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A GEOLOGICAL INVESTIGATION OF THE OFFSHORE AREA ALONG FLORIDA'S NORTHEAST COAST YEAR FIVE (STATE FISCAL YEAR 2011-2012) ANNUAL REPORT SUBMITTED TO THE UNITED STATES DEPARTMENT OF THE INTERIOR

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EXECUTIVE SUMMARY

The Bureau of Ocean Energy, Management, Regulation and Enforcement (BOEMRE) (formerly the U.S. Minerals Management Service [MMS]) and the Florida Geological Survey (FGS) have a long history of studying the marine sediment resources offshore of the state of Florida through cooperative investigations. Currently this includes a multi-year study titled "A Geological Investigation of the Offshore Area along Florida's Northeast Coast" (Under MMS-FGS Cooperative Agreement Award No. M10AC20019). Specific goals of this study include the identification of the location, areal extent and volumes of potentially available restoration-quality sand resources (*i.e.* borrow material) underlying federal waters offshore of Nassau, Duval, St. Johns, Flagler, Volusia and northern Brevard Counties and the characterization of current beach sediments in the study area.

This report discusses data and interpretations derived from specific tasks accomplished during Year Five (State Fiscal Year 2011-2012) of the agreement. Offshore exploratory work was conducted in federal waters adjacent to state submerged lands offshore extending from three nautical miles (5.6 kilometers [km]) from the coast of Volusia and northern Brevard Counties, Florida, out to approximately 13 nautical miles (24.1 km). This report provides an interim update of ongoing investigations of available restoration-quality sand resources within the study area prior to the completion of a final report. It also references those data presented in previous yearly reports and includes in its analyses data collected from offshore of Volusia County in Year Four.

Sampling and marine geophysical data collection to date include native beach sediment sampling, bottom sediment sampling, and seismic profiling. While the task of beach sediment sample collection on the beaches of Brevard County was conducted by the FGS independent of this study, analyses of a portion of those sediment samples were conducted in Year Five. Seismic reflection profiler data acquired in Year Five were collected in federal waters offshore of Volusia County and the northern portion of Brevard County. Data from offshore vibracores collected by consultants to Volusia County were utilized as well.

The analyses of sediment samples, and the acquisition and processing of seismic reflection profiler data are summarized as follows:

- *Seabed Sample Analyses:* A total of 18 samples collected from the seabed in federal waters offshore of Volusia County were described and granulometrically analyzed. Photographs, descriptions and the results of granulometric analyses of those samples, and three samples collected offshore of Volusia County in 2005, are provided in this report.

- *Beach Sample Analyses:* A total of 28 samples, which comprised the swash zone samples from 28 locations previously collected from the beaches of Brevard County, were described and granulometrically analyzed. Photographs, descriptions and the results of granulometric analyses of those samples, and the back-beach samples from these locations, are provided in this report. These data were incorporated with the analyses of beach sediments of Volusia County and curves were prepared of mean grain size and carbonate percentages for Volusia and northern Brevard Counties.

- *Vibracore Analyses:* Vibracore logs and data from 120 vibracores, collected offshore of Volusia County by others, were analyzed for the purposes of qualifying and quantifying available offshore restoration-quality sand reserves.

- *Seismic Reflection Profiler Data:* approximately 387 statute miles (623 km) of seismic reflection profile data collected in federal waters offshore of Volusia and northern Brevard Counties in Year Five were processed, interpreted and plotted with those data collected offshore of Volusia County in the preceding years. The seismic reflection profile data collected in Year Five offshore of Volusia and northern Brevard Counties, as well as those data collected offshore of Volusia County in Year Four, are provided as processed images.

- Analysis of the shoals in federal waters offshore of Volusia County was performed and a compilation made of estimations of their reserves of beach restoration-quality sand.

Seismic stratigraphic analyses of the seismic reflection profiler data collected in previous years indicated the presence, offshore of Volusia County, of areas of anomalous dip in the subsurface which exhibit no relief on the seafloor. These features are believed to be related to the dissolution of underlying strata.

INTRODUCTION

Beach erosion is a constant concern in Florida and shore protection options, in substantial portions of the region, are limited by extensively urbanized coastal sectors which have significant commercial and residential development proximal to the beach. Such conditions make the option of asset relocation or abandonment generally unpalatable. The shore protection measure of choice is the periodic placement of sand along the beach (Phelps *et al.* 2009).

Despite the recent prolonged economic recession, it is anticipated that coastal development of the state will continue to proceed. As readily available onshore sources of suitable borrow material are increasingly depleted or uneconomical to extract and demand has exceeded the supply of suitable material offered by the periodic dredging of inlets to insure adequate channel depths for their safe navigation, offshore sand bodies have been sought after as sources of beach restoration-quality sand. To address this need, the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) of the United States Department of the Interior and the Florida Geological Survey (FGS) entered into a multi-year cooperative agreement to investigate the available restoration-quality sand resources offshore of the northeastern coast of Florida. Its purpose is to locate and characterize both the areal extent and volume of restoration-quality sand resources lying in federal waters offshore of northeastern Florida which are available for beach renourishment. This goal is being accomplished through the use of seismic reflection profiling, seabed sampling and beach sediment sampling, as well as the analyses of offshore vibracore data.

This report documents the findings of the Year Five investigation. It provides and discusses in detail those data obtained and/or analyzed in Year Five (State Fiscal Year 2011-2012), and presents conclusions drawn from those data. This report deals with data acquired on the beaches and in federal waters offshore of Volusia and northern Brevard Counties. As the southern portion of Volusia County's beaches lie within the Cape Canaveral National Seashore, it is anticipated that most, if not all, future beach restoration efforts will be conducted in northern and central Volusia County and north of Ponce de Leon Inlet.

Information derived from this study will assist the BOEMRE in making decisions concerning the future use of the available restoration-quality sand deposits delineated within the study area and serve to expedite sand replenishment of beaches adversely impacted by hurricanes and-or winter storms in future years. This report includes photographs and granulometric analyses of samples collected by the FGS on the beaches of Brevard County and offshore of Volusia County. It ties vibracores collected in federal waters offshore of Volusia to seismic data collected both in Year Five in federal waters offshore of Volusia and the northern portion of Brevard Counties and in Year Four offshore of Volusia County. Both sets of geophysical data are provided in this report. This information can be accessed using one of four methods:

1. From the on-disk ArcMap project. Please note that ArcMap 9.x is required to access it. Please see the ArcGIS Project page for further information.

2. From the ArcPublisher map. Please note that accessing this web project requires downloading and installing the free ArcReader on your machine. This reader can be obtained at the following URL address:
   http://www.esri.com/software/arcgis/arcreader/download.html
   Please see the ArcGIS Project page for further information.

3. From the sample or seismic reflection profile indices, as appropriate, within the DVD.

4. From the pertinent appendices within this report text.

DEFINITIONS

That portion of the state of Florida and adjacent federal waters, consisting of the beaches and inner continental shelf offshore of Volusia and northern Brevard counties comprise what is herein referred to as "**the study area**". The study area is shown in Figure 1.

Grab samples of beach sediments are herein referred to as "**beach samples**". The individual sites selected for the collection of multiple beach samples are herein referred to as "beach sampling locations". The beach sampling locations utilized are shown in Figure 1. Photographs of individual beach samples can be found in Appendix A. Grab samples of surficial seabed sediments are herein referred to as "seabed samples". The locations of these seabed samples are shown on Figure 1. Photographs of individual seabed samples can be found in Appendix B.

Depictions of vibracores, illustrating sedimentological change with depth, are referred to herein as "**core boring logs**". Core boring logs utilized in this report can be found in Appendix C. Geographically oriented depictions of multiple core boring logs, used to illustrate both lateral and vertical sedimentological change, are referred to herein as "**cross sections**".

Sediment analyses conducted to characterize a beach, seabed or vibracore sample's grain size distribution are referred to herein as "**granulometric analyses**". These granulometric analyses are graphically displayed on grain size determination "**GSD**" curves. GSD curves created from beach, seabed and vibracore samples can be found in Appendices A, and B and C, respectively. The sediment fraction referred to herein as "**fines**" is that material which will pass through the 4.00 phi, 0.0025 inch (63 micron) mesh opening of a # 230 sieve.

