Numerical simulation of net longshore sediment transport and granulometry of surficial sediments along Chandeleur Island, Louisiana, USA

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Abstract

The formation and spatial evolution of Chandeleur Island, Louisiana, has been investigated extensively during the past several decades. No significant evaluation of the longshore sediment system, which is instrumental in the island’s evolution and morphodynamic maintenance, has been completed. This paper provides the first quantitative description of the longshore transport system that operates along this transgressive, overwash-dominated barrier island system.

The net longshore sediment transport system was investigated via the wave refraction model, WAVENRG, which provided estimates of the transport volumes and drift directions alongshore. Surficial samples were collected from the foredune, midtidal and step environments in an effort to characterize the sediments along the island and determine if textural or compositional trends have developed in response to a predicted longshore sediment transport system.

Data obtained during this research indicate that the longshore transport system along Chandeleur Island is characterized by a bi-directional drift system, with drift directed both north and south from a nodal point located in the south-central portion of the barrier island. Analysis of the predicted transport volumes indicates that the degree of wave refraction, and therefore the breaker angle, is more instrumental in controlling the alongshore volume rate of sediment transport than the breaker wave heights. Additionally, a larger magnitude of sediment transport is predicted in the southern portion of the barrier, which is in a greater state of deterioration than the north and central portion of the island. This apparent contradiction indicates that factors such as a variable subsidence rate along the island are contributing to the alongshore geomorphology. No significant textural or compositional trends were identified alongshore. This absence of granulometric trends is attributed to the lack of variability of the sediments that comprise the barrier and the frequency of overwash events which occur on this low-profile island.

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1. Introduction

The Chandeleur Island arc, with a length of 72 km, is the largest barrier island system in Louisiana (Fig. 1). This island arc formed from the abandonment of the Mississippi River St. Bernard Delta complex approximately...
2000 yr BP (Frazier, 1967; Boyd and Penland, 1988; Penland et al., 1988; Suter et al., 1988). A significant amount of research has been conducted on this barrier island system as well as the other barriers in Louisiana. The majority of this research has focused on the formation and spatial evolution of the islands. Very limited work has been conducted on quantifying longshore transport along these islands and none along the Chandeleur arc. This lack of knowledge perpetuates a poor understanding of the morphosedimentary maintenance of some of the nation’s fastest eroding barriers.

In this paper, we present the first quantitative description of the longshore transport system along Chandeleur Island. The importance of longshore transport systems in the evolution and maintenance of barrier islands is well established (Bodge, 1989; Williams et al., 1991; Wang et al., 1998). Several researchers (Kahn, 1980; Otvos, 1985; Boyd and Penland, 1988; Ritchie et al., 1992) have provided limited qualitative information of the longshore transport system along Chandeleur Island. Their descriptions are based largely on various geomorphic indicators (i.e., the arcuate shape of the island, orientation of the island to the dominant wave climate, and the occasional spit accretion at the island’s north and south termini). This paper provides a better understanding of the relationship between nearshore wave energy gradients and textural variability. Together, these data provide an understanding of sediment dynamics in the coastal environment of this area.

1.1. Objectives

The three primary research objectives of this study are: (1) to identify and quantify the longshore transport system
of Chandeleur Island; (2) to provide a comprehensive study of the surficial sediments which characterize the foredune, midtide and step environments alongshore; and (3) to determine if textural or compositional trends have developed in response to the alongshore wave energy distribution or the longshore transport system.

In addition to the primary objectives of the study, the potential for seasonal differences in the surficial sediments, due to variations in the wave climate, will be examined. The sediment-sampling scheme will also allow the traditional textural distinction between the three foreshore environments to be investigated. A cursory comparison of the shoreline change information and the computer predicted longshore transport system will also be made.

2. Study area

Chandeleur Island is part of a chain of narrow barrier islands composed of reworked sands from the Mississippi River’s abandoned St. Bernard Delta complex. It is a transgressive, low-profile, overwash-dominated barrier. The 300 km wide deltaic plain of Louisiana is the product of continuous accumulation of sediment deposited by the Mississippi River and its distributaries over the past 7000 to 8000 yr (Williams et al., 1991; Roberts, 1997; Coleman et al., 1998). Coastal Louisiana is experiencing one of the highest wetland loss and barrier island erosion rates in the country in part due to a rapid relative sea level (RSL) rise (Penland and Ramsey, 1990). Relative sea level rise is an integral part of the evolution of Chandeleur Island (Kahn, 1980; Penland et al., 1991). Two distinct averages of RSL or subsidence rates have been calculated for Chandeleur Island and a third RSL rise rate has been calculated for the Mississippi River delta plain. Russell (1936) calculated a rise in RSL of 0.24 cm/yr for the last 2000 yr based on borings in the southern portion of the Chandeleur Island arc. Analysis of two tide gauge records in the St. Bernard delta plain by Penland and Ramsey (1990) indicates a rise in RSL of 1.05 cm/yr since 1931. Radiocarbon dating of situ peat horizons has yielded RSL rise rates of 0.85 cm/yr for the entire Mississippi River delta plain during the past 6000 yr (Penland et al., 1987).

