Taphonomic Redistribution of Mollusk Shells in a Tidal Inlet Channel, Sapelo Island, Georgia[1]

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Inlet shoals at the southern end of Georgia barrier islands typically are separated from the beach by a prominent longshore channel, which functions as a shortcut connection between the adjacent sound and the nearshore shelf. This open-ended channel constitutes an excellent natural flume for the taphonomic study of shell distributions.

The central part of the channel—a relatively deep scour hole resulting from tidal jets—is a nodal point between ebb and flood effects. In spite of ebb-dominant tidal currents through most of the system, landward transport of shells occurs from this node into adjacent parts of the sound; seaward transport of shells is predominant from the node onto adjacent parts of the shelf. The scour hole itself is a stratigraphic leak for relict Holocene and Pleistocene shells. During transport, shell assemblages are mixed temporally and tend to be homogenized with respect to valve sizes and original habitat distributions, and bivalves are disarticulated.

Such reworked assemblages probably are common among ancient barrier island/tidal inlet/shoal deposits. Indiscriminate approaches to the paleoecology and biostratigraphy of these facies yield correspondingly misleading results.

INTRODUCTION

Although much has been written about the provenance and taphonomy of transported skeletal remains, specific source areas and transport routes generally remain difficult to discern among coastal depositional systems. The barrier island coast of Georgia is no exception (Frey et al., 1975). However, our attention was drawn to a characteristic longshore channel separating the southern end of Georgia barrier islands from otherwise closely flanking shoals (Fig. 1). This channel, locally rich in detrital shells, is part of a complicated inlet-shoal system (Oertel and Howard, 1972; Oertel, 1974, 1985; Hubbard et al., 1979). Yet, it also functions as a discrete component of the tidal system and can be isolated for study.

Sampling sites included the mouth of Doboy Sound, the longshore channel itself, and the nearshore shelf adjacent to the northern end of the channel. Major objectives were (1) to determine the identity, diversity, and abundance of new and old shells at each site, (2) to distinguish estuarine, sound, and shelf species of shells, (3) to reconstruct patterns of shell transport responsible for the observed distributions, and (4) to relate these trends to prevalent hydrographic and sedimentologic regimes.

The results should be useful in taphonomic and paleoecologic interpretations of ancient shoal systems, such as the channeled offshore-shoal deposits reported by Fürsich and Heinberg (1983) from the Jurassic of Greenland. The observed temporal and environmental mingling of shells also should help clarify various biostratigraphic problems among ancient paralic deposits, such as the mixed Tertiary and Pleistocene faunas noted by Colquhoun et al. (1968) from South Carolina. Faunal mixing probably is the rule rather than the exception in most barrier island or shoal systems.

PHYSIOGRAPHIC AND HYDROGRAPHIC SETTING

Tidal inlets along the central part of the Georgia Bight are dominated by tides (Hubbard et al., 1979, fig. 1), and ebb-tidal effects predominate over flood-tidal effects. The result is a relatively large system of shoals and channels extending seaward from sound or estuary entrances between barrier islands (Oertel, 1974, 1975).

These inlet systems consist of several distinctive elements (Fig. 2). The major channel is deepest between barrier islands (inlet trough or "throat"). The shallower seaward end, an inlet-shoreface ramp, is flanked by a complex array of shoals and swash bars (Oertel, 1972, 1985) that exhibit three major configurations: (1) detached, segmented, partly intertidal ramp-margin shoals along the north side of the main inlet channel, (2) a terminal subtidal shoal seaward of and essentially perpendicular to the inlet ramp, and (3) attached, partly inter-

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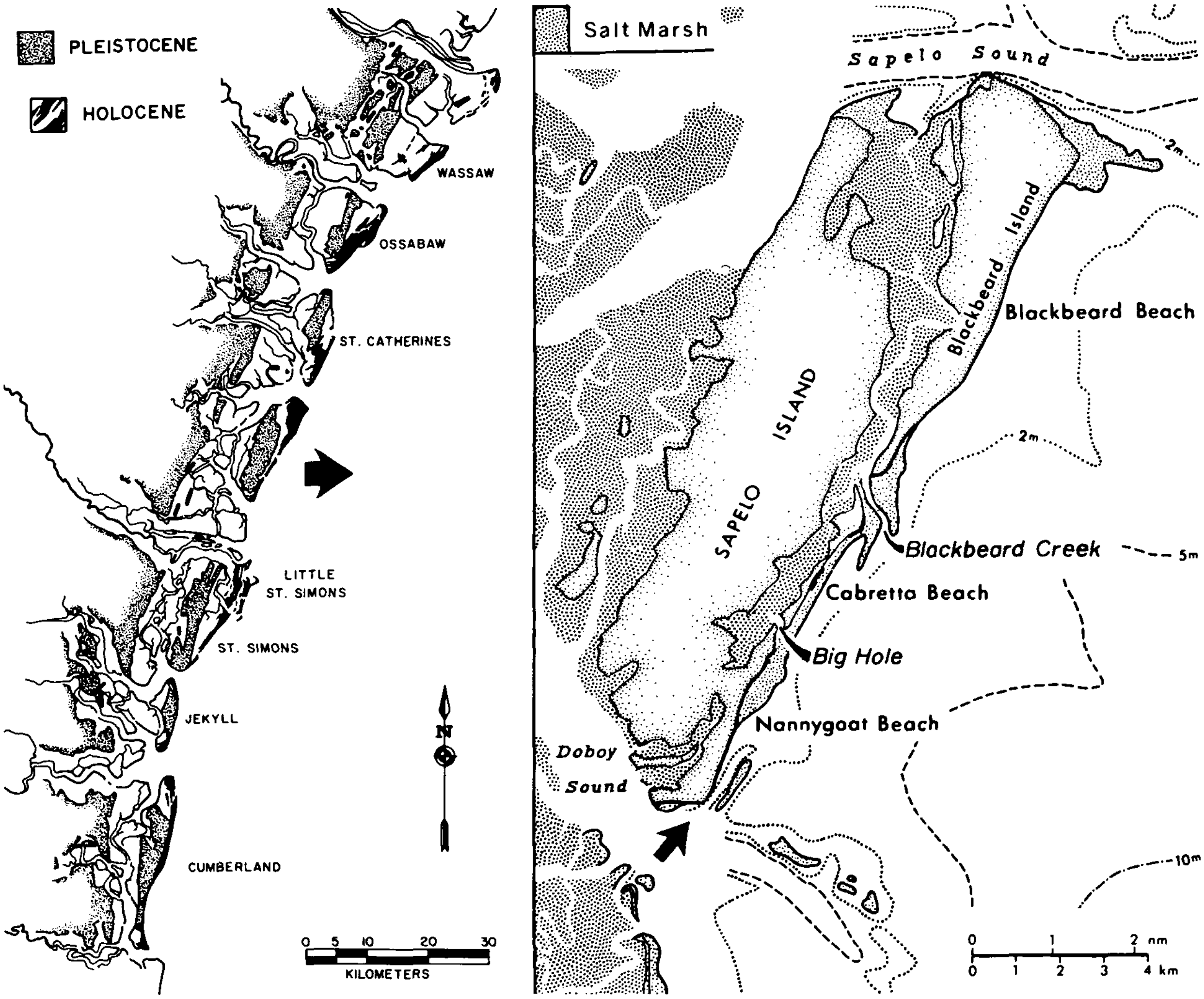

FIGURE 1—Index maps of the Georgia coast and the study area near Sapelo Island. The longshore channel (arrow) connects Doboy Sound with the shallow shelf off Nannygoat Beach. (Base maps courtesy of J. D. Howard.)

tidal ramp-margin shoals along the south side of the major channel. The detached north-side shoals are separated from the strand by a relatively deep, longshore tidal channel, the main subject of this report. Other spillover channels and shallows funnel water across the segmented north-side shoals (Oertel, 1974).

Tidal currents within the system are complicated (Oertel and Howard, 1972). Normal semidiurnal tidal flow is essentially onshore/offshore through the larger, long-established channels. Yet, transient coastal currents, generated mainly by variable winds, may cause deflections and gyres. Under some conditions, surface and bottom water may flow in opposite directions. In addition, the system commonly exhibits a separation of ebb- or flood-dominant channels and funnels (Oertel, 1975, fig. 6).

Within the longshore channel, bottom currents normally ebb from the time of predicted high water to 1 to 2 hours after predicted low water; the duration of flood flow is diminished accordingly (Oertel and Howard, 1972, figs. 159–161). Ebb velocities exceed flood velocities. Thus, net sediment movement is thought to be seaward (*ibid.*, fig. 162), although some shelf sediments reenter the longshore channel and move landward during maximum flood flow.

