Taphonomic and Paleoenvironmental Evidence of Holocene Shell-Bed Genesis and History on the Northeastern Gulf of Mexico Shelf

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Subsurface shell beds that are common on the eastern Alabama/western Florida Panhandle shelf provide paleoenvironmental and taphonomic data that demonstrate a dynamic depositional history with reactivation and amalgamation to the base of the Holocene marine transgressive package. In most of the ten shell beds we examined, shallow-marine mollusks, large soritid foraminifera, and cupularid bryozoans are common. Bioclasts occur in all preservation states, but a majority are pristine or only slightly altered. Normal grading, and concave-up, stacked, and random fabrics are common. In three of these shell beds, a relict estuarine component characterized by poorly-preserved Chione cancellata *can be detected. Three other shell beds contain 1 of 2 estuarine molluscan assemblages. One assemblage is characteristic of fine-grained and the other of coarser-grained substrates. In all estuarine shell beds, bioclast preservation ranges from excellent to mixed, and bioclasts have random fabrics and locally are normally graded.*

Most molluscan remains are indigenous and assemblages range from within-habitat time-averaged to environmentally condensed. Shell beds are thick (up to about 75 cm) and overlie bay or shoreface ravinement surfaces, indicating that shell beds first accumulated as coarse transgressive deposits, and are composite concentrations modified by multiple events. Shell beds, however, are amalgamated. Only fabrics reflecting the final modifying events are preserved, and evidence of previous accumulation processes are obliterated. For marine shell beds especially, these final agents were, and possibly continue to be, high-energy events such as storms (winter cold fronts, hurricanes) or currents associated with Loop Current eddies. Episodically high sedimentation rates associated with these events may have acted as a buffer, preventing a long history of reworking and exposure (thus reducing shell alteration) typical of transgressive lags. Our results indicate that: 1) within-habitat time-averaged and environmentally condensed assemblages can be distinguished by combining taphonomic and environmental data, even when the ranges of environmentally disparate species overlap, 2) transgressive-lag deposits can be composed of well-preserved bioclasts, and 3) transgressive lags can be reworked and amalgamated but still be recognizable on the basis of their stratigraphic context.

INTRODUCTION

The tectonically-stable northeastern Gulf of Mexico shelf experienced high sedimentation rates in the Quaternary (Coleman et al., 1991; Galloway et al., 1991; Donoghue, 1992), and has a well-preserved and detailed depositional record. Until recently, however, this part of the Gulf received less attention than the well-studied northwestern Gulf of Mexico shelf (e.g., Morton, 1981; Snedden and Nummedal, 1991; Anderson et al., 1992; Siringan and Anderson, 1994). The Holocene sections of these two regions differ in several ways. The northeastern Gulf Holocene package is a continuously thick (up to 5.5 m) sand sheet (Ludwick, 1964; Doyle and Sparks, 1980; McBride and Byrnes, 1995; McBride et al., 1995), whereas Holocene shelf sediments in the northwestern Gulf typically are thin (<2 m), except for isolated shoal areas, and are more muddy. In addition, relatively thick subsurface shell

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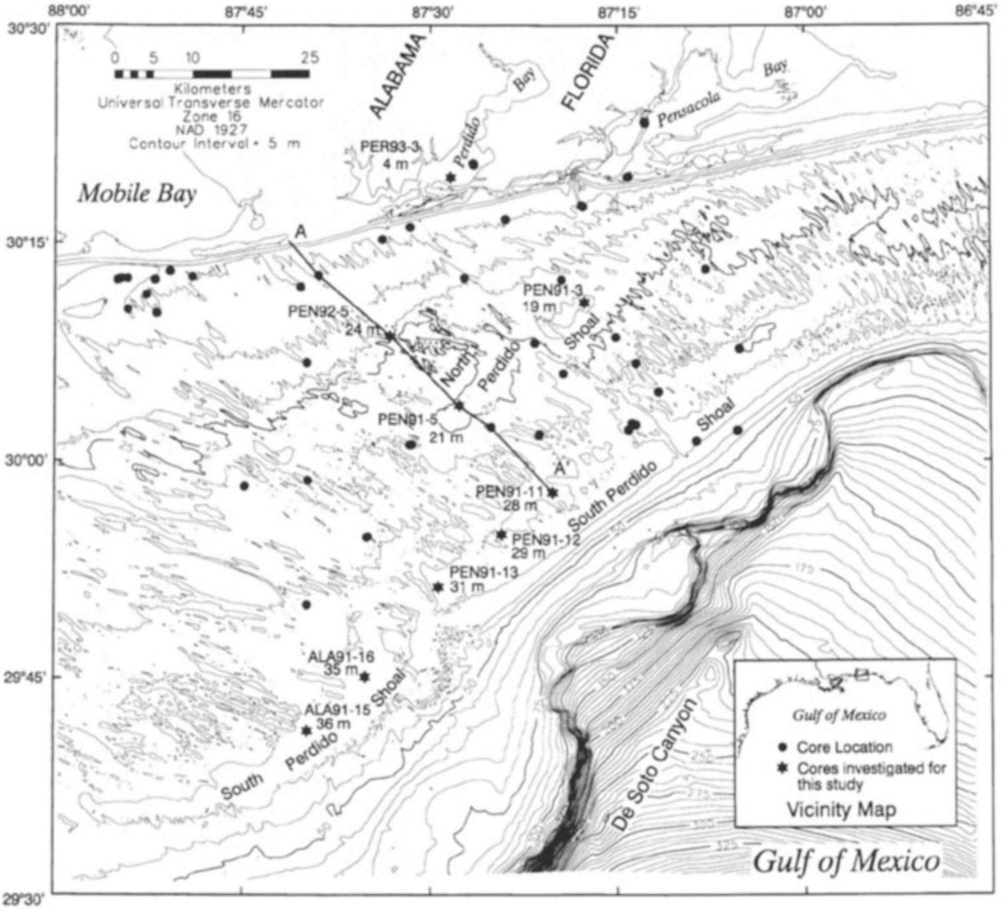


FIGURE 1—Study area showing vibracore localities (after McBride and Byrnes, 1995). Cores containing the shell beds discussed in this paper are marked with a star. Other vibracore localities are indicated by a circle. Cross section A–A′ is shown in Figure 15.

beds with a very well-preserved molluscan fauna are common in the northeastern Gulf. In contrast, shell beds of the northwestern Gulf typically are thin storm layers. These differences indicate a more complex shell-bed accumulation history in the northeastern Gulf, and reconstructing this history will help clarify depositional patterns throughout the Holocene in this region. The purpose of this study is to reconstruct the genesis and depositional history of these shell beds by determining: 1) paleoenvironmental settings, 2) bioclast sources, 3) time averaging, 4) relative time-scales of shell-bed accumulation, and 5) accumulation processes.

STUDY AREA

The study area is located on the continental shelf, shoreface, and inland waters between Mobile and Pensacola Bays (Fig. 1). Of 48 vibracores collected, about one-half contained shell beds. From this material, 10 well-developed shell beds from 9 cores were selected for detailed paleontologic analysis. Seven of these vibracores were from North and South Perdido Shoals that form long (up to 120 km), linear ridges on the middle to outer shelf and are subparallel to the modern shoreline (McBride and Byrnes, 1995). The two other vibracores are from Perdido Bay and from a bathymetric low landward of North Perdido Shoal.

METHODS

Bioclasts >1.4 mm ($<-0.5\ \phi$) were examined. Mollusks, which typically dominated assemblages, were identified to species, whereas other bioclasts were identified to higher taxonomic levels. For each taxon, the number of bioclasts, size of largest bioclast, and taphonomic grade (preservation) were recorded. Complete datasets are available from the authors on request. Bioclasts counted were whole valves and fragments with a hinge for bivalves, whole shells and fragments with the spire for gastropods, and whole individuals or colonies for other taxa. The anterior-posterior dimension in bivalves, distance along the spiral axis in gastropods, and longest dimension of other taxa were measured. Two taphonomic attributes were considered: taphonomic grade (Table 1), and bioclast fabric. Three composite taphonomic grades (Excellent, Fair, Poor) based on standard preservational criteria such as presence of original color, degree of corrasion (general deg-

TABLE 1—Categories, abbreviations, and criteria used to construct taphonomic grades.

	Excellent: minimal alteration
Corrasion:	• none to minor • gloss present • pallial line and muscle scars present (bivalves)
Rounding:	• none, ornament and edges sharp
Boring	• none to minor
Encrustation:	• none to minor
Color:	• original color pristine to moderate loss
	Fair: moderate alteration
Corrasion:	• moderate, may be partially chalky • gloss absent • pallial line indistinct
Rounding:	• ornament and edges moderately worn
Boring:	• moderate
Encrustation:	• moderate
Color:	• original color minimal to absent
	Poor: extensive alteration
Corrasion:	• major to extreme, chalky to pitted • gloss absent • pallial lines and muscle scars indistinct
Rounding:	• ornament nearly absent, edges smooth
Boring:	• extensive
Encrustation:	• extensive
Color:	• original color absent

TABLE 2—Environmental categories used in this paper, and defining salinity and depth ranges.

