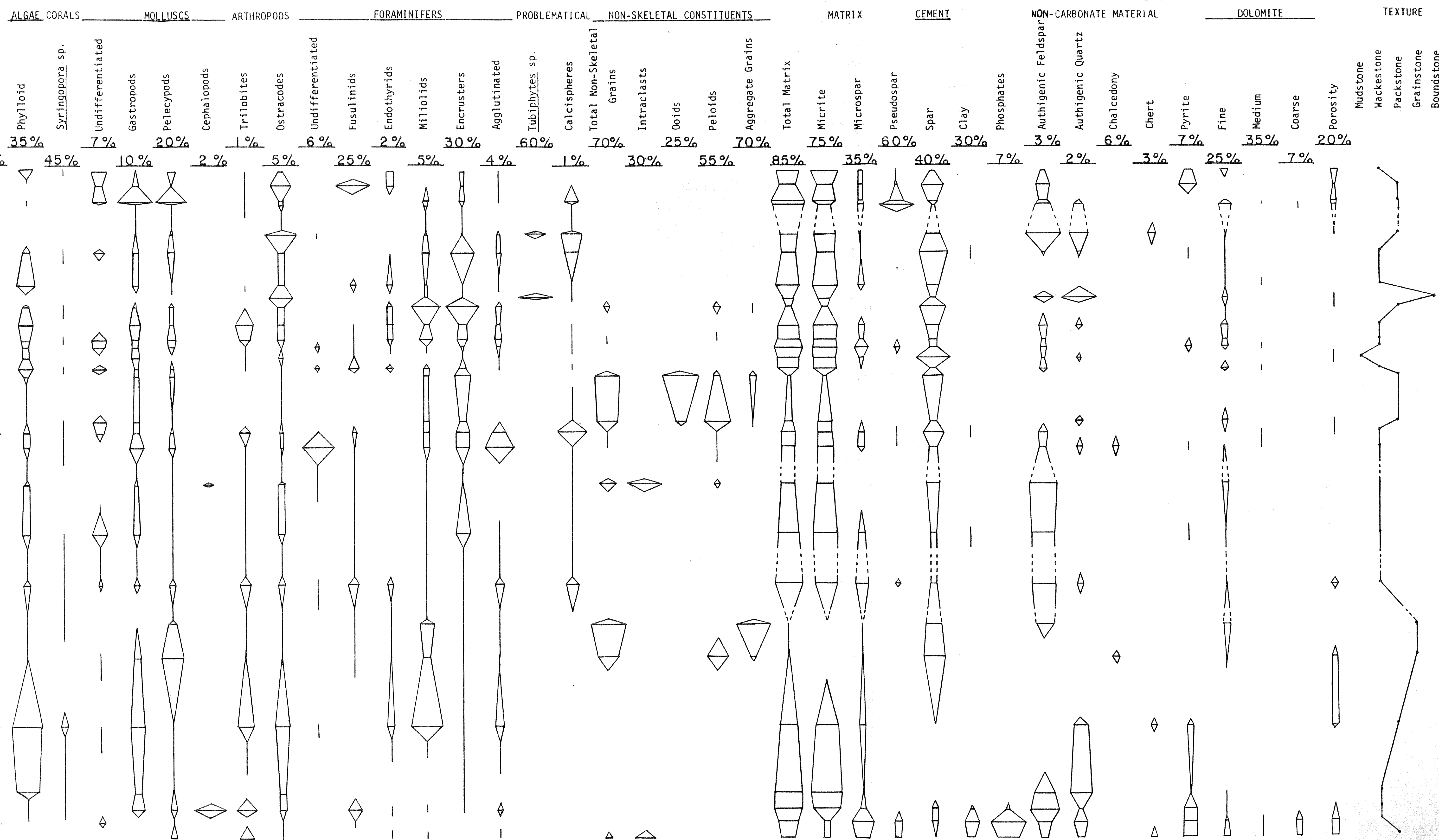

SECTION 2
chert
peloids
shells
burrows
mottled
meters
thin-sections
ECHINODERMS
BRYOZOANS
BRACHIOPODS
ALGAE
CORALS
MOLLUSCS
ARTHROPODS
FORAMINIFERS
PROBLEMATICAL
NON-SKELETAL CONSTITUENTS
Total Skeletal Grains 65%
Crinoids 20%
Echinoid Spines 4%
Cryptostomes 10%
Encrusters 1%
Impunctates 15%
Pseudopunctates 1%
Punctates 1%
Composita sp. 4%
Brachiopod Spines 2%
Phylloid 35%
Syringopora sp. 45%
Undifferentiated 7%
Gastropods 10%
Pelecypods 20%
Cephalopods 2%
Trilobites 1%
Ostracodes 5%
Undifferentiated 6%
Fusulinids 25%
Endothyrids 2%
Miliolids 5%
Encrusters 30%
Agglutinated 4%
Tubiphytes sp. 60%
Calcispheres 1%
Total Non-Skeletal Grains 70%
Intraclasts 30%
Ooids 25%
Peloids 55%
Aggregate Grains 70%
Total Matrix 85%
25
20
15
10
5
0
?

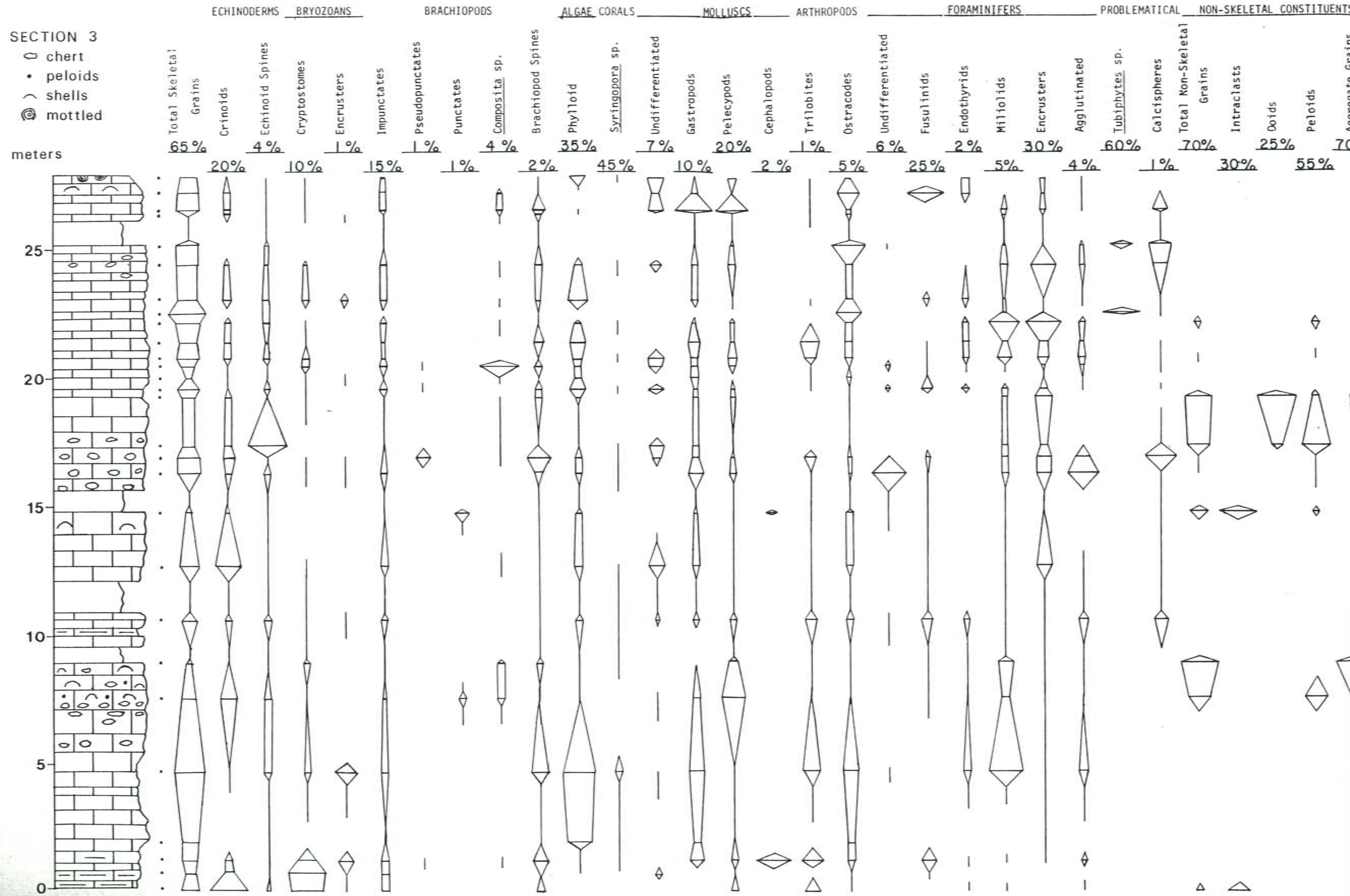
FIGURE 16

THIN-SECTION ANALYSIS OF SECTION 3


MATRIX
CEMENT
NON-CARBONATE MATERIAL
DOLOMITE
TEXTURE
Micrite
Microspar
Pseudospar
Spar
Clay
Phosphates
Authigenic Feldspar
Authigenic Quartz
Chalcedony
Chert
Pyrite
Fine
Medium
Coarse
Porosity
Mudstone
Wackestone
Packstone
Grainstone
Boundstone
75%
60%
30%
3%
6%
7%
35%
20%
35%
40%
7%
2%
3%
25%
7%



ALGAE
CORALS
MOLLUSCS
ARTHROPODS
FORAMINIFERS
PROBLEMATICAL
NON-SKELETAL CONSTITUENTS
MATRIX
CEMENT
NON-CARBONATE MATERIAL
DOLOMITE
TEXTURE
Phylloid 35%
Syringopora sp. 45%
Undifferentiated 7%
Gastropods 10%
Pelecypods 20%
Cephalopods 2%
Trilobites 1%
Ostracodes 5%
Undifferentiated 6%
Fusulinids 25%
Endothyrids 2%
Miliolids 5%
Encrusters 30%
Agglutinated 4%
Tubiphytes sp. 60%
Calcispheres 1%
Total Non-Skeletal Grains 70%
Intraclasts 30%
Ooids 25%
Peloids 55%
Aggregate Grains 70%
Total Matrix 85%
Micrite 75%
Microspar 35%
Pseudospar 60%
Spar 40%
Clay 30%
Phosphates 7%
Authigenic Feldspar 3%
Authigenic Quartz 2%
Chalcedony 6%
Chert 3%
Pyrite 7%
Fine 25%
Medium 35%
Coarse 7%
Porosity 20%
Mudstone
Wackestone
Packstone
Grainstone
Boundstone



SECTION 3
chert
peloids
shells
mottled
meters
ECHINODERMS
BRYOZOANS
BRACHIOPODS
ALGAE
CORALS
MOLLUSCS
ARTHROPODS
FORAMINIFERS
PROBLEMATICAL
NON-SKELETAL CONSTITUENTS
Total Skeletal Grains
65%
Crinoids
20%
Echinoid Spines
4%
Cryptostomes
10%
Encrusters
1%
Impunctates
15%
Pseudopunctates
1%
Punctates
1%
Composita sp.
4%
Brachiopod Spines
2%
Phylloid
35%
Syringopora sp.
45%
Undifferentiated
7%
Gastropods
10%
Pelecypods
20%
Cephalopods
2%
Trilobites
1%
Ostracodes
5%
Undifferentiated
6%
Fusulinids
25%
Endothyrids
2%
Miliolids
5%
Encrusters
30%
Agglutinated
4%
Tubiphytes sp.
60%
Calcispheres
1%
Total Non-Skeletal Grains
70%
Intraclasts
30%
Ooids
25%
Peloids
55%
Aggregate Grains
70%
25
20
15
10
5
0

Table 2. Constituent analysis of the carbonate sequence

Constituent	FACIES 1 Bryozoan-Crinoidal Wackestone/Packstone (8)		FACIES 2 Phylloid Algal Wackestone/Packstone (10)		FACIES 3 Grainstone and poorly washed Grainstone (9)		FACIES 4 Wackestone to in part Packstone (31)		SUBFACIES 4a *Apterrinella* sp. Packstone (6)		SUBFACIES 4b *Tubiphytes* sp. Packstone/Boundstone (3)		SUBFACIES 4c Mudstone/Wackestone Crystalline Carbonate (8)	
	mean (%)	range	mean (%)	range	mean (%)	range	mean (%)	range	mean (%)	range	mean (%)	range	mean (%)	range
Total Skeletal Grains	23	14-34	33	21-49	13	5-20	27	5-50	22	4-39	37	13-62	22	3-40
Echinoderms (total)	6	TR-19	3	0-9	5	0-9	3	0-13	3	2-5	TR	0-TR	1	0-3
Crinoids	6	0-19	3	0-9	5	0-9	2	0-13	2	1-3	—	—	1	0-3
Bryozoans (total)	6	3-9	TR	0-2	1	0-2	1	0-4	TR	0-1	—	—	TR	0-2
Cryptostomes	6	3-9	TR	0-2	1	0-2	1	0-4	TR	0-1	—	—	TR	0-2
Brachiopods (total)	2	0-4	1	0-2	1	0-3	2	1-13	1	0-3	TR	0-1	2	0-4
Phylloid Algae	TR	0-3	23	13-34	2	0-9	6	0-33	1	0-4	—	—	5	0-27
Molluscs (total)	4	1-9	2	0-8	3	0-8	4	0-11	4	1-6	TR	0-1	5	0-30
Gastropods	1	0-2	1	0-3	1	0-1	1	0-4	2	1-3	TR	0-TR	2	0-10
Pelecypods	2	0-8	1	0-2	2	0-7	1	0-5	2	TR-3	TR	0-1	3	0-17
Ostracodes	TR	0-1	TR	0-2	TR	0-TR	1	0-3	TR	0-TR	3	2-5	1	0-2
Foraminifers (total)	2	0-12	3	0-7	2	0-7	10	1-32	11	TR-23	1	0-3	7	0-26
Fusulinids	1	0-10	TR	0-3	1	0-4	3	0-21	TR	0-1	—	—	6	0-24
Endothyrids	TR	0-TR	TR	0-1	TR	0-1	TR	0-2	—	—	—	—	TR	0-1
Miliolids	TR	0-1	1	0-4	TR	0-1	1	0-4	TR	0-1	TR	0-1	TR	0-1
Encrusters	TR	0-1	1	0-4	1	0-3	5	0-28	13	TR-23	TR	0-1	1	0-2
Agglutinated	TR	0-1	TR	0-2	—	—	1	0-3	TR	0-1	TR	0-TR	TR	0-1
Tubiphytes sp.	—	—	—	—	—	—	TR	0-13	—	—	32	11-59	—	—
Calcispheres	—	—	—	—	—	—	TR	0-1	—	—	TR	0-1	TR	0-TR
Ooids	—	—	—	—	1	0-4	—	—	7	0-24	—	—	—	—
Peloids	—	—	—	—	21	0-41	1	0-12	25	9-52	—	—	—	—
Aggregate Grains	—	—	—	—	29	2-69	TR	0-2	4	1-14	—	—	—	—
Micrite/Microspar/Pseudospar	56	18-79	61	47-74	2	0-12	55	12-82	19	6-34	46	28-70	50	16-82
Micrite	45	7-75	56	37-66	1	0-11	43	12-66	18	6-31	46	28-70	24	0-58
Spar (cement)	3	1-6	1	0-5	32	20-43	11	0-39	19	8-30	12	4-17	7	0-22
Clay	7	0-31	—	—	—	—	TR	0-2	—	—	—	—	—	—
Phosphates	2	0-7	—	—	—	—	—	—	—	—	—	—	—	—
Pyrite	2	1-5	TR	0-1	—	—	1	0-7	—	—	—	—	1	0-3
Dolomite	2	0-5	1	0-8	2	0-5	2	0-14	1	0-4	1	0-2	13	0-60
Porosity	1	0-4	1	0-2	1	0-4	1	0-3	TR	0-1	TR	NA	5	0-21

TR < .5%

megascopic fabric relationships were examined using a hand lens or binocular microscope on 125 carbonate slabs. Staining techniques were extensively relied upon for determination of carbonate mineralogy (Dickson, 1966). Both alizarin red S and potassium ferricyanide were employed as staining reagents.

Bryozoan-Crinoidal Wackestone/Packstone Facies

Bryozoan-crinoidal wackestones and packstones are recognized in each of the three sections and occupy the lowermost 1.6 to 1.9 meters of the carbonate sequence. Characteristics unique to this interval include greater than "average" abundance of pelmatozoans, bryozoans (cryptostomes, mainly fenestrates), phosphates, clay, and pyrite. Skeletal constituents (usually bioclasts) occur within the lowest carbonate bed and range in size from very fine to coarse sand. Above the packed, abraded, and poorly-sorted basal carbonates, mud-supported rocks are observed displaying disarticulated, but non-abraded fenestrate bryozoans, crinoids, and pelecypods. Other notable characteristics of this facies include low biotic diversity and an abundance of eurytopic organisms (pelecypods, gastropods, ostracodes, and foraminifers excluding fusulinids). Most rock types can be assigned to one of the following categories which are listed in approximate order of decreasing abundance:

1. biomicrite/biomicrudite
2. crinoidal clayey biomicrite
3. pseudospar clayey biomicrosparite
4. microspar crinoidal intramicrudite

Matrix and Cement

Matrix is defined as mechanically deposited intergranular and intragranular material and is distinct from precipitated cement (Bathurst, 1975). When studying carbonate rocks, matrix generally refers to micrite, microspar, and pseudospar which are diagenetic products of original carbonate mud. According to Folk (1959) microcrystalline calcite or micrite has an upper size limit of 4 microns. Microscopic examination revealed that most carbonate material less than 5 or 6 microns could not be identified as either micrite, microspar, or finely comminuted fossil debris. In order to facilitate point-counting, an arbitrary boundary of 5 microns was selected to distinguish micrite from microspar. Matrix larger than 20 microns was considered pseudospar. Thus, micrite is extended herein to matrix of undetermined origin less than or equal to 5 microns in diameter. Matrix (within Facies 1) accounts for approximately 56 percent of the rock, but varies from 18 to 79 percent. Lower matrix values are observed within carbonate rocks located near the carbonaceous shale contact. Thin-sections from this region display an abundance of clay and phosphate, appearing as rounded to subrounded clasts or nodules (Figure 17). Section 2 does not contain clay or phosphatic material. The basal portion of Section 2 is not well exposed, and thus, the interval containing clay and phosphatic material may not have been sampled.

Precipitated or spar cement is rare (generally less than 5 percent). A vast majority of spar is associated as intragranular cement located within bryozoans, ostracodes, and fusulinids.

Skeletal Constituents

Biotic constituents vary considerably throughout the bryozoan-crinoidal wackestone/packstone facies, ranging from 14 to 34 percent. The mean is 23 percent with pelmatozoans (crinoids), bryozoans (cryptostomes and encrusting varieties), and molluscs (largely pelecypods) comprising the bulk. Most organisms are well preserved.