CHARACTERISTIC SEDIMENTS

At least six distinctive sediment types comprise inlet-shoal subfacies, ranging from clean cross-bedded fine sand on high-energy parts of ramp-margin shoals to interbedded sand and shell or mud-clast lags in deeper channels (Oertel, 1973a, fig. 2; Pinet and Frey, 1977, fig. 10). Sediments on the shallow flank of Doboy Sound consist mainly of interbedded sand and

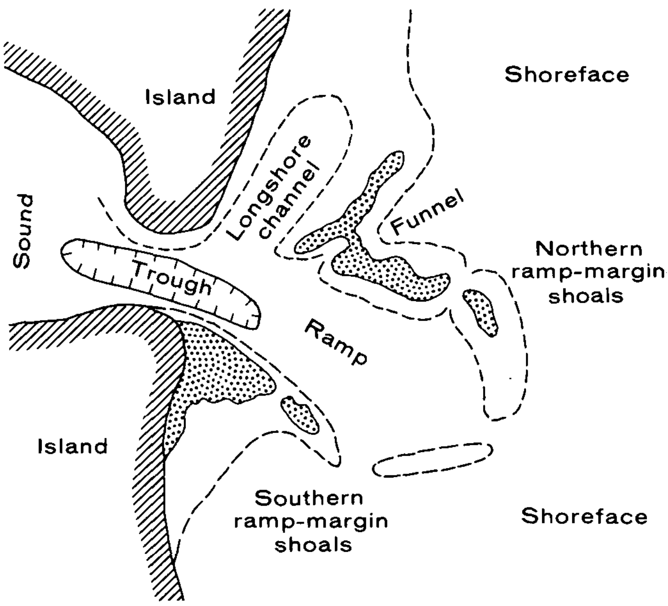

FIGURE 2—Diagrammatic reconstruction of major geomorphic features associated with Georgia inlet-shoal systems. The shoals commonly extend 5 to 7 km offshore. Relative size of the longshore channel is exaggerated slightly, for emphasis. (Adapted from Oertel, 1972; Oertel and Howard, 1972.)

mud (Mayou and Howard, 1975). These sediments grade landward to bioturbated muddy fine sands and seaward to cleaner, ripple-laminated fine sands, according to respective energy levels. Shell concentrations commonly are present; most shell orientations and bedding fabrics have been modified by bioturbation (Salazar-Jiménez et al., 1982).

In the deepest part of the longshore channel, layers of imbricated mud clasts may be intercalated between thin foresets of rippled sand. These deposits, toward shallower seaward and soundward parts of the channel, grade to interbedded sand and mud. The mud layers consist typically of sand-size fecal pellets and organic detritus, and are intercalated with small-scale ripple foresets (Oertel, 1973a, 1973b). Laminated muds and mud layers also may be present. Adjacent shoal sands exhibit an array of complex bedforms reflecting interactions between wave surge and tidal flow (Oertel, 1973c).

Sediments on the nearshore shelf just seaward of the longshore channel are composed primarily of fine-grained, ripple-laminated, moderately bioturbated, clean to muddy sand. Mud layers are common (Howard and Reineck, 1972, fig. 10). Much of the mud seems to derive from turbid waters ebbing through the longshore channel (Howard and Frey, 1985, fig. 2); however, some muds directly overlie shell beds and may represent resuspensions following storms.

These shell layers (Fig. 3) have a matrix of fine sand and mud. The base of the layer may exhibit a sharp erosional contact with underlying sediments or may be gradational from a shelly sand. The top of shell beds ordinarily is gradational. Most such shell concentrations are attributable to storms. Yet, they do not comprise a single, laterally continuous depositional unit; rather, several broad local lenses interfinger. Areas of skeletal carbonate enrichment in fact occur along the entire seaward flank of the shoal system (Frey and Pinet, 1978).

Clasts and shells in the beach-shoal system also may be derived from relict Holocene muds (Frey and Basan, 1981; Pemberton and Frey, 1985) and or older deposits breached by tidal scour holes (Howard and Frey, 1973; Frey et al., 1975).

METHODS

Eight stations (Fig. 4) were established along a traverse from the northern flank of Doboy Sound to the nearshore shelf off Nannygoat Beach. A Smith-McIntyre grab sampler was used to obtain 0.025 m^3 of sediment at each site. Sediments were sieved through a 1.5 mm mesh screen.

Disarticulated valves were tallied as individual specimens; articulated valves (Appendix 2) were tallied as two specimens for most purposes, but were later analyzed separately. Both

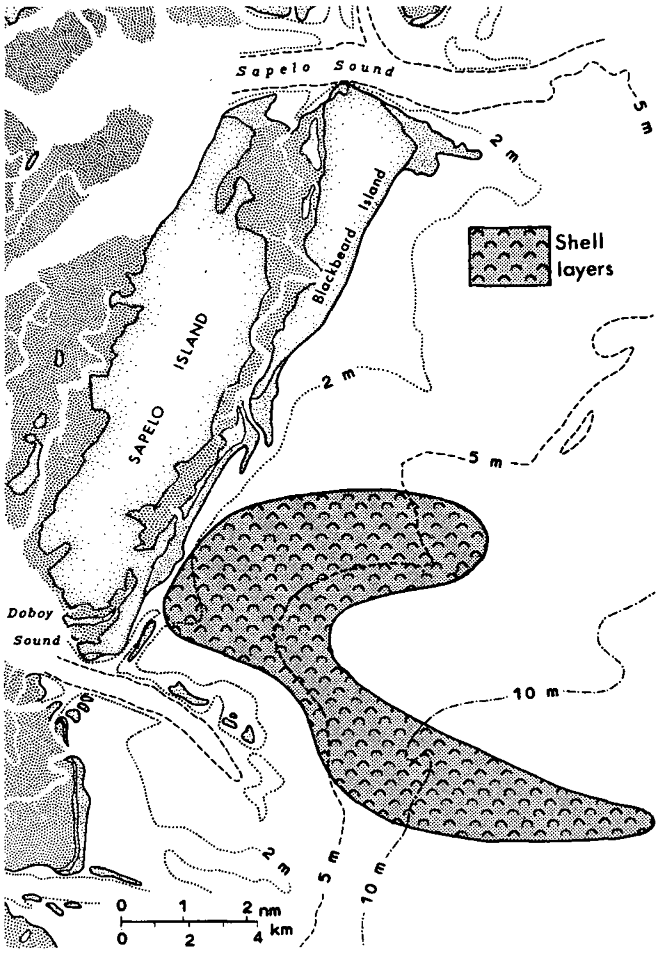

FIGURE 3—Distribution of interfingering subsurface shell layers on the nearshore shelf off Sapelo Island, reconstructed from box cores. (Adapted from Howard and Reineck, 1972.)

whole and fragmented shells were counted, although care was taken not to duplicate valve fragments.

Specimens classified as new (dead) valves possessed original shell color or gloss, or organic components such as the periostracum or ligament. Old or relict valves lacked these pristine features, and many were further characterized by bleached to chalky, porous surfaces; furthermore, because of their weakened condition, old valves generally were more abraded than new valves (cf. Panin et al., 1983). [On this coast, old detrital shells—discussed in greater detail on subsequent pages—may range in age from late Tertiary to subrecent Holocene (Frey et al., 1975).] Valves also were classified according to qualitative size-weight shell classes, where 1 = tiny (~ 1–4 mm), 2 = small (~ 4–10 mm), 3 = medium (~ 10–30 mm) 4 = large (~ 30–100 mm), and 5 = ponderous (~ 100–150 mm). Because of variations in shell masses, however, a smaller, thicker shell may appear in the same class as a larger, thinner shell (Appendix 1). These classes (modified from Dörjes et al., 1985) refer to local faunas rather than to mollusk species in general.

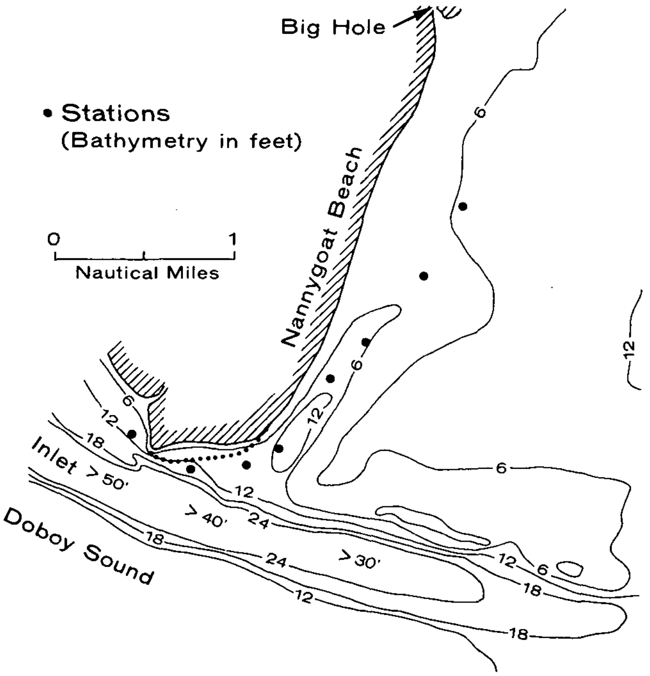

FIGURE 4—Physiographic and bathymetric distribution of sampling sites. Compare with Figure 1.

