Backbarrier Contributions to a Littoral Sand Budget, Virginia Eastern Shore, USA

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ABSTRACT


When analyzing the availability of sand for a retrograding barrier island system, both the beach sand and the backbarrier sediments should be included. The latter may be located below the barrier beach sands, exposed in the surf zone, and reworked. Subsequently, "new" sand is made available which may be added to a sand budget. As the barrier island translates landward the amount and size of the sand in backbarrier sediments may change. This causes an increase or decrease in the sand budget and subsequent respective changes in barrier island position.

ADDITIONAL INDEX WORDS: Barrier island, line sink, line source, lithosome, point sink, point source, sand budget. 

INTRODUCTION

A sand budget is based on sand removal, transportation, and the resulting excesses or deficiencies of material quantities. Generally, elements in a littoral zone sand budget include point sources (rivers, longshore transport in), point sinks (inlets, longshore transport out), line sources (dune, headland and beach erosion), and line sinks (beach storage, washover fans), among others (U.S. ARMY COASTAL ENGINEERING RESEARCH CENTER, 1977). With respect to beach erosion on coasts of relatively thin sand coverage, reference has only generally been made (BRUUN, 1983) to the material type below the sand beach that is annually removed and reworked. This material will contribute to a littoral sand budget and thus should be included.

The area of investigation is south of the Maryland-Virginia state line and is commonly referred to as Virginia's Eastern Shore (Figure 1). The Holocene geology of this region has been studied by NEWMAN and MUNSART (1968), HALSEY (1978) and FINKELSTEIN (1986). Holocene barrier islands along the Virginia Atlantic shore show evidence of retreat by the transgressive stratigraphy (FINKELSTEIN, 1986) and exposure of backbarrier sediments in the shoreface (Figure 2). This material, when reworked by waves, may contribute sand to replenish these predominantly sand starved islands and potentially reduce further island narrowing and/or landward migration. Sand budget increase or decrease and subsequent respective changes in barrier island translation is partially dependent upon the amount and size of the sand in the backbarrier sediments. As the island migrates landward, the size distribution of backbarrier sediments encountered may change. The purposes of this study are (1) to show how the percent of sand-sized material in the sediments of the shoreface is presently affecting its retreat rate, (2) to determine how changes in the sand contribution that occur as the shoreface retreats may slow or speed that retreat, and (3) to describe a methodology to quantify sand budget contributions from exposed beach and backbarrier sediments. Assawoman and Smith Islands (Figure 1) are used as examples. Mockhorn Island, a coarser grained pre-Holocene sand island, (FINKELSTEIN, 1986) located landward of Smith Island, (Figure 1) is included as it may affect the Smith Island sand budget in the future.

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Figure 1. The regional setting of the study area. Assawoman and Smith Islands, Virginia show evidence of landward retreat by their transgressive stratigraphy and exposure of backbarrier sediments in the shoreface. Thus backbarrier sediments are reworked by waves and may contribute sand to a sand budget.

**METHODS**

**Criteria**

Vibratory cores from the barrier islands and backbarrier regions were collected. Surface and subsurface core sediments were found to range in age from pre-Holocene to modern and represent the entire sequence of estuarine depositional environments. The core data established the sand content of the subsurface. The sediment consisted almost entirely of terrigenous sand, silt, and clay. Shell and shell fragments of mollusks and forams along with authigenic grains of glauconite comprised most of the non-terrigenous component of the sediment.
Figure 2. Backbarrier sediments in the lower foreshore and shoreface of Metomkin Island. Note the southern (left) portion of the island, backed by open lagoonal water, is retreating at a rate of at least twice that of its marsh backed northern half. A loss of barrier island sand to the subaqueous lagoon and no otherwise new input of sand from reworked backbarrier sediments may be responsible for this.

The descriptions of the core and the surface samples provide sufficient data for the recognition of seven Holocene lithosomes: beach, modern marsh, oyster dominated muddy tidal flat, mixed flat, sand flat, sheltered lagoon, basal Holocene, and one comprehensive pre-Holocene lithosome. The principal lithosomes are shown in Figure 3 as a schematic drawing.

