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A SEDIMENTOLOGICAL AND GRANULOMETRIC ATLAS OF THE BEACH SEDIMENTS OF FLORIDA'S SOUTHWEST COAST AND KEYS

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ABSTRACT

This Florida Geological Survey (FGS) study was funded by the National Oceanic and Atmospheric Administration (NOAA). This study characterizes recently sampled sediments from the beaches of Pinellas, Hillsborough, Manatee, Sarasota, Charlotte, Lee, Collier and Monroe counties. A total of 390 samples from 214 sites along the southwest coast of Florida and 33 samples from 28 sites in the Florida Keys archipelago were collected and described. Of those samples, 214 from the southwest coast and 28 from the Keys were also granulometrically analyzed. Photographs, descriptions and the results of granulometric analyses are provided.

The study areas on the southwest coast of Florida and Florida Keys archipelago were broken down into 22 and two reaches respectively. These reaches are defined by geographic boundaries, such as inlets and passes as well as the mouths of rivers, harbors, and bays. The study showed a frequent correlation between these boundaries and significant changes in grain size. Additionally, frequent correlation between these boundaries and significant changes in carbonate percentages were also found on the southwest coast of Florida.

Changes in grain size, both before and after digestion of carbonate material, as well as the percentage of carbonate material in the samples define four regions in the southwest coast of Florida. A direct correlation between the grain size and carbonate percentage curves was seen; in that where carbonate percentages increase so does grain size. A significant separation between the pre and post-carbonate digestion curves was noted where the carbonate percentage curve rises above 25 percent. The carbonate sediment fraction present in the samples are generally coarser than the non-carbonate fraction. While the ratio of carbonate material to non-carbonate material varies substantially, the general trend from north to south along the southwest coast of Florida shows an increase in the percentage of carbonate material within the samples, which broadly peaks in central Sarasota County, central Lee County and at the Lee County/Collier County line and then slightly declines southward to Cape Romano.

The two regions in the Florida Keys archipelago identified within the study area were defined both by the geographic boundary separating the middle and lower Keys and a nearly coinciding distinct change in sediment grain size, with the sediments of the beaches of the lower Keys being the coarser of the two. Sediments collected from the Florida Keys archipelago were almost exclusively carbonate. The only exceptions to this, on Little Crawl Key, Munson Island and Key West, are probably the result of beach replenishment activities. The grain size curve peaks broadly from the Spanish Harbor Keys sample to the east end of Long Beach on Big Pine Key and then, when the effects of beach replenishment are considered and discounted, declines westward.

INTRODUCTION

This is the second in what is intended to be three studies which will ultimately comprise a complete atlas of the beach sediments of Florida. It encompasses the Gulf of Mexico beaches of the southwest coast of Florida extending southward from the northern border of Pinellas County through Collier County and includes the Florida Straits facing beaches of the middle and lower portions of the Florida Keys archipelago of Monroe County. The study area is shown on Figure 1.

With the exception of three major offsets at Indian Rocks, Sanibel Island and Cape Romano, in Pinellas, Lee and Collier counties respectively, the orientation of the southwest coast of Florida is northwest to southeast. The Florida Keys are an elongate arcuate archipelago oriented northeast to southwest. They are over 220 miles (354.1 kilometers (km)) long and stretch from Soldier Key, at the northeast end, southwest to the Dry Tortugas. They are separated from the mainland by Florida Bay. (Clark,1990).

This report is a companion to Phelps *et al.* (2009) which reported on the beach sediments of the east coast of Florida extending from the Florida/Georgia state line southward to Key Biscayne offshore of central Miami-Dade County. As was reported in that study:

> *"Beach erosion is a constant concern in Florida (Clark, 1993) 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."*

A review of available records suggests that the earliest recorded beach replenishment projects conducted on the southwest coast of Florida and in the Florida Keys archipelago, were done on Clearwater Beach in Pinellas County, in 1950 and 1951, and at Smathers Beach on Key West in 1960 (Western Carolina University Program for the Study of Developed Shorelines (PSDS), 2009). Projects such as these, with increasing volume and frequency, have continued to the present day. As has been reported previously in Phelps *et al.* (2009):

> *"Sediments to be placed… must substantially match those in situ, the present study is intended to provide a base line analysis of sediments on the beaches in order to facilitate such matching. The primary sedimentary parameters of concern in sediment matching are grain size and the varying ratio of non-carbonate to carbonate material. A secondary parameter of importance, generally from an aesthetic viewpoint, is color."*

Regarding the issue of differentiating between beaches that have been replenished and those left to nature, as was the case in Phelps et al. (2009):

