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Benthic Substrate Classification Map: Gulf Islands National Seashore

By Dawn Lavoie, James Flocks, Dave Twichell, and Kate Rose

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Acknowledgments

The Coastal and Marine Ecological Classification Standard (CMECS) categories were reviewed by Becky Allee of National Oceanic and Atmospheric Administration (NOAA) Gulf Coast Services Center. The data processed herein were collected by Jim Flocks and his group from the USGS St. Petersburg office. Some of the data processing was accomplished in the USGS Woods Hole office by Dave Twichell and his group. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Conversion factors, Abbreviations, and Datum

Multiply	By	To obtain
micrometer (um)	0.003937	inch (in.)
meter (m)	3.281	foot (ft)

BCC	Biotic Cover Component
CMECS	Coastal and Marine Ecological Classification Standard
GFC	Geoform Component
GPS	Global positioning system
GUIS	Gulf Islands National Seashore
MSBI	Mississippi barrier islands
MSCIP	Mississippi Coastal Improvements Program
NAVSTAR	Navigation Signal Timing and Ranging
NGOM	Northern Gulf of Mexico
NOAA	National Oceanographic and Atmospheric Association
NPS	National Park Service
SGC	Surface Geologic Component
USGS	U.S. Geological Survey

Horizontal information referenced to the North American Datum of 1983 (NAD83)

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Introduction and Background

The 2005 hurricane season was devastating for the Mississippi Gulf Coast. Hurricane Katrina caused significant degradation of the barrier islands that compose the Gulf Islands National Seashore (GUIS). Because of the ability of coastal barrier islands to help mitigate hurricane damage to the mainland, restoring these habitats prior to the onset of future storms will help protect the islands themselves and the surrounding habitats.

During Hurricane Katrina, coastal barrier islands reduced storm surge by approximately 10 percent and moderated wave heights (Wamsley and others, 2009). Islands protected the mainland by preventing ocean waves from maintaining their size as they approached the mainland. In addition to storm protection, it is advantageous to restore these islands to preserve the cultural heritage present there (for example, Fort Massachusetts) and because of the influence that these islands have on marine ecology. For example, these islands help maintain a salinity regime favorable to oysters in the Mississippi Sound and provide critical habitats for many migratory birds and endangered species such as sea turtles (*Chelonia mydas*, *Caretta caretta*, and *Dermochelys coriacea*), Gulf sturgeon (*Acipenser oxyrinchus desotoi*), and piping plovers (*Charadrius melodus*) (U.S. Army Corps of Engineers, 2009a).

As land manager for the GUIS, the National Park Service (NPS) has been working with the State of Mississippi and the Mobile District of the U.S. Army Corps of Engineers to provide a set of recommendations to the Mississippi Coastal Improvements Program (MsCIP) that will guide restoration planning. The final set of recommendations includes directly renourishing both West Ship Island (to protect Fort Massachusetts) and East Ship Island (to restore the French Warehouse archaeological site); filling Camille Cut to recreate a continuous Ship Island; and restoring natural regional sediment transport processes by placing sand in the littoral zone just east of Petit Bois Island. Prevailing sediment transport processes will provide natural renourishment of the westward islands in the barrier system (U.S. Army Corps of Engineers, 2009b).

One difficulty in developing the final recommendations is that few data are available to incorporate into restoration plans related to bathymetry, sediment type, and biota. For example, the most recent bathymetry available dates to when East and West Ship Islands were a single continuous island (1917). As a result, the MsCIP program has encouraged post-hurricane bathymetric data collection for future reference. Furthermore, managing a complex environment such as this barrier island system for habitat conservation and best resource usage requires significant knowledge about those habitats and resources. To effectively address these issues, a complete and comprehensive understanding of the type, geographic extent, and condition of marine resources included within the GUIS is required. However, the data related to the GUIS marine resources are limited either spatially or temporally. Specifically, there is limited knowledge and information about the distribution of benthic habitats and the characteristics of the offshore region of the GUIS, even though these are the habitats that will be most affected by habitat restoration. The goal of this project is to develop a comprehensive map of the benthic marine habitats within the GUIS to give park managers the ability to develop strategies for coastal and ocean-resource management and to aid decisionmakers in evaluating conservation priorities.

Methods

A detailed bottom-substrate map has been developed for the NPS and MsCIP program using acoustic data, associated bathymetry, and other ancillary data within the jurisdictional boundaries of the GUIS at East and West Ship, Horn, and Petit Bois Islands, Mississippi (fig. 1). A significant suite of bottom and sub-bottom data within the GUIS boundaries was collected by the U.S. Geological Survey (USGS) as part of the Northern Gulf of Mexico (NGOM) Ecosystem Change and Hazard Susceptibility project during the summers of 2008 and 2009. The goal of this NGOM project is to understand the evolution of coastal ecosystems on the northern Gulf Coast, the impact of human activities on these ecosystems, and the vulnerability of ecosystems and human communities to more intense and frequent hurricanes in the future.