The instrument used to collect geophysical profiles of sub-seabed sediments, variously referred to in the scientific literature as a sub-bottom profiler, a sub-surface acoustic profiler, and a continuous seismic reflection profiler is herein referred to as a "**seismic reflection profiler**". The signal source of the seismic reflection profiler used in the Year Five survey generates repetitive impulses in two frequency bands. The returning reflections off the seabed and stratigraphic horizons within the sub-seabed sediments are received on hydrophones as pressure pulses. This data collection process, variously referred to in scientific literature as continuous seismic reflection profiling, subsurface acoustic profiling, and sub-bottom profiling is here in referred to as "**seismic profiling**". The seismic reflection profiler records produced through that process, either in digital or analog format, are referred to herein as "**seismic profiles**". The system utilized by the FGS in Year Five for this survey produced impulses, known as "**chirps**", in two bands of frequencies. While it simultaneously produced both high frequency, 8 to 23 kilohertz (kHz), and low frequency, 2 to 7 kHz seismic profiles, the high frequency profiles, due to the hard bottom conditions encountered, did not contain usable stratigraphic data. The seismic profiles produced can be found in Appendix D.

Signal energy for the survey conducted in Year Four was provided by an Applied Acoustic Engineering boomer sled towed approximately 30 feet (ft) (9.1 meters [m]) behind the survey vessel. For the Applied Acoustic Engineering sled, an Innovative Transducers, Inc. streamer cable was deployed for signal detection. The sled-mounted Applied Acoustic Engineering boomer signal source was towed at an approximate speed over the seabed of 4 knots, fired at a shooting interval of 500 milliseconds with record lengths of 100 or 120 milliseconds. A boomer generates its signal via the use of a rapidly moving electromagnetically controlled plate that imparts a pulse into the water column. For the Year Four survey, the boomer was configured so that most of the source energy had a frequency of 4 kHz. Data collected offshore of Volusia County in Year Four is included in this report.

The map trace of an individual seismic profile, as depicted in Figure 1, is referred to as a "**seismic line**". The assemblage of seismic lines, as depicted in Figure 1, is referred to as a "**seismic grid**". Individual seismic lines within the seismic grid lineating in a predominately east-west direction, as they run parallel to the regional dip of strata, are referred to as "**dip lines**". In contrast, individual seismic lines within this seismic grid lineating in a predominately north-south direction, as they run perpendicular to the regional dip of strata and/or along and thus parallel to the crest of linear bathymetric highs, are referred to as "**strike lines**". Individual seismic lines which intersect multiple dip lines facilitating the direct lateral correlation, from seismic profile to seismic profile, of various reflectors are referred to as "**tie lines**".

Geographical data acquired and used throughout this document use the World Geodetic System of 1984, herein cited as "WGS84," or NAD 1983 State Plane Florida East (feet), herein cited as "State Plane," as the datum. Maps included in this document use either WGS84 or State Plane as their primary coordinate systems. Bathymetric and elevation data acquired and used throughout this document use the North American Vertical Datum of 1988, herein cited as "NAVD 88," or National Geodetic Vertical Datum of 1927, herein cited as "NGVD 29," as the datum. Global Positioning System instrumentation used to collect geographic global positioning fixes and/or reference points are referred to as "GPS" instrumentation, fixes or points as applicable.

All "unit conversion factors", English to the International System of Units, i.e. Le Système International d'Unités, (SI) and SI to English, used in this report can be found listed on Table 1. These conversion factors were obtained from Eshbach and Souders (1975). Within the body of this report, when recourse to quantification of distance, weight or volume is required, quantifications are first expressed in English units followed, enclosed in parentheses, by their expression in SI units.

PREVIOUS WORK

Meisburger and Field (1975, 1976) discussed the results of their investigations of the Florida inner continental shelf from the Florida-Georgia state line to Cape Canaveral. In their studies, they collected and analyzed more than 1,153 nautical miles (2,137 km) of high resolution seismic profiles and data from 197 vibracores acquired in the late 1960s as part of the Inner Continental Shelf Sediment and Structure (ICONS) Program. The Meisburger and Field (1975) study discussed the geomorphology and shallow sub-bottom structure of the continental shelf within the study area as well as its surficial and sub-bottom sediments. The shoal nomenclature used in this report is that of Meisberger and Field (1975).

Offshore of Volusia County lie the shoals they designated as A9 and A10 as well as those they designated as B10 through B18. They did not vibracore shoals B10 through B18. However, they did find these linear, roughly north-south trending shoals to be morphologically similar to linear accretionary shoals off Fort Pierce and Cape Canaveral, as well as to shoals A9 and A10, all of which were vibracored by them and found to contain beach restoration-quality sand. They thought the B11 shoal to be a particularly good prospect as it appeared to them to be continuous with shoal A9. They describe shoals B15 and B16 as large flat-topped irregular shoals. While they did not core these two shoals, they did find clean medium sand in vibracores at their margins. All of these shoals, both A and B series, are shown on Figure 2.

Nocita *et al*. (1991) further analyzed vibracores collected for the ICONS Program and suggested that the region had several sites that might be potential borrow sites for beach renourishment purposes. Continental Shelf Associates, (Continental) working for Coastal Technology Corporation, (Coastal) did Volusia County offshore sand resource exclusionary mapping to identify offshore biological resources proximal to areas potentially containing reserves of beach restoration-quality sand (Continental Shelf Associates, 2004). Subsequent to that study Alpine Ocean Seismic Survey Inc. (Alpine) and Continental collected 29 reconnaissance vibracores offshore of Volusia County as part of Coastal's investigation of potential offshore reserves of available beach restoration-quality sand suitable for beach nourishment in Volusia County (Parkinson, 2005).

In that study, vibracores were obtained from shoals A9, A10, B10 through B14 as well as B17 and B18. Parkinson (2005) provided two sets of estimates of reserves of restoration-quality sand. The diminished available volumes provided in the lower of these two sets of estimates was a direct result taking into account the findings of the Continental (2004) report. Subsequently, portions of three shoals, designated by them as borrow areas B11-3, B12-1 and B13-3, were extensively vibracored by Alpine for Coastal (Parkinson and Budde, 2006). Ninety-one vibracores were spaced in a grid pattern among the three borrow areas with spacing within each borrow area generally equal to 1,000 ft (304.8 m). Vibracore length and spatial distribution was selected by them to ensure stratigraphic closure at the base and lateral margins of each of these prospective borrow areas. Phelps *et al*. (2006) discussed geophysical data collected in federal waters offshore of Flagler County as well as northern and central Volusia County. They noticed significant paleo-karstic features within the sediments for which no sea floor expression was observed. Zarillo and Zarillo (2011) investigated combining geological and numerical models to evaluate sand resources of shoals A9, B11 and B12 within the study area. These studies further analysed both the surficial seabed sediments and approximately the first 20 ft (6.1 m) of sediments comprising various shoals identified by Meisburger and Field (1975), both offshore of Volusia County and further north. Phelps *et al*. (2009), reported the results of sampling of the beach sediments of the east coast of Florida, conducted at a one mile sampling interval. Their analysis discussed in detail the sediments of the beaches of Volusia County and how they related to those sediments to the north and south on Flagler County beaches and Brevard County beaches, respectively. Some samples collected as part of that study, from the beaches of northern Brevard County, were granulometrically processed and analyzed for this study.

FIELD PROCEDURES AND LABORATORY ANALYSES

The exploratory phase of Year Five of this program involved the use of seismic profiling offshore of Volusia and northern Brevard Counties, analyses of beach samples from northern Brevard County, and the collection of seabed samples offshore of Volusia County. Seismic lines for the seismic profiling survey conducted offshore of Flagler and northern Volusia Counties were laid out as a reconnaissance seismic grid, with a north-south line spacing of one nautical mile, (1.85 km) between dip lines (Figure 1). The seismic grid lies in federal waters from three nautical miles (5.6 km) to over 13 nautical miles (24.1 km) offshore. North-south trending tie lines were collected offshore of Volusia and northern Brevard Counties. The reconnaissance grid spacing was a continuation of the Years One through Four seismic grid acquired offshore of Nassau, Duval, St. Johns, Flagler and Volusia Counties (Phelps *et al.,* 2003, 2004, 2005, 2006). The grid provides sufficient density to determine where additional supplementary seismic profiling and later reconnaissance seabed sampling might be conducted in future years.

As previously discussed in the Years One through Four reports (Phelps *et al.,* 2003; 2004; 2005; 2006) as well as Phelps *et al.* (2009), a simple alphanumeric scheme was utilized to identify unconsolidated sediment samples. All beach samples discussed in this report are identified with a two letter designation such as BV for Brevard County. This is followed by consecutive beach location numbers 01, 02, 03, 04, etc., and completed by a two letter designation indicating the sample's placement on the beach profile. More specifically, samples collected from the swash zone, beach berm, mid-beach and back-beach are designated SS, B, MB and BB, respectively. For example, a sample collected in Brevard County at sample location 1 in the swash zone would be delineated as BV-01-SS.