FIGURE 17

PHOTOMICROGRAPH OF A PHOSPHATE NODULE (P)
WITHIN THE BASAL CARBONATES OF UNIT 1
(cross-polarized light; bar for scale is 1 millimeter long)

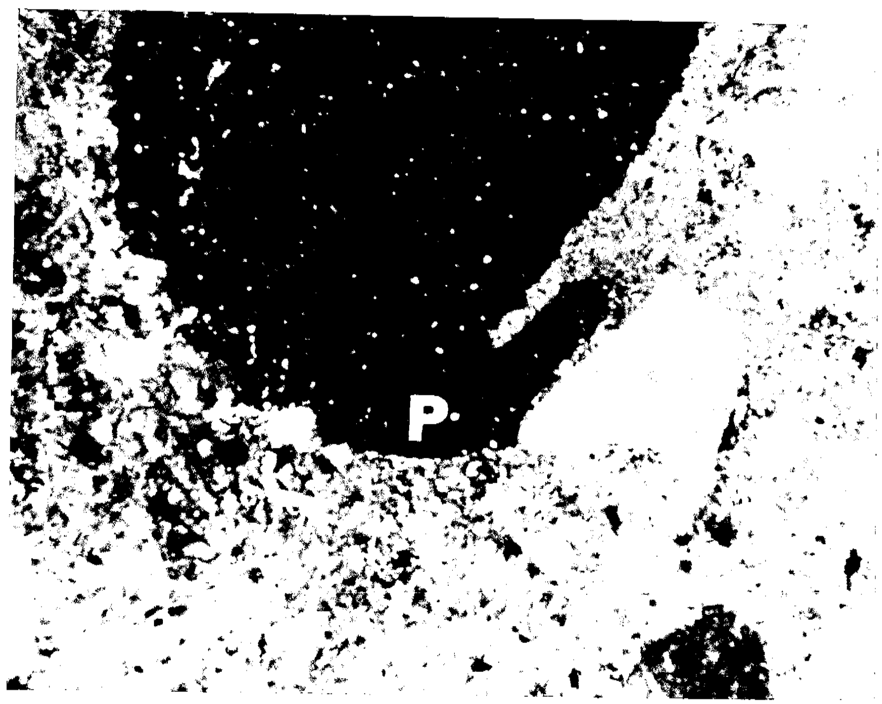


Figure 17

Silicification and dolomitization, when present, replace isolated external margins of skeletal grains. Pyrite replacement (Figure 18) is fairly common especially within brachiopods and bryozoans.

Pelmatozoans. Pelmatozoans of greatest concern to this study are crinoids, generally observed as disarticulated ossicles, arm plates, and stems. Crinoidal abundance "averages" 6 percent throughout this lowermost facies, but near the carbonate-black shale contact, crinoids account for one-fifth of all constituents. Crinoid grains appear gray to yellow-gray and consist of a single calcite crystal with a porous microstructure. This microporous or meshwork structure is usually filled with micrite, but less commonly, sparry calcite occurs. Recrystallization has little effect on preservation of crinoids, but their porous structure may serve as a site for partial silicification.

Bryozoans. Cryptostomes (particularly fenestrates), encrusting varieties, and an occasional trepostome, are locally important grain types, especially within the lowermost 1.5 meters of Facies 1. Bryozoans seem most abundant in areas of abundant carbonate matrix. The wall structure of these organisms is usually laminated or fibrous, and recognition is enhanced by presence of zooecia or tubes of various widths. Fragments, which do not contain recognizable portions of zooecia, could be confused with coral fragments. Bryozoan fibers are usually too fine to be confused with brachiopod microstructure.

Brachiopods. Brachiopods tend to be ubiquitous throughout the carbonate sequence; within Facies 1 brachiopods range from 0 to 4 percent (mean of 2 percent). The well-preserved articulate brachiopod fragments are identified by their fine fibrous structure. Most shells are impunctate, but smaller numbers of both pseudopunctate and punctate forms exist.

FIGURE 18

PHOTOMICROGRAPH OF PYRITE REPLACING A SKELETAL GRAIN
(plane-polarized light; bar for scale is 1 millimeter long)

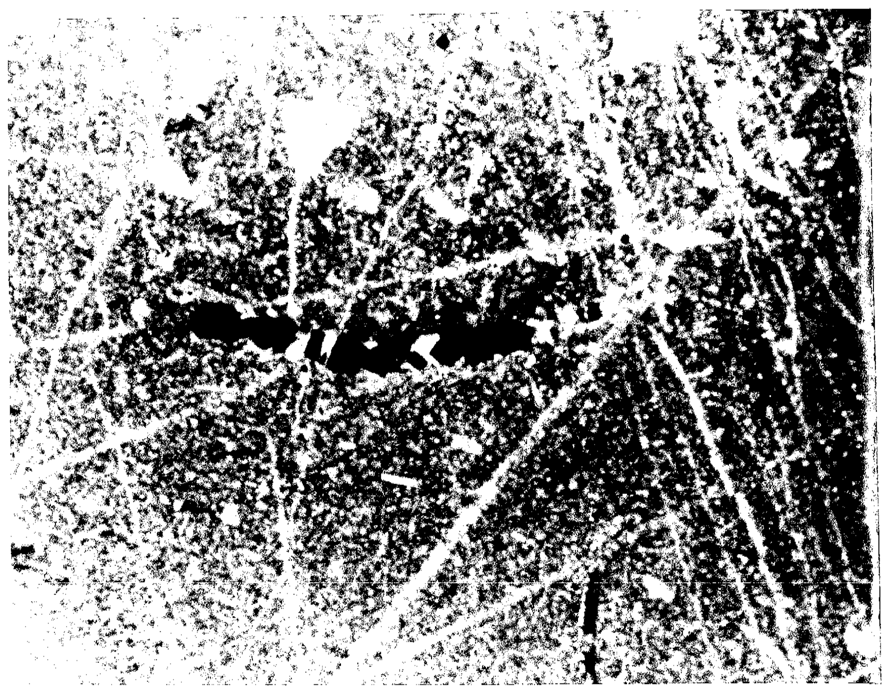


Figure 18

Brachiopod shells may be subdivided into an outer fibrous layer oriented obliquely to an inner prismatic layer. Many brachiopod grains consist entirely of this fibrous layer, commonly impregnated with pyrite crystals. Of all biota observed in thin-section, brachiopods seem to be most resistant to silicification and dolomitization. Brachiopod spines are commonly encountered. In cross-section they are circular and usually hollow, with concentric laminations. In longitudinal section they exhibit parallel laminations with a fibrous microstructure similar to that of the shell.

Molluscs. Gastropods, pelecypods, and cephalopods have been identified within the carbonate sequence. Cephalopods, although present in each section, only occur in trace amounts. On the other hand gastropods and pelecypods generally account for 2-5 percent (of the rock) regardless of stratigraphic position. Pelecypods are usually present in slightly greater abundance. Original microstructure of molluscs is rarely preserved; this preservation has been observed in only some pelecypods. In these unusual cases, the shell consists of two layers: an outer, dense, white, calcite layer and an inner layer of blocky spar. Presumably, the outer layer represents original calcite shell material in which the microstructure has been preserved. The inner, spar-rich layer was probably aragonite where structural details were destroyed during dissolution (of original aragonite) and subsequent precipitation of sparry calcite cement. Molluscs usually display blocky calcite cements due to the diagenetic processes of dissolution/precipitation, but it is possible that an original aragonitic shell could undergo neomorphism to pseudospar exhibiting relict structures of its initial microstructure. Evidence supporting this process was not seen.

Phylloid Algal Wackestone/Packstone Facies

Phylloid algal wackestones and packstones (Facies 2) are located stratigraphically above the bryozoan-crinoidal wackestone/packstone facies. This interval is 3.6 to 4.6 meters thick and occurs within each of the three sections. The most diagnostic feature of Facies 2 is the dominance of phylloid algae which account for 70 percent of the total skeletal fraction. Most phylloid algal thalli are fragmented, angular, and large (some 12-15 millimeters, most around 3-4 millimeters in longest dimension), indicating minor transportation. Sorting of the rock is poor due to an abundance of micrite. Phylloid algal biomicrudite (Folk, 1980) is the only rock type identified from this interval.

Matrix and Cement

Micrite (56 percent) is the most abundant matrix while both microspar and pseudospar rarely exceed 5 percent of the rock. Sparry calcite cement (0 to 5 percent) occupies intragranular regions within ostracodes, bryozoans, and foraminifers. Two distinct cement phases occur: 1) bladed isopachous rim cements and 2) blocky cements.

Skeletal Constituents

Phylloid algae vary from 13 to 34 percent and average 23 percent of the rock within Facies 2. Other skeletal grains such as foraminifers, although masked by the dominance of phylloid algae, display slight increases in diversity and abundance when compared to Facies 1; bryozoans and crinoids are the only skeletal grains to decrease substantially in abundance over this interval. As in Facies 1, micritization of skeletal grains is not observed.

Phylloid Algae. According to Bathurst (1975), "phylloid algae" is a convenient term used to describe a group of leaf-like algal constituents, which were very common in the late Paleozoic. Dissolution of their original aragonitic fronds (thalli) and subsequent precipitation of blocky-textured calcite cement destroys all previously existing microstructure making identification difficult. Two types of phylloid algae are identified in this study: *Archaeolithophyllum* sp. and *Eugonophyllum* sp., but other varieties probably exist. *Archaeolithophyllum* sp., a corallinacean alga (Johnson, 1956), has a calcified, undulating, encrusting thallus with thicknesses from 250 to 800 microns. It has conceptacles and a cellular structure divisible into hypothallus and perithallus (Toomey, 1969). The hypothallus and perithallus were not seen, but conceptacles were identified. The second most common phylloid alga is *Eugonophyllum* sp. (probably codiaceans, after Wray, 1964). The blades or thalli appear to weave and branch and are typically greater than 200 microns. A diagnostic feature of *Eugonophyllum* sp. is their regularly spaced micrite-filled utricles found along the periphery of filaments.

Corals. With the exception of *Syringopora* sp., corals rarely occur in thin-section. Coral wall structures (observed in this study) are composed of fine calcite fibers which under cross-polarized light exhibit a "feathery" extinction pattern. Recrystallization has had little effect on structural details of corals, apparently because of an original calcitic skeleton, but fibrous corallite walls seem susceptible to silicification especially by chalcedony.

Grainstone and Poorly Washed Grainstone Facies

Grainstones (Facies 3), located in each section, extend 2.8 meters above Facies 2. In terms of the field study, this interval occupies the upper one-half of Unit 3. Microscopic examination revealed several important characteristics of this facies. Intragranular and intergranular regions are filled with sparry calcite cement, occasionally thin-sections exhibit isolated micritic zones. Non-skeletal grains such as ooids, peloids, and aggregate grains account for one-half of the rock. Decreases in biotic abundance are observed when compared to previously discussed facies, but this may be expected because most finer-grained material has been winnowed and coarser material has experienced sorting. Thin-sections display well to very well-sorted bioclasts, ooids, peloids, and aggregate grains. Identification of bioclasts is possible in some instances. Echinoderms, molluscs, brachiopods, and some foraminifers seem most resistant to abrasion and micritization. This interval contains the following rock types which are listed in order of decreasing abundance:

1. peloidal biosparite/biosparrudite
2. biointrasparite (Flugel, 1978)
3. *Syringopora* sp. biolithite

Matrix and Cement

Each thin-section examined from this facies exhibits a grain-supported fabric, and where minor amounts of matrix occur the term "poorly washed" (after Folk, 1980) is applied. Poorly washed implies that processes responsible for winnowing were incomplete. Micrite rarely exceeds 1-2 percent (one thin-section contained 11 percent micrite) whereas, sparry calcite is found in all rock types of Facies 3, containing 20 percent from poorly washed grainstones to 43 percent within the most spar-rich rocks. Six cement types are present; fibrous, bladed, and blocky cements dominate this interval, but syntaxial, micritic, and ferroan calcite cements can be locally important. Ferroan cement appears blue after staining (Dickson, 1966) and usually occupies late-stage fractures, but occasionally, this cement fills remaining intragranular and intergranular pores.

Non-Skeletal Constituents

Peloids (0.25 millimeters to several millimeters in diameter) are round to slightly elongate, structureless grains generally accounting for one-fifth of all constituents within Facies 3. Ooids, aggregate grains, and bioclasts, with micritic envelopes, also dominate this interval. Most ooids are composed of a single tangential calcite ring from 0.01 to 0.03 millimeters thick surrounding an inner bioclastic or peloidal nucleus. These superficial ooids are commonly asymmetrical, and rarely exceed 0.3 millimeters (Carozzi, 1961). Bathurst (1975) describes similar ooids within low energy environments from the Bahama Banks. Although aggregate grains have been observed throughout this interval (Facies 3), their abundance exceeds 60 percent within the uppermost bed. They appear as slightly rounded, strongly micritized particles (ooids, peloids, and bioclasts) which are tightly bonded to one another by micritic cement.

Wackestone to in Part Packstone Facies

Wackestones and packstones (Facies 4) occupy the upper 18 meters of the carbonate sequence (the equivalent of Units 4, 5, and 6) and occur in each of the three sections. This interval contains the greatest variation of environmentally significant fossils, sedimentary structures, and rock types. The following rock names are listed in decreasing order of abundance:

1. microspar biomicrite/biomicrudite
2. phylloid algal-*Apterrinella* sp. biomicrudite
3. molluscan-fusulinid biomicrudite
4. dismicrite
5. intramicrudite/intramicrite
6. poorly washed foraminiferal-*Tubiphytes* sp. biopelsparite

Apterrinella sp. packstones, *Tubiphytes* sp. packstones/boundstones, and mudstone/wackestone crystalline carbonates are subfacies within Facies 4 and will be discussed later.

Matrix and Cement

Throughout this interval (Facies 4), a gradational micrite microfabric (from pelletal to clotted to dense) is present, and an individual thin-section may exhibit all three textures. The microfabric is particularly obvious where small amounts of intergranular spar coexist with micrite.

Spar-cemented rocks occur in isolated horizons. The equidimensional crystals of blocky-textured cements are most abundant, but some fibrous, bladed, and ferroan cements occur.

Non-Skeletal Constituents

The petrography of peloids, ooids, and aggregate grains is similar to the preceding interval (Facies 3) and need not be reviewed again, but previously unencountered grains such as pellets and intraclasts will be described. Even though a pelletal matrix is suspected throughout much of this interval, "obvious" pellets are only associated with *Tubiphytes* sp.-rich rocks containing abundant ostracodes. Rod-shaped pellets, with maximum diameters between 30 to 50 microns, have length:width ratios approaching 2:1.

Intraclasts, appearing as separate pieces of micrite less than 5 millimeters in longest dimension, can be volumetrically significant within some rocks. It is possible that these intraclasts resulted from early diagenetic movements within the sediment, but a preponderance of bored skeletal grains and matrix indicates that these intraclasts are pseudo-intraclasts (Wobber, 1965) which have originated from bioturbation.

Skeletal Constituents

Skeletal grains are usually non-abraded and very well preserved (except organisms originally composed of aragonite which now display mosaics of sparry calcite). Eurytopic organisms increase in abundance especially within the upper two-thirds of Facies 4, and calcispheres are present throughout this interval, rarely exceeding 1 percent of the rock. No distinct pattern exists concerning diversity trends within Facies 4, but in general, the biota identified from this interval are more tolerant of environmental stresses (Heckel, 1972). Occasionally, the environment becomes "more" stressful resulting in rocks composed almost exclusively of foraminifers (miliolids, encrusters, and agglutinated varieties), ostracodes, and _Tubiphytes_ sp., while adjacent strata contain "more normal" marine biota.

Ostracodes. Ostracodes occur throughout the carbonate sequence, but are most abundant within the upper one-half of Facies 4. Most have thin, non-ornamented shells ranging from 0.1 to 1.0 millimeter. Generally, ostracode shells overlap (when articulated), exhibiting internal recurved margins and prismatic microstructures; these characteristics are useful in distinguishing whole and fragmented ostracodes from other thin-shelled skeletal grains such as foraminifers and pelecypods.

Ostracodes are capable of living in a wide range of aquatic environments and thrive under conditions that few organisms can tolerate (Dodd and Stanton, 1981). Rocks containing an abundance of ostracodes with few other organisms usually represent restricted environments.

Eleutherozoans. Although ubiquitous, eleutherozoans (echinoid spines) occur in minor abundance (less than 2 percent of the rock). Eleutherozoans are easily identified microscopically because each spine acts as a single crystal of calcite (unit extinction under cross-polarized light) similar to individual elements of pelmatozoans. Also, echinoid spines appear yellow-gray and display radially oriented microporous structures.

Foraminifers. Various forams occur throughout the carbonate sequence, but this interval (Facies 4) displays the most diverse and abundant foraminiferal assemblage. The degree of abundance is indicated as follows:

Encrusting Calcareous Forms

Apterrinella sp.	very abundant
Calcivertella sp.	common
Tuberitina sp.	common
Tetrataxis sp.	common

Mobil Calcareous Forms

Globivalvulina sp.	common
fusulinids	common
Cornuspira sp.	rare
Bradyina sp.	rare

Mobil Agglutinated Forms

Textularia ssp.	common

Encrusting, calcareous foraminifers dominate many horizons in Facies 4 with the genus *Apterrinella* being most abundant. Encrusting forams are characterized by a simple shell structure which consists of a chamber leading to a long unchambered tube. Fusulinids and Globivalvulina sp. outnumber mobile calcareous forams of Cornuspira sp. and Bradyina sp. Only a few specimens of Cornuspira sp. and Bradyina sp. are noted, but Textularia ssp. occur in much greater abundance. Textularia ssp. are mobile agglutinated forams, and their presence probably depends upon the availability of fine sand and silt sized particles. Although the previously described foraminifers possess characteristic wall structures, preservation is variable because most wall structures are reduced to dense, microcrystalline calcite. Consequently, general morphology is heavily relied upon for recognition.

Tubiphytes sp. Tubiphytes sp., a presumed alga (Croneis and Toomey, 1965) or calcareous sponge (Flugel, 1978), exhibits a dark, dense, fine-grained texture (Figure 19) and broad layering (Figure 20) and commonly contains clear calcite (spar-filled areas) surrounded by faint (3 or 4 microns thick), concentric laminae. Tubiphytes sp. is porcellaneous, milky white in direct light and dark in transmitted light and is located exclusively within Facies 4 between 21 and 26 meters above the basal bed of the carbonate sequence. Tubiphytes sp. occurs from equivalent horizons in each of the three sections.

Calcispheres. These problematical microorganisms occur soley within Facies 4; they have been identified in trace amounts from nearly all thin-sections, but attain greatest abundance within strata adjacent to the Tubiphytes sp.-rich rocks. Most calcispheres resemble spheres constructed of a calcite wall enclosing a spar-filled chamber (Figure 21). Several, thin, concentric layers extending from the calcite wall may or may not be traversed perpendicularly by radial partitions. Where radial partitions occur, calcispheres display a cellular appearance.