Taxonomic names were adapted from Abbott (1974), although additional literature was consulted when necessary to confirm identifications. Habitat preferences for the various species (Appendix 1) were established by a combination of our observations and previously published local work (e.g., see references cited by Dörjes et al., 1985).

CHARACTERISTICS OF SHELL ASSEMBLAGES

Altogether, 31,556 specimens and 70 species were identified (Appendix 1). Dominant species of detrital shells included the gastropod *Acteocina canaliculata* and the bivalves *Mulinia lateralis*, *Tellina versicolor*, *Donax variabilis*, *Abra aequalis*, and *Anadara ovalis*.

Previous work on Georgia beaches (Dörjes et al., 1985) and the continental shelf (Frey and Howard, in press) revealed considerable disparity between numbers of detrital gastropod and bivalve shells. The same is true of present results; 32 species and 549 specimens of gastropods, and 38 species and 30,929 specimens of bivalves (equivalent to ~15,465 whole bivalves) were represented among detrital shells. The disparity resulted primarily from prodigious numbers of valves contributed by the small clam *Mulinia lateralis*.

Such generalities obviously are more meaningful where applied to specific depositional sites, as discussed below. The eight stations thus reduce to three major geomorphic areas (Fig. 5): (1) the northern flank of Doboy Sound, (2) the longshore tidal channel, and (3) the shallow shelf near the seaward end of the channel. Each area is mutually intergradational. However, subsequent analyses revealed that the seaward end of the longshore channel also is highly intergradational with lateral components of the shoal system, including peripheral carbonate lobes among both surficial sediments (Frey and Pinet, 1978, fig. 2) and subsurface shell layers (Fig. 3).

Dominant Gastropod and Bivalve Shells

Diversity and abundance trends among old gastropod shells cannot be discerned from the few specimens recovered (Appendix 1). Among new gastropod shells, however, seven species accounted for the preponderance of specimens (Fig. 6). *Acteocina canaliculata* was predominant within the tidal channel and on the shelf, whereas *Polinices duplicatus* was predominant within Doboy Sound. *Natica pusilla* was well represented in the sound and channel but not on the shelf, even though live populations occur there (Dörjes, 1972).

Orders of dominance among bivalve valves were more disparate. *Mulinia lateralis* predominated at every site (Table 1). Only three other species of new shells and four other species of old shells were noteworthy in this context. However, old shells were rare on the shelf, and were more than twice as abundant in Doboy Sound than in the tidal channel (Appendix 1). At these last two sites, old *Donax variabilis* shells were important.

Shell Distributional Patterns

Shell distributions varied considerably through the eight individual sites (Fig. 7). The number of live specimens decreased abruptly from west to east along Doboy Sound, fell to zero in the soundward end of the tidal channel, attained an essentially constant value through the remainder of the channel and adjacent shelf, and increased at the seaward end of the traverse (Figs. 4 and 5). The number of species of live individuals was too low to depict a trend.

Total detrital specimens also declined abruptly from west to east, into the soundward end of the channel, but increased dramatically toward the shelf end of the channel; abundance then declined on the shelf itself. The number of species of detrital shells followed the same general trend, albeit less pronounced; however, minimum diversity occurred on the shelf

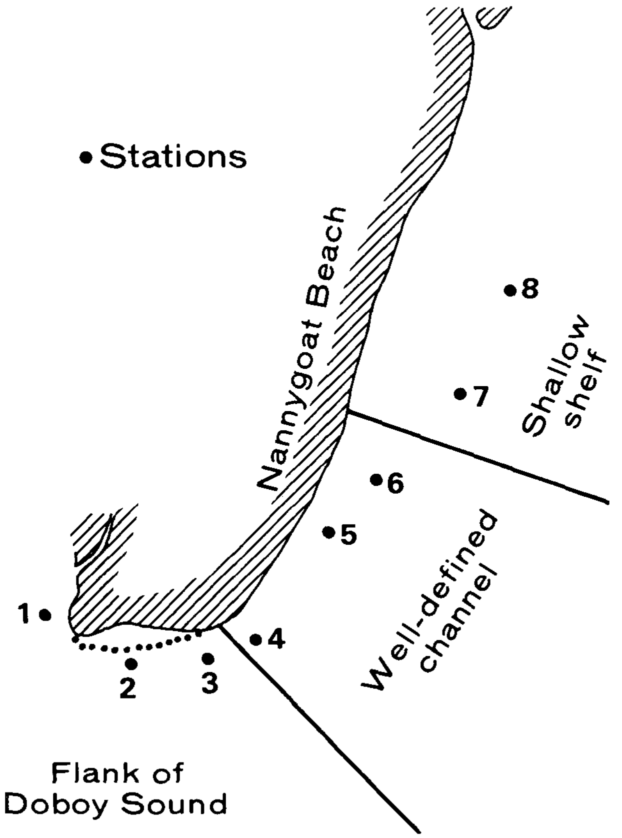

FIGURE 5—Classification of sampling sites. Compare with Figure 4.

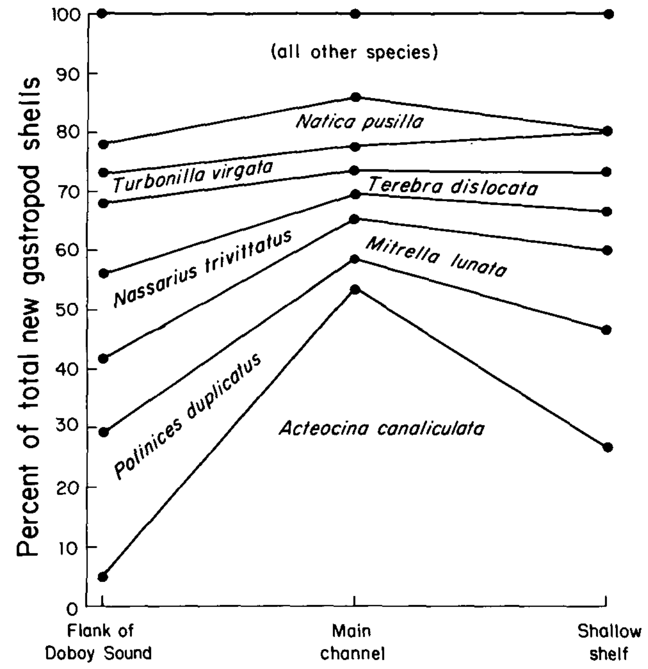

FIGURE 6—Predominant species of new detrital gastropod shells, collectively, at sound, channel, and shelf sites.

end of the traverse, rather than at the soundward end of the channel.

Detrital bivalve trends (Fig. 8) were very similar to those of total mollusks (Fig. 7). However, old valves were substantially less abundant everywhere, especially around the soundward end of the tidal channel, and were absent at the seaward end of the traverse. Numbers of species of old and new shells were not strikingly different in trend within Doboy Sound and at the seaward end of the channel. Yet, species of old shells were conspicuously less abundant in the soundward end of the channel and on the shelf.

Species and specimens of old gastropod shells were significant only at the seaward end of the tidal channel and well within Doboy Sound (Fig. 9). Trends in species and specimens of new shells were rather similar. They also were generally similar to the overall trends of new bivalve shells (Fig. 8). Unlike bivalves, however, new gastropod shells were slightly more abundant in the soundward end of the tidal channel than to either side of that site, and specimens were least abundant at the seaward end of the traverse.

TAPHONOMIC AND BIOSTRATINOMIC ANALYSES

The total diversity and abundance of shells (Appendix 1) implies high levels of productivity among local mollusk faunas, particularly the bivalves. However, the standing crop of live individuals is substantially less (Dörjes, 1972) and the populations exhibit considerable seasonal periodicity; peak density occurs in March (Smith, 1973). In addition, the paucity of live individuals here, especially in deeper parts of the longshore channel, suggests that population densities are reduced locally by high-energy turbulence and sediment transport.

