Net Longshore Sediment Transport and Textural Changes in Beach Sediments along the Southwest Alabama and Mississippi Barrier Islands, U.S.A.

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INTRODUCTION

The Mississippi and southwest Alabama coast is comprised of five late Holocene barrier islands; Dauphin Island in Alabama, Petit Bois, Horn, East and West Ship Islands in Mississippi (Figure 1). The five islands are located approximately 5 to 20 km seaward of the mainland shoreline of Mississippi Sound. They are elongated east to west, and the chain of barrier islands and tidal passes extends for approximately 100 kilometers.

The islands are characterized by a distinctive tourmaline-kyanite “Appalachian” suite of heavy minerals typical of the eastern Gulf petrologic province (HSU, 1960). The immediate source of the barrier island sands is considered to be the erosion of pre-Holocene headlands along the Alabama-Florida coasts (i.e., Grayton Beach, Florida, see STONE et al., 1992), and the reworking of sediments previously deposited on the inner continental shelf by streams and rivers during the Pleistocene glacial stages (RUCKER and SNOWDEN, 1989). The possibility of onshore movement of sediment from the continental shelf has been reported by FOXWORTH et al. (1962) and OTVOS (1970). According to VAN ANDEL and POOLE (1960), the ultimate source of the barrier island chain sands is an igneous-metamorphic complex of the southern Appalachians.

Sediment transport along the southwest Alabama and Mississippi barrier islands, although crucial to an understanding of coastal morphology in the area, has not yet been investigated. The sedimentology of surficial sediments in addition to the nearshore sediment transport dynamics along these barriers remains largely unknown. A sediment budget has not been constructed for the area, and thus, the morphological maintenance of the coast remains poorly understood.

Sediment transport models have been developed recently for the southeast Alabama and northwest Florida coast (STONE, 1991; STONE et al., 1992; STONE and STAPOR, 1996), and the Chandeleur Island in Louisiana (ELLIS, 1998). The present study area lies between both sites. It is the objective
of this paper to present a model that will contribute to and enhance our understanding of sediment transport along the entire Northeast Gulf coast region.

This goal will be achieved through two independent data sets:

1) Numerical modeling of the net longshore sediment transport from Mobile Pass, Alabama to West Ship Island, Mississippi, in order to enhance our comprehension of sediment transport along the site and to investigate further the hypothesis of alternative sources of sediment supply developed in the sedimentological component of this research. Potential directions and volumes of net longshore sediment transport will be analyzed in light of the beach sediment characteristics and results from similar studies conducted along the adjacent northwest Florida and southeast Alabama coast (STONE, 1991; STONE et al., 1992; STONE and STAPOR, 1996).

2) A detailed analysis of the texture and composition of sediments that characterize the foreshore (step), beach (mid-tide level), and the primary dune system of the Gulf side of the five barrier islands under study. This approach is designed to investigate the potential for beach sediment grading along the site, such as coarsening or fining in the down-drift direction when interpreted within the framework of wave energy conditions alongshore.

METHODS

Computer Simulation of Net Longshore Sediment Transport

The methodology used in this study to predict net longshore transport rates is based on computer simulations using a wave energy dissipation model, WAVENRG (MAY, 1974; STONE, 1991). WAVENRG simulates the behavior of shoaling waves and the resulting longshore transport. The simulation is based on refraction, shoaling, and bottom friction of monochromatic waves as they propagate from deep water toward the coastline. A suite of breaker wave statistics is computed to calculate longshore sediment transport (STAPOR and MAY, 1983). Input to the program consists of: 1) a computational bathymetric grid representing the inner shelf of the study area extending seaward to depths of one-half the wavelength of the incident deep-water wave; 2) deep-water wave statistics including: wave height, period, and angle of approach by percent frequency of occurrence. Critical to the study was the procurement of long-term, statistically significant wave information for the offshore region. In this specific case wave information was obtained from the Coastal Engineering Research Center's (CERC) Wave Information Study (hereafter referred to as WIS). The WIS data were produced by numerical simulation of wave growth, propagation and decay using historical wind fields in the Gulf of Mexico (HUBERTZ et al., 1989). WIS inputs to WAVENRG are based on hindcasts for the period 1956–1975, computed at three hour intervals (STONE et al., 1992).

Beginning with a deep water wave origin, WAVENRG tracks a wave ray shoreward, over a known bathymetry, along with a companion ray in order to monitor ray spacing changes (i.e., convergence or divergence) due to wave refraction. Shoaling effects on wave height and wavelength are constantly recomputed based on changes in water depth as well as the dissipation of wave energy due to frictional drag (STONE, 1991). At frequent intervals along the wave ray sev-
eral parameters are computed, including spatial coordinates, water depth, wavelength, wave height, wave angle (direction), energy-dissipation rate and others (May, 1973). At the point where the wave height exceeds 0.78 the still-water depth, the wave is assumed to break (McCowan, 1894) and breaker parameters are computed by the model. These include breaker height ($h_b$), group velocity ($c_g$), breaker angle ($\beta$), longshore component of wave power ($P_{l1}$) and net longshore transport volume ($Q_{l1}$) (May, 1973; Stapor and May, 1983; Stone, 1991; Stone et al., 1992).