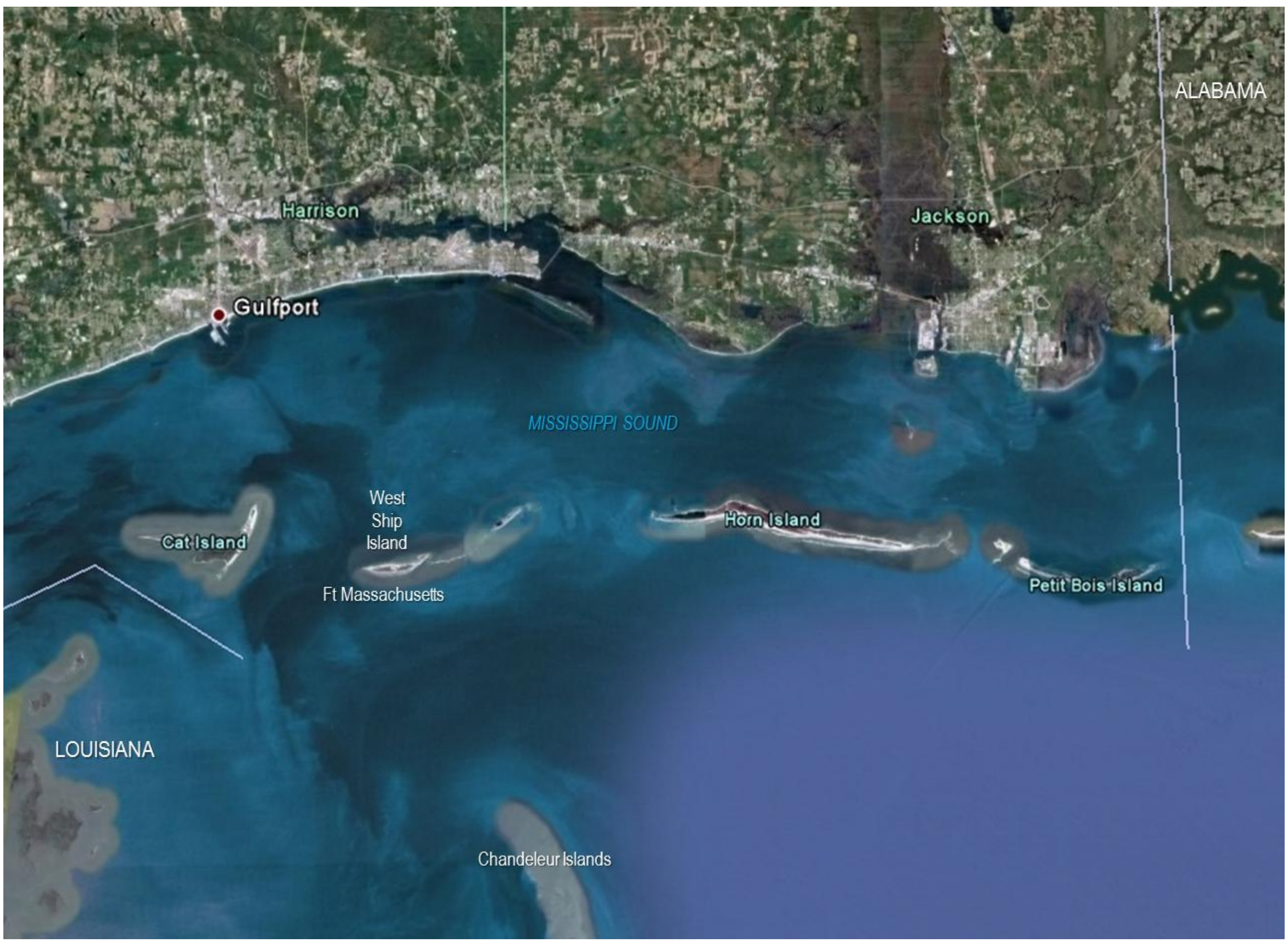

Figure 1. Map of the Mississippi barrier islands that compose the Gulf Islands National Seashore: Petit Bois, Horn, East and West Ship, and portions of Cat Island.

Data Acquisition

Benthic substrate types were surveyed for approximately 1,191 kilometers (km) of seafloor within the GUIS boundary surrounding East and West Ship, Horn, and Petit Bois Islands using side-scanning interferometric-swath bathymetry sonar. Substrate data were collected concomitantly during a survey conducting sub-bottom profiling (fig. 2, tracklines). Because sub-bottom profiling requires a less intense sonar coverage than benthic habitat assessments, data collected for this study provide a high-quality initial assessment of habitats rather than a high-resolution map detailing benthic habitats.

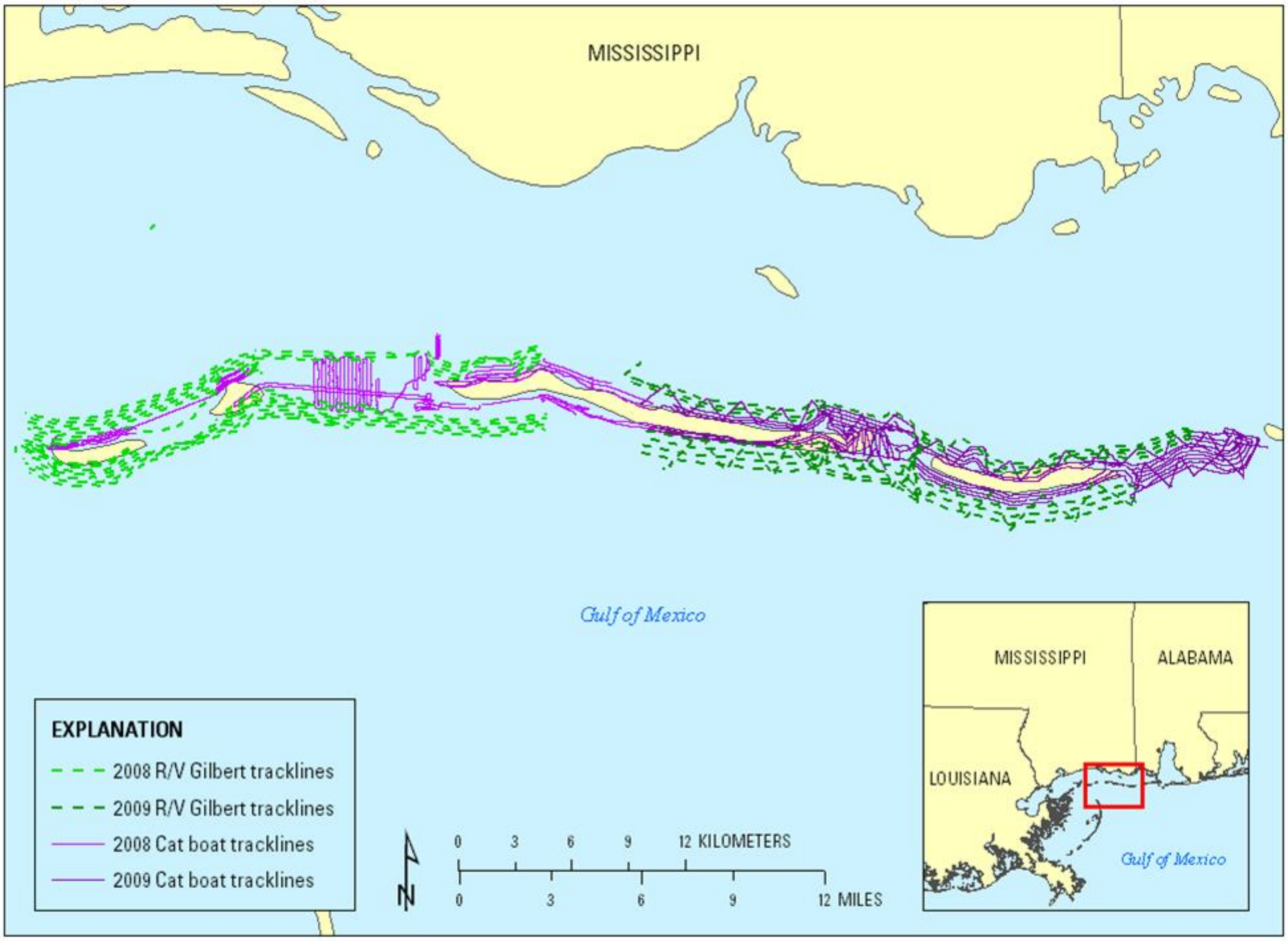

Figure 2. Tracklines from the 2008 and 2009 summer surveys that collected data used in the benthic substrate map. The surveys were funded as an in-kind contribution from the U.S. Geological Survey's Coastal and Marine Geology Program's Northern Gulf Of Mexico project.

