USGS
science for a changing world

Summary and Discussion

Chapter I of

Sand Resources, Regional Geology, and Coastal Processes of the Chandeleur Islands Coastal System: an Evaluation of the Breton National Wildlife Refuge

Scientific Investigations Report 2009–5252

U.S. Department of the Interior
U.S. Geological Survey

Summary and Discussion

By Dawn Lavoie, Michael D. Miner, Ioannis Y. Georgiou, Sarah Fearnley, Asbury H. Sallenger, Jr., S. Jeffress Williams, David Twichell, James Flocks, and Mark Kulp

Chapter I of

Sand Resources, Regional Geology, and Coastal Processes of the Chandeleur Islands Coastal System: an Evaluation of the Breton National Wildlife Refuge

Edited by Dawn Lavoie

In cooperation with the U.S. Fish and Wildlife Service

Scientific Investigations Report 2009–5252

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2009

This and other USGS information products are available at http://store.usgs.gov/
U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225

To learn about the USGS and its information products visit http://www.usgs.gov/
1-888-ASK-USGS

Suggested citation:
Lavoie, D., Miner, M., Georgiou, I.Y., Fearnley, S., Sallenger, A.H., Jr., Williams, S.J., Twichell, D., Flocks, J., and Kulp, M., 2009, Chapter I. Summary and discussion, *in* Lavoie, D., ed., Sand resources, regional geology, and coastal processes of the Chandeleur Islands coastal system—an evaluation of the Breton National Wildlife Refuge: U.S. Geological Survey Scientific Investigations Report 2009–5252, p. 169–180.

Chapter I. Summary and Discussion

By Dawn Lavoie,[1] Michael D. Miner,[2] Ioannis Y. Georgiou,[2] Sarah Fearnley,[2] Asbury H. Sallenger, Jr.,[3] S. Jeffress Williams,[4] David Twichell,[4] James Flocks,[3] and Mark Kulp[2]

Abstract

Breton National Wildlife Refuge, the Chandeleur Islands chain in Louisiana, provides habitat and nesting areas for wildlife and is an initial barrier protecting New Orleans from storms. The U.S. Geological Survey (USGS) in partnership with the University of New Orleans Pontchartrain Institute for Environmental Sciences undertook an intensive study that included (1) an analysis of island change based on historical maps and remotely sensed shoreline and topographic data; (2) a series of lidar surveys at 3- to 4-month intervals after Hurricane Katrina to determine barrier island recovery potential; (3) a discussion of sea level rise and effects on the islands; (4) an analysis of sea floor evolution and sediment dynamics in the refuge over the past 150 years; (5) an assessment of the local sediment transport and sediment resource availability based on the bathymetric and subbottom data; (6) a carefully selected core collection effort to ground-truth the geophysical data and more fully characterize the sediments composing the islands and surrounds; (7) an additional survey of the St. Bernard Shoals to assess their potential as a sand resource; and (8) a modeling study to numerically simulate the potential response of the islands to the low-intensity, intermediate, and extreme events likely to affect the refuge over the next 50 years.

Results indicate that the islands have become fragmented and greatly diminished in subaerial extent over time: the southern islands retreating landward as they reorganize into subaerial features, the northern islands remaining in place. Breton Island, because maintenance of the Mississippi River-Gulf Outlet (MRGO) outer bar channel requires dredging, is deprived of sand sufficient to sustain itself. Regional sediment transport trends indicate that large storms are extremely effective in transporting sand and controlling the shoreline development and barrier island geometry. Sand is transported north and south from a divergent zone near Monkey Bayou at the southern end of the Chandeleur Islands. Numerical simulation of waves and sediment transport support the geophysical results and indicate that vast areas of the lower shoreface are affected and are undergoing erosion during storm events, that there is little or no fair weather mechanism to rework material into the littoral system, and that as a result, there is a net loss of sediment from the system. Lidar surveys revealed that the island chain immediately after Hurricane Katrina lost about 84 percent of its area and about 92 percent of its prestorm volume. Marsh platforms that supported the islands' sand prior to the storm were reduced in width by more than one-half. Repeated lidar surveys document that in places the shoreline has retreated about 100 m under the relatively low-energy waves since Hurricanes Katrina and Rita; however, this retreat is nonuniform. Recent high-resolution geophysical surveys of the sea floor and subsurface within 5–6 km of the Chandeleur Islands during 2006 and 2007 show that, in addition to the sand that is rebuilding portions of the island chain, a large volume of sand is contained in Hewes Point, in an extensive subtidal spit platform that has formed at the northern end of the Chandeleur Islands. Hewes Point appears to be the depositional terminus of the alongshore transport system. In the southern Chandeleurs, sand is being deposited in a broad tabular deposit near Breton Island called the southern offshore sand sheet. These two depocenters account for approximately 70 percent of the estimated sediment volume located in potential borrow sites. An additional large potential source of sand for restoration lies in the St. Bernard Shoals, which are estimated to contain approximately 200×10^6 m^3 of sand.

Successful restoration planning for the Breton National Wildlife Refuge should mimic the natural processes of early stages of barrier island evolution including lateral transport to the flanks of the island chain from a centralized sand source that will ultimately enhance the ability of the islands to naturally build backbarrier marsh, dunes, and a continuous sandy shoreline. Barrier island sediment nourishment should be executed with the understanding that gulf shoreline erosion is inevitable but that island area can be maintained and enhanced during retreat (thus significantly prolonging the life of the island chain) with strategic sand placement.

---

[1] U.S. Geological Survey, Stennis Space Center, Miss.

[2] University of New Orleans, Pontchartrain Institute for Environmental Sciences, New Orleans, La.

[3] U.S. Geological Survey, St. Petersburg, Fla.

[4] U.S. Geological Survey, Woods Hole, Mass.

