Source of Tidal Creek Sand on a Tide-Dominated Barrier Island, St. Catherines Island, Georgia—Fourier Shape Analysis

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ABSTRACT


Seaside Creek, as well as other tidal creeks of St. Catherines Island (a barrier island in the Georgia Embayment), is a sand bottomed channel incising fine grained marsh sediment. The coarse channel bottom sediment can be derived from either or both of two sources. Headwardly, the creeks erode into the Pleistocene core of the island. At the inlets, sand is being contributed by littoral drift. Fourier analysis of the shape of quartz fine sand (180-250 microns) shows that the major source of sand in Seaside Creek (and, presumably, other creeks on St. Catherines Island) is the island core with contributions of littoral drift sediment only at the tidal inlet throat.

ADDITIONAL INDEX WORDS: Ebb-dominated, sink, sediment transport

INTRODUCTION

Although tidal marshes are dominantly composed of silt and clay, sand may be common in the channels draining the marshes. When this is the case, the marsh is a sink for sand and this should be considered in the complete analysis of sediment budgets of barrier islands. For example, FINKELSTEIN (1986) demonstrated that backbarrier deposits can be an important source of sediment for the littoral sand budget during shoreline retreat.

Two major sources of sand in tidal creeks are: (1) sand contributed to the tidal inlet by littoral processes and (2) sand contributed by erosion of landward areas. This sediment is transported by tidal creek currents in the flood direction in the former case, and in the ebb direction in the latter. Although measurement of current duration and velocity, coupled with observation of sedimentary structures, provide insight into the transport direction and sediment transport volume it is often difficult to quantify the amount of sediment supplied by various sources. This is especially true if there are only minor differences in the sediment composition of the sources.

A preliminary study of the sand in Seaside Creek on St. Catherines Island, Georgia, was undertaken to determine the usefulness of grain shape analysis for sediment source differentiation in situations of negligible compositional variation. The first step of this study is to determine if there is a difference in shape of the beach sand near the inlet throat and the sand of the island core. If so, the second step is to determine the shape characteristics of the tidal creek sand to determine its source. Of ancillary interest is the origin of the differences in shape of the sand. Although this is discussed briefly, not enough samples have been analyzed to answer this latter question.

GEOLOGIC SETTING

The Georgia Embayment of the southeastern U.S. extends from Cape Hatteras, North Carolina, to Cape Canaveral, Florida. The central portion of this area (Figure 1), corresponding approximately to the Georgia coast portion of the state of Georgia,
is considered to be tide dominated (Hubbard, 1977). The coast consists of numerous short (10-30 km) barrier islands separated by relatively stable sounds. Most of these islands are Pleistocene barriers with Holocene beaches and beach ridges (Howard and Frey, 1980).

St. Catherines Island consists of both fine-grained and coarse-grained environments (Figure 2). Fine-grained sediments (silt and clay) accumulate in the tidal marshes and coarse-grained sediments (sand) are found in the island's core, beaches, dunes, washover fans and tidal creek channels.

Seaside Creek, in the northern portion of the island (Figure 3), is the focus of this study. Some sediment in Seaside Creek is clearly derived from the island's Pleistocene core where tributaries have cut banks up to 4 meters high (Figure 4). Sediment is also brought to the tidal inlet throat by means of littoral processes along North and Middle Beaches.

METHODS

Sample Collection

Sample locations are shown in Figure 3. Samples 11 and 12 of the island core were gathered by taking
a small amount of sediment at intervals along the entire height of cut banks (Figure 4). The beach samples (B1 and B2) were collected on a short traverse along North and Middle Beaches, perpendicular to shore at low tide. The two island core samples were then combined as were the two beach samples. The remaining samples (C1, C2, C3, and C4) were bottom grab samples collected from the deeper portions of the Seaside Creek channel.