A combination of two boats was used: a 22-foot (ft) Catboat for surveying in shallow water to 3 meters (m) in depth, and the *R/V Gilbert*, owned by the USGS, was used for collecting data in water depths from 3 to 20 m. Survey lines were spaced approximately 200 m apart in a shore-parallel orientation with tie-lines crossing at an oblique (zigzag) pattern (fig. 2). Data were collected from the oblique survey tie-lines in order to maximize the number of crossings within the available timeframe and to correlate with survey tracklines collected in the 1890s.

The acquisition hardware consisted of four separate units: a differential global positioning system (GPS) on land (base station), a differential GPS on the survey vessel (rover), a motion sensor (vessel heave, pitch, and roll), and a 468-kilohertz (kHz) Swath*plus* interferometric sonar (SEA, 2009). The hardware units on the vessel were mounted in-line on a rigid pole with the swath transducers just below the waterline. The motion sensor was housed in a watertight steel container mounted above the transducers, and the GPS choke-ring antenna was mounted at the top of the pole 3 m above the transducers.

The antennas received the positioning signal from the Navigation Signal Timing and Ranging (NAVSTAR) GPS satellite constellation. Two Ashtech Z-Xtreme GPS receivers with internal data card storage recorded simultaneously 12-channel full-carrier-phase positioning signals (L1/L2) from the satellites. The base and rover receivers recorded their positions concurrently at 1-second recording intervals throughout the survey period. Boat motion (heave, pitch, and roll) was recorded at 50-millisecond (ms) intervals using a TSS DMS-05 sensor. Two land-based benchmarks maintained by the National Geodetic Survey are located on the mainland of Ship Island, and a third benchmark was installed by the USGS on Horn Island. These stations recorded position relative to GPS satellites throughout the survey.

Data from the GPS receiver and motion sensor were streamed in real time to a laptop computer running the HYPACK MAX version 4.3A (HYPACK, Inc.) marine surveying, positioning, and navigation software package. The acquisition software combines the data streams from the various components into a single raw data file, time-stamped to the nearest millisecond. The software also manages the planned-transect information, providing real-time navigation, steering, correction, data quality, and instrumentation-status information to the boat operator. Swath data were recorded separately and merged with the navigation data during post-processing using Caris SIPS software (Version 7.0).

Data Processing

Swath Backscatter Data

Backscatter data generated by the Swath*plus* system were processed separately from the bathymetry data by reading raw data files (.sxrs) through Swath*plus* (versions 3.5.19 and 3.6.0) two times and specifying output parameters for each data type. Generating two separate processed files, one for bathymetry and one for backscatter, allowed the utilization of SXPtools, which was created specifically for enhancing backscatter contained in processed Swath*plus* data files (.sxps) (Finlayson, 2008). SXPtools runs on .sxp files created by saving all the sounding data, such that both the rejected and accepted soundings identified by bathymetry filters are preserved. SXPtools computed an empirical gain normalization on the soundings in the original .sxp file and wrote a new .sxp file with processed amplitudes. The new .sxp file was then imported into SonarWiz.Map, and tiff images at 0.25- and 0.5-m were created from the normalized backscatter data (CTI, 2009).

Initial interpretations of backscatter data defined six major categories of backscatter intensity: high backscatter, low backscatter, high-medium backscatter, low-medium backscatter, irregular, and patchy/speckled. These data are inverted so that dark regions in the data represent high backscatter and are interpreted as coarser-grained sediments (sand) and light regions are low backscatter and represent finer-grained sediments, specifically, mud composed of silt or variable mixtures of silt and clay (fig. 3*A*).