All samples collected offshore with a "clam shell" dredge sampler, are labeled with the beginning two letter geographic codes referenced above, followed by a multi digit sample number and the two letter designator "CG" for clam shell grab. Thus, a seabed sample collected offshore of Volusia County might be designated VO-104-CG.

Beach Sample Collection

Sampling locations were spaced at an approximate one statute mile (1.6 km) interval and at every fifth beach monument survey point, as established by the Florida Department of Environmental Protection's (FDEP) Bureau of Beaches and Coastal Systems (BBSC), where practicable. These sample locations are shown in Figure 1. Table 2 ties beach monument survey points to beach sampling locations. While it was intended that at each sampling location beach samples would be collected from the swash zone, the beach berm, mid-beach and back-beach, due to the narrowness of the beach, only swash zone and back-beach samples were collected from the beaches of Brevard County. These samples were collected as part of a project funded by the National Oceanic and Atmospheric Administration (NOAA). Fifty-six samples from a total of 28 locations in Brevard County, from the Volusia-Brevard County line to Cape Canaveral, were included in this study. GPS readings were obtained for each of the sampling points. While the elevation of the sediment surface relative to mean sea level was not recorded, these elevations did not exceed five ft (1.5 m). At each sampling point within an individual sampling location four individual replicate sediment samples, each totaling approximately 2 ounces (56.7 grams), were obtained for granulometric analysis. Samples were collected by scooping sediments from the surface to an approximate depth of one inch (25.4 millimeters [mm]) below the beach surface at each sample point using an approximately two ounce (56.7 gram) scoop. Photographs and granulometric analysis of the beach samples collected from the beaches of Volusia County, previously included in the Year Four report (Phelps *et al*., 2006), and Brevard County, north of Cape Canaveral, can be found in Appendix A.

Seabed Sample Collection

Seabed sample sites for Year Five were chosen to emphasize those areas with indicated potential for the presence of restoration-quality sands and to supplement those areas vibracored. Grain size distribution and percent carbonate content were determined for all seabed samples collected offshore of Volusia County in Years Four and Five.

Sample collection offshore of Volusia County for Year Five, was performed on August 4, 2011. Samples were recovered in Year Five using the FGS's Carolina Skiff and the clam shell dredge sampler illustrated in Figure 3. A total of 18 seabed samples were obtained. Sample VO-116-CG was obtained by consolidating the results of two sampling attempts. Photographs and granulometric analyses of the seabed samples collected in Year Five by the FGS, as well as three samples collected on September 29, 2006 and reported in Phelps *et al*. (2006), can be found in Appendix B.

Sediment Sample Processing

The sieve nest used in sample processing (Figure 4) by the FGS is described in Table 3. All granulometric analyses were conducted using the general guidelines of the American Society for Testing and Materials (ASTM) (2000a, 2000b) and specific procedures advanced by the FGS sedimentology laboratory (Balsillie, 1995; 2002a; 2002b; Balsillie and Tanner, 1999; Balsillie, *et al.* 1999; Balsillie *et al.* 2002a; Balsillie *et al.* 2002b; Balsillie and Dabous, 2003). Each sample was initially weighed after oven drying. The sample was then wet sieved through a 230 sieve (0.063 mm or 4 phi), oven dried and re-weighed with the weight loss being assigned to the fine fraction. The sample was then dry sieved and the portion of the pan fraction obtained during dry sieving was added to the fine fraction. The sample was then digested with a 4 molar hydrochloric acid solution, rinsed, oven dried, resieved and weighed again to establish the distribution of non-carbonate material.

Cumulative grain size distribution curves reflect the total grain size distribution (GSD) of each sediment sample. The weight of the fine fraction, consisting of the weight loss from wet sieving plus weight of the fraction passing through the sieve nest to the pan, was assigned to the finer than 4 phi fraction. Separate GSDs were determined for the carbonate and non-carbonate fractions of each beach and offshore sample along with the combined GSD for each sample. A link is provided in the grain size analysis column of the indices for beach and seabed samples (Appendices A and B, respectively).

For beach samples, sample #1 of the set was processed as described above. Sample #2, subsequent to being dried, was described and photographed. These descriptions and photographs can be accessed via the index under the photograph column and in Appendix A. Sample #3 of the set was dried and, of these samples, 17 samples were again processed like sample #1, for the purpose of granulometric analysis quality control. The results of the granulometric analyses are provided in Appendix E. Those samples not selected for processing were archived in the FGS's sediment sample repository.

For seabed samples, the procedures described above for beach samples were followed, with the exception that the seabed samples obtained were split using a sample splitter to obtain a suitable sample volume for sediment processing.

Restoration-Quality Sand Parameters

It is important to note that the thickness of available restoration-quality sand is determined in part by the percent fines content. Thus, restoration-quality sand resources are often limited vertically by the depth at which the fines content exceeds five percent, as specified in Chapter 62-41.007(5J) of Florida Administrative Code (Florida Administrative Code, 2001), unless the fines content on the beach to be renourished exceeds five percent and then only up to that percentage. With these provisos in mind, reserve estimates of restoration-quality sand at various sites offshore of Volusia County have been provided at five percent or less fines, using a boundary condition sand thickness of two feet (0.6 m).

Grain Size Distribution Curves

GSD curves are presented in the respective indices for beach and seabed samples. Separate GSDs were made for the carbonate and non-carbonate fractions of each sample obtained by the FGS along with a combined GSD of the entire sample.

Sediment Processing Quality Control

As a quality control check, a replicate sample was processed separately for 17 of the beach samples, 11 from Volusia County and six from Brevard County. The granulometric results were compared statistically with those obtained from the first samples to test similarity of the grain size distributions. Using the Mann-Whitney Test to compare the distribution medians and Levene's Test to compare the variances, at a 95 percent confidence there is no significant difference found between the distributions of the first and replicate samples. Graphical comparisons of initial and replicate samples can be seen in Appendix E.

Seismic Reflection Profiling

Seismic Reflection Profiler Data Collection

Approximately 387 statute miles (623 km) of seismic reflection profiler data were acquired in Year Five, with the bulk of these data being acquired offshore of Volusia County in federal waters, i.e. greater than three nautical miles (5.6 km) offshore. The data collection program consisted of 52 dip lines, 33 east-west and 19 north-south, and eight strike lines, two north-south and six northwest-southeast. A few short dip lines extend from longer dip lines or strike lines to the start of other longer dip or strike lines. Some strike lines cross and thus tie multiple dip lines while others extend from adjacent dip lines' end and start points. Locations for the east-west lines were chosen, on minutes of latitude, to provide an approximate one nautical mile (1.9 km) north-south grid. Figure 1 displays the location of all seismic reflection profiler data collected to date.

Past studies have shown that the highest quality sand accumulations are associated with bathymetric highs. The length of dip lines and the placement of the tie lines offshore of Flagler, Volusia and Brevard Counties were therefore determined by the eastward extent of bathymetric highs, and, in the case of tie lines, the strike of the crest of those highs.

The seismic profiles recorded for this study were collected aboard the FGS vessel R-V GeoQuest. The instrument utilized to collect the data for Year Five was a Benthos Chirp II® system. This system emits low frequency pulses from 2 to 7 kHz and high frequency pulses from 8 to 23 kHz at a rate of 240 pulses per minute. A Benthos Chirp II® towfish was towed approximately 30 ft (9.1 m) behind the boat below the sea surface. Figure 5 shows the Benthos Chirp II® towfish ready for deployment from the back deck of the R-V GeoQuest. Signal energy for the survey previously conducted in Year Four was provided by an Applied Acoustic Engineering boomer sled towed approximately 30 ft (9.1 m) behind the survey vessel. An Innovative Transducers, Inc. streamer cable was deployed for signal detection. The signal sources in both Year Four and Year Five were towed at an approximate speed over the seabed of four knots. The boomer system was configured so that most of the source energy had a frequency of four kHz.

Limitations imposed by weather, equipment, safety, personnel availability and the need to complete the project expeditiously substantially constrained the time window for seismic reflection profiler data acquisition in both Years Four and Five. In addition, Year Four data could only be acquired during day-light hours and over a two week period in a time of the year not particularly notable for good sea conditions in the study area. The data quality of the seismic reflection profiles obtained during the marine geophysical survey in Year Four was occasionally impacted by adverse sea conditions.