FIGURE 19

PHOTOMICROGRAPH OF TUBIPHYTES sp. EXHIBITING DARK, DENSE, FINE-GRAINED TEXTURE AND SPAR-FILLED AREAS (plane-polarized light; bar for scale is 1 millimeter long)

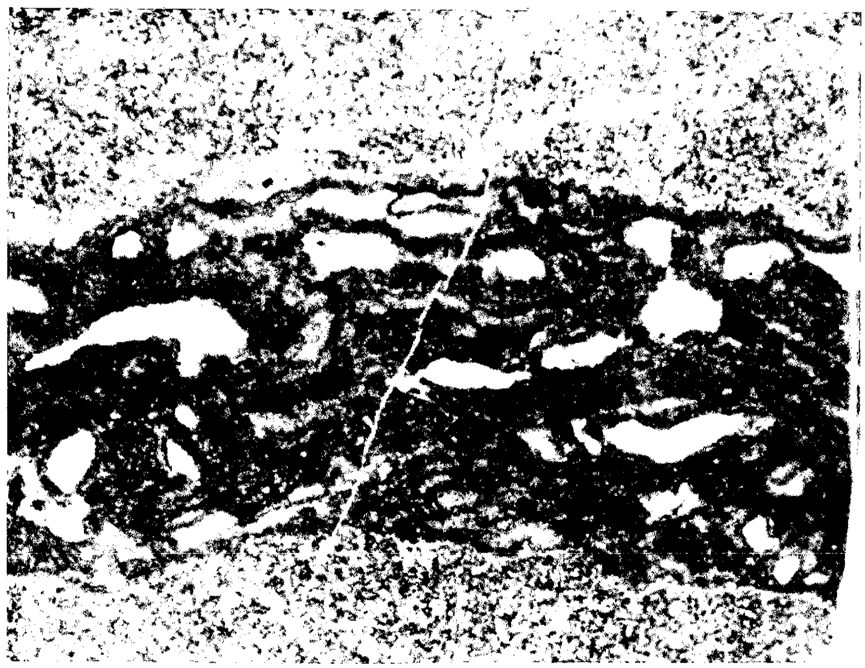


Figure 19

FIGURE 20

PHOTOMICROGRAPH OF *TUBIPHYTES* sp. (T) DISPLAYING BROAD LAYERING AND SPAR-FILLED AREAS (plane-polarized light; bar for scale is 1 millimeter long)

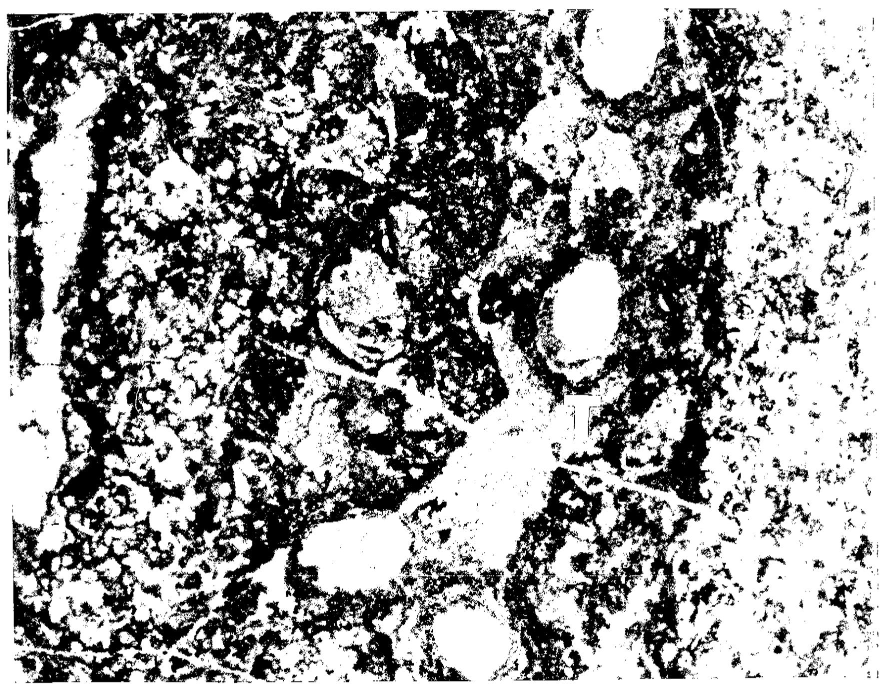


Figure 20

FIGURE 21

PHOTOMICROGRAPH OF CALCISPHERES (C) IN WHICH THE CALCITE WALL ENCLOSES A SPAR-FILLED CHAMBER (plane-polarized light; bar for scale is 0.1 millimeters long)

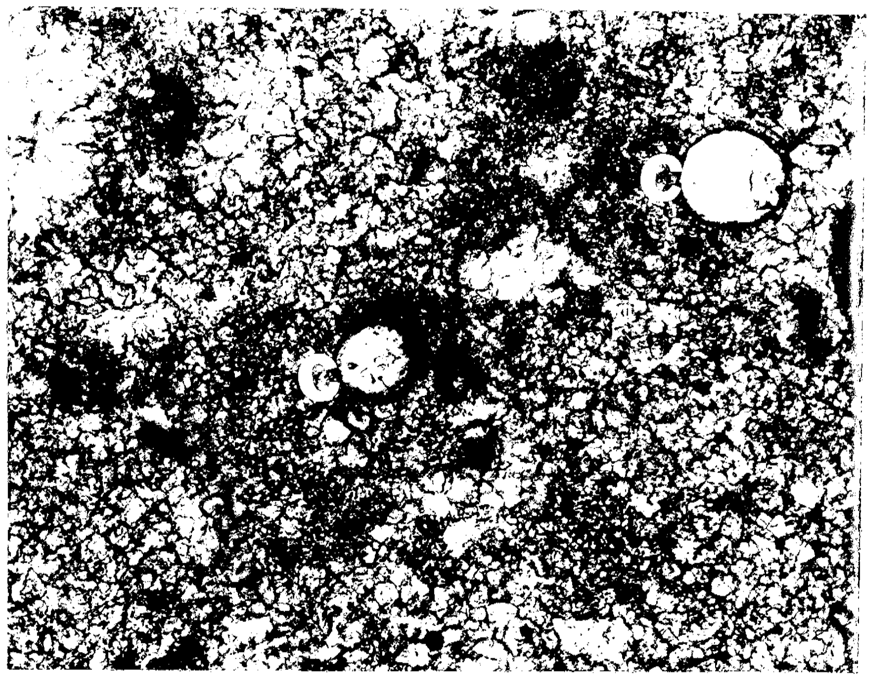


Figure 21

Apterrinella sp. Packstone Subfacies

Apterrinella sp. packstones occur within the upper 2 meters of Unit 5 and extend 1 meter into Unit 6, approximately 8 meters below the top of Facies 4. *Apterrinella* sp. occasionally encrusts skeletal grains, but is ordinarily observed "loose" (Figure 22). These unattached forms may have originally encrusted perishable supports because they exhibit no abrasion and occur in long strands. Additional characteristics important to this subfacies include spar and micrite occurring in subequal abundance, and ooids and peloids accounting for one-third of all constituents. The following rock names typify the subfacies:

1. poorly washed peloidal *Apterrinella* sp. biosparite
2. peloidal *Apterrinella* sp. oosparite

Tubiphytes sp. Packstone/Boundstone Subfacies

Tubiphytes sp. packstones and boundstones are characterized as *Tubiphytes* sp. biopelmicrites or pelletal *Tubiphytes* sp. biolithites. *Tubiphytes* sp. accounts for 95 percent of all biota and is associated with ostracodes, less commonly foraminifers. Ostracodes and forams display smaller than usual sizes and exhibit very thin shells and tests. Thus, biotic size, diversity, and abundance undergo drastic reductions when compared to previously described strata.

Mudstone/Wackestone Crystalline Carbonate Subfacies

The mudstone/wackestone crystalline carbonate subfacies is observed from each section occupying the uppermost 0.9 to 1.5 meters of Facies 4 and is characterized by dolomitization and secondary porosity (Figure 23). Usually, dolomite replaces micrite and leaves skeletal grains unaffected except peripherally where they are in contact with the matrix. Dolomite occurs as small (50 microns), clear, euhedral crystals which are not zoned and generally do not possess a distinct nucleus.

FIGURE 22

PHOTOMICROGRAPH OF *APTERRINELLA* sp. (A)
UNATTACHED AND ENCRUSTING A MOLLUSC
(plane-polarized light; bar for scale is 1 millimeter long)

Figure 22

FIGURE 23

PHOTOMICROGRAPH OF SECONDARY POROSITY (S) WITHIN
THE UPPER PORTION OF THE CARBONATE SEQUENCE
(plane-polarized light; bar for scale is 1 millimeter long)

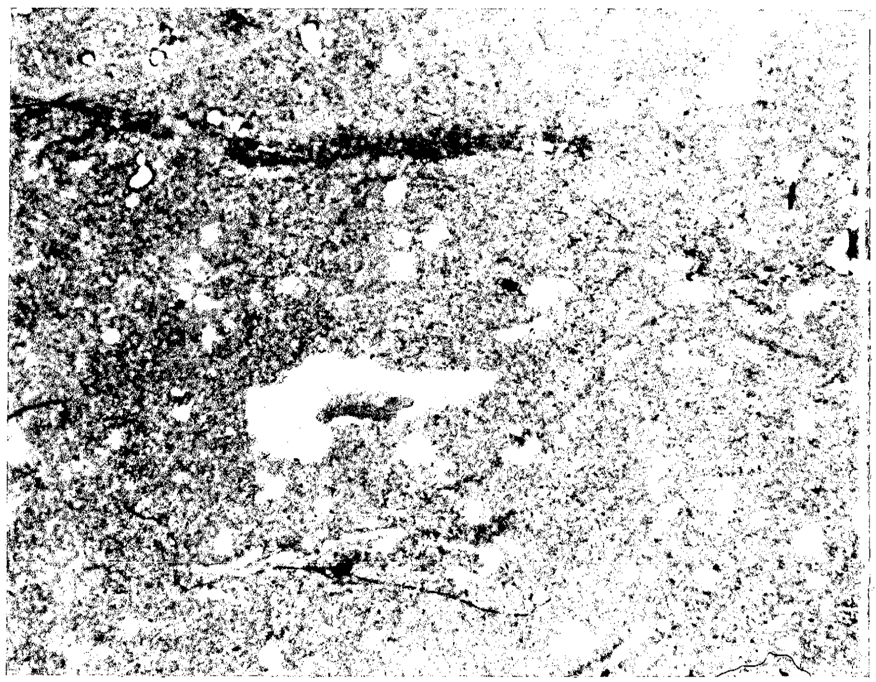


Figure 23

Folk classifications in decreasing order of abundance are as follows:

1. molluscan-phylloid algal-fusulinid microspar biomicrudite
2. microspar pseudospar dolomitized micrite
3. finely crystalline biogenic porous dolomite

Trends

The purpose of this discussion is to investigate general trends among the various facies, whereas, the previous discussion described important characteristics within each facies. Trends under investigation include biotic diversity and abundance and intergranular materials. Subsequent discussions concerning biotic diversity and abundance will focus on a distinction between stenotopic and eurytopic organisms. Within this investigation stenotopic organisms include crinoids, brachiopods, corals, echinoid spines, bryozoans, and phylloid algae; whereas, eurytopic organisms comprise ostracodes, gastropods, pelecypods, and foraminifers (except fusulinids). These taxa were assigned to their respective categories (stenotopic or eurytopic) based on a review of modern organisms conducted by Heckel (1972). According to Heckel (1972), certain aspects of ecologic tolerance may have changed through geologic time. Thus, problems may occur when comparing modern biotic distributions to ancient distributions, but the data obtained using stenotopic and eurytopic organisms seem to be consistent with field and petrographic data.

Absolute standard deviations (s) indicate mean diversity values ($\bar{x}$) are of little statistical importance (Table 3).

TABLE 3

DIVERSITY STUDY INVOLVING ALL BIOTIC CONSTITUENTS WHERE:
n = number of thin-sections analyzed, $\bar{x}$ = mean diversity,
s = standard deviation, c = relative standard deviation, and r = range

Facies	n	$\bar{x}$	s	c(%)	r
1	8	16.13	3.36	21	12-22
2	10	17.30	3.47	20	13-23
3	9	17.89	2.42	14	15-22
4	47	22.04	5.91	27	9-30

Relative standard deviations (c) are important; they relate standard deviations and means by expressing the absolute standard deviation as a percentage of the mean and thus, allow comparison of data (i.e., $c = (s/\bar{x})(100\%)$). Within this study relative standard deviations are used to note the general stability of an environment. In other words, environments that fluctuate from "normal" to stressful should exhibit higher relative standard deviations (not necessarily higher absolute standard deviations), compared to non-fluctuating environments. Because relative standard deviations, ranges, and (to a certain extent) mean diversity values are similar for Facies 1, 2, and 3, their results will be combined (Table 4). The average relative standard deviation (C) for stenotopic organisms reveals a greater relative standard deviation within Facies 4 (as compared to Facies 1-3), whereas, eurytopic organisms exhibit an inverse relationship concerning relative standard deviations. Thus, environmental conditions within Facies 4 have a "more" profound effect upon stenotopic rather than eurytopic organisms. Environmental fluctuations would more-likely affect stenotopic organisms, which are not capable of surviving in environments that deviate from normal or near-normal marine salinities.

TABLE 4

DIVERSITY OF VARIOUS "TYPES" OF ORGANISMS WHERE:
n, $\bar{x}$, s, c, and r are similar to Table 3 and eurytopic = ostracodes, gastropods, pelecypods, and foraminifers (except fusulinids) while stenotopic = crinoids, brachiopods, corals, echinoid spines, bryozoans, and phylloid algae

		Section 1		Section 2		Section 3		Sections 1-3	
		Facies 1-3	Facies 4	Facies 1-3	Facies 4	Facies 1-3	Facies 4	Facies 1-3	Facies 4
"All"	n	12	13	8	13	7	21		
organisms	$\bar{x}$	16.25	20.85	18.38	21.31	17.29	23.24		
	s	2.86	6.05	2.45	6.03	3.95	5.80		
(%)	c	18	29	13	28	23	25		
	r	12-23	9-30	16-22	10-29	12-23	9-30		
average (%)	C							18	27
eurytopic	n	12	13	8	13	7	21		
organisms	$\bar{x}$	7.92	10.31	8.38	10.92	8.71	12.24		
	s	2.45	3.82	2.39	3.25	3.40	2.93		
(%)	c	31	37	29	30	39	24		
	r	5-14	5-17	4-11	5-16	4-14	5-16		
average (%)	C							33	30
stenotopic	n	12	13	8	13	7	21		
organisms	$\bar{x}$	7.33	7.46	8.25	7.62	7.43	7.90		
	s	1.56	2.44	1.98	1.98	1.51	2.79		
(%)	c	21	33	24	26	20	35		
	r	6-10	1-10	5-11	3-12	5-9	1-12		
average (%)	C							22	31

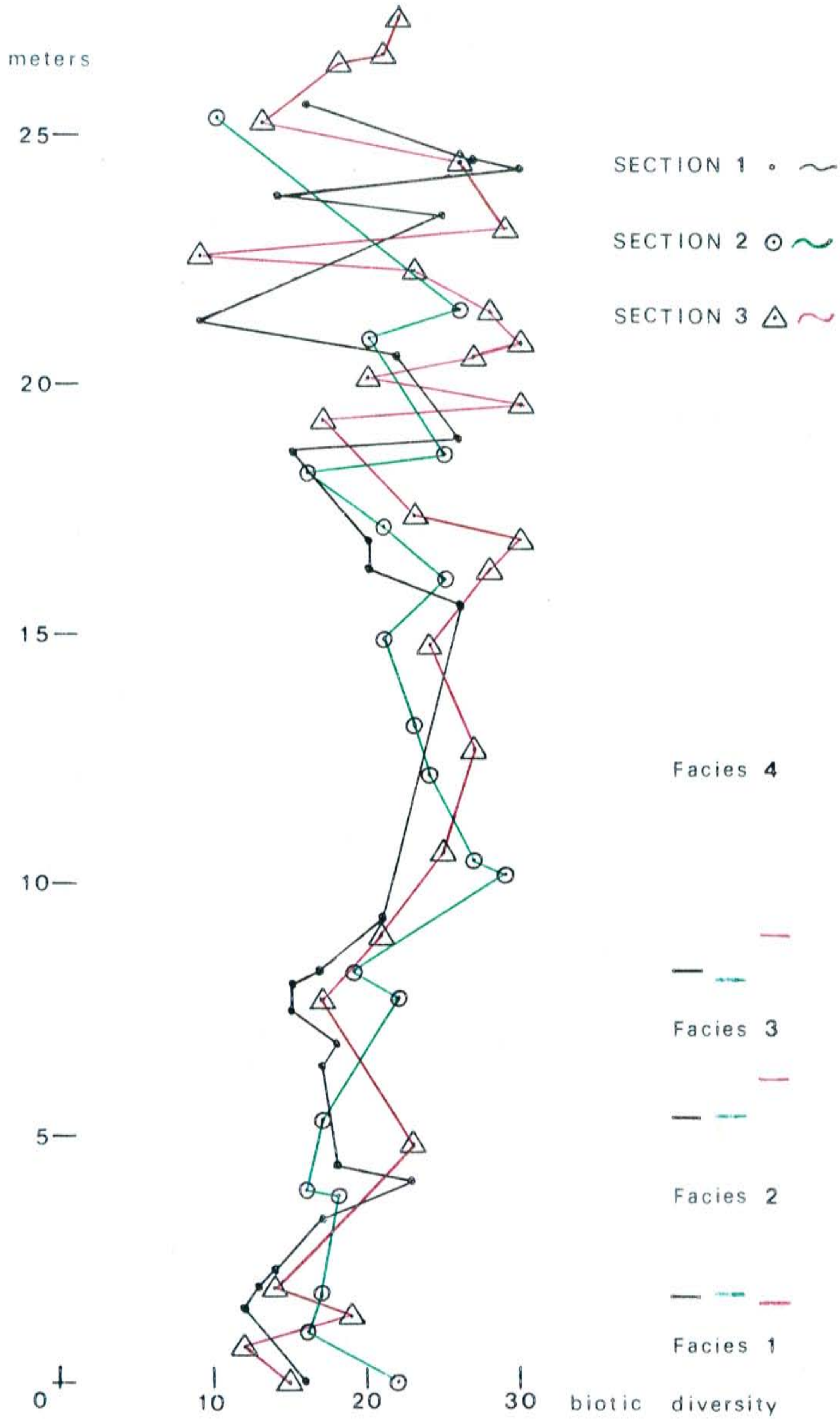
Figure 24 results from a compilation of "petrographic" fossil diversity, and according to Smosna and Warshauer (1978), petrographic fossil diversity is the total number of all dissimilar fossil types observed in thin-section. Variability of petrographic diversity (among Sections 1, 2, and 3) remains quite low throughout the lower 15 meters of the carbonate sequence, but the uppermost 10 meters of strata exhibit increased variability (ranging from 9 to 30).

Figure 25 represents a ratio of stenotopic diversity to total biotic diversity. Diversities obtained for stenotopic organisms generally constitute 40-60 percent (of the total biotic diversity) within the lower two facies of the carbonate sequence. Above Facies 2 stenotopic organisms decrease in diversity relative to non-stenotopic organisms. Within Facies 4 stenotopic diversities average 34 percent, rarely accounting for more than 40 percent.

Perhaps Figures 26 and 27are the most revealing of all graphs; they express eurytopic and foraminiferal abundance as a percentage of the total biotic abundance. Eurytopic organisms rarely account for more than 45 percent of all skeletal grains within the lower three facies, but Facies 4 displays eurytopic abundance in excess of 80 percent (average 55-60 percent) (Figure 26). From Figure 27 it is obvious that foraminifers account for the majority of eurytopic abundance. Endothyrids, miliolids, agglutinated, and encrusting varieties comprise the foraminiferal assemblage occurring in Figure 27; encrusting forms are most abundant, especially in Facies 4. Throughout the lower 12 meters of the carbonate sequence foraminifers rarely exceed 20 percent of all biotic constituents, but above this interval foram abundance commonly exceeds 40 percent (of all skeletal grains). Figures 26 and 27 display increased biotic variability within Facies 4.