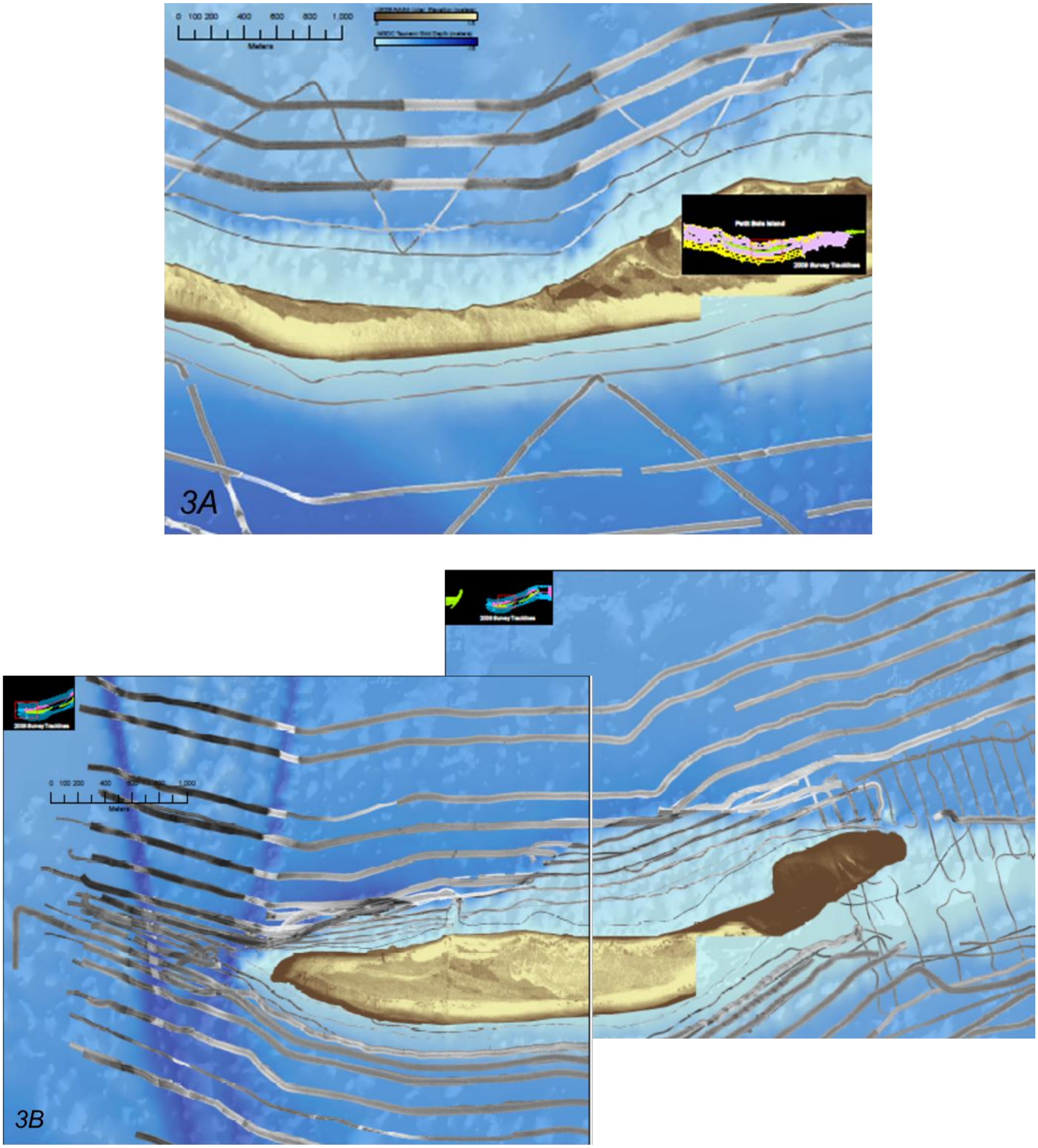

Figure 3. *(A)* Examples of backscatter returns north of Petit Bois Island. The light returns or low reflectivity (signals have been inverted 180° during data processing) are interpreted to be fine-grained muds whereas the dark returns are interpreted to be sandy sediments. *(B)* Examples of backscatter returns from West Ship Island; the light returns from the Gulfport shipping channel represent fine-grained muds while the dark returns between the old and new shipping channels are coarse to medium sands.

Areas of low backscatter are present north of the islands; for example, the backscatter returns between the old and new Gulfport ship channels are portrayed as very dark areas (high returns) compared with the lighter areas (low returns) from the channels themselves (fig. 3*B*). The dark areas are interpreted to be sands; the lighter areas are interpreted to be muds. The various categories and boundaries were mapped and are interpreted to be analogous to sand, mud, transitional sandy mud, muddy sand, structures with some relief (for example, sand ripples), and a patchy bottom that may be biological in nature (seagrass or other similar growth), respectively. The shipping channels are well defined in the data and are a seventh category included within the anthropogenic class of bottom types.

ArcGIS

Processed backscatter tiff images were compiled in an ESRI ArcGIS file geodatabase for classification of substrate type. The tiff files (0.25-m resolution for 2008 data and 0.50-m resolution for 2009 data) were converted to raster format, projected using the North American Datum of 1983, Universal Transverse Mercator Zone 16N coordinate system, and loaded into ArcMap. A directory was created consisting of six feature classes representing the major types of backscatter return. These were interpreted as classes and subclasses within primary major components following the Coastal and Marine Ecological Classification Standard (CMECS) guidelines. Briefly, CMECS is a classification standard developed by the National Oceanographic and Atmospheric Association (NOAA) to streamline classification schemes among agencies (fig. 4); the standard contains a geological component to classify surface geology. The CMECS classes utilized in this mapping region are as follows:

Surface Geology Component (SGC)

- Class 1: Unconsolidated Bottom
  - Subclass 1: high backscatter (sand)
  - Subclass 2: high to medium backscatter (sand/mud intermediate)
  - Subclass 3: medium to low backscatter (sand/mud intermediate)
  - Subclass 4: low backscatter (mud)

Geoform Component (GFC)

- Class 1: Anthropogenic
  - Subclass 1: dredged channels
  - Subclass 2: disposal area
- Class 2: Geologic features
  - Subclass 1: geologic features, geologic structure (sand waves, ripples, irregular bottom)

Biotic Cover Component (BCC)

- Class 1: Aquatic bed
  - Subclass 1: rooted vascular, biotic group: seagrass
  - Subclass 2: patchy/speckled backscatter (possible organic component)