Tides along Chandeleur Island are mixed, predominately diurnal with a mean range of 0.35 m (U.S. Department Of Commerce, 1988). Boyd and Penland (1981) indicate that meteorological tides of up to 1.2 m frequently account for 50% or more of the daily water level fluctuations.

Winds are predominately from the southeast from March through August, becoming more southerly during mid-summer. An easterly direction of wind approach prevails during September. The fall and winter months are dominated by northwest winds. Mean wind speeds for all months range from 11 to 15 km/h, with winter winds being slightly stronger than during summer (Kahn, 1980).

Hindcast deep-water wave data (Hubertz et al., 1989) indicate that the dominant direction of wave approach along Chandeleur Island is from the southeast (112° to 135°), with a significant wave height of 1.1 m and a mean wave period of 5.4 s. Wave heights during the winter months average 1.3 m and decrease during the summer months to an average 0.75 m.

Numerous investigations into the rate of shoreline change along the Louisiana coast, and in particular Chandeleur Island, have been made (Morgan and Larimore, 1957; Penland and Boyd, 1981; Morgan and Morgan, 1983; Shabica et al., 1984). The most comprehensive analysis of gulf and bayside shoreline change (1853 to 1989) is provided in Williams et al. (1992). The rate of gulf shoreline change varies greatly from north to the south of Chandeleur Island. The average rate of gulf shoreline change for the entire island for the 134-yr record is −6.5 m/yr, while the bayside change rate for the same period is 2.9 m/yr (McBride et al., 1993).

3. Methodology

3.1. Numerically derived net longshore sediment transport

A wave refraction model (WAVENRG) developed by May (1974) and further modified by Stone (1991) was used to simulate the predicted volume and direction of net longshore sediment transport along Chandeleur Island. The model has been used extensively along other parts of the Gulf of Mexico (Stone, 1991; Stone et al., 1992; Stone and Stapor, 1996; Cipriani and Stone, 2001; Stone and Zhang, in press). The model simulates refraction, shoaling and energy dissipation of monochromatic waves as they propagate from deep water to the breaker point.

Transport rates are based on the wave energy flux method (Komar, 1998). The model derives the longshore component of wave power \( P_L \) as

\[
P_L = 0.5EC\sin2\beta
\]

(1)

where \( C_n \) is the group velocity, \( \beta \) the wave angle and \( E \) is the wave energy density and is given by

\[
E = 0.125\rho gH_s^2
\]

(2)

where \( \rho \) is the mass density of water (1000 kg/m³) and \( g \) is the acceleration due to gravity. The net longshore
transport volume \( (Q_L) \), given in cubic meters per year (m\(^3\)/yr), is given by

\[
Q_L = 1000P_L
\]  \( (3) \)

Eq. (3) was derived from the relation equating the longshore component of wave power \( (P_L) \) to the immersed weight transport rate \( (I_L) \)

\[
I_L = kP_L
\]  \( (4) \)

where \( k \) is a dimensionless coefficient and is assigned the value of 0.31 (Stapor and May, 1983; Stone, 1991; Cipriani, 1998). The immersed weight transport rate \( (I_L) \) is converted to the volume transport rate \( (Q_L) \) by

\[
I_L = Q_L(\rho_s - \rho)ag
\]  \( (5) \)

where \( \rho_s \) is the density of quartz sand (2650 kg/m\(^3\)) and \( a \) is a packing coefficient with a value of 0.6.

3.2. Boundary conditions

The model requires input of a detailed bathymetric matrix to formulate the computational grid and a deep-water wave climate.

3.2.1. Bathymetry

The dimensions of the bathymetric matrix were determined by the length of the shoreline being investigated, the depth at which a wave is considered to be in deep water and the slope of the subaqueous profile. Given the arcuate nature of Chandeleur Island, a line measuring 42 km bisecting the north and south tips of the island was projected to determine the \( X \)-axis of the matrix. An additional 68 km, 28 km north and 40 km south, were added to this line to account for refraction of waves from various angles of approach. The total length of this line was calculated to be 110 km. Assuming refraction is negligible at depths greater than 0.5L, where \( L \) is wavelength, the relationship between wavelength and wave period in deep water can be used to determine the water depth at which wave propagation begins, i.e., \( 0.78(T)^2 = d \) where \( T \) is the wave period, 0.78 is a constant derived from the wave period/wavelength relationship and \( d \) is the propagation depth. A mean peak wave period of 5.7 s was used for this area based on the WIS data (Hubertz et al., 1989). Thus, wave propagation began at the 25.3 m isobath. A distance of 39 km was measured from the north/south bisecting line to the calculated deep-water depth. The overall dimensions of the bathymetric matrix were 110 km by 39 km providing a coverage area of 4290 km\(^2\) (Fig. 1).