FIGURE 24

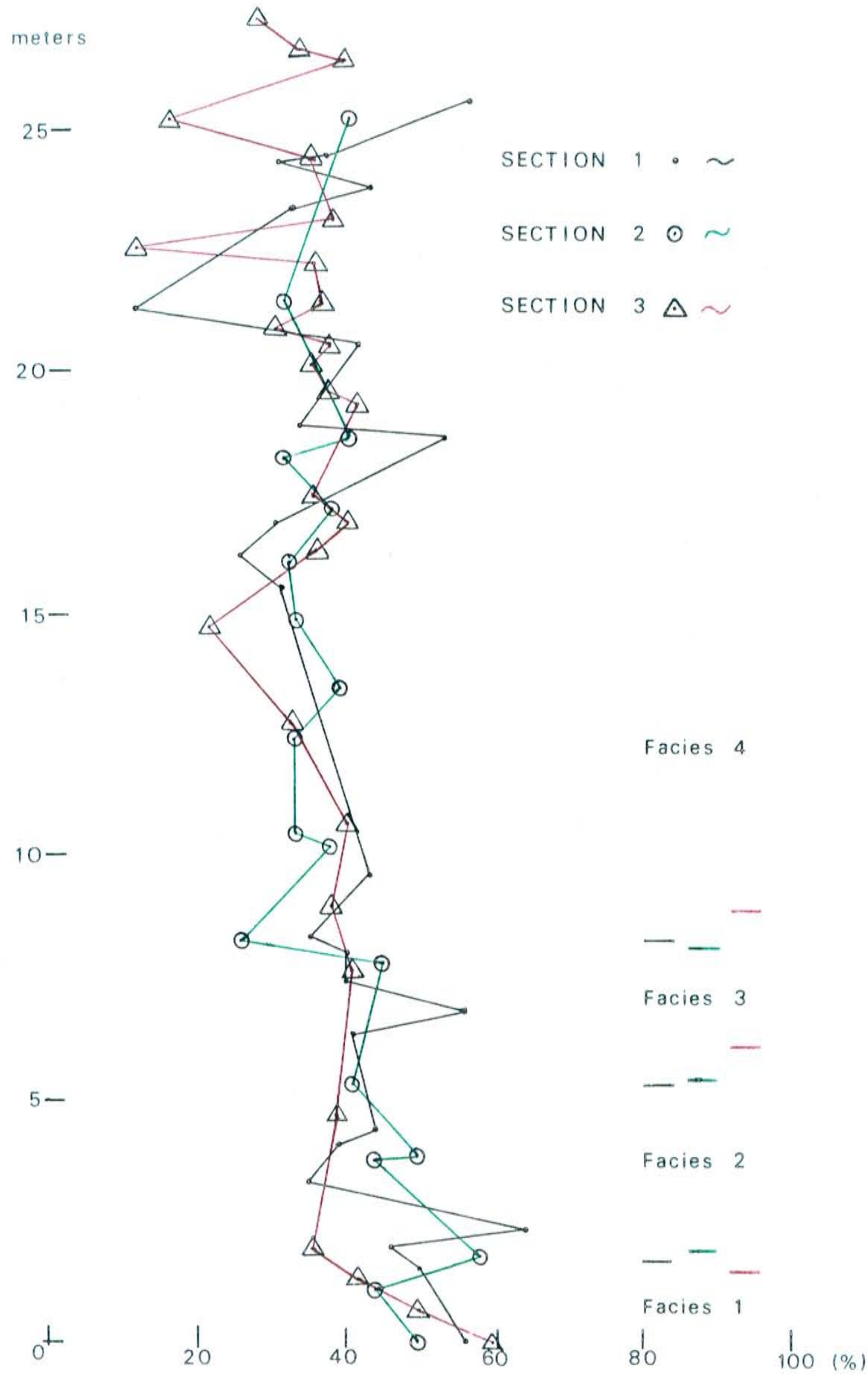
DIVERSITY CORRELATION OF ALL SKELETAL CONSTITUENTS



meters
25
20
15
10
5
0
10
20
30
biotic diversity
SECTION 1
SECTION 2
SECTION 3
Facies 4
Facies 3
Facies 2
Facies 1

FIGURE 25

STENOTOPIC ORGANISM DIVERSITY/TOTAL BIOTIC DIVERSITY X 100%



meters
25
20
15
10
5
0
20
40
60
80
100 (%)
SECTION 1
SECTION 2
SECTION 3
Facies 4
Facies 3
Facies 2
Facies 1

FIGURE 26

EURYTOPIC ABUNDANCE/ABUNDANCE OF ALL SKELETAL GRAINS X 100%

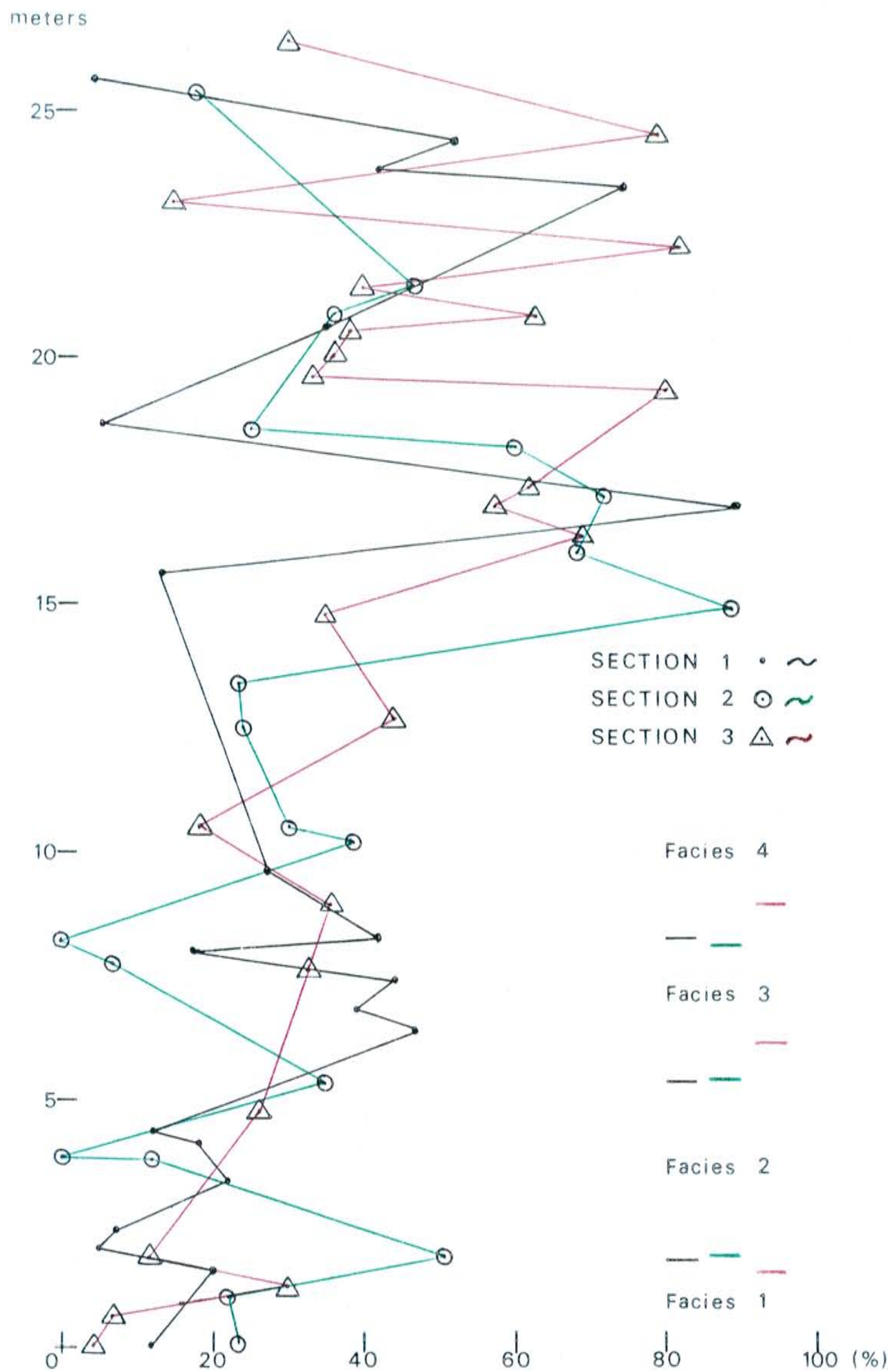
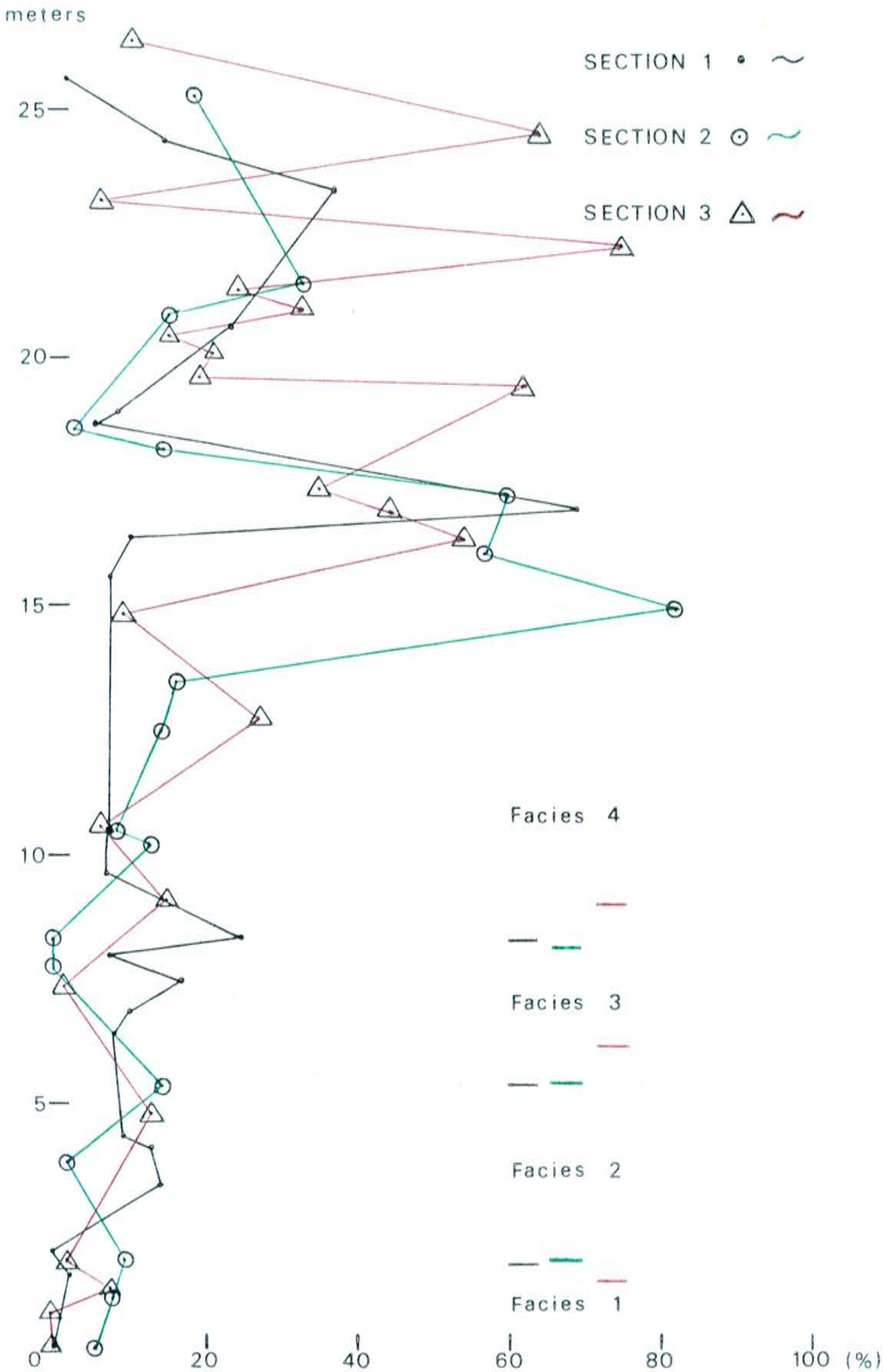

meters
25—
20—
15—
10—
5—
0
20
40
60
80
100 (%)
SECTION 1
SECTION 2
SECTION 3
Facies 4
Facies 3
Facies 2
Facies 1

FIGURE 27

FORAMINIFERAL ABUNDANCE/ABUNDANCE OF ALL SKELETAL GRAINS X 100%

forams include:

endothyrids
miliolids
encrusters
agglutinated

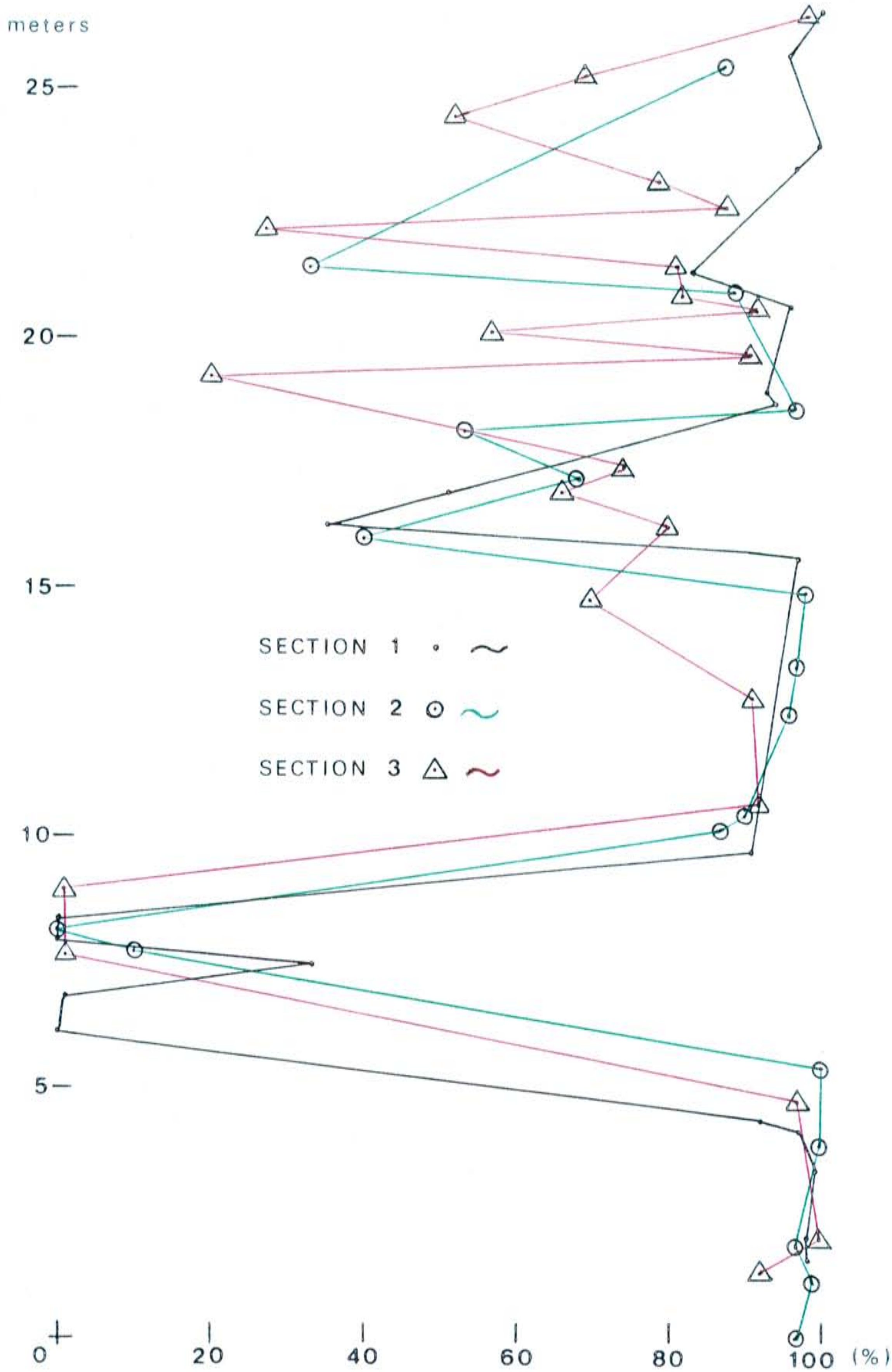


meters
SECTION 1
SECTION 2
SECTION 3
25—
20—
15—
10—
5—
Facies 4
Facies 3
Facies 2
Facies 1
0
20
40
60
80
100 (%)

The occurrence of matrix and spar (Figure 28) vary considerably throughout the carbonate sequence. Intergranular regions in the lower two facies are composed essentially of 100 percent matrix (micrite, microspar, and pseudospar), whereas, Facies 3 approaches 100 percent spar, occupying intergranular areas. The upper one-half of Figure 28 (Facies 4) displays variable matrix-spar relationships ranging from 20-99 percent.

FIGURE 28

MATRIX (MICRITE, MICROSPAR, AND PSEUDOSPAR)/MATRIX PLUS SPAR X 100%



meters
25—
20—
15—
10—
5—
0
20
40
60
80
100 (%)
SECTION 1
SECTION 2
SECTION 3

DIAGENESIS

Diagenesis includes all of the processes of solution, cementation, lithification, and alteration of the sediments during the interval between deposition and metamorphism (Flügel, 1978).

Degradation of Carbonate Grains

Both physical and biological degradation are apparent in the carbonate sequence. Physical degradation formed broken and abraded skeletal grains within the grainstone facies (Facies 3). Biological degradation, in the form of micritized grains and micrite rims, is common in Facies 3 and in *Apterrinella* sp. packstones subfacies of facies 4. Bioturbation is another type of biological degradation and usually occurs within the wackestones and packstones of Facies 4.

Dissolution

Solution of carbonate grains is common in all facies. Dissolution is predominantly fabric selective, but non-selective leaching occurs and is represented by voids that cut across skeletal grains, matrix, and cements. Grains that were commonly subjected to dissolution include phylloid algae, molluscs, and ooids.

Cementation

A wide variety of cements is identified from the carbonate sequence. Thin-sections reveal micritic, fibrous, syntaxial, bladed, blocky, and ferroan cements. Micritic cements are cryptocrystalline, and bind peloids, ooids, and bioclasts to one another forming aggregate grains. Fibrous cements appear as thin, fibrous crystals displaying a drusy texture around grains. The long axis of these crystals is perpendicular to pore walls or grain boundaries. Syntaxial cements rarely account for more than a few percent. They occur exclusively within the grainstones, as large, optically continuous crystals surrounding echinoderm fragments, but occasionally, foraminifers exhibit these "overgrowths". Bladed and blocky cements occur together; the drusy textured bladed cements form first, and are followed by blocky textured cements. Blocky cements range from 10 to 60 microns and display anhedral to subhedral crystals. This cement has no preferred crystal orientation. Ferroan cement, never exceeding 5 percent of the rock, typically occurs as fracture fillings; less commonly it does fill intragranular and intergranular pores.

Neomorphism

Neomorphism is a term that was introduced by Folk (1965) to include all mineral transformations in which the mineral either remains intact or is converted into a polymorphous mineral. Aggrading neomorphism of micrite, the only commonly recognized neomorphic process, has produced some microspar and pseudospar (Figure 29).

Replacement

Dolomite

Clay to sand size dolomite occurs in all three sections and can be identified from each facies, but the upper meter of Facies 4 contains the greatest abundance of dolomite. There appears to be two generations of dolomitization: an "early" replacement of carbonate matrix, and a more pervasive "late" stage that replaces both matrix and grains.

Silica

Silicification is minor, usually less than 5 percent, but occurs throughout the carbonate sequence. Silica minerals can be divided into three fabrics or textural (crystal structure) types: authigenic quartz, chalcedony, and chert. Authigenic quartz crystals range from 0.2 to 0.5

FIGURE 29

PHOTOMICROGRAPH OF PSEUDOSPAR (P), SOME MICROSPAR (M) EXISTS
(cross-polarized light; bar for scale is 0.5 millimeters long)

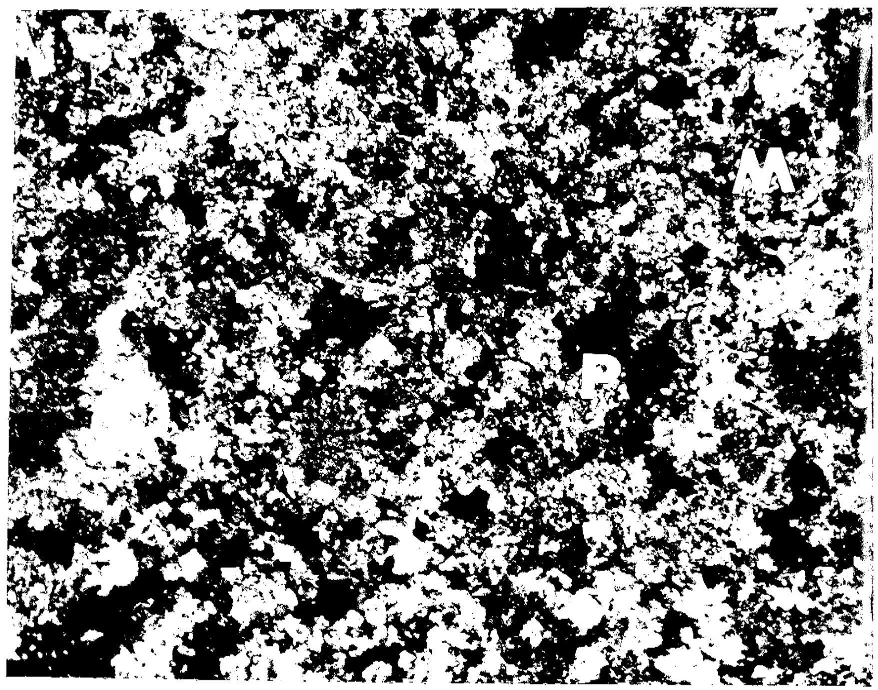


Figure 29

millimeters. Evidence for an authigenic origin includes euhedral crystal form, carbonate inclusions (within quartz crystals), and cross-cutting relations between crystal boundaries and host rock fabrics. Authigenic quartz commonly replaces matrix, but occasionally occurs within phylloid algae and molluscs. On the other hand fibrous chalcedony (if present) is usually identified within skeletal grains. Skeletal grains most susceptible to this replacement are Syringopora sp., fusulinids, brachiopods, and bryozoans. Chert or polycrystalline microquartz, the third fabric association commonly identified, occurs exclusively in skeletal grains, mainly crinoids.