Rationale

Breton National Wildlife Refuge is composed of a discontinuous barrier island chain along the eastern side of the Mississippi River Delta in Louisiana that trends north-south for approximately 85 km from the northern Chandeleur Islands to Breton Island in the south. In addition to providing habitat and nesting areas for endangered species (for example, brown pelican [*Pelecanus occidentalis*], least tern [*Sterna antillarum*], piping plover [*Charadrius melodus*]), and other wildlife species (nesting and wading birds, waterfowl, rabbits, raccoons, and loggerhead sea turtles [*Caretta caretta*]), the refuge provides an initial barrier to storms for the southeastern Louisiana wetlands and is a fundamental component of the geomorphologic features that protect the metropolitan New Orleans area. The refuge has been impacted by hurricanes throughout history but never as severely as by Hurricane Katrina in 2005, during which the island chain lost 84 percent of its aerial extent. In the 3 years following the hurricane, the islands have shown only limited and slow recovery. The severity of damage brings into question what the future configuration of the island chain will be, what protective function the islands will provide for the mainland wetlands and New Orleans, and whether the refuge can continue to provide the same level of functional habitat for endangered species and other wildlife as it did prior to the 2005 hurricane season.

The U.S. Geological Survey (USGS) in partnership with the University of New Orleans Pontchartrain Institute for Environmental Sciences undertook an intensive year-long study to provide the U.S. Fish and Wildlife Service (FWS) with information needed to answer these and similar questions and make management decisions relating to the future of the Breton National Wildlife Refuge. The effort built on the Barrier Island Comprehensive Monitoring (BICM) program's bathymetric data collection effort funded by the Louisiana Coastal Area Science and Technology Program (jointly funded by the Louisiana Department of Natural Resources and the U.S. Army Corps of Engineers) that surveyed all of the sandy shorelines of Louisiana. The FWS effort included (1) an analysis of island change based on historical maps and remotely sensed shoreline and topographic data; (2) a series of lidar surveys at 3- to 4-month intervals after Hurricane Katrina to determine barrier island recovery potential; (3) a discussion of sea level rise and effects on the islands; (4) an analysis of sea floor evolution and sediment dynamics in the refuge over the past 150 years; (5) an assessment of the local sediment transport and sediment resource availability based on the bathymetric and subbottom data; (6) a carefully selected core collection effort to ground-truth the geophysical data and more fully characterize the sediments composing the islands and surrounds; (7) an additional survey of the St. Bernard Shoals to assess their potential as a sand resource; and (8) a modeling study to numerically simulate the potential response of the islands to the low-intensity, intermediate, and extreme events likely to affect the refuge over the next 50 years. A summary of information resulting from these investigations is synthesized in this chapter.

Summary

The location of the Chandeleur Islands is controlled by the late Holocene development of the Mississippi River Delta, which started forming on the shelf about 7,000 years before present (BP) (refer to chaps. D, E, and F for a complete discussion and references). Sites of active deltaic deposition shifted over time as the receiving basin filled and the Mississippi River sought a more favorable gradient. One of the intermediate deltas, the St. Bernard Delta Complex, forms the foundation beneath the Chandeleur Islands.

Once the St. Bernard Delta Complex was abandoned, the Chandeleur Islands started to form about 2,000 years BP in response to erosion of deltaic headlands and spit elongation driven by longshore transport. With continued subsidence of the underlying deltaic deposits, the islands became separated from the subaerial part of the delta and, consequently, from their original sand source. Historically, the islands have decreased in subaerial extent largely by narrowing, but they have not moved landward appreciably. After Hurricane Katrina, the islands became more fragmented and greatly diminished in subaerial extent (chaps. A and B).

An analysis of hurricane impacts and resultant shoreline change since the early 1700s shows very clearly the dynamic nature of the Chandeleur Islands. Maps from the age of discovery show the Chandeleur Islands and the Biloxi Marshes behind the present islands although the location and extent of the marshes differ on all four maps, possibly because navigation was more primitive; however, these maps are our record of the region before the extensive influence of humans. Since the advent of the U.S. Coast and Geodetic Survey topographic smooth sheets in 1970s, shoreline position and change can be measured accurately.

The long-term evolution of the northern Chandeleur Islands has been characterized by Gulf of Mexico shoreline erosion and island arc rotation because of variations in rates of erosion and accretion along the shoreline. The gulf shoreline erosion has not accompanied by increased land area in the backbarrier or a landward migration of the backbarrier shoreline; therefore, the islands have been rapidly decreasing in area. The islands maintained a steady rate of erosion of about 35 ft/yr between 1922 and 2004 with brief periods (between 1965 to 1969) of accretion prior to Hurricane Camille and between 2002 to 2004 prior to Hurricane Ivan. A simple extrapolation of the rate of diminishing land area suggests that the islands will either become shoals or disappear altogether by 2064 if no significant storms the magnitude of Hurricane Katrina occur. If in this changing global climate with storms expected to bring more intense wind fields and rain the northern Chandeleurs are hit again, the islands' lifespan might end as soon as 2013 (see chap. A, especially fig. 10, for details).

The southern Chandeleur Islands—which include Breton Island, Grand Gosier Islands, Curlew Islands, and Errol Islands (historical)—have shown a different and more dramatic storm impact response and mode of recovery over time than have the northern Chandeleur Islands. Like the northern barrier arc, the southern Chandeleur Islands are characterized by shoreface retreat; however, major storm impacts have resulted in complete island destruction and conversion to inner shelf shoals. During extended periods of calm weather following storm impacts, new islands have emerged along this sector. Because the islands have been completely destroyed during storms, it has been difficult to relate storm impacts to shoreline position. Moreover, island area change through time has not been linear because relatively long periods of calm weather produced more robust islands. Over the long term, however, the rate of shoreline retreat was approximately 50 ft/yr for the time period from 1869 to 1996. Island area for the time period from 1869 to 2005 decreased from 1,939.8 acres to 43.6 acres (see chap. A for details).

Hurricane impacts to the Chandeleur Island chain are dependent upon storm intensity, path, and duration, and so the geomorphic response to each storm and subsequent recovery are highly variable. The recorded period (1855–2005) of evolution has been characterized by a continual decrease in island area driven by storm impacts from 11,004 acres to 1,164 acres. Almost instantaneously, strong storms greatly increased the rate of shoreline retreat and reduction in island area. Any increase in storm frequency and intensity rapidly accelerates the land loss, and with each storm impact the islands have become less efficient at poststorm recovery because of decreased sediment supply (chap. A).