Breaker wave parameters are calculated using the following formulae: The longshore component of wave power ($P_{l1}$) is calculated by

$$P_{l1} = 0.5EC_\alpha \sin 2\beta$$

where $E$ is the wave energy density:

$$E = 0.125\rho g h_b^4$$

and $\rho$ is the mass density of water and $g$ is the acceleration due to gravity. Net longshore transport volume (cubic meters/year) is given by:

$$Q_{l1} = 1000P_{l1}$$

For use in WAVENRG equation (3) was derived as follows (Stone, 1991): The immersed weight transport rate ($I_{l1}$) is given by:

$$I_{l1} = K_1 P_{l1}$$

where $K_1$ is a dimensionless constant with the value of 0.31 for WAVENRG (Stapor and May, 1983; Stone, 1991; Stone et al., 1992), and where $I_{l1}$ is converted to $Q_{l1}$ by:

$$Q_{l1} = I_{l1}(\rho_d - \rho)g$$

where $\rho_d$ is the density of sediment (2650 kg/m$^3$), $\rho$ is the density of water (1000 kg/m$^3$), $g$ is the acceleration due to gravity (9.81 m/sec$^2$), and $a$ is a dimensionless packing coefficient (0.6) (Stone, 1991). Thus,

$$Q_{l1} = 1.03 \times 10^{-4} I_{l1} \text{ (m$^3$/sec)} = 3.19 \times 10^{-4} P_{l1} \text{ (m$^3$/sec)}$$

$$= 1000P_{l1} \text{ (m$^3$/yr)}$$

Bathymetric data were derived from 1:80,000 scale National Oceanic and Atmospheric Administration (NOAA) nautical charts. The charts were digitized and formatted in an X-Y-Z matrix (Figure 2). The bathymetric grid has 800 m grid spacing.

Deep water wave statistics used as input to WAVENRG include breaker height, wave period, wave angle, wave direction, wave energy, and wave height. Wave energy is estimated by:

$$Q_{l1} = 1000P_{l1}$$

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The wave climate includes winter storms as well as fairweather conditions.

**Sedimentological Analysis**

A sampling grid was established along the barrier islands at one kilometer intervals on West and East Ship Island, and at two kilometer intervals on Horn, Petit Bois and Dauphin Island, providing a total of 45 sampling stations. West and East Ship Islands are considerably shorter than the remaining barriers to the east, thus a one kilometer sampling interval was used to secure additional samples. Five additional sampling stations were established at 2 kilometer intervals to the east of the study area, along the western end of Fort Morgan Peninsula, in order to compare the composition of beach sediment on both sides of Mobile Bay with previous studies (Stone, 1991; Stone et al., 1992). All samples were collected during prolonged non storm conditions.

At each of the 50 sites a minimum of four sediment samples were collected from the beach at the following positions: step (usually located in about 30 to 40 cm water depths in the lower-foreshore), mid-tide level, and foredune crest. The four samples (hereafter referred to as replicates) collected at each site and at each position on the beach profile were taken respectively every 15 meters along a 45 meter long shore-parallel transect. Only the upper 2 cm-thick layer was sampled. In total, 600 sediment samples were collected during the summer of 1994. Sample locations are consistent with work undertaken at other sites in the Gulf (Stone, 1991; Stone et al., 1992; Ellis, 1998; Ellis and Stone in prep.) and the Atlantic coasts (Stapor and May, 1982) and are discussed in more detail in Stapor and May (1982) and Stone et al. (1992).

Laboratory work consisted mainly of two phases: 1) grain size analysis, and 2) determination of the carbonate (shell) fraction. Dry sieving at 1/4 phi intervals for 2.5 minutes was performed using a Gilson AutoSiever, model GA-1. The exceptional speed and efficiency of sonic sieving of sand-size grains was the primary criterion used in choosing this method. In addition, recent work suggests sieving to be superior to settling tube analysis (Tanner, 1997). Step samples were digested with 6N hydrochloric acid to remove the carbonate (shell) fraction (shells were not found in mid-tide and foredune sediments). Sediment samples were sieved and heavy minerals were separated from the retained sand in the respective sieves (after weighting).

Analysis of grain-size data was accomplished using the program GRANULO.ORG, which calculates, using the Folk and Ward (1957) approach, the following grain-size parameters: mean, sorting, skewness, and kurtosis of the sediment sample. At each sampling station 4 samples (15 m apart) were taken from the step, mid-tide and foredune crest respectively for a total of 12 samples. Each sample was dry sieved at 1/4 phi intervals for 2.5 minutes using sonic sieving equipment and grain size parameters were calculated using the Folk and Ward (1957) approach. Mean size, sorting, skewness, and kurtosis values of each sample among the four replicates were averaged to obtain a mean value. The standard deviation among the four replicates was calculated.
RESULTS

Net Longshore Sediment Transport

Net longshore transport rates are shown in Figure 3. Positive values of predicted net longshore transport rates ($Q_L$, expressed in $m^3/yr$) indicate net eastward sediment transpor...
Table 1. Deep water wave climate obtained from WIS Stations 26 and 27 over the hindcast period 1956–1975 (HUBERTZ et al., 1989; STONE, 1991; STONE et al., 1992).