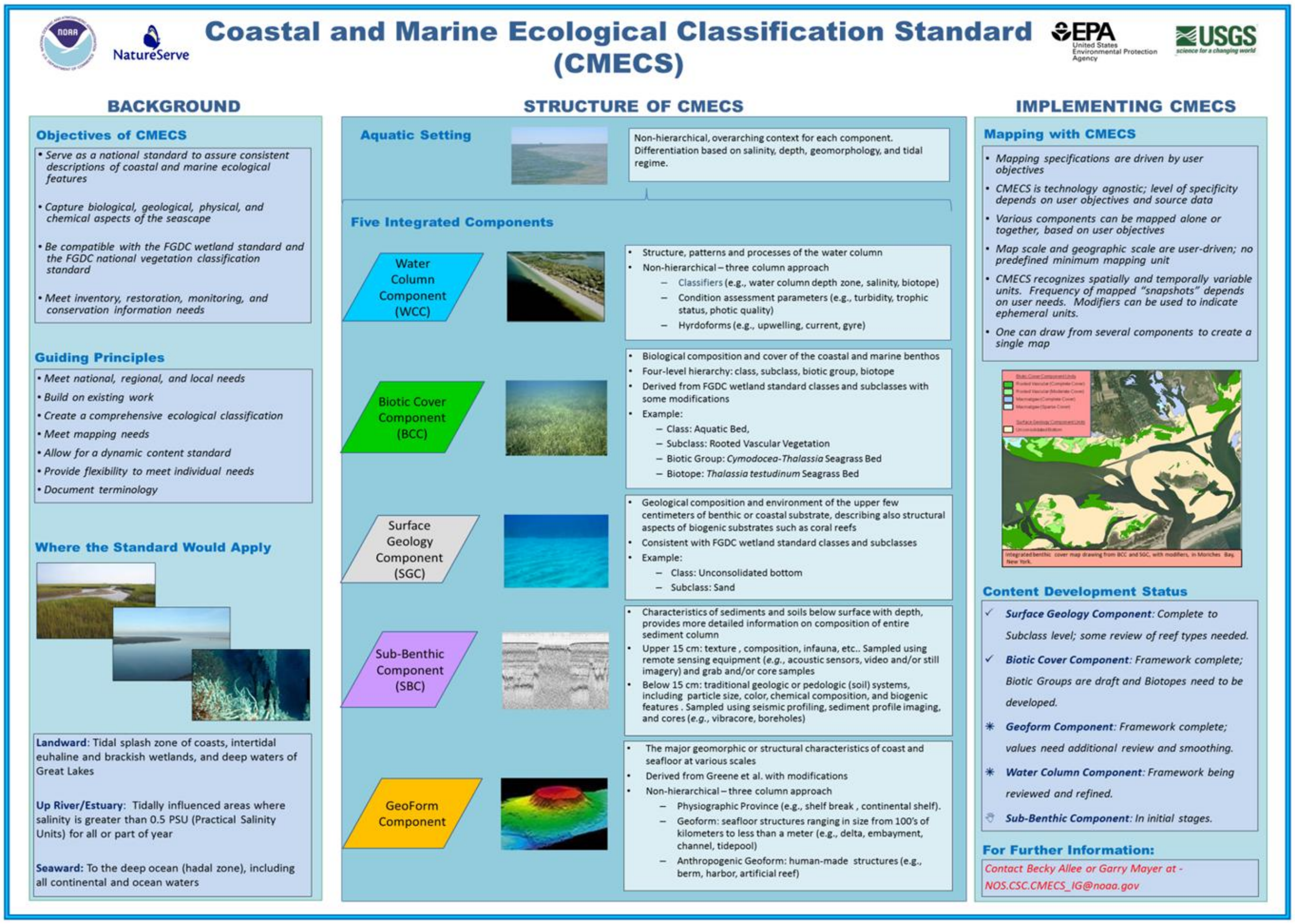

Figure 4. Coastal and Marine Ecological Classification Standard (CMECS) classification scheme developed by NOAA. Components interpreted in the Gulf Islands National Seashore include the surface geology component, the geoform component, and the biotic cover component.

An initial attempt was made to analyze the data using a supervised classification scheme; however, the line spacing was such that the data density did not support this method. Therefore, polygons for each subclass were drawn and edited with ArcEditor based on visual interpretation of backscatter intensity and presence of geoforms. The finalized polygons were then smoothed manually and cleaned.

Seagrass locations in regions shallower than 2 m were added to the map based on "Decadal-scale changes in seagrass coverage on Mississippi barrier islands, Northern Gulf of Mexico" by Carter and others (2009). Additional areas of seagrass or other organic bottom material were interpreted from the backscatter return.

All of the preceding interpreted categories of backscatter data are based on return-signal characteristics that were compiled into a benthic substrate classification map (fig. 5). The geoform component categories were verified by collecting grab samples and photographs in areas where swath backscatter data were unresolvable. Grain-size analyses on these samples were used to calibrate acoustic boundaries delineated on the benthic substrate map.

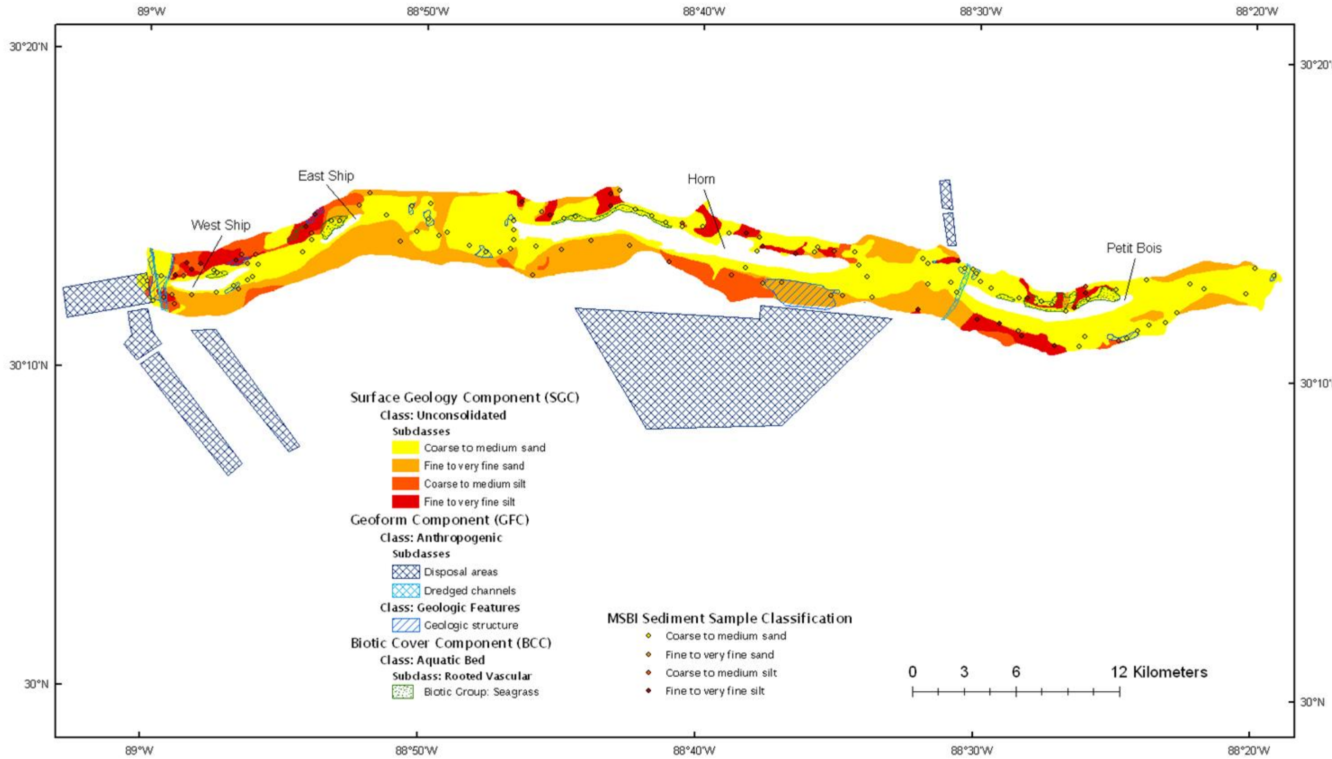

Figure 5. Mississippi barrier islands benthic substrate classification. Geology components are based on geophysical data. Core samples were analyzed to verify geophysical interpretations and are denoted by small circles overlain on interpreted surface geology components.

Ground Truth Data

In March 2010, 132 sites were sampled to ground truth acoustic interpretations. Photographs using a bottom camera were taken when possible at each site and augmented with photographs of recovered samples on board the ship. Photographs illustrate a homogeneous sandy bottom (fig. 6), except in a few instances where seagrass is present or between the passes where burrowing is common (fig. 7). Much of the non-sand bottom is covered by a layer of very soft mud (fig. 8); in some areas, the sand was also covered by the same soft, muddy layer.