Environmental category	Salinity (‰)	Depth (m)
Estuary		
River-influenced	8–11	1–6
Transitional	10–25	1–9
Marine-influenced	25–38	1–9
Lagoon	20–40	1–4
Inlet (includes inlet throat and flood and ebb tidal deltas)	30–35	<17
Shoreface	36	0–15
Shelf	36	>15

radation caused by dissolution, bioerosion, or abrasion [Brett and Baird, 1986]), rounding of edges and ornament, boring, and encrustation (see Brett and Baird, 1986; Parsons and Brett, 1991) were used. We did not consider fragmentation because of numerous potential causes not directly related to shell-bed accumulation, including predation (Trewin and Welsh, 1976; Powell et al., 1989; Cadée, 1994; Cate and Evans, 1994) and collection. Bioclasts were assigned to one of these three grades and data were plotted on ternary taphograms to show relative proportions of grades for selected species (see Kowalewski et al., 1995). Fabric refers to the orientation of bioclasts relative to each other and to overall bedding. Bioclast fabrics were examined qualitatively by examination of cores and core photographs.

Species' environmental preferences are based on published information organized into categories based on depth and salinity conditions (Table 2; sources include Ladd, 1951; Ladd et al., 1957; Perry and Schwengel, 1955; Parker, 1956, 1959, 1960; Lyons et al., 1971; Jervey, 1974; Andrews, 1977). We used nonmetric Multidimensional Scaling (MDS) to compare molluscan assemblages of the shell beds. Only mollusks were incorporated into this analysis because: 1) mollusks dominated most assemblages, 2) more environmental information was available for this group than for other macrofauna, and 3) taphonomic and sedimentologic evidence indicates that mollusks are indigenous (see Paleoenvironmental Setting and Bioclast Source Section below). Input data were ranked abundances of the 41 species that made up >1% of at least one core and >20 individuals in all cores. For MDS, the number of bivalve bioclasts was divided by two (because bivalves provide two bioclasts to the death assemblage) before species selection and ranking. For greater consistency in sample intervals across cores, species counts were pooled into 10–15 cm intervals. These intervals were selected on similar lithology and taxonomic composition.

SHELL-BED DESCRIPTIONS

Core PER-93-3

Core PER-93-3 (total length 4.9 m) is from Perdido Bay (Fig. 1), and contains a 13-cm thick shell bed with an erosional base and a sharp upper contact (Fig. 2a). The shell bed is underlain by a bioturbated silty sand with rip-up clasts and is overlain by 3.9 m of gray laminated clay. Shell-bed bioclasts have a random fabric and are loosely packed in muddy quartz sand. The assemblage is characterized by estuarine species such as *Chione cancellata, Nuculana acuta,* and *Crassostrea virginica* (Fig. 2b). Bioclast preservation within this core is mixed, as illustrated for *Chione cancellata* (Fig. 3).

Core PEN-92-5

Core PEN-92-5 (total length 2.5 m) is from a bathymetric low landward of North Perdido Shoal (Fig. 1), and contains a 78 cm-thick shell bed at its base. Bioclasts in the upper part of the shell bed (170–206 cm) are graded as seen in the decrease in bioclast size and increase in bioclast number per sample (Fig. 4a, c, d). The shell bed grades into a massive, silty quartz sand (63 cm) that grades into a laminated clay (52 cm). The clay is erosionally truncated and overlain by a 45 cm-thick sand with scattered bioclasts. Shell-bed bioclasts are size sorted, have a random fabric and are loosely packed in muddy quartz sand. Both estuarine and shelf species are common

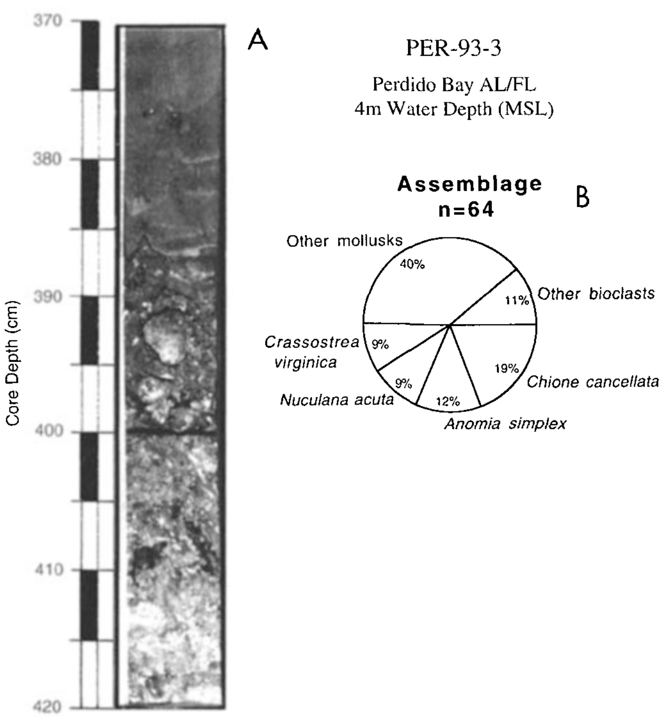


FIGURE 2—A) Photo-mosaic of core PER-93-3 shell bed (388–400 cm) and super- and subjacent units. B) Pie diagram showing proportions of common bioclasts in the core. Sampled interval is 388–400 cm (incorporated into one sample).

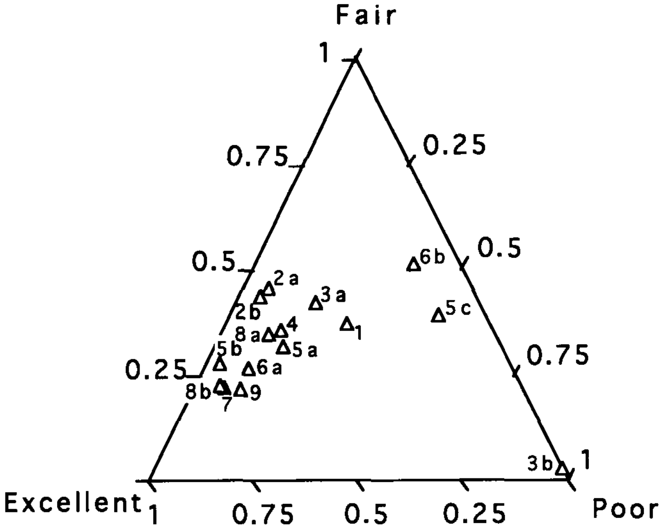


FIGURE 3—Ternary taphogram (see Kowalewski et al., 1995) showing the relative proportions of three composite taphonomic grades for key molluscan species from each shell bed. Preservation generally is good except for reworked estuarine species in marine shell beds (#3b, 5c, 6b). See Table 1 for criteria to distinguish grades. 1 = *Chione cancellata* from core PER-93-3; 2a = *Mulinia lateralis* and 2b = *Corbula operculata* from core PEN-92-5; 3a = *Chione intapurpurea* and 3b = *C. cancellata* from core PEN-91-3; 4 = *Macrocallista maculata* from core PEN-91-5; 5a = *M. maculata* from the marine portion of core PEN-91-11, 5b = *C. cancellata* from the estuarine portion of core PEN-91-11, and 5c = *C. cancellata* from the marine portion of core PEN-91-11; 6a = *M. nimbosa* and 6b = *C. cancellata* from core PEN-91-12; 7 = *M. maculata* from core PEN-91-13; 8a = *Ervilia nitens* and 8b = *Mulinia lateralis* from core ALA-91-16; and 9 = *Macrocallista maculata* from core ALA-91-15.

(Fig. 4b). *Mulinia lateralis, Nuculana concentrica,* and *Anadara transversa,* which range from transitional estuaries to the shoreface, are most abundant, but shelf inhabitants such as *Corbula* (*Varicorbula*) *operculata* also are common. Preservation is relatively good in both marine and estuarine species (Fig. 3), although many bioclasts are blackened.

Core PEN-91-3

Core PEN-91-3 (total length 3.9 m), from the eastern part of North Perdido Shoal (Fig. 1), has a 19 cm-thick shell bed at its base. This shell bed grades into a 3.7 m-thick, massive sand with scattered bioclasts. Shell-bed bioclasts are graded, are densely packed in clean quartz sand, and bivalves have concave-up, stacked, and vertical fabrics (Fig. 5a, d). The assemblage is dominated by large soritid foraminifera, and fragments of the coralline red algae *Lithothamnion?* are abundant in the upper part of the shell bed (Fig. 5b, c). The molluscan assemblage is a mixture of very poorly preserved estuarine species (e.g., *Chione cancellata*) and moderately well-preserved shallow-marine species (e.g., *C. intapurpurea*) (Figs. 3; 6a,b).

Core PEN-91-5

Core PEN-91-5 (total length 4.6 m) is from the western part of North Perdido Shoal (Fig. 1). The base of the core contains an 11 cm-thick bioclast-supported shell bed with a clean quartz sand matrix (Fig. 7a). Overlying the shell bed is about one meter of crudely stratified sand with scattered large bioclasts, which grades into a 3.7 m-thick sand with widely scattered bioclasts. In both the shell bed and overlying scattered-bioclast units, bioclasts are not *in situ,* and bivalves have concave-up and stacked fabrics. The fauna is dominated by large soritid foraminifera and cupularid bryozoans (Fig. 7b). The molluscan assemblage is shoreface- or shelf-derived with *Pleuromeris tridentata, Macrocallista maculata* and *Anomia simplex* most common. No progressive size or abundance trends are apparent through the sampled interval (Fig. 7c, d). Bioclasts are moderately well-preserved, as illustrated by *M. maculata,* which falls midway along the excellent-fair axis of the ternary taphogram (Fig. 3).