Sample Preparation

Because shape is to some degree a function of mineralogy and particle size, care was taken to eliminate those variables. The samples were air dried and microsplit to a small volume. To ensure that only quartz sand was studied, steps were taken to “purify” the samples. Hydrogen peroxide was added to dissolve organic material and dilute hydrochloric acid was added to remove any carbonate material present. Binocular microscope inspection indicated that the processed samples were almost pure quartz. The cleaned, dried splits were then sieved into half phi intervals using vibration for fifteen minutes. In this study only the 180 micron to 250 micron size fraction was analyzed. The sample was cone-and-quartered and a small subsample was dispersed uniformly on a microscope slide.

Data Acquisition

The system used for data acquisition is explained in detail in FICO (1980) and KENNEDY (1985) and is summarized below. A TV image of the quartz particles is digitized using an IBM PC/XT based image analysis system. The image is scanned in an edge finding subroutine and the coordinates of grain maximum projection periphery points are saved for further analysis. The slide is systematically scanned to obtain a representative sample. In this study, a sample consists of scans of two slides totaling approximately 600 grains.

Data Analysis

The shapes of the grains in each sample were analyzed using Fourier grain shape analysis in closed form (EHRlich and WEINBERG, 1970). In the Fourier series, the shape of each grain is reconstructed by adding to a circle of average radius a series of 24 harmonics each consisting of a harmonic amplitude and a phase angle, and is defined by the equation:

$$R\theta = R_0 + \sum_{n=1}^{24} R_n \cos (n\theta - \phi_n)$$

where $R_0$ represents the average radius of a particle and is the foundation from which the overall shape is constructed. To the circle of average radius, a series of cosine curves (the harmonics) of various amplitudes ($R_n$) and phase angle values ($\phi$) are added. Each of the harmonics represents a specific aspect of the grain’s shape. For example, the second harmonic represents elongation, the third harmonic represents triangularity, and the nth harmonic represents a figure with n “bumps” along its edge. For harmonics 2 through 24 (the first harmonic is an error term and is not analyzed), the am-

Figure 2. Map of St. Catherines Island showing muddy and sandy environments of deposition. The muddy areas are marsh deposits while the sandy areas are Pleistocene core, beach, dune and washover fans. In addition, the tidal creeks have sandy bottoms.
plitude of that harmonic represents the overall contribution of that harmonic to the grain's shape. The greater the amplitude of the harmonic, the greater its contribution to the particle's overall shape.

Because each sample consists of the amplitudes of about 600 grains for each of the 23 harmonics, the amount of data is quite large. To reduce the amount of data and to make the data easier to work with, they are simplified. For each harmonic, a frequency distribution of the harmonic amplitudes can be constructed. There are, however, a number of ways to do this. We chose the concept of maximum entropy to construct amplitude frequency distributions (FuLi et al., 1984).

In this method, the amplitudes of one harmonic for all the grains in 6 samples are considered the grand sample. If the grand sample consists of NG grains and the frequency distribution is to have intervals, the interval widths are adjusted so that each interval will have NG/I grains. The grand sample would be represented as a flat topped frequency distribution, all intervals containing the same number of grains. Then, each sample can be cast as an amplitude frequency distribution using the interval widths defined above, and as such convey the most information.

The procedure is repeated for each harmonic and the entropy for each distribution is calculated. If all samples within a grand sample are identical each sample will be portrayed as a flat topped frequency distribution and will have the maximum possible value when the entropy for all samples are summed. The more the spectra deviate from the flat topped distributions the lower the calculated entropy.

Finally, the calculated entropy is normalized by dividing it by the maximum possible entropy to obtain a value called the relative entropy. If contrast among samples is slight, the relative entropy is high
Figure 4  Photograph of tidal creek bank showing a series of subsamples. Scale is 15 cm.
Because there are only subtle shape differences, the harmonics which are related to finer aspects of grain shape (15 to 24) were studied more closely.

**Shape**

The data for the amplitudes of harmonics 15 to 24 for each sample are shown in Figure 6. In order to conveniently show all data on a single figure, the percent deviation of each individual sample mean from the combined six sample mean is plotted for each harmonic. The greater the positive deviation, the more angular the grains; the greater the negative deviation the smoother the grains.