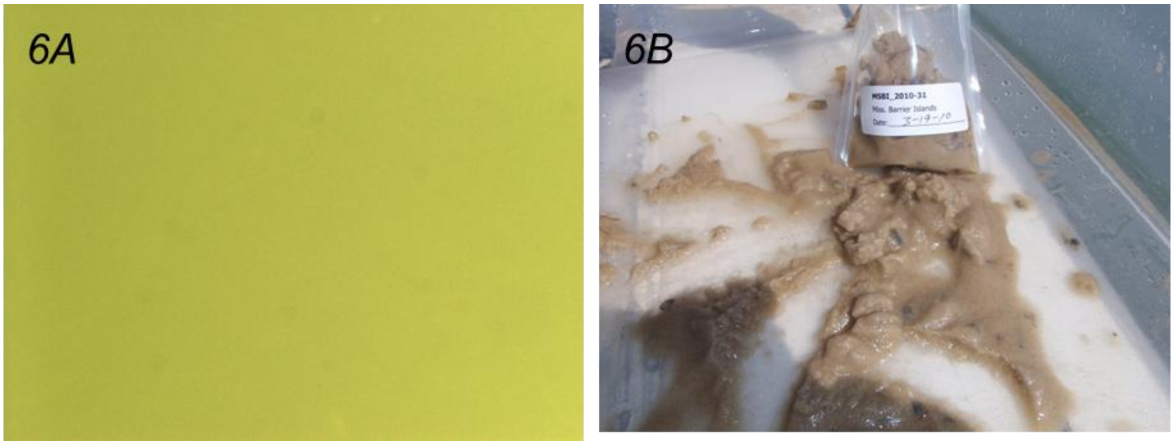

Figure 6. *(A)* Bottom photograph of typical sandy substrate near West Ship Island and *(B)* topside photograph of the same homogeneous sand, similar to beach sand near East Ship Island.

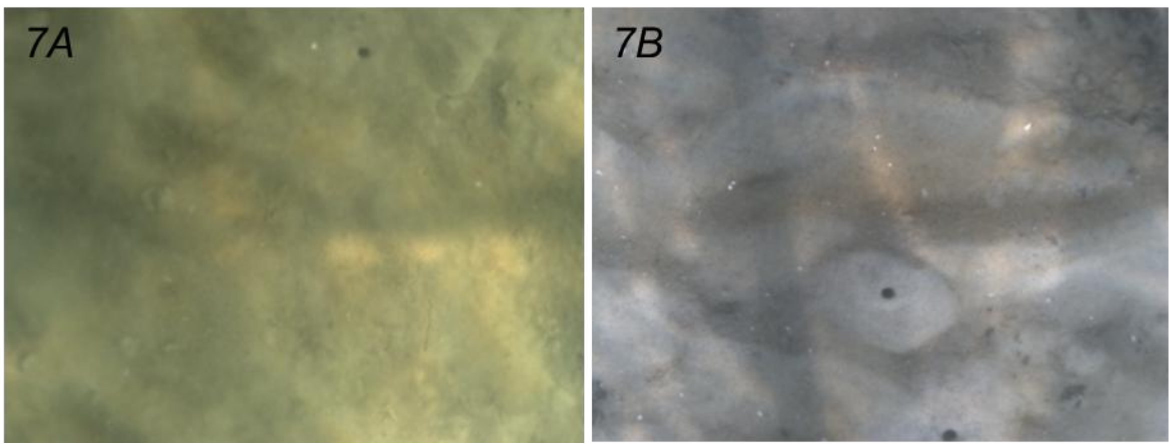

Figure 7. Photographs showing *(A)* seagrass from the northern side of West Ship Island (C10) and *(B)* burrowing east of West Ship Island (C16) and commonly found in the passes between the islands.

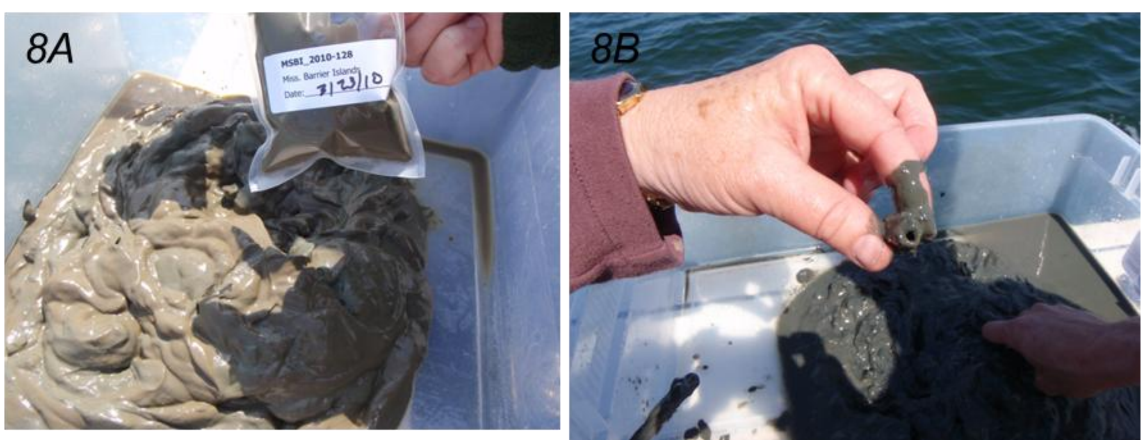

Figure 8. Photographs showing *(A)* soft mud covering much of the non-sandy bottom (C4) just north of West Ship Island and *(B)* burrows in muddy bottom north of East Ship Island (C29).

Samples were collected using a ponar grab sampler and stored for textural analyses by the USGS Coastal and Marine Science Center in St. Petersburg, Florida. Analyses were conducted using a Beckman Coulter *LS 200* particle-size analyzer. This instrument utilizes laser diffraction to measure the size distribution of sedimentary particles 0.375 to 2000 microns (μm) in diameter by shining a laser on particles suspended in solution. The light is scattered in characteristic patterns based on particle size and is measured by photodetectors as intensity per unit area and sorted into 92 size-classification channels. The relative amplitude of light intensity for each channel is interpreted as the relative volume of spherical particles of that size. The bin counts produced by the *LS 200* were used to calculate cumulative weight percentages for the 5, 10, 16, 25, 50, 75, 84, 90, and 95 percentiles. From these measurements, mean grain size and sorting (Inman, 1952) are reported in mm and phi intervals. The utility of the *LS 200* is the high reproducibility of measurements, rapid acquisition of results, ability to accurately and quickly provide quantitative measures of extremely small grain-size fractions, and customizable data output.