Computer Processing of Seismic Reflection Profiler Data

As was the case for data acquired in previous years, processing of the seismic reflection profiler data collected or acquired in Year Five was accomplished using the Sonar Web Pro© software package developed by Chesapeake Technologies, Inc. The sonic velocity utilized in data processing was 4921.2 ft/sec (1500.00 m/s), i.e. the average velocity of sound in sea water. While this is in keeping with standard practice in the processing of seismic reflection profiler analog records, the actual sonic velocity in the near seafloor sediments investigated, due to their higher density relative to sea water, progressively increases with depth and probably averages nearer to 5,905.44 ft/sec (1,800.00 m/s). As previously discussed in our Year Four Report (Phelps *et al*., 2006), this assumption is based on sonic velocities reported in Meisberger and Field (1975). They divided the sequence they investigated into three velocity layers:

- The uppermost layer, lying from 0 to 90 ft (0 to 27.5 m) below mean sea level (MSL), was estimated to exhibit a sonic velocity approximating that of sea water.

- The second layer, extending downward from 90 ft (27.5 m) below MSL, to its base ranging from 200 to 900 ft (61 to 274 m) below MSL, was estimated to exhibit sonic velocities ranging from 5,169 to 6,300 ft/sec (1,576 to 1,920 m/s).

- The third layer extending downward from its base ranging from 200 to 900 ft (61 to 274 m) below MSL to below the base of our recorded data was estimated to exhibit sonic velocities ranging from 7,218 to 9,514 ft/sec (2,200 to 2,900 m/s).

The top of their third layer lies near or below the base of data collected in Year Four and well below the base of the data collected in Year Five. As we lack sonic velocity data for the water column collected at the time the digital data were acquired, a detailed sonic velocity profile for the subsurface sediments being investigated, as well as recourse to sophisticated computer software capable of modeling such variable velocity gradients and utilizing the resultant output as a processing parameter, 4,921.2 ft/sec (1,500.00 m/s) was deemed an acceptable compromise value as it provides the most accurate depth estimations for the near seabed sediments of concern. The depth scales provided on individual seismic profiles should be considered to be approximations with the accuracy of those approximations declining with increasing depth. All digital data collected have been retained so that more sophisticated processing might be applied in the future. All of the seismic reflection profiler data collected in Year Five and those data collected offshore of Volusia County in Year Four can be accessed in Appendix D.

DATA ANALYSES

Beach Sediment Analyses

Phelps *et al.* (2009) divided the east coast of Florida into five regions based on mean grain size and carbonate percentage. The beaches of Flagler, Volusia and Brevard Counties, north of False Cape, lie in region two. In that region, they report that "…mean grain size and carbonate percentages both periodically spike in tandem and then decline southward. Where mean grain size and carbonate percentages spike, there is a strong separation between the pre- and post-carbonate curves. This separation suggests that the carbonate fraction is coarser (p.27)." They further state that "…south of Matanzas Pass the mean grain size and carbonate percentage curves spike with carbonate percentages going from less than 10 percent to over 80 percent (p.27)." They found that the curves gradually decline to a point south of Ponce de Leon Inlet where they spike again. They report that "…carbonate percentages at that point go from 10 percent or less to over 60 percent. From that spike, both sets of curves again decline with the decline in the carbonate curve the more apparent (p.27)." They locate the beginning of their third region at False Cape, in northern Brevard County, south of which there is a dip in the carbonate percentage curve followed by a substantial rise. Photographs as well as granulometric analyses of the samples collected from Volusia County and northern Brevard County, from the Volusia-Brevard County line to Cape Canaveral, are provided in Appendix A.

Figures 6 and 7, from Phelps *et al.* (2009), relate curves of average grain size both before and after carbonate digestion, obtained from back-beach samples, from Matanzas Pass in southern St. Johns County to Ponce de Leon Inlet in central Volusia County and from Ponce de Leon Inlet to Port Canaveral in Brevard County, respectively, to the coastline. Figure 8 provides mean grain size curves before and after carbonate removal, by acid digestion, obtained from Volusia County and northern Brevard County beach samples collected from both the back-beach and swash zone. The amount of carbonate material which comprises the coarser portion of individual samples is reflected in the separation between the pre-carbonate digestion and the post carbonate digestion curves. Figure 9 provides carbonate percentages for the same samples.

Comparison of the curves from both Figures 8 and 9 shows that where carbonate percentages are high, so is mean grain size. Comparison of these curves also shows that at sampling locations where mean grain size is low, carbonate material comprises more of the back-beach samples compared to swash zone samples. The inverse is true at sampling locations when mean grain size is high and carbonate material predominate the samples. Across Volusia County and into Brevard County examination of Figures 8 and 9 reveal distinct shifts in both mean grain size and carbonate percentages. Mean grain size and the percentage of carbonate material both gradually decline southward toward Ponce de Leon Inlet, which lies between sample locations VO-30 and VO-31. That decline is interrupted by localized peaks in the back-beach sample set in both figures at sample locations approximately three miles (4.8 km) north and two miles (3.2 km) south of the inlet. Curves comparing grain size from back-beach samples collected immediately adjacent to, as well as approximately one mile (1.6 km) north and south of the inlet are shown in Figure 10. Those grain size curves show virtually no difference immediately north and south of the inlet. The curve sets on both Figures 8 and 9 rise dramatically south of sample location VO-37, approximately eight miles (12.9 km) south of the inlet. The mean grain size shown on the pre-digestion curves averages less than 0.25 mm on Figure 8 north of sample location VO-37 and increases to greater than 0.5 mm south of that location. The carbonate percentages of both the swash zone and back-beach samples are ten percent or less on Figure 9 north of sample location VO-37 and rise to greater than 60 percent south of that location. As shown on Figures 8 and 9, mean grain size and carbonate percentages for both swash zone and back-beach samples gradually decrease southward to False Cape, locations BV-16 through BV-20, after which they increase again.

Photographs, as well as granulometric analysis, of the samples collected from the beaches of Volusia County and Brevard County, north of Cape Canaveral, can be found in Appendix A.

Offshore Data Analyses

Three sets of offshore data, consisting of seabed grab samples, vibracores and sub-bottom profiler seismic lines were analyzed. Twenty-one seabed samples were collected by the FGS offshore of Volusia County, three in 2005 and eighteen in 2011. One hundred and twenty vibracores, collected by Alpine and processed by Coastal for Volusia County, were analyzed. Approximately 387 miles (623 km) of sub-bottom profiler data were collected, processed and analyzed. These data sets are provided in Appendices B, C and D. In Year One, bathymetric data were acquired through the National Geophysical Data Center's (NGDC) Geophysical Data System (GEODAS) of NOAA. The data included a collection of bathymetric surveys; however, the primary surveys were from 1983 from the United States Geological Survey (USGS) Branch of Pacific Marine Geology.

As all of these data were collected to analyze potential reserves of beach restoration-quality sand, and those sands are located on shoals, our analyses of the data proceeds shoal-by-shoal from north-to-south. The locations of these shoals, as identified by in Meisberger and Field (1975), in comparison to a 60 foot bathymetric contour generated from the more recent data (1983), are shown in Figure 2. In addition, ten cross-sections spanning these shoals were identified and are also shown in Figure 2. These cross-sections, in addition to showing vibracoring accomplished in the area, show the bathymetry from surveys accomplished in 1983 and 2004. Cross sections provided in this shoal-by-shoal analysis frequently show that the seabed, in the time between bathymetric surveying in 1983 and vibracoring in 2004 and 2005, has changed over the years in response to storms and currents. For the vibracores collected in 2005 that are shown on these cross sections, comparisons of their tops to the seabed shown in the 2004 survey illustrates that such changes can occur even over a short period of time. Parkinson and Budde (2006) discuss in detail the bathymetric change evidenced between bathymetric surveys done in November 2004 and December 2005 in response to four hurricanes and tropical storms that impacted the area in the months between them. It has now been over five years since the last vibracores were obtained in September and October of 2005.