The two potential sediment sources are shown as solid symbols joined by heavy solid lines. The beach sediment (closed circles) is consistently smoother than the island core sediment (closed squares). The four tidal creek sediment samples, shown as open symbols joined by fine lines, form two groups; one about the island core sample and the other about the beach sample (Figure 6). Creek samples C1 and C2 are in the same group as the island core. This is not surprising as these sample locations are very close to the island core (Figure 2). Sample C4, located in the tidal inlet throat, falls into the same group as the beach sample. Again, this is not surprising due to the proximity of locality C4 to the beach. Although sample C3 is located closer to the beach (about .4 km) than to the island core (about 1 km to its nearest point) it also falls into the island core group.

### RESULTS

**Entropy**

A plot of the relative grand entropy squared versus harmonic number is shown in Figure 5A. There is little variability in the entropy of different harmonics, and these values are considerably higher than those of other studies (Figure 5B from MAZZullo et al., 1984; Figure 5C from KENNEDY and EHRlich, 1985). This consistently high entropy suggests that there is not a great deal of variability among the samples and that all harmonics carry about the same amount of information, and there is no compelling reason to choose one particular harmonic.

The lower harmonics deal with the grosser aspects of grain shape, while the higher harmonics represent small scale perturbations of grain shape.
The data analysis of Fourier shape data shows that the two potential sources of Seaside Creek fine sand (island core and beach) are clearly differentiable. Because the shape of fine sand in Seaside Creek reflects these two sources this parameter can be used to monitor the contribution of these sources to the creek sediment. Three samples of creek sand group with the Pleistocene core and one with the beach sediment. The only sample reflecting the beach source is that sample within the throat of the tidal inlet itself. Even though sample C3 is located closer to the beach than to the Pleistocene Island core, its sediment is clearly derived from the core. Thus, the dominant sand transport direction in this small tidal creek is seaward.

### ORIGIN OF SHAPE DIFFERENCES

If one wants to speculate further, the question may be asked: Why is the beach sand smoother than the island core sand? Presently there are not enough data to answer the question, but enough to allow conjecture. The presence of a 7 meter wave cut cliff on the northern 2 km of North Beach (Figure 2, see also Figure 8) suggests that much of the beach sediment is derived from erosion of the island core. There is the possibility that some sediment derived from the ebb dominated St. Catherines Sound may be contributed to North Beach resulting in a change in shape characteristics of the beach sediment. However, the sound sediment is presumably derived, in part at least, from coastal plain sources which are, again presumably, more angular in shape than the beach sand (BROWN et al., 1980). If contamination from this source is pervasive, beach sediment would become more angular rather than less angular.

If the sediment of North Beach is derived from the island core, and if the island core sediment behind North Beach is similar in shape to that behind Seaside Creek, then some process associated with the two to three km transport results in the sediment becoming less angular with transport distance. Selective transport could modify the shape composition of the sample. However, KENNEDY and FERM (1983) showed that sediment transported by lake littoral processes becomes more angular with transport distance.

Finally, the shape changes could be brought about by abrasion, either subaerial or subaqueous. Transport of quartz sand by waves is not likely to

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**Table 1** Chi-squared results of 2-sample by 10-cell comparisons. Degrees of freedom = 9. Critical value at 95% probability level = 16.92.

<table>
<thead>
<tr>
<th>Samples Compared</th>
<th>Chi-Square Value</th>
<th>Null Hypothesis</th>
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<tr>
<td>CORE-BEACH</td>
<td>32.84</td>
<td>REJECT</td>
</tr>
<tr>
<td>CORE-C1</td>
<td>8.97</td>
<td>ACCEPT</td>
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<td>CORE-C2</td>
<td>6.50</td>
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<td>CORE-C4</td>
<td>54.35</td>
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<td>38.96</td>
<td>REJECT</td>
</tr>
<tr>
<td>BEACH-C3</td>
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<td>REJECT</td>
</tr>
<tr>
<td>BEACH-C4</td>
<td>12.01</td>
<td>ACCEPT</td>
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</tbody>
</table>

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**Figure 7** Average deviation of harmonics 15 to 24 from the mean vs. seaward distance from the creek head.
result in abrasion due to the cushioning effect of the water. However, MAZZULLO et al. (1986) show that subaerial abrasion occurs within a short distance of transport and this may be the reason for the differences in shape of beach and island core sand found on St. Catherines Island.