The data indicate that the Chandeleur Islands have undergone a higher frequency of storm events during the past two decades than during the entire previous 150 years. A simple extrapolation of existing data suggests that the Chandeleur Islands may disappear as early as 2013 if storm frequency remains the same as documented during the past two decades; however, the islands may persist in their present condition until 2037 if storm frequency decreases to the level documented between 1855 and 1988. In the absence of another major storm impact and with limited sediment availability, the northern Chandeleur Islands will likely disappear between 2013 and 2064 (fig. 9 in chap. A).

Storm track has emerged as a key factor in estimating shoreline erosion rates from an approaching storm. Hurricanes Camille and Katrina caused the most severe rates of shoreline erosion on the northern Chandeleur Islands largely because the storm tracks passed directly over the southern portions of the islands. The tracks resulted in the eastern eye wall, with the highest winds and surge levels, passing over the northern islands and causing extensive shoreline erosion. Other Category 3 storms of similar size to Hurricane Katrina that passed more than 75 miles to the west of the islands (for example, Hurricane Betsy) or more than 75 miles to the east (Hurricane Ivan) did not result in the same amount of shoreline erosion; in fact, the passage of Hurricane Ivan actually resulted in accretion of the shoreline during the time period 2002–4 (fig. 11 in chap. A).

The next stage of evolution of the northern Chandeleur Islands may be represented by the present-day configuration of the southern Chandeleur Islands. The southern Chandeleur Islands are ephemeral barrier islands undergoing early stages of transgressive submergence and conversion to an inner shelf shoal. Storm intensity and frequency, as the major controls on island/shoal evolution, destroyed and converted the southern Chandeleur Islands to submerged shoals during periods of high storm frequency and allowed them to emerge and rebuild as relatively robust barrier shorelines during extended periods of calm weather. During the two periods of relative quiescence, Curlew and Grand Gosier Islands were able to recover from complete destruction and increase in area from 39 acres to 596 acres. Also during this quiescent period, backbarrier marsh and mangrove swamp accreted in the shelter of the sandy shoreline, and extensive submerged grass bed meadows blanketed the sea floor landward of the islands. Unfortunately, this period of relative quiescence was followed by the stormiest period on record for the Gulf of Mexico, during which four major hurricanes resulted in the destruction and submergence once again of these southern islands.

The submergence of the southern islands after storms and subsequent reemergence at locations landward of their prestorm positions result in the landward translation of the entire barrier island. This landward barrier retreat in response to relative sea level rise is driven by poststorm hydrodynamics that reorganize the islands into a subaerial feature, which is in contrast to the northern islands, where minimal landward translation of the subaerial barrier occurs. The disparity between the northern and southern islands' responses to storms, storm recovery periods, and sea level rise is attributable to the absence of a well-established backbarrier marsh along the southern chain (with the exception of small portions of Breton Island). As the northern islands erode and are stripped of sand during storms, this backbarrier marsh becomes exposed. Because it is composed of a thick organic root mat within a cohesive fine-grained sediment matrix, the marsh resists rapid erosion and prohibits island submergence.

It is important to note that Breton Island does not follow the same trends in island area change exhibited by Curlew and Grand Gosier Islands to the north. This difference is attributed to the construction and maintenance of the Mississippi River-Gulf Outlet (MRGO) outer bar channel for navigation purposes. Sand that would naturally be transported alongshore and delivered to Breton Island is either deposited updrift of the MRGO channel by the strong tidal currents that flush the channel of sand or is mechanically removed from the navigation channel during maintenance dredging efforts and transported to an offshore disposal site, thereby removing it from the littoral system (chap. A, especially fig. 8). This process prohibits Breton Island from recovering from storms in a similar manner to the islands to the north and has resulted in long-term reduction in Breton Island area.

Sediment Transport

A sea floor digital elevation change model was constructed from a comparison of bathymetric and shoreline data collected in 2006 and 2007 and similar historical data from the U.S. Coast and Geodetic Survey from the 1970s and 1920s (see chap. D for details). Regional sediment transport trends were inferred from this comparison based on zones of erosion and accretion, and calculations of the volume of sediment eroded or accreted for each zone were then used to derive a long-term sediment budget for the system. The results demonstrate that processes that occur offshore along the lower shoreface govern sediment supply to the shoreline and, ultimately, the long-term evolution of the island chain. Results based on hydrodynamic data and modeling (chap. H) illustrate that these lower shoreface sediment transport processes are active during large storms; thus, the shoreface retreat and large volumes of sediment eroded and accreted measured in this study cannot be accounted for by typical sediment transport in the littoral zone.

Shoreline development and barrier island geometry are controlled by the orientation of the abandoned Mississippi River deltaic headland relative to the dominant wave approach. Wave-induced lateral transport, the most significant factor in the development of the Chandeleur Islands chain, produces sand-rich flanking barrier islands. Because the transgressive shoreline is now isolated from its original source, the sediment load of the Mississippi River, only a finite supply of sediment is available for natural island maintenance.

In earlier stages of the island chain development, significant amounts of sand were derived from erosion of the shoreface deposits. Once that deltaic sediment source was reworked, or subsided below effective wave base (about 7 m for the Chandeleur Islands), in order for the barrier system to maintain exposure during relative sea level rise, barrier and lagoonal deposits must be continually recycled at the shoreface during retreat.

Prior to this study, it was suggested that the net loss of sediment from the Chandeleur Islands system was driven by an imbalance between onshore sediment transport volumes during fair weather conditions and offshore sediment transport volumes during storm conditions. This net export of sediment in an offshore direction produces a thin transgressive sand sheet offshore of the islands that is too deep for onshore transport by constructive fair weather waves. Based on model results, transgressive submergence eventually occurs because development of this sand sheet constantly removes sediment from the barrier system until a threshold is reached, beyond which the islands cannot maintain exposure. In contrast, this study demonstrates that sand is indeed being lost from the nearshore system to deepwater sinks, but the process is more complicated than the previously suggested cross-shore sediment budget model and (similar to the early stages of barrier island development) is driven by lateral sediment transport to the flanks of the island arc.