Shoal A9

The morphology of shoal A9, as seen in Figure 2, is more complex than most of the shoals that lie offshore of Volusia County. While the main body of the shoal follows the general north-south trend of the shoals in the region, its southern end bifurcates with its seaward lobe extending at an angle to the main trend. This seaward lobe is approximately the same orientation and distance from the coast as shoals A2, A3a and A3b lying offshore of Nassau and northern Duval Counties, the southern portions of shoal A7 offshore of St. Johns County and shoal A8 offshore of Flagler County. These features were discussed in detail in our previous yearly reports. (Phelps *et al.*, 2003; 2004; 2005 and 2006)

Meisburger and Field (1975) described shoal A9 as an irregular, low relief shoal containing over 11 ft (3.4 m) of clean uniform medium sand. The location of shoal A9 is shown on Figure 2. Based on the single core they recovered, the estimated probable reserves of beach restoration-quality sand were 61 million cubic yards (mcy) (46.6 million cubic meters [mcm]).

Parkinson (2005) divided this shoal into four areas, A9-1 through A9-4, and placed vibracores in each of them. He found that all four vibracores he obtained from shoal A9 penetrated a surface layer of white to light gray, poorly-graded, fine-grained, shelly quartz sand in excess of eight ft (2.4 m) thick. Review of the core logs shows that A9-1 penetrated 13 ft of clean, white to gray quartz sand lying on layer of fine-grained, muddy, shelly quartz sand which continues to the bottom of the core at 17 ft (5.2 m). A9-2 penetrated, to the bottom of the core at 19.3 ft (5.9 m), fine-grained, shelly, light gray to gray quartz sand. A9-3 penetrated, to the bottom of the core at 11.4 ft (3.5 m) below the seabed, fine-grained, white to light gray quartz sand. A9-4 penetrated 10.3 ft (3.1 m) of fine-grained, white to light gray quartz sand lying on muddy, fine-grained quartz sand, inter-layered with two thin clay layers, which persisted to the base of the core at 16.6 ft (5.1 m). Parkinson (2005) estimated 39.8 mcy (30.4 mcm) of beach restoration-quality sand to be present within those four potential borrow areas. This was broken down into 10.3 mcy (7.9 mcm) in area A9-1, 13.4 mcy (10.2 mcm) in area A9-2, 8.8 mcy (6.7 mcm) in area A9-3 and 7.3 mcy (5.9

mcm) in area A9-4. He thought that the recoverable volume might be reduced by the findings of offshore sand resource exclusionary mapping (Continental Shelf Associates, 2004) identifying offshore biological resources proximal to area A9-4 and indicated that areas A9-2 and A9-3 showed the most promise. He found the mean carbonate content of potential borrow area A9–2 to be 19 percent greater than the native adjacent beach while the content of potential borrow area A9–3 was only eight percent greater. He gave preference to area A9–3.

Cross section A to A′, a north-to-south trending cross section spanning shoal A9, is provided in Figure 11. Its location, and that of the shoal, is shown on Figure 2. This cross section illustrates the degree to which the shoal's morphology has changed since 1983 in that vibracores A9-1, A9-2 and A9-4 all begin above the 1983 seabed and A9-3 begins below it. This shoal is crossed by seismic lines collected in both Years Four and Five. These lines can be accessed from Appendix D.

Shoal A10

Meisburger and Field (1975) found that surface sand in their core from this long narrow ridge to be a clean, medium-grained quartz sand. Below about two ft (0.6 m), however, they found similar but slightly silty sand extending to seven ft (2.1 m) below the seafloor. They stated that the quality of the material in that shoal did not appear to be as good as sand in either area A8, which lies offshore of Flagler County to the north, or shoal A9. The locations of shoals A9 and A10 are shown on Figure 2. They estimated that shoal A10 contains 5.0 mcy (3.8 mcm) of sand of which about 1.6 mcy (1.2 mcm) is probably beach restoration-quality.

Parkinson (2005) divided this shoal into two potential borrow areas A10-1 and A10-2 and placed a vibracore in area A10-2. He states that the vibracore penetrated a light gray, poorly-graded, fine-grained quartz sand surface layer in excess of eight ft (4.4 m) thick. Review of the core log shows that it penetrated nine ft (2.7 m) of fine-grained, light gray quartz sand lying on fine-grained, silty, shelly quartz sand which persisted to the base of the core at 19 ft (5.8 m). Parkinson (2005) estimated that potential borrow area A10-2 contained less than 0.1 mcy (0.076 mcm) of beach restoration-quality sand. He suggested that that recoverable volume estimate might be further reduced by areas of possible concern, discussed in Continental Shelf Associates (2004), which lie in close proximity to this borrow area.

Clam shell grab samples V0-104-CG and VO-105-CG were collected on the north and south ends of this shoal, respectively. Sample VO-104-CG was 9.83 percent carbonate material and exhibited a mean grain size of 2.63 phi (0.16 mm). It contained 2.34 percent fine material. Sample VO-105-CG was 10.78 percent carbonate material and exhibited a mean grain size of 2.53 phi (0.173 mm). It contained 3.04 percent fine material. Photographs and complete granulometric analyses of these samples can be found in Appendix B.

This shoal is crossed by seismic lines collected in both Years Four and Five. These lines can be accessed from Appendix D.

Shoal B10

Parkinson (2005) divided this shoal into three potential borrow areas, B10-1, B10-2 and B10-3, and obtained a vibracore from each. He stated that the vibracores from borrow areas B10-1 and B10-2 penetrated a white to light gray, poorly-graded, fine-grained quartz sand at least eight ft (4.4 m) thick. Review of the core log for B10-1 shows that it penetrated 8.2 ft (2.5 m) of fine-grained, white to light gray quartz sand which overlies a muddy, silty quartz sand that persists to the base of the core at 15.7 ft (4.8 m) below the seabed. Core B10-2 penetrated 9 ft (2.7 m) of fine-grained, white to light gray quartz sand which overlies a muddy, shelly quartz sand which persists to the base of the core at 9.6 ft (2.9 m) below the seabed. The vibracore in area B10-3 encountered 0.8 ft (0.24 m) of muddy quartz sand which is underlain by a 6.7 ft (2.0 m) thick layer of muddy, shelly quartz sand whose mud and shell content increases with depth. That sand terminates in a layer of rounded rock cobbles and claystone. Below that lies 3.6 ft (1.1 m) of fine-grained quartz sand with abundant shells overlying a 3.5 foot (1.1 m) thick muddy, fine-grained quartz sand which also contained shells and became increasingly clayey with depth. The core ended in a final 0.8 ft (0.24 m) of clay. Borrow area B10-3 was deemed unusable and 1.6 mcy (1.2 mcm) of beach restoration-quality sand was estimated to be present within borrow areas B10-1 and B10-2 (Parkinson, 2005). This was broken down into 1.2 mcy (0.92 mcm) in area B10-1 and 0.4 mcy (0.3 mcm) in area B10-2. Parkinson (2005) suggested that the recoverable volume might be reduced by areas of possible concern, discussed in Continental Shelf Associates (2004), which lie in close proximity to borrow areas B10-1 and B10-2. Parkinson, (2005) estimated the potentially recoverable reserves of beach restoration-quality sand to be 1.0 mcy (0.76 mcm) in B10-1 and 0.3 mcy (0.23 mcm) in B10-2.

Cross section B to B′, a north to south trending cross section spanning shoal B10, is provided in Figure 12. Its location, and that of the shoal, is shown on Figure 2. Of the three vibracores in this shoal, only the top of vibracore B10-2 rises above, and is thus at variance with, the 1983 seabed. This shoal is crossed by seismic lines collected in Year Four. These lines can be accessed from Appendix D.

Shoal B11

Parkinson (2005) divided this shoal into four areas, B11-1 through B11-4, and placed vibracores in each of them. The vibracore in area B11-1 penetrated 3.5 ft (1.1 m) of fine-grained quartz sand followed by 2.8 ft (0.9 m) of muddy, fine-grained quartz sand lying upon clay that extended to the bottom of the vibracore at 13.7 ft (4.2 m) below the seabed. The vibracore in area B11–2 penetrated an upper layer of sand 16 ft (4.9 m) thick. However, the lower nine ft (2.7 m) consists of relatively dark (gray) sand. Due to its color alone, that dark sand was not considered by Parkinson to be beach compatible. The vibracore in area B11–3 penetrated a white to light gray, poorly-graded, fine-grained quartz sand 14.3 ft (4.4 m) thick, lying upon muddy, shelly, fine-grained quartz sand that persists to the base of the core at 20 ft (6.1 m) below the seabed. Parkinson (2005) estimated 3.3 mcy (2.5 mcm) of beach restoration-quality sand reserves in potential borrow area B11–3. The core in area B11-4 penetrated seven ft (2.1 m) of fine-grained, white quartz sand that contained less than ten percent shell material. That sand is underlain by 2.5 ft (0.8 m) of muddy, fine-grained, white to light gray quartz sand that becomes increasingly silty with depth. Below that sand is 9.1 ft (2.8 m) of muddy, shelly quartz sand that becomes more shelly and silty with depth. The core terminated in 0.4 ft (0.1 m) of sandy clay.