Similarly, most local shell assemblages are related to levels of wave or current energy. The position of major shell concen-

TABLE 1—Predominant species of detrital bivalve valves.
A—New shells (percent)

Bivalve Species	Doboy Sound	Main channel	Shallow shelf
Mulinia lateralis	92.6	92.9	90.3
Tellina versicolor	2.1	3.3	7.3
Donax variabilis	2.1	1.4	0.3
Abra aequalis	0.9	0.6	1.5
all other species	2.3	1.8	0.6
B—Old shells (percent)			
Mulinia lateralis	77.0	53.7	100.0
Donax variabilis	13.3	39.1	—
Tellina versicolor	2.7	—	—
Anadara ovalis	2.4	—	—
Crassostrea virginica	2.1	0.4	—
all other species	2.5	6.8	—

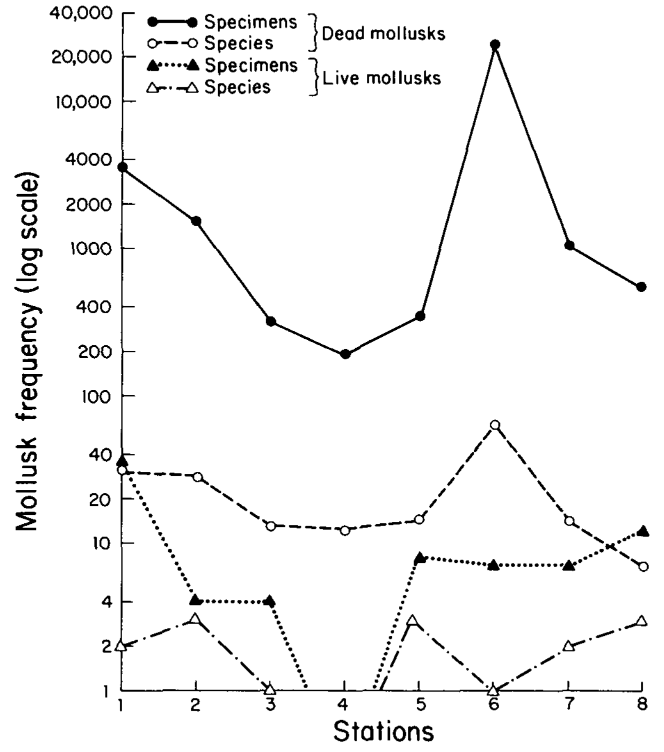

FIGURE 7—Diversity and abundance of total mollusks per depositional site. Individual bivalve valves were tallied as single specimens (see methods). Compare with Figures 4 and 5.

trations on the nearshore shelf (Fig. 3) is governed partly by the obstruction of the inlet-shoal system to shoreface sediment transport. Also, northeasterly winds and storms drive waves southwestward into the apex between the shoal and the barrier island, thereby focusing surface drift currents and helping to maintain the position of the longshore channel. (Gentle southerly winds ordinarily are insufficient to reverse this process or to generate comparable configurations along south-side shoals.)

Our samples were collected during the low-energy conditions of summer, yet all analyses imply considerable tidal current transport of shells through the longshore channel. Furthermore, the generally close similarities between bivalve and gastropod shell distributions (Figs. 8, 9, and 13) suggest that individual valve shapes, sizes, and hydraulic equivalences were mainly subordinate to prevailing tidal energy levels. These aspects are evaluated in greater detail, below.

New: Old Valve Ratios

Differences in lateral distributions of new and old valves (Table 2) are greater than those between bivalve and gastropod distributions (Table 4). Old shells represent a complex combination of factors, including (1) greater residence time within the system and correspondingly greater influences by longer term sedimentary and hydrodynamic processes—an *in loco* "aging" process for surficial shells, and (2) reworking, through submarine scour within the channel, of relict shells—a stratigraphic leak potentially involving late Tertiary to subrecent Holocene deposits. Temporal admixing of shells thus is an inherent part of the stratinomic process here.

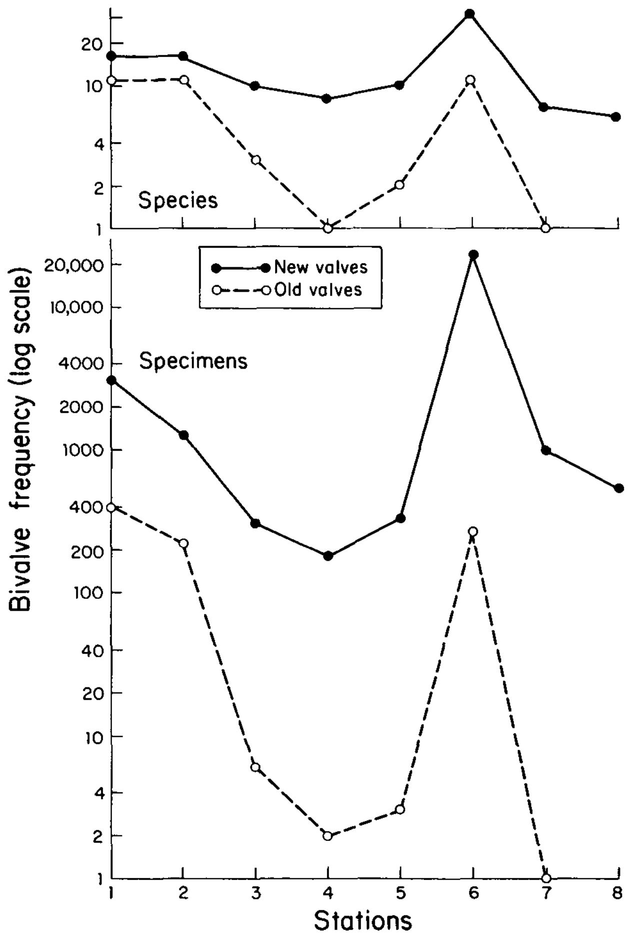

FIGURE 8—Diversity and abundance of detrital bivalve shells per depositional site.

Many Tertiary specimens may be distinguished taxonomically, of course, but criteria for distinguishing between new and old shells of extant species are not entirely straightforward. The following features were discounted during our analysis because of their inconsistent implications: intensity of shell boring by endobionts, black or brown coloration, breakage, and local shell dissolutions (cf. Pilkey, 1964; Pilkey et al., 1969a). For instance, shells of the gastropod *Ilyanassa obsoleta* and the bivalve *Geukensia demissa* commonly exhibit shell dissolution even while the animals are alive (Wiedemann, 1972), and shells of the bivalves *Anomia simplex* and *Crassostrea virginica* blacken rapidly when exposed to a reducing environment (Pilkey et al., 1969b). Many endobionts bore as readily in live as in dead shells (Bromley, 1970). In short, the various shell parameters listed above are related more closely to ecologic

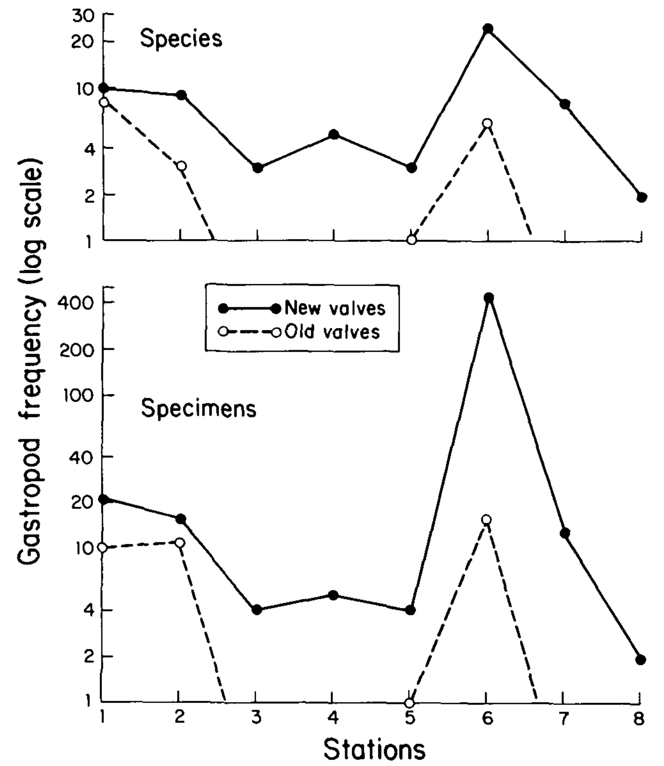

FIGURE 9—Diversity and abundance of detrital gastropod shells per depositional site.

and taphonomic events than to antiquity per se (Frey and Howard, in press). On the other hand, old shells tend to be more abraded than new shells (cf. Trewin and Welsh, 1972; Panin et al., 1983).

Although somewhat subjective, our criteria for classification (see methods) were applied consistently and are deemed to be reliable on the whole. Taxonomic and biostratinomic analyses revealed no extinct Tertiary components within the overall assemblage, though numerous Pleistocene and early Holocene shells are present (based mainly on the stratigraphic position or datum of the scoured channel deposits; cf. Antoine and Henry, 1965). Tertiary deposits nevertheless have been breached in this vicinity, probably in the inlet trough (Darby and Hoyt, 1964), because we have collected guide fossils from adjacent beach drift.