Bathymetric data for the area surrounding Chandeleur Island are extremely limited. Only two hydrographic surveys have been completed in the area to date. The first survey was completed in 1886 and the second in 1922. A complete set of the 1920–1922 U.S. Coast and Geodetic Survey (USCGS) smooth sheets were obtained from the National Oceanic and Atmospheric Administration (NOAA) for the area. The sheet numbers and dates of the surveys are as follows: H-4171 (1920), H-4212 (1921-1922) and H-4223 (1922). Approximately 3500 depth values were digitized utilizing MicroStation® software. The smooth sheets provided bathymetric data to approximately –3 m mean sea level (MSL). Additional bathymetric data were required for the computational grid for wave breaking.

In order to obtain an estimate of the bathymetry from –3 m MSL to 0 m MSL (the shoreline) an accurate shoreline position was required. The shoreline data from the 1920 topographic survey were utilized. These data were acquired from the Louisiana Geologic Survey (LGS) and are described in detail in McBride et al. (1991) and McBride et al. (1993). The Modular GIS Environment (MGE®) software package and the MicroStation® software package were utilized to combine the topographic and hydrographic data sets. The horizontal distance of the bathymetric data gap was calculated to be approximately 500 m, which accounts for less than 0.5% of the total offshore (\( Y \)-axis) distance of the bathymetric matrix.

Once the topographic and bathymetric data were combined, an estimate of the depth values from –3 m MSL was calculated by assuming a near linear profile. A high degree of accuracy was not required in this area of the subaqueous profile because it was represented by a limited number of grid cells. A surface elevation model was then constructed from the bathymetry using the Terrain Analyst module of MGE®. The bathymetric matrix, which comprised 195 columns and 550 rows, providing a grid cell dimension of 200 m by 200 m, was then implemented into the model.

3.2.2. Deep-water wave parameters

The mean significant wave height of 1.1 m was calculated to be in deep water off Chandeleur Island at water depths greater than 25.3 m. The Wave Information Study (WIS) data were used to obtain the deep-water wave characteristics for this study. These data allowed the wave height, period, direction of approach and frequency of occurrence to be input into the program. The WIS data were selected because of their duration of record and apparent accuracy. Comparisons of WIS data to in situ observations have indicated a good correlation (Hubertz et al., 1989; Stone, 1991; Hubertz et al., 1994; Tillotson and Komar, 1997). These hindcast data represent fair weather wave conditions along the study site from the period 1956–1975.
computed at 3-h intervals. A more comprehensive discussion of the techniques used to generate WIS data can be found in Corson et al. (1980) and Resio et al. (1982). Three stations, Gulf WIS 24 to Gulf WIS 26, are located along the study area in water depths ranging from 622 m to 26 m. The locations of the WIS stations are shown in Fig. 1. Station 25 was selected to represent the wave climate along the study area. Only those waves from Station 25 that have the potential to generate longshore transport along the Gulf side of the island were selected as inputs to the model. Table 1 is a summary of the wave parameters from WIS Station 25 and several initial boundary conditions used as inputs to the model.

3.3. Textural and compositional analysis of surficial sediments

Four excursions were made to Chandeleur Island for collection of surficial sediment samples. Two trips, representing summer conditions, were made in late June and in August. Winter conditions were investigated with the two trips made in February and March. Sampling stations were established at approximately 1 km intervals along the beach with the aid of a Trimble Navigation™ Global Positioning System (GPS). Using the GPS system facilitated the reoccupation of the same sampling locations during the winter trips. A total of 49 sampling stations were established on the island. The locations of the sampling stations are provided in Fig. 2.

Surficial sediment samples were collected from the foredune, midtide and step environments at each sampling station using a hand trowel. Similar environments were sampled by Stapor and May (1983), Stone (1991), Stone et al. (1992) and Cipriani (1998) to characterize the surficial sediments along the barrier coasts of Mississippi, Alabama and Florida. Larson et al. (1997) recommended a similar cross-shore sampling strategy. Four independent samples were obtained from each environment by collecting only the upper 2 cm of sediment. A total of 1176 samples were collected.

All textural and compositional analyses were performed in the Coastal Morphodynamics Lab (CML) at Louisiana State University. The procedures used are based on the dry sieving techniques outlined by Folk (1980) and discussed in Larson et al. (1997). Textural analysis was completed with a Gilson™ Ultrasonic AutoSiever® (Model GA-1). The calcium carbonate composition of the surficial sediments was determined by a modified method of digestion.