As demonstrated by the sea floor change digital elevation model, the dominant sediment transport trends are shoreface erosion and deposition in deepwater sinks at the northern and southern flanks of the island arc. Backbarrier deposition is minimal relative to the volumes eroded from the shoreface, indicating that for the most part sand is not being transferred in a landward direction for future recycling. Instead, lateral spit accretion to the north and south of a nodal point, sourced by island and shoreface erosion, has led to sand being sequestered in downdrift, deepwater sinks, removed from the littoral system.

One of the most apparent trends demonstrated in the profile data is the relation among shoreface retreat rates, shoreline erosion rates, and decreasing shoreface slope through time. The southern Chandeleurs have a relatively gentle shoreface slope and are characterized by barrier landward retreat, barrier shoals, and ephemeral barrier islands with no well-established backbarrier marsh. The northern Chandeleurs have a relatively steep shoreface and are characterized by barriers that are undergoing shoreline erosion not accompanied by barrier island landward migration. These northern islands are backed by a well-established backbarrier marsh (thought to be more than 150 years old on the basis of historical maps). Within the period of study some sections of coast (for example, the central Chandeleurs just south of Monkey Bayou [see fig. 4, chap. D, for location]) converted from the steeply sloping/shoreline erosion category to the gently sloping/ephemeral barrier type. Along sections of coast where a thick backbarrier marsh is present, the shoreline is somewhat anchored by the cohesive sediment and root mat that makes up the marsh deposits. The presence of these marsh deposits serves as a nucleation site upon which sand accumulates during storm recovery periods. This erosion-resistant substrate prevents total destruction of islands during storms and slows the rate of shoreline erosion. It forms a barrier, beyond which sand transported by waves cannot pass, and therefore sand accumulates as bars weld to the shoreline. In contrast, where no backbarrier marsh is present or is destroyed during storms, sand in the nearshore zone can be transported in a landward direction by waves, but there is no nucleation site for sand to accumulate.

The Chandeleur Islands are undergoing transgressive submergence by means of a multistage process that involves the following:

- Decreased barrier sand supply restricts new backbarrier marsh development.

- Continued Gulf of Mexico and backbarrier shoreline erosion results in barrier thinning and segmentation. Landward migration is limited because islands are stabilized by backbarrier marsh deposits that inhibit landward transfer of sediment by waves.

- Overwash and eolian processes are not effective at facilitating landward migration because of the paucity of sand in the subaerial barrier.

- Fragmented marsh islets that are the remnants of landward protrusions from the backbarrier shoreline (for example, Redfish Point, Schooner Harbor, Monkey Bayou) anchor the longshore sediment transport system.

- Spits laterally accrete to form a continuous shoreline between these islets.

The gulf shoreline ultimately reaches the backbarrier shoreline, and islands are no longer stabilized by backbarrier marsh, resulting in a sandy ephemeral barrier and the onset of transgressive submergence. The ephemeral barriers are destroyed during storms when the sand is dispersed both offshore and into the backbarrier. During calm weather, sand is moved in volumes that are sufficient to maintain island exposure in response to relative sea level rise. This transport forces a shift in the sediment transport regime from the previously dominant longshore direction to one dominated by cross-shore processes where the system becomes more efficient at recycling sediment. Increased storm frequency accelerates landward retreat rates and in turn inhibits the ability for sand to be reorganized into linear shoals.

Effects from climate change are not uniform but vary considerably from region to region and over a range of time periods because of regional and local differences in atmospheric, terrestrial, and oceanographic processes. The processes driving climate change are complex, and so-called feedback interactions between the processes can both enhance and diminish sea level rise impacts, making prediction of long-term effects difficult. Accelerated global sea level rise, a major outcome of climate change, will have increasingly far-reaching impacts on coastal regions of the United States and around the world. Sea level rise impacts are already evident for many coastal regions and will increase significantly during this century and beyond, causing changes to coastal landforms (for example, barrier islands, beaches, dunes, marshes), as well as ecosystems, estuaries, waterways, and human populations and development. Low-lying coastal plain regions, particularly those that are densely populated including the north-central Gulf of Mexico, are especially vulnerable to sea level rise and its associated impacts (see chap. C for details).

Sand Resources

Sediment transport studies indicate a zone of divergence near Monkey Bayou at the southern end of the Chandeleur Islands, which is where the barrier island lithosome is narrowest and thinnest. North of this divergence, net alongshore transport is directed to the north, whereas south of the divergence transport is southerly. Hewes Point extends northward beyond the northernmost extent of the Chandeleur Islands into deeper water. As such, it appears to be the depositional terminus of the alongshore transport system. As sediment accumulates at Hewes Point in relatively deep water it may be removed from the littoral zone.

The original St. Bernard Delta Plain consisted of a network of distributary channels separated by interdistributary marsh deposits that incised the subaerial part of the delta. They were mostly filled with muddy sand and sandy mud, but sand-rich bars were common at their mouths (see chap. E for details). Interdistributary marsh deposits occupied areas between the channels and primarily consisted of organic-rich sandy silt. Delta-front deposits accumulated offshore of the distributary channel and interdistributary marsh deposits. These deposits contained silt layers and thin sand laminae that dipped gently seaward and graded into adjacent prodelta deposits. The proximal edge of delta-front deposits was sandier than the distal edge, which merged with prodelta muds. Prodelta deposits accumulated farthest from the river mouth and were the finest grained. These deposits primarily consisted of clay with occasional silt beds that were deposited on the continental shelf well beyond the subaerial extent of the delta. As the delta complex expanded, distributary channel and interdistributary marsh deposits advanced seaward over the previously deposited delta-front deposits which, in turn, advanced over prodelta deposits. After the delta complex was isolated from its fluvial source, these sedimentary facies became the primary source of local sediment supply as they were eroded by inner shelf waves and currents.