<table>
<thead>
<tr>
<th>Station</th>
<th>26</th>
<th>26</th>
<th>26</th>
<th>27</th>
<th>27</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Direction</td>
<td>Azimuth (deg.)</td>
<td>Height H (m)</td>
<td>Period T (sec)</td>
<td>Percent Occurrence</td>
<td>Wave Height H (m)</td>
<td>Period T (sec)</td>
</tr>
<tr>
<td>ESE</td>
<td>112.5</td>
<td>1.1</td>
<td>5.4</td>
<td>11.1</td>
<td>1.1</td>
<td>5.5</td>
</tr>
<tr>
<td>SE</td>
<td>135.0</td>
<td>1.1</td>
<td>5.7</td>
<td>23.6</td>
<td>1.1</td>
<td>5.7</td>
</tr>
<tr>
<td>SSE</td>
<td>157.5</td>
<td>1.0</td>
<td>5.4</td>
<td>9.6</td>
<td>1.2</td>
<td>5.8</td>
</tr>
<tr>
<td>S</td>
<td>180.0</td>
<td>0.8</td>
<td>4.6</td>
<td>3.1</td>
<td>1.0</td>
<td>5.4</td>
</tr>
<tr>
<td>SSW</td>
<td>202.5</td>
<td>0.8</td>
<td>4.3</td>
<td>1.9</td>
<td>0.9</td>
<td>5.0</td>
</tr>
<tr>
<td>SW</td>
<td>225.0</td>
<td>0.8</td>
<td>4.3</td>
<td>1.8</td>
<td>0.9</td>
<td>4.8</td>
</tr>
<tr>
<td>WSW</td>
<td>247.5</td>
<td>0.8</td>
<td>4.3</td>
<td>2.2</td>
<td>0.9</td>
<td>4.8</td>
</tr>
</tbody>
</table>

port, whereas negative values indicate net westward sediment transport.

The curves indicate dominant net westward longshore transport with the exception of a localized reversal along the eastern end of Dauphin Island. The drift divide is located approximately 6 km to the west of Dauphin Island's eastern end (Figure 3). Net longshore transport rates show a general increase from the drift divide toward the east on eastern Dauphin Island (approximately 4,000 m³/yr at site 45 eastern end of Dauphin Island), and toward the west along central Dauphin Island, where sediment transport reaches a maximum value of approximately 62,000 m³/yr near site 35 (Figure 3). West of site 35, net transport rates decrease to approximately 8,000 m³/yr at the western tip of Dauphin Island (site 32) (Figure 3).

Westward sediment transport along Petit Bois Island increases from zero (approximately 200 m³/yr) at the eastern tip (site 31) to a maximum of approximately 60,000 m³/yr 4 km to the west, and then decreases to near zero (approximately 300 m³/yr) at site 28, along central Petit Bois Island, approximately 5 km to the west of the island’s eastern end (Figure 3). West of site 28 westward net transport rates increase toward the west end of Petit Bois Island and attains values of approximately 45,000 m³/yr at its western tip (site 25) (Figure 3).

Along Horn Island, westward sediment transport ranges from values of approximately 30,000 m³/yr at the eastern island tip (site 24) to approximately 65,000 m³/yr along the western 2 km of the island (site 15), decreasing to a minimum of approximately 24,000 m³/yr at its western tip (site 14) (Figure 3).

Along East Ship Island, net longshore transport rates are

Figure 3. Net longshore transport curve along the study area. Transport values above the zero line indicate the net transport direction is to the east and below the zero line, net transport to the west. Sediment sampling transect locations are numbered.
westward and increase from a minimum value of approximately 2,000 m³/yr at the eastern tip (site 13) to a maximum of approximately 13,000 m³/yr along the western 2 km of the island (site 9). Transport rates remain fairly constant along the remainder of the barrier to the western tip adjacent to “Camille Cut”. Along West Ship Island, predicted net transport rates increase from 24,000 m³/yr at the eastern end (site 6) to a maximum of approximately 37,000 m³/yr toward the western end (site 2) (Figure 3).

The magnitude of predicted net longshore sediment transport is highly dependent on the breaker wave height (Equation 2). WAVENRG-predicted breaker wave heights for the study area are shown in Figure 4.

Composition and Texture of Sediments

Sediments sampled along the study area are composed of quartz sand, heavy minerals and shell. Step samples contain more than 90% quartz sand, and less than 2% carbonates by weight. Samples obtained from grabs in the field at the mid-tide level contained 99% quartz sand and 1% heavy minerals; by contrast, foredune samples contained 50–100% quartz sand with heavy minerals comprising up to 50%.

Heavy minerals found in foredune samples (sites 4, 17 and 28) were: Hornblende, Ilmenite, Kyanite, Hematite, Staurolite, and Tourmaline. These minerals are in agreement with the Eastern Gulf petrologic province defined by HSU (1960), and with heavy minerals identification by FOXWORTH et al. (1962).

