

Charlotte M. Varlashkin. COMPARATIVE PETROGRAPHY OF INTRA- AND EXTRA-MACROFOSSIL SEDIMENT WITHIN PLEISTOCENE TO CRETACEOUS STRATA OF THE NORTH CAROLINA COASTAL PLAIN. (Under the direction of Dr. Lee J. Otte) Department of Geology, March, 1986.

Macrofossils can protect the enclosed sediment from certain diagenetic agents. The protected intra-macrofossil sediment can then be a useful device for interpreting primary sediment character if the shell has had sufficient closure. The frequency of variation in sediment character between intra- and extra-macrofossil deposits, if not caused by depositional processes, is a measure of diagenetic barrier capability of the shell. Twenty-six percent of the samples in this study are effective diagenetic barriers. Brachiopods, bivalves, and gastropods appear to be the most efficient barriers. Carbonate rock type and fine-grain size also increase the frequency of variation between intra- and extra-macrofossil sediment character.

The samples in this study are Pleistocene to Cretaceous in age. The frequency of variation between intra- and extra-macrofossil sediment character increases with age. Usefulness of intra-macrofossil deposits therefore increases with age. The youthfulness of samples in this study provided less opportunity for diagenetic change and therefore less opportunity to produce a variation between intra- and extra-macrofossil sediment character. Older deposits would likely have a greater percentage of variations.

The processes which produced the most frequent diagenetic variations in this study include compaction, calcite spar precipitation, dissolution, aggradation of lime mud grain size, glauconitization, pyritization, and dolomitization.

COMPARATIVE PETROGRAPHY OF INTRA- AND EXTRA-MACROFOSSIL SEDIMENT
WITHIN PLEISTOCENE TO CRETACEOUS STRATA
OF THE NORTH CAROLINA COASTAL PLAIN

A Thesis

Presented to
the Faculty of the Department of Geology
East Carolina University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Geology

by

Charlotte M. Varlashkin

March, 1986

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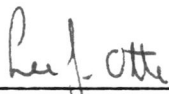
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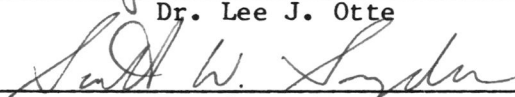
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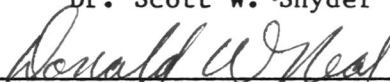
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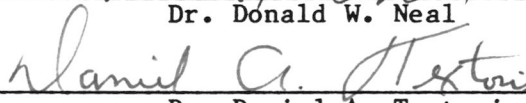
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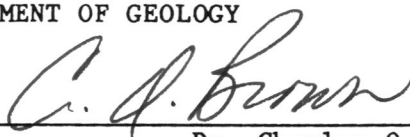
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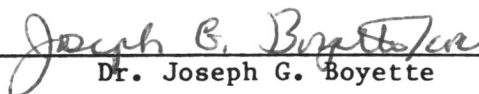
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INTRODUCTION

PURPOSE

Reconstruction of ancient depositional environments is based on interpretations made from physical, biological, and chemical characteristics of a sediment or rock. Examples of characteristics typically observed include:

- (1) Physical- grain textures and sedimentary structures;
- (2) Biological- organic remains and biological traces;
- (3) Chemical- composition of allochems, matrix, and diagenetic products.

Analysis of data derived from these characteristics provides information on life, climate, water depth, water temperature, current energy, direction and nature of sediment influx, water and sediment chemistry, and organism-substrate interaction at the time of deposition. Much information about depositional environments can be drawn from the matrix element of a deposit. Studies of matrix material usually have not included deposits within macrofossils. Macrofossils can act as protective barriers against post-depositional processes and thereby preserve original sediment character. Intra-macrofossil sediment may be entirely, partially, or not at all protected from post-depositional processes. The accumulation of unaltered deposits within macrofossils and the usefulness of these deposits in petrographic studies depends on the ability of the fossil to accumulate the original sediment and its sedimentary structures, and also on the shell's ability to protect the enclosed deposits from external diagenetic agents. Certain shell types are more efficient barriers than others. The variety of environments in

which macrofossils occur makes the internal sediment a useful device for interpreting primary sediment character of numerous rock types.

In an attempt to enhance the reliability of environmental interpretations made for sedimentary deposits, intra-macrofossil deposits were examined. Fossil types (bivalves, gastropods, brachiopods, echinoids, crabs, oysters), moldic versus non-moldic macrofossils, fine- versus coarse-grained deposits, age of the sample, and terrigenous versus carbonate deposits were evaluated to assess their association with frequency of variation between intra- and extra-macrofossil sediments. Observed variations were separated into depositionally-induced and diagenetically-induced categories.

Depositionally-induced variations do not reflect the ability of a shell to protect the internal sediment from diagenetic change. Samples having only depositional variations were not included in statistical calculations made to evaluate fossil type, sediment type, moldic type, age and grain size for likelihood of providing variation.

Depositionally-variable samples do have some value in environmental interpretation, as will be demonstrated in a later section describing specific variations observed.

Diagenetically-variable samples were evaluated to determine (1) the process(es) causing change(s) in sediment character, (2) the characteristics of the deposit (grain size, mineralogy, etc.) that made the sample a candidate for a particular diagenetic change, and (3) the role the shell played in barring change within.

LOCATION

The study area encompasses Beaufort, Pender, Duplin, New Hanover, Onslow, Pitt, and Craven Counties on the North Carolina Coastal Plain (Fig. 1). Figure 2 is a generalized stratigraphic column of units sampled in this study. Samples were taken from quarries and natural outcrops listed in Table 1. Cretaceous to Pleistocene strata sampled include the following lithologic units.

Rocky Point Member of the Peedee Formation (Cretaceous)- The Rocky Point Member was deposited as a shallow marine cape-shoal complex (Harris, 1975). Littoral drift convergence at the cape apex provided the mechanism for deposition of the shoals seaward onto the middle to outer continental shelf. Harris (1975) identified five lithologies within the Rocky Point: biosparrudite, biosparite, quartz arenite, biomicrudite, and a biomicrite.

Beaufort Formation (Paleocene)- The Beaufort Formation was deposited on an open-marine shelf within the Albermarle Embayment (Whitehead, 1981). Whitehead suggested that low energy conditions are indicated by in situ glauconite and the presence of micrite, and that open-marine conditions are indicated by bioturbation and abundance of echinoids. The Beaufort Formation is a silty, quartzose, glauconitic foraminiferal biomicrosparite.

Castle Hayne Limestone (Eocene)- The Castle Hayne Limestone was deposited in a coastal embayment within a subtropical to warm temperate climatic zone (Otte, 1981). Otte (1981) recognized five major lithofacies: (1) shallow-water, low-energy, phosphate-pebble

Sample Locations

- 1- Lee Creek Mine
- 2- Ideal Cement Quarry
- 3- Flanner Beach- Neuse River
- 4- Maple Hill East Coast and Lanier Quarries
- 5- Fussel Quarry
- 6- Martin Marrietta Belgrade Quarry
- 7- Mosley Creek
- 8- Green Mill Run
- 9- Rainbow Banks Landing- Tar River

-  Quaternary
-  Plio-Pleistocene
-  Pliocene
-  Miocene
-  Eocene
-  Paleocene
-  Cretaceous- Peedee Fm
-  Upper Cretaceous undifferentiated

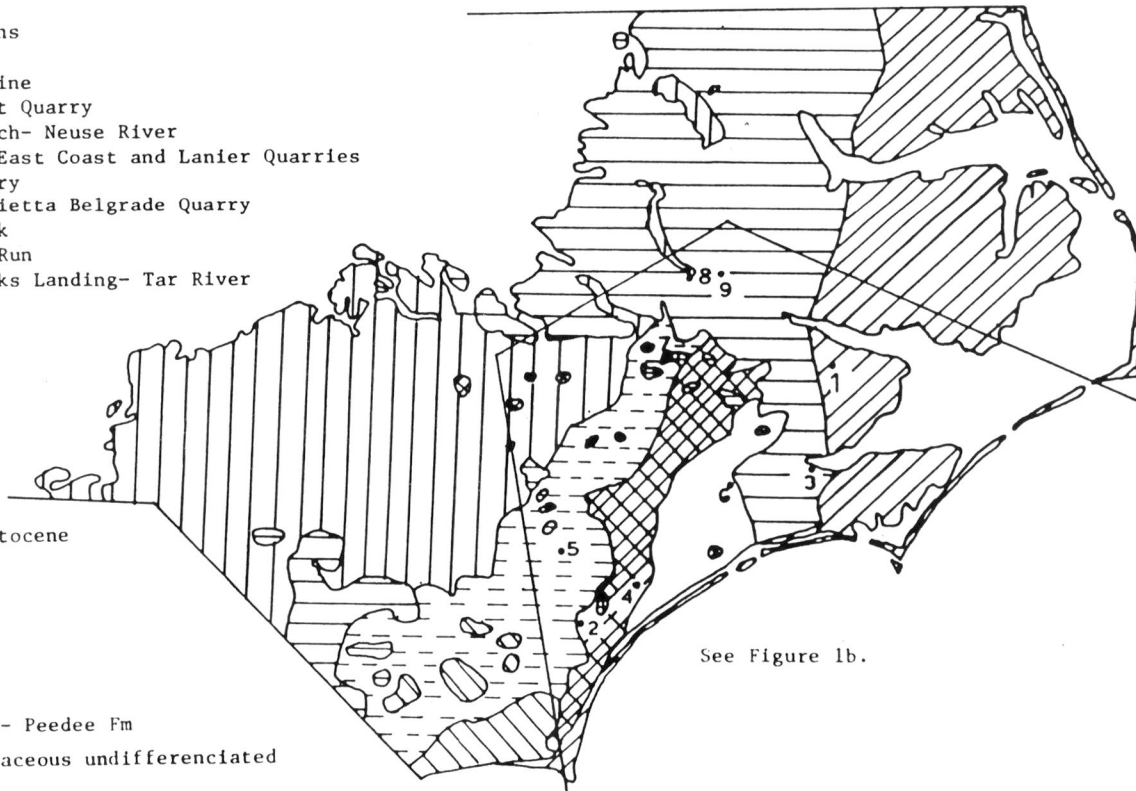


Figure 1a. STUDY AREA: Major outcrop belts (after Hoffman, 1985) and sample locations on the North Carolina Coastal Plain. See Table 1 for the formations sampled at each locality.

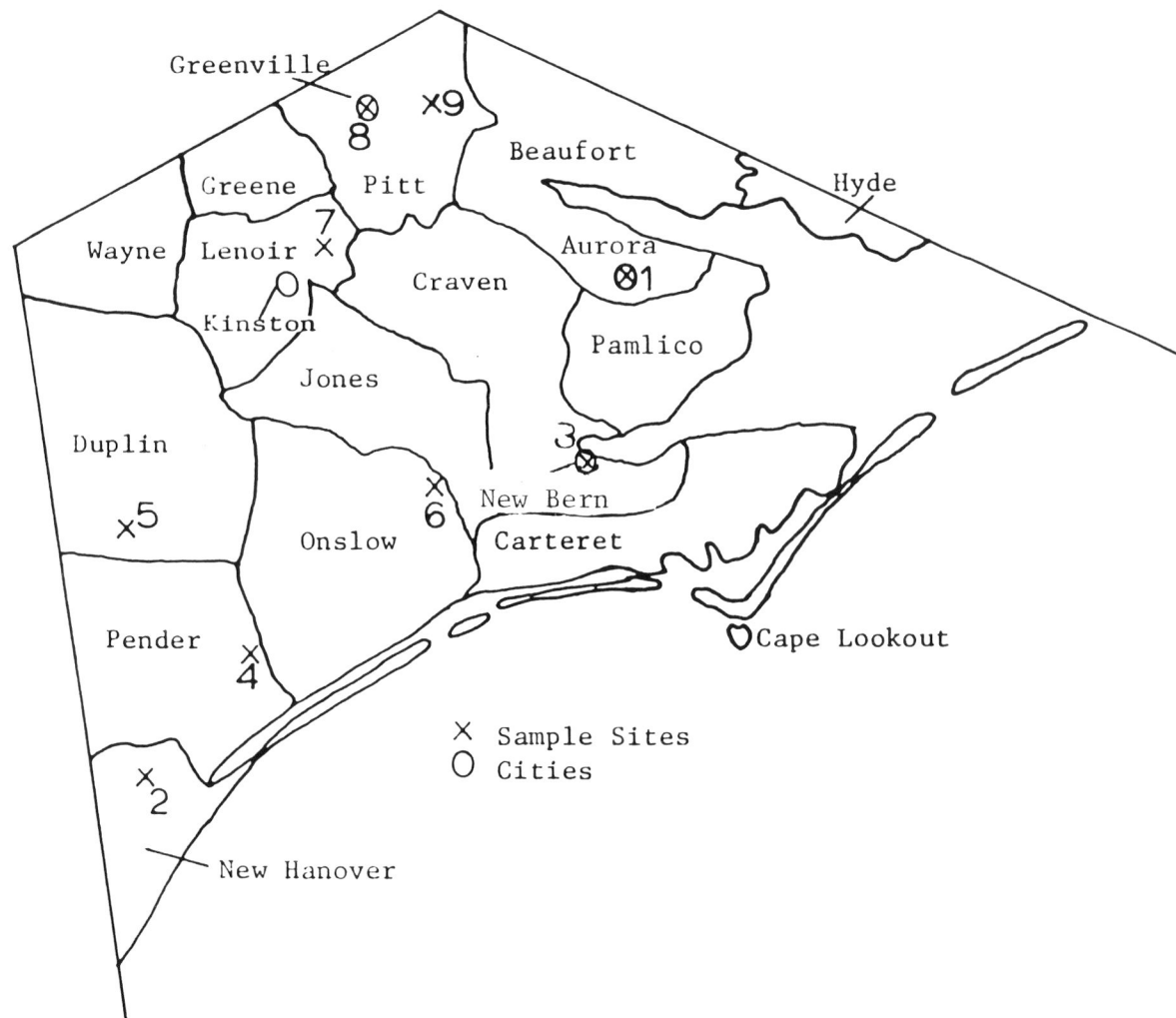


Figure 1b. Study are enlarged. Counties are indicated.

TABLE 1. LIST OF SAMPLE LOCATIONS BY AGE AND FORMATION

<u>Site #</u> <u>(Fig.1)</u>	<u>Formation</u>	<u>Age</u>	<u>Location</u>
1	Unnamed shell unit	Pleistocene?	Lee Creek Mine; Beaufort County; Aurora, NC
3	Flanner Beach	Pleistocene	Neuse River; Craven County; Flanner Beach, NC
1	Croatan	Plio-Pleist.	Lee Creek Mine; Beaufort County; Aurora, NC
1	Yorktown	Pliocene	Lee Creek Mine; Beaufort County; Aurora, NC
8	Yorktown	Pliocene	Green Mill Run; Pitt County; Greenville, NC
9	Yorktown	Pliocene	Tar River; Pitt County; Rainbow Banks Landing
1	Pungo River	Miocene	Lee Creek Mine; Beaufort County; Aurora, NC
6	Belgrade	Miocene	Martin Marrietta Quarry; Onslow County; Belgrade, NC
2	Castle Hayne	Eocene	Ideal Cement Quarry; New Hanover County, NC
4	Castle Hayne	Eocene	East Coast Quarry; Pender County; Maple Hill, NC
4	Castle Hayne	Eocene	Lanier Quarry; Pender County; Maple Hill, NC
5	Castle Hayne	Eocene	Fussell Quarry; Duplin County; Rose Hill, NC
7	Beaufort	Paleocene	Mosley Creek; Lenoir- Craven County line, NC
2	Peedee	Cretaceous	Ideal Cement Quarry; New Hanover County, NC
8	Peedee	Cretaceous	Green Mill Run; Pitt County; Greenville, NC

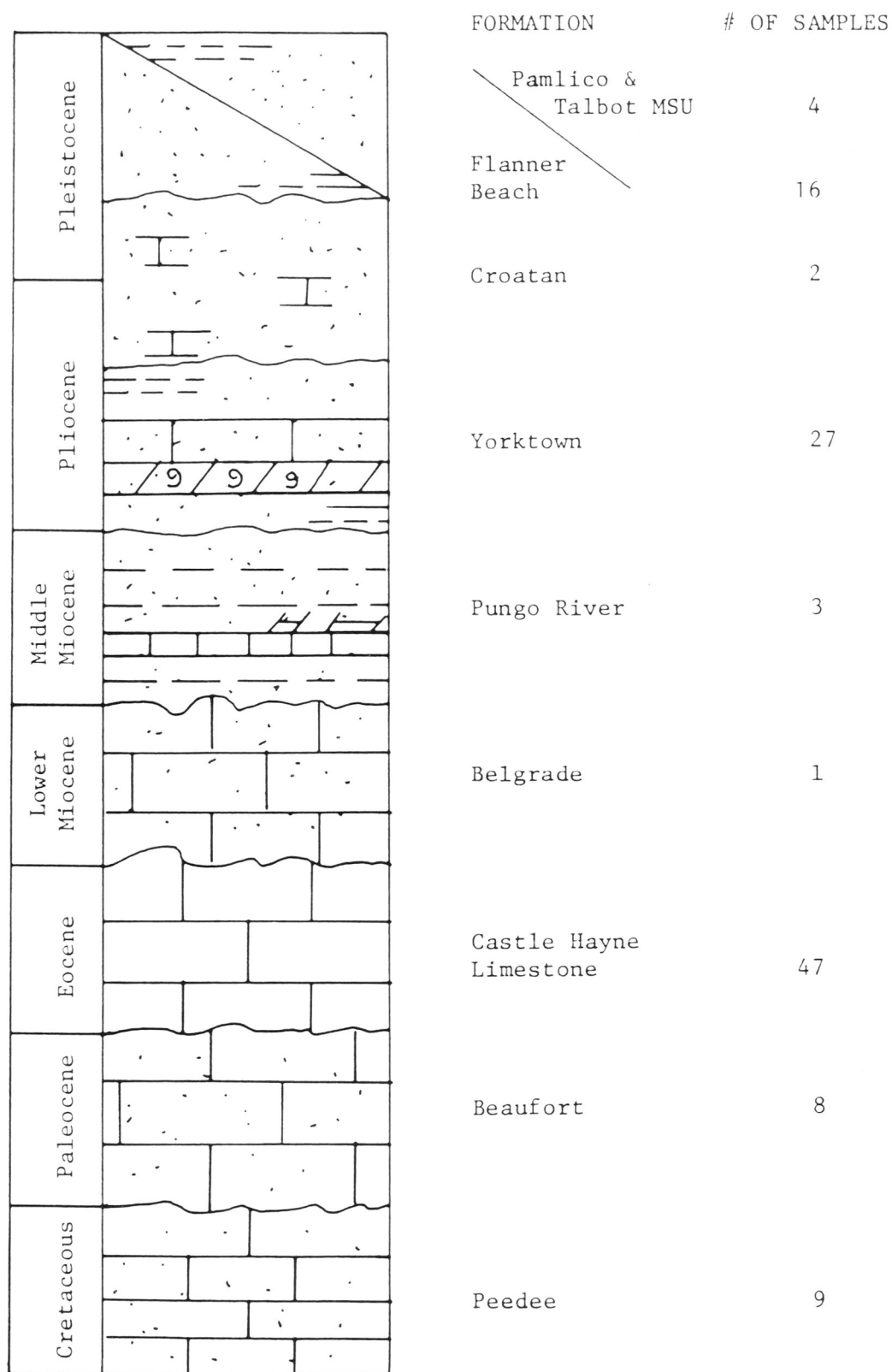


Figure 2. Generalized stratigraphic section of the formations sampled. See Table 2 for the percent of carbonate material in each formation.

biomicrudite; (2) shallow-water, high-energy, bryozoan biosparrudite; (3) intermediate-depth, low-energy, sandy, sponge-spicule-bearing biomicrite; (4) intermediate-depth, low-energy, sandy, foraminiferal, echinoderm biomicrite; (5) deep-water, low-energy, bryozoan biomicrudite. Otte also recognized three minor lithofacies:

(1) dolomitized biomicrite; (2) a molluscan-mold, bryozoan biomicrudite; (3) bryozoan, foraminiferal biomicrite.