3.3.1. Textural analysis

The textural analysis of the surficial sediments used a dry sieving technique (Folk, 1980; CERC, 1988; Gilson,
1992; Larson et al., 1997). This technique was chosen because samples were largely free of clay and silt and the sieving method can provide accurate results for these sediments. Calculations of the grain size statistics used the graphic method as defined by Folk and Ward (1957).

The original surficial sediment samples were sub-sampled (or split) to provide the sample volume required for the sieving technique. Approximately 20 g of sediment were used to perform the test (Gilson, 1992). Samples were then triple-washed with water to remove any salts and to disaggregate any conglomerated grains. The water was carefully decanted between washes so that no sediment was lost from the sample. Once washed, the samples were placed in a low temperature oven (35 °C to 40 °C) to dry.

The Gilson™ ultrasonic siever combines three different motions that provide rapid and accurate grain size results. A vertical column of air created by a low frequency pulse suspends the sediment, a repetitive mechanical pulse provides additional vertical movement, and a mechanical horizontal pulse helps eliminate sediment agglomeration (CERC, 1988; Gilson, 1992). Three-inch diameter acrylic sieves in 1/4 phi (φ) intervals were used. The set of sieves used ranged from 1.0φ to 3.75φ, with the fines collector representing sediment ≤ 4.0φ. All samples were run for 2.5 min. The sieves were cleaned daily to prevent an accumulation of lodged grains in the mesh.

An integrated system was developed in the MicroCal™ Origin software package that allowed the weights by sieve to be directly imported into a spreadsheet. Once in the spreadsheet, grain size statistics were calculated using the graphic methods of Folk and Ward (1957). The graphic methods of Folk and Ward (1957) were selected over the method of moments (Friedman, 1962; Friedman and Sanders, 1978) to allow comparisons of results with those of previous studies in the northern Gulf of Mexico. Additionally, if small errors associated with the sieves were present, the resulting statistical output would still be valid if the graphic methods were used (Folk, 1964; Larson et al., 1997). Comparisons of the two methods can be found in Folk (1964), Swan et al. (1978), Swan et al. (1979), Folk (1980) and Larson et al. (1997). All grain size statistics were calculated in φ and were converted to millimeters (mm) where appropriate.

### 3.3.2. Textural analysis

Samples from all three environments had the potential to contain calcium carbonate; therefore, the traditional method of hydrochloric (HCl) acid digestion was not used on all samples. A method termed “numeric” digestion was employed, which allowed the calcium carbonate percent by weight to be removed after the samples were texturally analyzed.

It was determined that the 1.0φ, 1.25φ and 1.5φ sieves contained calcium carbonate with no sand grains (see Table 2). The 1.75φ sieve contained approximately 50% calcium carbonate. A procedure was developed that allowed sieve weights for the 1.0φ, 1.25φ and 1.5φ sieves to be removed from the total sample weight after the grain size statistics were calculated. If the cumulative weight of the 1.0φ, 1.25φ and 1.5φ sieves was ≤ 0.5%, the “numeric” digestion was not performed. Sieve weights for the 1.75φ sieve were not removed from the total sample weight because the cumulative weight for this sieve was never greater than 0.75%.

### 4. Results

#### 4.1. Predicted net longshore sediment transport

Five angles of deep-water wave approach were used in the boundary conditions because they had the greatest potential to generate longshore sediment transport along

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<th>Sieve size (phi)</th>
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the Gulf side of Chandeleur Island. The net transport volumes are weighted according to the frequency of occurrence of the five directions of wave approach. As noted in Fig. 3, the maximum southerly transport is 86,650 m$^3$/yr and the maximum northerly transport is 62,883 m$^3$/yr. Negative transport volumes indicate southerly transport while positive transport volumes indicate northerly transport. Northerly transport dominates the system accounting for approximately 62% of the predicted net transport. Variations in wave energy along the coast can be inferred from the breaker wave heights ($H_b$) (Eq. (2)). The distribution of breaker wave heights alongshore is provided in Fig. 4. The maximum breaker wave height is 0.70 m, which occurs at a net longshore transport reversal. Also evident from Fig. 4 is the decrease in breaker wave heights toward the distal ends of the barrier. The minimum breaker wave height of 0.32 m occurs approximately 7 km south of the northern tip of the island.