By our criteria for extant species, old shells are most abundant in Doboy Sound, are next most abundant in the longshore channel, and are virtually absent from the nearshore shelf (Figs. 8 and 9). In contrast, new shells are tremendously more abundant in the tidal channel (primarily because of Station 6), are next most abundant in Doboy Sound, and are least abundant on the shelf. Ratios of new to old valves (Fig. 10) thus increase dramatically from the sound flank to the longshore channel. Trends among new and old gastropod and bivalve shells were essentially the same, although relatively few specimens of old gastropod shells were recovered.

Our observations suggest that even though total shells are most abundant at Station 6, Stations 1 and 2 (Doboy Sound flank) are important accumulation sites on a long-term basis. Proportionately greater numbers of valves remain in transit at Station 6. A corollary is the apparently short residence time for surficial shells on the adjacent shelf and a corresponding dearth of old shells there.

Finally, despite the present inapplicability of most aspects of these new-old shell analyses in the fossil record, our results demonstrate (1) their usefulness in discerning the provenance of various components of "modern" assemblages, and (2) the problems inherent in traditional layercake paleoecology and biostratigraphy of such paralic strata. An important facet of this problem is the temporal heterogeneity of shells within seemingly isochronous deposits (Fig. 10); between-site variations of this sort may help explain some of the peculiarities of certain coastal plain shell beds (Oaks and DuBar, 1974; Kidwell, 1982). Heterochroneity is even more problematic among "host-epizoan" relationships; elsewhere in Georgia estuaries, for instance, we have observed pristine (unabraded) Tertiary index fossils now free of all matrix and encrusted with modern oysters, barnacles, and bryozoans.

TABLE 2—Percentages of new and old detrital valves.

Valves	Doboy Sound	Main channel	Shallow shelf
new	88.0	98.8	99.9
old	12.0	1.2	0.1

Articulated:Disarticulated Valve Ratios

The tremendously disparate numbers of articulated and disarticulated bivalve shells (Appendices 1 and 2) also indicate substantial valve transport and reworking (cf. Fürsich and Heinberg, 1983). Some disarticulation probably resulted from the sediment-sieving process, although visual inspection of samples confirmed that the vast majority already were disarticulated; furthermore, the samples were treated consistently,

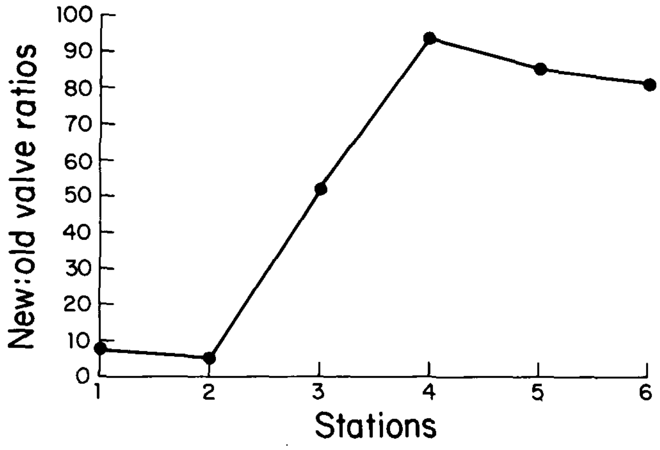

FIGURE 10—Valve ratios per depositional site, excluding the shallow shelf (where old shells are rare). (Total new valves divided by total old valves.)

and artificial disarticulations should not mask the overall trend. In general, the distribution of articulated valves (Fig. 11) is like that of total new bivalve shells (Fig. 8), the newer shells having suffered less disarticulation than the old shells.

Articulated specimens were rare to absent in soundward reaches of the tidal channel and adjacent parts of Doboy Sound. They were especially prominent at the seaward end of the channel and adjacent shelf. Yet, their importance at the seaward end of the traverse was slightly less than that well within Doboy Sound.

The actual ratio of disarticulated to articulated valves was considerably less at Station 7 than at Station 6. We thus conclude that energy levels (and consequent rates of disarticulation) are rather similar at the seaward end of the longshore channel and immediately adjacent parts of the shelf but that surficial shells are relatively newer and are in-residence at Station 7 for shorter periods of time.

Shell Size-Weight Classes

Considering most of the trends discussed above, the observed constancy of shell classes (Table 3) was somewhat unexpected. Valves were divided into size-weight categories for three reasons: (1) to help characterize overall size-weight aspects of these assemblages, (2) to help convey, via this crude measure, some impression of the relative amounts of skeletal carbonate accumulating at each site, but especially (3) to discern possible shell sorting or mixing at the various sites.

The analysis reveals an overwhelming predominance of small shells throughout the area as well as a striking consistency, among new valves, in relative proportions of the size classes. Old shells seem to be more variable but are too scarce at most sites to depict reliable trends; at Stations 1, 2, and 6, however, the slightly increased proportions of tiny, medium, and large shells may be significant. The constant proportions of shell classes among new valves indicates extremely little between-site variation in mechanisms of shell transport; if mixing or sorting occurred, it was consistent throughout the system. Relative proportions of gastropods and bivalves (Table 4) are almost equally consistent, despite the hydraulic inequivalence of these shells.

The same classification was applied to local live faunas studied by Dörjes (1972, pls. 1 and 2). [He sampled subtidal communities along two transects perpendicular to Nannygoat Beach (Fig. 5); his southern transect crossed the longshore channel in the vicinity of our Station 6, and his northern transect passed in the vicinity of our Station 8.] These trends (Table 5) disclose less lateral consistency between transects than that between our stations (Table 3), which further implies a homogenization of the shell assemblages. Proportions of the respective shell classes also are somewhat different; relative to the standing crop of live mollusks, detrital valve assemblages seem to be slightly impoverished in tiny and medium shells but are correspondingly enriched in small shells.

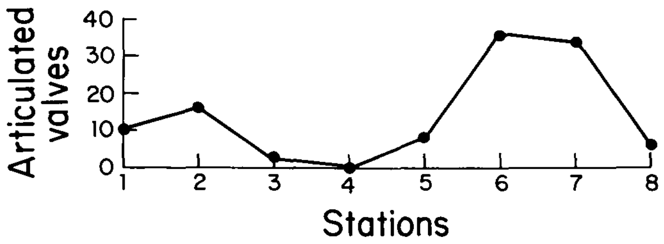

FIGURE 11—Distribution of articulated bivalve shells per depositional site.

Nevertheless, absolute size differences between live populations and shell assemblages probably are less than such tabulations would imply, because variations in productivity and mortality among individual species are ignored (Craig, 1967). For example, the relatively low population density of the small bivalve *Mulinia lateralis* (Dörjes, 1972) is counterbalanced by a periodically high reproductive rate (Walker and Tenore, 1984) that ultimately yields prodigious quantities of shells. On the other hand, shell sorting is definitely indicated by the spatial separation of left and right valves of *Donax variabilis* and *Abra aequalis* (Table 6); total samples indicate a near match between numbers of left and right valves of each species, whereas sound and shelf samples reveal excesses of right valves and channel samples exhibit excesses of left valves. In final analysis, therefore, valve-sorting processes must have enriched the shell assemblages in small valves (Table 3), but not to the full extent implied by qualitative data on live populations (Table 5).

Original Habitats and Shell Provenance

Shell distributional patterns of environmentally distinctive species (Figs. 12 and 13) also were somewhat unexpected. These patterns were evaluated in order to help discern prevailing directions of valve transport (landward or seaward) and the degree of environmental mixing of shells (Howard and Frey, 1973, figs. 9 and 10). These habitat assignments refer mainly to Georgia waters; latitudinal variations in habitat adaptations are exhibited by some Atlantic-Gulf mollusk species (cf. Parker, 1960, 1969; Bird, 1970). Furthermore, these local habitat adaptations overlap broadly because of the sound-mouth ecotone between estuarine and marine species; in places, the

TABLE 3—Classification of assemblages by size-weight shell classes. [1 = tiny, 2 = small, 3 = medium, 4 = large, 5 = ponderous; see Abbott (1974) for descriptions of individual species, Appendix 1.] Ponderous shells were negligible within the study area.

A—New shells (percent)

Shell Class	Stations								Total Shells
	1	2	3	4	5	6	7	8	
1	0.5	1.1	2.2	2.1	2.1	2.1	0.6	0.4	1.8
2	98.4	97.8	96.5	96.2	95.9	97.0	98.7	99.0	97.2
3	0.4	0.3	1.0	0.5	—	0.2	0.3	—	0.2
4	0.7	0.8	0.3	1.1	2.1	0.8	0.4	0.7	0.8

B—Old shells (percent)

Shell Class	1	2	3	4	5	6	7	8	Total Shells
1	1.2	6.5	16.7	—	—	4.4	—	—	3.6
2	90.9	92.2	83.3	100.0*	75.0*	93.5	100.0*	—	91.9
3	1.5	—	—	—	—	1.7	—	—	1.2
4	6.4	1.3	—	—	25.0*	0.3	—	—	3.2

*Insufficient data.