Belgrade Formation (Upper Oligocene- Lower Miocene)- The Belgrade Formation is a mixed carbonate and terrigenous deposit, containing both high (well-sorted, clean, quartz sand) and low (microspar-micrite) energy elements (Griffin, 1982). Griffin (1982) proposed a barrier island/ back barrier lagoon complex, with an inlet to the south, as the depositional environment. Introduction of sand into this quiet bay or lagoon may have been from washover or from a migrating inlet. The Belgrade Formation has a lower quartz arenite facies which grades upward into a sandy, pelecypod-mold biomicrudite facies (Baum, Harris, and Zullo, 1978).

Pungo River Formation (Miocene)- The Pungo River Formation sampled for this study was deposited within the Aurora embayment, a smaller Miocene depocenter within the Albermarle embayment. Kimery (1965) described the Pungo River Formation as interbedded phosphatic sands, silts, and clays; diatomaceous clay, and phosphatic and non-phosphatic limestones and silty claystones. The Pungo River Formation in the Lee Creek Mine area can be divided into four sedimentary units which are separated by minor unconformities (Riggs, Lewis, Scarborough, and Snyder, 1984). Each sedimentary unit represents one cycle of a repeated depositional

sequence. The sequence begins with clayey phosphorite quartz sands which grade upward into clayey phosphorite sands. Abundantly fossiliferous carbonate deposits with minor terrigenous and phosphate sediment and with abundant invertebrate fauna complete the sequence.

Yorktown Formation (Pliocene)- The lower to middle Yorktown sediments within the Albermarle embayment represent open-marine, inner to middle shelf deposits overlain by marginal marine deposits (Gibson, 1983). The lithology of Yorktown deposits changes geographically due to the many environments which are represented. A bluish clayey sand is the most abundant lithology, followed by a bluish sandy clay (Gibson, 1983). Weathered deposits are buff to yellow in color. Molluscan shells are common. Broken shells constitute over half of the shell hash beds (Gibson, 1983). Mauger (1979) recognized a bed containing turretellid molds in which fine to very fine calcareous quartz mud makes up 37-47% of the sediment.

Croatan Formation (Pliocene-Pleistocene)- The Croatan Formation was first proposed by Dall (1892). Dubar, Solliday, and Howard (1974) called the Croatan Formation equivalent to the James City Formation of the Neuse River area. The James City Formation was described by Dubar and Solliday (1963) as unconsolidated calcareous sandy clays and argillaceous sands. Hazel (1983) called Gibson's (1967) Yorktown units 6 through 9 the Croatan Formation. Gibson (1967) described these units as fossiliferous blue clayey sands. Gibson (1967) believed the Croatan sediments were deposited in warm-temperate subtidal waters at depths of 15 meters or less. The Croatan Formation within the Lee Creek Mine area may represent mass mortality deposits produced by local catastrophic

events (Curran and Parker, 1983). Evidence for mass mortality includes (1) the preservation of fossils in good condition, (2) numerous articulated bivalves of many sizes, and (3) the close packing of shells with little matrix. Wheeler, Daniels, and Gamble (1983) referred to the Croatan Formation as the Small Sequence. Wheeler and others described an eastern facie, of fossiliferous loamy sands, with some silty or clayey beds near the top, which probably corresponds to the Croatan in the Lee Creek Mine.

Unnamed Pleistocene(?) sediments of the Lee Creek Mine- No published description exists for the post-Croatan sediments of the Lee Creek Mine which were sampled for this study. These sediments might be included within the Pamlico or Talbot morphostratigraphic units (msu) as described by Wheeler and others (1983). The Talbot msu and the Pamlico msu overlie the Croatan Formation. The Pamlico msu includes all non-Holocene surficial sediments east of the Suffolk Scarp. Wheeler described the Pamlico msu of the Lee Creek Mine as nearshore marine and estuarine sands and silty sands with varying amounts of dispersed shell material. Wheeler and others described the Talbot msu as sticky loam with fine sand. More sand occurs at the base. Wheeler and others stated the Talbot and the Pamlico msu may be one unit.

PREVIOUS WORK

Some of the sampled lithologic units have published descriptions and some do not. Publications concerning the units sampled in the study are noted in the previous section.

Many publications deal with the processes, products, and factors influencing diagenesis. Some of the more informative publications are here listed. Krumbein (1942) presented a summary of diagenetic processes. Chilingar, Bissell, and Wolf (1979) and Bathurst (1975) provided detailed discussion of the processes and products of carbonate diagenesis. Von Englehardt (1977) comprehensively discussed depositional and diagenetic processes. Murray (1960) discussed the origin of porosity in carbonate rocks. Coogan and Manus (1975) discussed the factors of compaction for carbonate rocks. Meade (1966) and Allen and Chilingarian (1975) discussed compaction of terrigenous sediments. Dapples (1962) discussed cementation and stages of diagenesis. Chilingar, Bissell, and Wolf (1979) discussed the geochemistry of dolomite formation and replacement, and the physical characteristics of dolomite.

Use of sediment within fossils to indicate the horizontal depositional plane has been discussed by Collinson (1938). Murray (1965) spoke of the preservation of micrite pellets within shells while peloidal texture is lost outside. No other literature could be found that deals with the concept of macrofossils acting as diagenetic shelter zones.

PROCEDURES

Macrofossils were sampled along with the adjacent in situ sediment from various rock quarries and natural outcrops on the North Carolina Coastal Plain (Table 1). Samples vary from consolidated to unconsolidated. Lithologic units sampled include terrigenous deposits,

pure carbonate rocks, and gradations between these two rock types (Table 2).

Unconsolidated to loosely consolidated samples were indurated by impregnation with EPON 815 epoxy-resin while contained in a vacuum. Least permeable samples required a less viscous impregnating fluid. For these samples, the epoxy was diluted with acetone or toluene in a 1:5 or less ratio of acetone or toluene to epoxy. Acetone and toluene both decrease the viscosity of the epoxy and thereby increase penetration capability. Both proved to be equally effective fluidizing agents. Samples with the highest clay fraction required the most fluid impregnating agent.

Samples were sectioned along a plane which provided the best exposure of intra-macrofossil sediment character. Slides were prepared for both intra- and extra-macrofossil sediment for 117 samples. Intra- and extra-macrofossil sediment may be on the same or separate slides depending on the size of the sample.

Each intra-macrofossil and each extra-macrofossil portion of the variable samples had a total of 300 points counted as three 100 point count trials. All material within microfossils was counted as the microfossil itself. This material was also counted separately to ascertain whether there was a difference in intra-microfossil sediment between samples of a given location, and to judge whether this difference would alter the composition determined by my original point counts. Components point counted are listed in Table 3. In order to sort samples which showed no differences between internal and external sediment character into grain size groups, these samples were point

TABLE 2. PERCENT CARBONATE SEDIMENT OF THE TOTAL DETRITAL MATERIAL
FOR EACH SAMPLED FORMATION AND LOCATION BASED ON POINT
COUNT DATA

FORMATION	LOCATION	% CARBONATE SEDIMENT
Unnamed Shell Unit	Lee Creek Mine	9
Flanner Beach	Flanner Beach-Neuse River	1
Croatan	Lee Creek Mine	39
Yorktown	Lee Creek Mine	70-turretellid bed
Yorktown	Rainbow Banks Landing	6
Yorktown	Green Mill Run	3
Pungo River	Lee Creek Mine	43-phosphorite interval 82-carbonate interval
Belgrade	Martin Marrietta Quarry	54
Castle Hayne	Lanier Quarry	100
Castle Hayne	Ideal Cement Quarry	97
Castle Hayne	East Coast Quarry	93
Castle Hayne	Fussell Quarry	81
Beaufort	Mosely Creek	91
Peedee	Ideal Cement Quarry	54
Peedee	Green Mill Run	9

counted for two components: fine grains and coarse grains. The data is presented in Appendix B. The grain size group sorting will be discussed at the end of this section.

TABLE 3. EXAMPLE OF POINT COUNT DATA SHEET

Micrite:	Terrigenous Grains:
Microspar:	quartz
Calcite Spar:	sedimentary rock fragments
equant	meta. and ig. rock frags.
bladed	clay
isopachous	feldspar
fibrous	mica
drusy	chlorite
syntaxial overgrowth	Orthochemical Grains:
Porosity:	glauconite
interparticle	phosphate
moldic	pyrite
vug	hematite
shrinkage	chert
shelter	evaporites
Peloids:	
Bioclasts:	
foraminifers	
ostracodes	
molluscs	
barnacles	
worm tubes	
bryozoans	
brachiopods	
bone fragments	
crab fragments	
echinoderms	
plant fragments	
coral	
algae	

X-ray diffraction with Cu-K α radiation was used to identify cryptocrystalline dolomite present in some samples. The (104) reflection plane, which yielded a peak at $31^{\circ} 2 \theta$ ($d=2.88\text{\AA}$), was used to identify dolomite. With the goniometer first set on the (104) dolomite peak and then set on the (104) calcite peak, ten second counts

were taken to measure the general relative intensity of the two peaks and therefore the general relative abundance of the two minerals (Brown, 1972). Samples included in the x-ray diffraction analyses were either in the form of a thin section or a powder adhered to a glass slide by silicon gel. The Mineral Powder Diffraction File Search Manual (1980) and Brown (1972) were used to identify peaks. Scanning electron microscopy was used to confirm x-ray identification of cryptocrystalline dolomite and also to visually check abundance.

After petrographic examination and point counts were completed, mean values were calculated for each component within: (1) the intra-macrofossil portion for each sample, (2) the extra-macrofossil portion for each sample, (3) the intra-macrofossil portion together with the extra-macrofossil portion for each sample, (4) all intra-macrofossil portions at a location, (5) all extra-macrofossil portions at a location, and (6) all intra- plus extra-macrofossil portions at a location. Point count data is presented in Appendix A and sample codes are listed in Table 4.

Samples were categorized by five variable properties, which correspond to the five major sample groups listed in Table 5. Each sample falls into one of the categories within each major sample group. Therefore, each sample fits into a slot defined by a specific combination of categories of the five sample groups. For each slot, the number and the percentage of samples having a variation between intra- and extra-macrofossil sediment character were determined to search for trends in frequency of variation. Some categories are limited in sample number and therefore could not be evaluated relative to the categories

in the other major sample groups. For example, there are few moldic samples in the terrigenous group and therefore moldic type could not be evaluated as a subcategory for the terrigenous group. All percentages in this study are rounded to the nearest whole number.

TABLE 4. LOCATION/FORMATION IDENTIFICATION OF SAMPLE NUMBER CODES

PI-	Rocky Point Member of the Peedee Formation; Ideal Cement Quarry; New Hanover County, North Carolina
PG-	Peedee Formation; Green Mill Run; Pitt County, North Carolina
BM-	Beaufort Formation; Mosely Creek; Lenoir-Craven County Line, North Carolina
CI-	Castle Hayne Limestone; Ideal Cement Quarry; New Hanover County, North Carolina
CF-	Castle Hayne Limestone; Fussel Quarry; Duplin County, North Carolina
CL-	Castle Hayne Limestone; Lanier Quarry; Pender County, North Carolina
CE-	Castle Hayne Limestone; East Coast Quarry; Pender County, North Carolina
BLM-	Belgrade Formation; Martin Marietta Quarry; Onslow County, North Carolina
PL-	Pungo River Formation; Lee Creek Mine; Beaufort County, North Carolina
YL-	Yorktown Formation; Lee Creek Mine; Beaufort County, North Carolina
YT-	Yorktown Formation; Tar River; Pitt County, North Carolina
YG-	Yorktown Formation; Green Mill Run; Pitt County, North Carolina
CRL-	Croatan Formation; Lee Creek Mine; Beaufort County, North Carolina
FN-	Flanner Beach Formation; Neuse River; Craven County, North Carolina
UL-	Upper Shell Unit; Lee Creek Mine; Beaufort County, North Carolina

TABLE 5. MAJOR SAMPLE GROUPS

Fossil Groups: bivalves, gastropods, brachiopods, echinoids, crabs,
oysters

Rock Type Groups: terrigenous, carbonate, phosphorite

Moldic Type Groups: non-moldic, moldic

Grain Size Groups: 1, 2, 3, 4 (See Table 6)

Epochs: Pleistocene, Pliocene, Miocene, Eocene, Paleocene, Cretaceous

In order to sort samples into one of the four grain-size groups, the following procedures were used. Each sample component included in the point counts was first separated into one of two grain size categories. Micrite, microspar, detrital clay, and clay-sized dolomite were included in the fine category. All other grains, excluding authigenic minerals (but including coarse replacement dolomite) were included in the coarse grain category. A ratio of the number of fine grains to the number of coarse grains was calculated for the intra-macrofossil and for the extra-macrofossil portion for each sample. The value of this ratio was used to sort each portion of each sample into a grain size group (Table 6).

TABLE 6. GRAIN GROUPS

Fine Grains/ Coarse Grains	Group
$F/C < .33$	1
$.33 \leq F/C < 1$	2
$1 \leq F/C < 3$	3
$3 \leq F/C$	4

A ratio had to be calculated for each portion of each sample (as opposed to one ratio for an entire sample) because the internal and external sediments (portions) were frequently of different grain sizes.

Chi-square values and contingency coefficients were calculated for each major sample group. These values can be found at the end of the Discussion section (Tables 38 and 39).

VARIATION BETWEEN INTRA- AND EXTRA-MACROFOSSIL SEDIMENT

Differences in sediment character between intra- and extra-macrofossil sediment can be produced diagenetically and/or depositionally. Variation in sediment character between intra- and extra-macrofossil sediment has been assessed by visual observation. Degree and frequency of variation were quantified by point count data. Differences in the amount and type of diagenetic products between internal and external sediments can result from the shell protecting the internal sediment (while allowing exposure of external sediment) from diagenetic agents. The amount of variation between the internal and external sediment will depend on (1) the degree of closure and strength of the shell, (2) the nature and duration of diagenetic action, and (3) the mineralogy and texture of the sediment. The internal sediment may be protected by the shell only from some diagenetic agents. For example, a shell may be rigid enough to protect the internal sediment from the compactional pressure that external sediment is receiving, but not from the penetration of calcium carbonate-saturated waters.

Variation in sediment character between internal and external sediment can also be produced by depositional processes. Variations of this sort do not reflect a macrofossil's ability to protect the internal sediment from diagenetic alteration. Samples with depositional differences can be useful in that they may provide information on current activity or sediment source. These differences are discussed at the end of this section.

Twenty-six percent of the samples studied show a diagenetic variation between internal and external sediment. Fifteen percent show a depositional variation. Five percent have both diagenetic and depositional variations. Variations produced by diagenetic processes will be discussed first. Refer to Table 4 for sample codes, Appendix A for point count data, Appendix C for sample group identification, and Appendix D for description of variation in each sample. A flowchart of the diagenetic pathways leading to the most frequent variations in sediment character between intra- and extra-macrofossil deposits is presented in Figure 3.

DIAGENETIC VARIATION

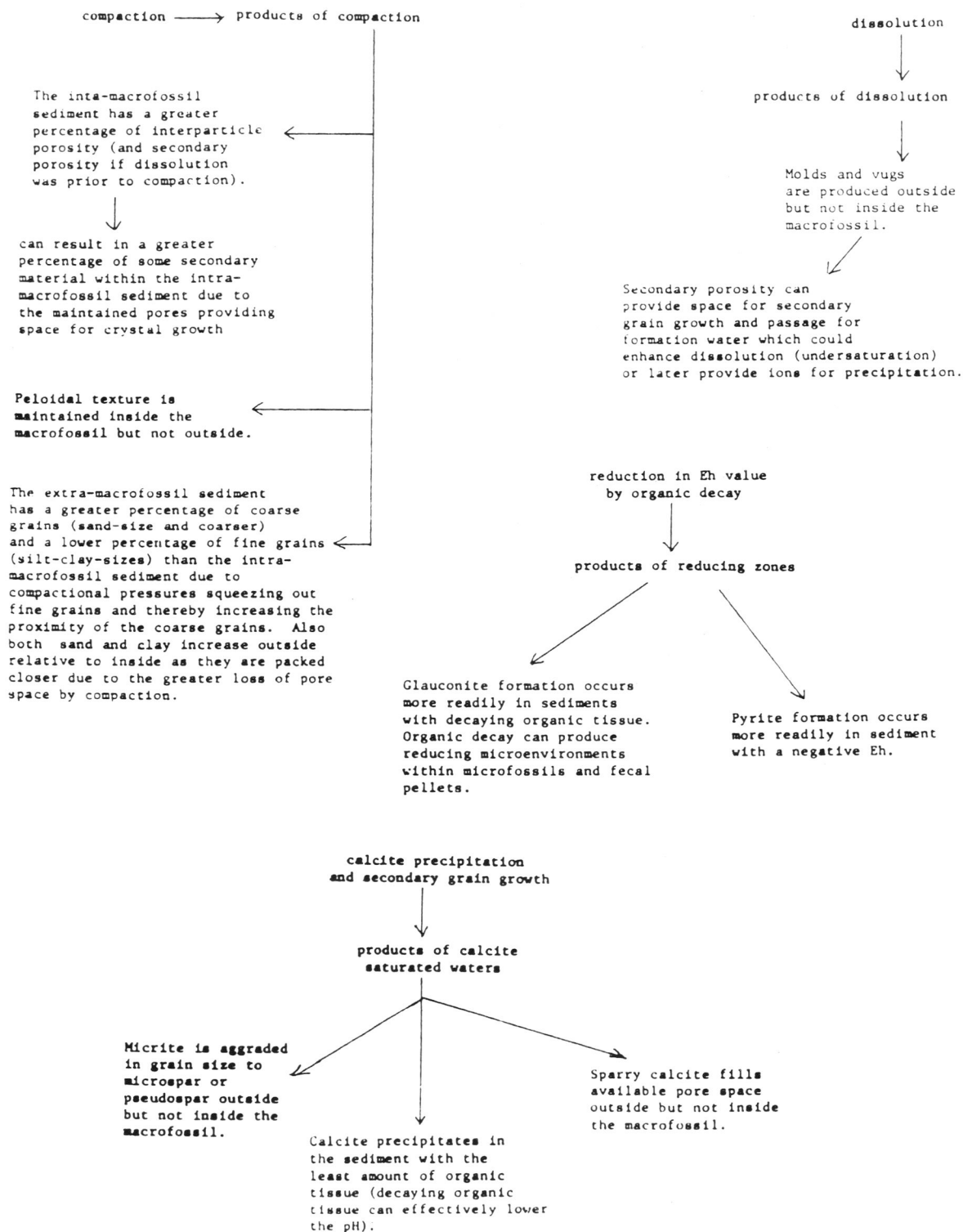
Variation in diagenetic products between intra- and extra-macrofossil sediment suggests that macrofossils are capable of acting as a diagenetic barrier. Variations observed during the course of this study will be presented and the causes postulated.

The most frequently observed diagenetic differences between internal and external sediment character result from variations in (1) calcite dissolution and precipitation (the shell is a permeability barrier), (2) fabrics and textures (the shell is a barrier preventing compaction of internal sediment), and (3) authigenic mineralization (the interior of the shell can provide an isolated chemical environment).

Calcite Dissolution

Six samples (PI-2, CI-4, CI-5, CI-43, CI-44, and CI-45) have greater percentages of secondary porosity within the extra-macrofossil sediment (Fig. 4). The external sediment may have had more extensive

FIGURE 3. IDEALIZED FLOWCHART OF THE DIAGENETIC PROCESSES NOTED TO HAVE PRODUCED A VARIATION BETWEEN INTRA- AND EXTRA-MACROFOSSIL SEDIMENT CHARACTER



exposure to solutions undersaturated with respect to calcium carbonate than did the internal sediment due to the shell acting as a barrier against solution passage. Similar fossil types in both intra- and extra-macrofossil sediment, for each of these samples, negates the possibility of mineralogy controlling variation in dissolution.

Calcite Precipitation

If the macrofossil is an effective barrier, undersaturated as well as saturated solutions would be unable to significantly penetrate the shell. Internal sediment would maintain more of the original character than would external sediment. Excluding calcium carbonate-saturated waters from the shell interior can produce a variation in the degree of aggradation of micrite grain size and the precipitation of calcite spar cements.