Analysis of the predicted net transport volume and breaker wave height for each angle of approach provides additional insight into the dynamics of the longshore transport system of Chandeleur Island. As noted in Fig. 5, waves propagating from an initial azimuth of 45° (northeast) generate a southerly dominated transport direction. This wave approach accounts for 10.40% of the wave climate simulated by the model. As the direction of propagation becomes more from the east (azimuth of 68°), northerly transport begins to occur due to refraction (approximately 27%). Waves from this direction of approach account for 13.90% of the modeled wave climate. A true east angle of approach (azimuth of 90°), which accounts for 18.69% of the wave climate, generates a very low volume of southerly dominated transport (approximately 60%). Both an east–southeast (azimuth of 113°) and southeast (azimuth of 135°) angle of approach generate considerably larger volume transport directed predominantly to the north. Waves

![Fig. 3. Raw directional net longshore transport volumes in cubic meters per year (A) and smoothed net transport curves (B) showing cell delineation and areas of potential erosion and deposition.](image)

![Fig. 4. Distribution of the mean breaker significant wave height (m) along Chandeleur Island.](image)

![Fig. 5. Net longshore transport values (m$^3$/year) for various deep water wave approach angles and corresponding breaker wave heights along Chandeleur Island.](image)
with these approach angles dominate the wave climate, with frequencies of occurrence of 27.38% and 29.63%, respectively, totaling 57.01% for the record used.

4.2. Texture and composition of surficial sediments

The mean grain size for all summer samples ranges from 0.12 mm (3.02φ) to 0.23 mm (2.125φ), which is classified as fine sand. Sediment sorting ranges from 0.228φ to 0.403φ, which is classified as well sorted to very well sorted. Skewness values range from −0.234 to 0.204, which are classified as fine-skewed to coarse-skewed. The minimum and maximum kurtosis values for all summer samples are 0.757 and 1.273, respectively. This range of kurtosis values classifies the samples as leptokurtic to platykurtic. When viewed collectively, the summer samples for all three environments have an average mean grain size of 0.150 mm (2.754φ), an average sorting of 0.297φ, an average skewness of −0.066 and an average kurtosis of 1.034. Summer samples are classified as mesokurtic, nearly symmetrical, very well sorted fine sand.

Summer foredune samples have the highest standard deviation for all four grain size statistics. The average grain size statistics for the foredune samples are: mean grain size, 0.161 mm (2.637φ); sorting, 0.302φ; skewness, −0.015; and kurtosis, 1.058. Based on these values, the summer foredune sediments are classified as mesokurtic, nearly symmetrical, very well sorted fine sand.

Summer midtide samples are similar to foredune samples, but are slightly more coarsely skewed and are finer. The averages for the grain size statistics for the midtide samples are: mean grain size, 0.148 mm (2.760φ); sorting, 0.291φ; skewness, −0.112; and kurtosis, 1.048. Based on these values, the summer midtide sediments are classified as mesokurtic, coarsely skewed, very well sorted fine sand.

Summer step samples have similar statistics as both the foredune and midtide samples. The averages for the grain size statistics for the step samples are: mean grain size, 0.138 mm (2.850φ); sorting, 0.299φ; skewness, −0.071; and kurtosis, 0.995. Based on these values, the summer step sediments are classified as mesokurtic, nearly symmetrical, very well sorted fine sand.

The mean grain size for all winter samples ranges from 0.14 mm (2.856φ) to 0.19 mm (2.419φ), which is classified as fine sand. Sediment sorting ranges from 0.230φ to 0.411φ, which is classified as well sorted to very well sorted. Skewness values ranged from −0.176 to 0.155, which correspond to fine-skewed to coarse-skewed classifications. The minimum and maximum kurtosis values for all winter samples are 0.857 and 1.31, respectively. This range of kurtosis values classifies the samples as leptokurtic to platykurtic. When viewed together, the winter samples for all three environments have an average mean grain size of 0.159 mm (2.657φ), an average sorting of 0.303φ, an average skewness of −0.011 and an average kurtosis of 1.052. Winter samples are classified as mesokurtic, nearly symmetrical, very well sorted fine sand.

The three environments sampled during winter conditions are characterized by very similar mean grain size statistics. The average mean grain size for the foredune, midtide and step environments is 0.166 mm (2.590φ), 0.158 mm (2.662φ) and 0.152 mm (2.719φ), respectively. Average sorting values of 0.286φ, 0.310φ and 0.313φ are recorded for the foredune, midtide and step samples, respectively. Slightly negative average skewness values were reported for the midtide (−0.028) and step (−0.036) samples, while a slightly positive value was reported for the foredune (0.030) samples. Average kurtosis values for the foredune, midtide and step samples are 1.084, 1.040 and 1.032, respectively. Based on these average statistics, the sediments from all three environments are classified as mesokurtic, nearly symmetrical, very well sorted fine sands.

The percent carbonate from 13 samples was calculated using both the “numeric” and hydrochloric acid digestion techniques. A t-test (paired means) was performed to determine if the average percent carbonate of the two techniques was significantly different. Results of the t-test indicated that the means were not significantly different at the 95% confidence level. It was concluded that the “numeric” technique accurately represents the percent carbonate present in a sample.

Carbonate percentages range from 0.0% to 96.4%, with both the highest and lowest percentages being recorded in foredune samples. Step samples contain the highest average percent carbonate for the three environments at 28.5%. Percent carbonate averages of 11.1% and 2.3% were reported for the foredune and midtide samples, respectively.