Pyrite

Although pyrite is present throughout the carbonate sequence, Facies 1 and 4 contain the greatest abundance of pyrite (up to 7 percent). Pyrite varies in size; it is identified by its opaque nature and cubic crystal form. Authigenic pyrite is generally recognized within matrix, but disseminated, euhedral crystals exist within brachiopods, bryozoans, and drusy textured cements.

Feldspar

Authigenic feldspar rarely accounts for more than 2 or 3 percent of the rock. Differentiation between authigenic feldspar and authigenic quartz can be difficult; both exhibit euhedral crystal terminations, carbonate inclusions, and cross-cutting relationships. Authigenic feldspars, unlike authigenic quartz, are smaller (average 0.2 millimeters), display twins, and have different crystal shapes.

ENVIRONMENTS OF DEPOSITION

Diagnosis of Environmental Factors

Carbonaceous Shales

Carbonaceous shales occur because an insufficient concentration of dissolved oxygen reaches the substrate to decompose accumulating, organic material (Tucker, 1981). The amount of oxygen available to the seafloor or substrate is largely dependent on water circulation (Flügel, 1978), and depending upon the degree of water circulation, a substrate may be oxygen-deficient or totally anoxic (Tucker, 1981). Within an oxygen-deficient environment most organic matter is preserved, but surficial sediments could support benthic epifaunae, although of low diversity. An anoxic substrate liberates hydrogen-sulfide into the water, preventing inhabitation by benthic organisms; at the present time anoxic or euxinic conditions occur within the Black Sea.

Field studies from the carbonaceous shales indicate pellet-rich rocks lacking observable biota, but thin-section analysis (of these shales) reveals an abundance of ostracodes. The ostracodes are generally small and disarticulated (Figure 30), but articulated tests exist. Ostracodes, observed from modern habitats, are usually benthic epifaunae (Dodd and Stanton, 1981). In addition, small calcareous foraminifers exist within the carbonaceous shales. Thus, the impoverished benthos occurring within the carbonaceous shales suggests reduced water circulation within a restricted (oxygen-deficient) environment rather than poor water circulation in an euxinic environment.

Carbonaceous shales of Virgilian age occurring in the San Andres Mountains result from deposition within shallow, deltaic/brackish-water

FIGURE 30

PHOTOMICROGRAPH OF SMALL, DISARTICULATED OSTRACODES (O)
WITHIN THE CARBONACEOUS SHALE
(plane-polarized light; bar for scale is 1 millimeter long)

Figure 30

environments (Kottlowski and others, 1956). Deltaic environments are generally divided into two facies; the delta plain, characterized by extensive lowland areas which comprise distributary channels and interdistributary bays, and the prodelta or delta front, areas where sediment laden fluvial currents (distributary channels) enter the basin and are dispersed while interacting with marine processes (Elliott, 1978).

Fine to very coarse-grained sandstones, located beneath Section 2 within the carbonaceous shales, were deposited in a high-energy environment. These sandstones were either deposited within a distributary channel associated with the delta plain facies or as a mass-gravity transport of sediment (turbidity current) within the prodelta facies. Field observations and thin-section analysis eliminates the possibility of allochthonous deposition within the prodelta; these sandstones are well-sorted and thin-bedded, lack intergranular clay matrix, are not vertically extensive, lack pelagic or normal marine fauna, and exhibit and upward increase in grain size.

The carbonaceous shales (located above and below the carbonates under investigation) lack fossilized plant debris (Kottlowski and others, 1956). Plant debris may not occur within these carbonaceous shales for the following reasons: 1) arid paleoclimatic conditions were unfavorable for supporting plant life and/or 2) deposition of these black shales took place in saline waters. It is generally recognized that deposition throughout much of the United States during Late Pennsylvanian occurred within humid, tropical to subtropical environments (Wilson, 1975; Heckel, 1980).

Bryozoan-Crinoidal Wackestone/Packstone Facies

The occurrence of phosphate nodules within the lowermost carbonate bed represents a transition between carbonaceous shale and carbonate deposition. Assuming the phosphate nodules have not undergone extensive transportation, their presence within the basal carbonate bed suggests the following: upwelling of nutrient-rich water, sediments rich in organic detritus, low concentrations of dissolved oxygen, and reduced rates of sedimentation (Manheim and others, 1975). Originally, phosphates were thought to precipitate directly from seawater, but recent workers (Manheim and others, 1975; Birch, 1979) proposed a diagenetic replacement just below the sediment-water interface. According to Birch (1979), decomposition of organic matter in the sediment releases phosphate, which is precipitated in pellets, skeletal grains, and lime mud eventually forming nodular phosphate.

Although the basal carbonate bed within the bryozoan-crinoidal wackestones and packstones (Facies 1) contains intergranular carbonate matrix, the occurrence of grain-supported bioclasts (fragmented and abraded) and claystone clasts indicates periodic, vigorous currents. Above the basal carbonates, mud-supported and non-abraded skeletal grains occur which imply a low-energy depositional environment.

Phylloid algae, considered ancestors of modern red (corallinacean) and green (codiacean) algae, occur within Facies 1. Allochthonous deposition of phylloid algae has been discounted because long (several millimeters), non-abraded thalli occur in this lithofacies. Presumably, phylloid algae were capable of photosynthesis restricting their occurrence to shallow water (photic zone). Phylloid algal facies (Heckel, 1969; Toomey and others, 1973 and 1977; Welch, 1977; Flügel, 1978) are located along inner shelf regions, occasionally from the outer shelf.

Lower biotic diversity is apparent in the basal carbonate beds. Within this interval transportation and sorting of the bioclasts could explain the reduction in diversity, however, it is possible that these carbonate grains underwent very minor transportation. In this case reduced diversity values could be explained by stressful environmental conditions. The occurrence of phosphate within the basal carbonates probably indicates reduced concentrations of dissolved oxygen. Oxygen levels may have been low enough to inhibit growth of some organisms. Above the basal carbonates (within Facies 1), mean biotic diversity is essentially equivalent to values observed from Facies 2 and 3 (Table 3). The main criterion used to support near-normal marine salinity involves eurytopic organisms. Eurytopic diversity values are similar within Facies 1, 2, 3, and 4, but eurytopic abundance varies drastically over this same interval (Table 4; Figures 26 and 27). Within Facies 1, eurytopic organisms only account for 25 percent of all biotic constituents.

Dissolved sulfide and iron along with a reducing environment are prerequisites for the formation of pyrite; these requirements can be explained by a pre-lithification anaerobic decay of organic matter below the sediment-water interface (Berner, 1970), overlying waters are not necessarily poorly oxygenated or inhospitable to life. On the other hand, it is possible to precipitate pyrite on or even above the sediment-water interface; this phenomenon occurs within anoxic environments of the Black Sea. For two reasons, the occurrence of a pre-lithification (but diagenetic) model is suspected for the Virgilian carbonates. Within the carbonates under investigation: 1) pyrite generally occurs in rocks containing an abundant and diverse assemblage of benthic organisms and 2) disseminated, euhedral pyrite crystals are commonly observed replacing skeletal grains.

In oxidizing environments most organic debris decays to carbon dioxide and water before burial, but some organic material is more resistant to decomposition and persists long enough to be buried (Berner, 1970). Under this condition localized areas of undecayed organic matter can accumulate within the lime mud. Once buried, the carbon compounds are protected from oxidation and undergo anaerobic decay. During anaerobic conditions, sulfur within the organic matter converts to hydrogen sulfide, which reacts with iron ions eventually forming pyrite (Berner, 1970).

Pyrite occurs in greatest abundance near the carbonaceous shales (lowermost 4 meters and uppermost 3 meters of the carbonate sequence). Rapid carbonate sedimentation, incorporating an abundance of unoxidized organic matter, and migration of hydrogen sulfide, formed within nearby carbonaceous shales, probably are not major factors contributing to the abundance of pyrite within the carbonate sequence (Facies 1, 2, and 4). Although Facies 1 is dark gray (possibly indicative of unoxidized organic debris) and exhibits fetid odors (perhaps related to hydrogen sulfide), Facies 2 and 4 did not appear dark or exhibit fetid odors. In general, most carbonates are deficient in iron (Berner, 1970). As a result, carbonate muds, such as those in Florida Bay, may be rich in organic matter and hydrogen sulfide, but lack the iron to produce pyrite (Berner, 1970). Thus, migration of iron ions supplied by detrital minerals (mainly within carbonaceous shales) could account for the stratigraphic distribution of pyrite. Although carbonates may acquire iron from organic sources, it is largely unreactive with sulfide ions (Berner, 1970).

Carbonate beds within Facies 1 are separated by thin shale partings. These partings result either from near-cessation of lime mud deposition for long periods of time while the normal, slow influx of terrigenous mud continued or represent a rapid influx of terrigenous mud. No evidence was obtained from the carbonate sequence to support either hypothesis.

Phylloid Algal Wackestone/Packstone Facies

Phylloid algal wackestones and packstones (Facies 2) are similar to much of the previously described lithofacies. Both lithofacies exhibit low-energy depositional environments (excluding the basal carbonates of Facies 1), deposition within the photic zone, and near-normal marine salinities (eurytopic abundance averages 15 percent of the total biotic abundance within Facies 2). Also, the occurrence of Zoophycos, within this interval (Facies 2), may support a shallow-marine environment of deposition. Zoophycos occurs where sediments are poorly-sorted (Heckel, 1972), and according to Plicka (1968), these trace fossils are formed by annelid worms in shallow-water environments of rapid deposition.

The vast majority of chert observed within the carbonate sequence is nodular chert, which may coalesce to form near-continuous layers resembling bedded cherts. Chert, although ubiquitous throughout the carbonate sequence, is being discussed within the phylloid algal wackestones and packstones; thin-sections have been examined from chert nodules occurring within this lithofacies.

Although recent workers have established a replacement or diagenetic model for the occurrence of nodular chert, controversy can exist concerning an origin for the silica. Detrital quartz, clay weathering, extrabasinal sources, radiolarians, and volcanic sources (submarine and subaerial) have been proposed as possible sources for silica within chert nodules. In Mississippian limestones of New Mexico (Sacramento Mountains), Meyers (1977) concluded that the major factor controlling chert distribution was indigenous silica, mainly from siliceous sponge spicules.

Within nodular cherts occurring from Facies 2, originally calcareous grains (skeletal debris) are preserved in silica. In addition, intergranular regions, presumably once filled with micrite, display microcrystalline quartz, whereas silica replacement of skeletal grains is commonly coarser-grained. Field observations and thin-section analysis of chert nodules (within the carbonate sequence), do not allow discrimination among the previously proposed sources for silica.

Grainstone and Poorly Washed Grainstone Facies

Cross-bedded, broken, and abraded carbonate grains occur within the grainstones of Facies 3 and indicate a high-energy environment of deposition, but a possible exception exists to this high-energy environment within the uppermost portion of this lithofacies. This upper horizon contains an abundance of aggregate grains, which generally form in shallow-water environments of restricted circulation (Winland and others, 1974). The occurrence of superficial ooids and a cephalopod debris bed within the aggregate grain grainstones may imply periodic changes in water circulation. An absence of matrix within limestones composed of aggregate grains is probably due to non-sedimentation of original carbonate mud (Flügel, 1978).

Because phylloid algae may have been transported into the photic zone (within Facies 3), environmental interpretations based on the occurrence of phylloid algae will not be attempted. However, aggregate grains, superficial ooids, bahamite peloids, and micrite envelopes (around skeletal grains), which occur throughout Facies 3, are usually formed and deposited in shallow-marine environments (Flügel, 1978). Bahamite peloids result from extensive micritization of skeletal grains by boring organisms (Beales, 1958). Beales (1958) determined a similarity in composition and possibly origin between peloid-rich Paleozoic limestones and peloidal carbonates of the Great Bahama Bank; the ancient peloids were termed bahamite peloids. Beales (1958) concluded that peloids found in association with progressive micritization and cortoid development (micritic envelopes) should be an indication of bahamite peloids. Swinchatt, 1969; Perkins and Halsey, 1971; and Kobluk and Risk, 1977 proposed the use of micritized, carbonate bioclasts as paleobathymetric indicators of water depth, usually postulating water depths less than 15-20 meters. There are inherent dangers associated with this interpretation. Potential problems involved with the use of micrite envelopes and bahamite peloids as indicators of water depth include: 1) not all boring organisms are dependent upon light and hence, depth (i.e., fungi) and 2) micritization by organisms may not be the only process involved in the formation of micritized grains.

Another line of reasoning supporting a shallow-marine depositional environment within Facies 3 involves the presence of *in situ* phylloid algae within Facies 2 and 4.

Mechanically transported bioclasts occur within Facies 3, and thus, paleoenvironmental interpretations based on fossil abundance and diversity will not be attempted.

Wackestone to in part Packstone Facies

This lithofacies (Facies 4) generally consists of non-winnowed biomicrites/biomicrudites and fine-grained clastic intervals (calcareous shales) indicative of a low-energy depositional environment. Apterrinella sp. packstones are a slight exception to this low-energy environment. Within these packstones the occurrence of intergranular sparry cement, superficial ooids, and non-abraded skeletal grains indicate a degree of agitation sufficient to partially rework calcareous mud and suspend the ooid nuclei, but insufficient to abrade skeletal grains. Another exception to the low-energy depositional environment includes the high abundance low diversity debris beds, containing fusulinids, molluscs, or brachiopods. These beds occur within the upper portion of Facies 4 and probably result from storm sedimentation. Dense, shell accumulations may form by storm action in two ways. If water turbulence is not too great, calcareous muds can be winnowed out, leaving behind a lag deposit of (essentially) autochthonous shells. Under conditions of greater water energy, skeletal grains may be transported and deposited as allochthonous accumulations. For several reasons these debris beds are more-likely the result of allochthonous sedimentation: 1) broken and abraded fossils are common (fusulinids are rarely fragmented and abraded, but other skeletal grains contained within the fusulinid debris beds such as agglutinated forams and phylloid algae exhibit abrasion), 2) most shells and tests are current lineated, 3) bivalves are disarticulated, 4) disarticulated valves are commonly observed concave-down, and 5) locally, lime mud intraclasts occur with skeletal debris.

The gradational micrite microfabric (pelletal to clotted to dense) observed throughout Facies 4 was discussed by Ginsburg (1957). He described how recent pelletal muds in Florida Bay lost most of their characteristics and became virtually indistinguishable from non-pelletal muds a few centimeters below the sediment-water interface. Based on observable fabrics and modern analogs, much of the micrite within Facies 4 resulted from bioturbation and (perhaps) compaction of pellet-rich carbonate mud. "Obvious" pellets only occur within flat-laminated horizons containing an abundance of Tubiphytes sp. and ostracodes. Ostracodes, prolific producers of fecal pellets in modern environments, are thought to be responsible for the pellets observed from flat-laminated horizons. These fecal pellets occur within a micrite matrix (some intergranular spar exists) and are suspected of forming in a low-energy depositional environment, although very weak currents may have lead to a slight reworking of calcareous mud.

The occurrence of phylloid algae throughout much of Facies 4 along with rarely observed algal fragments of Epimastopora sp. and Foliophycus sp. offer evidence supporting shallow-water deposition within the photic zone. In addition, aggregate grains, superficial ooids, bahamite peloids, and micrite envelopes occur within this lithofacies (usually implying shallow-marine depositional environments).

Although Facies 4 contains the most diverse assemblage of marine organisms, a more restricted depositional environment is being postulated (compared to previously discussed lithofacies). The biota within Facies 4 is largely eurytopic. In fact, eurytopic abundance averages nearly 60 percent and commonly exceeds 80 percent of the total biota. The presence of calcispheres, which have been described from restricted lagoons (Flügel, 1978), and an upward increase in foraminifers, ostracodes, and other eurytopic organisms suggests that this lithofacies was deposited in progressively shallower and more restricted marine waters. The flat-laminated and pelletal carbonates (located near the top of Facies 4) represent the most restricted environment of deposition. This horizon exhibits low biotic diversity and small size of biotic components relative to adjacent "less restricted" marine environments. In addition, biotic abundance of the few organisms present is high.

Dolomite, although ubiquitous, occurs in greatest abundance within the uppermost 2 meters of the carbonate sequence and is a result of replacement, not primary deposition. Primary dolomite is very fine-grained (less than 0.01 millimeters; Folk, 1980), whereas, the carbonates under investigation exhibit dolomite averaging 0.05 millimeters in diameter. The seepage and evaporative reflux models for the formation of secondary dolomite fail to explain dolomitization within this carbonate sequence for two reasons: 1) distribution of dolomite within the carbonate sequence is too sporadic and 2) inferred paleoenvironments of these proposed models probably did not exist within the carbonate sequence. Instead it seems more-likely that dolomite precipitated from magnesium-rich pore waters with reduced salinity (Folk, 1980).

Deep-Water Carbonaceous Shales

Although a shallow-water depositional environment has been postulated for carbonaceous shale deposition (within Virgilian strata of Rhodes Canyon), a deep-water model may be equally applicable to these shales. One model which might apply to the carbonaceous shales under investigation was discussed by Heckel (1972 and 1980). According to Heckel (1980), environments responsible for carbonaceous shale-carbonate deposition include a simple transgressive-regressive sequence representing one long-term oscillation of sea level. Deposition of the carbonaceous shale occurs during the furthest landward advancement of the strandline. It is during this transgression that water depths become sufficiently deep to develop a thermocline strong enough to prevent oxygenation of the substrate by wind-driven vertical circulation (Heckel, 1972). Deposits formed during a regression of the sea overlie the transgressive carbonaceous shales (Heckel, 1980). These regressive sequences generally result in the deposition of silty-sandy detrital sediments and/or marine carbonates, assuming the water becomes shallow enough to destroy the thermocline. A transgression will begin another cycle of similar lithologies.

For several reasons I believe a deep-water model probably is not responsible for deposition of the carbonaceous shales which border the carbonate sequence under investigation. The upper portion of the carbonate sequence was deposited in a very shallow, restricted marine environment. Above the uppermost carbonate bed, carbonaceous shales occur without an apparent transition to a deeper-marine environment. The fine to coarse-grained sandstones which occur just beneath the carbonates of Section 2 exhibit inverse graded-bedding, are well-sorted and thin bedded, lack clay matrix, are not vertically extensive, and lack pelagic or normal marine biotas. Collectively, this information seems to discount a submarine mass-gravity transport of sand grains. An investigation of lithologies which exists within the San Andres

Mountains was conducted by Kottlowski and others (1956) who concluded that Virgilian sediments were deposited within shallow-marine to brackish/deltaic waters.

Proposed Model for Carbonate Sedimentation

1. Carbonaceous shales (located beneath the carbonate sequence) were deposited in a brackish-water environment of the delta plain facies. The fine to coarse sandstones resulted from deposition within a distributary channel, whereas, the disaerobic carbonaceous shales formed within adjacent interdistributary bays.