Parkinson and Budde (2006) conducted an evaluation of potential borrow area B11-3 using data derived from analyses of 36 sand samples collected from 29 cores. Their composite analysis of those data indicated the available beach restoration-quality sand reserves present consisted of a white to light gray, moderately sorted, fine-grained quartz sand with less than ten percent carbonate material. They estimated 2.45 mcy (1.87 mcm) of available beach restoration-quality sand to be associated with potential borrow area B11-3. These reserves were broken down by them into two cells, A and B, containing 2.1 mcy (1.6 mcm) and 0.35 mcy (0.27 mcm), respectively.

Analyses of the vibracores collected to date show that the typical sequence on this shoal consists of an interval of beach restoration-quality sand of varying thickness underlain by muddy shelly, fine-grained quartz sand, which is underlain by clay, clayey sand or muddy gravel. In some cores, a fine-grained quartz sand is encountered below the clay or clayey sand. Figure 13 contains a beach restoration-quality sand thickness map of potential borrow area B11-3 and shows where the cross sections C to C′ and D to D′, provided as Figures 14 and 15, cross the area west-to-east and north-to-south, respectively. Their locations are illustrated in Figure 2. Our calculations indicate that borrow area B11-3 may contain up to 0.375 mcy (0.287 mcm) of beach restoration-quality sand reserves. Figure 14 illustrates the degree to which the bathymetry has changed both since 1983 and 2004 in that vibracores shown on this cross section, which were collected in 2005, all begin below those surfaces. Figure 15 further illustrates the degree to which the bathymetry over the shoal has changed since 1983 in that all the vibracores shown on in this cross section begin either significantly below or, in the case of vibracore B11-3, above that surface. Comparison of the tops of vibracores collected in 2005 (vibracores B11-307, B11-310, B11-314, B11-321, B11-325 and B11-329) to the 2004 seabed further illustrates the degree to which this shoal's morphology can change over a short period of time. Of those vibracores, only the top of vibracore B11-

329 coincides with the 2004 seafloor. Appendix F provides information regarding the manner in which these various bathymetric data sets were collected. The entire shoal, from north-to-south, is represented on this cross section. This shoal is crossed by seismic lines collected in Year Four. These lines can be accessed from Appendix D.

Shoal B12

Parkinson (2005) divided this shoal into four areas B12-1 through B12-4 and placed vibracores in each of them. He reported that vibracores B12–1, B12–2, and B12–3 penetrated white to light gray, poorly-graded, fine-grained quartz sand in excess of eight ft (2.4 m) thick. Review of core B12-1 shows that it penetrated nine ft (2.7 m) of quartz sand, the upper eight ft (2.4 m) of which was fine-grained, white to light gray with the lower one foot (0.3 m) being medium grained, white sand with an admixture of gravel-sized shell material. This was underlain by muddy, medium-grained, shelly quartz sand that persisted to the base of the core at 12.5 ft (3.8 m). The B12-2 core contained 17 ft (5.2 m) of fine-grained quartz sand which was inter-bedded with layers of shell and coarse sand to gravel sized shell. Below 17 ft (5.2 m) is a muddy fine-grained quartz sand with some gravel-sized shell. That layer persisted to the base of the core at 20.7 ft (6.3 m) below the seabed. The B12-3 core penetrated 11.5 ft (3.5 m) of fine-grained, white to light gray quartz sand which lay upon a layer of muddy, silty, shelly, fine-grained quartz sand that persisted to the base of the core at 19.6 ft (6.0 m) below the seabed. The beach restoration-quality sand volume contained in potential borrow areas B12-1, B12-2, and B12-3 was estimated by Parkinson (2005) to be 10.4 mcy (7.95 mcm). This was broken down into 2.2 mcy (1.68 mcm) in B12-1, 5.0 mcy (3.8 mcm) in B12-2 and 3.2 mcy (2.45 mcm) in B12-3. He suggested that the recoverable volume might be reduced by areas of possible concern, lying in close proximity to these borrow areas with 1.9 mcy (1.45 mcm) recoverable in B12-1, 2.9 mcy (2.2 mcm) recoverable in B12-2 and 3.1 mcy (2.37 mcm) recoverable in B12-3 (Continental Shelf Associates, 2004). Core B12-4 penetrated only 0.7 ft (0.2 m) thick layer of fine-grained, white quartz sand below which is a 6.6 ft (2.0 m) thick layer of muddy, shelly, fine-grained quartz sand containing both coarse gravel and cobble sized shell fragments as well as whole shells. That sand is underlain by clay which persisted to the base of the core at 15 ft (4.6 m) below the seabed.

Parkinson and Budde (2006) conducted an evaluation of potential borrow area B12-1 using data derived from analyses of 63 sand samples collected from 35 cores. Their composite analysis of those data indicated the available beach restoration-quality sand reserves present consisted of a white to light gray, moderately-sorted, fine-grained quartz sand with less than 10 percent carbonate material. They estimated 1.72 mcy (1.32 mcm) of available beach restoration-quality sand to be associated with potential borrow area B12-1. These reserves were divided into three cells A, B, and C, containing 0.855 mcy (0.65 mcm), 0.725 mcy (0.554 mcm) and 0.17 mcy (0.13 mcm), respectively.

Analyses of the vibracores collected to date show that the typical sequence on this shoal contains restoration-quality sand of varying thickness underlain by muddy, shelly quartz sand which is itself underlain by muddy gravelly sand, muddy gravel or clay. Figure 13 contains a beach restoration-quality sand thickness map of potential borrow area B12-1 and shows where the cross sections, E to E′ and F to F′, provided in Figures 16 and 17, cross it west-to-east and north-to-south, respectively. Their locations are illustrated in Figure 2. Our calculations indicate that borrow area B12-1 may contain up to 0.558 mcy (0.427 mcm) of beach restoration-quality sand reserves. Figure 16 illustrates the degree to which the bathymetry has changed since 1983 and 2004 in that all the vibracores shown on it, except for B12-124, either begin significantly below those surfaces or, in the case of B12-121, begin above them. The top of B12-124 begins below the 1983 seabed but above the 2004 seabed. As all of the vibracores shown on this cross section were collected in 2005, comparison of the tops of these vibracores to the 2004 seabed shows that the morphology of this shoal is not static. Figure 17 further illustrates the degree to which the shoal's morphology has changed since 1983 in that all but two of the vibracores shown on it either begin significantly below or, in the case of vibracore B12-121, above that surface. Comparison of the tops of vibracores collected in 2005 (vibracores B12-101, B12-111, B12-114, B12-121, B12-126 and B12-131) to the 2004 seabed again illustrates the degree to which this shoal's morphology can change over a short period of time. Appendix F provides information regarding the manner in which these various bathymetric data sets were collected. The entire shoal, from north-to-south, is represented on Figure 17, cross section F to F′.

Clam shell grab sample VO-106-CG was collected on the south end of this shoal. Sample VO-106-CG was 20.73 percent carbonate material and exhibited a mean grain size of 2.89 phi (0.14 mm). Its fines content was 4.77 percent. A photograph and complete granulometric analysis of this sample can be found in Appendix B.

This shoal is crossed by seismic lines collected in both Years Four and Five. These lines can be accessed from Appendix D.