Micrite has aggraded to larger grain sizes within the external sediment in some samples (CI-5, CI-42, CE-20, and BLM-3) (Fig. 5). In sample PI-2, the internal micrite matrix has aggraded to microspar only in spots, while the external matrix has completely aggraded to microspar. The external matrix likely has had more extensive exposure to calcium carbonate-saturated waters (Folk, 1959).

Several of the samples have a greater percentage of calcite spar within the shell (PI-7-1, PI-7-2, BM-6, BM-7, CI-4, CI-5, CI-21, CI-47, CE-2, CE-8, CE-9, CE-20, and CF-3) (Figs. 6 and 7). A greater percentage of calcite spar inside the shell can not be explained as easily as a greater percentage outside the shell. A greater percentage of calcite spar outside the shell could be explained by the shell acting

FIGURE 4. PHOTOMICROGRAPHS OF THE INTRA-MACROFOSSIL (TOP) AND THE EXTRA-MACROFOSSIL (BOTTOM) SEDIMENT OF SAMPLE CI-43

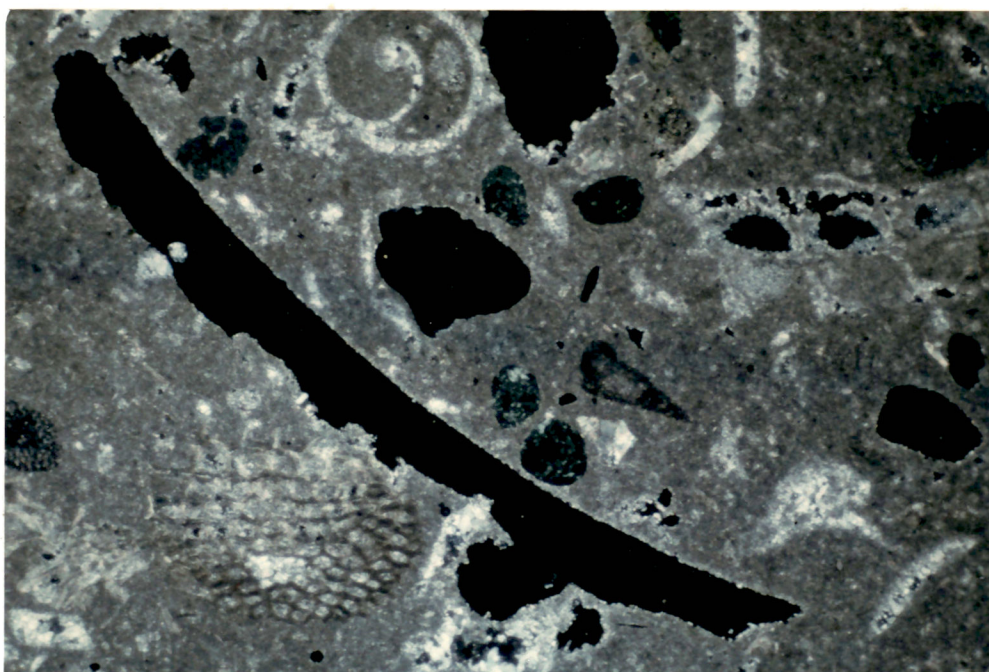
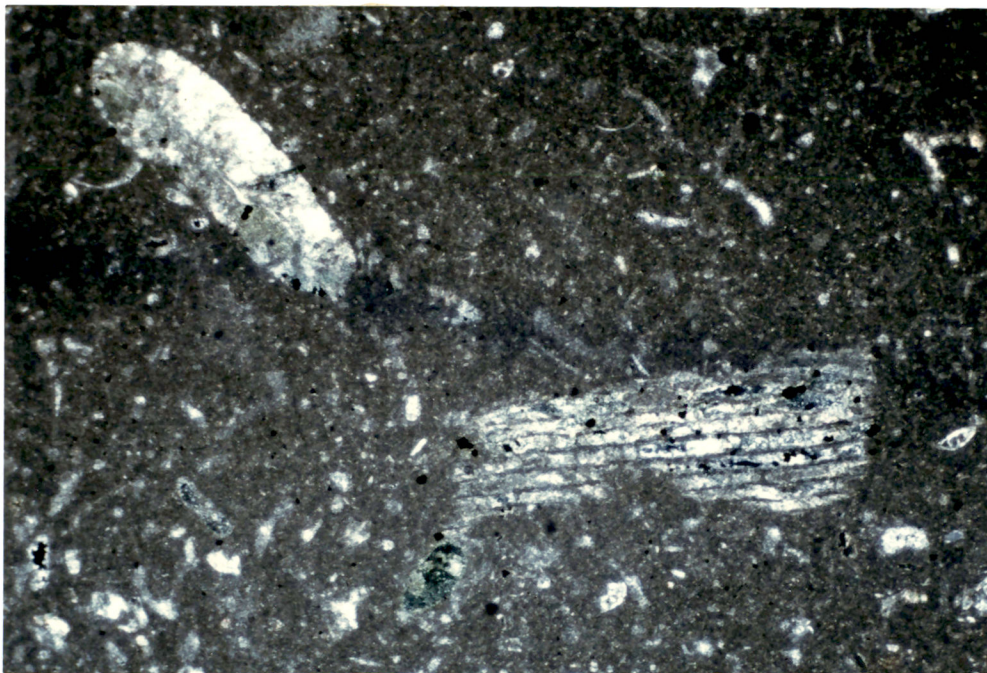
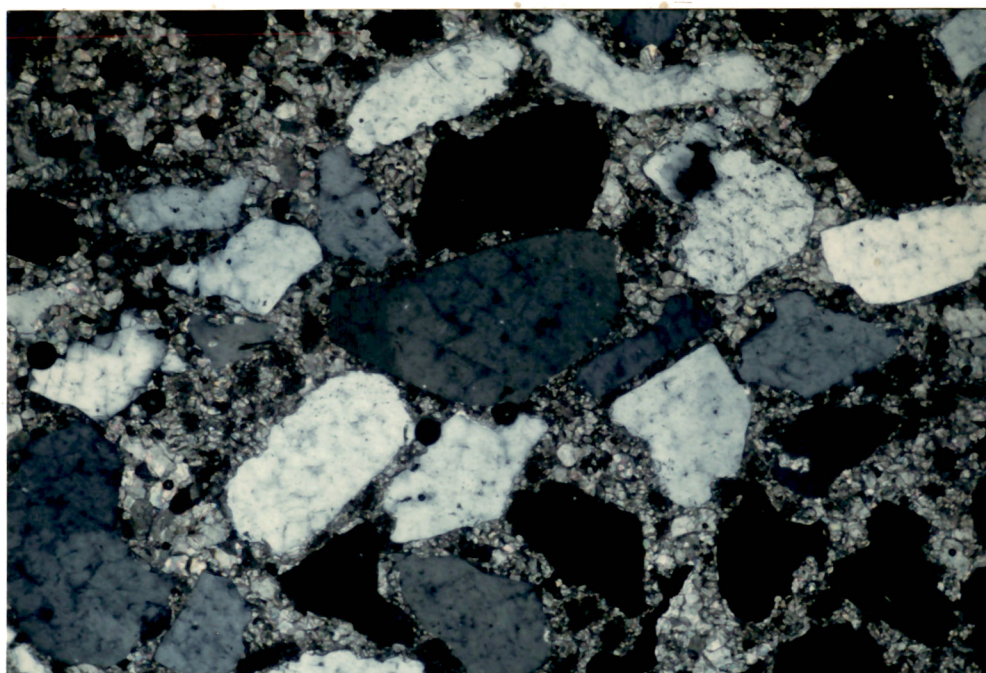
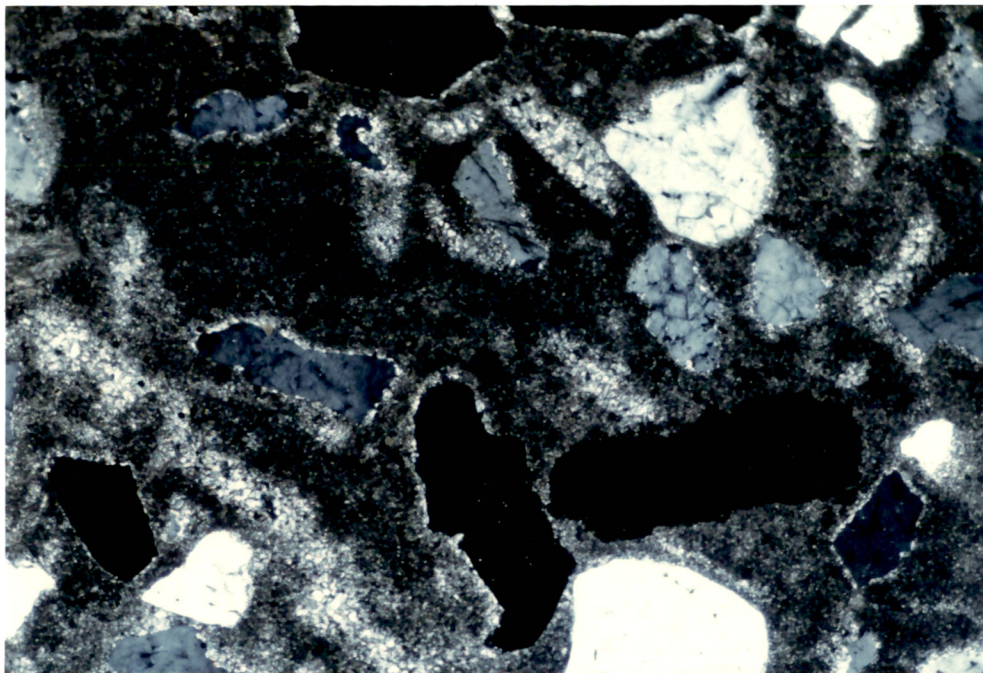


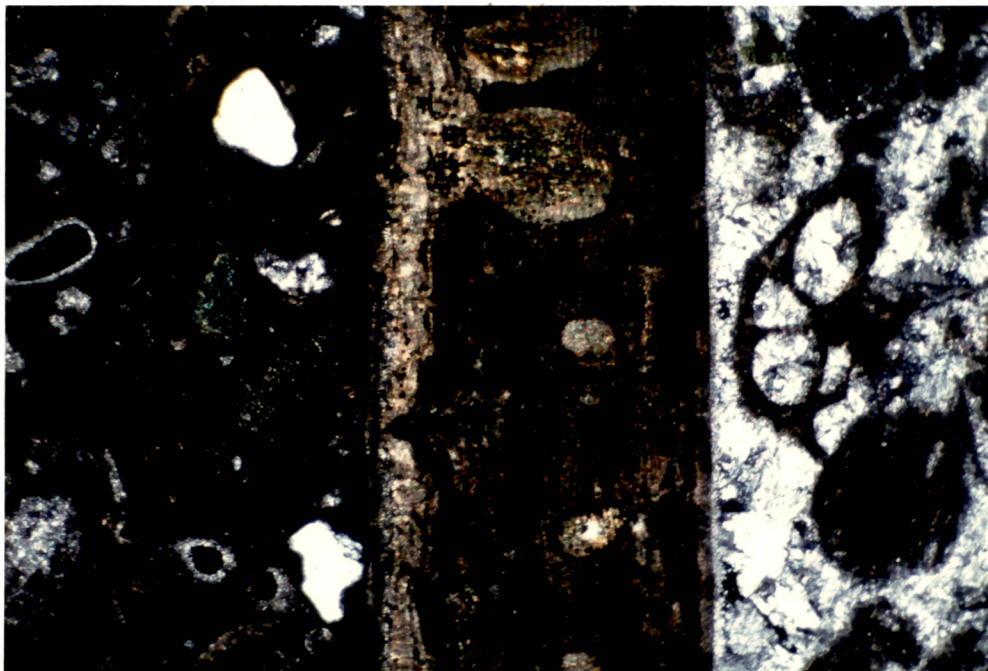
FIGURE 5. PHOTOMICROGRAPHS OF THE INTRA-MACROFOSSIL (TOP) AND THE EXTRA-MACROFOSSIL (BOTTOM) SEDIMENT OF SAMPLE BLM-3



as a permeability barrier, preventing internal precipitation of cements. In order to determine the process(es) involved in precipitating a greater percentage of calcite spar internally, the factors governing calcite precipitation must be considered. Chemical conditions favoring calcite spar precipitation may have been different between intra- and extra-macrofossil sediments. In order for calcite to precipitate inside the shell, calcium carbonate-saturated waters must first permeate pore space outside the shell. If external porosity and permeability are sufficiently high to allow solution migration, yet pore size is very small outside versus inside, coarse spar cements may precipitate only within the shell, while fine cements would precipitate outside. Pore size and not pore volume would be the limiting factor.

Calcite solubility decreases with increasing temperature, calcium concentrations, evaporation, and with decreasing $p\text{CO}_2$ and concentrations of sodium salts (Chilingar, Bissell, and Wolf, 1979). The concentration of phosphate and magnesium ions can also influence calcite precipitation. Orthophosphate ions attach to kinks on calcite grains and inhibit crystal growth or dissolution (Berner and Morse, 1974). When the Mg/Ca ratio is greater than about 3 or 4 at 20°C , aragonite and high-Mg calcite will precipitate instead of low-Mg calcite (Von Engelhardt, 1977). Magnesium ions can inhibit low-Mg calcite precipitation (Von Engelhardt, 1977). There is no evidence to suggest that sodium salts, calcium, magnesium, and phosphate ion concentrations or temperature were different inside versus outside the macrofossil. These probably were not limiting factors.

FIGURE 6. PHOTOMICROGRAPH OF SAMPLE CE-20 (RIGHT-INTRA, LEFT-EXTRA)



The pH can be altered by anaerobic bacterial activity. Reduction of sulfate by anaerobic bacteria produces H_2S . If iron is present, the sulfur is fixed as iron sulfides. The result is an increase in pH, due to a reduction in the amount of H_2SO_4 that is produced. An increase in the amount of ammonia (a by-product of reduction of sulfate) also encourages calcite precipitation (Wardlaw and Reinson, 1971). If iron is not present, the water will become acidic (Chilingar, Bissell, and Wolf, 1979). If iron were only available inside the macrofossil, the water inside the macrofossil would have a higher pH value than the water outside. A variation in the amount of anaerobic bacteria (and sulfate reduction) could also produce a variation in the amount of H_2SO_4 and, therefore, a variation in pH. If anaerobic bacteria were more abundant outside the macrofossil (and in the absence of iron), a lower pH could result. Anaerobic bacteria require a source of carbon and oxygen (Chilingar, Bissell, and Wolf, 1979). Organic tissue is a frequent source of these elements in the marine system. Organic tissue may have only been available outside the shell. Evidence for anaerobic bacteria and organic debris is not usually (and not in this case) preserved in the sediment record.

Compaction

The macrofossil can act not only as a permeability barrier but also as a structural barrier protecting the internal sediment from compaction. Lime sediments can compact to half their depositional volume under overburden of as little as 100 meters (Choquette and Pray, 1960). Compaction can increase the coarse to fine ratio of grains by (1) expelling pore water, thereby reducing the clay or lime mud volume;

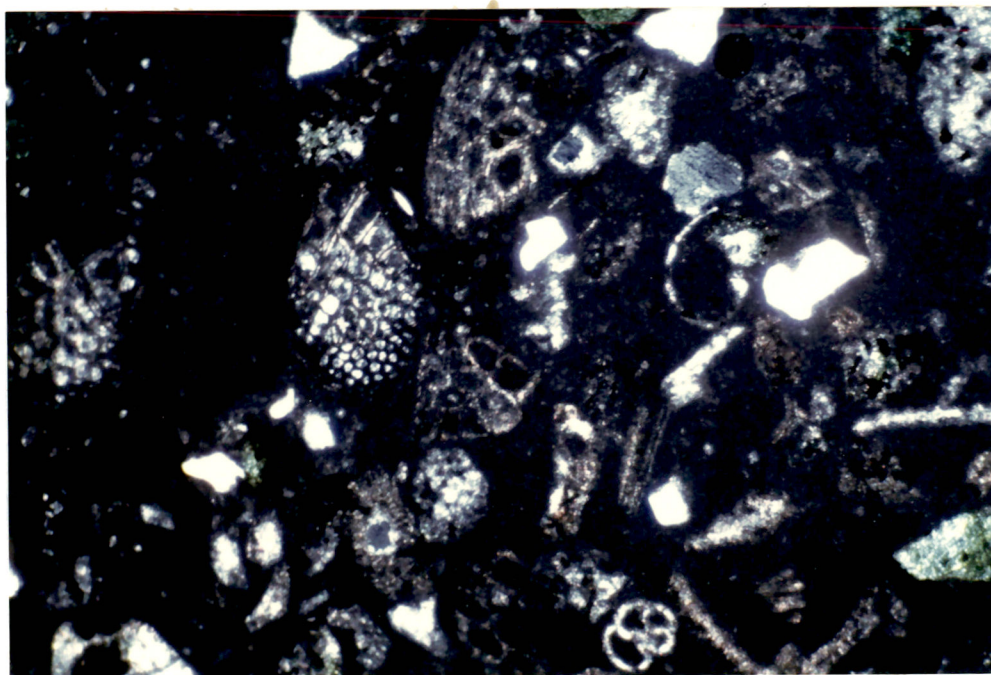
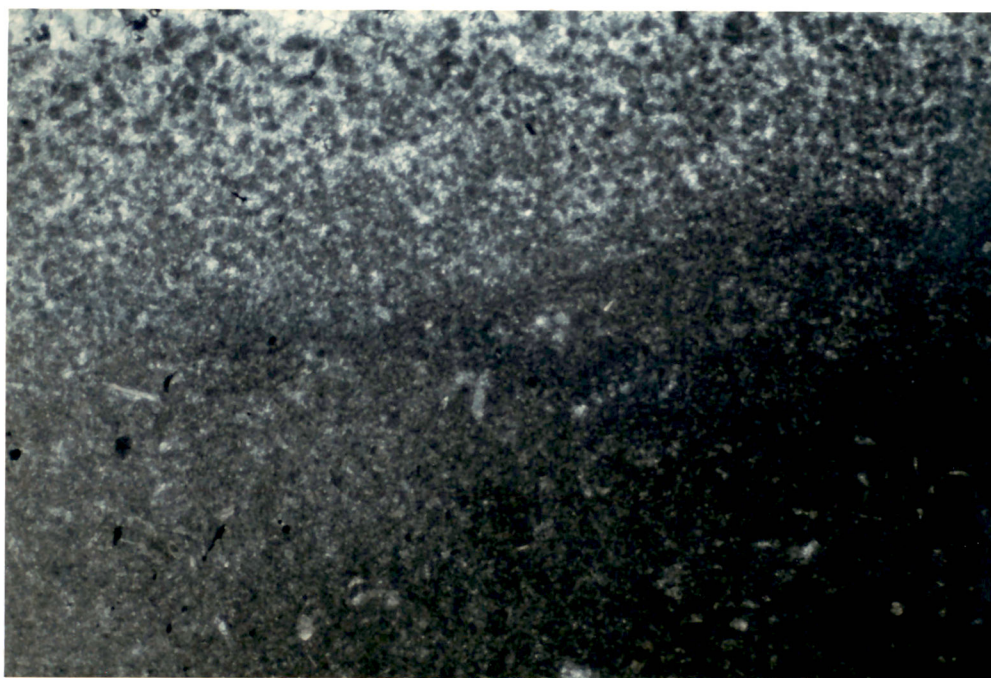
(2) orienting platy clay grains for closer packing, which would also reduce clay volume; and (3) compressing fine grains into available pore spaces. If the extra-macrofossil sediment has a significantly higher coarse/fine ratio, it may have experienced more compaction than the protected intra-macrofossil sediment. The variation in the ratio of coarse to fine grains can be produced both diagenetically and depositionally. If the opening(s) into the shell was too small for large grains to pass, the internal sediment would have a greater percentage of fine grains. If large grains are present both inside and outside, and uniformly spread throughout the matrices, a greater abundance outside, would not be the result of the size of the opening(s) into the shell. The higher ratio of coarse to fine grains would more likely have resulted from compaction of the external sediment. In samples which have coarse grains both inside and outside, the higher ratio of coarse to fine grains outside the shell was attributed to compaction. In samples with coarse grains only outside the shell, the higher ratio was attributed to selective sieving by the shell (depositional variation). Comparing coarse to fine ratios of internal and external sediments for each sample, 15 samples have significantly higher coarse to fine ratios (ratios are sufficiently different to classify internal and external sediments into different grain size groups) in the external sediment (Fig. 4). In ten samples, the ratio is interpreted as the result of compaction for the reasons presented (PI-2, CI-3, CI-4, CI-31, CI-43, CI-44, CI-45, CL-12, CE-9, and YL-1).