Each lithosome is reworked by shore processes when exposed in the surf zone and will add sand that may be significant in slowing barrier and shoreface retreat. The information needed for quantifying annual sand replenishment of this type is (1) the grain size distribution of sand lithosomes, and the percentage and grain size of sand in subsurface sand and mud lithosomes, (2) the annual rate of shoreline retreat and sea level change, (3) the closure depth or approximate maximum water depth for sand erosion and sediment transport by an extreme wave condition of 12 hrs/yr (HALLERMEIER, 1981), and (4) the average barrier height. Each measure is described below.

Sand, silt, and clay percentages and subsequent textural analyses of the sand fraction were performed on 56 subsurface and marsh samples from the primary lithosomes of the backbarrier region. Additional grain size measurements were completed on 12 beach sand samples. Average abundance of sand/silt/clay and mean grain sizes for all primary individual lithosomes are shown in Table 1. Two examples of a profile of each of the lithosomes are shown in Figures 4A and 4B. These data provide a picture of the material type and grain size that would be found in the shoreface of the future.

Barrier island retreat on Smith Island, Virginia (Figure 1, 4B), is estimated at 8 m/yr (RICE et al., 1976). Local present day sea level rise is 0.2 to 0.36
Figure 3. A schematic drawing of a generalized core showing the primary lithosomes.

As long as the barrier island retreats in its equilibrium profile, the percentage of each lithosome reworked each year may be estimated from barrier and backbarrier core data. A barrier island retreat without sea level rise, resulting in a flat offshore profile, is sketched in Figure 5. This figure is probably representative of the annual shore retreat along the barrier islands of this study. This assumption may be proven by approximating a sea level rise of $3.0 \times 10^{-1}$ cm/yr and a shore retreat of $8.0 \times 10^2$ cm/yr which yields a near horizontal slope of $3.75 \times 10^{-4}$. However, the rise in sea level may require some material to be deposited in the nearshore zone (BRUUN, 1983).

The closure depth along a Virginia barrier island offshore profile may be estimated by approximating the break in nearshore slope from the bathymetry. The subtle break in slope along the offshore Smith Island profile is approximately 8.7 m below mean water level (EVERTS, 1978). This depth can also be determined by calculating the landward boundary of the shoal zone, which is derived from values of two Froude numbers, wave climate data, and local sand characteristics (HALLERMEIER, 1981). Using this latter method, HALLERMEIER (1981) found a closure depth of 5.4 m for nearby Assateague Island, Maryland (Figure 1). In an earlier work, HALLERMEIER (1977) estimated a short term closure depth to be twice the height of the highest breaking waves. Additionally, HALLERMEIER (1977) noted that unpublished bathymetry studies at the Coastal Engineering Research Center (CERC) summarized by DUANE (1976) show little bed change seaward of 6.1 m below mean water for the U.S. Atlantic coast. With reference to the three possible closure depths calculated, a depth of 6.5 m below mean water is used in this study.

Most of Smith Island is 1 to 2 m above mean water level. The addition of another 1.5 m of upper intertidal and subaerial barrier island sands causes sediments 8.0 m thick to be reworked during landward barrier island translation.

Assumptions

Placement of borrow material on the shore to restore or maintain the beach and subsequent sand budget calculations have been shown (U.S. ARMY COASTAL ENGINEERING RESEARCH CENTER, 1977). The establishment and periodic replenishment of such material is termed artificial beach nourishment. To determine periodic renourishment requirements,
JAMES (1975) defines a renourishment factor, $R_j$, which is the ratio of the rate at which borrow material will erode to the rate at which natural beach material will erode. This factor is dependent upon the mean and standard deviation of the natural and borrow materials. Calculations of the renourishment factor, $R_j$ and isolines, from values of phi mean difference and phi sorting ratio, are shown in Table 2D and Figure 6, respectively.

In this study the assumption is made that beach sands, comprising the beach lithosome, are composed of natural material (Table 2C). All other sand sources from other lithosomes are borrow material that could be potentially useful in accreting onto the foreshore and shoreface.

Sand budget contributions from longshore losses and gains as well as offshore and landward sediment sinks are not addressed. A maximum net southerly longshore drift of $0.5 \times 10^6$ m$^3$/yr is estimated at Cedar and Parramore Islands (Figure 1) (BYRNE et al., 1974). A net loss or gain of sand for a particular section of the beach from this mechanism was not determined. Sand from longshore drift is assumed to be in a dynamic equilibrium with the shore, i.e., equal amounts of sand were transported to and from the barrier islands studied.