2. The basal carbonates of Facies 1 were deposited during a transgression. Marine waters covered the previously deposited carbonaceous shales and displaced the deltaic environment landward.

3. Facies 1 and 2 were deposited within the photic zone, below normal wave base, and in normal or near-normal marine waters (Figure 31-a).

4. Deposition within the basal portion of Facies 3 occurred near the lower limit of normal wave base; marine waters became progressively shallower throughout the remainder of Facies 3. Within the uppermost portion of Facies 3 very shallow marine waters existed, but much of the wave and current action had been reduced; such an environment could occur along the trailing edge of a prograding shoal (Figure 31-b).

The lower three facies of the carbonate sequence were deposited within an open-marine, subtidal, depositional environment where carbonate sedimentation occurred more rapidly than basinal subsidence. Use of the term "subtidal" does not imply that tidal forces were actively influencing carbonate sedimentation. In fact, no evidence exists (within the carbonates under investigation) for the occurrence of

FIGURE 31

SCHEMATIC PROFILES DRAWN PERPENDICULAR TO DEPOSITIONAL STRIKES SHOWING VARIATION IN BARRIER (SHOAL) POSITION

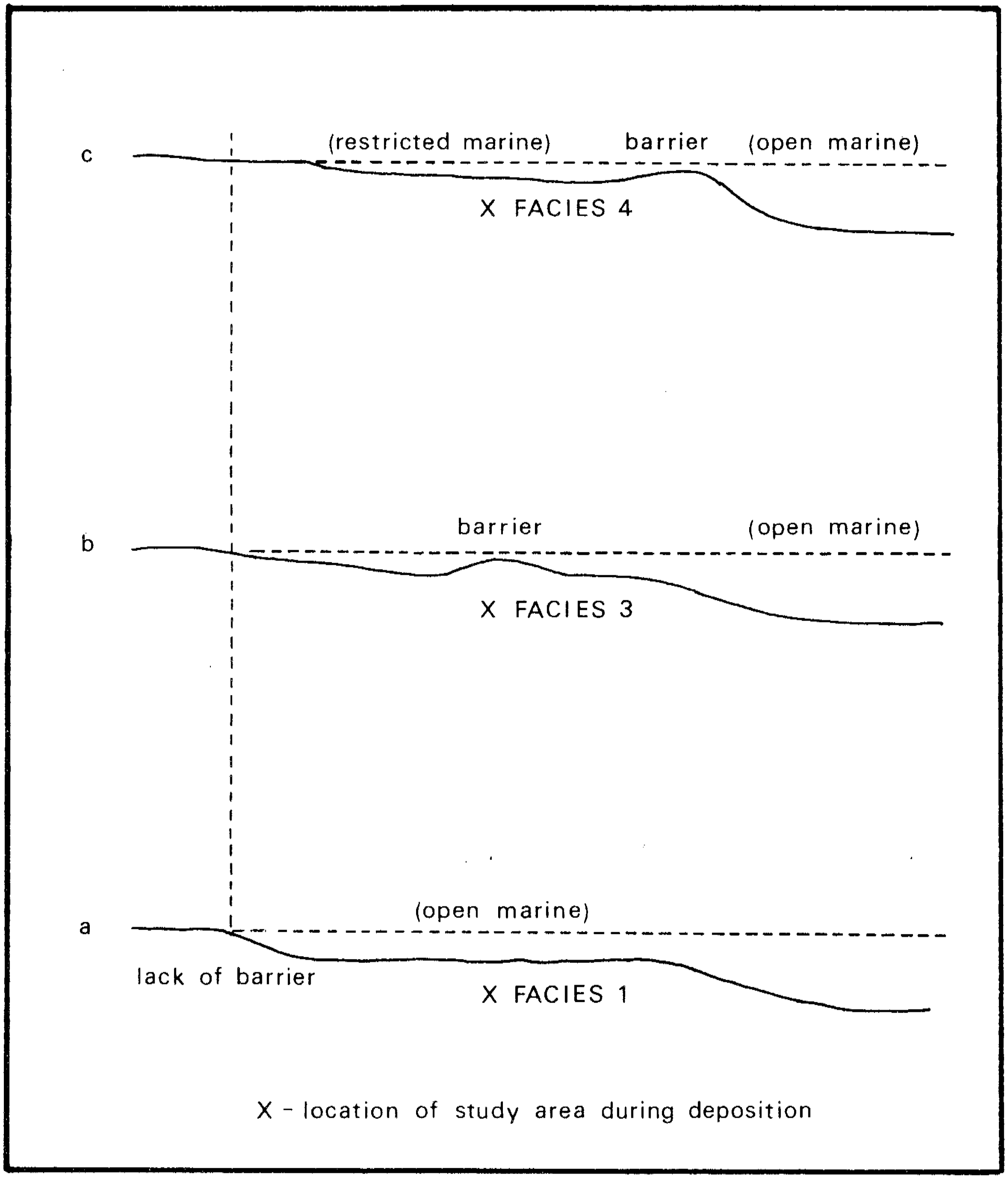

c
(restricted marine)
barrier
(open marine)
X FACIES 4
b
barrier
(open marine)
X FACIES 3
a
(open marine)
lack of barrier
X FACIES 1
X - location of study area during deposition

Figure 31

tides; bimodal-bipolar paleocurrent directions, flaser-bedding, and herring-bone cross-beds were not observed.

5. Carbonates within Facies 4 were deposited in a restricted environment (Figure 31-c). This back-barrier lagoonal environment was located landward from the prograding shoal sequence (Facies 1-3). Carbonate sedimentation within Facies 4 was only slightly greater than basinal subsidence which resulted in progressively shallower and more restricted marine waters. As progradation of the shoaling sequence continued, toward the center of the Orogrande basin, carbonates within the upper portion of Facies 4 became further removed from the effects of normal marine waters.

6. The carbonaceous shales, located above Facies 4, were not examined in much detail, but these shales probably represent a return to deltaic sedimentation.

PETROLEUM POSSIBILITIES

Effective porosity is one of the most important aspects controlling the development of a petroleum reservoir. In reservoir rocks pore spaces must be interconnected to permit movement and extraction of fluids. The formation of porosity within carbonate rocks is complex, many interrelated factors are involved. Pore development may be associated with deposition and diagenesis in the original depositional environment and/or related to succeeding phases of diagenesis (i.e., burial and exposure)(Aquitaine and others, 1982).

Depositional Environments and Reservoir Development

According to Aquitaine and others (1982), an initial pore network in a carbonate sediment depends largely on high-energy depositional environments. In addition, *in situ* growth of organisms can contribute markedly to primary porosity; for two reasons *Syringopora* sp., a frame-building organism, did not contribute substantially to initial carbonate porosity: 1) *in situ* *Syringopora* sp. occurred only in isolated regions within the carbonate sequence and 2) the framework pores within these boundstones were usually filled with fine-grained matrix.

Within the grainstones of Facies 3, a high-energy depositional environment resulted in the formation of interparticle porosity. Although interparticle porosity probably existed throughout much of eogenesis, subsequent cementation filled most of these primary pores. Other types of primary porosity (such as intraparticle and shelter porosity) occurred within the carbonates under investigation. These pore spaces are rarely preserved.

Diagenesis and Reservoir Development

Moldic and fracture porosity was ubiquitous throughout the carbonate sequence but filling of these void spaces by blocky textured cements drastically reduced effective porosity of these rocks. The greatest potential for the accumulation of petroleum may exist within the upper portion of the carbonate sequence where vuggy porosity exceeds 20 percent of the rock. Although intercrystalline porosity is not readily observed from this horizon, it may be present, especially within the dolomitized limestones.

Conclusions

This investigation suggests that major accumulations of oil and gas are unlikely, but the possibility does exist for profitable extraction of hydrocarbons from the carbonate sequence within the subsurface of the Tularosa Basin. Carbonaceous shales, located above and below the carbonate sequence, could serve as source and cap rocks.

Based on the data contained within this study, potential zones of high porosity in the subsurface can be predicted for the carbonates under investigation. The ability to predict high porosity stratigraphic zones exists.

SUGGESTED FUTURE WORK

An environmental analysis of the upper limestone sequence exposed in Rhodes Canyon (the lower carbonate sequence was the focus of this study), a detailed investigation of the carbonaceous shales, and an increase in the distance between measured sections may reveal a greater understanding of Virgilian paleoenvironments in Rhodes Canyon.

Although many geologic studies could be conducted within the San Andres Mountains, particularly exciting investigations to a sedimentary petrologist might include the following:

1. Depositional and/or post-depositional studies involving Virgilian bioherms of Hembrillo Canyon.

2. Integration of subsurface data and field mapping to derive detailed lateral and vertical facies relations of Virgilian strata within the Tularosa Basin and San Andres Mountains.

3. Environmental analysis of Virgilian strata from the southern portion of the San Andres Mountains where fine to coarse clastics, carbonates, and evaporites occur.

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APPENDICES

APPENDIX A

GLOSSARY OF PERTINENT GEOLOGIC TERMS NOT DEFINED IN THE TEXT

APPENDIX A

GLOSSARY

Argillaceous - Applied to all rocks or substances composed of clay, or having a notable proportion of clay in their composition (less than 50 percent clay if used as a modifier to rock name).

Bedding - Classification is modified after McKee and Weir (1953):
Thick-bedded - 1.2-0.6 meters (4-2 feet)
Medium-bedded - approximately 0.6 meters
Thin-bedded - 0.6 - .05 meters (2 feet-2 inches)

Benthic - Of, related to, or occurring at the bottom of a body of water; usually pertains to marine bottom-dwelling forms of life.

Bioclasts - Result from biological, mechanical, and chemical destruction of skeletal grains.

Biotic Abundance - The number of individuals per unit volume or area in a rock belonging to a single taxon.

Biotic diversity - The number of different kinds of organisms or taxa present in a sample.

Clay - This term has three implications: a natural material with plastic properties, an essential composition of particles of very fine size grades, and an essential composition of crystalline fragments of minerals that are essentially hydrous aluminum silicates or occasionally hydrous magnesium silicates (Trowbridge, 1962).

Cross-bedding - Beds characterized by included minor beds that are oblique and inclined to the main stratification (Kottlowski and others, 1956).

Eogenesis - The time interval between final deposition and burial below the depth of significant influence by processes that either operate from the surface or depend upon proximity to the surface (Bathurst, 1975).

Epifauna - An organism that lives on or above the seafloor.

Eurytopic - Environments that deviate or fluctuate from normal marine conditions (salinity is usually the most important physical factor of the environments).

Friable - Loosely cemented rocks that crumble or break easily into individual grains (Kottlowski and others, 1956).

Grain-supported - Refers to the fabric of a rock in which the grains are in contact with one another (Dunham, 1962).

Grains (allochems) - Materials that have formed by chemical or biochemical precipitation within the basin of deposition, and for the most part have undergone transportation (i.e., ooids, skeletal particles, pellets, etc.) (Folk, 1959).

Lithographic Limestone - A very fine-grained, crystalline limestone.

Missourian - Upper Middle Pennsylvanian.

Mud-supported - Refers to the fabric of a mudstone in which the grains are separated from one another by a micrite matrix (Dunham, 1962).

Primary porosity - Forms as a result of processes of sedimentation.

Roundness - Angular, subangular, subrounded, rounded, to well rounded; based on visual estimation charts.

Secondary porosity - Pore spaces that form in a sediment or rock after final deposition (during diagenesis).

Shale - A laminated sediment in which the constituent particles are predominantly of the clay grade (Trowbridge, 1962).

Shale partings - Thin shale laminae between limestone beds.

Sorting - Based upon the central 68 percent of particles:

very well-sorted	one size grade
well-sorted	two size grades
moderately-sorted	three size grades
poorly-sorted	four size grades
very poorly-sorted	five or more size grades

Spar or sparry calcite - Generally refers to pore-filling or precipitated cement.

Stenotopic - Refers to a narrow range of adaptability to changes in environmental conditions.

Stromatolitic - A laminated, but otherwise structureless body generally formed by blue-green algae.

Virgilian - Upper Pennsylvanian.

Zooecium - Skeleton of an individual bryozoan animal.

APPENDIX B

DESCRIPTIONS OF MEASURED SECTIONS

APPENDIX B

Section 1

SE$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 14 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
1-1	0.8	0.8	Wackestone; abraded crinoids, phylloid algae, fusulinids, and bryozoans; fresh fracture dark gray, weathered surface light brown; nodular bedding with shale interbeds 5 centimeters thick; silicified patches
1-2	0.5	1.3	Mudstone; phylloid algae and fusulinids; fresh fracture dark gray; thin-bedded; spar filled voids
1-3	0.4	1.7	Mudstone; whole shell brachiopods and fenestrate bryozoans; thin-bedded with shale partings
1-4	1.0	2.7	Mudstone; phylloid algae; fresh fracture dark gray, weathered surface brown; nodular-wavy beds; shale partings becoming less abundant
2-1	0.6	3.3	Mudstone; bryozoans and phylloid algae; fresh fracture light gray; thin-bedded
2-2	0.1	3.4	Wackestone; phylloid algae; thin-bedded; nodular chert
2-3	0.4	3.8	Wackestone to packstone; phylloid algae, brachiopods, gastropods, and crinoids; fresh fracture medium gray, weathered surface gray-brown; thin-bedded; chert nodules
2-4	0.7	4.5	Packstone, grainstone, and *Syringopora* sp. boundstone; phylloid algae, crinoids, gastropods, bryozoans, fusulinids, horned corals, and brachiopods; discontinuous bedding; chert nodules

APPENDIX B

Section 1 (continued)

SE¼ SE¼ Sec. 14 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
2-5	0.3	4.8	Mudstone; barren; fresh fracture dark gray, weathered surface drab to dark gray with brown silicified zones; thin-bedded; chert nodules; shale partings
3-1	0.2	5.0	Mudstone; barren; thin-bedded
3-2	1.9	6.9	Wackestone to packstone; straight and coiled cephalopods, brachiopods, crinoids, and gastropods; fresh fractures drab gray, weathered surface tan-brown exhibiting extensive solution pitting; discontinuous bedding surfaces; elongate chert nodules; spar filled voids
3-3	1.3	8.2	Grainstone; crinoids, fusulinids, bryozoans, brachiopods, gastropods; cephalopods (uppermost bedding surface), and phylloid algae; thin-bedded; fine to coarse-grained shell hash; horizontal and vertical burrows; cross-bedded
4-1	0.6	8.8	Shale; calcareous and silty; weathered surface pale green; slope former
4-2	0.2	9.0	Wackestone; <u>Syringopora</u> sp., fusulinids, phylloid algae, and molluscs; fresh fracture light gray, weathered surface drab gray; thin-bedded; <u>Syringopora</u> sp. silicified
4-3	0.3	9.3	Shale; partly covered; calcareous

APPENDIX B

Section 1 (continued)

SE¼ SE¼ Sec. 14 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
4-4	0.6	9.9	Packstone in part wackestone and grainstone; gastropods, fusulinids, phylloid algae, and Syringopora sp.; fresh fracture dark gray, weathered surface light gray; thin-bedded; chert nodules
4-5	1.5	11.4	Covered interval probably calcareous shale
5-1	2.7	14.1	Wackestone in part mudstone and packstone; phylloid algae, large gastropods, straight-shelled cephalopods, fusulinids, and brachiopods; thick-bedded
5-2	0.3	14.4	Covered interval probably calcareous shale
5-3	0.9	15.3	Wackestone to packstone; bryozoans, fusulinids, crinoids, small brachiopods, and phylloid algae; fresh fracture light gray, weathered surface light to drab gray; thick-bedded; oncolitic horizon near base
5-4	0.3	15.6	Wackestone to packstone; phylloid algae, fusulinids, and Syringopora sp.; much silicification, 1.3 centimeters chert bed is locally continuous
5-5	0.3	15.9	Wackestone; crinoids, brachiopods, and phylloid algae
5-6	0.9	16.8	Grainstone; fresh fracture light gray, weathered surface drab gray; thick bedded; large chert nodules; peloidal

APPENDIX B

Section 1 (continued)

SE¼ SE¼ Sec. 14 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
5-7	1.1	17.9	Packstone to in part grainstone; phylloid algae, brachiopods, fusulinids, and gastropods; thick bedded; basal portion peloidal
6-1	2.2	20.1	Wackestone to packstone in part mudstone; brachiopods, crinoids, molluscs, and fusulinids; weathered surface appears mottled; thin-bedded; some silicification and perhaps dolomitization
6-2	1.1	21.2	Mudstone to wackestone; possible blue-green algal laminations; mottled appearance; thin-bedded
6-3	1.1	22.3	Covered interval possibly calcareous shale; slope forming
6-4	0.4	22.7	Mudstone; barren; fresh and weathered surface light gray
6-5	0.7	23.4	Wackestone; *Syringopora* sp., crinoids, brachiopods, and gastropods; thin-bedded; pyrite crystals oxidized
6-6	0.5	23.9	Mudstone; barren; thin-bedded; some intraclasts
6-7	2.3	26.2	Packstone and grainstone (debris beds); fusulinids, gastropods, pelecypods, crinoids, phylloid algae; fresh fracture light gray, weathered surface dark gray; thin-bedded; some intraclasts; flat laminated horizon (encrustations)

APPENDIX B

Section 2

SW¼ NE¼ Sec. 14 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
1-1	1.1	1.1	Mudstone; crinoids and phylloid algae; fresh fracture dark gray, weathered surface dark gray; thin-bedded; at base shale beds 5.1 centimeters thick grading into shale partings
1-2	1.1	2.2	Wackestone to packstone; fenestrate bryozoans, fusulinids, phylloid algae, and crinoids; thin-bedded; chert nodules
1-3	0.6	2.8	Mudstone; brachiopods; fresh fracture dark gray, weathered surface tan-brown; thin-bedded; upper bedding surface mottled (bioturbation)
2-1	0.3	3.1	Mudstone; stoney and fenestrate bryozoans and brachiopods; thin-bedded
2-2	0.5	3.6	Mudstone; barren; thin-bedded; void fill spar
2-3	0.3	3.9	Mudstone to wackestone; phylloid algae, brachiopods, and crinoids; fresh fracture medium gray, weathered surface light brown; thin-bedded
3-1	1.2	5.1	Wackestone to in part packstone; phylloid algae, crinoids, and brachiopods; discontinuous bedding; chert nodules
3-2	1.2	6.3	Wackestone and *Syringopora* sp. boundstone; phylloid algae, crinoids, and brachiopods; weathered surface drab gray; discontinuous bedding; chert nodules

APPENDIX B

Section 2 (continued)

SW$\frac{1}{4}$ NE$\frac{1}{4}$ Sec. 14 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness (Meters)	Description
3-3	0.7	7.0	Mudstone; phylloid algae; discontinuous bedding; chert nodules
3-4	1.2	8.2	Grainstone; crinoids, fusulinids, and brachiopods; fresh fracture light gray, weathered surface tan-brown; thin-bedded; fine to coarse-grained shell hash; cephalopod debris bed located on uppermost bedding surface
4-1	1.8	10.0	Covered interval probably calcareous shale; slope former
4-2	0.6	10.6	Wackestone to packstone; phylloid algae, fusulinids, crinoids, and molluscs; fresh fracture light gray, weathered surface drab gray; thin-bedded
4-3	1.2	11.8	Shale; calcareous, perhaps silty; weathered surface greenish
5-1	0.6	12.4	Wackestone to packstone; phylloid algae, molluscs, and perhaps ostracodes; medium-bedded
5-2	1.2	13.6	Wackestone isolated packstone; phylloid algae, crinoids, molluscs, and brachiopods; weathered surface light gray; thick-bedded, discontinuous at base
5-3	0.3	13.9	Mudstone to wackestone; crinoids, brachiopods, large gastropods, and straight-shelled cephalopods; uppermost bedding surface oncolitic
5-4	0.8	14.7	Covered interval probably calcareous shale

APPENDIX B

Section 2 (continued)