A greater percentage of micrite outside the macrofossil can also result from compaction. If the original sediment both inside and outside was predominantly fine grained and porous, subsequent compaction of the external sediment would increase the percentage of fine grains by relatively decreasing the percentage of porosity. Samples PI-7-1, CI-5, CE-8, and CE-20 are evidence of this. Micrite to pore space ratios as well as coarse to fine grain ratios must be checked.

Compaction can reduce the percentage of interparticle porosity outside the macrofossil. Samples PI-7-2, BM-6, YG-12, and YL-1 have lower percentages of interparticle porosity outside the macrofossil. Sample CI-21 has a greater percentage of interparticle porosity outside the macrofossil. The morphology of this gastropod has protected some external sediment from compaction. A portion of external sediment, caught beneath the cone of the gastropod and against the depositional surface, was protected from compaction. Variation in grain size between internal and external sediment can also produce a variation in percent interparticle porosity. An uncompacted mud within the shell could have a greater percentage of pores than a sandy external matrix (depositional features).

Compaction can also destroy peloidal texture. Peloids are present inside but not outside the macrofossil in samples CI-41 and CE-9 (Fig. 7). Compaction has altered the external peloids to a textureless mud. Whether the peloids are "hardened" or not at the time of deposition partly governs whether or not the peloids will resist compaction and be preserved (Chilingar and others, 1979a).

FIGURE 7. PHOTOMICROGRAPHS OF THE INTRA-MACROFOSSIL (TOP) AND THE EXTRA-MACROFOSSIL (BOTTOM) SEDIMENT OF SAMPLE CI-41

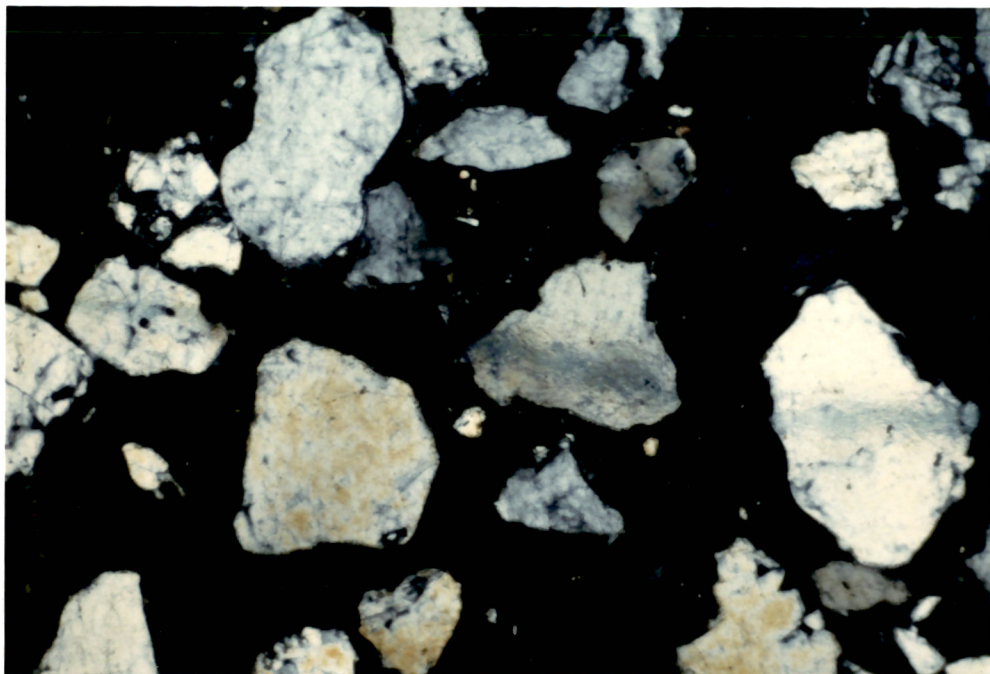


Glaucunitization

The percentage of glauconite varies significantly between intra- and extra-macrofossil sediment in 4 samples (BM-6, BM-7, BM-10, and PG-11). Two samples have greater percentages of glauconite inside and two samples have greater percentages outside. Glauconite formation is most favorable with a pH of 7 to 8, a negative sedimentation rate, a temperature range of 15° to 20° C, low water turbulence, and a negative Eh value (McRae, 1972). All of these factors were likely the same inside and outside the macrofossil, except possibly Eh. Glauconite is frequently associated with reducing microenvironments produced by the decay of organic tissue (McRae, 1972). Sediment with a greater percentage of reducing microenvironments could more readily produce a greater percentage of glauconite. Also, the extra-macrofossil clay in sample PG-11 may have provided more of the ions necessary for glauconitization (Fig. 8). Fe, K, and Mg must be available for glauconitization (Cloud, 1955).

The percentage of glauconite in two Paleocene samples (BM-6 and BM-7) is greater inside the shell. BM-6 has 17.3% glauconite inside and 3.3% outside the shell. BM-7 has 19.3% inside and 3.0% outside. A third Paleocene sample (BM-10) has a greater percentage of glauconite outside the shell. The internal matrix has 8.7% and the external matrix has 15.0% glauconite. Glauconite is more abundant in the extra-macrofossil sediment in one Paleocene sample and yet more abundant in the intra-macrofossil sediment in the other two. This may be explained by differing amounts of organic debris buried within the sediment inside and outside a fossil from place to place.

FIGURE 8. PHOTOMICROGRAPHS OF THE INTRA-MACROFOSSIL (TOP) AND THE EXTRA-MACROFOSSIL (BOTTOM) SEDIMENT OF SAMPLE PG-11



The amount of pore space may have played a more important part. Glauconite occurrence could also be a function of porosity. In the Paleocene samples, a general correlation exists between percent porosity and percent glauconite (Table 7). In the samples with a greater percentage of glauconite inside, there is also a greater percentage of porosity. The percentage of glauconite generally increases with an increase in porosity. This may be due to ion diffusion for glauconitization being more efficient where greater pore space exists.

TABLE 7. PERCENTAGE OF GLAUCONITE AND POROSITY IN THE PALEOCENE SAMPLES HAVING A VARIATION IN SEDIMENT CHARACTER BETWEEN INTERNAL AND EXTERNAL SEDIMENT

Sample #	% Glauconite	% Porosity
BM-7 intra	19.3	21.7
BM-6 intra	17.3	14.0
BM-10 extra	15.0	4.3
BM-10 intra	8.7	4.0
BM-6 extra	3.3	4.0
BM-7 extra	3.0	5.0

Pyritization

Samples YG-12 and YL-1 have a greater percentage of pyrite outside the macrofossil. FN-2 has a greater percentage of pyrite inside the macrofossil. In sample YT-1, iron is present as pyrite outside the shell, but only as a stain on clays inside. Where there is a greater percentage of pyrite, there also must have been a greater or more renewable source of iron. Iron may be supplied as adsorptions on clays or organics, carried in solution as a colloid, or oxidized to hematite

(Tucker, 1981). In sample YT-1, a source of iron was not a limiting factor preventing pyrite formation inside the shell (pyrite outside, iron-staining inside). Factors which control the precipitation of iron minerals include Eh, pH, concentration of CO_3 ions, and the activity of sulfur (pS^{2-}) (Tucker, 1981). Sulfide ions are provided mainly by the bacterial reduction of sulfate in pore water, but are also provided by proteins from decaying organic tissue (Von Engelhardt, 1977). The availability of sulfate ions is probably not the limiting factor in this sample, with seawater present both inside and outside the shell providing a more than sufficient supply. Anaerobic bacteria that reduce sulfate can be found at depths of thousands of meters, and can tolerate wide ranges in pH, temperature, and pressure. These bacteria, however, only survive under anaerobic conditions (Von Engelhardt, 1977). The Eh must be negative for anaerobic reduction of sulfate. Therefore, pyrite formation is associated with negative Eh values. Bacterial decomposition of organic matter can effectively lower Eh. The lack of iron as pyrite inside the shell may have been caused by a lack of organic matter within the shell to create a local reducing zone habitable to anaerobic bacteria. The Eh value may have allowed pyrite formation outside and not inside the macrofossil.

Dolomitization

Two Pliocene samples have variations in dolomite between internal and external sediment. The internal and external matrices of sample YL-1 are mostly dolomite (both approximately 94% dolomite based on x-ray diffraction data). Dolomite within the macrofossil is coarser grained than dolomite outside. Greater initial porosity within the shell

(porosity maintained inside the shell by protection from compaction) may have provided larger pores allowing grains to grow to larger sizes. Whether the initial grains were aragonite, calcite, or dolomite, the interparticle porosity could still have determined the size to which the grain would grow (aggradation of grain size or multiple generations of growth).

In sample YL-9 the matrix within the shell underwent more extensive dolomitization than the external matrix (greater dolomite:calcite ratio by x-ray diffraction data). The internal sediment is approximately 91% dolomite and the external sediment 71%. The internal matrix may have achieved an overall higher Mg/Ca ratio. The Mg/Ca ratio of the formation water can be increased by (1) high-Mg calcite to low-Mg calcite conversion, (2) clay mineral contributions, (3) freshwater recharge, (4) precipitation of Ca minerals, and (5) sulfate reduction. Sulfate reduction produces NH_4^+ as a by-product, which frees Mg^{2+} by substitution in silicate minerals (Bukes and Kastner, 1981). Bukes and Kastner state that sulfate ions also act as inhibitors on dolomitizing surfaces. Sulfate reduction would then encourage dolomitization. Both intra- and extra-macrofossil sediments were probably equally effected by most of the factors above. The internal and external sediments have nearly equivalent percentages of high-Mg calcite fossils and clay minerals. Since dolomite is present both inside and outside (and with a greater percentage inside), both must have been exposed to dolomitizing solutions. Freshwater recharge and calcium carbonate-saturated waters should then have been able to permeate both internal and external sediment. If sulfate ions were more frequently reduced within the

macrofossil by bacteria, dolomitizing surfaces would be less inhibited by sulfate ions inside. Bacteria would have to be more abundant per volume of sediment within the shell for this to be a factor. If organic tissue (nutrient supply for bacteria) were more abundant within the shell, the bacteria may more readily flourish. The greater percentage of dolomite of the total carbonate in the intra-macrofossil sediment could also have been achieved by Mg depletion. Dolomite may have precipitated both inside and outside the macrofossil until Mg was depleted (or became sufficiently low). From that point, low-Mg calcite was free to precipitate. Low-Mg calcite precipitation can be inhibited by Mg ions (Drever, 1982)). The external sediment could then have obtained more calcite by being exposed to calcium carbonate-saturated waters. Dolomitization may have provided additional closure for the intra-macrofossil sediment which would prohibit further precipitation within the shell. The proportion of dolomite to calcite would then become lower outside the macrofossil. The external matrix may also be more dolomitic if the precursor material was finer grained inside the macrofossil. Finer grains are more subject to dolomitization due to greater surface area per unit volume.

DEPOSITIONAL VARIATION

Samples with only depositionally produced variations between intra- and extra-macrofossil sediment do not reflect a macrofossil's ability to protect the internal sediment. In the samples with variations due to depositional processes, the internal matrix may not be an accurate representation of the depositional environment. The difference in

intra- and extra-macrofossil sediment character might have arisen by selective sieving of grains by the size of the opening(s) into the shell and/or the shell acting as a low-energy pocket within a higher-energy regime. The first reason could yield a predominantly fine-grained intra-macrofossil deposit, whereas the latter reason would likely yield a fine plus coarse-grained intra-macrofossil deposit (if fine plus coarse grains were being carried by the moving water). False interpretations of the depositional environment might be produced when using only the internal matrix of these depositionally-variable samples. The fine grains captured would indicate a lower-energy regime than really existed. Intra-macrofossil sediment must be observed in conjunction with extra-macrofossil sediment when reconstructing the depositional environment.

The intra-macrofossil portions of depositionally-variable samples do have their place within the interpretation. Drastic differences in sediment character inside versus outside the shell might indicate transport of the intact macrofossil from an adjacent depositional system. Also, the fine grains captured within the shell (if not present outside the shell due to selective winnowing of the fine grains) might give clues to total sediment influx into the depositional basin, or clues on proximal depositional regimes (clay minerals possibly indicating source). The shell would act as a low-energy pocket capturing fine grains that would otherwise remain in suspension and be carried off outside the shell. If a depositional variation is observed, it should be considered when making interpretations of the depositional environment.

Five types of depositional variations between intra- and extra-macrofossil sediment were observed during the course of this project. These variations are: (1) the intra-macrofossil sediment has a coarser grained assemblage than the extra-macrofossil sediment, (2) clay is present as mud clasts within the shell but is disseminated outside the shell, (3) the intra-macrofossil sediment has a finer grained assemblage than the extra-macrofossil sediment, (4) the intra-macrofossil sediment has a greater percentage of interparticle porosity than does the extra-macrofossil sediment, and (5) extra-macrofossil sediment is more poorly sorted.

The intra-macrofossil sediment has a coarser grained assemblage in samples PI-7-1, PG-11, BM-2, CI-47, YT-7, YT-10, YG-9, YG-10, YG-12, FN-1 and CRL-3. The shell may have captured the internal sediment during higher energy episodes. The external sediment, with a greater percentage of fine grains, may have accumulated as water energy decreased.

The samples with clay as mud clasts or clumps within the macrofossil are YT-8 and FN-12. The extra-macrofossil sediment was subjected to water energy levels that the intra-macrofossil sediment, being protected by the shell, was not. Mud clasts are dispersed outside the macrofossil, but intact inside. Bioturbation may also have disaggregated mud clumps.

The intra-macrofossil sediment has a finer grained assemblage in samples CI-41, CI-42, YG-1, YL-5, and CRL-3. The size of the opening(s) into the macrofossil was likely too small to allow coarser grains to enter the intra-macrofossil portion of these samples.

The samples which have a greater percentage of interparticle porosity inside the shell are YG-9 and YG-10. This greater percentage of porosity within the shell is due to the coarser grained matrix (less compactable) producing larger interparticle pores. Even though the macrofossil might have protected the internal sediment from compaction, coarser grain character would play the major role in maintenance of pore space (during early diagenesis) by resistance to compaction. Since the coarser grained assemblage inside is a depositional feature, the variation in interparticle porosity here is a product of depositional (grain size) and possibly diagenetic (compaction) influence.

In one sample (YG-12), the external sediment is more poorly sorted. The shell may have captured more quartz sand during a high energy episode, for example during a storm or tidal event. The more poorly sorted external sediment probably accumulated as water energies subsided. The poorer sorting of grain sizes could be due to rapid burial of the macrofossil.

DISCUSSION

Samples with lithologic differences between intra- and extra-macrofossil sediment due to diagenesis are termed "variable" samples. Those samples with no observed diagenetic differences are termed "non-variable" samples. The five major sample groups (Table 5) were analyzed for their part in producing variation between intra- and extra-macrofossil sediment character. Twenty-six percent of all the samples are variable. Reasons for 74% of the samples being non-variable will be presented at the end of this section. One should keep in mind while reading the following text that factors which least promote variation between internal and external sediment are factors likely promoting non-variability.

CARBONATE VERSUS TERRIGENOUS VARIABILITY

Samples were separated into two groups based on rock type: terrigenous-dominated (less than 50% carbonate sediment) and carbonate-dominated (greater than 50% carbonate sediment). Carbonate percentages for each location/formation are given in Table 2. Carbonate-dominated samples will hereafter be referred to as the carbonate group/samples and terrigenous-dominated samples as the terrigenous group/samples. The one phosphorite sample in this study is separated from these two groups.

Thirteen percent of the terrigenous samples and 34 percent of the carbonate samples are variable. The higher percentage of variation within the carbonate group is partly due to the fact that the carbonate samples in this study are older than terrigenous samples (Table 8). The older samples have had more opportunity to be exposed to diagenetic

agents. The carbonate samples are Pliocene to Cretaceous in age. The terrigenous samples are Pleistocene to Pliocene in age, with the exception of one Cretaceous sample.

TABLE 8. NUMBER OF CARBONATE, TERRIGENOUS, PHOSPHORITE, AND TOTAL SAMPLES IN EACH EPOCH

	Pleistocene	Pliocene	Miocene	Eocene	Paleocene	Cretaceous
Carbonate	0	10	3	47	8	8
Terrigenous	22	17	0	0	0	1
Phosphorite	0	0	1	0	0	0
Total	22	27	4	47	8	9

Fossil type, grain size, and moldic type were investigated to determine if any had influenced sample variability in the carbonate and terrigenous groups. The terrigenous group is composed mainly of gastropods and bivalves, two fossil groups with higher percentages of variable samples (Table 14). Hence, fossil type is not the cause of carbonate variation exceeding terrigenous variation.

Grain group 4 is the most variable grain group (highest % of variable samples) followed by grain group 2 for the terrigenous group and grain group 1 for the carbonate group (Tables 10 and 11). The variability of grain groups will be discussed later in more detail. Table 15 shows that grain group 4 composes 6% and grain group 1 composes 18% of the carbonate samples. Grain group 4 composes 15% and grain group 2 composes 39% of the terrigenous samples. The sum of percentages of samples from the two most variable grain groups within carbonate samples (24%) is less than the sum from the two most variable

TABLE 9. PERCENTAGE OF VARIABLE SAMPLES IN THE FOSSIL AND GRAIN GROUPS

Fossil Group	1	G r a i n 2	G r o u p 3	4	%-ByFossil Group
Bivalves	17	21	0	57	25
Gastropods	6	48	24	29	27
Brachiopods	60	10	17	0	31
Echinoids	0	14	13	0	13
Crabs	100	100	100	0	100
Oysters	0	100	0	0	33
%-By Grain Group	21	29	19	48	26

TABLE 10. CARBONATE SAMPLES: PERCENTAGE OF VARIABLE SAMPLES IN THE FOSSIL AND GRAIN GROUPS

Fossil Group	1	G r a i n 2	G r o u p 3	4	%-By Fossil Group
Bivalves	50	38	0	100	45
Gastropods	33	77	28	40	43
Brachiopods	60	10	17	0	31
Echinoids	0	14	13	0	13
Crabs	100	100	100	0	100
Oysters	0	0	0	0	0
%-By Grain Group	44	36	21	67	34

TABLE 11. TERRIGENOUS SAMPLES: PERCENT VARIABLE SAMPLES FOR THE FOSSIL AND GRAIN GROUPS

Fossil Group	G r a i n G r o u p				%-By Fossil Group
	1	2	3	4	
Bivalves	6	14	0	40	16
Gastropods	0	0	0	0	0
Brachiopods	0	0	0	0	0
Echinoids	0	0	0	0	0
Crabs	0	0	0	0	0
Oysters	0	100	0	0	100
%-By Grain Group	3	16	0	33	13

TABLE 12. TOTAL NUMBER OF SAMPLES BY FOSSIL TYPE AND GRAIN GROUP

Fossil Type	G r a i n G r o u p				Total
	1	2	3	4	
Bivalves	24	29	5	14	72
Gastropods	17	21	29	7	74
Brachiopods	10	10	6	0	26
Echinoids	4	28	16	0	48
Crabs	2	5	1	0	8
Oysters	4	2	0	0	6
Total	61	95	57	21	234

TABLE 13. NUMBER OF CARBONATE SAMPLES BY FOSSIL TYPE AND GRAIN GROUP

Fossil Type	G r a i n G r o u p				Total
	1	2	3	4	
Bivalves	6	8	4	4	22
Gastropods	3	13	25	5	46
Brachiopods	10	10	6	0	26
Echinoids	4	28	16	0	48
Crabs	2	5	1	0	8
Oysters	2	0	0	0	2
Total	27	64	52	9	152

TABLE 14. NUMBER OF TERRIGENOUS SAMPLES BY FOSSIL GROUP
AND GRAIN GROUP*

Fossil Type	G r a i n G r o u p				Total
	1	2	3	4	
Bivalves	18	21	1	10	50
Gastropods	14	8	4	2	28
Brachiopods	0	0	0	0	0
Echinoids	0	0	0	0	0
Crabs	0	0	0	0	0
Oysters	0	2	0	0	2
Total	32	31	5	12	80

*- The one phosphorite sample was an oyster with both the intra- and the extra-macrofossil sediment within grain group 1.

grain groups within terrigenous samples (54%). Grain group representation, therefore, could not cause the difference in frequency of variation between carbonate and terrigenous samples.