Shoal B13

Parkinson (2005) divided this shoal into four areas B13-1 through B13-4 and placed vibracores in each of them. He reports that vibracores in areas B13-1, B13-2, and B13-3 recovered an upper layer of light gray to gray, poorly-graded, shelly quartz sand with a thickness greater than eight ft (2.4 m). Review of the core from B13-1 showed it penetrated 15 ft (5.6 m) of medium- to fine-grained, shelly, light gray to gray quartz sand underlain by fine-grained, shelly quartz sand, containing sand- to cobble-sized shell material, which persisted to the base of the core at 17.5 ft (5.3 m) below the seabed. The core in B13-2 encountered 12.5 ft (3.8 m) of medium- to fine-grained, shelly, light gray quartz sand underlain by muddy, shelly quartz sand that persisted to the base of the core at 19 ft (5.8 m) below the seabed. The core in B13-3 showed 11.3 ft (3.4 m) of fine-grained, light gray quartz sand underlain by 7.4 ft (2.3 m) of muddy, fined-grained quartz sand. That layer was underlain by fine-grained, light gray quartz sand that persisted to the base of the core at 20 ft (6.1 m) below the seabed. The volume of sand associated with these potential borrow areas was estimated by Parkinson (2005) to be 20.5 mcy (15.7 mcm). This was broken down into 6.1 mcy (4.7 mcm) in B13-1, 7.2 mcy (5.5 mcm) in B13-2, and 7.2 mcy (5.5 mcm) in B13-3, but, as was the case elsewhere, he suggested that the recoverable volume might be reduced by areas of possible concern which lie in close proximity to these borrow areas (Continental Shelf Associates, 2004). He suggests that 3.3 mcy (2.5 mcm) in B13-1, 4.1 mcy (3.1 mcm) in B13-2 and 5.0 mcy (3.8 mcm) in B13-3 of beach restoration-quality sands are recoverable. The vibracore in area B13-4 consisted of five ft (1.5 m) of fine-grained quartz sand with increasing shell and fines toward its base. Below that is four ft (1.2 m) of muddy, shelly, fine-grained quartz sand containing many cobble sized whole shells and which is clayey at its base. Below that sand is 3.3 ft (1.0 m) of clay overlying 2.3 ft (0.7 m) of weathered limestone lying on top of fine-grained quartz sand which extends to the base of the core at 16.3 ft (5.0 m) below the seafloor.

Parkinson and Budde (2006) conducted an evaluation of potential borrow area B13-3 using data derived from analyses of 60 sand samples collected from 30 cores. Their composite analysis of all those data indicated the available beach restoration-quality sand reserves present consisted of a white to light gray, moderately-sorted, fine-grained quartz sand with less than 15 percent carbonate material. They estimated 0.778 mcy (0.595 mcm) of available beach restoration-quality sand to be associated with potential borrow area B13-3. At over 4 mcy (3.1 mcm) difference, this was a substantial reduction from the volume calculated by Parkinson (2005).

Analyses of the vibracores collected to date shows that the typical sequence on this shoal consists of beach restoration-quality sand of varying thickness underlain by muddy, shelly quartz sand which is underlain by clay. In some cores limestone is encountered below the clay. Figure 13 contains a beach restoration-quality sand thickness map of potential borrow area B13-3 and shows where cross sections G to G′ and H to H′, provided in Figures 18 and 19, cross it west-to-east and north-to-south, respectively. Their locations are illustrated in Figure 2. Our calculations indicate that borrow area B13-3 may contain up to 0.615 mcy (0.470 mcm) of beach restoration-quality sand reserves. Figure 18 illustrates the degree to which the morphology of this shoal has changed since 1983 and 2004. The vibracores shown on it were all collected in 2005 and all begin below the 1983 surface. Comparison of the tops of those vibracores to the 2004 seabed shows that this shoal's morphology is not static even over a short period of time. Vibracore 3-318 begins well below the 2004 seabed and vibracores 3-319 and 3-320 begin above it.

Figure 19 further illustrates the degree to which the shoal's morphology has changed since 1983 in that most of the vibracores shown on it begin either significantly below or above that surface. Comparison of the tops of vibracores collected in 2005 (vibracores B13-302, B13-305, B13-308, B13-311, B13-313, B13-316, B13-319, B13-322, B13-325 and B13-328) to the 2004 seabed further illustrates how much this shoal's morphology can change over a short period of time. Appendix F provides information regarding the manner in which these various bathymetric data sets were collected. The entire shoal, from north-to-south, is represented on Figure 19, cross section H to H′.

Clam shell grab samples VO-107-CG and VO-108-CG were collected on the north and south ends of this shoal, respectively. Sample VO-107-CG was 23.11 percent carbonate material and exhibited a mean grain size of 1.89 phi (0.27 mm). Its fines content was 1.32 percent. Sample VO-108-CG was 6.80 percent carbonate material and exhibited a mean grain size of 2.47 phi (0.18 mm). Its fines content was 2.42 percent. Photographs and complete granulometric analyses of these samples can be found in Appendix B.

This shoal is crossed by seismic lines collected in Year Five. These lines can be accessed from Appendix D. Seismic line VO-4004, which runs north-south, ties the following vibracores B13-1, B13-2, B13-302, B13-305, B13-308, B13-311, B13-316, B13-319, B13-322, B13-325, B13-328 and B13-4. Efforts were made to identify the base of beach restoration-quality sand in this seismic section. The top of the muddy, fine-grained quartz sand which typically underlies it on this shoal, seen at 8.9 ft (2.7 m) below the seabed in vibracore B13-319, can be identified on seismic line VO-4004 and interpolated northward to vibracore B13-316 where it is seen at 4.6 ft (1.4 m) below the seabed and southward to vibracore B13-322 where it is seen at eight ft (2.4 m) below the seabed. A similar sequence can be seen underlying beach restoration-quality sands in vibracores B13-311, B13-308, B13-305, B13-302, and B13-2 and in vibracores B13-325, B13-328, B13-4, which lie to the north and south of vibracore 13-319, respectively. The top of that muddy fine-grained quartz sand seen in those cores, and thus the base of beach restoration-quality sand, cannot be further identified on seismic line VO-4004.

Shoal B14

Parkinson (2005) divided this shoal into four areas B14-1 through B14-4 and vibracored each of them. The vibracore in area B14-1 found only 0.3 ft (0.1 m) of muddy, quartz-rich, coarse-grained, "skeletal", i.e. carbonate, sand lying on 3.9 ft (1.2 m) of muddy, shelly quartz sand which graded downward into shelly, sandy clay. Beneath that is 1.5 ft (0.5 m) of clayey sand grading down to fine-grained quartz sand, which is underlain, to the bottom of the core at 7.8 ft (2.4 m) below the seabed, by coarse-grained quartz-rich skeletal sand or possibly weathered limestone broken up by the vibracoring process. The vibracore in area B14-2 contained 5.9 ft (1.8 m) of fine-grained quartz sand lying on 9.1 ft (2.8 m) of muddy, fine-grained quartz sand overlying clay, which persisted to the bottom of the core at 16.7 ft (5.1 m) below the seabed. Parkinson (2005) found that the vibracore in area B14–3 penetrated a white, poorly-graded, fine-grained quartz sand layer in excess of 8 ft (2.4 m) thick. Review of the vibracore in area B14-3 shows that it penetrated 10.7 ft (3.3 m) of fine-grained, white to gray quartz sand. That sand overlies 5.5 ft (1.7 m) of fine-grained, light gray to dark gray quartz sand. The volume of beach restoration-quality sand associated with potential borrow area B14–3 was estimated by Parkinson (2005) to be 0.3 mcy (0.23 mcm). The vibracore in B14-4 encountered 2.5 ft (0.76 m) of fine-grained quartz sand inter-layered with two thin layers of mud. That sequence is underlain by 2.4 ft (0.73 m) of muddy quartz sand, which lies upon a 3.8 foot (1.2 m) thick layer of layer of muddy quartz sand with shells and clay which, at its base, becomes a clayey quartz sand with limestone clasts. Beneath that clayey quartz sand lies a 2.7 foot (0.8 m) thick layer of weathered limestone. Underlying the weathered limestone is a fine-grained quartz sand that continues to the base of the core at 12.3 ft (3.7 m) below the seabed.

Figure 20, cross section I to I′, provides a north-to-south trending cross section across shoal B14. Its location is illustrated in Figure 2. This figure illustrates the degree to which the shoal's morphology has changed since 1983 in that, of the vibracores shown on it, all but B14-3 begin either significantly below or above that surface.

This shoal is crossed by seismic lines collected in Year Five. These lines can be accessed from Appendix D. The contact between the limestone seen at the base of vibracore B14-4 and the clayey quartz sand that overlies it can be seen in the east-west seismic line VO-5002.