Core PEN-91-11

This and remaining cores are from South Perdido Shoal (Fig. 1). Two shell beds occur in core PEN-91-11 (total length 4.1 m). The lower shell bed is 15 cm thick and grades upward into a 34 cm-thick bioturbated muddy sand with scattered bioclasts (Fig. 8a). Bioclasts of the lower shell bed are loosely packed in a muddy quartz sand. Bio-

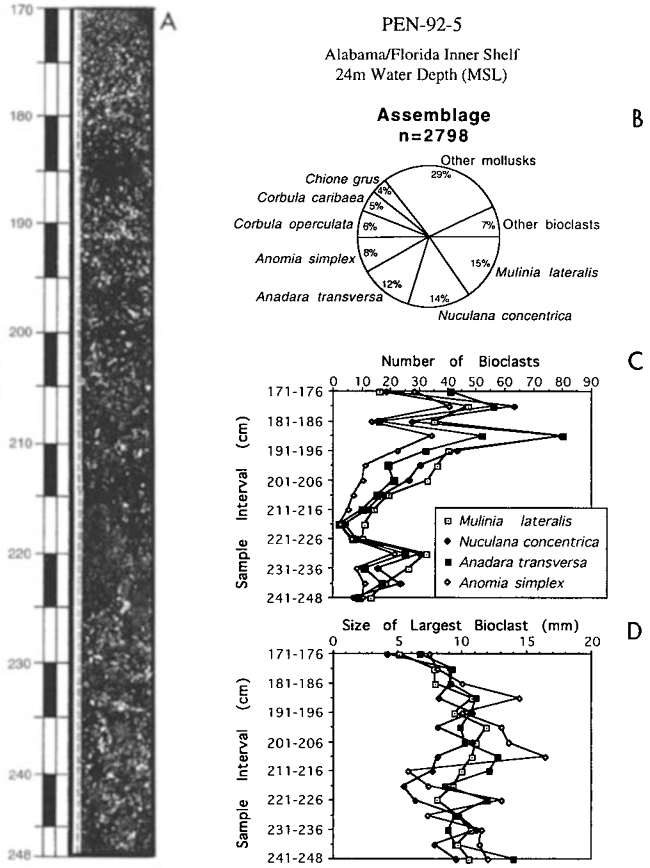


FIGURE 4—A) Photo-mosaic of core PEN-92-5 shell bed (171–248 cm). B) Pie diagram showing proportions of common bioclasts in the core. Total sampled interval is 171–248 cm. C) Number of bioclasts per sample with depth for common species. D) Size of largest bioclast per sample with depth for abundant species.

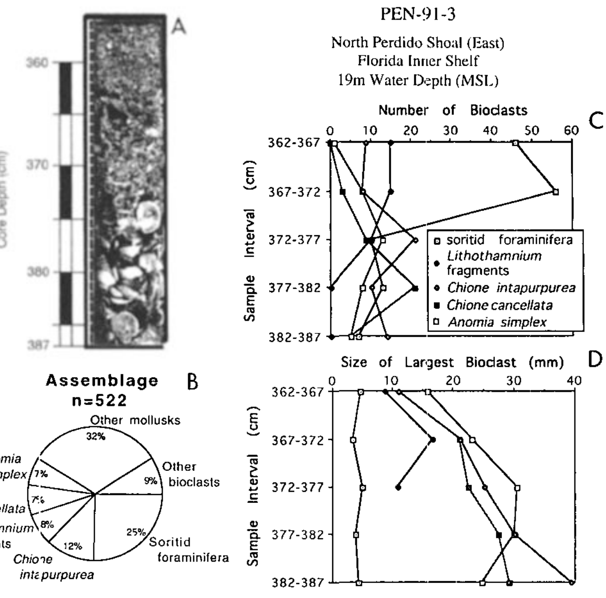


FIGURE 5—A) Photograph of core PEN-91-3 shell bed (370–387 cm) and overlying sediment. B) Pie diagram showing proportions of common bioclasts in the core. Total sampled interval is 362–387 cm. C) Number of bioclasts per sample with depth for common species. D) Size of largest bioclast per sample with depth for abundant species.

clasts in both the shell bed and overlying muddy sand have a random fabric and *Chione cancellata* and *Parvilucina multilineata,* which typically inhabit marine-influenced estuaries, are common (Fig. 8b, c). The foraminiferal assemblage also is estuarine (Anderson et al., 1994). Preservation is very good in both lower units, and 69% of *C. cancellata* valves have excellent preservation (Figs. 3, 6d).

The upper shell bed is 18 cm thick, has a sharp erosional base, and grades into a 3.4 m-thick massive to poorly-laminated sand with scattered bioclasts (Fig. 8a). Upper-shell-bed bioclasts are loosely to densely packed in clean quartz sand. Bioclasts show slight grading and have a random fabric (Fig. 8a, d). Cupularid bryozoans, large soritid foraminifera, and moderately well-preserved *Macrocallista maculata* are abundant (Fig. 8b, c). *Chione cancellata* also is common in the upper shell bed but is very poorly preserved and probably is reworked (Figs. 3; 6c, d).

Core PEN-91-12

A 37 cm-thick shell bed occurs at the base of core PEN-91-12 (total length 4.5 m). The shell bed has a sharp upper contact and is overlain by a 4.1 m-thick, massive to horizontally-laminated sand with scattered bioclasts. Shell-bed bioclasts are densely packed in clean quartz sand, are slightly graded (as seen in the size decrease of *Macrocallista nimbosa* and increased abundance of *Ervilia nitens*), and bivalves have stacked and concave-up fabrics (Fig. 9a, c, d). The molluscan assemblage is derived from an inlet-influenced area and/or the upper shoreface, and *M. nimbosa, E. nitens,* and *Anomia simplex* are common (Fig. 9b). Preservation is good for marine species such as *M. nimbosa,* although chalky textures are common in larger bioclasts (Figs. 3; 6e). However, the estuarine species *C. cancellata* is poorly preserved (Fig. 3).

Core PEN-91-13

The 28 cm-thick shell bed at the base of core PEN-91-13 (total length 4.0 m) consists of two bioclast-supported intervals separated by a 5 cm-thick sand (Fig. 10a). The shell bed has a sharp upper contact and is overlain by a 3.7 m-thick sand with scattered bioclasts. Bioclasts are not *in situ,* and bivalves have concave-up and stacked fabrics. The largest bioclasts in the lower bioclast-supported unit are gastropods, but are bivalves in the upper bioclast-supported unit (Fig. 10a). Soritids are extremely abundant, and cupularid bryozoans, *Macrocallista maculata,* and *Ervilia nitens* are common (Fig. 10b). No trends in abundance or size are apparent (Fig. 10c, d). Bioclasts are very well-preserved in this core, and for *M. maculata,* 71% of bioclasts have excellent preservation (Fig. 3). Other bioclasts in this shell bed are unusually pristine, retaining remnants of ligament and periostracum, or original color and gloss. (Fig. 6f, g).

Core ALA-91-16

Core ALA-91-16 (total length 4.0 m) contains a 38 cm-thick shell bed with an erosional base that overlies a bioturbated muddy sand with rip-up clasts (Fig. 11a) and an estuarine foraminiferal fauna (Anderson et al., 1994). The shell bed grades into a 2.7 m-thick massive to horizontally laminated sand with small scattered bioclasts. Shell-bed bioclasts are graded, size-sorted, and randomly oriented in quartz sand (Fig. 11a, b, d, e). The molluscan assemblage contains both characteristically estuarine (*Mulinia lateralis, Parvilucina multilineata*) and shoreface/shelf (*Macrocallista maculata, Ervilia nitens, Olivella floralia*) species in abundance (Fig. 11c). Marine species such as *E. nitens* and *Oliva sayana* often are pristine, retaining original color and gloss (Figs. 3, 6h). These marine species are better preserved than estuarine species such as *M. lateralis,* although the differences are not dramatic and preservation of *M. lateralis* is comparable to non-reworked species in other shell beds (Fig. 3).

Core ALA-91-15

Core ALA-91-15 (total length 2.0 m) contains a 12 cm-thick shell bed at its base. The upper contact of the shell bed is sharp and is overlain by a 1.9 m-thick massive sand with scattered bioclasts. Shell-bed bioclasts are densely packed and randomly oriented in clean quartz sand (Fig. 12a). Large soritid foraminifera and lower-shoreface- and shelf-derived mollusks such as *Linga pensylvanica, Macrocallista maculata,* and *Argopecten gibbus* characterize the assemblage (Fig. 12b). Bioclast preservation is generally very good, as seen in *M. maculata* (Fig. 3), although serpulids and bryozoans commonly encrust a number of larger bioclasts, especially *A. gibbus* (Fig. 12b).