TABLE 4—Percentages of bivalve and gastropod valves.

A—New shells

Mollusks	Stations 1	2	3	4	5	6	7	8
Gastropods	0.7	1.2	1.3	2.7	1.2	1.9	1.3	0.4
Bivalves	99.3	98.8	98.7	97.3	98.8	98.1	98.7	99.6

B—Old shells

Mollusks	Stations 1	2	3	4	5	6	7	8
Gastropods	2.5	4.7	—	—	25.0*	5.8	—	—
Bivalves	97.5	95.3	100.0*	100.0*	75.0*	94.2	100.0*	—

*Insufficient data.

lower reaches of sounds and the inlet-shoal system exhibit increased species diversity because of the corresponding "edge effect". We thus concentrated on estuary-sound versus sound-shelf species of shells; eurytopic species, sound-preferring species, and two species of unknown ecologic range (Appendix 1) were excluded.

Relatively few shells of estuary-sound species were recovered. Gastropod and bivalve trends were extremely similar, thus these data were combined (Fig. 12). Their overall distributional pattern was similar to trends discussed previously, including greater proportions of old shells at Station 1 than at Station 6. The distribution of shells of sound-shelf species (Fig. 13) also was similar to other trends, except that new to old valve ratios (Table 7) were much lower than among whole assemblages (Fig. 10, Table 2). The bulk of the whole assemblages thus was contributed by eurytopic species, most of which also are dominant among live mollusk faunas (Dörjes, 1972).

Among new total valves (Table 8A), percentages of estuary-sound, sound-shelf, and eurytopic species were very similar throughout the transect. Significant numbers of old valves were recovered only at Stations 1, 2, and 6; among these (Table 8B), sound-shelf species were relatively more abundant than among new valves, mostly at the expense of shells of eurytopes.

TABLE 5—Size-weight shell classification of live mollusk faunas from the nearshore shelf off Sapelo Island. Bivalves were tallied as two specimens, to make these data comparable to those in Table 3. Class 5 shells were negligible. (Adapted from Dörjes, 1972; personal communications, 1978–79.)

Shell classes (percent)	Southern transect (N = 697)	Northern transect (N = 2192)	Total (N = 2889)
1	6.5	12.3	10.9
2	84.9	79.8	81.1
3	6.2	7.0	6.8
4	2.4	0.9	1.3

Reduced new:old valve ratios among sound-shelf species of shells (Table 7; cf. Fig. 10) suggest that (1) long-distance valve transport is comparatively slow, (2) significant numbers of new shells age during the process, but (3) most old shells are derived from scour and stratigraphic leakage in the vicinity of Station 4. However, these trends tend to be masked by those of the entire assemblages and might not be obvious in the fossil record. Additionally, and perhaps most important, the constancy in relative proportions of estuary-sound, sound-shelf, and eurytopic species (Table 8) indicates a widespread homogenization of the assemblages with respect to original habitat differences, whether or not eurytopes are included in the analysis.

Also, sound-shelf species of shells are everywhere more abundant than estuary-sound species. The trend is more pronounced among old shells than new shells, suggesting a slight, long-term, soundward migration of valves. A net seaward migration presumably would have been reflected in greater proportions of estuary-sound species of shells at Station 6, a temporary shell trap, and in all species of shells on the nearshore shelf. On the other hand, shell concentrations at Station 6 also are related to larger scale carbonate lobes flanking the shoal system (Frey and Pinet, 1978); these represent southwestward shelf-sediment transport and lodgement of shells and other sediments against the north-side shoals (Fig. 2), as explained below.

Patterns of Sediment Transport

Previous work has established a cellular system of sediment transport and recycling within the inlet-shoal system (Oertel and Howard, 1972; Oertel, 1975). Because of ebb-dominance, major net sediment movement is seaward from the large inlet trough between barrier islands. However, numerous separate landward gyres return much of the sediment to the outer flanks of the shoal system. Skeletal carbonate concentrations there thus represent a combination of (1) shoreface shells migrating toward the ramp-margin shoals and (2) sound shells migrating first through the principal inlet channel (ebbward) and then turning landward along shoal margins; some tend to be driven southwestward through the shoal funnel (Fig. 2), its apex being characterized by net residual flood-tidal currents (Oertel, 1974).

This work also suggests a net ebb-current transport of sediment through the longshore channel (Oertel and Howard, 1972). Yet, our data show that some components of net shell movement are directed soundward. Such inequalities are explained by asymmetries in the duration and velocity of ebb and flood tidal currents and their relationship to the threshold

TABLE 6—Left:right valve ratios, selected species of shells. (From Frey and Henderson, in prep.)

Taxa	Doboy Sound	Main channel	Shallow shelf	Total
Donax variabilis	0.69	1.12	3.0*	0.98
Abra aequalis	0.78	1.26	0.58	1.05

*Insufficient data.

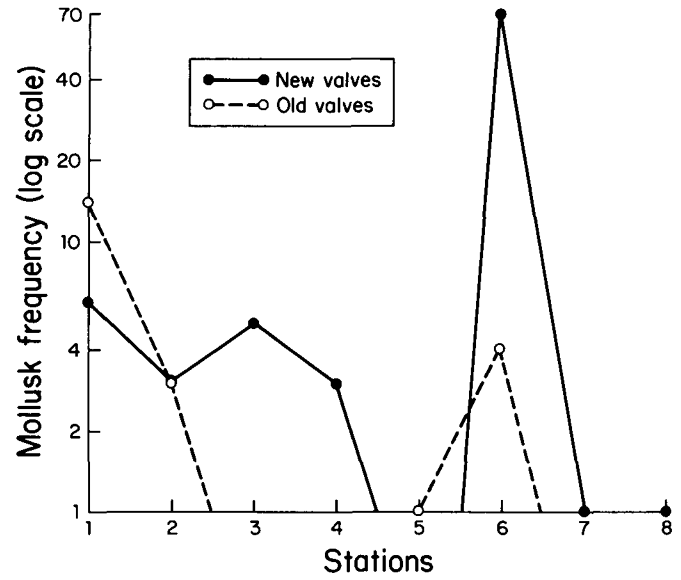

FIGURE 12—Distribution and abundance of shells of estuary-sound species.

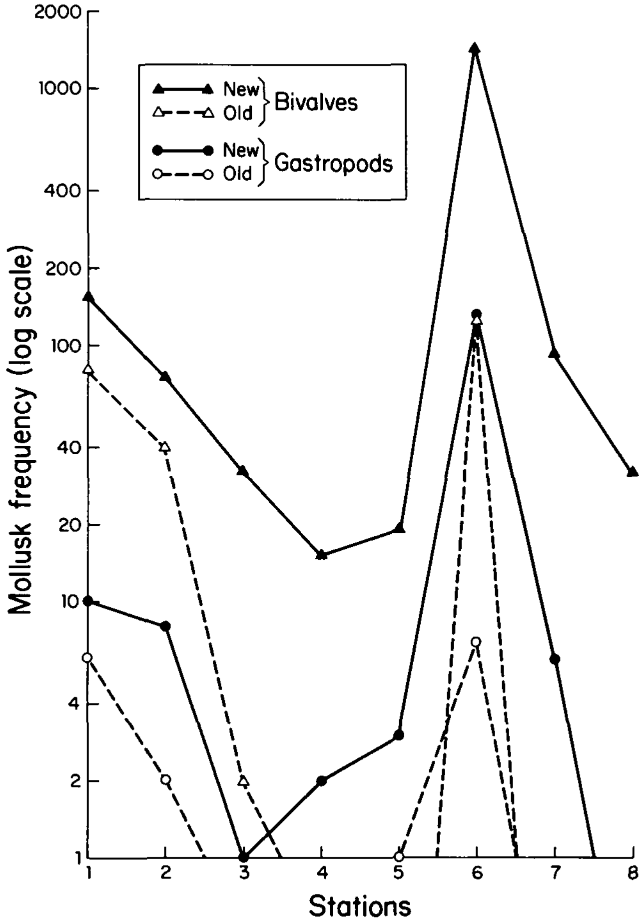

FIGURE 13—Distribution and abundance of shells of sound-shelf species.

velocities required to entrain sediments of a given size (Oertel, 1974). The deepest part of the channel (near Station 4) depicts maximum confinement of tidal waters within the channel, and the corresponding jet effect causes substantial scour. Present data indicate that this hole represents a pivotal or nodal point in net sediment movement; ebb currents, after being jetted past the node, apparently predominate on the seaward end of the channel, whereas flood currents, after jetting past this point, predominate on the soundward end. Unfortunately, hydrodynamic measurements have not been made within the channel per se, especially with regard to hydraulic equivalencies of mollusk shells, hence our observations remain qualitative.