TABLE 15. DISTRIBUTION OF EACH GRAIN GROUP (BY PERCENT) IN THE CARBONATE GROUP AND OF THE TERRIGENOUS GROUP

		G r a i n G r o u p		
	1	2	3	4
Carbonate	18	42	34	6
Terrigenous	40	39	6	15
Phosphorite	100	0	0	0

The one phosphorite sample was non-variable and therefore does not merit any detailed discussion.

The percentage of moldic samples was checked to determine if moldic character had influenced the number of variable samples in the carbonate and terrigenous groups. The term "moldic sample" will refer to samples in which the macrofossil is a mold. Moldic samples exhibited more variation than non-moldic samples. Moldic sample variability will be discussed later in more detail. Moldic samples account for 36% of carbonate samples and 0% of terrigenous samples. The high percentage of moldic samples within the carbonate group may have partly produced the high percentage of variability; if moldic character induces variation in sediment character between intra- and extra-macrofossil deposits. Variability due to moldic character may actually be variability due to age or rock type. This concept will be discussed in the section on moldic types and their variability.

The higher percentage of variable samples within the carbonate group compared to the terrigenous group is mostly due to (1) their older age, (2) possibly the higher percentage of moldic samples and (3) the fact that minerals common to marine terrigenous deposits are generally more stable than carbonate minerals.

VARIABILITY VERSUS AGE

The percentage of variable samples increases with increasing age of the sample. The potential for variation is theoretically greater for older rocks than for younger, because older rocks have had more time to interact with diagenetic agents. Diagenetic differences between intra- and extra-macrofossil sediment should occur more frequently in older rocks. Table 16 shows an increase in percent variable samples through time. In order to make certain that the increase seen in Table 16 is due to age, other factors which might have produced the trend were investigated.

The percentage of moldic samples was examined to determine if the increase in percent variable samples with age was due to a corresponding increase in the percent of moldic samples through time. While Table 17 shows (1) the highest percentage of moldic samples are in the Cretaceous and (2) the Pleistocene has no moldic samples, there is no orderly change in the percentage of moldic samples. For example, there are no moldic Paleocene samples, yet the Paleocene is second only to the Cretaceous in percent of variable samples (Table 16). Therefore, variability due to increasing age is not a function of percent of moldic samples.

The percentage of samples from the most variable grain groups was examined to determine if the increase in percent variable samples through time is due to a corresponding increase in percent samples from the most variable grain groups. Grain group 4 (highest in percent variable samples) samples constitute 0% of the Cretaceous, 0% of the Paleocene, 4% of the Eocene, 0% of the Miocene, 30% of the Pliocene, and 2% of the Pleistocene (Table 18). Grain group 2, second in percent variable samples, constitutes 50% of the Cretaceous, 31% of the Paleocene, 52% of the of the Pleistocene samples. Percentages of samples in grain group 4 plus grain group 2 for each epoch are 50% of the Cretaceous, 31% of the Paleocene, 56% of the Eocene, 13% of the Miocene, 60% of the Pliocene, and 36% of the Pleistocene samples. No increase in percent of samples from the two most variable grain groups occurs through time, indicating that grain size has not produced the increase in percent variability with increasing age.

TABLE 16. NUMBER AND PERCENT VARIABLE SAMPLES IN EACH EPOCH

	Total Number of Samples	# of Variable Samples	% of Variable Samples
Pleistocene	22	1	5
Pliocene	27	5	19
Miocene	4	1	25
Eocene	47	17	36
Paleocene	8	3	38
Cretaceous	9	4	44

TABLE 17. PERCENT OF MOLDIC SAMPLES IN EACH EPOCH

	Total # Samples	# of Moldic Samples	% Moldic Samples
Pleistocene	22	0	0
Pliocene	27	5	19
Miocene	4	3	75
Eocene	47	12	26
Paleocene	8	0	0
Cretaceous	9	7	78

TABLE 18. PERCENT OF SAMPLES FROM EACH GRAIN GROUP WITHIN EACH EPOCH

	G R A I N G R O U P		
	1	2	3
Pleistocene	59	34	5
Pliocene	11	30	30
Miocene	38	13	50
Eocene	7	52	36
Paleocene	63	31	6
Cretaceous	50	50	0

Fossil type was examined to determine if the increase in percent variable samples with age is due to an increase in the percent of fossil types with the highest percent of variable samples. Brachiopods, gastropods, and bivalves are the fossil groups in this study (excluding the few crab samples) with the highest percent of variable samples. Fossil type, as a producer of variation between internal and external sediment, will be discussed later in more detail. Table 19 shows that

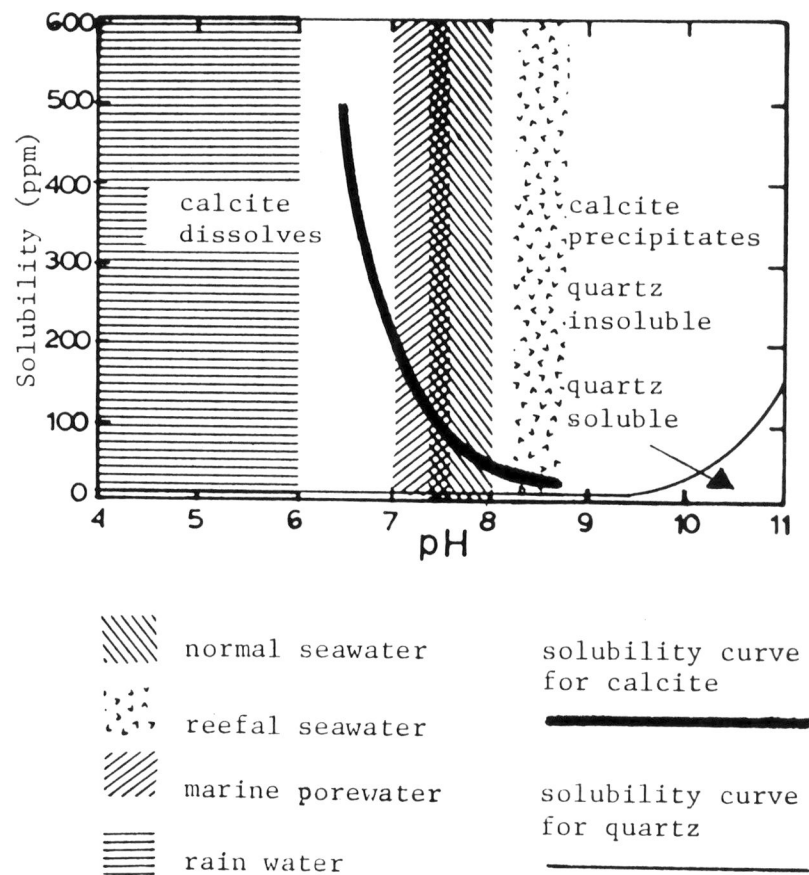
Miocene through Cretaceous samples generally have a lesser representation of fossil groups with the highest percent of variable samples than the Pliocene through Pleistocene samples. The increase in percent of variable samples through time is, therefore, probably not related to fossil type.

TABLE 19. TOTAL NUMBER OF SAMPLES BY AGE AND FOSSIL GROUP

	Bivalves	Gastropods	Brachiopods	Echinoids	Crabs	Oysters	Total
Pleistocene	11	11	--	--	--	--	22
Pliocene	19	28	--	--	--	--	27
Miocene	--	3	--	--	--	1	4
Eocene	1	13	5	24	4	--	47
Paleocene	--	--	8	--	--	--	8
Cretaceous	5	2	--	--	--	2	9

Rock type was investigated to determine if the increase in percent variable samples through time was due to a corresponding increase in the percent of carbonate samples. Earlier, the greater percentage of variability for carbonate samples over terrigenous samples was partly attributed to the greater age of the carbonate samples. Older samples have generally had more opportunity for change. Conversely, the higher percentage of variable samples within older samples may result from a higher percentage of carbonate samples. Carbonate minerals are less chemically stable in most depositional systems than minerals typical of terrigenous sediments (Fig. 9). This instability encourages diagenetic change, such as dissolution and recrystallization of minerals. The

Figure 9. Solubility versus pH for calcite and quartz. The pH fields for common natural waters are noted. Modified after Blatt, Middleton, and Murray (1980) and Friedman and Sanders (1978).



higher percentage of variable samples in successively older epochs has in part been produced by the greater percentage of carbonate samples. Table 16 shows a systematic increase in variability with age. Though abundant carbonate samples in older epochs may have increased percent variability, the uniform increase in percent variable samples with age is not the result of a corresponding increase in the percent of carbonate samples. The terrigenous end of the age spectrum (Pleistocene-Pliocene) increases in percent variable samples with age just as does the carbonate end of the age spectrum (Pliocene-Cretaceous) (Tables 8 and 16).

The increase in the percent variable samples with age is not a direct result of moldic character, fossil type, grain size, or rock type.

VARIABILITY OF FOSSIL GROUPS

The percentages of variable samples for bivalve, gastropod, brachipod, echinoid, crab, and oyster sample groups are listed in Table 20. Oysters were separated from the other bivalves due to their morphologic differences making them poorer diagenetic barriers.

Oysters have 33% variable samples. This percent is based on one variable sample out of three oyster samples analyzed. The accuracy of this percentage is obviously low. Oysters lack hinge teeth, which might lead to imperfect closure of the valves, as was observed in the oysters sampled. Several oysters sampled were not used in this study due to the extreme offset of the valves.

TABLE 20. PERCENTAGE OF VARIABLE SAMPLES AND TOTAL NUMBER OF
SAMPLES FOR EACH FOSSIL TYPE

	Total #	% of Variable Samples
Bivalves	36	25
Gastropods	37	27
Brachiopods	13	31
Echinoids	24	13
Crabs	4	100
Oysters	3	33

All of the crab samples are variable. Only four crab samples were used, and all were taken from the same location and formation. Crab carapaces examined in this study appear to be good barriers. Without crab samples from other lithologic units and rock types, their actual effectiveness (percent variable samples) as diagenetic barriers could not be determined.

Echinoids, with only 13% variable samples, provide the least effective barrier. The echinoid corona consists of fused calcareous plates with oral and aboral openings and ambulacral pores (Tasch, 1973). These numerous openings may allow penetration of solutions after death of the organism. Pores may also weaken the skeletal structure and increase the risk of fracture of the shell. Fracturing would destroy the ability of a shell to act as a diagenetic barrier. The shell would offer less resistance to compaction and solutions could enter pore space within the internal sediment.

The most variable fossil types (with the exception of the crabs) are brachiopods, gastropods, and bivalves. These fossil types provide more complete closure than the echinoids and the oysters. Bivalves can produce complete closure by retraction of the soft parts (Shrock and Twenhofel, 1953). Brachiopods have only one opening, called the foramen (Tasch, 1973). In some articulate brachiopods this opening may be partially closed by growth of accessory plates. More importantly, brachiopod valves remain closed with the relaxation of the diductor and adductor muscles, whereas bivalve valves open with relaxation of the adductor muscles (Shrock and Twenhofel, 1953). The relaxed position of the muscles may allow brachiopods to maintain closure upon death more frequently than bivalves. Brachiopods therefore have more potential to be successful diagenetic barriers. The effectiveness of a gastropod shell as a barrier is influenced by the number of its whorls. Sediment deposited deeper within the shell and away from the aperture would more likely be protected. Also, effectiveness of gastropods as barriers depends on size of the aperture and the nature of coiling.

Grain size, rock type, age, and moldic type were investigated to determine if any had influenced the percentage of variable samples in the different fossil groups.

Grain size did not greatly influence the percent of variable samples in each of the fossil groups. Brachiopods rank highest in the percent of variable samples and yet this fossil group has no samples within the most variable grain group (4) (Table 9). Table 21 presents the sum of the percentages of samples within the two most variable grain groups, for each fossil group. Grain groups 2 and 4 have the highest,

and 3 and 1 the lowest, percentages of variable samples. Bivalves, echinoids, and crabs are the three fossil groups in which there are a dominance (greater than 50%) of samples from the most variable grain groups. The low percentage of variable samples for echinoids exists despite the dominance of samples from grain groups 2 and 4. Two of the most variable fossil types (gastropods and brachiopods) have less than 50% of their samples within the two most variable grain groups. The dominance of samples from grain groups 2 and 4 may have preferentially increased the percentage of variable samples more so for the bivalves, crabs, and echinoids than for the other fossil groups. Without samples in all the grain size groups, for each fossil type, it is impossible to determine if variability was caused by grain size or by fossil type.

TABLE 21. SUM OF THE PERCENTAGES OF SAMPLES WITHIN GRAIN GROUPS 2 AND 4 FOR EACH FOSSIL TYPE

	G R A I N G R O U P		
	4	2	4 and 2
Bivalves	19	40	59
Gastropods	9	28	37
Brachiopods	0	38	38
Echinoids	0	58	58
Crabs	0	63	63
Oysters	0	33	33

If we artificially increased the percent of samples from grain groups 2 plus 4 for gastropods and brachiopods from 37% and 38%, respectively, to 50% (thereby giving the two most variable and the two least variable grain groups equal representation) the percent of

variable samples should theoretically increase. This means if there was an equal number of samples in each grain group, for each fossil type, the percent of variable samples for gastropods and brachiopods should be higher than the previously calculated. Gastropods and brachiopods would still rank among the highest of the fossil groups in percent of variable samples. If we reduced the percent of samples from grain groups 2 plus 4 for echinoids from 58% to 50%, an already low percentage of variable samples would theoretically be further reduced. The oyster group percentage of variable samples might increase after recalculation for equal grain group representation. One must wonder if the percent of variable samples for bivalves has been influenced by 59% of the bivalves being included in grain groups 2 and 4. Table 22, Row 3 presents the recalculated percentages for bivalves and gastropods giving equal bearing to each grain size group. These percentages are the unweighted means of the percentages of variable samples through all grain size groups for bivalves and then for gastropods (means derived from percentages in Table 9). Means for the other fossil groups could not be determined in this manner due to the lack of samples in some grain size groups. With an equal representation of each grain group, a reduction occurred in the percentage of variable samples for bivalves from 25% (original unaltered percent) to 24%, but there was no change with the gastropod percent. We must conclude that grain group representation did not greatly influence the percentage of variable samples in the different fossil groups.

Rock type was also investigated to determine if it had influenced the percent of variable samples in the different fossil types. All brachiopod and crab samples are from the carbonate group, but so are the echinoid samples (Table 23). Echinoids are the least variable fossil type, whereas brachiopods and crabs are two of the most variable fossil types.

TABLE 22. RECALCULATED PERCENTS OF VARIABLE SAMPLES FOR GASTROPODS AND BIVALVES

Row		Bivalves	Gastropods
1	Original %	25	27
2	Recalculated for Moldic Representation	32	23
3	Recalculated for Grain Group Representation	24	27
4	Recalculated for Rock Type Representation	31	22
5	Recalculated for both Rock Type and Grain Size	31	22
6	Mean of Rows 2, 3, and 4	29	24

TABLE 23. PERCENT OF CARBONATE, TERRIGENOUS, AND PHOSPHORITE SAMPLES FOR EACH FOSSIL TYPE

	Carbonate	Terrigenous	Phosphorite
Bivalves	31	69	-
Gastropods	62	38	-
Brachiopods	100	-	-
Echinoids	100	-	-
Crabs	100	-	-
Oysters	33	33	33

Being that carbonate samples out-numbered terrigenous samples 2 to 1, percentages were recalculated that would give carbonate and terrigenous samples equal representation (Table 22, Row 4). This percentage is the mean of the percent variable samples for the carbonate group and the percent of variable samples for the terrigenous group. This unweighted mean value could only be calculated for those fossil groups that have both terrigenous samples and carbonate samples (gastropods and bivalves). Recalculation for rock type does shift the percent variable samples for the gastropod and bivalve groups. The percent of variable samples for bivalves increases (reducing the effect of 69% being terrigenous samples) and decreases for gastropods (reducing the effect of 62% being carbonate samples). Referring to Tables 22 and 23, the ratio of carbonate samples to terrigenous samples may have influenced the percentages of variable samples in the different fossil groups.

Age of the samples was investigated next to determine if it had influenced the percent of variable samples in the fossil groups. Table 24 shows that bivalves and gastropods have the majority of their samples in the younger epochs. Earlier, it was shown that the percent of variable samples increases with age. Artificially increasing the percentage of older samples in the bivalve and gastropod groups (to allow for the few number of older samples) would only tend to increase the percent of variable samples. Gastropods and bivalves would still rank among the fossil types with the highest percent of variable samples. Percentages could not be recalculated to allow for unequal numbers of samples in each epoch because none of the fossil groups had

at least one sample in each epoch on which to base percentages. From Tables 24 and 16, one could only postulate that the gastropod and bivalve percentages of variable samples might in reality (equal representation of all the epochs) be higher and that brachiopod, echinoid, and crab samples might be lower. Postulating in this manner, brachiopod, bivalve, and gastropod percentages would then be approximately equal. The general ranking of the fossil groups by percent variable samples was otherwise not affected by age of the samples.

TABLE 24. PERCENT OF SAMPLES FROM EACH EPOCH FOR EACH FOSSIL GROUP

	Pleistocene	Pliocene	Miocene	Eocene	Paleocene	Cretaceous
Bivalves	31	53	-	3	-	14
Gastropods	30	22	8	35	-	5
Brachiopods	-	-	-	38	62	-
Echinoids	-	-	-	100	-	-
Crabs	-	-	-	100	-	-
Oysters	-	-	33	-	-	67

Moldic samples are now examined to determine if they have influenced the percent of variable samples in each fossil group. The moldic sample group has a higher percent of variable samples than the non-moldic sample group. Table 25 gives the percent of moldic samples for each fossil group. If we altered the percent of moldic samples to 50% in all the fossil groups (50% moldic and 50% non-moldic), all of the fossil group variable sample percentages, except for the gastropods,

would tend to increase. All of the percentages of moldic samples are presently less than 50% as seen in Table 25. Table 22, Row 2 gives the recalculated percent of variable samples for gastropods and bivalves by calculating the unweighted mean of the percent of variable samples for the moldic group and the percent of variable samples for the non-moldic group. The bivalve percent increases slightly and the gastropod percent decreases slightly. With an equal number of moldic and non-moldic samples, all the fossil groups might have slightly higher percentages of variable samples, except for the gastropods, which might have a slightly lower percentage.

TABLE 25. PERCENT OF MOLDIC SAMPLES IN EACH FOSSIL GROUP

	# of Samples	% of Moldic Samples	% Variable Samples for Each Fossil Group
Bivalves	36	14	25
Gastropods	37	59	27
Brachiopods	13	0	31
Echinoids	24	0	13
Crabs	4	0	100
Oysters	3	0	33

Brachiopods, bivalves, and gastropods appear to be more efficient barriers than oysters and echinoids. The unequal number of samples in each grain group did not appear to affect the percentages of variable samples for each fossil type. Rock type does appear to have affected, to some degree, the percent of variable samples in each fossil type. All of the fossil types except bivalves have a predominance of carbonate samples. With an equal number of carbonate and terrigenous samples,

bivalves would likely have a higher, and the other fossil types a lower, percentage of variable samples. From the data available, the number of samples in each epoch does not appear to have affected the hierarchical arrangement of fossil types by percent variable samples. Gastropods are the only fossil type with a predominance of moldic samples. This predominance may have caused the percent of variable samples to be a little high for gastropods and a little low for the other fossil types. Row 6 gives a recalculated percent, which would take into account moldic type, grain size, and rock type. The gastropod group has 24% and the bivalve group has 29% variable samples. The percentages calculated in this study fluctuated when recalculated to compensate for other factors such as grain size, rock type, moldic type, fossil type, and age. Even so, there are no drastic fluctuations in these percentages. The percentages of variable samples for the various fossil types must be near the true percentages.

VARIABILITY OF MOLDIC VERSUS NON-MOLDIC MACROFOSSILS

In this study "moldic" samples refer to those samples in which the macrofossil shell has been dissolved. "Non-moldic" samples refer to those samples in which the macrofossil is still present. Nineteen of 89 (21%) non-moldic samples are variable and 12 out of 27 (44%) moldic samples are variable.