SW$\frac{1}{4}$ NE$\frac{1}{4}$ Sec. 14 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
5-5	0.5	15.2	Wackestone in part mudstone; brachiopods, phylloid algae, crinoids, fusulinids, and molluscs; weathered surface drab gray; thick-bedded; chert nodules; possibly oncolitic
5-6	1.2	16.4	Grainstone and packstone; phylloid algae, fusulinids, and molluscs; thick-bedded; chert nodules
5-7	0.8	17.2	Mudstone; barren; fresh fracture light gray; thick-bedded, some discontinuous; weathering of some pyrite crystals
6-1	0.7	17.9	Wackestone; brachiopods, crinoids, and molluscs; weathered surface drab gray to brown; thin-bedded; spar filled voids
6-2	0.9	18.8	Packstone in part wackestone; phylloid algae, fusulinids, crinoids, articulate brachiopod shells, and molluscs; fresh fracture dark gray, weathered surface dark gray; thin-bedded; uppermost bed mottled (bioturbated)
6-3	1.7	20.5	Wackestone; phylloid algae, brachiopods, crinoids, and bryozoans; fresh fracture green-gray, weathered surface dark gray; thin-bedded; thin shale beds
6-4	0.9	21.4	Mudstone; phylloid algae; thin-bedded; chert nodules
6-5	0.5	21.9	Packstone; brachiopods, crinoids, phylloid algae, and molluscs; weathered surface tan-brown; medium-bedded; chert nodules; mottled

APPENDIX B

Section 2 (continued)

SW¼ NE¼ Sec. 14 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
6-6	0.5	22.4	Covered interval probably calcareous shale
6-7	1.1	23.5	Mudstone; phylloid algae; medium-bedded; bioturbated
6-8	0.6	24.1	Covered interval probably calcareous shale
6-9	1.2	25.3	Packstone and grainstone (debris beds); brachiopods (abraded) phylloid algae, fusulinids, molluscs, and a shark's tooth; thin-bedded; mottled; iron stained

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Section 3

NW¼ NW¼ Sec. 23 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
1-1	0.7	0.7	Wackestone; crinoids, gastropods, and bryozoans; fresh fracture dark gray, weathered surface dark gray; nodular-wavy bedded; 5-13 centimeters thick shale beds
1-2	0.4	1.1	Mudstone; crinoids and bryozoans; thin-bedded; shale partings
1-3	0.5	1.6	Wackestone to packstone; fusulinids, stoney and fenestrate bryozoans, and crinoids; weathered surface dark gray; thin-bedded; shale partings
1-4	0.5	2.1	Wackestone; phylloid algae, pelecypods, gastropods, and horn corals; nodular and thin-bedded; isolated shale partings; pyrite crystals

APPENDIX B

Section 3 (continued)

NW¼ NW¼ Sec. 23 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness (Meters)	Description
2-1	0.4	2.5	Wackestone to packstone; phylloid algae, bryozoans, and crinoids; thin-bedded; occasional shale partings
2-2	1.1	3.6	Packstone; phylloid algae and crinoids; fresh fracture drab gray, weathered surface dark gray; thick-bedded
2-3	1.3	4.9	Wackestone; brachiopods and crinoids; medium-bedded
3-1	2.4	7.3	Wackestone in part mudstone; phylloid algae, *Syringopora* sp., and molluscs; fresh fracture dark gray, weathered surface light gray; discontinuous bedding; chert nodules; spar filled shells
3-2	1.8	9.1	Packstone to grainstone; crinoids, phylloid algae, fusulinids, and cephalopods (uppermost bedding surface); fresh fracture dark gray, weathered surface brown; discontinuous bedding; chert nodules; thin mudstone along base
4-1	0.6	9.7	Covered interval probably calcareous shale
4-2	1.3	11.0	Wackestone, packstone, and poorly exposed argillaceous limestone; phylloid algae, brachiopods, and fusulinids; fresh fracture light to drab gray, weathered surface light brown to chalky white; thin-bedded
4-3	1.2	12.2	Shale; calcareous; partly covered; light green-gray; slope

APPENDIX B

Section 3 (continued)

NW$\frac{1}{4}$ NW$\frac{1}{4}$ Sec. 23 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
5-1	0.3	12.5	Wackestone to packstone; small brachiopods, pelecypods, gastropods, and possibly ostracodes; discontinuous bedding
5-2	1.2	13.7	Wackestone in part mudstone; phylloid algae, fusulinids, brachiopods, and crinoids; fresh fracture light gray, weathered surface drab gray; thick-bedded
5-3	0.7	14.4	Wackestone; phylloid algae; thick-bedded; weathered surface extensively pitted; pyrite; iron staining
5-4	0.5	14.9	Wackestone and mudstone; pelecypods, crinoids, brachiopods, and gastropods (3.8-6.4 centimeters in diameter); weathered surface brown; thick-bedded; mottled; possibly some dolomite
5-5	0.8	15.7	Covered interval probably calcareous shale
5-6	2.1	17.8	Mudstone to wackestone; large gastropods, phylloid algae, brachiopods, fusulinids, and crinoids; fresh fracture dark gray, weathered surface dark gray; medium-bedded; chert nodules and bedded chert (1.3 centimeters); mottled; partially intraclastic
5-7	1.4	19.2	Grainstone; brachiopods, bryozoans, phylloid algae, fusulinids, and crinoids; thick-bedded; some silicification; mottled
6-1	1.2	20.4	Packstone in part wackestone; brachiopods, fusulinids, phylloid algae, and bryozoans; thin-bedded; mottled; in part intraclastic

APPENDIX B

Section 3 (continued)

NW¼ NW¼ Sec. 23 T. 13 S. R. 3 E.

Unit No.	Thickness (Meters)	Cummulative Thickness(Meters)	Description
6-2	0.9	21.3	Packstone in part wackestone, grainstone, and *Syringopora* sp. boundstone; crinoids, fusulinids, phylloid algae, and *Syringopora* sp.; weathered surface dark gray; thick-bedded; silicification
6-3	2.8	24.1	Packstone to wackestone; phylloid algae and possibly blue-green algae; fresh fracture light gray, weathered surface dark gray; thin-bedded; mottled; flat-laminations; possibly small ooids; silicified zones
6-4	0.8	24.9	Packstone; crinoids, fusulinids, and phylloid algae; thick-bedded; chert nodules; oncolites; flat-laminations; uppermost bed mottled
6-5	0.8	25.7	Covered interval possibly calcareous shale
6-6	0.7	26.4	Packstone to grainstone (debris beds); brachiopods, fusulinids, crinoids, and molluscs; weathered surface dark gray; thin bedded; uppermost bed mottled
6-7	0.9	27.3	Packstone to grainstone (debris bed); brachiopods, fusulinids, and crinoids; oncolites; thin-bedded

APPENDIX C

POINT COUNT ANALYSIS

APPENDIX C

Section Number	1	1	1	1	1	1	1
Unit Number	1	1	1	1	2	2	2
Meters (from base of unit)	0.0	1.5	2.0	2.3	0.6	1.4	1.6
	Subsequent numbers (%)						
Echinoderms: (total)	16.6	0.3	0.9	2.8	9.3	3.0	3.4
Pelmatozoans	16.6	—	0.9	2.8	9.3	3.0	3.1
Bryozoans: (total)	8.8	8.0	—	—	0.3	0.3	0.5
Cryptostomes	8.8	7.0	—	—	0.3	0.3	0.5
Brachiopods: (total)	3.7	1.3	—	1.3	—	0.7	1.3
Impunctates	3.1	1.3	—	1.3	—	0.7	1.3
Brachiopod Spines	0.3	0.3	0.3	—	0.8	0.3	—
Phylloid Algae	—	—	23.6	18.2	14.4	12.6	23.8
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	0.3	—	—	—	—	—	—
Syringopora sp.	—	—	—	0.5	—	—	0.3
Molluscs: (unidentified)	1.6	0.3	—	—	—	—	—
Gastropods	0.6	—	—	—	0.5	—	0.5
Pelecypods	1.6	8.3	1.1	0.5	1.8	0.7	0.3
Cephalopods	—	—	—	—	—	—	—
Trilobites	—	—	—	—	—	—	—
Ostracodes	0.3	—	0.3	0.5	0.3	0.3	0.3
Tubiphytes sp.	—	—	—	—	—	—	—
Foraminifers: (unidentified)	—	—	—	—	—	—	—
Fusulinids	—	—	—	—	—	—	3.1
Endothyrids	—	—	—	—	—	—	—
Miliolids	—	—	—	0.5	0.8	1.5	3.1
Encrusters	—	1.3	—	0.3	3.6	1.2	0.3
Agglutinated	—	—	—	—	—	—	—
Calcispheres	—	—	—	—	—	—	—
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	—	—	—	—	—	—	—
Ooids	—	—	—	—	—	—	—
Peloids	—	—	—	—	—	—	—
Aggregate Grains	—	—	—	—	—	—	—
Micrite	6.3	67.7	60.5	66.0	59.0	63.6	50.3
Microspar	6.6	7.0	0.9	4.1	4.6	9.2	3.4
Pseudospar	5.0	0.3	—	—	0.8	1.2	1.3
Spar (cement)	5.6	1.6	1.1	0.5	0.3	2.5	4.7
Authigenic Feldspars	0.3	0.5	2.6	1.1	0.5	0.3	1.0
Authigenic Quartz	—	0.5	2.5	1.0	0.5	1.0	1.1
Chalcedony	—	—	—	0.3	0.3	1.5	—
Chert	2.2	—	—	0.5	1.0	—	0.3
Clay	30.6	—	—	—	—	—	—
Dolomite	4.1	—	3.4	—	—	—	—
Phosphates	3.4	—	—	—	—	—	—
Pyrite	1.9	1.0	0.6	0.3	0.4	—	—
Porosity	0.3	1.6	2.0	1.8	1.0	0.3	1.1

APPENDIX C

Section Number	1	1	1	1	1	1	1
Unit Number	3	3	3	3	3	4	5
Meters (from base of unit)	1.6	2.0	2.6	3.2	3.5	1.4	4.1
	Subsequent numbers (%)						
Echinoderms: (total)	5.0	7.4	6.4	—	1.8	2.7	2.0
Pelmatozoans	5.0	7.4	6.4	—	1.8	2.4	1.7
Bryozoans: (total)	2.1	1.0	0.3	—	—	—	—
Cryptostomes	2.1	1.0	0.3	—	—	—	—
Brachiopods: (total)	—	1.1	0.3	—	—	1.5	12.0
Impunctates	—	0.5	0.3	—	—	1.5	11.7
Brachiopod Spines	0.3	0.3	—	—	—	0.3	0.7
Phylloid Algae	—	1.2	—	—	—	7.2	—
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	—	—
Syringopora sp.	—	—	—	—	—	0.3	—
Molluscs: (unidentified)	—	—	1.6	—	—	1.2	—
Gastropods	1.2	0.3	1.1	—	—	1.2	0.7
Pelecypods	4.1	4.4	1.9	—	—	0.9	0.7
Cephalopods	—	—	—	—	—	—	—
Trilobites	—	—	—	—	—	—	—
Ostracodes	0.3	0.3	0.3	—	—	0.6	—
Tubiphytes sp.	—	—	—	—	—	—	—
Foraminifers: (unidentified)	—	—	—	—	—	—	1.0
Fusulinids	0.3	1.5	3.5	—	—	2.4	5.3
Endothyrids	0.3	—	1.1	—	—	0.6	0.3
Miliolids	0.3	0.3	0.3	—	—	0.9	—
Encrusters	0.6	—	1.6	—	—	—	0.3
Agglutinated	—	—	—	—	—	—	—
Calcispheres	—	—	—	—	—	—	—
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	—	—	—	—	—	—	—
Ooids	4.4	0.5	—	—	—	—	—
Peloids	41.2	31.1	37.8	2.7	1.8	—	—
Aggregate Grains	2.1	1.5	2.1	62.5	60.3	—	—
Micrite	—	—	10.6	—	—	42.9	42.3
Microspar	—	0.5	1.6	—	—	21.9	10.0
Pseudospar	—	—	—	—	—	3.6	6.3
Spar (cement)	37.1	42.5	24.5	30.2	31.8	6.9	2.0
Authigenic Feldspars	—	—	0.3	0.3	—	0.9	0.3
Authigenic Quartz	0.6	1.0	0.5	1.4	0.5	0.6	0.7
Chalcedony	0.3	5.4	0.5	—	—	—	0.3
Chert	—	—	0.3	—	—	—	—
Clay	—	—	—	—	—	—	—
Dolomite	—	—	—	3.0	—	0.6	13.9
Phosphates	—	—	—	—	—	—	—
Pyrite	—	—	—	—	—	—	—
Porosity	—	0.3	3.7	—	3.7	2.7	1.0

APPENDIX C

Section Number	1	1	1	1	1	1	1
Unit Number	5	5	6	6	6	6	6
Meters (from base of unit)	4.8	5.4	0.7	0.9	2.6	3.2	5.3
	Subsequent numbers (%)						
Echinoderms: (total)	1.9	2.1	—	5.9	1.1	—	2.0
Pelmatozoans	1.9	2.1	—	4.5	0.8	—	2.0
Bryozoans: (total)	—	—	2.4	4.2	0.6	—	1.3
Cryptostomes	—	—	1.5	3.9	0.6	—	1.3
Brachiopods: (total)	—	1.0	0.9	1.7	1.7	0.9	2.0
Impunctates	—	1.0	0.9	1.7	1.7	0.9	2.0
Brachiopod Spines	—	0.3	0.6	—	0.3	—	—
Phylloid Algae	—	—	25.0	3.9	2.0	—	—
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	—	—
Syringopora sp.	—	—	—	—	—	—	0.3
Molluscs: (unidentified)	—	3.4	—	—	—	—	3.6
Gastropods	1.2	2.8	—	0.3	0.6	—	2.0
Pelecypods	0.2	—	—	0.3	0.6	—	1.3
Cephalopods	—	—	—	—	—	—	—
Trilobites	—	—	—	—	—	—	—
Ostracodes	—	—	—	—	—	2.0	0.7
Tubiphytes sp.	—	—	—	—	—	10.5	—
Foraminifers: (unidentified)	—	—	—	0.8	1.1	—	5.8
Fusulinids	—	1.0	0.6	1.4	0.8	—	—
Endothyrids	—	—	—	—	—	—	0.7
Miliolids	0.2	—	—	0.3	0.6	—	0.3
Encrusters	0.2	20.1	0.9	0.3	0.6	—	0.7
Agglutinated	—	—	—	—	—	—	—
Calcispheres	—	—	—	—	0.3	—	—
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	—	1.3	—	—	—	—	—
Ooids	10.0	5.7	—	—	—	—	—
Peloids	51.6	21.9	—	—	—	—	—
Aggregate Grains	2.4	2.1	—	—	—	—	—
Micrite	11.0	16.8	57.7	56.3	51.5	69.6	60.1
Microspar	—	1.0	4.0	13.9	22.3	—	10.1
Pseudospar	—	—	—	3.6	8.4	—	2.9
Spar (cement)	20.1	16.8	4.0	5.9	3.6	14.5	2.3
Authigenic Feldspars	—	—	1.2	—	0.6	1.1	0.7
Authigenic Quartz	0.7	—	—	0.6	1.4	0.6	0.3
Chalcedony	0.5	—	—	0.3	0.3	0.6	—
Chert	—	—	—	—	—	—	—
Clay	—	—	—	—	—	—	—
Dolomite	—	4.0	2.2	0.6	0.3	—	2.6
Phosphates	—	—	—	—	—	—	—
Pyrite	—	—	—	—	—	—	0.7
Porosity	—	—	0.3	—	1.7	0.3	—

APPENDIX C

Section Number	1	1	1	1	1	2	2
Unit Number	6	6	6	6	6	1	1
Meters (from base of unit)	5.8	6.3	6.5	7.6	8.4	0.0	1.1
	Subsequent numbers (%)						
Echinoderms: (total)	0.6	2.1	3.2	—	—	5.4	1.8
Pelmatozoans	0.6	1.8	2.9	—	—	4.8	1.8
Bryozoans: (total)	—	—	0.9	0.5	1.6	3.0	3.6
Cryptostomes	—	—	0.9	0.5	1.6	3.0	3.6
Brachiopods: (total)	1.6	1.3	0.9	—	2.8	0.6	—
Impunctates	1.6	1.0	0.9	—	2.8	0.6	—
Brachiopod Spines	0.6	0.3	—	—	—	—	—
Phylloid Algae	—	—	—	26.6	—	3.3	—
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	—	—
Syringopora sp.	—	0.5	—	—	—	—	—
Molluscs: (unidentified)	—	7.1	1.4	—	0.6	—	—
Gastropods	—	0.8	3.4	0.9	—	0.6	1.5
Pelecypods	0.3	3.0	0.6	—	—	3.3	0.6
Cephalopods	—	—	—	—	—	—	—
Trilobites	0.6	—	—	—	—	0.3	0.3
Ostracodes	0.6	1.3	1.2	—	—	0.6	—
Tubiphytes sp.	—	—	—	—	—	—	—
Foraminifers: (unidentified)	1.3	1.3	1.2	0.2	—	0.6	0.6
Fusulinids	—	11.6	20.6	—	—	—	—
Endothyrids	—	1.8	0.9	—	0.3	0.3	0.3
Miliolids	—	1.3	—	—	—	0.3	—
Encrusters	0.3	—	—	—	—	—	—
Agglutinated	—	0.3	0.3	—	—	0.3	0.3
Calcispheres	—	—	—	—	—	—	—
Sponge Spicules	—	—	—	—	—	2.0	2.7
Intraclasts	19.9	—	—	—	—	—	—
Ooids	—	—	—	—	—	—	—
Peloids	—	0.3	0.3	—	—	—	—
Aggregate Grains	—	—	—	—	—	—	—
Micrite	66.3	34.0	20.6	33.7	—	65.5	78.2
Microspar	0.3	8.6	17.8	26.8	8.4	6.3	3.6
Pseudospar	—	2.3	2.9	8.3	7.5	1.5	0.3
Spar (cement)	—	12.1	14.0	2.5	—	2.1	0.6
Authigenic Feldspars	2.5	2.0	1.7	0.2	2.2	2.1	1.8
Authigenic Quartz	1.3	1.0	0.6	—	1.3	0.9	—
Chalcedony	—	0.3	—	—	1.9	—	0.3
Chert	—	0.5	—	—	—	—	—
Clay	—	—	—	—	—	—	—
Dolomite	2.0	—	2.9	0.2	49.9	0.3	2.1
Phosphates	—	—	—	—	—	—	—
Pyrite	1.6	6.8	4.9	—	3.1	0.9	1.5
Porosity	0.3	—	—	—	20.6	—	—