Field observations indicated heavy mineral concentrations > 40% (visual inspection) in foredune samples obtained along eastern West Ship Island (sites 4, 5 and 6), central East Ship Island (sites 8 to 12), eastern Horn Island (sites 17 to 23), and central Petit Bois Island (sites 26 to 29). Along Dauphin Island heavy minerals (30–40%) were found in the foredune samples of sites 34, 38 and 43 only, while along Fort Morgan Peninsula no heavy minerals were found.

The texture of heavy minerals commonly ranged between 2.25 phi (0.21 mm) and 3.0 phi (0.125 mm) (fine sand as defined by KRUMBEIN, 1934), with a peak concentration at 2.75 phi (0.149 mm). Heavy minerals were always finer than quartz grains. In fact, they were in the range of fine and medium sand in samples where quartz grains were as coarse as very coarse sand (−1.0 phi to 0.0 phi) or granule (−2.0 phi to −1.0 phi).

The weight percent calcium carbonate (shell) for step sediment samples along the study area is shown in Figure 5. Respective site weight percent calcium carbonate values were smoothed by a three-point moving average.

Maximum concentration of weight % CaCO₃ in step samples along the study area did not exceed 2%. This finding is
in agreement with values found by Stone (1991) and Stone et al. (1992) along the northwest Florida and southeast Alabama coast (with the exception of Perdido Key, where weight % CaCO₃ reached values of approximately 6%).

A peak in the weight % CaCO₃ occurs at stations 28 and 29 on Petit Bois Island (Figure 5). No statistically significant regional trend extending from Fort Morgan Peninsula, Alabama, to West Ship Island, Mississippi, could be identified in the step samples with respect to weight percent calcium carbonate.

The distribution of quartz mean grain size (Mz) alongshore is shown for foredune, mid-tide and step sediments in Figure 6, smoothed by a three-point moving average. Step sediments have mean grain size ranging from 0.71 phi (0.611 mm) to 1.87 phi (0.274 mm), lying in the coarse sand and medium sand classes as defined by Krumbein (1934).

On the beach face at mid-tide level, sediments range from 1.347 phi (0.393 mm) to 2.079 phi (0.237 mm), lying in the medium sand and fine sand range except for three sites (sites 1, 3, and 48) where Mz values are finer than 2.0 phi (0.25 mm) lying in the fine sand range. Foredune sediments have mean grain sizes ranging from 1.508 phi (0.352 mm) to 2.266 phi (0.208 mm), lying in the medium and fine sand range. Thus, step samples are much coarser than foredune sediments along the study area with the exception of sites 49 and 50 along Fort Morgan Peninsula. No regional trend in mean size alongshore exists from Fort Morgan Peninsula to West Ship Island for step, mid-tide, and foredune sediment samples. Step sediments, however, tend to be significantly coarser than mid-tide and foredune sediments (Figure 6).

Foredune and mid-tide sediments have similar mean grain sizes along the study area (Figure 6). The two curves intercept several times, indicating that at certain sites foredune sediments are coarser than mid-tide sediments. This inverse relationship has been found in previous studies; i.e., Gathen (1994), along central Horn Island, Stone (1991) and Stone et al. (1992) along northwest Florida and the southeast Alabama coast, and in some instance is attributable to overwash.

Quartz grain sorting values (σt) are shown in Figure 7 for step, mid-tide and foredune sediment samples. Respective means among the four replicates for each sampling site were smoothed by a three-point moving average. Sediments sampled from the study area have sorting values ranging from 0.231 phi (very well sorted, after Folk and Ward, 1957) to 0.806 phi (moderately sorted). It is interesting to note that in general, mid-tide sediments are better sorted (lower σt) than foredune sediments.

Step sediment sorting (σt) and mean grain size (Mz) dis-
tributions along the study area are plotted together on Figure 8 to show their correlation: step sediments are generally more poorly sorted (higher $\sigma_b$ values) when coarser (lower $M_z$ \([\text{phi units}]\)), while finer samples tend to be better sorted (lower $\sigma_b$ values).

**DISCUSSION**

**Net Longshore Transport and Morphology**

Results of the numerical modeling of net longshore sediment transport along southwest Alabama and the Mississippi barrier islands indicate the existence of a cellular structure of the coast similar to the adjacent northwest Florida and southeast Alabama coast as reported by Stone (1991), and Stone et al., (1992). The variations in magnitude of net longshore transport rates which, in turn, is representative of the cellular structure of the coast under study, is shown in Figure 9. In addition, when there is an absolute increase in the volume of transported sediments, this is an indication of an area of potential erosion. An absolute decrease in the volume of transported sediments indicates a potential zone of deposition (Figure 10) (Stapor and May, 1983), i.e., spit progradation (in this particular case the western end of the barrier islands) (Stone et al., 1992). Documented historic westward migration of the Mississippi barrier islands by progradation, and erosion along the eastern end (Byrnes et al., 1991) confirms that western island tips may function as cell termini. Tidal inlets between adjacent barriers may be considered as sediment sinks, at least in recent years, because part of the sediment that naturally is stored in the inlets in the form of ebb and flood shoals is periodically dredged to maintain navigable channels (Rucker and Snowden, 1990). Ship Island, Dog Keys, Horn Island, and Mobile Bay passes host navigation channels for Gulfport, Biloxi, Pascagoula and Mobile harbors respectively.