SHELL-BED GENESIS AND HISTORY

Paleoenvironmental Setting and Bioclast Source

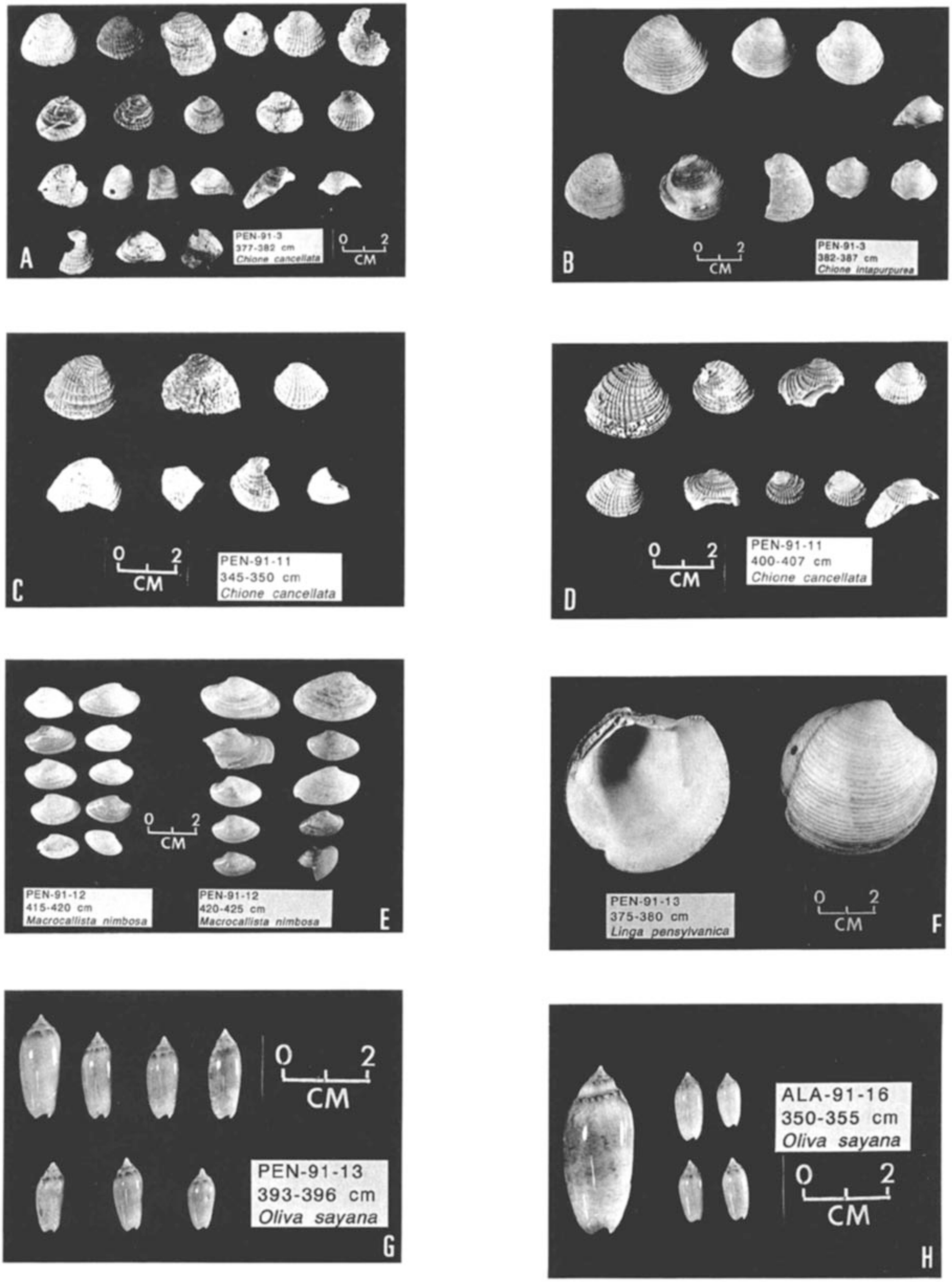
Paleoenvironmental settings of shell beds were defined using the environmental preferences and ranges of common species, and by determining whether assemblages were indigenous or exotic using criteria outlined by Kidwell and Bosence (1991). Q-mode nonmetric Multidimensional Scaling (MDS) using ranked abundances of molluscan species produced three primary environmental clusters (Fig. 13). These clusters show little separation because: 1) many species are common to most or all cores, and 2) reworked estuarine species are relatively common in some marine shell beds (see Time-Averaging Section below).

A cluster labeled "muddy estuarine" includes only samples from core PEN-92-5. Both characteristically estuarine (*Mulinia lateralis*) and marine species (*Corbula operculata*) with similar preservation states are common. Several species such as *Nuculana concentrica, Corbula caribaea,* and *Chione grus* that are common in this shell bed are rare or absent in other cores, causing the PEN-92-5 assemblages to cluster separately from those of other cores. The assemblage is similar to ones reported by Parker (1956, 1960) from fluid clays of lower Breton Sound and adjacent prodelta slope, and from mud on the shelf (22–64 m) east of the Mississippi River Delta. The fauna in core PEN-92-5 probably represents a community that inhabited an open bay or sound with a strong marine influence but that also received significant amounts of fine-grained sediment from a nearby fluvial system, possibly the Mobile River.

Assemblages from core PER-93-3 and the lower portion of core PEN-91-11 form a "sandy estuarine" cluster. These samples are characterized by abundant *Chione cancellata, Parvilucina multilineata,* and *Nuculana acuta* and the assemblage closely resembles those of marine-influenced parts of estuaries with muddy sand substrates in the northern Gulf of Mexico (Parker, 1956, 1959, 1960). A third large cluster incorporates the remaining cores, and represents a sandy shallow-marine setting. These samples contain assemblages with species typical of sandy substrates on the shoreface and/or shallow shelf. *Macrocallista maculata* and *Ervilia nitens* are abundant in all cores, and other species such as *Argopecten gibbus, Lucina radians, Pleuromeris tridentata, Olivella* spp., *Oliva sayana, Polinices duplicatus, Crepidula fornicata, Chione intapurpurea, Mulinia lateralis,* and *Macrocallista nimbosa* locally are abundant. Molluscan assemblages within this cluster are very similar to shoreface and offshore sandplain biotic zones described by Jervey (1974) off Destin, Florida. The upper shell bed of PEN-91-11 is included in this cluster even though most samples fall close to the sandy estuarine cluster. These samples are considered marine because *M. maculata* and *E. nitens* are abundant and well preserved. The samples fall near the sandy estuarine cluster because poorly-preserved, reworked *C. cancellata* are especially abundant.

Even though some shell beds show evidence of size sorting and formation in episodically high-energy conditions (see Accumulation Processes Section below), most molluscan bioclasts in the shell beds probably are indigenous. First, shell-bed matrix is comparable to the substrate preferences of common species (shallow infaunal mud dwellers dominate the fine-grained substrate of core PEN-92-5; infaunal muddy-sand dwellers are found in the lower shell bed of core PEN-91-11 and core PER-93-3; and epifaunal and infaunal sand-dwellers dominate the clean sands of the remaining shell beds). Second, shell-bed assemblages have modern analogs in life assemblages near the study area. Third, in most shell beds with mixed marine and estuarine assemblages, estuarine species are more poorly preserved and probably are relict rather than exotic (see Time-Averaging Section below).

The source of abundant, large, and excellently preserved soritid foraminifera in the shallow-marine shell beds is problematic, as is the abundance of the coralline red algae *Lithothamnion?* in core PEN-91-3. Apparently,


A
PEN-91-3
377-382 cm
Chione cancellata
0 2
CM
B
0 2
CM
PEN-91-3
382-387 cm
Chione intapurpurea
C
0 2
CM
PEN-91-11
345-350 cm
Chione cancellata
D
0 2
CM
PEN-91-11
400-407 cm
Chione cancellata
E
0 2
CM
PEN-91-12
415-420 cm
Macrocallista nimbosa
PEN-91-12
420-425 cm
Macrocallista nimbosa
F
PEN-91-13
375-380 cm
Linga pensylvanica
0 2
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G
0 2
CM
PEN-91-13
393-396 cm
Oliva sayana
H
ALA-91-16
350-355 cm
Oliva sayana
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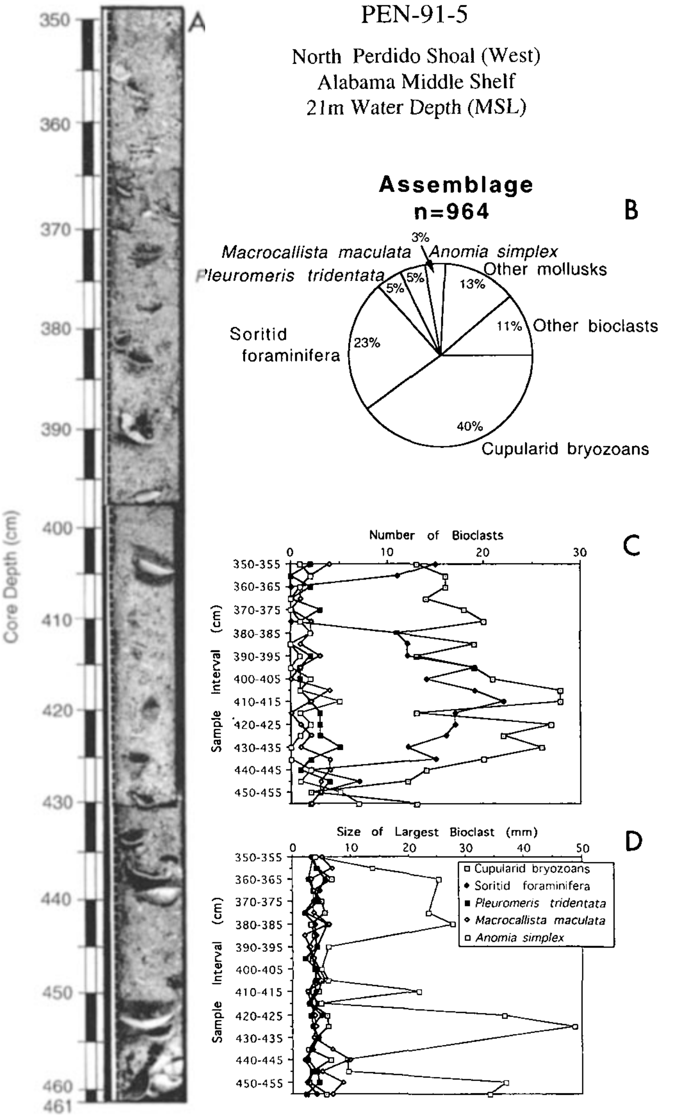

FIGURE 7—A) Photo-mosaic of core PEN-91-5 shell bed (450–461 cm) and overlying scattered-bioclast unit (357–450 cm). B) Pie diagram showing proportions of common bioclasts in the core. Total sampled interval is 350–461 cm. C) Number of bioclasts per sample with depth for common species. D) Size of largest bioclast per sample with depth for abundant species.