Prior to analysis in the *LS 200* module bath, sediment samples were resuspended in water by stirring and sonication; however, if the material resembled silt or clay, a sodium hexametaphosphate solution was added to aid in disaggregation. Samples were dispersed by pipette until an 8- to 12-percent solution concentration was obtained. This procedure was repeated three times for each of three sample aliquots to calculate standard deviation. Nine values, the three measurements for each of the three aliquots, were averaged to produce a single analysis per sample. If one measurement of an aliquot departed from the other two by greater than one standard deviation, it was considered a statistical anomaly and was removed, leaving the remaining two measurements. Because the *LS 200* treats all sediment particles as spherical, some aliquots containing nonspherical sediment resulted in statistical outliers and were reanalyzed to produce reliable results.

Sediment data output was compiled and analyzed using Gradistat (Version 8.0). The Gradistat program produces an output of versatile statistical results calculated arithmetically and geometrically (in metric units) and logarithmically (in phi units) using statistical moments and Folk and Ward graphical methods. Statistical moment includes mean, mode, sorting, skewness, and other statistics to provide the most robust comparisons of compositionally variable sediments (Blott and Pye, 2001).

Samples were texturally classified to a descriptive size classification and mean percentages of sand, silt, and clay were reported for each sediment sample in the Gradistat data output. The percentage data provided for each sample were combined and plotted onto a ternary diagram.

Results

The figure 9 maps indicate that, in general, the predominant bottom type around the islands is interpreted from a high backscatter to be sand that generally becomes finer with increasing distance from the islands. For example, East and West Ship Islands are surrounded by coarse-to-medium sand (high backscatter), and Camille Cut between the two islands is entirely sandy. The bottom becomes muddy (low backscatter) relatively close to the islands to the north. To the south, the bottom remains sandy although the grain size decreases to a fine sand with only small patches of mud present. These interpretations have been confirmed by sediment textural analyses. Toward the west, the bottom substrate remains sandy, containing a few patches of biological cover.

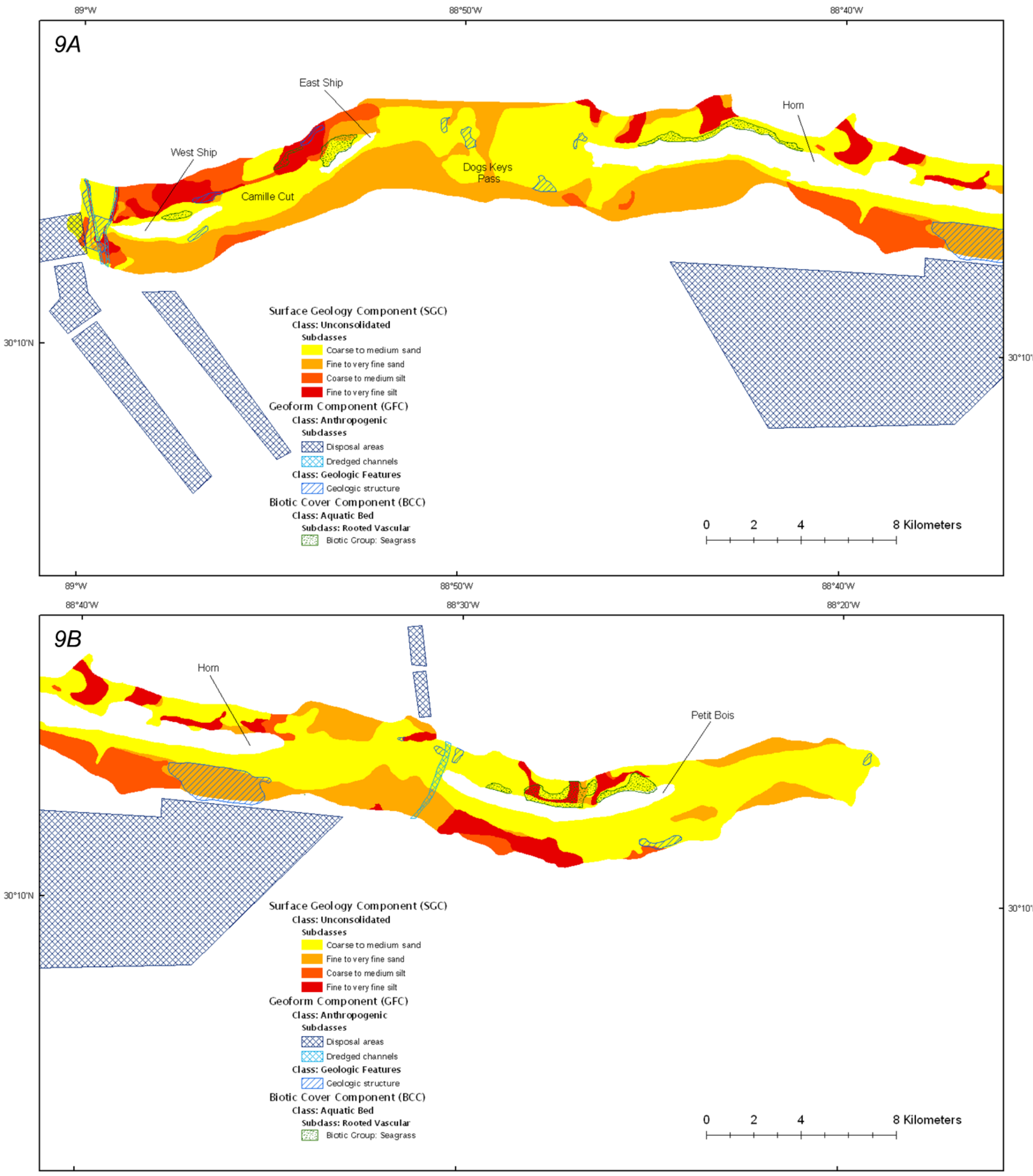

Figure 9. *(A)* Low-intensity backscatter returns north of East and West Ship Islands (red) are fine-grained muds that predominate north of the islands and in the dredged shipping channels. The high-intensity backscatter returns (in yellow) are medium- to coarse-grained sands and are primarily south of the islands and in the passes between the islands. *(B)* A similar pattern of sand as in *(A)* is present at Horn and Petit Bois Islands. Both islands are surrounded closely by sands (yellow), with interfingering finer-grained sediments on the north side the islands and to the south of Petit Bois Island.