PERSPECTIVE AND CONCLUSIONS

These collective observations suggest that the individual sampling sites and major parameters may be characterized as follows:

Doboy Sound—Stations 1 and 2 represent lower energy conditions along the shallow flank of the sound (Fig. 4), away from the main inlet trough and the longshore channel. Flood currents sweeping through lateral parts of the channel deposit shells there, some of which are not reentrained by the subsequent ebb. The overall result is a long-term soundward gain in shelf shells, many of them derived by scour of older sediments within the longshore channel itself, and consequent larger numbers of old shells accumulating along the periphery of the sound mouth.

Station 3, being proximal to and perhaps a part of the channel, is subject to correspondingly higher energy levels (Oertel and Howard, 1972) and therefore is less suited for shell accumulation. The extreme disarticulation of valves, the separation of left and right bivalve valves, and the homogenization of assemblages with respect to shell size and original habitat distributions indicate appreciable bidirectional transport through most of the sound/channel/shelf system, Station 3 representing a soundward threshold.

Longshore Channel—Although Stations 4 through 6 fall within the best defined parts of the channel, they exhibit individual responses to varying geomorphic and hydrodynamic regimes. Station 4, the deepest part of the channel, is analogous to the inlet trough and hydraulic "jet effect" between barrier islands (Pinet and Frey, 1977, fig. 11); the depression tends to be swept clean of shells and constitutes a significant stratigraphic leak for old shells, even though muds may accumulate there during times of high suspended-sediment concentrations following storms. [Larger, deeper scour holes tend to be sediment traps for lag clasts and heavy shells (Darby and Hoyt, 1964; Frey et al., 1975).] Station 5 is only slightly shallower and reflects somewhat comparable conditions; shells thus remain sparse.

In contrast, Station 6, at the seaward end of the channel, functions as a major trap for shells. The shells are deposited by

TABLE 7—Relative dominance of shells of environmentally distinctive mollusk species. Compare with Figures 12 and 13.

A—Estuary-sound species

Shell types (abundance)	Doboy Sound	Tidal channel	Shallow shelf
Total new shells	14	72	2
Total old shells	17	5	—
New:old ratio	0.8	14.4	—

B—Sound-shelf species

Shell types (abundance)	Doboy Sound	Tidal channel	Shallow shelf
Total new shells	284	1616	131
Total old shells	132	134	—
New:old ratio	2.2	12.1	—

waning tidal currents, especially during the ebb, and many are not reentrained by the next reversed flow. Total quantities of shells there evidently exceed those at Station 1, deposited by a somewhat similar flood process, because of (1) an overall ebb dominance through the channel and (2) an equilibrium between wave and ebb/flood tidal effects near the periphery of the main inlet-shoal system (cf. Hubbard et al., 1979, p. 1079). Increased numbers of articulated valves at Station 6 indicate slightly lower energy levels, relative newness of shells in transit, and probable proximity of life sites.

Nearshore Shelf—Station 7 (like Station 3) is proximal to and influenced by the longshore channel. This site therefore is intermediate between conditions of Stations 6 and 8. Gradual net shell winnowing and landward transport apparently characterize Station 8—albeit beyond the main hydraulic influence of the inlet-shoal system—as evidenced by the dearth of old shells there. Net hydraulic effects of shoreface wave trains apparently are more important here than tidal currents. During fair-weather conditions, however, this relatively low-energy site also may accumulate greater quantities of clastic sediments that dilute the shells and reduce their abundance per unit volume of sample. Additional work is needed to characterize nearshore shelf conditions and shell accumulations per se.

TABLE 8—Classification of detrital assemblages by habitat preferences of live individuals.

A—New shells (percent)

Habitat	Stations							
	1	2	3	4	5	6	7	8
Estuary-sound	0.2	0.2	1.6	1.6	—	0.3	0.1	0.2
Sound-shelf	5.3	6.5	10.6	9.0	6.5	6.6	9.8	6.1
Eurytopes	94.5	93.3	87.8	89.4	93.5	93.1	90.1	93.7

B—Old shells (percent)

Habitat	1	2	3	4	5	6	7	8
Estuary-sound	3.4	1.3	—	—	25.0*	1.4	—	—
Sound-shelf	21.7	18.1	33.3*	—	—	45.4	—	—
Eurytopes	74.9	80.6	66.7*	—	75.0*	53.2	—	—

*Insufficient data.

Finally, in addition to the trends mentioned above, this overall regime results in significant heterochroneity of components within otherwise contemporaneous shell assemblages (Fig. 10). Individual valves in transit range in age from Pleistocene to Holocene; rare Tertiary components are possible locally.

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APPENDIX 1—Diversity, abundance, distribution, and condition of mollusks recovered during the study. Compare with Figures 4 and 5. For habitat designations, E = main reaches of estuaries or sounds, Sm = lower reaches of sounds or sound mouths, and Sh = nearshore shelf; italicized symbols indicate predominance. Parenthetical numbers following species names are size-weight classes, as explained in text.

Subenvironments	Flank of Doboy Sound			Main Channel			Shallow Shelf			
Mollusk Species / Stations	1	2	3	4	5	6	7	8	Total	Original Habitat
Live Gastropods:										
Polinices duplicatus (Say)	—	2	—	—	—	—	—	—	2	E, Sm, Sh
Terebra dislocata (Say)	—	—	—	—	—	—	—	2	2	Sm, *Sh*
Total Live Gastropods:	—	2	—	—	—	—	—	2	4	
Dead Gastropod Valves:	new/old	new/old	new/old	new/old	new/old	new/old	new/old	new/old	new/old	
Acteocina canaliculata (Say)(1)	2/1	–/9	—	1/–	—	244/–	3/–	1/–	251/10	E, *Sm*, Sh
Anachis avara (Say)(2)	—	—	—	—	—	2/–	—	—	2/–	Sm, Sh
Anachis lafresnayi (Fischer & Bernardi)(2)	—	—	—	—	—	1/–	—	—	1/–	Sm, Sh
Anachis obesa (Adams)(2)	—	—	—	—	—	4/–	—	—	4/–	Sm, Sh