The thickness, distribution, and volume of the barrier island lithosome extend from the northern tip of Hewes Point to the southern end of the platform beneath Breton Island. The total volume of the barrier island lithosome is approximately $1{,}600 \times 10^6$ m^3. It has been divided into five sections from north to south: (1) Hewes Point, (2) the Chandeleur Islands, (3) Curlew Island, (4) Grand Gosier Island, and (5) Breton Island (fig. 11 in chap. E). The Hewes Point section contains the largest volume of sediment (379×10^6 m^3), has the largest volume per unit area (3.2×10^6 m^3/km^2), and is the thickest part of the barrier island lithosome (maximum thickness of 8.9 m). The Chandeleur Islands section covers the largest area and contains the second largest volume of sediment (284×10^6 m^3) but has the smallest volume per unit area ($1.5 \text{ x } 10^6$ m^3/km^2). It also is the narrowest section of the barrier island lithosome (1.5–4.2 km) and like the three sections to the south (Curlew, Grand Gosier, and Breton Islands) has a maximum thickness that does not exceed 5.5 m. Large parts of this section are less than 3 m in thickness. The Curlew Island section is slightly broader than the Chandeleur Islands section (3.7–5.2 km), has a similar maximum thickness (5.2 m), and has a larger volume per unit area (1.7×10^6 m^3/km^2). The Curlew and Grand Gosier Islands sections are separated by an erosional channel that exceeds 9 m in depth. The Grand Gosier Island section is 7–12 km wide, covers the smallest area of the five sections, reaches 5.4 m in thickness, and has the smallest volume of the five sections. The Breton Island section is separated from the Grand Gosier section by a broad erosional depression that was dredged to accommodate the Mississippi River-Gulf Outlet channel. This section also reaches a maximum thickness of about 5.5 m, but it is broader than the Chandeleur and Curlew sections (5.2–7.6 km wide) and has the second largest volume per unit area (2.1×10^6 m^3/km^2).

The two stratigraphic units identified in the seismic-reflection profiles and cores that have the most potential to be sand resource sites are (1) the northern and southern ends of the barrier island lithosome and (2) sections of the distributary channels that are exposed on the sea floor seaward of the islands. In total, six deposits have been identified that could contribute sediments suitable for shoreline renourishment. Two of these sites are modern deposits that developed contemporaneously or subsequent to the formation of the islands, and four are the offshore extensions of distributary channels that are associated with development of the St. Bernard Delta Complex.

The two sediment bodies of the barrier island lithosome that could serve as sand resource sites are (1) the Hewes Point deposit and (2) the offshore part of the broad, thin sand sheet north of the Mississippi River-Gulf Outlet in the Grand Gosier section of the lithosome (herein referred to as the "southern offshore sand sheet"). These sites lie at the northern and southern ends of the coastal transport pathways and appear to represent sediment that has been removed from the littoral zone and is in a setting that modern oceanographic processes can no longer rework. The total volume of sediment in the Hewes Point deposit is 379×10^6 m^3, and approximately 190×10^6 m^3 is available within 2 m of the sea floor. The southern offshore sand sheet near the Mississippi River-Gulf Outlet is smaller in aerial extent and thinner. Much of this deposit is only 2 m thick, and assuming it has a uniform thickness of 2 m, its total volume is 71×10^6 m^3.

The four distributary channel deposits appear to be less desirable targets because they are smaller and more irregular in shape than the Hewes Point and southern offshore sand sheet, and their fills display variable grain-size distributions. In addition, their shallower depths suggest that the hydrography might be altered with significant sand removal.

The St. Bernard Shoals are a series of shoals located in about 20 m of water just beyond the edge of the modern subaerial Mississippi River Delta marshes and barrier islands approximately 25 km southeast of the Chandeleur Islands. They are up to 6 m thick and locally consist of as much as 100 percent fine- to medium-grained sand. The shoals are derived from sediment that was deposited by a depositional system similar to that which formed the Chandeleur Islands. Consequently the sediment that constitutes the shoals is similar to the sediment that constitutes the Chandeleur Islands, which may make them an ideal borrow site for renourishment of the Chandeleur Islands system (chap. G).

The removal and relocation of sediment from borrow sites will alter the sea floor topography and consequently the bathymetric profile of the dredged area, resulting in an increase in the water depth at the dredged area. Since the direction and magnitude of currents and sediment transport cells are in part controlled by sea floor topography, currents in the shallow borrow sites noted above may be significantly altered by dredging. In the deeper borrow sites (for example, Hewes Point, the southern offshore sand sheet, and the St. Bernard Shoals), winter storm simulations have demonstrated the storms' limited ability to rework some of this material back into the littoral system (chap. H); however, large volumes of sand are far enough beyond wave base that the sediment cannot return to the system. Thus, the negative impacts to the island chain caused by altered hydrology from dredging the St. Bernard Shoals or Hewes Point may be slim to nonexistent. In contrast, storm wave simulations have indicated that large areas of the lower shallow shoreface are activated during storms (chap. H); thus, dredging these four potential borrow sites may not be beneficial for maintaining island area.

Conclusions and Implications for Island Management

Understanding the phases of island evolution and sediment dynamics is fundamental to formulating sustainable island management strategies. The Chandeleur Islands evolution model based on framework geological data and previous investigations demonstrates that the islands built laterally to the north and south from sediment sourced from an erosional headland located along the central portion of the modern shoreline. Sea floor change analysis (fig. 1), subbottom profile data, and model-derived longshore transport predictions confirm that this phenomenon of lateral spit accretion at the flanks of the island arc has continued into recent times. During the early stages of island development, this lateral accretion process allowed for the development of robust backbarrier marsh upon relict spit platforms, landward of the shoreline. This process resulted in the broad backbarrier marshes fronted by a retreating sandy shoreline. This sandy shoreline continues to migrate landward, truncating the backbarrier marshes. During the past century new backbarrier marsh formation has been insignificant and limited to localized areas.