Longshore transport simulations indicate the existence of six littoral cells from Dauphin Island to West Ship Island (Figure 9). Cell I extends from the eastern end of Dauphin Island approximately 6 km to the west (between sites 41 and 42) and experiences net eastward transport which increases in magnitude downdrift toward Mobile Pass. Cell II occurs along the remainder of Dauphin Island and experiences net westward transport which increases gradually in magnitude downdrift (west) to reach a maximum value approximately 5 km to the east of the western end (site 35) (Figure 9). The implication for erosion related to the absolute increase in the
volume of transported sediments (Figure 10) was confirmed by field observations and air photo comparisons made by Smith (1990). WAVE东西-predicted net longshore sediment transport decreases along the western 5 km of Dauphin Island, to reach a minimum value of approximately 8,000 m$^3$/yr at its western tip (Figure 9). Potential deposition related to the absolute decrease in the volume of transported sediments (Figure 10) is confirmed by westward migration of Dauphin Island’s western end at a rate of approximately 55.3 m/yr over the period 1848–1986 (Byrnes et al., 1991). Sediment eroded along central Dauphin Island is deposited at the western end of the island, indicating an internal source of sediment.

Cell III, which experiences net westward transport, extends from the eastern end of Petit Bois Island to central Petit Bois Island, approximately 5 km to the west (site 28 area), where net longshore sediment transport decreases to zero (Figure 9). Central Petit Bois Island is a depositional site since net longshore sediment transport decreases to zero.

Cell IV occurs along the remainder of Petit Bois Island and experiences net westward transport which increases uniformly downdrift toward the western end of the island (Figure 9). Horn Island Pass, which separates Petit Bois Island from Horn Island to the west, has a single channel near its eastern margin that reaches natural depths of approximately 14 meters below mean low water (MLW) (Rucker and Snowden, 1990). This channel forms part of the Horn Island Ship Channel, which extends from Pascagoula, Mississippi, across Mississippi Sound to the Gulf of Mexico, passing to the west of Petit Bois Island. The westward migration and accretion of Petit Bois Island has resulted in sediment deposition in the channel throat, requiring continual dredging to maintain a navigable channel (Rucker and Snowden, 1990). Navigation channel maintenance has prevented any significant degree of sediment by-passing, at least for the last forty years. Material is routinely dredged from the channel and dumped offshore in deeper water, beyond the littoral zone. For this reason it would seem likely that the western end of Petit Bois Island constitutes a cell terminus resulting in no net communication of sediment with Horn Island to the west.

Cell V extends along the entire length of Horn Island (Figure 10) and experiences net westward transport. The structure of the longshore transport curve indicates that the island is characterized by internal sources of sediment. Historical changes in shoreline position between 1849 and 1986 exhibit steady lateral migration to the west with no significant island.
retreat along the Gulf side (BYRNEs et al., 1991). For this reason BYRNEs et al. (1991) classified Horn Island as the most stable over the last century among the southwest Alabama and Mississippi barrier islands.

Cell VI occurs along East and West Ship Island, and experiences net westward transport which increases from the eastern end of East Ship Island to the western end of West Ship Island (Figure 9). Sediment by-passing may occur at Camille Cut given its shallow nature (Figure 2). Rates of shoreline retreat along East Ship Island over the last century are more than double (−4.2 m/yr between 1848 and 1986) those associated with barrier islands to the east (BYRNEs et al., 1991). The presence of the Gulfport Harbor ship channel passing to the west of West Ship Island (Figure 9) has probably prevented any significant degree of sediment bypassing to the west, toward Cat Island, Mississippi. For this reason the western tip of West Ship Island would seem likely to constitute a cell terminus.

Historic shoreline trends are useful in testing the demarcation of a predicted cellular structure of the coast under study. For example, a mature sediment source constituting the updrift cell boundary should exhibit erosion, assuming negligible inputs to the source (STONE et al., 1992). Along eastern Dauphin Island, the drift divide is located at a site which has experienced long term erosion as documented by SMITH (1990) for the period 1917–1974, and by DOUGLASS (1994). In the former study, SMITH reports shoreline loss rates greater than 3 m/yr at the site (1917–1974). In the latter, eastern Dauphin Island shoreline monitoring over the period September 1990–September 1991, showed a maximum rate of erosion of 15 meters at the site. Long term erosion is also confirmed by the presence of tree stumps retained in the growth position on the beach and the foreshore at the site.

Updrift cell boundaries exhibit chronic erosion also. Eastern Dauphin Island is such an example where the coastal structures have been built to prevent shoreline retreat (DOUGLASS, 1994). The eastern margin of Petit Bois Island has migrated to the west at a rate of 89.9 m/yr over the period 1848–1986 (BYRNEs et al., 1991). The eastern ends of Horn and Ship Islands have experienced westward migration over the last century (39.3 m/yr for Horn Island, and 7.5 m/yr for East Ship Island [BYRNEs et al., 1991]).