Shoals B15 and B16

Shoals B15 and B16 are proximal to each other and are considered by us to be a single shoal complex. This feature extends further offshore than all but portions of shoal A9. Both this shoal complex and portions of A9 extend further offshore than, and lie at an angle to, the general trend of shoals offshore of Volusia County. Meisburger and Field (1975) describe shoals B15 and B16 to be large, flat-topped and irregular. While they did not core these shoals they found clean, medium sand in vibracores at their margin. Neither Parkinson (2005) or Parkinson and Budde (2006) investigated these shoals. Clam shell grab samples VO-109-CG, VO-110-CG and VO-111-CG were collected north of, but proximal to, the shoal complex. These grab samples showed sediments that were composed of five percent or less fines, 58.75 percent or less carbonate and exhibited mean grain sizes of 0.53 phi (0.7 mm), 1.3 phi (0.41 mm) and 1.8770 phi (0.27 mm), respectively. Clam shell grab samples VO-112-CG, VO-115-CG, VO-117-CG, VO-118-CG, and VO-121-CG were collected central to the shoal complex. These grab samples contained sediments that were 2.65 percent or less fines. Of these samples all but VO-121-CG and VO-118-CG were 21.85 percent or less carbonate material and exhibited mean grain sizes of 1.65 phi or greater (0.32 mm or smaller). Sample VO-118-CG was 55.85 percent carbonate material and exhibited a mean grain size of 0.41 phi (0.75 mm). Sample VO-121-CG was 34.49 percent carbonate material and exhibited a mean grain size of 1.37 phi (0.39 mm). Sample VO-113-CG was collected proximal to the east of the shoal complex. It was 5.17 percent carbonate and exhibited a mean grain size of 2.42 phi (0.19 mm) and contained 2.45 percent fines. Samples VO-114-CG, VO-116-CG, VO-119-CG and VO-120-CG were collected proximal to the south of the shoal complex. These samples were 19.15 percent or less carbonate, 3.23 percent or less fines and exhibited mean grain sizes of 1.92 or greater phi (0.26 mm or less). Photographs and full granulometric analyses of these samples is provided in Appendix B.

This shoal complex is crossed by seismic lines collected in Year Five. These lines can be accessed from Appendix D.

Shoal B17

Parkinson (2005) investigated shoal B17 with three vibracores. He reported that none of the vibracores recovered an upper sand layer in excess of eight ft (2.4 m) thick. Review of the vibracore B17-1 shows that it penetrated 2.9 ft (0.9 m) of fine-grained, white quartz sand followed by 0.8 ft (0.2 m) of muddy, coarse-grained quartz sand and shell hash. Below that is 1.3 ft (0.4 m) of fine-grained, light gray quartz sand. That sand overlies 3.5 ft (1.1 m) of muddy, quartz-rich, coarse-grained, skeletal sand which was underlain to the base of the core at 12.5 ft (3.8 m) by clayey sand containing large bivalves and limestone clasts at its base. Vibracore B17-2 penetrated 5.5 ft (1.7 m) of fine-grained, light gray quartz sand. That sand was underlain by muddy, fine-grained, dark gray quartz sand to the base of the core at 5.8 ft (1.8 m) below the seabed. Vibracore B17-3 penetrated 2.6 ft (0.8 m) of fine-grained, white quartz sand. Beneath that sand is 3.1 ft (0.9 m) of muddy, fine-grained, gray to dark gray quartz sand. That sand is underlain by 5.3 ft (1.6 m) of muddy, shelly quartz sand which grades downward into muddy, quartz-rich, skeletal sand, with occasional articulated bivalves. Below that sand is three ft (0.9 m) of clay, which gradationally transitioned into skeletal gravel. Underlying the skeletal gravel is a sequence of medium- to coarse-grained, skeletal sand or possibly weathered limestone which persisted to the base of the core at 17.6 ft (5.4 m) below the seabed.

Figure 21, cross section J to J′, provides a northeast-to-southwest trending cross section across shoal B17. Its location is illustrated in Figure 2. It shows the maximum thickness of beach restoration-quality sand in the vibracores on this shoal to be 5.5 ft (1.7 m) in vibracore B17-2. This figure illustrates the degree to which the morphology of this shoal has changed since 1983 in that only vibracore 17-2 intersects the 1983 seabed.

This shoal is crossed by seismic lines collected in Year Five. These lines can be accessed from Appendix D. Stratigraphic analysis of seismic line VO-6003, which runs north-south and ties vibracores B17-1, B17-2 and B17-3, does not indicate that an appreciable thickening of beach restoration-quality sand occurs on this shoal. The top of clayey sand seen in vibracore B17-1 at ten ft (3.0 m) below the seabed can be identified on both that seismic line and on seismic line VO-5002 which runs east-west.

Shoal B18

Parkinson (2005) divided shoal B18 into three potential borrow areas: B18-1, B18-2 and B18-3. However, vibracore logs were provided only for B18-1 and B18-3. Both vibracores B18–1 and B18–3 are reported by him to contain an upper sediment layer consisting of white, poorly-graded, fine-grained, shelly quartz sand in excess of eight ft (2.4 m) thick. Review of the core log for B18-1 shows 10.4 ft (3.2 m) of fine-grained, white quartz sand underlain by a muddy, shelly quartz sand which, at a depth of15 ft (4.6 m) in the core, is underlain by clay. This clay continues to the bottom of the core at 19.5 ft (5.9 m) below the sea bed. Review of the core log for B18-3 shows 8.4 ft (2.6 m) of fine-grained, white quartz sand underlain by silty, shelly quartz sand to the base of the core at 15.3 ft (4.7 m). Parkinson (2005) estimated 1.8 mcy (1.4 mcm) of beach restoration-quality sand associated with the two potential borrow areas B18-1 and B18-3. This was broken down into 1.7 mcy (1.4 mcm) in B18-1 and 0.1 mcy (0.8 mcm) in B18-3 (Continental Shelf Associates, 2004). Again, as was the case elsewhere, Parkinson (2005) suggests that the recoverable volume might be reduced by areas of possible concern which are in close proximity to borrow areas B18-1 and B18-3. He suggests that 1.3 mcy (0.99 mcm) and 0.1 mcy (0.08 mcm) are recoverable from areas B18-1 and B18-3, respectively.

Clam shell grab samples VO-116-CG and VO-119-CG were collected on the north end of this shoal. Full statistical analyses of these samples is provided in Appendix B.

This shoal is crossed by seismic lines collected in Year Five. These lines can be accessed from Appendix D. The top of the muddy, shelly quartz sand seen in vibracore B18-1, which at 10.4 ft (3.2 m) underlies beach restoration-quality sand, and the clay that lies at 15 ft (4.6 m) below the seabed can be identified on the east-west seismic line VO-5002. The north-south seismic line VO-6005 ties vibracores B18-1 and B18-3 but does not record the seismic stratigraphic features seen on seismic line VO-5002. This suggests that the beach restoration-quality sand seen in vibracore B18-1 may not be laterally continuous.

CONCLUSIONS AND RECOMMENDATIONS

Figures 7 and 8 reveal that there is a substantial dichotomy between beach samples obtained north and south of sample location VO-37. Figure 7 shows that the samples to the north of that location are less than 0.50 mm in mean grain size and typically are less than 0.25 mm. Curves to the south of sample location VO-37 show that the samples peak at greater 1.0 mm in mean grain size and gradually decline southward in mean grain size to less than 0.25 mm, after which they increase in mean grain size again. Figure 8 shows that the carbonate percentage curves peak at 40 percent carbonate material on the north end of Volusia County and that the samples north of sample location VO-37 are typically composed of 15 percent or less carbonate material. South of location VO-37 the carbonate percentage curves rise past 60 percent with the carbonate percentage for the swash zone sample curve exceeding 70 percent. The carbonate percentage curves gradually decline southward to False Cape, locations BV-16 through BV-20, after which the percentage of carbonate within the samples increases again. In only one swash zone sample does the carbonate percentage in the area south of location VO-37 fall below 10 percent.

Table 4 provides a history of estimates of beach restoration-quality sand resources contained within those shoals offshore of Volusia County identified in Meisberger and Field (1975). A shoal-by-shoal examination of cross sections frequently shows that the seabed bathymetry is continuously being modified in response to storms and currents. Estimates of reserves of beach restoration-quality sand based on sand thicknesses contained in the vibracores collected to date are approximations, the accuracy of which degrades over time. The evidence indicates that reserve estimates should be recalculated based upon bathymetric surveys conducted contemporaneous to when those reserves are to be utilized.

Shoals B11 and B12, as shown on Figure 2, can be considered the southern extension of shoals A9 and A10, respectively. Parkinson (2005) and Parkinson and Budde (2006) found reserves of beach restoration-quality sand in shoals B11 and B12 concentrated in the southern half of shoal B11 and the northern half of shoal B12. It is recommended that, as the reserves of beach restoration-quality sand assessed to date are relatively limited, further reconnaissance vibracoring be conducted on shoal A9, as it has the potential to contain the largest reserves of beach restoration-quality sand offshore of northern Volusia County and in potential borrow areas B13-1 and B31-2, of shoal B13.

Based on the work of Meisberger and Field (1975), it is recommended that reconnaissance vibracoring of the shoal complex B15 and B16 be accomplished as well.

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