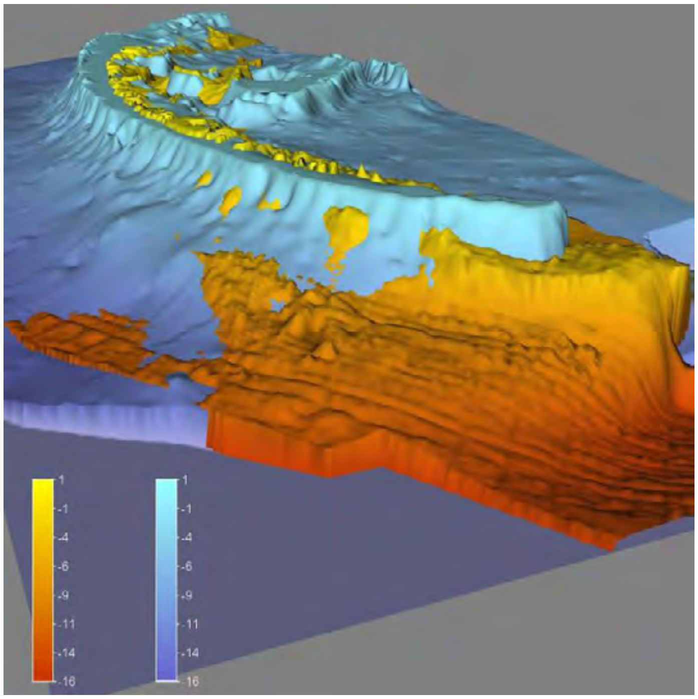

Figure 1. View to the south of the sea floor surfaces of the Chandeleur Islands, La., of the 1870s (blue) versus those of 2006 (orange). Note the large accretionary zone north of Hewes Point, La. (orange in foreground).

Long-term reduction in island area is driven by pulses of rapid land loss triggered by storm events (fig. 2). The islands do not fully recover from storm impacts because sand is transported to the flanks of the arc, thereby removing it from the littoral system. The marsh islands are the "backbone" that stabilizes the barrier chain. The long-term rate of island area reduction accelerated from about 40 acres/yr for the time period from 1855 to 1996 to about 250 acres/yr since 1999, which is associated with increased tropical cyclone frequency. On the basis of a linear regression analysis of historical island area and shoreline change, the projected disappearance of the remnant marsh islands is predicted to occur between 2013 and 2037. The earlier date corresponds to projected storm frequency conditions consistent with that of the past decade, while the later date is based on a linear regression derived from relatively quiescent historical periods. As this marsh disappears, the formerly marsh-backed islands will begin to behave similarly to the southern ephemeral sandy barriers (Curlew and Grand Gosier Islands) by migrating landward as ephemeral barrier islands or shoals.

Because of long-term volume reduction in the littoral and subaerial island sand budget (a trend that was greatly accelerated by Hurricane Katrina; fig. 2), the islands are not capable of maintaining exposure by means of landward transfer of sand by overwash processes and subsequent colonization of overwash deposits by backbarrier marsh vegetation. It has been observed that during the poststorm recovery period, landward transfer of sand is facilitated by (1) landward migration of offshore bars that weld to marsh islets, (2) recurved spit formation at hurricane-cut inlets, (3) eolian processes (dunes, wind tidal flats, and deposition on the marsh surface), and (4) shoal aggradation and landward migration (figs. 3 and 4). The islands are sediment starved, and these recovery processes appear to have exhausted most of the available sand supply, thereby limiting further recovery.

The long-term diminished sediment supply, location of sediment sinks, and storm recovery processes documented in this study provide an understanding of the mechanism that drives barrier island arc transgressive submergence and the natural sediment dispersal processes at work that prolong submergence. On the basis of this newly developed understanding of where the sand is going, how long it takes to get there, and how the islands naturally respond to a rapid introduction of new sediment, efficient barrier management strategies can be developed.

The dominance of lateral transport over cross-shore transport is important. Sand is not being removed and deposited offshore in thin sand sheets as proposed by previous works; instead, sand is being concentrated as thick sediment bodies at the flanks of the island arc (fig. 1). These downdrift sand reservoirs lie outside of the littoral system and provide a unique, quasi-renewable resource for nourishing the updrift barrier system (that is, the central arc).

Restoration goals might mimic the natural processes of early stages of barrier island evolution (fig. 5) including lateral transport to the flanks from a centralized sand source that will ultimately enhance the islands' ability to naturally build backbarrier marsh, dunes, and a continuous sandy shoreline (fig. 6). Barrier island sediment nourishment should be executed with the understanding that gulfside shoreline erosion is inevitable; however, island area can be maintained and enhanced during retreat with strategic sand placement if the following are accomplished:

- Nourishment sand recovered from deepwater sinks at the flanks of the island arc is reintroduced to the barrier sand budget at a centralized location chosen on the basis of longshore sediment transport predictions.

- Distribution of naturally occurring hurricane-cut passes is maintained as storm surge/overwash pathways. These natural high-energy environments should be avoided as sand placement areas.

Figure 2. Time series of oblique aerial photographs taken along the central portion of the island arc of the Chandeleur Islands, La. Arrow in each photograph designates a fixed geographic location. Note that Hurricane Katrina on August 29, 2005, stripped nearly 100 percent of the sand from the islands, leaving behind a series of small marsh islets separated by wide (up to 3,000 m) hurricane-cut tidal inlets. Also note the continued shoreline erosion after the storm impact. In subsequent years (after 2006) these marsh islands have served as nucleation sites for sand accumulation (fig. 3).

Figure 3. Oblique aerial photograph of the northern section of the Chandeleur Islands, La. (left), and a 2005 satellite image for reference. The oblique photograph clearly shows the phases of hurricane-cut inlet closure during recovery along this relatively sediment-rich section of the island arc. This natural process of storm recovery can serve as a model for how the islands will naturally distribute new sand introduced to the littoral system during restoration.

Figure 4. Photograph taken during summer 2008 at the same location as shown in figure 3. Subsequent to hurricane-cut inlet closure and onshore bar migration, eolian processes continue to transport sand landward and build dunes. Note the black mangrove and roseau cane, which are not typical dune vegetation but instead are common to the backbarrier. Between August 2007 and May 2008 dunes such as these accreted (reaching up to 1.5 m elevation) in areas that were backbarrier marsh in August 2007. Also note the high concentration of shells on the beach in the background indicating a deflated surface that is starved of sand. View is to the north, and Gulf of Mexico is in distance.