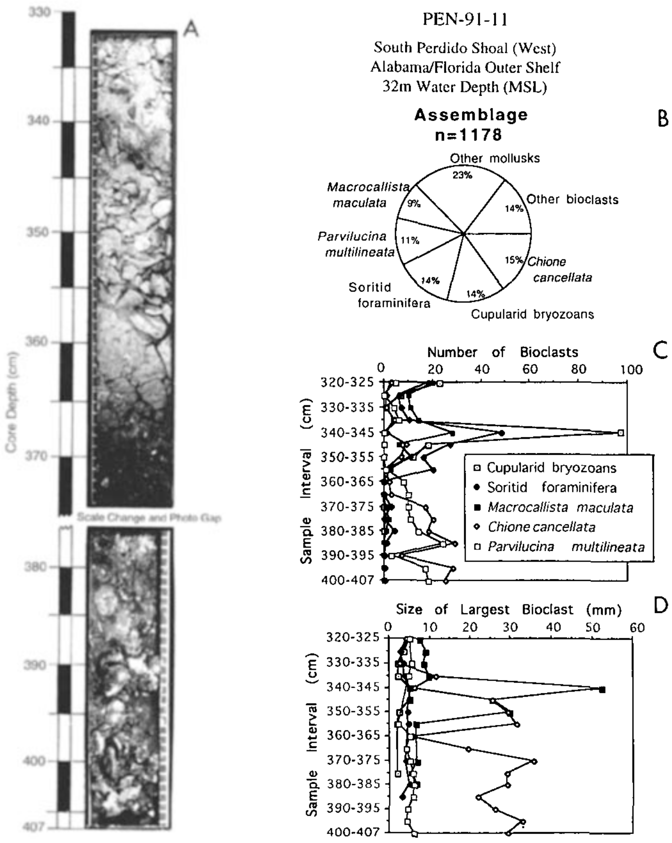

FIGURE 8—A) Photo-mosaic of core PEN-91-11 shell beds (392–407 cm and 340–358 cm), intervening muddy sand, and overlying clean sand. B) Pie diagram showing proportions of common bioclasts in the core. Total sampled interval is 320–407 cm. C) Number of bioclasts per sample with depth for common species. D) Size of largest bioclast per sample with depth for abundant species.

soritids no longer inhabit the northeastern Gulf of Mexico, but their remains are abundant in surficial sediments of this part of the shelf (Lowman, 1949; Parker, 1954; Bandy 1956; Phleger, 1960; Walton, 1964). Today, soritids commonly inhabit shallow-marine carbonate environments of South Florida and typically are epiphytic on marine grasses (Bandy, 1956; Murray, 1991; Hallock and Peebles, 1993). Abundant soritids and *Lithothamnion?* are thought to be reworked from late Pleistocene shelf-edge reefs in the northern Gulf of Mexico (Parker and Curray, 1956; Ludwick and Walton, 1957; Phleger, 1960). Bathymetric highs and hard bottoms on the inner and middle shelf of

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FIGURE 6—Examples of bioclast preservation. A) *Chione cancellata* (representative estuarine species), and B) *C. intapurpurea* (representative marine species) from core PEN-91-3. Note the greater corrasion, rounding, boring, and loss of original color and gloss in *C. cancellata. Chione cancellata* valves represent reworked, relict bioclasts (see also Fig. 3). C), D) *C. cancellata* from the upper marine shell bed (C) and lower estuarine shell bed (D) of core PEN-91-11. *Chione cancellata* valves represent reworked, relict bioclasts in the upper shell bed. E) *Macrocallista nimbosa* from core PEN-91-12. Note the range in quality of preservation and chalky texture of some valves. F) *Linga pensylvanica* and G) *Oliva sayana* from core PEN-91-13. Note excellent preservation of bioclasts. *Linga pensylvanica* retains remnants of ligament and periostracum. H) Pristine bioclasts of *O. sayana* from core ALA-91-16.

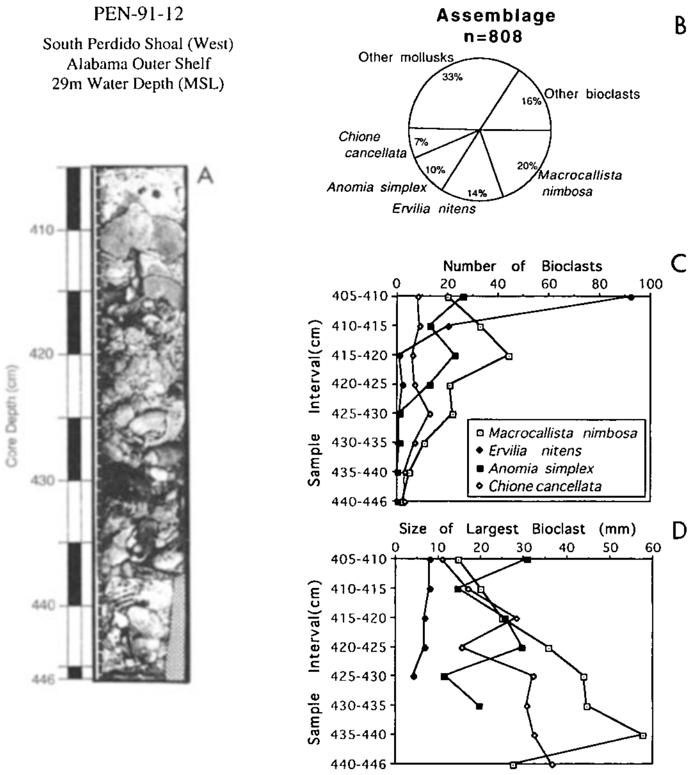

FIGURE 9—A) Photo-mosaic of core PEN-91-12 shell bed (410–446 cm) and overlying sediment. B) Pie diagram showing proportions of common bioclasts in the core. Total sampled interval is 405–446 cm. C) Number of bioclasts per sample with depth for common species. D) Size of largest bioclast per sample with depth for abundant species.

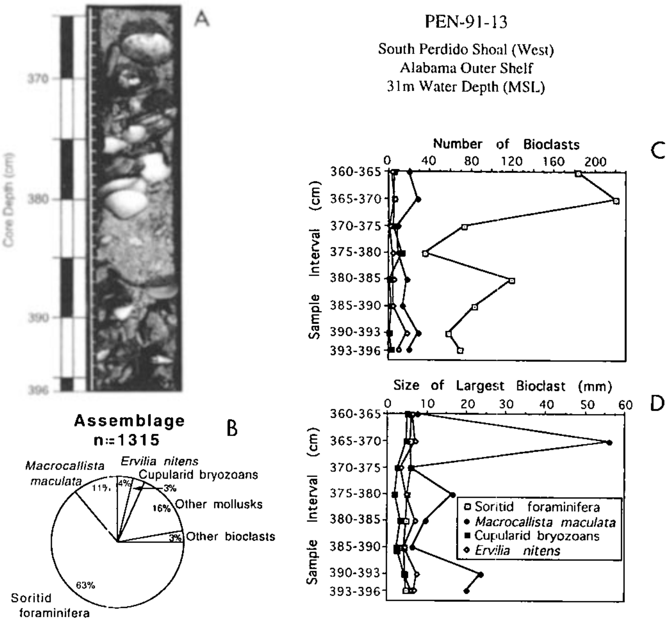

FIGURE 10—A) Photograph of core PEN-91-13 shell bed (367–396 cm). B) Pie diagram showing proportions of common bioclasts in the core. Total sampled interval is 360–396 cm. C) Number of bioclasts per sample with depth for common species. D) Size of largest bioclast per sample with depth for abundant species.

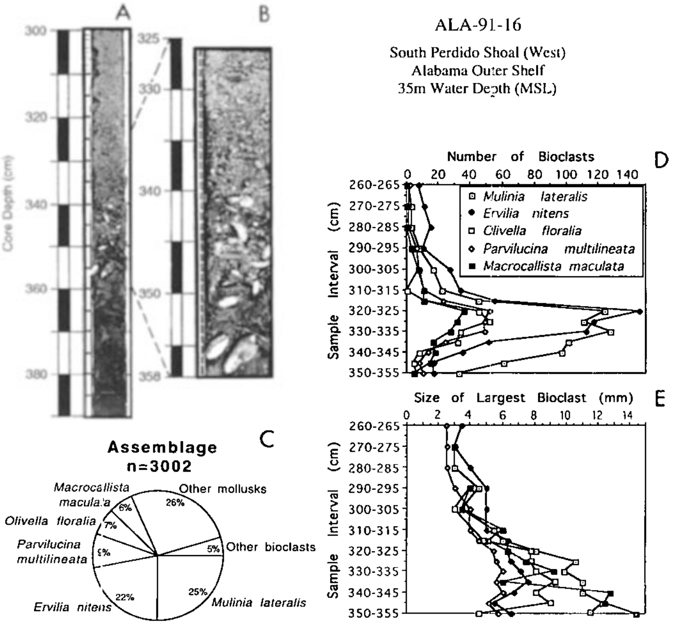

FIGURE 11—A) Photograph of core ALA-91-16 shell bed (270–355 cm) and underlying sediment. B) Close-up photograph of the lower part of the shell bed. C) Pie diagram showing proportions of common bioclasts in the core. Total sampled interval is 260–355 cm. D) Number of bioclasts per sample with depth for common species. E) Size of largest bioclast per sample with depth for abundant species.

the northeastern Gulf are among other potential sources of soritids although the foraminiferal fauna of these areas has not yet been characterized (Schroeder et al., 1988a, 1988b, 1989; Gittings et al., 1990, 1992). Seagrass thickets that presently occur in Perdido and Pensacola Bays do not support soritids, and therefore this habitat does not appear to be a source area for these bioclasts in our samples (Gangopadhyay et al., 1996).