**CALCULATIONS**

**Uniform Approach**

Along a nearshore profile of Smith Island (Figures 1, 4B), 64 m$^3$ of sediment are eroded per linear meter of beach per year from a scour of 8 m in depth over 8 m of landward translation. The typical resulting profile is shown in Figure 5. Of the 8 meters scoured, the approximate mean thickness and sand content of each primary lithosome are: 2 m of beach sand at 100% sand, 1 m of highly organic rich mud (marsh) at 15% sand, 2 m of muddy tidal flat at 30% sand, 2.5 m of mixed flat at 60% sand, and either 0.5 m of sand flat at 95% sand, 0.5 m of sheltered lagoon at 10% sand, or a combination of the two (Table 2A, B). The mean grain sizes for the sand fractions of the backbarrier sand and mud lithosomes are approximately 3.0 $\phi$ with a standard deviation of 0.6 $\phi$ (Table 1, 2B). Smith Island foreshore and backshore sands have a mean size of 2.4 $\phi$ with a standard deviation of 0.5 $\phi$ (Table 1, 2A). The sand portion of Mockhorn Island is also 2 m thick but contains a coarser 1.70 $\phi$ mean sand size with a standard deviation of 0.8 $\phi$ (Table 1, 2A).

The Smith Island beach sands and the reworked backbarrier sands are the natural and borrow material, respectively (Table 2C). It can be determined from $R_j$ and Figure 6A, that sand from reworked backbarrier lithosomes will erode 2.8 times faster than the Smith Island beach sands (Table 2D). Therefore, though 21.8 to 18.4 m$^3$/yr of sand per linear meter of beach is available, only 7.8 to 6.6 m$^3$/yr-m of sand is really available to the retreating barrier island (Table 2B, D, E). This sand may be added to Smith Island provided there is no loss downdrift, offshore or to backbarrier sinks. Smith Island has historically migrated landward, as have all of the Virginia barrier islands (RICE et al., 1976). This is due in part to a rise in sea level, but more importantly, due to a scarcity of available sand because more is lost downdrift than is received from updift. The quantity of this backbarrier sand

<table>
<thead>
<tr>
<th>Pure Sand Lithosomes</th>
<th>No. of Samples</th>
<th>Mean Grain Size, $\phi$</th>
<th>Standard Deviation, $\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith Island Foreshore and Backshore</td>
<td>4</td>
<td>2.40 (fine sand)</td>
<td>0.5</td>
</tr>
<tr>
<td>Mockhorn Island Foreshore</td>
<td>8</td>
<td>1.70 (medium sand)</td>
<td>0.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sand and Mud Lithosomes</th>
<th>No. of Samples</th>
<th>Average Sand/Silt/Clay Abundance</th>
<th>Mean Size Sand Fraction, $\phi$</th>
<th>Standard Deviation, $\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marsh</td>
<td>7</td>
<td>15/55/30</td>
<td>3.00 (fine sand)</td>
<td>0.70</td>
</tr>
<tr>
<td>Muddy Tidal Flat</td>
<td>11</td>
<td>30/50/20</td>
<td>3.05 (fine sand)</td>
<td>0.65</td>
</tr>
<tr>
<td>Mixed Flat</td>
<td>15</td>
<td>60/50/10</td>
<td>3.05 (fine sand)</td>
<td>0.55</td>
</tr>
<tr>
<td>Sand Flat</td>
<td>15</td>
<td>95/5/3</td>
<td>2.90 (fine sand)</td>
<td>0.55</td>
</tr>
<tr>
<td>Sheltered Lagoonal Mud</td>
<td>8</td>
<td>10/55/35</td>
<td>3.00 (fine sand)</td>
<td>0.65</td>
</tr>
</tbody>
</table>
ASSAWOMAN ISLAND TRANSECT

SMITH ISLAND TRANSECT
Figure 4. (Facing page) A profile showing the primary lithosomes along a transect from A, Assawoman Island, and B, Smith Island, to their respective mainland shores. Cores are shown as solid lines, numbered at top. The potential for a change in the type of lithosome encountered as the barrier island migrates landward can be readily seen. This may subsequently cause a change in the amount of sand available from nearshore reworking and thus a change in the rate of barrier movement.

source and subsequent accretion is not great enough to appreciably slow barrier island translation.