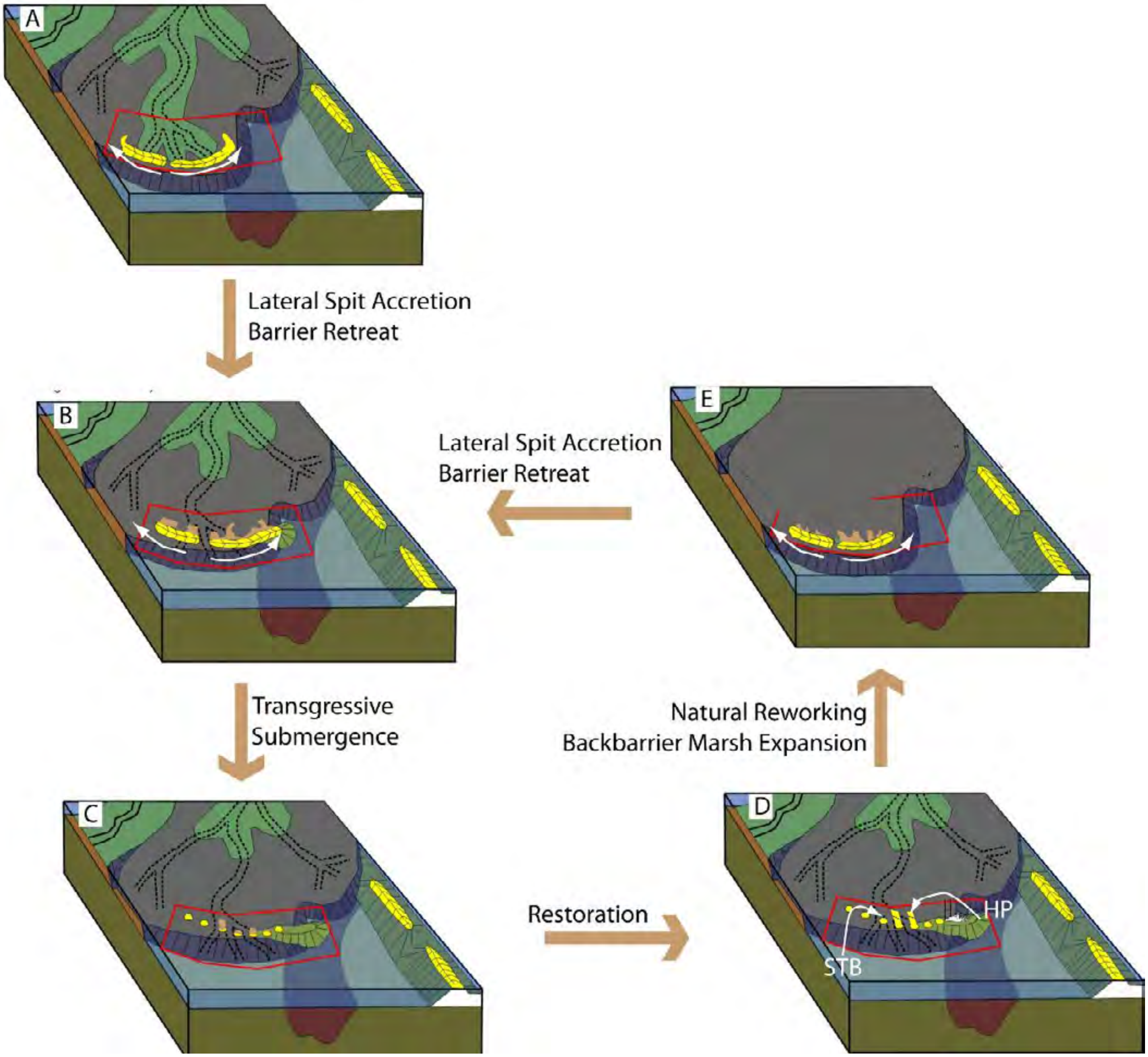

Figure 5. Conceptual model demonstrating barrier island management approach that would employ natural physical processes to extend the lifespan of the Chandeleur Islands, La. The model is based on a conceptual model of Chandeleur Islands evolution (stages *A*–*C*; Twichell and others, chap. E) interpreted from framework geological data. *A*, Natural island formation is the result of mainland detachment from an abandoned deltaic headland. *B*, Continued wave reworking of the headland and island arc results in barrier landward retreat, and sediment that is sourced from a centralized location is transported alongshore to the flanks of the island arc. *C*, Continued transport to the flanks removes sediment from the littoral system and results in exhaustion of centrally located sand sources forcing island degradation and eventually transgressive submergence. *D*, The process of transgressive submergence can be reversed by mechanical removal of sediment from the Hewes Point, La., sink in the north (HP) or St. Bernard Shoals, La., offshore to the east (STB) and strategic sand placement at a central location along the island arc. *E*, Sand will be naturally distributed from this central location by longshore currents to close inlets, broaden beaches, and increase dune elevations. This will make sand available for overwash and spit building upon which backbarrier marsh vegetation will colonize. Updrift reintroduction of sand that was lost from the system effectively sets back the clock to stages *A*–*B*.