Downdrift cell boundaries, located primarily along the western ends of the islands, exhibit net deposition because...
Figure 9. Net longshore transport cells delimited from the transport curve and transport vectors within cells.

Figure 10. Potential zones of erosion (E) and deposition (D) as interpreted from the net longshore transport curve.
littoral transport shows a decreasing trend. Westward migration of the western end of Dauphin Island over the period 1848–1986 has been measured by Byrnes et al. (1991) at a rate of approximately 55.3 m/yr. Over the same period the western end of Petit Bois Island and Horn Island migrated to the west at rates of 31.3 m/yr and 34.5 m/yr respectively (Byrnes et al., 1991). A sediment budget for Ship Island Pass, constructed by Knowles and Rosati (1989) quantifies historic net accretion rates at West Ship Island’s western tip. These data confirm the historical behavior of the lateral migratory trends, for certain periods of time, corroborating model output that the western island tips act as cell termini, and adjacent tidal inlets serve as sediment sinks.

WAVERNG predicted an eastward reversal of net sediment transport in Cell I along eastern Dauphin Island (Figure 10) in response to an established refraction pattern across Mobile Pass ebb shoals, prevalent during predominant southeast deep water wave approaches (see Carter et al., 1982; Stapor and May, 1985; Stone, 1984, 1991; Stone et al., 1992 for similar cases). The Mobile Pass ebb-tidal delta system includes all of the shoals around the inlet and was defined by the 10 meter isobath from Douglass (1994) (Figure 2). Pelican Island (sometimes referred to as Sand Island) is part of the ebb-tidal delta system and is presently located southeast of Dauphin Island. The influence of Pelican Island on the wave climate along the eastern 5 kilometers of Dauphin Island is significant (Douglass, 1994). The east side of the island is sheltered from the open Gulf waves, especially from southwesterly waves, even though the remaining ebb-tidal shoals absorb wave energy associated with southeasterly waves (Douglass, 1994) (Figure 2). The progressive evolution of Mobile Pass ebb-tidal shoals will probably influence wave refraction patterns inducing a migration of the drift divide or western terminus of Cell I. This response has been demonstrated at other locations (Lowry and Carter, 1982; Carter et al., 1982; Stone et al., 1992).

Comparison of Computed Net Transport Rates

Previous estimates of net longshore transport along eastern Dauphin Island (Douglass, 1994) and West Ship Island (Knowles and Rosati, 1989) show poor agreement with this study. We provide the following discussion to acknowledge previous work, but stress that the differences are primarily in magnitude of longshore sediment transport. These differences are of little significance given the objectives of the present study.

Net longshore transport rates were estimated by Douglass (1994) from visually observed breaker height and angle using an empirical relationship between the longshore component of wave energy flux (P_L) and the immersed weight transport rate (I_L) (U.S. Army Corps of Engineers, 1984). For that study visual wave observations were made using the Littoral Environmental Observation (LEO) approach (Schneider, 1981). Waves were observed every day for one year at three stations along eastern Dauphin Island, located approximately at sites 41, 44, and 45 of the present study (Figure 3). At all three sites net sand transport for the year was westward. Estimated net sand transport rates were 20,000 m³/yr at site 45 (eastern tip), 30,000 m³/yr at site 44, and 200,000 m³/yr at site 41. WAVERNG-predicted net transport rates are 4,000 m³/yr to the east at site 45, 1,500 m³/yr to the east at site 44, and 13,000 m³/yr to the west at site 41. Differences in net transport rates in the two studies are quite significant, as are the differences in the methodology used to estimate them.

At the three sites along Dauphin Island WAVERNG-predicted net longshore transport values are much lower than those estimated by Douglass (1994). However, along the northwest Florida and southeast Alabama coast Stone et al. (1992) found that net longshore transport estimates based on Littoral Environment Observations (LEO) obtained over a one-year period by Gorsline (1966) and Balsillie (1975) were higher than WAVERNG-predicted values. Along the northeast Florida coast Stapor and May (1983) found that the WAVERNG computer simulations, using both the U.S. NAVY (1963) Oceanographic Atlas and U.S. Army Waterways Experiment Station (Cobron et al., 1981) wave data predicted littoral drift volumes significantly less than estimates by previous workers (Stapor and May, 1983).

In order to project a re-alignment of the Gulfport Harbor Ship Channel, which extends from Gulfport, Mississippi, across Mississippi Sound to the Gulf of Mexico, and passes to the west of West Ship Island, Knowles and Rosati (1989) studied net longshore transport rates along East and West Ship Islands, with particular emphasis on the western end of West Ship Island. The study consisted of two methods: 1) a comparison of volumetric changes along the west end of West Ship Island through time, and 2) the use of a numerical wave refraction model. With the first method they obtained a volumetric change rate of 121,500 m³/yr. As recognized by the authors, the volume measured was the combination of both Gulf and Sound side transport (Knowles and Rosati, 1989).