Mockhorn Island sands erode at a rate 1/7th (Figure 6B) that of the Smith Island sands, indicating a potential valuable sand source for barrier island stabilization (Table 2D, E). But at the average annual translation rate of 8 m/yr, it will take 750 years for Smith Island to weld onto a stationary Mockhorn Island. Thus, Mockhorn Island sand resources will not be made available to the littoral zone for a long time. Even by using the recent more rapid retreat rate of 15 m/yr that has occurred since 1955 (RICE et al., 1976) it will take 400 years for the two islands to join. An approximate sea level rise of 1.3 cm/yr over 750 year only raises the sea 2.25 m, thus, Mockhorn Island, even if inundated, should still be a viable source of sand in the future.

Calculations in Table 2 show 16 m$^3$/yr of sand per near meter of beach is derived from the pure sand lithosomes and a functional sand value of 7.8 $>$ 6.6 m$^3$/yr per linear meter of beach from backbarrier sand and mud lithosomes. These figures can be applied to the approximate 11.4 km length of Smith Island to determine a volume of sand annually removed from the beach and shoreface by erosion (Table 3). The pure sand beach volume is thus 182,400 m$^3$/yr and an additional 88,920 to 75,240 m$^3$/yr or approximately 45% from the backbarrier lithosomes are collectively available for annually renourishing the retreating island. Equally thick Mockhorn Island sands may be considered seven times less likely to erode than those on Smith Island. Thus, a functional annual contribution of 1,276,800 m$^3$ is calculated along with a similar addition from subsurface backbarrier lithosomes estimated at 88,920 to 75,240 m$^3$ (Table 3).

Specific Approach

The Smith Island example uses average grain size measurements from primary lithosomes with thicknesses averaged. Figures 4A (Assawoman Island) and 4B (Smith Island) provide actual thicknesses of the lithosomes. A retrograding island and the resulting transgressing surf zone would encounter such backbarrier lithosome thickness. For example, in Figure 4A the 8 m of presently reworked lithosomes consist of 2 m of beach sand, 1.5 m of marsh, 2 m of mud flat, 0.5 m of mixed flat, and 2 m of sheltered lagoon. Using a similar 8 m/yr landward translation, a beach length of 5,100 m for Assawoman Island, and the average grain size measurements of Table 1, 81,600 m$^3$/yr of pure beach sand and approximately 50,500 m$^3$/yr of fine sand from backbarrier sand and mud lithosomes are available. When tak-
Table 2. Potential Barrier and Backbarrier Sand Resources for Smith Island

<table>
<thead>
<tr>
<th>Lithosome</th>
<th>Mean Thickness m</th>
<th>Annual Trans. m</th>
<th>% Sand</th>
<th>An. Erosion m³/m</th>
<th>M/σφ*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith Island Foreshore and Backshore</td>
<td>2</td>
<td>8</td>
<td>100</td>
<td>16</td>
<td>2.40/0.5</td>
</tr>
<tr>
<td>Mockhorn Island Foreshore</td>
<td>2</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>1.70/0.8</td>
</tr>
<tr>
<td>Total (A)</td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lithosome</th>
<th>Mean Thickness m</th>
<th>Annual Trans. m</th>
<th>% Sand</th>
<th>An. Erosion m³/m</th>
<th>M/σφ*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marsh</td>
<td>1</td>
<td>8</td>
<td>15</td>
<td>1.2</td>
<td>3.0/0.6</td>
</tr>
<tr>
<td>Muddy Tidal Flat</td>
<td>2</td>
<td>8</td>
<td>30</td>
<td>4.8</td>
<td>1.0/0.6</td>
</tr>
<tr>
<td>Mixed Flat</td>
<td>2.5</td>
<td>8</td>
<td>60</td>
<td>12.0</td>
<td>3.0/0.6</td>
</tr>
<tr>
<td>Sand Flat</td>
<td></td>
<td></td>
<td></td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>Sheltered Lagoonal Mud</td>
<td>0.5</td>
<td>8</td>
<td>10</td>
<td>0.4</td>
<td>3.0/0.6</td>
</tr>
<tr>
<td>Total (B)</td>
<td></td>
<td></td>
<td></td>
<td>21.8 to 18.4</td>
<td></td>
</tr>
</tbody>
</table>

*Mean Grain Size (M) Standard Deviation (σ) φ.