The range of winter carbonate percentages, 0.0% to 93.3%, is similar to summer conditions except the maximum value was recorded from a step sample. The highest average carbonate percentage, 41.1%, was reported for the step samples. Foredune and midtide percent carbonate averages of 3.9% and 5.7%, respectively, were reported.

5. Discussion

5.1. Predicted net longshore transport system

The predicted net longshore transport volume distribution reveals the presence of two transport cells
The volumes of sediment transport predicted by the model are estimates based on the assumption that an unlimited amount of sediment is available for transport and, as such, represent a reasonable estimate of the net longshore transport system. Predicted transport volumes along Chandeleur Island are similar in magnitude to those found along the Mississippi, Alabama and Florida coasts (Stone, 1991; Stone et al., 1992; Stone and Stapor, 1996; Cipriani, 1998; Cipriani and Stone, 2001).

Variations in the magnitude of predicted sediment transport provide additional insight into the longshore transport system of Chandeleur Island. The larger volume of sediment transport predicted in Cell II indicates that the breaker angle ($\beta$), rather than the breaker wave height ($H_b$), explains the different volume rate transport along the island. A larger volume of sediment transport would be expected in the northern portion of the island as the dominant wave approach is from the southeast. Analysis of wave refraction patterns (Ellis, 1998) indicates that refraction is occurring at a greater distance offshore in the southern portion of the island due to a decreased shoreface slope. The change in slope alongshore can be seen in Fig. 1. The dominance of breaker angle in determining the predicted transport volumes is also evident in the northern portion of the island. Comparison of breaker wave heights to the predicted transport volumes (Fig. 5) reveals that the maximum breaker wave heights occur in the central portion of the island while the greatest transport volumes occur on both the north and south ends of the island.

The more pronounced deterioration of the southern portion of Chandeleur Island with the larger predicted volume of sediment transport in this area brings into question the factors that control the alongshore geomorphology. In addition to the longshore transport system, two other factors may be influencing this system. First, the active St. Bernard delta complex preferentially supplied sediment to the northern portions of Chandeleur Island during the formation of the Chandeleur Island arc (Frazier, 1967; Boyd and Penland, 1981; Kindinger et al., 1991). Second, subsidence rates appear to be variable along the Chandeleur Island chain. This variability is related to both the original deposition of the St. Bernard delta lobes and the active deposition of the modern Balize delta. Sediments of the St. Bernard delta lobes were deposited on a rather stable subsurface platform (Pleistocene deposits) in the northern portion of the Gulf. This Pleistocene platform is present at depths of 15 m to 20 m under the Mississippi barrier islands immediately to the north of Chandeleur Island (Otvos, 1985). In contrast, sediment deposition in the southern reaches of the St. Bernard deltaic complex had more accommodation space in the basin because the stable Pleistocene platform is encountered at a much greater depth. The increased basin area allowed for a larger accumulation of deltaic facies to occur. This thicker sequence of Holocene deltaic deposits is more prone to sediment compaction and subsidence. Active deposition in the modern Balize deltaic complex might also be contributing to some of the subsidence in the southern areas of the Chandeleur Island arc. It appears that the deposition of sediments on a more stable subsurface platform coupled with a northern longshore transport component allowed the northern portion of the barrier island to develop into a more established system. The shoreline retreat rates calculated from 1855 to 1989 viewed with the predicted sediment transport volumes along the island appear to lend credence to this argument. Additional research to quantify the variability of the subsidence rate within the Chandeleur Island arc is needed.

Utilizing the cellular drift model proposed by May and Tanner (1973), the nodal point represents the location where bi-directional drift originates. Analysis of the predicted volumes, within the framework of the cell drift direction, can indicate areas with the potential for erosion and deposition. An increase in sediment volume in the direction of drift can indicate a zone of potential erosion while a decrease can indicate a zone of potential deposition. A review of Fig. 3 reveals several potential erosional and depositional zones within both cells. Inspection of the raw volume transport data indicates a highly complex system of erosional/depositional couplets operating alongshore. A general indication of the existence of this complex differential availability of sediment alongshore could not be inferred from the pattern of breaches, which occur during overwash events.

The response and recovery of Chandeleur Island to the passage of a hurricane has been documented by several researchers. Instrumental to the recovery of the island is the redistribution of sediment by the longshore transport system that seals breaches through the island. As mentioned above, fluctuations in the volume of sediment transported alongshore might help explain the pattern of breaching seen during overwash events. If sediments have not been lost from the transport system, then the pattern of recovery can be qualified by the longshore transport...
system predicted during this investigation. The detailed study of the recovery of Chandeleur Island after the passage of hurricane Frederic by Kahn (1980, 1986) indicated a more rapid recovery of the northern portion of the barrier island. As mentioned above, variability in the subsidence rates along the island coupled with the northward directed sediment transport would explain the more rapid recovery of the northern portion of the barrier. Additional support to the validity of the predicted longshore transport system is the increase in island area from 1922 to 1951 documented by McBride et al. (1992, 1993). The breaches in the northern portion of Chandeleur Island seen on the 1922 shoreline map are sealed and form a relatively continuous shoreline in the 1951 shoreline map, while several breaches in the southern portion of the island are present in both the 1922 and 1951 shoreline maps.