A similar pattern of bottom-substrate types is present around Horn Island. The nearshore bottom substrate south of the island is coarse-to-medium grained, becoming finer-grained farther south. North of Horn Island, sand is the predominant bottom type close to the island, although muddy patches appear to intrude from the north (red in fig. 9). Again, this pattern has been confirmed by bottom sampling. Petit Bois shows the same pattern, including the tongues of mud that intrude from the north. However, a more extensive mud bottom exists farther to the south of Petit Bois compared to Horn island.

Bedforms are found in many areas, particularly to the south of the islands (fig. 9). Owing to widely spaced tracklines, it was assumed that the bedforms remained continuous over the entire patches outlined on the bottom-substrate map: for example, the small patch south of Petit Bois Island, the much larger patch to the south of the eastern part of Horn Island, those in the middle portions of Dog Keys Pass, and those unexpectedly found to the north of the eastern tip of West Ship Island.

Seagrass, where mapped, is located in the shallow waters on the north sides of the islands where protected from surge, shrimping activities, and excessive turbidity. Most of these data, depicted as patchy seagrass, were taken from Carter and others (2009) (fig. 9); however, the large patches outlined in green were interpreted from the returned backscatter signals. These beds were verified with bottom photos and samples.

Anthropogenic features are primarily ship channels, clearly defined in the backscatter records. No attempt was made to classify the bottom substrate within these features.

Textural analyses plotted on a ternary diagram indicate that the primary bottom substrates range between sand and silt, with very little actual clay (fig. 10). Actual grain size analytical data show clay composition is generally less than 10 percent, although it ranges up to 14 percent in nine cases.

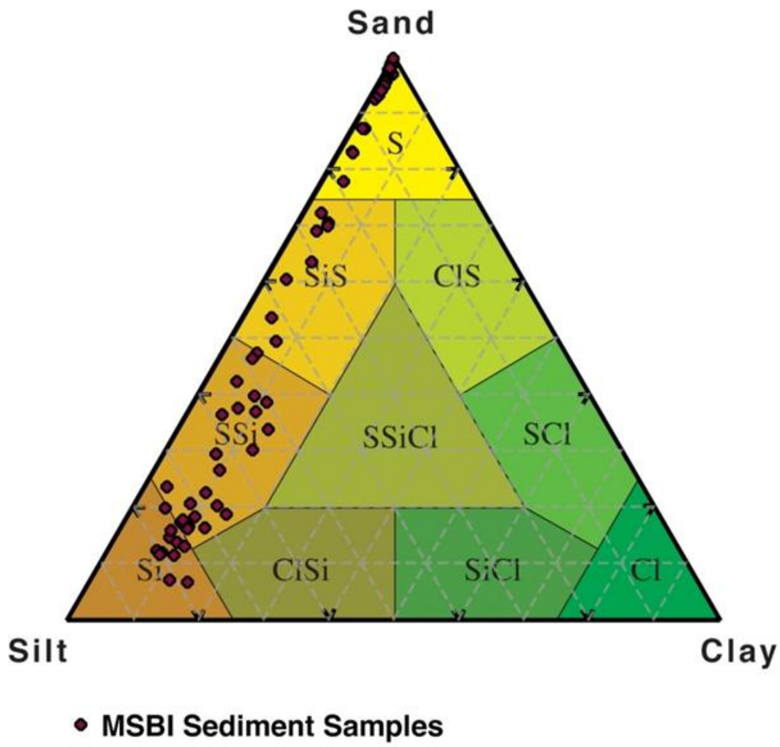

Figure 10. Ternary diagram of grain size results for the 132 samples collected around the Mississippi barrier islands. Most samples plot as sand, or between sand and silt.

Discussion

West and East Ship, Horn, and Petit Bois Islands form an east-west string of linear, shore-parallel barriers that probably resulted from the aggradation of sediments over a Pleistocene ridge during the late Holocene (Otvos, 2004). At that time, a surplus of sand in the alongshore sediment-transport system nourished and sustained the islands. Although the islands are much decreased in size, they are the subaerial expression of a nearly continuous sand platform that is substantially shallower than the surrounding Gulf of Mexico and Mississippi Sound (Morton, 2007).

The Mississippi barrier islands are highly dynamic, eroding on the eastern ends and accreting on the western ends, resulting in an east-to-west alongshore sediment-transport system. The islands are especially vulnerable to storms, during which island segments may migrate landward as a result of Gulf-side erosion and overwash fan deposition. Waves and currents rework the sandy overwash, and much of the sand is incorporated into the sandy platform and molded into large subaqueous bedforms (Morton, 2007).

These large subaqueous bedforms may be represented on the bottom-substrate map as large yellow patches (high-backscatter areas of return) immediately to the south (particularly) of Petit Bois and Horn Islands and as smaller patches south of East and West Ship Islands (fig. 5). The passes between the islands are predominantly medium-to-fine grained sand; currents within the passes probably keep fine-grained material in suspension.

The fine-grained material is present in the quieter hydrodynamic regime primarily north of the islands where deposition is possible. Similarly, the material in the bottom of the dredged channels (red) is fine to very fine grained silt. A large patch of fine-grained sediment immediately to the south of West Ship Island and adjacent to the Gulfport shipping channel may represent the terminus of the sediment-transport system and may be part of a wider part of the channel or spoil area.

The Mississippi Sound is underlain by muddy sediments, primarily kaolinite and illite, similar to sediments from Mobile Bay (Milne and Shott, 1961). The increasing montmorillonite content in the western portion of Mississippi Sound and north of East and West Ship Islands may reflect the influence of the Mississippi River Delta. Barrier-island sands have spread over this characteristically muddy bottom and are reflected in the overlying sandy fingers on the northern side of the islands.

If closely spaced sub-bottom records were available, they would probably show sandy beds within the muddy bottom areas reflecting the impacts of large storms. For example, sandy Camille event beds have been recorded (Keen and others, 2004) and undoubtedly, other storm beds from Hurricane Katrina are present as well.

The areas mapped as geologic structures may be sand waves; their exact size was not determined through ground truth sampling. However, these areas of bottom structure are in relatively high-energy regions south of the islands and are not found in the protected low-energy regions north of the islands. The distribution of these structures may be more extensive than noted in the bottom-substrate map herein because isolated detections in the returns were ignored. With closer line spacing, it seems probable that many more areas of sand waves and similar bedforms could be identified.

Seagrass locations from Carter and others (2009) were found on the northern side of the islands. The data for Petit Bois and Horn Islands were taken directly from Carter and others (2009). Other data interpreted from backscatter returns are probably valid close to the islands on their northern sides, and areas interpreted as organic bottom away from the islands were targeted during the spring ground-truthing cruise; however, bottom sampling was inconclusive. Burrowing was evident in some of the areas delineated as organic bottom.

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