C. Assumptions
1. Smith Island foreshore and backshore sands are natural material.
2. All other lithosomes are borrow material.
3. Use renourishment factor R, from JAMES (1975); this is the rate at which borrow material will erode to the rate at which natural material will erode. Isolines of the renourishment factor R, for values of φ mean difference and phi sorting ratio, are shown in Figure 6.
4. Standard deviation is a measure of sorting.

D. Calculations
 Sorting of natural material

\[ σφ_n = 0.5 \]

 Sorting of borrow material (Mockhorn Island)

\[ σφ_{mb} = 0.8 \]

 Sorting of borrow material (backbarrier sand and mud resources)

\[ σφ_{bsm} = 0.6 \]

 Phi mean diameter of natural material

\[ Mφ_n = 2.40 \]

 Phi mean diameter of borrow material (Mockhorn Island)

\[ Mφ_{mb} = 1.70 \]

 Phi mean diameter of borrow material (backbarrier sand and mud resources)

\[ Mφ_{bsm} = 3.00 \]

Use phi mean difference \((Mφ_{mb} - Mφ_n) / σφ_n\) and phi sorting ratio \(σφ_{mb} / σφ_n\)

1. For backbarrier mud and sand as borrow material:

\[ (Mφ_{bsm} - Mφ_n) / σφ_n = 0.60 / 0.50 = 1.2 = \text{mean difference}; \]

\[ σφ_{bsm} / σφ_n = 0.60 / 0.50 = 1.2 = \text{sorting ratio}; \text{ From Figure 6, } R_j = 2.80 \]

2. For Mockhorn Island sand as borrow material:

\[ (Mφ_{mb} - Mφ_n) / σφ_n = -0.70 / 0.50 = -1.4 = \text{mean difference}; \]

\[ σφ_{mb} / σφ_n = 0.80 / 0.50 = 1.6 = \text{sorting ratio}; \text{ From Figure 6, } R_j = 1/7 \text{ or 0.143} \]

E. Conclusions
1. Annually, 21.8 to 18.4 m³/m of sand are potentially available from backbarrier lithosomes to help renourish the foreshore and upper shoreface. But because this sand is finer, it will erode 2.8 times faster than the Smith Island sands. Therefore, a functional sand value of only 7.8 to 6.6 m³/m is really available.

2. When and if Smith Island migrates landward to the point it collides with Mockhorn Island, its location should at least temporarily stabilize. The Mockhorn Island sands will erode at a rate only 1/7th that of the Smith Island sands.
Figure 6. Isolines of the renourishment factor, $R_j$, for values of phi mean difference (horizontal axis) and phi sorting ratio (vertical axis) (from James, 1975). A: Smith Island backbarrier mud and sand as borrow material; B: Mockhorn Island sand as borrow material. See Table 2D for calculations of these values.

DISCUSSION AND CONCLUSIONS

If all of the barrier island sand is conserved and additional, reworked, backbarrier sand is introduced, shore retreat should slow down or cease. This is certainly not the case as the open bays and channels behind the islands provide a sink for a good portion of the sand by washover and/or inlet deposition; therefore, barrier island narrowing and/or retreat continues. Nevertheless, the type of sand input outlined in this study may help explain why,
for example, the southern half of Metomkin Island (Figures 1, 2) which is backed by mostly open lagoonal water, is retreating at a rate at least twice (RICE, et al., 1976) that of its marsh backed northern half. Only fringing marsh atop washer deposit's exists along the southern landward shore of Metomkin Island. A line sink for sand loss exists from Metomkin Island wind and washer events. This together with no otherwise additional sand input from reworked backbarrier sediments in the south Metomkin Island nearshore zone contribute to the lateral coastal change in the rate of retreat. The resistance of muddy lithosomes to erosion, which assists in this offset, should also be considered.

Backbarrier sediments and beach sands are reworked in the shoreface and foreshore and contribute to the littoral sand budget of a retreating barrier island coast. Calculations are based on the grain size distribution, rate of shoreline retreat, barrier height, and the closure depth. As expected, where backbarrier sediments are thick and sandy, barrier retreat may be relatively less.

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LITERATURE CITED