Time-Averaging of Assemblages

All shell beds show evidence of time-averaging, the mixing of skeletal elements of non-contemporaneous populations or communities (Fürsich, 1990). Using the classification of Kidwell and Bosence (1991), shell beds of cores PER-93-3, PEN-91-5, PEN-91-11 (lower shell bed), PEN-91-13, ALA-91-15, and ALA-91-16 show within-habitat time-averaging (contain assemblages composed of multiple generations from a single community). These assemblages are either estuarine or marine, show variability in taphonomic grade, have few articulated bivalves, have no

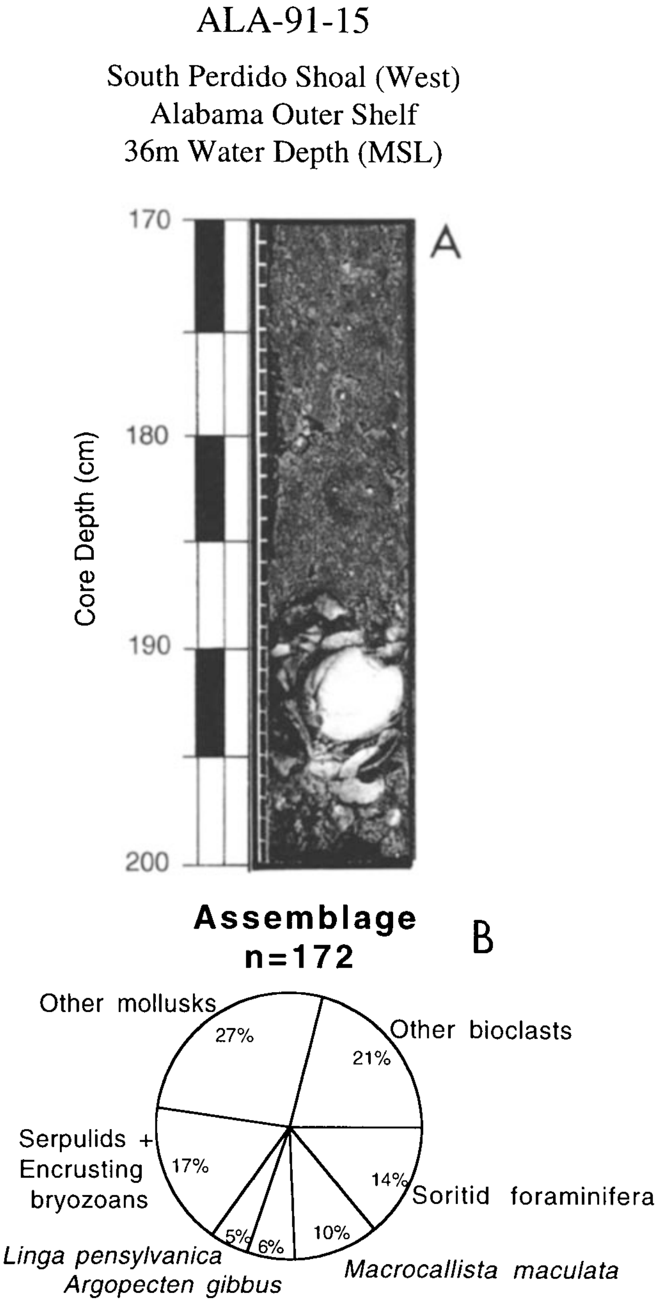

FIGURE 12—A) Photograph of core ALA-91-15 shell bed (188–200 cm) and overlying sediment. B) Pie diagram showing proportions of common bioclasts in the core. Total sampled interval is 188–200 cm (incorporated into one sample).

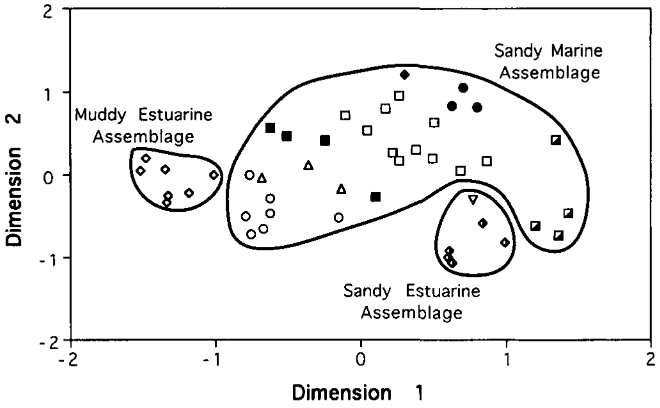

FIGURE 13—Results of nonmetric Multidimensional Scaling of ranked abundance data for molluscan species. Samples fall into three main clusters that represent three distinct environmental settings (see Paleoenvironmental Setting and Bioclast Source section for description). Symbols denote samples for separate cores: ▽ = PER-93-3; ◇ = PEN-92-5; ● = PEN-91-3; □ = PEN-91-5; ◈ = estuarine portion of PEN-91-11; ◪ = marine portion of PEN-91-11; ■ = PEN-91-12; △ = PEN-91-13; ○ = ALA-91-16; and ◆ = ALA-91-15.

in situ bioclasts, and contain a mix of species with different substrate preferences.

Shell beds of cores PEN-91-3, PEN-91-11 (upper shell bed), and PEN-91-12 are environmentally condensed (contain assemblages of ecologically unrelated species that accumulated over a period of environmental change). Where underlying sediment was observed, these shell beds occur at facies boundaries (at the base of marine deposits overlying estuarine sediment). Few articulated bivalves, and a mix of species with different preservation states and substrate preferences are evident in these shell beds. Moreover, estuarine species are more poorly preserved than marine species in these assemblages, indicating that the estuarine species are reworked and relict. This pattern is especially dramatic in core PEN-91-11 where *Chione cancellata* shows a marked shift in taphonomic condition from stratigraphically lower estuarine beds, where it is relatively well-preserved, into overlying marine beds, where it is poorly preserved (Figs. 3; 6c, d).

The shell-bed assemblages of cores PEN-92-5 and ALA-91-16 also contain both characteristically estuarine and marine species. The two environmental groups, however, have similar preservation states (Fig. 3) and therefore these assemblages probably show within-habitat time-averaging rather than environmental condensation. The assemblage of core ALA-91-16 probably is derived from a community inhabiting the upper shoreface or an inlet-influenced area; areas where the environmental ranges of contained common species overlap. For core PEN-92-5, the assemblage is composed of species that inhabited an open, marine-influenced bay that received fine-grained sediment from a nearby fluvial system (see Paleoenvironmental Setting Section above).

Many shell beds contain both infaunal soft-substrate and epifaunal hard-substrate species (i.e., *Anomia simplex* and *Crepidula* spp.). Taphonomic feedback, the response of a living community to changing substrate conditions as bioclasts accumulate in its benthic habitat (Kidwell and Jablonski, 1983), is one mechanism for producing assemblages with mixed substrate preferences. Taphonomic feedback probably did not have a significant effect on shell beds in the study area, however, because no trends of increased abundance of shell-gravel dwellers are observed in more shell-rich parts of cores (see Kidwell, 1986). In addition, the generally good preservation of bioclasts indicates that shell beds did not persist at the sediment-water interface and did not serve as a habitat for shell-gravel dwellers. Instead, this mix of species probably is due to within-habitat transport and reworking.

Accumulation History of Shell Beds

Accumulation history refers to the time over which a deposit forms (Kidwell, 1991, 1993). This concept is not equivalent to time-averaging because a rapidly-accumulated deposit can contain a significantly time-averaged assemblage. Accumulation history and time-averaging are not completely independent, however. Deposits that accumulate over long time periods typically contain significantly time-averaged assemblages. Kidwell (1991) outlines categories and recognition criteria for a classification of accumulation history. These categories are, from short to long time-scales: event, composite, hiatal, and lag concentrations. Kidwell (1991) defines lags as concentrations formed by significant erosional or corrosional truncation resulting in a residuum of highly durable skeletal material. A long time-scale of accumulation is explicitly incorporated into the definition. However, another common use of the term in sedimentology denotes concentrations of coarse-grained material produced by physical sorting and reworking that are time independent (e.g., channel lag). In the following sections, we use "lag" in the sedimentologic sense, and do not imply a time-scale of accumulation.