Only general comparisons can be made between the shoreline change information and the predicted longshore transport system. Because Chandeleur Island is a transgressive, overwash-dominated barrier island system, cross-shore sediment transport is also instrumental in the nearshore processes that shape the barrier. Longshore sediment transport has been modeled exclusively during this investigation and no attempts have been made to quantify the volume of cross-shore transport.

The bi-directional longshore transport system coupled with a variable subsidence rate in the St. Bernard delta plain has allowed Chandeleur Island to evolve into the arcuate shape seen today. Alongshore topographic variability, storm response, post-storm recovery, shoreline position and area change are linked to the bi-directional, two-cell drift system identified here.

5.2. Sediment texture and composition

Examination of the four grain size statistics alongshore for both summer and winter conditions reveals no significant regional trends (Figs. 6–9). A slight increase in the mean grain size in the southern portion of the island is apparent in the summer foredune and winter foredune samples. This increase in mean grain size of the non-carbonate fraction of sediment is attributed to the overwash deposits found in this area. These deposits represent the proximal position in the initial deposition of the overwash fans. Overwash fans typically exhibit a fining
trend from the core to the more distal portions of the fan (Leatherman et al., 1977; Leatherman, 1979, 1981; Stone, 1998). Additionally, these deposits are characterized by a high percent carbonate (approximately 75% to 95% shell hash) and are not indicative of foredune deposits. Distinct areas of increased percent carbonate can be seen in summer and winter foredune samples from the southern portion of the island (Fig. 10). These carbonate increases result from deposition of shell hash during overwash events. The rapid retreat rate allows for a greater amount of shell to be reworked in this area. Overwash events result in the deposition of the reworked shell hash on the subaerial beach. The shell hash deposits inhibit plant colonization and limit incipient dune formation, which prevents stabilization of the beachfront through sediment storage thus reinforcing the rapid landward retreat rate in the area (Ritchie and Penland, 1988).

5.3. Environmental distinctions

Several researchers have employed various methods to distinguish beach and dune sands based on textural parameters (Mason and Folk, 1958; Friedman, 1961; Shepard and Young, 1961; Duane, 1964; Shideler, 1974). Differentiation of the textural parameters arises from variations in the hydrodynamics of the transport regimes. In general, the foredune sediments tend to be finer grained, better sorted and positively skewed while the step samples are coarser grained, more poorly sorted and negatively skewed. Stapor and May (1983), Stone et al. (1992), Cipriani (1998) and Cipriani and Stone (2001) have found similar trends along the northeast and northwest coasts of Florida and the northwest coasts of Alabama and Mississippi barrier islands. As shown on Figs. 6–9, the typical textural trends associated with the three environments are not found along Chandeleur Island. A high degree of variability, which prohibits a distinction to be made, is found among the three environments. Comparison of the mean grain size among the three environments (Fig. 6) reveals slightly coarser sediment being found in the foredune samples from the central and southern portions of the island. This apparent reversal in mean grain size and the lack of environmental distinctions based on sorting, skewness and kurtosis suggests that different physical properties operate on Chandeleur Island as opposed to other barrier islands. The most significant difference between Chandeleur Islands and
other barrier islands in the northern Gulf of Mexico is the frequency of overwash events. Overwash events appear to have distorted the typical textural trends (Leatherman et al., 1977; Leatherman, 1979; Stone, 1998) found on other barriers by depositing coarser sediment on overwash platforms and along the foredune system. These deposits, consisting primarily of shell hash, are due in part to the rapid shoreline retreat rates that have reactivated the older dune systems and breached the dunes along the island. Additionally, the limited textural variability found in the original source material coupled with the degree of sediment reworking associated with the formation and evolution of the barrier island has restricted the ability of the different transport regimes to produce texturally distinct environments.

The percent carbonate associated with the three environments does allow for a limited amount of environmental differentiation. As noted in Fig. 10, the highest percent carbonate is found in the step environment followed by the midtide and foredune environments. This represents a typical trend for the three environments, where the increase in carbonate can roughly be associated with a coarser grain size (Stapor and May, 1983; Stone, 1991; Stone et al., 1992; Cipriani, 1998; Cipriani and Stone, 2001). Obvious deviations to this trend occur in the southern portion of the island where the foredune samples have a greater percent carbonate than the step samples. These reversals of the carbonate trend attest to the importance of overwash events in redistributing sediment across Chandeleur Island.