Before determining the mechanism involved in causing moldic samples to be more frequently variable, we should first eliminate any other factors. Possible influential factors are: 1) the percentage of samples from highly variable grain groups (2 and 4), 2) the percentage of highly

variable fossil types (crabs, gastropods, bivalves, brachiopods), 3) the percentage of carbonate samples, and 4) the percentage of samples from the older epochs in this study.

Table 26 shows the percentage of moldic and non-moldic samples in each grain group. The non-moldic sample group has a higher percentage of samples from grain groups 2 and 4 than does the moldic group. Also, the moldic group has the greatest percentage of its samples within the least variable grain group (3). The higher percentage of variation in the moldic group does not appear to be related to grain size.

TABLE 26. PERCENTAGE OF SAMPLES FROM EACH GRAIN GROUP IN MOLDIC AND NON-MOLDIC SAMPLE GROUPS

	G r a i n G r o u p			
	1	2	3	4
Moldic Group	14	33	45	5
Non-moldic Group	29	43	17	11

All of the moldic samples are in the highly variable fossil groups (bivalves and gastropods) (Table 27). Some of the non-moldic samples are in the least variable fossil groups (echinoids and oysters). The fossil type representation in the moldic and non-moldic groups may have partly caused the higher percentage of variation for moldic samples than for the non-moldic samples. Focusing on bivalve and gastropod groups more accurately reflects the variation in the moldic versus non-moldic groups. Both moldic and non-moldic groups would have only samples from fossil types with similar percentages of variable samples (bivalves and gastropods). Gastropods and bivalves are also the only two fossil types with both moldic and non-moldic samples. Table 28 shows that moldic

bivalve and moldic gastropod samples have a higher percentage of variable samples than non-moldic bivalve and non-moldic gastropod samples. The moldic samples are still more frequently variable than the non-moldic samples (Table 28) regardless of the fossil types present.

TABLE 27. PERCENT OF SAMPLES FROM EACH FOSSIL TYPE IN THE MOLDIC AND THE NON-MOLDIC GROUPS

	Bivalves	Gastropods	Brachiopods	Echinoids	Crabs	Oysters
Moldic	14	59	0	0	0	0
Non-moldic	86	41	100	100	100	100

TABLE 28. PERCENTAGES OF VARIABLE SAMPLES WITHIN BIVALVE-MOLDIC AND -NON-MOLDIC AND GASTROPOD-MOLDIC AND -NON-MOLDIC GROUPS

Bivalve Moldic	40
Bivalve Non-moldic	23
Gastropod Moldic	45
Gastropod Non-moldic	0

The number of carbonate samples was investigated to determine if it had influenced the percentage of variable samples in the moldic and non-moldic groups. All of the moldic samples are in the carbonate group (100%). Fifty-five percent of the non-moldic samples are in the carbonate group. The higher percent of carbonate samples in the moldic group has probably produced, in part, the higher percentage of variable samples. As previously noted, carbonate minerals are generally less chemically stable and, therefore, more susceptible to diagenetic alteration than minerals common to terrigenous deposits. There are no moldic-terrigenous samples in this study, therefore the frequency of

variation of the moldic-terrigenous group could not be determined. To eliminate the factor of a higher percent of carbonate samples in the moldic group, we will look at moldic versus non-moldic variation just within the carbonate group. Twelve out of 27 moldic samples are variable (44%), and 14 out of 49 non-moldic samples are variable (29%) in the carbonate group. The moldic samples are still more variable than the non-moldic samples. Variation of the moldic group is generally independent of rock type variation.

The moldic group may have slightly greater representation in the older epochs (Table 29). No real association exists between age and the percentage of variable samples in each moldic group.

TABLE 29. PERCENTAGE OF SAMPLES FROM EACH EPOCH WITHIN THE MOLDIC GROUP AND THE NON-MOLDIC GROUP

	Pleistocene	Pliocene	Miocene	Eocene	Paleocene	Cretaceous
Moldic	0	19	75	26	0	78
Non-moldic	100	81	25	74	100	22

Grain size did not produce the greater percentage of variable samples in the moldic group. It could not be determined if a slightly greater number of older samples in the moldic group may have contributed to the difference in the frequency of variation between the moldic and non-moldic groups.

Moldic character was examined to determine if it may have been a factor in producing a variation between internal and external sediment. All diagenetic variations in this study result from processes that preceded dissolution of the shell. These diagenetic processes are

discussed in the previous section. The higher percentage of variable samples among moldic samples could be a result of the cumulative effect of moldic samples being mostly from the carbonate group, the highly variable fossil groups, and the older epochs. It is not likely that the variation in the moldic group is actually due to the moldic character.

VARIABILITY DUE TO GRAIN SIZE

The grain groups 1 through 4 were defined in the procedures section (Table 4). Tables 9-14 list the percentages of variable samples, and the total number of samples by grain size, fossil type, and rock type. Grain group 4 is the most variable grain group for the carbonate group, for the terrigenous group, and for the total samples. Grain group 2 is the second most variable grain group for the terrigenous group and for the total samples. Grain group 1 is the second most variable grain group for the carbonate group. Grain group 3 is the least variable group for the terrigenous group, the carbonate group, and for the total samples. Factors which might have influenced the high percentage of variable samples in grain group 4 and the low percentage in grain group 3 are (1) the percentage of samples from the most variable fossil groups, (2) the percentage of samples from the oldest epochs, (3) the percentage of moldic samples, and (4) the percentage of carbonate samples.

Table 9 shows that all of grain group 4 samples are either gastropods or bivalves (100%). Grain group 3 has 71%, grain group 2 has 68%, and grain group 1 has 87% of its samples from fossil groups with the highest percent of variable samples (gastropods, bivalves, brachiopods, and crabs). Grain group 4, having the highest percent, may

have partly contributed to the higher percent of variable samples. The only fossil types present in all the grain groups are bivalves and gastropods. If we look at the percent of variable samples for just these two fossil types in each grain group, we can eliminate the effects of the least variable fossil types depressing the percent of variable samples for some of the grain groups. Table 30 shows that after eliminating the factor of uneven percentages of fossil types in the different grain groups, grain group 4 is still the most variable grain group. Grain group 3 is still (along with group 1) the least variable. The percentage of variable fossil types in each grain group did not drastically change the hierarchial order (by percentage of variable samples) of the grain groups.

TABLE 30. PERCENT OF VARIABLE SAMPLES IN EACH GRAIN GROUP FOR BIVALVES AND GASTROPODS, THE MEAN OF THESE PERCENTAGES BY GRAIN GROUP , AND THE PERCENT VARIABLE SAMPLES FOR BIVALVES AND GASTROPODS TOGETHER

Grain Group	Bivalves	Gastropods	Mean of Bivalves & Gastropods	% of Variable Samples Overall	% of Variable Samples for Bivalves & Gastropods
1	17	6	12	12	21
2	21	48	35	29	32
3	0	24	12	19	21
4	57	29	43	48	48

Age of the samples was investigated to determine if it had influenced the percentage of variable samples in each grain group. Table 31 gives the percentages of samples from each epoch for each grain group. Grain group 4 has most of its samples (76%) in the Pliocene and

no samples in the Paleocene or Cretaceous. Since it was shown earlier that the percent of variable samples increases with age, age is not related to the high percentage of variable samples in grain group 4.

TABLE 31. PERCENT OF SAMPLES IN EACH EPOCH FOR EACH GRAIN GROUP

Grain Group	Pleistocene	Pliocene	Miocene	Eocene	Paleocene	Cretaceous
1	43	10	5	11	16	15
2	16	17	1	52	5	9
3	4	28	7	60	2	0
4	5	76	0	19	0	0

If the mean was calculated for the percentages of variable samples within each epoch for each grain group, each epoch would have equal representation in the percent of variable samples for a grain group. Table 32 gives the percentages of variable samples within each epoch for each grain group and the mean of these percentages. For those grain groups where there are no samples for an epoch or epochs, the mean is calculated just for the percentages available. Without at least one sample in a grain group for one age group, one could not determine the percent of variable samples for that age-grain group. The blank spaces on Table 32 correspond to these discrepancies in sample numbers. Recalculating in this manner, may distort the data. After recalculating the percentages in this manner, grain group 4 is still the most variable and grain group 3 is still the least variable. From the data available, the percentages of variable samples in the different grain groups do not appear to have been produced by age of the samples.

TABLE 32. MEAN OF THE PERCENTAGES OF VARIABLE SAMPLES IN EACH EPOCH FOR EACH GRAIN GROUP

Grain Group	Pleistocene	Pliocene	Miocene	Eocene	Paleocene	Cretaceous	Mean
1	0	17	33	43	60	22	29
2	7	13	100	37	0	67	37
3	0	0	0	32	0	---	6
4	100	44	---	50	---	---	65

Moldic character was examined to determine if it had influenced the percentage of variable samples in each grain group. Table 33 shows that each grain group consists mostly of non-moldic samples. Grain group 4 has one of the lowest percentages of moldic samples, yet has the highest percent of variable samples. Grain group 3 has the greatest number of moldic samples yet has the least number of variable samples. Table 34 gives the recalculated percentages of each grain group so that moldic and non-moldic samples are equally represented. Grain group 4 still has the highest and grain group 3 the lowest percent of variable samples. The percentage of variable samples in the different grain groups was not the result of the abundance of moldic samples.

TABLE 33. PERCENT OF MOLDIC AND NON-MOLDIC SAMPLES IN EACH GRAIN GROUP

Grain Group	Moldic	Non-Moldic
1	13	87
2	19	81
3	44	56
4	14	86

TABLE 34. PERCENTAGES OF VARIABLE SAMPLES FOR (1) THE MOLDIC GROUP, (2) THE NON-MOLDIC GROUP, (3) THE MEAN OF THE PERCENTS FOR THE MOLDIC AND THE NON-MOLDIC GROUPS, AND (4) TOTAL SAMPLES, FOR EACH GRAIN GROUP

Grain Group	Moldic	Non-moldic	Mean	Original % of Variable Samples Within the Total Samples
1	38	19	29	21
2	67	21	44	29
3	28	13	21	19
4	67	44	56	48

Rock type was investigated to determine if it had influenced the percent of variable samples in each grain group. The carbonate group proved to be more frequently variable than the terrigenous group. Table 35 gives the number of samples and the percentages of terrigenous, carbonate, and phosphorite samples for each grain group. Grain group 4 has the lowest percent carbonate samples and grain group 3 has the highest percent of carbonate samples.

Table 36 gives the mean of the percentages of variable samples within terrigenous and carbonate groups for each grain group. This mean would represent the percent of variable samples for a grain group in which terrigenous and carbonate samples had equal representation. Recalculating in this manner would eliminate the effects of a dominance of samples from the carbonate group. With these new percentages grain group 4 still has the highest and grain group 3 the lowest percent of variable samples. The percentage of variable samples in each grain group was not likely the result of the percentage of carbonate samples.

TABLE 35. THE NUMBER AND PERCENTAGE OF CARBONATE, TERRIGENOUS, AND PHOSPHORITE SAMPLES IN EACH GRAIN GROUP

Grain Group	# of Carbonate Samples	% of Carbonate Samples	# of Terrigenous Samples	% of Terrigenous Samples	# of Phosphorite Samples	% of Phosphorite Samples
1	27	44	32	52	2	3
2	64	67	31	33	0	0
3	52	91	5	9	0	0
4	9	43	12	57	0	0

TABLE 36. MEAN OF THE PERCENT VARIABLE SAMPLES IN THE CARBONATE GROUP AND THE TERRIGENOUS GROUP FOR EACH GRAIN GROUP

Grain Group	Carbonate	Terrigenous	Mean
1	44	3	24
2	36	16	26
3	21	0	11
4	67	33	50

Fossil type, age moldic type, nor rock type produced the percentages of variable samples in the different grain groups.

Now we will investigate why grain group 4 has the greatest percentage of variable samples. Each grain group has the same types of diagenetic variations between intra- and extra-macrofossil sediment. No one type of variation has exclusively caused the frequency of variable samples in grain group 4. The variations simply occurred most frequently within predominately fine-grained samples. Most of the variations observed in this study are most commonly associated with fine grain size. Many of the variations are products of compaction. Predominantly fine-grained deposits are generally more "compactable" than predominantly coarse-grained deposits (Von Engelhardt, 1977).

Predominantly fine-grained samples would, therefore, most likely have the greatest amount of variation. The types of observed variation which are associated with compaction are: (1) preferential loss of pore space outside of the shell, (2) precipitation of sparry calcite in the maintained pores within the shell, (3) loss of peloidal texture, and (4) closer packing of coarser grains in a fine-grained matrix due to squeezing out of fine grains upward, laterally, and into pore spaces (to areas of lesser pressure) (Dickinson, 1970). Other variations observed also resulting from processes more often associated with fine-grained sediments include: (1) glauconitization, (2) dolomitization, (3) pyritization, (4) aggradation of micrite grain size, and (5) vug porosity development. Glauconitization is often associated with a clay or organic parent (Hower, 1961). The samples in this study which underwent dolomitization were fine-grained (clay to silt sizes). Pyritization requires a source of iron. Iron is transported mainly as: (1) a colloidal suspension, (2) a chelation or adsorption on to organic matter, or (3) a structural part or a surficial attachment onto clays (Tucker, 1981). Pyrite would frequently have a fine-grain association in the sedimentary regime. Aggradation of micrite to microspar and vug porosity development are obviously diagenetic processes of fine-grained sediment. With most of the variations related to fine-grained sediment, grain group 4 should have the highest percent of variable samples.

REASONS FOR NON-VARIABILITY

Seventy-four percent of the samples are "non-variable". Diagenetic variation between extra- and intra-macrofossil sediment is dependent on the ability of a shell to protect the enclosed sediment and its associated water from agents of diagenesis such as compaction and migrating super-saturated or under-saturated solutions. The shell must be able to withstand lithostatic pressures and have sufficient closure. Morphologic differences between fossil types produce differences in ability to protect the internal sediment. Shell types such as echinoids and bivalves obviously differ in morphology. Bivalves can have more closure than echinoids.

The character of the sediment itself is also a factor in whether a variation results. Less stable minerals and finer grain sizes (more surface area for reaction) would offer a better opportunity for post-depositional change. A higher percentage of samples with these characteristics would likely produce a higher percentage of variable samples (and a lesser percentage of non-variable samples).

Age also is an important factor in the percentage of non-variable samples. Had this study been performed with Mesozoic or Paleozoic samples, the percentage of non-variable samples would likely have been lower. More time would provide more opportunity for diagenetic change and the resulting variations between intra- and extra-macrofossil sediment.

The non-variable samples failed to produce a variation in sediment character between intra- and extra-macrofossil sediment due to one or more of the following reasons. (1) The sample was included in one or

more of the groups determined in this study to have the least percentage of variable samples. The sample may be included within the least variable fossil type, grain group, rock type, epoch, and moldic group. The sample was non-variable due to these groups providing conditions unfavorable for production of a diagenetic variation between intra- and extra-macrofossil sediment. (2) The shell was fractured, bored, or otherwise insufficiently closed. The internal sediment was not protected. (3) Within each fossil group, less rigid forms exist that might not withstand pressures. (4) Due to the youthfulness of the samples in this study, minimal diagenetic history for some samples would allow less opportunity for the production of a variation between intra- and extra-macrofossil sediment.

TABLE 37. FACTORS PROMOTING VARIABILITY AND NON-VARIABILITY

<u>Promoting Variability</u>	<u>Promoting Non-variability</u>
finer grain sizes	coarser grain sizes
bivalves, brachiopods, gastropods	echinoids, oysters
carbonate mineralogy	stable terrigenous minerals
age of the sample	youth of the sample
rigid shell	fractured shell
alignment of valves	offset of the valves

STATISTICAL VERIFICATION

In order to verify whether or not the samples in this study are "variable" or "non-variable" because of the sample groups with which they are associated, certain statistical analyses were conducted with the original data. Chi-square distribution was used to determine the

association between the sample groups listed on Table 4 (independent variable) and whether or not the sample is "variable" (dependent variable). Chi-square can be used to determine independence of two factors. In this case, the two factors are: (1) "variability" and (2) sample group (i.e., fossil type). The null hypothesis is that "variability" and a sample group are independent (no association). Rejection of this hypothesis is possible with sufficiently high chi-square values or corresponding low probability values (probability due to chance). A value of 0.05 or less is commonly considered the acceptable statistical value for probability due to chance (95% confidence). Of course, the acceptable limit for the probability value depends on the nature of the data (how strong a relationship is required between the two factors to reject the null hypothesis). I set 0.05 as a limit. All sample groups (fossil type, grain group, age, moldic type, and rock type) are indicated as being highly associated with the "variability" of the samples. All of the chi-square values have probability values of less than or equal to 0.05 (Table 38). That is, less than 5% of the time the outcome of the dependent variable ("variability" versus "non-variability") was due to chance. The independent variable (i.e. fossil type), therefore, influenced the outcome of the dependent variable. The chi-square value for age was determined differently (Mantel-Haenszel chi-square) from the other sample groups in order to also evaluate the linear trend (increase in % samples with age) within this sample group. This chi-square value for the age group indicates extremely high correlation (0.002 probability due to chance) between age and percent of variable samples. A Mantel-

Haenszel chi-square value could only be calculated for the age sample group because the levels (or epochs) within this group have an ordinal arrangement (age/time) that the other sample groups did not.

TABLE 38. CHI-SQUARE VALUES FOR EACH SAMPLE GROUP

Sample Group	Chi-square	Degree(s) of Freedom	Confidence Interval
Fossil Type	13.751	5	0.017
Age	10.574	5	0.002*
Grain Group	8.165	3	0.043
Rock Type	6.706	2	0.035
Moldic Type	5.806	1	0.016

*- Mantel-Haenszel Chi-Square

Being that there was only one phosphorite sample, the unreliability of the percentage of variable samples for this rock type may have distorted the Chi-square value. A chi-square value was also calculated for the rock type sample group to exclude phosphorite as a rock type. This chi-square value is equal to 6.3 with 1 degree of freedom. Probability due to chance for this chi-square value is between 0.02 and 0.01. There is even less probability due to chance when we evaluate only terrigenous and carbonate as rock type categories.

A contingency coefficient (C) is a measure of the strength of the relationship between the independent and dependent variables. The n

$$C = \sqrt{\frac{\chi^2}{n + \chi^2}}$$

value is the total number of frequencies, or in this case, samples. χ^2

is the chi-square value. The value of C ranges between 0 and 1. The contingency coefficient can then be expressed as a percentage (Table 39).

Using contingency coefficients, the sample groups were arranged in an order of decreasing degree of relative influence on "variability" of the samples. In other words, the sample groups with the highest percentages in Table 39 most influenced variability. This order is as follows:

Fossil Type > Age > Grain Group > Rock Type > Moldic Type

Fossil type has the greatest degree and moldic type the least degree of influence on whether the sample is "variable" or "non-variable". One must keep in mind that all five independent factors are highly interrelated (i.e., moldic type and fossil type).

TABLE 39. CONTINGENCY COEFFICIENTS REPRESENTING OVERLAPPING PERCENTAGES OF INFLUENCE ON "VARIABILITY" BY EACH SAMPLE GROUP

Fossil Type	32-34%
Age	29-30%
Grain Group	26%
Rock Type	23-24%
Moldic Type	22%

CONCLUSIONS

Macrofossils have been shown to act as diagenetic barriers 26% of the time. The frequency of macrofossils as diagenetic barriers may actually be higher than 26%. The frequency of variable samples (the frequency of macrofossils acting as successful diagenetic barriers) increases with increasing age (Table 16). This study did not include any samples older than Cretaceous. In older strata, the percent of variable samples may be higher.

Bivalves, gastropods, brachiopods, echinoids, crabs, and oysters are the fossil types sampled in this study. Bivalves, gastropods, and brachiopods are about equally effective barriers (25%, 27%, and 31% variable samples, respectively). Crab carapaces proved to be effective barriers (100% variable samples). The small number of crab samples (all from one location) makes the percentage somewhat unreliable. Oysters and echinoids proved to be the least effective diagenetic barriers. Though oysters are given as 33% variable samples, the percent represents only 1 variable sample in 3. This percentage is unreliable due to the small number of samples. A change in the number of samples, plus or minus one sample, could highly alter the percentage. The lack of hinge teeth for oysters frequently allows offset of the valves for incomplete closure. I believe oysters are one of the least effective macrofossil diagenetic barriers. Echinoids are the least effective diagenetic barriers. The open network of the shell prohibits complete closure. The morphology and the rigidity of a shell are the keys to diagenetic barrier capability.