The second method used to predict net longshore sediment transport along Ship Island involved the use of the Regional Coastal Processes Numerical Modeling System (RCPWAVE) (Eresole et al., 1985), which is based on linear wave theory similar to WAVERNG. Wave data used by Knowles and Rosati (1989) were the same as those used for this paper, even though the former study only used hindcast data from WIS Station 26 (see Figure 1 for location). Their study considered three different island configurations and related nearshore bathymetry: 1848, 1917, and 1968. In all three cases Ship Island remained as one unit, thus comparisons of net longshore transport determined here have taken this into account. The former study obtained average potential sediment transport rates along the entire Gulf shoreline of Ship Island of 63,500 m³/yr (1848), 74,000 m³/yr (1917), and 67,000 m³/yr (1968). Average predicted sediment transport by WAVERNG in this study is approximately 30,000 m³/yr along East and West Ship Islands. It is interesting to note that the Knowles and Rosati (1989) average estimates are higher than those found in the present study because they obtained a peak in net longshore transport rates at the center of the island, coinciding with the current location of Camille Cut. This value is missing from the present study due to the presence of Camille Cut which causes a decrease in net longshore transport (Figure 9). At the western tip of Ship Island the previous study estimated a value of 93,000 m³/yr which is higher than
the WA VENRG-predicted value of 37,000 m³/yr at site 2, approximately 1 km to the east of West Ship Island's western end. It is important to note that Ship Island's western tip has constantly moved to the west as evidenced through shoreline comparisons made between 1848 and 1986 by BYRNES et al. (1991).

**Sedimentology**

Textural analyses of sediments from Dauphin Island reveal an increase in mean grain size for step and mid-tide samples, downdrift (westward) from the nodal point (Cell II in Figure 9) to site 37, approximately 10 km to the west. An increase in mean grain size in step and mid-tide samples to the west along Dauphin Island, (sites 44 to 37), was determined while foredune sediments tended to remain fairly constant (Figure 6).

Step and mid-tide sediment samples in Cell I, where predicted net longshore transport is eastward toward Mobile Pass, are finer than in Cell II. This may be attributed to the shadowing effect of Pelican Island, which reduces wave energy on the foreshore and swash-zone, as confirmed by a decrease in WA VENRG-predicted breaker wave heights (Figure 4). Foredune sediments, are coarser in the shadow zone (Cell I), especially at site 43, approximately 4 km west of Dauphin Island's eastern tip, where the dune field is particularly well developed.

Step sediments at the western prograding tips of Dauphin Island (site 32), Petit Bois Island (site 25), and Horn Island (site 14) are coarser than along the remainder of the barriers. This may be attributed to deposition of the coarse sand fraction during westward spit accretion coinciding with longshore transport values approaching zero at the cell termini or to winnowing of the fines by tidal currents.

On Petit Bois Island step and mid-tide sediments at sites 28 and 29, along the eastern 3 to 5 km of the island, are coarser than along the remainder of the island, except for the western island tip (site 25). At site 28 WA VENRG-predicted net longshore transport goes to zero, indicating a zone of potential deposition (Field visit 9). Field visits indicated that the beach face at site 28 was much steeper than at any other sampling station along the study area, suggesting a recent onshore bar welding event. In addition, step samples at sites 28 and 29 have the highest weight percent calcium carbonate (shell) along the study area (approximately 2%), and the coarsest quartz grains, up to ~2 phi (4 mm), *i.e.* granule range. Foredune samples at sites 28 and 29 have very high concentrations of heavy minerals, up to 40%, which results in a relatively high sorting value, especially for site 28 (0.492 phi, the third highest [less sorted] value for the study area). Combined, these morphological and sedimentological characteristics indicate the possibility of a source of sediment supply on the inner shelf adjacent to this stretch of Petit Bois Island. In addition, step sediment sorting values at sites 28 and 29 are relatively high (approximately 0.6 phi, *i.e.* moderately sorted after FOLK and WARD, 1957), and indicate a possible input of poorly-sorted material from offshore.

An important criterion used to evaluate the possibility of onshore sediment transport, is the inner shelf slope, and long term shoreline evolution (STONE et al., 1992). The inner shelf slope tends to decrease to the west of the study area (Figure 2). For example, adjacent to Dauphin Island the slope approximates 1:273. At West Ship Island it approximates 1:1,212. The lower gradient shelf increases the potential for sediment transport from offshore. STONE (1991) calculated the depth at which the critical threshold for particle entrainment occurs along the northwest Florida and southeast Alabama inner shelf, in order to evaluate the inner shelf's potential as a sediment source. Critical threshold depths were calculated by STONE (1991) for 0.4 mm (1.27 phi) quartz grains (present study area inner shelf average grain size) under a variety of deep water wave approaches ranging from east southeast to west southwest (directions used for wave refraction modeling in the present study; see Table 1). A significant increase in depths at which the critical threshold occurred was found, coinciding with a decrease in inner shelf slope, inducing an increase in the inner shelf's potential as a sediment source.

Overall, there is a grain size coarsening in the downdrift direction (westward) for step and mid-tide sediments along western Dauphin Island (from the longshore transport reversal to site 37), along eastern Petit Bois Island (between the eastern end and site 28, Cell III), and along Horn Island. In all three cases the wave energy dissipation model WA VENRG predicted an increase in breaker wave height (Figure 4) and consequently an increase in net longshore transport rates (Figure 3). Figure 11 shows the relationship between breaker wave height and sampling site positions along western Dauphin Island, and indicates how wave energy increases to the west.