Stratigraphic context, taphonomic grade, and bioclast fabrics of the shell beds examined indicate that these deposits are composite concentrations, which are defined as accumulations that are influenced by multiple events but that are not stratigraphically condensed. Evidence for composite concentrations include the thickness and relatively low number of shell beds in the Holocene section. Event beds would be thin and numerous in areas with high sedimentation rates (Kidwell, 1991) such as in the study area. In addition, these shell beds have erosional bases and overlie sediment of a distinctly different facies, and therefore are associated with significant erosion surfaces (Figs. 14, 15). For instance, in core PER-93-3 the shell bed overlies a bioturbated silty sand with clay rip-up clasts from an underlying soil horizon (Fig. 2). In the marine shell beds of cores ALA-91-16 and PEN-91-11, underlying deposits contain estuarine molluscan and/or foraminiferal assemblages (Anderson et al., 1994). The erosional bases of the shell beds represent bay ravinement (PER-93-3) and shoreface ravinement surfaces (ALA-91-16 and →

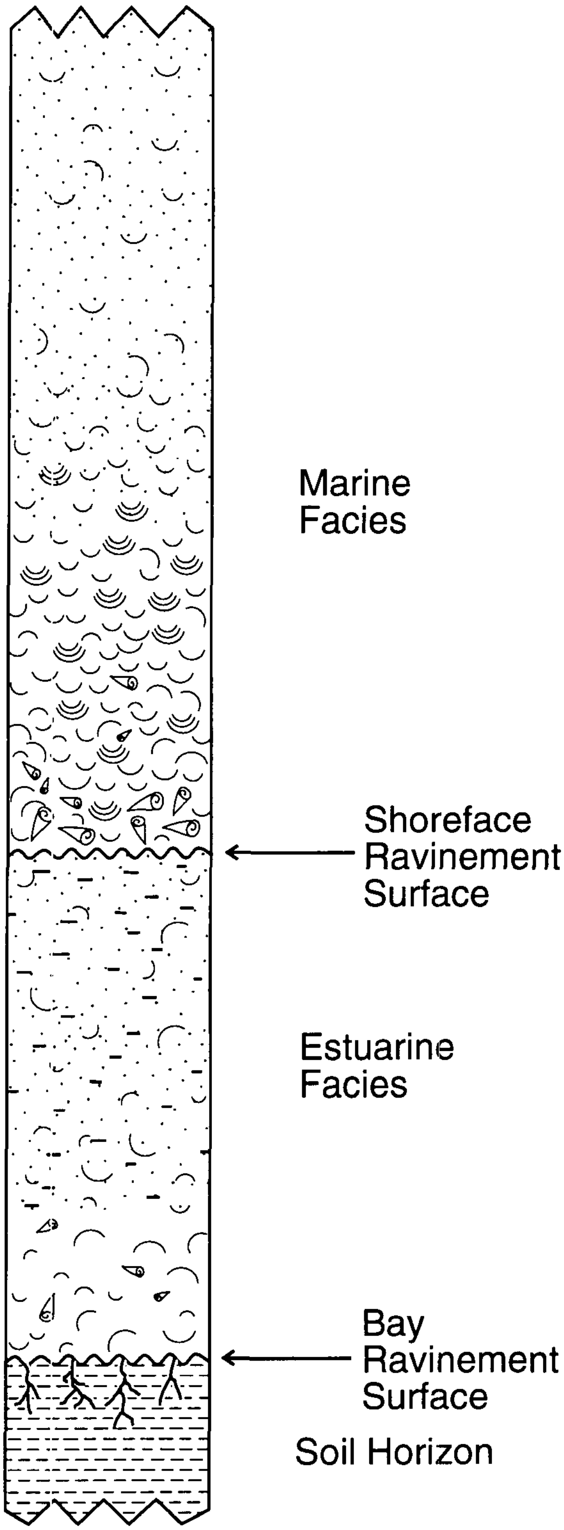

FIGURE 14—Composite sketch showing fabrics of marine and estuarine shell beds and their relation to the bay and shoreface ravinement surfaces. Estuarine shell beds have loosely-packed bioclasts with random orientations. These shell beds may be size-sorted and graded (not shown). Marine shell beds commonly are graded, have more large gastropods at their base, are densely packed in clean sand, and bivalves have concave-up, stacked, or random orientations.

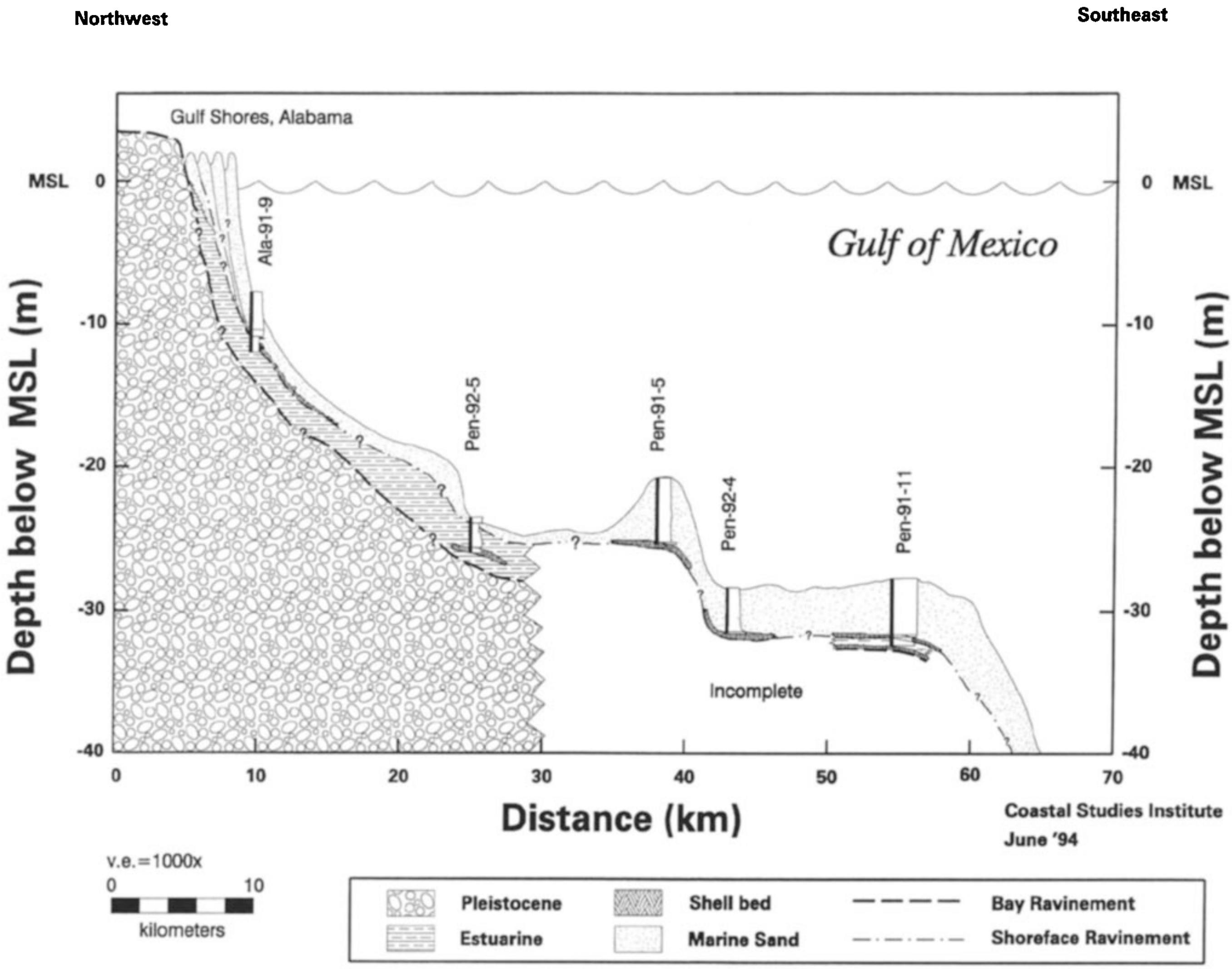

FIGURE 15—Representative dip section for the study area, showing the relationship of the shell beds to super-adjacent and sub-adjacent units and to bay and shoreface ravinement surfaces. Cores PEN-92-5, PEN-91-11, and PEN-91-5 are described in this paper. (After McBride et al., 1996).

the upper shell bed of PEN-91-11) (McBride et al., 1994, 1996).

The shell beds we examined, however, lack complex internal stratigraphies (recording short-term multiple episodes of deposition, erosion, omission, or bioturbation) that would record the effect of multiple events. These composite concentrations must have been amalgamated by the final modifying events. These final events obliterated evidence of previous accumulation processes, leaving only the signature of the final processes that influenced the shell beds.

Accumulation Processes

Understanding the processes that concentrate bioclasts is critical for interpreting shell-bed genesis. A general classification of Kidwell et al. (1986) is used as a framework to explore more specific genetic hypotheses of shell-bed formation. In this classification, bioclast accumulations are differentiated into three genetic categories: diagenetic, biogenic, and sedimentologic concentrations. As outlined below, sedimentologic processes were the primary bioclast-concentrating agents for these shell beds. However, biogenic processes cannot be ruled out for one shell bed. Shell beds in the study area have undergone no diagenetic alteration and therefore diagenetic processes did not serve as concentrating agents.

Biogenic Agents

Biogenic concentrations result from the activities of organisms, either through the gregarious behavior of shell

TABLE 3—Characteristics of specific biogenic and sedimentologic shell concentrations.