Fine-grained sediments have the highest percent of variable samples. Most of the diagenetic processes involved in producing the variation in sediment character in this study are more frequently associated with fine-grained sediments.

The more frequent variations in sediment character between intra- and extra-macrofossil sediment are the results of the macrofossil protecting the internal sediment from compaction and solution passage. The differences observed in sediment character include variations in: authigenic minerals, sparry calcite pore fill, secondary porosity, aggradation of micrite (neomorphism), and compaction of the matrix (loss of pore space and concentration of coarse grains).

Knowing the types of variation frequently occurring between intra- and extra-macrofossil sediment, and the fossil types, grain sizes, age, and rock types in which the variations most frequently occur, one can more easily locate macrofossils exhibiting primary sediment character. The intra-macrofossil sediment can then be used as an aid in reconstructing the depositional environment and the diagenetic history of a rock.

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APPENDIX A. POINT COUNT DATA OF VARIABLE SAMPLES

Numbers represent percentages calculated from 300 points.

Table 4 defines the sample number codes.

An "m" suffix indicates extra-macrofossil sediment.

Sample	micrite/microspar	calcite spar	porosity	peloids	quartz	sedimentary rock fragments	feldspar	clay	heavy minerals	chlorite	mica	ign & meta rock fragments	glauconite	phosphate	hematite	pyrite	chert	evaporites	dolomite	forams	ostracodes	molluscs	barnacles	bryozoans	brachiopods	bone	crab	echinoderms	organics	coral	algae	? fossils
PI-2	24	23	3	0	35	13	<1	0	0	<1	<1	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	<1	0	0	0
PI-2m	26	8	15	0	50	0	<1	0	0	0	0	<1	0	0	0	<1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
PI-7(1)	8	40	13	0	29	0	0	0	0	0	1	0	1	0	0	<1	0	0	0	0	0	4	0	0	0	0	0	3	0	0	0	0
PI-7(1)m	38	21	20	0	14	0	<1	0	0	1	0	<1	<1	0	0	0	<1	0	0	0	0	4	0	1	0	0	0	0	0	0	0	0
PI-7(2)	14	35	33	0	12	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	3	0	0	0	0
PI-7(2)m	38	21	20	0	14	0	<1	0	0	1	0	<1	<1	0	0	0	0	<1	0	0	0	4	0	1	0	0	0	0	0	0	0	0
PG-11	0	0	11	0	59	1	<1	24	0	0	0	2	0	<1	1	0	0	0	0	0	0	0	0	0	0	<1	0	0	0	0	0	0
PG-11m	25	17	9	0	29	0	1	0	0	0	0	0	16	0	0	1	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0
BM-6	0	57	14	0	7	<1	<1	0	0	0	0	0	17	0	0	<1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	<1
BM-6m	1	70	4	0	7	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	8	0	4	0	0	0	1	0	1	0	0	0
BM-7	0	42	22	0	12	0	0	0	0	0	0	0	19	1	0	<1	0	0	0	0	1	0	2	0	0	0	0	<1	0	0	0	0
BM-7m	15	57	5	0	5	0	0	0	0	0	0	0	3	0	0	<1	0	0	0	0	9	0	5	0	0	0	0	1	0	0	0	0
BM-10	0	75	4	0	6	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	4	0	2	0	0	0	0	1	0	0	0	0
BM-10m	1	57	4	0	8	0	0	0	0	0	0	0	15	0	<0	2	0	0	0	0	8	0	3	0	0	0	0	2	0	0	0	0
CL-12	51	1	6	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	8	0	4	0	21	0	0	0	3	0	0	0
CL-12m	47	1	6	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	8	0	4	0	28	0	0	0	4	0	0	0
CF-3	2	26	25	0	6	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	13	0	12	0	1	0	0	0	10	0	0	3
CF-3m	42	7	11	0	17	0	0	0	0	0	0	0	1	0	<1	1	0	0	0	0	6	1	6	0	2	0	2	3	0	0	0	0
CI-3	37	0	26	0	0	0	0	0	0	0	0	0	<1	0	0	0	0	0	0	0	1	0	1	0	31	0	<1	0	2	0	0	1
CI-3m	27	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	<1	9	0	21	0	0	0	7	0	0	<1
CI-4	46	10	4	0	<1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	7	0	3	0	20	0	0	0	9	0	0	0
CI-4m	32	2	12	0	<1	0	0	0	0	0	0	0	<1	0	<1	0	0	0	0	0	9	2	5	0	21	0	0	0	9	0	0	1
CI-5	25	2	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	<1	7	2	15	0	0	0	4	0	0	1
CI-5m	38	1	10	0	0	0	0	0	0	0	0	0	<1	1	0	<1	0	0	0	0	9	2	6	1	22	0	0	0	9	0	0	1
CI-21	35	10	3	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	1	1	0	25	0	0	0	17	0	0	0
CI-21m	29	<1	27	0	<1	0	0	0	0	0	0	0	<1	0	<1	0	0	0	0	0	3	0	2	0	34	0	0	0	3	0	0	<1
CI-31	50	2	3	0	0	0	0	0	0	0	0	0	1	<1	0	0	0	0	0	0	12	<1	5	1	16	0	0	0	15	0	0	1
CI-31m	32	3	5	2	0	0	0	<1	0	0	0	0	4	<1	0	2	0	1	0	13	0	5	0	9	0	0	0	21	0	0	0	<1
CI-41	92	1	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	4	0	0	0	0	0	0	0	<1
CI-41m	25	2	0	5	2	37	0	0	0	0	0	0	3	0	0	4	0	0	0	2	<1	5	0	13	0	0	0	0	0	0	0	1

Sample #	micrite/microspar	calcite spar	porosity	peloids	quartz	sedimentary rock fragments	feldspar	clay	heavy minerals	chlorite	mica	ign. meta rock fragments	glauconite	phosphate	hematite	pyrite	chert	evaporites	dolomite	forams	ostracodes	molluscs	barnacles	bryozoans	brachiopods	bone	crab	echinoderms	organics	coral	algae	? fossils	
CI-42	62	6	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	10	0	4	0	7	0	0	0	<1	0	0	0	7	
CI-42m	47	5	3	0	5	4	0	0	0	0	0	0	2	2	0	2	0	0	0	4	<1	6	0	21	0	<1	0	0	2	0	0	0	2
CI-43	73	1	<1	0	<1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	5	0	7	0	0	0	3	0	0	0	8	
CI-43m	47	3	8	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	23	0	0	0	<1	0	0	0	2	
CI-44	73	1	1	0	0	0	0	0	0	0	0	0	2	0	0	3	0	0	0	1	0	2	0	12	0	0	0	3	0	0	0	2	
CI-44m	43	3	8	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	23	0	0	0	<1	0	0	0	2	
CI-45	63	1	4	0	<1	0	0	0	0	0	0	0	<1	0	0	3	0	0	0	4	0	3	0	14	0	0	0	1	0	0	0	7	
CI-45m	43	3	8	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	23	0	0	0	<1	0	0	0	2	
CI-47	46	6	2	0	0	0	0	0	0	0	0	0	<1	0	0	<1	0	0	0	10	1	4	0	27	0	0	0	5	0	0	0	0	
CI-47m	56	<1	5	0	0	0	0	0	0	0	0	0	<1	0	0	0	0	0	0	8	0	3	0	17	0	0	0	10	0	0	0	0	
CE-2	43	12	2	0	6	0	0	0	0	0	0	0	1	0	0	1	0	0	0	2	0	1	0	26	0	0	2	5	0	0	0	0	
CE-2m	44	4	1	1	4	<1	0	0	0	0	0	0	2	0	0	2	0	0	0	6	0	1	0	26	0	0	<1	7	0	0	1	0	
CE-8	22	26	2	0	6	0	0	0	0	0	0	0	1	0	0	1	0	0	0	12	<1	3	0	24	0	0	0	6	0	0	1	0	
CE-8m	51	3	4	0	4	2	<1	0	0	0	0	0	5	0	0	1	0	0	0	6	0	4	0	18	0	0	<1	1	0	0	0	0	
CE-9	35	24	1	6	2	0	0	0	0	0	0	0	2	0	0	1	0	0	0	4	1	1	0	18	0	0	0	6	0	0	0	0	
CE-9m	41	11	<1	0	9	0	<1	0	0	0	0	0	3	0	0	2	0	0	0	7	0	2	0	19	0	0	2	2	0	0	0	2	
CE-20	24	24	1	0	1	0	0	0	0	0	0	0	<1	0	0	0	0	0	0	13	0	6	0	26	0	0	1	3	0	0	0	2	
CE-20m	46	3	<1	0	4	8	0	0	0	0	0	0	4	0	0	2	0	0	0	7	0	4	0	16	0	0	1	3	0	0	0	2	
BLM-3	43	8	1	0	41	0	<1	0	0	0	0	<1	0	0	0	0	0	0	0	<1	0	6	0	0	0	0	0	0	0	0	0	0	0
BLM-3m	5	40	1	0	49	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	
YL-1	0	1	13	0	24	0	0	0	0	0	0	0	0	0	0	<1	0	0	0	61	<1	0	0	0	0	0	0	2	0	0	0	0	
YL-1m	0	0	0	0	26	0	0	0	<1	0	0	0	<1	0	0	6	0	0	63	1	0	1	0	<1	0	<1	0	3	0	0	0	0	
YL-9	5	0	1	65	26	0	0	0	0	0	0	0	0	<1	0	<1	0	0	3	<1	0	1	0	0	0	0	0	0	0	0	0	0	
YL-9m	0	0	6	0	37	0	0	0	0	0	0	0	<0	0	0	<1	0	0	53	2	0	1	0	<1	0	<1	0	1	0	0	0	0	
YT-1	0	0	12	0	2	0	0	52	0	2	1	0	0	0	0	5	0	26	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
YT-1m	0	0	12	0	2	0	0	49	1	3	0	0	0	0	0	14	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
YG-12	0	0	25	0	59	0	2	10	0	0	0	<1	1	0	<1	1	0	0	0	0	0	0	0	0	0	<1	0	0	0	0	0	0	0
YG-12m	0	0	14	0	38	0	<1	29	0	0	1	0	3	0	1	4	0	0	0	0	0	4	0	0	0	7	0	0	0	0	0	0	0
FN-2	0	0	12	0	10	0	<1	54	0	0	<1	0	0	0	2	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FN-2m	0	0	7	0	36	5	0	42	0	1	<1	0	0	0	<1	6	0	0	0	0	0	1	0	0	0	<1	0	0	0	0	0	0	0

APPENDIX B. RATIO OF FINE TO COARSE GRAINS BY SAMPLE

Definitions of fine and coarse grains were presented in the Procedures section.

Table 4 defines the sample number codes.

An "m" suffix indicates extra-macrofossil sediment.

Variable Samples

Sample #	Ratio	Sample #	Ratio
PI-2	0.34	CI-43	2.84
PI-2m	0.43	CI-43m	1.11
PI-7-1	0.10	CI-44	3.48
PI-7-1m	0.91	CI-44m	1.11
PI-7-2	0.27	CI-45	2.12
PI-7-2m	0.91	CI-45m	1.11
PG-11	0.39	CI-47	0.87
PG-11m	0.50	CI-47m	1.46
BM-6	0.00	CE-2	0.81
BM-6m	0.01	CE-2m	0.87
BM-7	0.00	CE-8	0.30
BM-7m	0.20	CE-8m	1.30
BM-10	0.00	CE-9	0.57
BM-10m	0.01	CE-9m	0.75
CL-12	1.21	CE-20	0.31
CL-12m	1.04	CE-20m	0.96
CI-3	1.03	CF-3	0.03
CI-3m	0.94	CF-3m	0.94
CI-4	0.94	BLM-3	0.76
CI-4m	0.59	BLM-3m	0.06
CI-5	0.68	YG-12	0.17
CI-5m	0.75	YG-12m	0.58
CI-21	0.56	YL-1	0.00
CI-21m	0.66	YL-1m	1.08
CI-31	0.90	YL-9	0.05
CI-3m	0.60	YL-9m	0.00
CI-41	11.46	YT-1	7.92
CI-41m	0.37	YT-1m	10.78
CI-42	1.71		
CI-42m	0.84		

Non-variable Samples

Sample #	Ratio	Sample #	Ratio	Sample #	Ratio
PI-6	0.03	CI-26	0.75	CL-7	0.69
PI-6m	0.02	CI-26m	0.69	CL-7m	0.75
PI-11	0.27	CI-27	1.50	CL-11	1.22
PI-11m	0.43	CI-27m	0.69	CL-11m	0.69
PI-12	0.82	CI-28	0.54	CL-14	1.13
PI-12m	0.69	CI-28m	0.82	CL-14m	1.08
PI-15	0.25	CI-30	1.44	CL-16	1.13
PI-15m	0.06	CI-30m	1.08	CL-16m	0.72
PI-16	0.19	CI-32	0.96	CL-25	0.52
PI-16m	0.27	CI-32m	0.43	CL-25m	0.52
BM-2	0.21	CI-34	0.79	CE-1	2.85
BM-2m	0.32	CI-34m	1.38	CE-1m	2.85
BM-4	0.69	CI-35	1.27	CE-6	1.38
BM-4m	1.44	CI-35m	0.79	CE-6m	1.38
BM-5	0.25	CI-36	0.52	CE-12	0.79
BM-5m	0.20	CI-36m	1.04	CE-12m	0.79
BM-8	0.64	CI-37	0.02	PL-1	2.85
BM-8m	0.64	CI-37m	0.04	PL-1m	2.85
BM-9	0.57	CI-39	0.79	PL-2	2.13
BM-9m	0.52	CI-39m	0.82	PL-2m	2.13
CI-1	0.96	CI-40	0.49	PL-4	0.32
CI-1m	0.56	CI-40m	1.27	PL-4m	0.32
CI-17	1.22	CI-49	0.69	YL-2	1.04
CI-17m	0.56	CI-49m	1.08	YL-2m	1.04
CI-19	0.89	CF-1	4.26	YL-3	1.00
CI-19m	1.22	CF-1m	3.35	YL-3m	1.00
CI-20	0.64	CF-4	0.00	YL-4	1.38
CI-20m	0.82	CF-4m	0.00	YL-4m	1.78
CI-23	1.04	CL-2	1.56	YL-5	1.38
CI-23m	1.08	CL-2m	0.79	YL-5m	1.94
CI-25	1.08	CL-4	1.17	YL-6	11.50
CI-25m	0.82	CL-4m	0.69	YL-6m	1.33

Sample #	Ratio	Sample #	Ratio	Sample #	Ratio
YL-7	1.17	YG-5	0.67	FN-9	0.67
YL-7m	1.17	YG-5m	0.41	FN-9m	0.54
YL-8	1.50	YG-6	0.79	FN-10	0.45
YL-8m	1.50	YG-6m	0.41	FN-10m	0.41
YL-10	0.54	YG-7	0.37	FN-11	0.92
YL-10m	0.41	YG-7m	0.41	FN-11m	0.41
YT-2	6.69	YG-9	0.11	FN-12	0.10
YT-2m	9.00	YG-9m	0.43	FN-12m	0.37
YT-4	7.34	YG-10	0.13	FN-13	0.28
YT-4m	6.48	YG-10m	1.13	FN-13m	0.33
YT-5	1.94	CRL-2	0.10	FN-14	0.09
YT-5m	1.94	CRL-2m	0.04	FN-14m	0.30
YT-6	3.35	CRL-3	0.00	FN-21A	0.04
YT-6m	3.34	CRL-3m	1.60	FN-21Am	0.47
YT-7	3.21	FN-1	0.23	FN-21B	0.30
YT-7m	0.44	FN-1m	0.45	FN-21Bm	0.56
YT-9	0.22	FN-3	0.00	FN-22	0.16
YT-9m	0.23	FN-3m	0.27	FN-22	0.02
YT-10	4.26	FN-4	0.75	UL-1	0.14
YT-10m	4.56	FN-4m	0.75	UL-1m	0.02
YG-1	0.75	FN-7	1.50	UL-4	0.64
YG-1m	0.14	FN-7m	1.50	UL-4m	0.20
YG-3	0.79	FN-8A	0.03	UL-5	0.23
YG-3m	0.41	FN-8Am	0.20	UL-5m	0.23
YG-4	0.47	FN-8B	0.03	UL-6	0.09
YG-4m	0.41	FN-8Bm	0.20	UL-6m	0.15

APPENDIX C. LIST OF SAMPLES WITH MAJOR SAMPLE GROUP IDENTIFICATION

Table 4 defines the sample number codes.

An "m" suffix indicates extra-macrofossil sediment.

"---" indicates the same sample group category as that shown directly above it.

Sample #	Fossil Type	Grain Group	Rock Type	Moldic Group	Age
PI-2	gastropod	2	carbonate	moldic	Cretaceous
PI-2m	---	2	---	---	---
PI-6	oyster	1	carbonate	non-moldic	Cretaceous
PI-6m	---	1	---	---	---
PI-7(1)	bivalve	1	carbonate	moldic	Cretaceous
PI-7(1)m	---	2	---	---	---
PI-7(2)	bivalve	1	carbonate	moldic	Cretaceous
PI-7(2)m	---	2	---	---	---
PI-11	bivalve	1	carbonate	moldic	Cretaceous
PI-11m	---	2	---	---	---
PI-12	bivalve	2	carbonate	moldic	Cretaceous
PI-12m	---	2	---	---	---
PI-15	gastropod	1	carbonate	moldic	Cretaceous
PI-15m	---	1	---	---	---
PI-16	bivalve	1	carbonate	moldic	Cretaceous
PI-16m	---	1	---	---	---
PG-11	oyster	2	terrigenous	non-moldic	Cretaceous
PG-11m	---	2	---	---	---
BM-2	brachiopod	1	carbonate	non-moldic	Paleocene
BM-2m	---	1	---	---	---
BM-4	brachiopod	2	carbonate	non-moldic	Paleocene
BM-4m	---	3	---	---	---
BM-5	brachiopod	1	carbonate	non-moldic	Paleocene
BM-5m	---	1	---	---	---
BM-6	brachiopod	1	carbonate	non-moldic	Paleocene
BM-6m	---	1	---	---	---
BM-7	brachiopod	1	carbonate	non-moldic	Paleocene
BM-7m	---	1	---	---	---
BM-8	brachiopod	2	carbonate	non-moldic	Paleocene
BM-8m	---	2	---	---	---
BM-9	brachiopod	2	carbonate	non-moldic	Paleocene
BM-9m	---	2	---	---	---
BM-10	brachiopod	1	carbonate	non-moldic	Paleocene
BM-10m	---	1	---	---	---

Sample #	Fossil Type	Grain Group	Rock Type	Moldic Group	Age
CI-1	brachiopod	2	carbonate	non-moldic	Eocene
CI-1m	---	2	---	---	---
CI-3	gastropod	3	carbonate	moldic	Eocene
CI-3m	--	2	---	---	---
CI-4	gastropod	2	carbonate	moldic	Eocene
CI-4m	---	2	---	---	---
CI-5	echinoid	2	carbonate	non-moldic	Eocene
CI-5m	--	2	---	---	---
CI-17	echinoid	3	carbonate	non-moldic	Eocene
CI-17m	---	2	---	---	---
CI-19	gastropod	2	carbonate	moldic	Eocene
CI-19m	---	3	---	---	---
CI-20	echinoid	2	carbonate	non-moldic	Eocene
CI-20m	---	2	---	---	---
CI-21	gastropod	2	carbonate	moldic	Eocene
CI-21m	---	2	---	---	---
CI-23	echinoid	3	carbonate	non-moldic	Eocene
CI-23m	---	3	---	---	---
CI-25	echinoid	3	carbonate	non-moldic	Eocene
CI-25m	---	2	---	---	---
CI-26	echinoid	2	carbonate	non-moldic	Eocene
CI-26m	---	2	---	---	---
CI-27	echinoid	3	carbonate	non-moldic	Eocene
CI-27m	---	2	---	---	---
CI-28	echinoid	2	carbonate	non-moldic	Eocene
CI-28m	---	2	---	---	---
CI-30	brachiopod	3	carbonate	non-moldic	Eocene
CI-30m	---	3	---	---	---
CI-31	echinoid	2	carbonate	non-moldic	Eocene
CI-31m	---	2	---	---	---
CI-32	echinoid	2	carbonate	non-moldic	Eocene
CI-32m	---	2	---	---	---
CI-34	echinoid	2	carbonate	non-moldic	Eocene
CI-34m	---	3	---	---	---