At present we can only speculate on the origin of the shape differences of island core and beach sediment. An additional suite of samples, including St. Catherines ebb tidal delta, the wave cut cliff and North Beach have been collected for analysis.

CONCLUSIONS

The shape of samples of two potential source materials, Pleistocene island core sand and beach sand, and four tidal creek sand samples were analyzed via Fourier techniques. Results indicate that these two sources (beach and island core) could be distinguished; the beach fine sand is more rounded than the island core fine sand. The tidal creek sediment is derived directly from the island core and transported seaward, rather than derived from the beach and transported landward. Although these conclusions are based upon only 6 samples, it is suggested that in small tidal creeks of mesotidal marshes sediment transport is predominantly seaward. Thus, fine-grained tidal marshes may be sinks for land derived sand deposited as channel lag and point bar sediment.

ACKNOWLEDGEMENTS

We would like to thank Dr. Rollins and Dr. G. Ashley for critically reviewing earlier drafts of this manuscript. The image analysis was performed using the ARTI system designed by Symbiotic Concepts, Inc., West Columbia, South Carolina.

LITERATURE CITED


**RESUMEN**

Los cayos del lado del mar, al igual que otros cayos marailes de St. Catherines Island, son canales con fondo arenoso de grano fino procedente del sedimento marisnal. El sedimento grueso puede derivarse de una o dos fuentes. Primariamente, los cayos erosionaron el núcleo pleistoceno de la isla. En las desembocaduras o gargantas, se suministra la arena al transporte litoral longitudinal. El análisis de Fourier de la forma de los granos de arena fina de cuarzo (180-250 micrones) muestra que la principal fuente de arena del exterior del Cayo (y presumiblemente de otros cayos de St. Catherines Island) es el núcleo de la isla, contribuyendo al transporte litoral únicamente en el final del canal marisnal. —Miguel A. Losada, Universidad de Cantabria, Santander, Spain

**ZUSAMMENFASSUNG**

Seaside Creek, wie andere Gezeitenbuchen des St. Catherines Insel (ein Barrierinsel der Georgia Embayment), ist einer Kanal mit einem Sandboden, und er ritzt feine Sumpfsedimente ein. Die grobe Bodensedimente stammen aus einer oder aller beider zwei Quelle. Im Gebiet der Buchtenwaschen die Buchten das pleistozäne Herz des Inseln aus; in Gebiet der Buchtentreibenden gibt das Küstentreiben das Sand. Fourier Analyse der Form des feine Quarzsands (180-250 Mikron) zeigt, dass der Hauptquell Sands im Seaside Creek (und vermutlich die andere Buchten St. Catherines Insels) das Inseln Herz ist; Sedimente vom Küstentreiben sind nur bei der Buchtkehle wichtig. —Stephen A. Murdock, CERF, Charlottesville, Virginia, USA

**RÉSUMÉ**

Comme d'autres anses à marée, St. Catherine Island (le barrière de la baie de Géorgie, Seaside Creek) présente un chenal à fond sableux incisant les sédiments fins du marais. Les dépôts grossiers de chenal peuvent provenir de deux sources; en amont, les anses creusent le noyau pléistocène de l'île; dans les goulets, le sable contribue à la dérive littorale. Des analyses de Fourier sur la forme des grains fins de quartz (180-250 microns) montrent que le principale source de sable de Seaside Creek (ainsi, probablement que celle d'autres anses de St. Catherine Island) est le "noyau" de l'île. Seules les embouchures des goulets de marée contribuent à la dérive littorale. —Catherine Bressolier, EPHE, Montrouge, France