Few studies published in the literature have considered the nearshore wave climate (particularly breaker wave height) as a key to interpret grain size gradation alongshore (McCave, 1978; STONE, 1991; STONE et al., 1992). This is probably the reason why the prevailing thought in the literature is that grain size decreases downdrift from the primary sediment source, similar to that of a fluvial system (STONE, 1991; STONE et al., 1992).
et al., 1992). The amount of energy available for sediment entrainment along a beach is independent of the direction of regional transport (Stone et al., 1992). Grading mechanisms include: longshore variations in total wave energy, longshore wave energy flux factors, and addition to, removal from or mixing of sediment populations.

In light of the trends in breaker wave height and related net longshore transport, it is reasonable to assume that step and mid-tide sediment coarsening in the downdrift direction (westward) is probably due to a nearshore wave energy gradient, as found along the adjacent northwest Florida coast by Stone (1991). In Figure 12 a scatter plot of mean grain size and breaker wave height (Hb) is shown for values along Dauphin Island at the step position. The correlation between breaker wave height and sediment mean size is strong. Longshore grading in step and mid-tide sediments along the barriers to the west of Dauphin Island is progressively less evident, as is the relationship between breaker wave height and mean grain size. This may be due to an increase in the input of sediment from the inner shelf to the nearshore toward the west of the study area as implied by an increase in shell content along central Petit Bois Island and an increase in step sediment sorting (more poorly sorted) along the west flank of the study area (Figure 7).

An alternative explanation to grain size coarsening in the downdrift direction has been considered in the scientific literature (Carter, 1975; Stone, 1991; Stone et al., 1992) as a contribution of coarser grains from an offshore source. Several morphologic and sedimentologic criteria tend to support this hypothesis for site 28 on Petit Bois Island. In addition, step sediments become more poorly sorted in the downdrift direction (westward) along the study area. These findings are contrary to those derived from other work where sorting, among grain size parameters, is usually expected to decrease (better sorted) farther from the sediment source, assuming no external input of sediments (see McLaren, 1981).

The data presented here suggest that internal sources within cells are important in the morphological maintenance of the study site. Ultimately the source of sediment may have been the Mobile Pass ebb-shoal system or a mainland updrift source to the east along Fort Morgan Peninsula (OTVOS, 1973; DOUGLASS, 1994) over the past centuries, however, present day nearshore sediment transport modeling, and the fact that sand dredging at inlets is ongoing indicate that internal sources (nearshore-beach) within cells are more important.

**CONCLUSIONS**

Net westward longshore sediment transport occurs along the southwest Alabama and Mississippi barrier islands with the exception of a net longshore reversal along eastern Dauphin Island, due to wave refraction over the Mobile Pass ebb-tidal delta. The net longshore transport reversal predicted by Wavenryg questions the present day effectiveness of the Mobile Pass ebb-tidal delta and the beach farther east, as a source of sediment to the barriers located to the west.

Results from the net longshore sediment transport modeling indicate the existence of a cellular structure along the coast. Six littoral cells have been delineated from Dauphin Island to West Ship Island and are characterized by net westward sediment transport except for Cell I. In Cell I, located along eastern Dauphin Island, predicted longshore sediment transport is eastward, toward Mobile Pass. Contemporary drift cells appear to experience minimal net sediment exchange because of net longshore transport values approaching zero at most cell termini and ongoing maintenance sand dredging at inlets. Because of sand dredging, inlets have functioned as sediment sinks in recent years.

Results of textural and compositional analyses of step and mid-tide sediments indicate that Cell II (western Dauphin Island), Cell III (eastern Petit Bois Island), and Cell V (Horn Island) experience coarsening in the downdrift direction (westward). This textural trend, similarly noted by Stone (1991) along the adjacent northwest Florida and southeast Alabama coast, is probably due to both an increase in the energy of the transporting medium, and a coarse sediment contribution from an offshore source. To confirm the possibility of onshore sediment transport from the inner shelf there is an increase in step sediment sorting values (more poorly sorted) to the west. Alternative sources of sediment are internal to these barriers.

Granulometric trends in step and mid-tide samples support Wavenryg predictions. Longshore sediment grading (coarsening downdrift) is evident along Dauphin Island, and shows a strong relationship with predicted breaker wave height. Longshore sediment grading is less evident along the barriers to the west of Dauphin Island, likely due to the weak alongshore trend in breaker wave height and to the input of poorly sorted, coarse grained, shell and heavy mineral-rich sands from the inner shelf, and the absence of a strong trend in breaker wave height alongshore.

Onshore sediment transport may be a relevant factor in the sediment budget of this area, as initially proposed by Shepard (1960). This would support disposal of dredged material from tidal inlet throats currently along the inner shelf.
in relatively shallow water depths in order to keep the sedi-
ment into the active beach profile, or littoral system. Thus,
to increase the structural integrity of the Mississippi Sound
barrier islands it may be important to retain dredged sands
in the littoral system, versus dumping sediment in deep wa-
ter disposal sites.

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