Sample #	Fossil Type	Grain Group	Rock Type	Moldic Group	Age
CI-35	brachiopod	3	carbonate	non-moldic	Eocene
CI-35m	---	2	---	---	---
CI-36	echinoid	2	carbonate	non-moldic	Eocene
CI-36m	---	3	---	---	---
CI-37	echinoid	1	carbonate	non-moldic	Eocene
CI-37m	---	1	---	---	---
CI-39	gastropod	2	carbonate	moldic	Eocene
CI-39m	---	2	---	---	---
CI-40	echinoid	2	carbonate	non-moldic	Eocene
CI-40m	---	3	---	---	---
CI-41	gastropod	4	carbonate	moldic	Eocene
CI-41m	---	2	---	---	---
CI-42	gastropod	3	carbonate	moldic	Eocene
CI-42m	---	2	---	---	---
CI-43	gastropod	3	carbonate	moldic	Eocene
CI-43m	---	3	---	---	---
CI-44	gastropod	4	carbonate	moldic	Eocene
CI-44m	---	3	---	---	---
CI-45	gastropod	3	carbonate	moldic	Eocene
CI-45m	---	3	---	---	---
CI-47	brachiopod	2	carbonate	non-moldic	Eocene
CI-47m	---	3	---	---	---
CI-49	brachiopod	2	carbonate	non-moldic	Eocene
CI-49m	---	3	---	---	---
CF-1	gastropod	4	carbonate	non-moldic	Eocene
CF-1m	---	4	---	---	---
CF-3	bivalve	1	carbonate	non-moldic	Eocene
CF-3m	---	2	---	---	---
CF-4	echinoid	1	carbonate	non-moldic	Eocene
CF-4m	---	1	---	---	---
CL-2	echinoid	3	carbonate	non-moldic	Eocene
CL-2m	---	2	---	---	---
CL-4	echinoid	3	carbonate	non-moldic	Eocene
CL-4m	---	2	---	---	---

Sample #	Fossil Type	Grain Group	Rock Type	Moldic Group	Age
CL-7	echinoid	2	carbonate	non-moldic	Eocene
CL-7m	---	2	---	---	---
CL-11	echinoid	3	carbonate	non-moldic	Eocene
CL-11m	---	2	---	---	---
CL-12	echinoid	3	carbonate	non-moldic	Eocene
CL-12m	---	3	---	---	---
CL-14	echinoid	3	carbonate	non-moldic	Eocene
CL-14m	---	3	---	---	---
CL-16	echinoid	3	carbonate	non-moldic	Eocene
CL-16m	---	2	---	---	---
CL-25	echinoid	2	carbonate	non-moldic	Eocene
CL-25m	---	2	---	---	---
CE-1	gastropod	3	carbonate	moldic	Eocene
CE-1m	---	3	---	---	---
CE-2	crab	2	carbonate	non-moldic	Eocene
CE-2m	---	2	---	---	---
CE-6	gastropod	3	carbonate	moldic	Eocene
CE-6m	---	3	---	---	---
CE-8	crab	1	carbonate	non-moldic	Eocene
CE-8m	---	3	---	---	---
CE-9	crab	2	carbonate	non-moldic	Eocene
CE-9m	---	2	---	---	---
CE-12	echinoid	2	carbonate	non-moldic	Eocene
CE-12m	---	2	---	---	---
CE-20	crab	1	carbonate	non-moldic	Eocene
CE-20m	---	2	---	---	---
BLM-3	gastropod	2	carbonate	moldic	Eocene
BLM-3m	---	1	---	---	---
PL-1	gastropod	3	carbonate	moldic	Miocene
PL-1m	---	3	---	---	---
PL-2	gastropod	3	carbonate	moldic	Miocene
PL-2m	---	3	---	---	---

Sample #	Fossil Type	Grain Group	Rock Type	Moldic Group	Age
PL-4	oyster	1	phosphorite	non-moldic	Miocene
PL-4m	---	1	---	---	---
YL-1	bivalve	4	carbonate	non-moldic	Pliocene
YL-1m	---	4	---	---	---
YL-2	bivalve	3	carbonate	non-moldic	Pliocene
YL-2m	---	3	---	---	---
YL-3	gastropod	3	carbonate	moldic	Pliocene
YL-3m	---	3	---	---	---
YL-4	gastropod	3	carbonate	moldic	Pliocene
YL-4m	---	3	---	---	---
YL-5	gastropod	3	carbonate	moldic	Pliocene
YL-5m	---	3	---	---	---
YL-6	gastropod	4	carbonate	moldic	Pliocene
YL-6m	---	3	---	---	---
YL-7	gastropod	3	carbonate	moldic	Pliocene
YL-7m	---	3	---	---	---
YL-8	bivalve	3	carbonate	non-moldic	Pliocene
YL-8m	---	3	---	---	---
YL-9	bivalve	4	carbonate	non-moldic	Pliocene
YL-9m	---	4	---	---	---
YL-10	bivalve	2	carbonate	non-moldic	Pliocene
YL-10m	---	2	---	---	---
YT-1	bivalve	4	terrigenous	non-moldic	Pliocene
YT-1m	---	4	---	---	---
YT-2	bivalve	4	terrigenous	non-moldic	Pliocene
YT-2m	---	4	---	---	---
YT-4	bivalve	4	terrigenous	non-moldic	Pliocene
YT-4m	---	4	---	---	---
YT-5	gastropod	3	terrigenous	non-moldic	Pliocene
YT-5m	---	3	---	---	---
YT-6	gastropod	4	terrigenous	non-moldic	Pliocene
YT-6m	---	4	---	---	---

Sample #	Fossil Type	Grain Group	Rock Type	Moldic Group	Age
YT-7	bivalve	4	terrigenous	non-moldic	Pliocene
YT-7m	---	2	---	---	---
YT-9	gastropod	1	terrigenous	non-moldic	Pliocene
YT-9m	---	1	---	---	---
YT-10	bivalve	4	terrigenous	non-moldic	Pliocene
YT-10m	---	4	---	---	---
YG-1	bivalve	2	terrigenous	non-moldic	Pliocene
YG-1m	---	1	---	---	---
YG-3	bivalve	2	terrigenous	non-moldic	Pliocene
YG-3m	---	2	---	---	---
YG-4	bivalve	2	terrigenous	non-moldic	Pliocene
YG-4m	---	2	---	---	---
YG-5	bivalve	2	terrigenous	non-moldic	Pliocene
YG-5m	---	2	---	---	---
YG-6	bivalve	2	terrigenous	non-moldic	Pliocene
YG-6m	---	2	---	---	---
YG-7	bivalve	2	terrigenous	non-moldic	Pliocene
YG-7m	---	2	---	---	---
YG-9	bivalve	1	terrigenous	non-moldic	Pliocene
YG-9m	---	2	---	---	---
YG-10	bivalve	1	terrigenous	non-moldic	Pliocene
YG-10m	---	3	---	---	---
YG-12	bivalve	1	terrigenous	non-moldic	Pliocene
YG-12m	---	2	---	---	---
CRL-2	bivalve	1	terrigenous	non-moldic	Plio-Pleist.
CRL-2m	---	1	---	---	---
CRL-3	bivalve	1	terrigenous	non-moldic	Plio-Pleist.
CRL-3m	---	2	---	---	---
FN-1	bivalve	1	terrigenous	non-moldic	Pleistocene
FN-1m	---	2	---	---	---
FN-2	bivalve	4	terrigenous	non-moldic	Pleistocene
FN-2m	---	2	---	---	---
FN-3	gastropod	1	terrigenous	non-moldic	Pleistocene
FN-3m	---	1	---	---	---

Sample #	Fossil Type	Grain Group	Rock Type	Moldic Group	Age
FN-4	gastropod	2	terrigenous	non-moldic	Pleistocene
FN-4m	---	2	---	---	---
FN-7	gastropod	3	terrigenous	non-moldic	Pleistocene
FN-7m	---	3	---	---	---
FN-8a	gastropod	1	terrigenous	non-moldic	Pleistocene
FN-8am	---	1	---	---	---
FN-8b	bivalve	1	terrigenous	non-moldic	Pleistocene
FN-8bm	---	1	---	---	---
FN-9	gastropod	2	terrigenous	non-moldic	Pleistocene
FN-9m	---	2	---	---	---
FN-10	gastropod	2	terrigenous	non-moldic	Pleistocene
FN-10m	---	2	---	---	---
FN-11	bivalve	2	terrigenous	non-moldic	Pleistocene
FN-11m	--	2	---	---	---
FN-12	bivalve	1	terrigenous	non-moldic	Pleistocene
FN-12m	---	2	---	---	---
FN-13	bivalve	1	terrigenous	non-moldic	Pleistocene
FN-13m	---	1	---	---	---
FN-14	gastropod	1	terrigenous	non-moldic	Pleistocene
FN-14m	---	1	---	---	---
FN-21a	gastropod	1	terrigenous	non-moldic	Pleistocene
FN-21am	---	2	---	---	---
FN-21b	gastropod	1	terrigenous	non-moldic	Pleistocene
FN-21bm	---	2	---	---	---
FN-22	bivalve	1	terrigenous	non-moldic	Pleistocene
FN-22m	---	1	---	---	---
UL-1	bivalve	1	terrigenous	non-moldic	Pleistocene?
UL-1m	---	1	---	---	---
UL-4	bivalve	2	terrigenous	non-moldic	Pleistocene?
UL-4m	---	1	---	---	---
UL-5	gastropod	1	terrigenous	non-moldic	Pleistocene?
UL-5m	---	1	---	---	---
UL-6	gastropod	1	terrigenous	non-moldic	Pleistocene?
UL-6m	---	1	---	---	---

APPENDIX D. DESCRIPTION OF VARIATION BETWEEN INTRA- AND EXTRA-
MACROFOSSIL SEDIMENT BY SAMPLE

Cretaceous

PI-2: This sample is a bivalve mold from a carbonate-dominated rock.

The intra- and the extra-macrofossil sediment are both included within grain group 2 (Table 6). The extra-macrofossil sediment has a greater percentage of vug porosity and fossils, and a lower percentage of micrite/microspar/pseudospar than does the intra-macrofossil sediment.

PI-7: PI-7 is a bivalve mold from a carbonate-dominated rock. Two different lithologies representing two different depositional episodes are present within the macrofossil (PI-7-1 and PI-7-2). Both are poorly washed sandy biosparrudites but PI-7-1 has a higher percentage of quartz and a lower percentage of pore space than PI-7-2.

The intra-macrofossil sediment of PI-7-1 is included in grain group 1, while the extra-macrofossil sediment is included in grain group 2. The intra-macrofossil sediment has a higher percentage of calcite spar. The intra-macrofossil sediment also has a lesser percentage of lime mud and a greater percentage of quartz than does the extra-macrofossil sediment. The intra-macrofossil sediment of PI-7-2 is included in grain group 1, while the extra-macrofossil sediment is included in grain group 2. The intra-macrofossil sediment has a greater percentage of porosity and sparry calcite and a lesser percentage of lime mud than does the extra-macrofossil sediment.

PG-11: PG-11 is an oyster in a terrigenous-dominated lithology. The intra- and extra-macrofossil sediment are both included in grain group 2.

The extra-macrofossil sediment has a greater percentage of glauconite and a lesser percentage of quartz than does the intra-macrofossil sediment.

Paleocene Samples

All of the Paleocene samples are brachiopods from a carbonate-dominated formation. Both the intra- and the extra-macrofossil sediment are included in grain group 1. The matrix was formerly a micrite, but has subsequently aggraded in grain size. The matrix ranges from a microspar to a fine equant sparry calcite or pseudospar as defined by Folk (1959).

BM-6: The intra- and the extra-macrofossil sediment of sample BM-6 differ in percentages of intergranular porosity, blocky spar, and glauconite. A greater percentage of glauconite and intergranular porosity exists within the macrofossil due to the shell acting as a barrier against compaction. The glauconite is in situ (fills intergranular pores and has irregular shapes).

BM-7: The percentage of glauconite is greater within the macrofossil. Poikilotopic spar is present inside as a pore filler. Pore space is negligible outside the shell, which likely inhibited poikilotopic spar precipitation.

BM-10: In sample BM-10 glauconite, and the often associated pyrite, are more abundant outside the shell barrier. Some of the glauconite outside is bronze in color, possibly due to a higher oxidized iron content.

Eocene Samples

All of the Eocene variable samples are from a carbonate-dominated formation.

CI-3: This sample is a gastropod mold. The intra-macrofossil sediment is included in grain group 3 and the extra-macrofossil sediment is included in grain group 2.

A greater percentage of fossils and a lesser percentage of lime mud occur in the extra-macrofossil sediment.

CI-4: This sample is a gastropod mold. The intra- and the extra-macrofossil sediment are both included in grain group 2. The extra-macrofossil sediment has a greater percentage of secondary porosity (moldic and vug) and fossiliferous material and a lesser percentage of sparry calcite and micrite/microspar.

CI-5: This sample is an echinoid. Both the intra- and extra-macrofossil sediment are included in grain group 2. The intra-macrofossil sediment has a lower percentage of micrite/microspar and a greater percentage of interparticle porosity and sparry calcite. The lime mud outside the shell underwent more aggradation of grain size.

CI-21: This sample is a gastropod mold. Both the intra- and the extra-macrofossil sediment are included in grain group 2. A greater percentage of sparry calcite exists within the macrofossil. Interparticle porosity is greater outside the macrofossil.

CI-31: This sample is an echinoid. The intra- and the extra-macrofossil sediment are both included in grain group 2. In this sample a greater percentage of fossils and a lesser percentage of lime mud exist in the extra-macrofossil sediment.

CI-41: This sample is a gastropod mold. The intra-macrofossil sediment is included in grain group 4. The extra-macrofossil sediment is included in grain group 2. The intra-macrofossil sediment is a peloidal micrite. Figure 4 shows the gradational loss of texture from distinct peloids to homogenously textured mud. The extra-macrofossil matrix does not show peloidal texture. The extra-macrofossil sediment has a coarser grained component which includes fossils, quartz, and glauconite with pyrite. The intra-macrofossil sediment has only a minor fossil content and no quartz or glauconite.

CI-42: This sample is a gastropod mold. The intra-macrofossil sediment is included in grain group 3. The extra-macrofossil sediment is included in grain group 2. The micrite matrix within the macrofossil underwent less aggradation in grain size than the micrite matrix outside the macrofossil. The intra-macrofossil sediment has no sedimentary rock fragments and a lesser percentage of fossils than does the extra-macrofossil sediment.

CI-43: This sample is a gastropod mold. The intra- and the extra-macrofossil are both included in grain group 3. A greater percentage of secondary porosity is present within the extra-macrofossil sediment. A greater percentage of lime mud and a lesser percentage of fossils occur within the intra-macrofossil sediment.

CI-44: This sample is a gastropod mold. The intra-macrofossil sediment is included in grain group 4 and the extra-macrofossil sediment is included in grain group 3. The extra-macrofossil sediment has a greater percentage of secondary porosity than does the intra-macrofossil sediment. The extra-macrofossil sediment has a greater percentage of

quartz and fossils and a lesser percentage of lime mud than does the intra-macrofossil sediment. Large grains are included throughout the intra-macrofossil sediment.

CI-45: This sample is another gastropod mold. The intra- and the extra-macrofossil sediment are both included in grain group 3. The extra-macrofossil sediment has a greater percentage of secondary porosity than the intra-macrofossil sediment. The extra-macrofossil sediment has a lesser percentage of lime mud and a greater percentage of quartz and fossiliferous material than the intra-macrofossil sediment.

CI-47: This sample is a brachiopod. The intra-macrofossil sediment is included in grain group 2. The extra-macrofossil sediment is included in grain group 3. The intra-macrofossil sediment has more sparry calcite filling the pore space than does the extra-macrofossil sediment. The extra-macrofossil sediment has a slightly higher percentage of micrite/microspar and a lower percentage of microfossils than the intra-macrofossil sediment.

CL-12: This sample is an echinoid. The intra- and the extra-macrofossil sediment are both included in grain group 3. The extra-macrofossil sediment has a slightly greater percentage of fossils and a slightly lower percentage of micrite/microspar than does the intra-macrofossil sediment.

CE-2: This sample is a crab carapace. The intra- and the extra-macrofossil sediment are included in grain group 2. The intra-macrofossil sediment has more sparry calcite filling the pore space than does the extra-macrofossil sediment.

CE-8: This sample is a crab carapace. The intra-macrofossil sediment is included in grain group 1. The extra-macrofossil sediment is included in grain group 3. The extra-macrofossil sediment has a greater percentage of lime mud than the intra-macrofossil sediment. Pore space was maintained within the shell and later filled by sparry calcite.

CE-9: This sample is a crab carapace. The intra- and the extra-macrofossil sediment are both included in grain group 2. Peloids are present within the intra-macrofossil sediment but not the extra-macrofossil sediment. A higher percentage of quartz and a lower percentage of pore-filling sparry calcite occurs in the extra-macrofossil sediment.

CE-20: This sample is a crab carapace. The intra-macrofossil sediment is included within grain group 1. The extra-macrofossil sediment is included within grain group 2. The extra-macrofossil sediment has greater percentages of lime mud, quartz, glauconite pebbles, and sedimentary rock fragments than does the intra-macrofossil sediment. The intra-macrofossil sediment has a greater percentage of pore-filling sparry calcite than does the extra-macrofossil sediment. The micrite matrix of the intra-macrofossil sediment underwent more extensive aggradation of grain size than did the micrite matrix of the extra-macrofossil sediment.

CF-3: This sample is a bivalve. The intra-macrofossil sediment is included within grain group 1. The extra-macrofossil sediment is included within grain group 2. The intra-macrofossil sediment has a greater percentage of sparry calcite than does the extra-macrofossil sediment.

Miocene Samples

The only Miocene variable sample is BLM-3 from a sandy carbonate formation.

BLM-3: This sample is a gastropod mold. The intra-macrofossil sediment is included in grain group 2 and the extra-macrofossil sediment is included in grain group 1.

The extra-macrofossil micrite matrix underwent more extensive aggradation of grain size than did the intra-macrofossil micrite. Outside the shell, the micrite matrix has aggraded as far as fine equant calcite spar or pseudospar.

Pliocene

The six Pliocene variable samples are all bivalves from three locations and one formation.

YG-12: This sample has a terrigenous-dominated lithology. The intra-macrofossil sediment is included in grain group 1 and the extra-macrofossil sediment in grain group 2. Pyrite is finer grained and has a slightly greater percentage outside the macrofossil. The intra-macrofossil sediment has a greater percentage of quartz and interparticle porosity, a lesser percentage of clay and fossil fragments, and appears better sorted than the extra-macrofossil sediment.

YT-1: This sample is from a terrigenous-dominated lithology. The intra- and the extra-macrofossil sediments are both included in grain group 4.

YL-1: This sample is a bivalve from a sandy carbonate unit within a predominantly terrigenous formation. The intra- and the extra-macrofossil sediment are both included in grain group 4.

The intra-macrofossil sediment has a greater percentage of interparticle porosity and a lesser percentage of pyrite and fossiliferous material than does the extra-macrofossil sediment.

YL-9: This sample is another bivalve from a sandy carbonate unit. The intra- and the extra-macrofossil sediment are both included within grain group 4. The matrix within the shell underwent more dolomitization than the matrix outside the shell (greater dolomite:calcite ratio by x-ray diffraction data).

Pleistocene Samples

FN-2: This is the only Pleistocene variable sample. FB-2 is a bivalve from a terrigenous-dominated formation. The intra-macrofossil sediment is included in grain group 4. The extra-macrofossil sediment is included in grain group 2. The intra-macrofossil sediment has a greater percentage of pyrite than does the extra-macrofossil sediment.