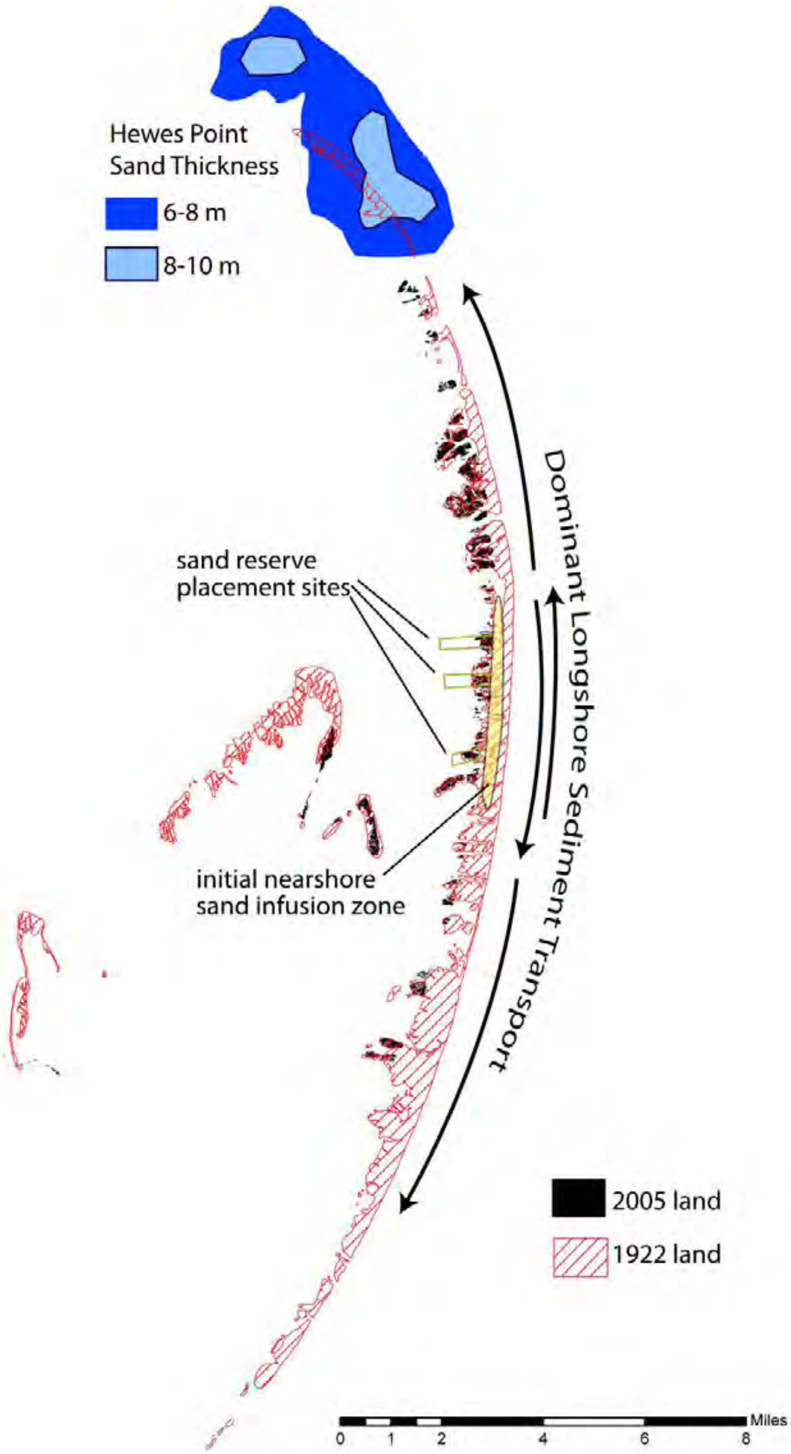

Figure 6. Plan view of the arc of the northern Chandeleur Islands, La., showing the location of the Hewes Point sand resource and possible placement sites that are centrally located within the zone of longshore sediment transport divergence. This divergent zone varies seasonally and was determined from wave modeling based on a 20-year wind record (Georgiou and Schindler, chap. H). The sand reserve placement sites constructed as shore-perpendicular ridges in the backbarrier would serve to continually nourish the island as the shoreline migrates landward, and the initial infusion zone would provide a rapid influx of sand to the littoral system for natural lateral distribution by wave-induced longshore currents.

- Sand is placed at a centralized location along the island arc from which it will naturally disperse to the flanks. Hurricane-cut inlets will heal by spit accretion and bar welding processes. These processes will increase sand in the littoral system and will nourish the beach, providing material for eolian dune building, which will result in increased island elevation and storm protection.
- Sand reserves are strategically placed in the backbarrier as shore-perpendicular platforms over which the island can migrate. These will also serve to reintroduce sand into the littoral system as the island migrates.
- An initial sand infusion to the littoral system along the central barrier arc fronting the backbarrier sand reserves, in the form of nearshore bars and beach, and area-specific restoration can simultaneously be placed.
- An additional or alternative sand source to the Hewes Point sand target is used. The St. Bernard Shoals lie about 25 km offshore of the southern Chandeleur Islands in water depths of less than 20 m. The textural properties of the St. Bernard Shoals sand match those of the Chandeleur Islands sand.

Island lifespan is a function of the magnitude of sand reintroduced and the placement locations. This relation is nonlinear. As sand volumes increase in the littoral system, they will lengthen the islands' lifespan, help reduce erosion rates, and increase island sustainability. When sufficient sand is introduced into the system, it will result in the natural development of robust backbarrier marshes. A naturally well-established (decadal to century scale) backbarrier vegetation is crucial to long-term sustainability because it acts as a nucleation site for material removed during overwash processes, is naturally more resilient to storms, and provides a stable migration or rollover platform. Periodic reintroduction will additionally ensure that the natural rebuilding process is successful.

Breton Island, because of its unique position and importance to habitat, might be treated somewhat differently. Breton Island has been sediment starved because of maintenance dredging of the Mississippi River-Gulf Outlet updrift of Breton Island, which has resulted in rapid island degradation. The island is in need of immediate sand nourishment. A significant volume of sediment (the largest accumulation in the study area during the past 130 years) has accumulated downdrift (southwest) of Breton Island. This accumulation is similar to the sediment sink found at the barrier island arc, north of Hewes Point. The proximity of this source and the location relative to modern processes (downdrift of the outermost littoral zone) make it ideal for restoration of Breton Island. The sandy portion of Breton Island could be nourished to produce a robust beach, beach slope, berm, and dune system. The existing marsh islands at the edges of the islands could also be fronted with a robust beach and dune compartment to maintain and protect the remaining marsh platform for nesting birds. Additional sand can be placed landward of the existing backbarrier to produce migration platforms, encourage colonization of vegetative species, and increase nesting grounds.

Publishing support provided by
Lafayette Publishing Service Center

Lavoie and others—**Summary and Discussion**—Scientific Investigations Report 2009–5252