Agent/deposit	Characteristics
Biogenic Concentrations	
Biogenic Graded Bedding (Rhoads and Stanley, 1965; Cadée, 1976)	• Irregular, undulatory base; massive, poorly sorted • Burrowed, mottled, disrupted laminae • In areas with very low sedimentation rates
Biogenic Stratification (Meldahl, 1987a, 1987b)	• Not graded; poorly-sorted, random fabrics • Pristine to poor preservation • In areas with very low sedimentation rates
Sedimentologic Concentrations	
Single storm events	
Graded storm bed (Kreisa, 1981; Aigner, 1982; Figueiredo et al., 1982; Henderson and Frey, 1986; Meldahl, 1987a, 1993; Fürsich and Oschmann, 1993; Siringan and Anderson, 1994)	• Erosional base, gradational upper contact • Graded, shells concentrated near base • Concave-up, convex-up, imbricated, random, concordant fabrics
Winnowed accumulations (Wilson, 1986; Norris, 1986; Feldman, 1989; Goldring, 1991)	• Sharp or gradational base • Coarse lag produced by removal of fines • Convex-up fabrics, not *in situ*
Washover deposits (Albertzart and Wilkinson, 1990; Noe-Nygaard et al., 1987; Meldahl and Cutler, 1992; Cuffe et al., 1991)	• Alternating beds of coarse and fine bioclasts • Ungraded, poorly sorted, cross-stratified • Convex-up, concave-up, random, nested fabrics
Obrution deposits (Brett and Baird, 1986; Parsons et al., 1988)	• Rapid burial of community; *In situ,* high articulation • Graded capping deposits; escape traces
Multiple storm events	
Transgressive lag (Swift, 1968; Figueiredo et al., 1982; Fürsich and Oschmann, 1993; Brett, 1995)	• Evidence of reworking and transport • Poorly sorted bioclasts, high encrustation and boring, low articulation; random, concordant fabrics
Bedform migration (sand ridge, megaripple or bar trough) (Figueiredo et al., 1982; Norris, 1986; Banerjee, 1981; Snedden et al., 1994)	• Erosional base, gradational top; winnowed • Thick, laterally continuous beds; trough cross-stratified • Random, imbricated, nested fabrics; bioclasts may be poorly preserved
Episodically exposed shell beds (Seilacher, 1985; Miller et al., 1988; Parsons et al., 1988; Speyer and Brett, 1991)	• Complex microstratigraphy with erosional and hardground surfaces; convex-up fabrics • Mix of infauna and epifanua; bioclasts encrusted on upper surfaces
Other Sedimentologic Concentrations	
Turbidites (Middleton, 1967; Banerjee, 1981; Prince et al., 1987)	• Erosional base; graded, unlaminated • Concave-up, vertical fabrics • Mix of shallow and deep water taxa

TABLE 3—Continued.

Agent/deposit	Characteristics
Tidal-channel and tidal-inlet lags (Kumar and Sanders, 1974; Meldahl, 1987a, 1987b; Moslow and Tye, 1985; Meldahl and Cutler, 1992; Cuffe et al., 1991; Savarese, 1994)	• Erosional base, gradational top, cross-stratified • Convex-up, imbricated, concordant fabrics, well-sorted, ±grading • Poorly preserved bioclasts (bored, encrusted, abraded)
Tidal currents (Fürsich, 1982; Fürsich and Oschmann, 1993; Speyer and Brett, 1991; Cuffe et al., 1991)	• Erosional base • Convex-up, imbricated, densely packed • Variable to poor preservation

makers or through bioclast-concentrating activity of other organisms (Kidwell et al., 1986). Subsequent reworking has obliterated evidence, if it existed, that gregarious behavior of shell producers accumulated bioclasts in the study area. Biogenic reworking, however, is a potential accumulation agent in the lower shell bed of PEN-91-11. Two types of biogenic concentrations have been described (Table 3): biogenic graded-bedding (Rhoads and Stanley, 1965; Cadée, 1976; Trewin and Welsh, 1976) and biogenic stratification (Meldahl, 1987a, 1987b). The lower shell bed of core PEN-91-11 shares several features with these types of biogenic bedding. The shell bed grades into an overlying bioturbated unit with fewer shells, has a random fabric, and has variably preserved bioclasts (Fig. 8). These characteristics also may be associated with sedimentologic accumulations (Table 3), however, and the role of biogenic reworking in this shell bed cannot be proven.

Other shell beds in the study area probably were not accumulated by biogenic processes because shell beds and overlying deposits are either massive or laminated, and typically show no evidence of bioturbation. Second, shell beds have sharp erosional bases. Third, although many observed bioclast fabrics may result from either bioturbation or physical agents (e.g., grading, random and concave-up fabrics), the sum of biostratinomic and sedimentologic evidence indicates that physical rather than biogenic processes were the major accumulation agents.

Sedimentologic Agents

The shell beds examined in this study commonly have erosional bases, upper contacts that are not erosionally truncated, very few articulated bivalves, and a paucity of *in situ* organisms (Fig. 14). Random, stacked, and concave-up fabrics also are common. Some shell beds are graded and one (PEN-91-13) shows a trend where the largest bioclasts mainly are gastropods in the lower portion and bivalves in the upper portion of the unit. Processes responsible for these fabrics include, rapid deposition, deposition out of suspension, physical reworking, and interference effects among shells in a dense concentration (Toots, 1965; Aigner, 1982; McKittrick, 1987; Allen, 1990; Goldring, 1991; Jeffery and Aigner, 1982; Kidwell and Bosence, 1991, Table 8 and references therein; Fürsich and Oschmann, 1993). Formative agents involving such processes are storm events and turbidity currents (discussed below). In contrast, shell-bed bioclasts do not show evidence of tractive transport (e.g., convex-down and imbricated fabrics), and therefore are not tidal-channel, tidal-inlet, or other accumulations formed by tidal currents on the shoreface and shelf (Table 3).

Because shell beds are considered amalgamated composite concentrations and only bioclast fabrics of the final event to influence the beds are preserved, the characteristics of storm event beds are addressed here. Storm event beds include graded storm beds, winnowed accumulations, storm-washover deposits, or obrution (smothered by rapid burial) deposits (Table 3). Of these, shell beds in the study area are most similar to graded storm beds. Graded storm beds containing bioclasts have been described by numerous authors (Kreisa, 1981; Henderson and Frey, 1986; Aigner, 1982; Figueiredo et al., 1982; Meldahl, 1987a, 1987b, 1993; Siringan and Anderson, 1994; Fürsich and Oschmann, 1993). Typically, these deposits have erosional lower contacts, gradational upper contacts, and are graded with shells concentrated near their bases. In addition, storm deposition can generate concave-up, convex-up, or random fabrics.

Multiple storm events can modify a shell bed and form a composite concentration through incremental addition and/or reworking of shells. Resulting accumulations include: 1) transgressive lags that result from reworking during erosional shoreface retreat, 2) shell concentrations in the troughs of migrating sand ridges, megaripples, or bars, and 3) shell beds that are repeatedly buried and re-exposed by storms (Table 3). Although shell beds of the study area rest on the bay- or shoreface-ravinement surfaces and probably represent transgressive-lag deposits, bioclasts typically are much better preserved than expected in a transgressive lag (Table 3). Three factors may explain the excellent preservation of bioclasts in these shell beds. First, marine shell beds apparently are underlain by only slightly older Holocene estuarine deposits (Fig. 14). Therefore, the transgressive surfaces associated with most shell beds do not represent significant amounts of geologic time (ca. 10^3 years). Second, high sedimentation rates may have resulted in rapid burial of the shell beds so that their exposure to destructive agents at or near the sediment-water interface was limited. Third, a rapid rise in sea level in the Holocene may have resulted in less reworking and greater preservation potential of shell beds.

Turbidity currents are another physical agent associated with turbulent flow, erosion, and transport in and deposition out of suspension. Bioclast-rich turbidites typically have an erosional base, are graded, unlaminated, have concave-up or vertical fabrics, and contain a mix of shallow- and deep-water species (Table 3). The characteristics of the shell beds in the study area share many features with such turbidites, but well-developed turbidity deposits have not been documented in shallow marine environments.

SUMMARY AND CONCLUSIONS

Holocene shell beds with many well-preserved bioclasts are common in the subsurface of the eastern Alabama/western Florida Panhandle shelf. These shell beds contain indigenous bioclasts, and assemblages show varying degrees of time-averaging from within-habitat time-averaged to environmentally-condensed. By combining detailed environmental and taphonomic data, these two categories, which can be difficult to differentiate, were easily detected, even though the ranges of the environmentally distinct species can overlap. Three molluscan assemblages can be distinguished: 1) a fine-grained-substrate, marine-influenced estuarine assemblage, 2) a muddy-sand-substrate, marine-influenced estuarine assemblage, and 3) a sand-substrate shoreface/shelf assemblage. Shell beds are coarse-grained deposits that directly overlie bay or shoreface ravinement surfaces (Figs. 14, 15). This stratigraphic position and the relative thickness (up to 0.75 m) of the shell beds indicate that they are composite concentrations that first accumulated as coarse-grained transgressive lags. Shell beds, however, lack complex internal stratigraphies and probably were amalgamated by the final modifying events, and as a result, evidence of previous depositional processes was obliterated. Sedimentologic agents (most likely storms) that caused erosion, reworking, and deposition (probably out of suspension for marine shell beds) were the final agents of shell-bed accumulation. Probable agents include strong winter cold fronts, hurricanes, and Loop Current eddies (McBride and Byrnes, 1995). Amalgamated storm deposits have been reported (Morton, 1988; Davis et al., 1989; Knowles and Davis, 1991; Anderson et al., 1992), although the detailed taphonomic signature of such deposits has not been documented previously. In addition, results based on radiocarbon dates of pristine shells support the conclusion of reactivation and amalgamation of shell beds (Anderson et al., 1994; McBride et al., 1996).

Shell beds possess several features that, at first glance, appear incompatible, but reveal much about the Holocene history of this shelf. First, the exceptional preservation of many bioclasts is unusual for transgressive lags (Brett, 1995). Nevertheless, the stratigraphic positions of shell beds demonstrate that the beds originated as coarse-grained deposits on bay or shoreface ravinement surfaces. Episodically high sedimentation rates, probably caused by the same high-energy events that amalgamated the shell beds, must have acted as a buffer to the shell beds, and prevented a long history of erosion and omission for contained bioclasts. Second, even though amalgamation obliterated previous evidence of accumulation processes and may have cannibalized the entire marine portion of the transgressive package, the transgressive surfaces and associated lags are still recognizable. Integrating paleoenvironmental, taphonomic, and stratigraphic data is critical for demonstrating the extremely dynamic Holocene history of this shelf.

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