Subenvironments	Flank of Doboy Sound			Main Channel			Shallow Shelf			
Stations / Mollusk Species	1	2	3	4	5	6	7	8	Total	Original Habitat
Busycon canaliculatum (Linné)(4)	—	—	—	—	2/–	—	—	—	2/–	Sm, *Sh*
Busycon carica (Gmelin)(4)	—	—	—	1/–	—	2/–	—	—	3/–	Sm, *Sh*
Circulus suppressus (Dall)(1)	—	—	—	—	—	1/–	—	—	1/–	Sh
Crepidula convexa Say(2)	1/–	—	—	—	—	—	—	—	1/–	*E*, *Sm*, Sh
Crepidula fornicata (Linné)(3)	1/–	1/–	—	—	—	5/–	—	—	7/–	E, Sm, Sh
Crepidula plana Say(2)	2/–	—	—	—	—	6/–	2/–	—	10/–	Sm, Sh
Cryoturris cerinella (Dall)(2)#	1/1	—	—	—	—	–/1	—	—	1/2	Sm, *Sh*
Epitonium humphreysi (Kiener)(2)	1/–	—	—	—	—	—	—	—	1/–	E, Sm, Sh
Epitonium multistriatum (Say)(2)	—	1/–	—	—	—	1/–	—	—	2/–	Sm, *Sh*
Epitonium rupicola (Kurtz)(2)	—	—	—	—	—	1/–	—	—	1/–	*E*, *Sm*, Sh
Ilyanassa obsoleta (Say)(3)	—	—	—	—	—	4/–	—	—	4/–	E, Sm
Littorina irrorata (Say)(3)	–/2	—	—	—	—	–/1	—	—	–/3	E
Melampus bidentatus Say(2)	—	—	—	—	—	–/1	—	—	–/1	E
Mitrella lunata (Say)(1)	1/–	2/–	2/–	1/–	—	28/–	1/–	1/–	36/–	*E*, *Sm*, Sh
Nassarius acutus (Say)(2)	—	—	—	—	—	–/7	—	—	–/7	?
Nassarius trivittatus (Say)(2)	3/1	2/–	1/–	1/–	1/–	18/–	1/–	—	27/1	Sm, *Sh*
Natica pusilla Say(1)	—	2/1	—	—	—	37/–	—	—	39/1	Sm, *Sh*
Odostomia impressa (Say)(1)	—	1/–	—	—	—	4/–	—	—	5/–	E, *Sm*
Odostomia seminuda (Adams)(1)#	—	—	—	—	—	5/–	—	—	5/–	Sm
Oliva sayana Ravenel(4)	—	—	—	—	—	1/–	—	—	1/–	Sh
Olivella floralia (Duclos)(2)	—	—	—	—	—	2/–	—	—	2/–	Sh
Olivella mutica (Say)(2)	–/1	–/1	—	—	–/1	10/4	—	—	10/7	Sm, Sh
Polinices duplicatus (Say)(4)	5/1	4/–	1/–	1/–	1/–	21/–	3/–	—	36/1	E, Sm, Sh
Terebra concava (Say)(3)	—	—	—	—	—	2/–	1/–	—	3/–	Sh
Terebra dislocata (Say)(3)	4/2	1/–	—	—	—	18/2	1/–	—	24/4	Sm, *Sh*
Triphora nigrocincta (Adams)(1)#	—	—	—	—	—	–/1	—	—	–/1	?
Turbonilla interrupta (Totten)(1)	–/1	—	—	—	—	9/–	—	—	9/1	E, *Sm*, *Sh*
Turbonilla virgata Dall(1)#	—	2/–	—	—	—	19/–	1/–	—	22/–	Sm, *Sh*
Total Gastropod Valves	21/10	16/11	4/–	5/–	4/1	445/17	13/–	2/–	510/39	
Live Bivalves:										
Abra aequalis (Say)	—	—	—	—	1	—	—	—	1	E, Sm, Sh
Donax variabilis Say	1	—	—	—	—	—	—	—	1	Sm, *Sh*
Mulinia lateralis (Say)	35	1	—	—	5	—	1	—	42	E, *Sm*, Sh
Solen viridis Say	—	—	—	—	—	—	—	1	1	Sm, *Sh*
Tellina versicolor DeKay	—	1	4	—	2	7	6	9	29	E, Sm, *Sh*
Total Live Bivalves:	36	2	4	—	8	7	7	10	74	
Dead Bivalve Valves:*	new/old	new/old	new/old	new/old	new/old	new/old	new/old	new/old	new/old	
Abra aequalis (Say)(2)	30/–	12/1	2/–	2/–	11/–	136/1	19/–	4/–	216/2	E, Sm, Sh
Anadara brasiliana (Lamarck)(4)	1/–	—	—	—	—	4/–	—	—	5/–	Sm, *Sh*
Anadara ovalis (Bruguière)(4)	12/14	6/1	—	—	3/–	146/–	1/–	4/–	172/15	E, *Sm*, *Sh*
Anadara transversa (Say)(3)	—	1/–	—	—	—	4/–	—	—	5/–	Sm, *Sh*
Anomia simplex Orbigny (2)	—	—	—	—	—	1/–	—	—	1/–	E, *Sm*, Sh
Barnea truncata (Say)(3)	—	—	3/–	—	—	2/–	—	—	5/–	*E*, *Sm*, Sh
Corbula barrattiana Adams(1)	—	1/–	—	—	—	14/–	—	—	15/–	Sm, Sh
Corbula swiftiana Adams(1)	–/1	1/1	2/–	—	4/–	36/–	—	—	43/2	Sm, Sh
Crassinella lunulata (Conrad)(1)	—	—	—	—	—	1/–	—	—	1/–	Sm, *Sh*
Crassostrea virginica (Gmelin)(4)	4/11	–/2	—	—	–/1	17/–	—	—	21/14	*E*, Sm
Cyrtopleura costata (Linné)(4)	—	—	—	—	1/–	—	—	—	1/–	E, *Sm*, Sh
Dinocardium robustum (Lightfoot)(5)	—	—	—	—	—	1/–	—	—	1/–	Sm, *Sh*
Diplothyra smithi Tryon(1)	8/–	—	—	—	—	—	—	—	8/–	E, *Sm*, Sh
Divaricella quadrisulcata (Orbigny)(2)	—	—	—	—	—	2/1	—	—	2/1	Sh
Donax variabilis Say (2)	83/54	10/29	5/–	3/–	4/–	327/110	5/–	—	437/193	Sm, *Sh*
Dosinia discus (Reeve)(4)	—	—	—	—	—	1/–	—	—	1/–	Sm, *Sh*
Ensis directus Conrad(2)	4/–	1/–	—	—	—	3/1	—	1/–	9/1	Sm, *Sh*
Ervilia concentrica (Holmes)(1)	1/1	2/2	2/–	—	—	18/–	—	—	23/3	E, Sm, *Sh*
Gemma gemma (Totten)(1)	—	–/1	—	1/–	—	11/–	—	—	12/1	*E*, Sm
Macoma tenta (Say)(2)	—	—	—	—	—	2/–	—	—	2/–	Sm, *Sh*
Mercenaria mercenaria (Linné)(5)	—	—	—	—	—	1/1	—	—	1/1	*E*, Sm
Mulinia lateralis (Say)(2)	2901/300	1190/176	260/4	164/2	305/2	21648/147	880/1	501/–	27849/632	E, *Sm*, Sh
Mysella planulata (Stimpson)(1)#	—	—	—	—	—	3/–	—	—	3/–	Sm, *Sh*
Nucula proxima Say(1)	—	1/–	—	—	—	7/–	—	—	8/–	Sm, *Sh*
Ostrea equestris Say(2)	—	—	—	—	—	6/–	—	—	6/–	*Sm*, Sh
Paramya subovata (Conrad)(1)	2/–	—	1/–	—	3/–	11/–	—	—	17/–	Sm, *Sh*
Parvilucina multilineata (Tuomey & Holmes)(1)	1/1	—	—	—	—	7/7	—	—	8/8	Sh
Petricola pholadiformis (Lamarck)(2)	4/2	5/1	11/–	—	1/–	18/–	—	—	39/3	E, Sm, Sh

APPENDIX 1—Continued

Mollusk Species	Stations 1	2	3	4	5	6	7	8	Total	Habitat
Pholas campechiensis Gmelin(3)	2/–	—	—	—	—	—	—	—	2/–	Sm
Pleuromeris tridentata (Say)(1)	—	1/1	–/1	1/–	—	33/5	—	—	35/7	Sh
Plicatula gibbosa Lamarck(2)	—	—	—	—	—	–/1	—	—	–/1	Sh
Raeta plicatella (Lamarck)(3)	5/–	1/–	—	—	—	2/–	1/–	—	9/–	Sm, Sh
Solen viridis Say(2)	12/–	9/–	1/–	1/–	1/–	42/–	—	1/–	67/–	Sm, *Sh*
Spisula solidissima similis (Say)(3)	–/1	—	—	—	—	–/1	—	—	–/2	Sh
Strigilla mirabilis (Philippi)(2)	—	—	—	—	—	1/–	—	—	1/–	Sh
Tagelus plebeius (Lightfoot)(3)	–/1	—	—	1/–	—	–/1	—	—	1/2	*E*, *Sm*, Sh
Tellina iris Say(1)	—	1/–	—	—	—	2/–	1/–	—	4/–	Sh
Tellina versicolor DeKay(2)	35/10	42/6	21/1	10/–	4/–	771/–	84/–	27/–	994/17	E, Sm, *Sh*
Total Bivalve Valves	3105/396	1284/221	308/6	183/2	337/3	23278/276	991/1	538/–	30024/905	
Total Mollusk Valves	3126/406	1300/232	312/6	188/2	341/4	23723/293	1004/1	540/–	30534/944	
Total Live Mollusks	36	4	4	—	8	7	7	12	78	

*Includes articulated valves; see Appendix 2.

[#] First reported occurrence, Sapelo Island waters.

APPENDIX 2—Articulated versus disarticulated new bivalve valves. Articulated valves were tallied as two specimens. All other species of bivalve shells (Appendix 1) were disarticulated. (D:A ratio = total disarticulated valves divided by total articulated specimens.)

Mollusk Species	Doboy Sound (A/D)	Main channel (A/D)	Shallow shelf (A/D)	Total (A/D)
Abra aequalis	—	2/9	—	2/9
Anadara ovalis	—	2/144	2/2	4/146
Corbula barrattiana	—	6/8	—	6/8
Corbula swiftiana	—	4/–	—	4/–
Diplothyra smithi	6/2	—	—	6/2
Donax variabilis	4/133	—	—	4/133
Ervilia concentrica	—	2/16	—	2/16
Gemma gemma	—	2/9	—	2/9
Mulinia lateralis	8/1358	14/21781	6/875	28/24014
Paramya subovata	—	2/1	—	2/1
Pleuromeris tridentata	—	2/36	—	2/36
Tellina versicolor	10/60	8/763	32/79	50/902
Total:	28/1553	44/22767	40/956	112/25276
D:A ratio:	55.5	517.4	23.9	225.7