APPENDIX C

Section Number	2	2	2	2	2	2	2
Unit Number	1	2	3	3	3	3	3
Meters (from base of unit)	1.8	1.1	0.0	1.5	1.8	3.9	4.4
	Subsequent numbers (%)						
Echinoderms: (total)	0.3	0.7	0.3	6.2	—	3.4	—
Pelmatozoans	0.3	0.7	0.3	5.0	—	3.4	—
Bryozoans: (total)	5.6	0.2	0.3	0.9	—	—	—
Cryptostomes	5.6	0.2	0.3	0.9	—	—	—
Brachiopods: (total)	1.3	—	—	0.9	—	3.4	—
Impunctates	1.3	—	—	0.9	—	3.4	—
Brachiopod Spines	—	0.2	—	0.6	—	—	—
Phylloid Algae	—	32.6	33.7	18.1	—	8.9	7.6
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	—	—
Syringopora sp.	—	0.5	—	—	43.5	—	—
Molluscs: (unidentified)	3.3	1.9	—	5.9	—	—	—
Gastropods	1.0	—	—	1.5	—	0.2	—
Pelecypods	1.3	1.7	—	0.6	—	1.0	—
Cephalopods	—	—	—	—	—	—	—
Trilobites	—	—	—	—	—	—	—
Ostracodes	0.3	0.2	—	0.3	—	—	—
Tubiphytes sp.	—	—	—	—	—	—	—
Foraminifers: (unidentified)	0.7	0.5	—	2.7	—	—	—
Fusulinids	—	—	—	0.3	—	—	—
Endothyrids	—	—	—	0.3	—	—	—
Miliolids	—	—	—	1.2	—	—	—
Encrusters	0.7	0.2	—	0.6	0.3	—	—
Agglutinated	—	—	—	1.5	—	—	—
Calcispheres	—	—	—	—	—	—	—
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	—	—	—	—	—	—	—
Ooids	—	—	—	—	—	2.9	—
Peloids	—	1.0	—	—	—	38.9	0.7
Aggregate Grains	—	—	—	—	—	2.2	53.9
Micrite	71.2	55.5	58.3	36.7	15.6	2.2	—
Microspar	3.9	1.0	4.0	10.4	22.4	1.0	—
Pseudospar	0.3	—	—	1.2	12.8	0.2	—
Spar (cement)	2.3	—	—	—	4.2	29.8	32.8
Authigenic Feldspars	1.3	0.2	1.7	—	0.3	—	0.7
Authigenic Quartz	1.0	1.0	0.6	1.2	—	0.2	0.7
Chalcedony	—	—	—	—	—	—	—
Chert	—	—	0.3	—	—	—	—
Clay	—	—	—	—	—	—	—
Dolomite	0.7	2.3	—	7.7	—	5.3	0.5
Phosphates	—	—	—	—	—	—	—
Pyrite	4.6	0.2	0.3	0.6	0.3	—	—
Porosity	0.3	—	0.6	0.9	0.8	0.5	2.9

APPENDIX C

Section Number	2	2	2	2	2	2	2
Unit Number	4	4	5	5	5	5	6
Meters (from base of unit)	2.0	2.3	0.6	1.6	3.0	4.1	0.0
	Subsequent numbers (%)						
Echinoderms: (total)	3.1	1.9	2.6	3.9	1.9	4.2	2.5
Pelmatozoans	2.4	1.6	2.1	2.6	1.3	3.4	2.2
Bryozoans: (total)	0.2	—	0.3	1.0	0.6	—	0.6
Cryptostomes	0.2	—	0.3	1.0	0.6	—	0.6
Brachiopods: (total)	1.0	1.8	1.1	0.6	1.1	1.9	2.2
Impunctates	1.0	1.3	1.1	0.6	1.1	0.8	2.2
Brachiopod Spines	—	—	—	—	—	0.3	0.6
Phylloid Algae	2.9	4.3	32.9	20.5	—	—	4.4
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	2.0	—
<u>Syringopora</u> sp.	—	0.5	—	—	0.3	—	0.6
Molluscs: (unidentified)	2.6	4.2	1.1	1.9	0.3	—	—
Gastropods	2.4	0.8	1.3	0.3	—	0.6	1.4
Pelecypods	2.2	0.8	1.6	—	—	0.8	2.8
Cephalopods	—	—	—	—	—	1.1	—
Trilobites	—	—	—	—	—	—	—
Ostracodes	0.7	0.3	0.8	0.3	0.3	0.8	0.6
<u>Tubiphytes</u> sp.	—	—	—	—	—	—	—
Foraminifers: (unidentified)	1.9	0.8	5.5	2.9	2.5	2.0	—
Fusulinids	11.0	11.0	1.1	1.0	—	0.8	—
Endothyrids	0.2	0.5	—	—	0.9	—	—
Miliolids	1.0	0.5	0.5	1.3	—	—	—
Encrusters	0.7	0.5	1.1	0.3	15.8	14.0	23.0
Agglutinated	0.2	—	0.3	1.0	—	0.6	—
Calcispheres	—	—	—	—	—	—	—
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	—	—	—	—	—	—	—
Ooids	—	—	—	—	—	—	—
Peloids	—	—	—	—	—	16.8	8.6
Aggregate Grains	—	—	—	—	—	2.8	0.8
Micrite	38.4	46.7	43.4	57.5	11.6	18.2	30.8
Microspar	13.9	14.6	0.8	3.8	23.1	1.4	3.6
Pseudospar	7.4	1.8	—	—	33.8	—	—
Spar (cement)	8.9	6.8	1.8	1.6	1.4	29.9	16.1
Authigenic Feldspars	0.2	1.0	0.3	1.0	1.4	0.3	0.8
Authigenic Quartz	0.2	0.5	—	0.3	0.9	0.8	—
Chalcedony	—	—	—	—	—	—	—
Chert	—	—	—	—	—	—	—
Clay	—	—	—	—	—	—	—
Dolomite	—	0.8	3.7	0.3	4.5	0.6	0.8
Phosphates	—	—	—	—	—	—	—
Pyrite	0.7	—	—	—	—	—	—
Porosity	—	—	—	0.6	—	0.3	—

APPENDIX C

Section Number	2	2	2	2	2	2	3
Unit Number	6	6	6	6	6	6	1
Meters (from base of unit)	1.0	1.4	3.6	4.2	7.2	8.1	0.0
	Subsequent numbers (%)						
Echinoderms: (total)	0.2	1.8	4.8	1.8	2.3	—	18.8
Pelmatozoans	0.2	1.3	4.2	1.3	2.3	—	18.3
Bryozoans: (total)	0.7	3.7	1.1	0.8	—	1.0	8.4
Cryptostomes	0.7	3.7	1.1	0.8	—	0.3	8.4
Brachiopods: (total)	0.7	1.6	1.1	0.8	0.3	1.7	1.0
Impunctates	0.7	1.6	1.1	0.8	0.3	1.7	1.0
Brachiopod Spines	—	0.3	0.3	0.3	—	—	0.3
Phylloid Algae	—	—	—	—	—	—	—
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	—	—
Syringopora sp.	—	0.3	—	0.5	0.3	—	—
Molluscs: (unidentified)	—	0.5	0.3	—	0.7	—	—
Gastropods	—	0.5	—	1.3	—	—	—
Pelecypods	1.7	1.0	2.5	0.3	0.7	0.3	1.3
Cephalopods	—	—	—	—	—	—	—
Trilobites	—	0.8	—	—	0.3	—	0.3
Ostracodes	0.5	1.6	0.6	3.2	0.3	0.3	—
Tubiphytes sp.	—	—	—	13.4	—	—	—
Foraminifers: (unidentified)	—	—	2.5	1.6	0.3	—	—
Fusulinids	0.2	3.4	0.6	—	23.5	—	—
Endothyrids	—	0.3	0.7	—	0.7	—	—
Miliolids	—	—	0.3	0.5	—	—	—
Encrusters	0.7	—	1.1	8.9	0.3	—	—
Agglutinated	—	—	—	0.3	1.3	—	—
Calcispheres	—	—	0.6	—	—	—	—
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	19.9	—	—	—	—	—	15.4
Ooids	—	—	—	—	—	—	—
Peloids	1.2	—	—	—	—	—	—
Aggregate Grains	—	—	—	—	—	—	—
Micrite	37.2	18.0	57.0	31.8	3.6	0.3	15.9
Microspar	1.9	26.1	11.7	0.3	32.4	21.7	10.7
Pseudospar	—	36.0	2.0	—	2.6	26.3	5.2
Spar (cement)	34.8	2.4	8.9	30.9	13.4	6.7	2.1
Authigenic Feldspars	0.2	1.0	0.8	0.3	0.7	1.0	0.5
Authigenic Quartz	—	0.5	0.3	0.3	1.0	—	0.3
Chalcedony	—	—	—	0.3	—	—	—
Chert	—	—	—	—	—	—	0.3
Clay	—	—	—	—	—	—	5.5
Dolomite	—	0.3	3.4	0.3	7.5	34.6	5.4
Phosphates	—	—	—	—	—	—	4.2
Pyrite	—	—	—	—	2.0	0.7	2.4
Porosity	—	—	—	2.2	5.9	5.3	2.1

APPENDIX C

Section Number	3	3	3	3	3	3	3
Unit Number	1	1	1	3	3	3	4
Meters (from base of unit)	0.7	1.3	1.9	0.0	2.9	4.2	1.6
			Subsequent numbers (%)				
Echinoderms: (total)	5.4	1.8	—	0.3	9.2	0.6	3.8
Pelmatozoans	5.4	1.8	—	—	8.5	0.6	3.5
Bryozoans: (total)	9.1	3.2	—	1.6	0.2	0.8	—
Cryptostomes	9.1	2.9	—	1.1	0.2	0.8	—
Brachiopods: (total)	2.1	2.1	0.6	0.8	1.6	0.6	1.3
Impunctates	2.1	2.1	0.6	0.8	0.7	0.3	1.3
Brachiopod Spines	—	0.8	—	0.8	—	0.3	—
Phylloid Algae	—	—	24.6	27.6	—	—	7.3
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	0.6	—
Syringopora sp.	—	—	0.3	4.2	—	—	0.3
Molluscs: (unidentified)	1.3	2.9	—	0.5	0.2	—	0.6
Gastropods	—	0.8	2.1	2.9	1.4	—	0.6
Pelecypods	—	1.8	0.6	0.8	6.7	1.1	1.6
Cephalopods	—	—	—	—	—	—	—
Trilobites	—	0.5	—	0.5	—	—	0.3
Ostracodes	—	0.5	0.3	1.9	—	—	0.3
Tubiphytes sp.	—	—	—	—	—	—	—
Foraminifers: (unidentified)	—	—	—	0.5	—	—	0.3
Fusulinids	—	10.2	—	—	0.2	0.6	8.0
Endothyrids	—	—	—	0.5	—	—	0.3
Miliolids	—	0.3	—	4.2	0.2	0.8	—
Encrusters	—	1.3	0.6	0.5	—	—	—
Agglutinated	—	0.5	—	0.8	—	—	1.0
Calcispheres	—	—	—	—	—	—	0.3
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	—	—	—	—	—	—	—
Ooids	—	—	—	—	—	—	—
Peloids	—	—	—	—	34.1	—	—
Aggregate Grains	—	—	—	—	4.3	68.6	—
Micrite	7.0	53.8	66.4	45.4	—	—	50.3
Microspar	25.2	5.0	1.2	1.9	0.2	0.3	9.6
Pseudospar	11.3	—	—	—	—	—	3.5
Spar (cement)	4.3	5.3	—	1.3	39.5	20.1	5.4
Authigenic Feldspars	1.3	2.6	1.8	—	—	1.4	1.9
Authigenic Quartz	0.8	0.3	1.2	0.5	—	—	0.3
Chalcedony	—	—	—	—	0.7	—	—
Chert	—	—	—	0.3	—	—	—
Clay	14.8	2.1	—	—	—	—	—
Dolomite	4.0	0.5	0.3	—	1.4	4.5	0.6
Phosphates	7.0	0.5	—	—	—	—	—
Pyrite	3.0	2.4	0.3	0.8	—	—	—
Porosity	3.5	0.8	—	1.1	0.2	—	2.2

APPENDIX C

Section Number	3	3	3	3	3	3	3
Unit Number	5	5	5	5	5	5	6
Meters (from base of unit)	0.6	2.6	4.1	4.7	5.2	7.1	0.3
	Subsequent numbers (%)						
Echinoderms: (total)	12.8	0.8	2.2	5.0	5.2	1.7	1.1
Pelmatozoans	12.5	0.8	1.9	5.0	1.3	1.7	0.8
Bryozoans: (total)	0.6	—	—	0.3	—	—	0.3
Cryptostomes	0.6	—	—	0.3	—	—	0.3
Brachiopods: (total)	1.3	0.6	2.2	1.6	0.5	0.3	1.3
Impunctates	1.3	0.3	2.2	1.6	0.5	0.3	1.3
Brachiopod Spines	—	—	0.3	1.3	—	0.3	0.3
Phylloid Algae	3.2	2.4	5.7	2.7	0.5	2.5	16.6
Coralline Algae	—	—	—	1.5	0.3	—	—
Corals: (unidentified)	—	—	—	—	—	—	—
Syringopora sp.	0.6	—	0.5	—	—	—	—
Molluscs: (unidentified)	3.2	—	—	1.3	2.9	—	2.8
Gastropods	1.9	0.5	3.8	1.8	1.3	1.5	1.3
Pelecypods	0.3	0.3	1.6	1.3	0.3	2.7	1.5
Cephalopods	—	0.3	—	—	—	—	—
Trilobites	—	—	—	0.3	—	—	—
Ostracodes	0.6	1.1	0.3	0.3	—	—	—
Tubiphytes sp.	—	—	—	—	—	—	—
Foraminifers: (unidentified)	—	0.3	5.5	0.5	—	—	0.8
Fusulinids	1.3	0.8	1.1	2.7	—	—	6.9
Endothyrids	—	—	—	—	—	—	0.5
Miliolids	—	—	1.1	0.8	0.8	0.5	0.5
Encrusters	9.7	0.3	11.2	12.7	5.0	13.8	5.6
Agglutinated	—	—	3.3	1.8	—	—	—
Calcispheres	—	—	—	0.8	—	—	—
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	—	28.7	—	—	—	—	—
Ooids	—	—	—	—	4.4	24.2	—
Peloids	—	8.0	4.1	1.8	38.6	10.1	—
Aggregate Grains	—	—	—	—	3.4	14.3	—
Micrite	52.7	35.1	40.9	29.2	22.7	5.7	49.4
Microspar	2.9	—	1.9	5.5	1.3	—	0.8
Pseudospar	—	—	0.3	2.7	—	—	—
Spar (cement)	5.8	15.2	10.9	19.2	8.4	22.5	2.6
Authigenic Feldspars	1.6	2.1	0.5	0.8	—	—	0.8
Authigenic Quartz	—	—	0.3	—	0.5	—	—
Chalcedony	—	—	0.5	—	—	—	—
Chert	—	—	—	—	—	—	—
Clay	0.6	—	—	1.5	—	—	—
Dolomite	0.3	3.7	1.4	1.8	3.4	—	7.2
Phosphates	—	—	—	—	—	—	—
Pyrite	0.3	—	0.5	—	—	—	—
Porosity	—	—	—	1.5	0.5	—	—

APPENDIX C

Section Number	3	3	3	3	3	3	3
Unit Number	6	6	6	6	6	6	6
Meters (from base of unit)	0.8	1.2	1.5	2.1	2.9	3.2	3.8
	Subsequent numbers (%)						
Echinoderms: (total)	0.6	0.5	3.4	1.8	2.9	0.3	3.8
Pelmatozoans	0.3	0.5	2.9	1.6	2.4	—	3.6
Bryozoans: (total)	0.3	1.3	0.5	—	—	—	2.1
Cryptostomes	0.3	1.3	0.5	—	—	—	1.9
Brachiopods: (total)	0.5	7.4	1.6	1.9	1.6	—	1.9
Impunctates	0.5	3.4	1.6	1.9	1.6	—	1.9
Brachiopod Spines	—	0.3	—	0.5	—	—	0.2
Phylloid Algae	4.7	4.5	6.8	15.9	2.9	—	15.0
Coralline Algae	—	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	—	—
Syringopora sp.	—	—	0.5	—	—	—	—
Molluscs: (unidentified)	—	2.4	3.7	—	—	—	—
Gastropods	1.0	1.1	2.1	3.0	0.5	—	1.2
Pelecypods	—	1.8	4.7	1.9	1.6	—	0.7
Cephalopods	—	—	—	—	—	—	—
Trilobites	—	—	0.3	0.5	0.8	—	—
Ostracodes	0.3	—	0.8	0.7	—	3.3	0.5
Tubiphytes sp.	—	—	—	—	—	58.5	—
Foraminifers: (unidentified)	—	0.5	0.3	—	—	—	—
Fusulinids	—	0.3	1.0	—	—	—	2.9
Endothyrids	—	—	0.3	0.2	0.3	—	0.2
Miliolids	—	—	1.8	0.7	3.7	0.3	0.2
Encrusters	1.6	2.4	9.4	6.8	27.8	—	1.5
Agglutinated	—	0.3	0.5	0.2	0.5	—	—
Calcispheres	—	—	—	—	—	—	—
Sponge Spicules	—	—	—	—	—	—	—
Intraclasts	—	—	—	—	—	—	—
Ooids	—	—	—	—	—	—	—
Peloids	—	—	0.3	—	11.5	—	—
Aggregate Grains	—	—	—	—	2.1	—	—
Micrite	46.9	50.8	47.4	49.0	11.5	27.9	50.4
Microspar	4.2	11.3	1.6	2.6	—	—	3.4
Pseudospar	—	4.5	—	—	—	—	—
Spar (cement)	38.8	5.5	10.5	12.3	31.6	3.9	14.0
Authigenic Feldspars	0.3	0.5	0.5	0.7	—	1.5	—
Authigenic Quartz	0.3	—	—	0.2	—	2.1	—
Chalcedony	—	—	—	—	—	—	—
Chert	—	—	—	—	—	—	—
Clay	—	—	—	—	—	—	—
Dolomite	—	3.7	2.3	1.2	0.3	2.1	1.7
Phosphates	—	—	—	—	—	—	—
Pyrite	—	1.1	—	—	—	—	—
Porosity	0.8	—	—	—	0.3	0.3	—

APPENDIX C

Section Number	3	3	3	3	3	3
Unit Number	6	6	6	6	6	6
Meters (from base of unit)	5.1	5.9	7.1	7.2	7.9	8.5
	Subsequent numbers (%)					
Echinoderms: (total)	3.1	0.3	1.5	3.3	1.2	0.9
Pelmatozoans	2.6	—	1.5	3.0	1.2	0.6
Bryozoans: (total)	0.5	—	—	—	0.3	—
Cryptostomes	0.5	—	—	—	0.3	—
Brachiopods: (total)	1.2	0.5	0.3	3.0	2.3	1.3
Impunctates	1.2	0.5	0.3	2.7	2.0	1.3
Brachiopod Spines	0.5	—	0.3	0.6	—	—
Phylloid Algae	1.9	—	—	1.5	—	14.3
Coralline Algae	—	—	—	—	—	—
Corals: (unidentified)	—	—	—	—	—	—
Syringopora sp.	0.7	—	—	—	—	1.0
Molluscs: (unidentified)	2.1	—	—	3.0	1.4	3.2
Gastropods	1.4	0.3	—	9.9	1.2	—
Pelecypods	1.7	0.8	—	16.8	0.6	4.1
Cephalopods	—	—	—	—	—	—
Trilobites	—	—	—	—	—	—
Ostracodes	0.2	4.5	0.6	0.3	2.3	0.3
Tubiphytes sp.	—	26.8	—	—	—	—
Foraminifers: (unidentified)	—	0.3	—	—	—	—
Fusulinids	—	—	—	—	22.9	—
Endothyrids	—	—	—	—	0.3	0.3
Miliolids	0.7	0.5	0.3	0.6	—	—
Encrusters	21.7	1.3	—	1.2	1.4	2.2
Agglutinated	0.2	0.3	—	0.3	—	—
Calcispheres	0.5	0.5	—	—	—	—
Sponge spicules	—	—	—	—	—	—
Intraclasts	—	—	—	—	—	—
Ooids	—	—	—	—	—	—
Peloids	—	—	—	—	—	—
Aggregate Grains	—	—	—	—	—	—
Micrite	32.3	40.2	20.1	38.9	35.0	57.6
Microspar	0.5	1.3	3.0	4.8	3.7	2.2
Pseudospar	—	—	59.3	3.0	0.3	0.3
Spar (cement)	28.3	17.1	0.6	9.6	22.1	4.5
Authigenic Feldspars	0.2	2.9	1.5	0.6	1.2	0.3
Authigenic Quartz	0.2	1.1	0.6	—	—	—
Chalcedony	—	—	—	—	—	—
Chert	—	0.8	—	—	—	—
Clay	0.7	—	—	—	—	—
Dolomite	1.2	0.5	8.5	—	—	3.8
Phosphates	—	—	—	—	—	—
Pyrite	0.2	—	—	—	3.4	1.6
Porosity	—	0.3	3.3	2.7	0.6	1.9