5.4. Seasonality signals in the sediments

Variations in the textural and compositional trends due to seasonal fluctuations in wave climates have been observed around the world (Basillie, 1987). Typically, winter conditions are associated with higher wave energy in the northern hemisphere due to the more frequent passage of storms; therefore, sediments from the winter beaches are usually coarser and more poorly sorted than summer beaches. Beaches commonly experience erosion during the winter and accretion during the summer. Events such as hurricanes or mild winters with few extratropical storms can skew the typical cycle (Larson et al., 1997).

An analysis of Figs. 6–9 reveals no significant seasonal distinction between the three environments along Chandeleur Island for the four grain size statistics. The same variability alongshore associated with the three environments is noted for the seasonal comparisons. The reason for the absence of seasonal distinctions is most likely related to the original source population being of such a limited textural variability because a more energetic wave climate does exist during the winter months. This theory is corroborated by the lack of seasonal differences in the percent carbonate for the three environments (Fig. 10).

5.5. Transport morphodynamics and inferences from sediment granulometry

As mentioned previously, textural and compositional trends can develop in response to wave energy gradients associated with the longshore transport system. Figs. 4 and 5 both reveal a decrease in breaker wave heights from the central portion of Chandeleur Island toward both the north and south ends. Assuming textural trends could develop in response to drift directions and energy gradients, a fining toward the distal ends of Chandeleur Island would be expected. Additionally, similar trends should be apparent in the other grain size statistics (i.e., sediments should be better sorted in the direction of drift) (Folk, 1980; Carter, 1988; Hsu, 1989). As noted above, no textural or compositional trends are observed with the exception of a slight increase in carbonate in the southern portion of the island. This increase in carbonate is related to the rapid retreat rate, increased introduction and
rereoking of shells, and depositional overwash events. It is speculated that no textural trends exist because of the limited variability associated with the source sediments and that cross-shore transport (overwash events) occurs frequently. A similar absence of significant textural grading alongshore in the presence of a mature longshore drift system was noted by May and Stapor (1996) along the South Carolina coast.

6. Conclusions

Based on the data collected during this investigation, the following conclusions are made: (1) the longshore transport system along Chandeleur Island is characterized by a net bi-directional drift system, with sediment drift directed both north and south from a nodal point located in the south-central portion of the island; (2) northward directed longshore sediment transport operates for approximately 25.5 km while southward transport operates for 16.5 km; (3) both transport cells contain areas of potential erosion and deposition alongshore; (4) the magnitude of predicted sediment transport is greater in the southern cell (Cell II) than the northern cell (Cell I). This increase in magnitude is attributed to the breaker angle rather than larger breaker wave heights underscoring the importance of refraction in controlling the predicted longshore volume rate of sediment transport; (5) the magnitude of longshore sediment transport along Chandeleur Island is similar to other barrier islands in the northern Gulf of Mexico. Maximum rates of approximately 87,000 m$^3$/yr and 63,000 m$^3$/yr were predicted for the southern cell and northern cell, respectively; (6) the potential exists that subsidence is important as a controlling factor in the alongshore geomorphology. The southern portion of Chandeleur Island should appear more stable than is currently observed given that a greater volume rate of sediment transport is predicted for this area. Additional research is needed to evaluate the variability of the subsidence rate within the Chandeleur Island arc; (7) the sediments that comprise Chandeleur Island are predominately mesokurtic, near-symmetrical, very well sorted, fine sands. (8) No significant textural or compositional trend has been recognized alongshore. The degree to which the sediments have been reworked during the formation and evolution of the island has provided a grain size distribution across and along the island with very little variability. The frequency of overwash events, which transport sediment both onshore and offshore, could also prohibit the development of sedimentological trends. Additionally, storm waves from various angles of approach can move large volumes of sediment in directions opposite that of the predicted net drift directions. These events could skew any alongshore grading that might develop; (9) the absence of textural and compositional trends alongshore does not allow for an independent validation of the modeled transport system. The geomorphic indicators, such as spit accretion and sealing of breaches, used by others to infer drift direction do agree with the predicted transport system; (10) no significant granulometric distinction can be made between the three environments sampled or between the seasonally collected samples attributable to the limited variability of sediments and the dynamic nature of this transgressive barrier island; (11) calcium carbonate (predominately shell hash) is ubiquitous to all three environments sampled due to the transgressive nature of the barrier; (12) a slight increase in carbonate percentage is observed in step samples from the southern portion of the island. This increase is attributed to the rapid retreat rate in this portion of the barrier, which allows a greater amount of shells to become reworked in the subaerial beach sediments; and (13) high calcium carbonate percentages observed in the southern dune samples result from overwash events which deposit shell hash on the low-profile platform associated with this area.

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