> *"No attempt was made in this document to distinguish between replenished beaches and those which remain in a natural state. To attempt to do so, given the history of beach development for residential and commercial purposes, replenishment projects and engineering projects related to inlet maintenance for navigation, would be problematic at best."*

It is assumed that, of the beaches of the southwest coast, the beaches of Three Rooker Bar, Honeymoon Island, Caladesi Island, Shell Key Shoal, Mullet Key, Egmont Key, La Costa Island, North Captiva Island, Little Marco Island, Kice Island and Cape Romano are in the most natural condition, i.e. the most minimally impacted by activities carried out on developed segments of beach and at inlets adjacent to them. Conversely, as Lido Key is the result of dredge and fill operations performed on several mangrove islands in the 1920's, it is assumed that the beaches of Lido Key are the most influenced by man. Of the beaches of the Florida Keys archipelago, it is assumed that the beaches of Key West are the most influenced by anthropogenic processes.

This report does not characterize the Monroe County beaches of Key McLaughlin and the mainland beaches of Cape Sable which have an aggregate reported length of 16.2 miles (26.07 km) (Clark, 1990). Those beaches lie within the confines of The Everglades National Park and access is difficult due to their remoteness. Similarly, this report does not characterize the Monroe County Gulf of Mexico beaches of the Florida Keys archipelago reported by Clark (1990) on Bahia Honda Key, the Content Keys, Sawyer Key, Marvin Key, Snipe Point and Mud Key with an aggregate length of 1.3 miles (2.09 km)(Clark, 1990). Those beaches are all located within the Great White Heron National Wildlife Refuge, the Key Deer National Wildlife Refuge and the Bahia Honda State Recreational Area and are, for all practical purposes remote. Additionally, also due to their remoteness, this report does not characterize the outer islands west of Key West, i.e. the Mule Keys, the Marquesas Keys and Dry Tortugas. The Mule Keys, with an aggregate length of 2.6 miles (4.2 km) of Straits of Florida beaches, and the Marquesas Keys, with an aggregate length of 4.4 miles (7.1 km) of Gulf of Mexico beaches, all lie within the Key West National Wildlife Refuge, Clark (1990). Further west, the Dry Tortugas, with an aggregate length of 4.2 miles (6.8 km) of Gulf of Mexico beaches (Clark, 1990), all of which lie within the boundaries of the Dry Tortugas National Park, are also not included in this study.

The sampling of beaches along the southwest coast of Florida and the Florida Keys archipelago was done primarily on a county by county basis. Specific reaches of beach, as defined by geographic boundaries, i.e. inlets, passes, rivers and the mouths of bays and harbors, are discussed in this report. These delineating features frequently affect the natural near shore flow of sediments. They also occasionally represent political/economic boundaries which may limit the lateral extent of beach replenishment projects. It should be noted that these boundaries, in such cases, only define the limits of where sediments were, are and will be initially placed on a beach. In such cases, the forces of nature may modify the final distribution of such sediments in a manner not necessarily concordant with man's avowed intent. Ebb tidal deltas associated with these geographically bounding features often serve as the sediment source for beach replenishment. The defined reaches, i.e. beach segments tied to sample site locations, are delineated in Table 1.

Grab sample sets of beach sediments collected at individual sampling points are referred to as "beach samples" or "samples". The individual sites selected for the collection of multiple beach samples are referred to as "beach sampling locations". The beach sampling locations are shown in Figure 1 and listed in Table 2. Individual sampling points within those locations utilized for the collection of beach samples are specified by their place on the beach profile. Photographs of individual beach samples can be found in Appendix A. Sediment analysis conducted to characterize a beach sample's grain size distribution is referred to as "granulometric analysis". This analysis is graphically displayed on grain size distribution (GSD) curves. These curves, created from selected beach samples at each location, can also be found in Appendix A. The sediment fraction referred to as "fines" is that material which will pass through a 4.00 phi, 0.0025 inch (63 micron) mesh opening (#230 sieve).

Maps included in this report use either the North American Datum of 1983, herein cited as "NAD83", or the World Geodetic System of 1984, herein cited as "WGS84". Global Positioning System (GPS) instrumentation used to collect geographic global positioning fixes and/or reference points is 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 in Table 3. These conversion factors are cited from Eshbach and Souders (1975) to four significant digits. 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 brackets, by their expression in SI units.

PREVIOUS WORK

Davis, (1994) and (1997) and Yale, (1997) discuss in detail the barrier islands of the Florida Gulf coast peninsula. Davis, (1994) states that it "…includes 30 barrier islands and related inlets and extends for 186.4 miles (300 km) between an open coast marsh system and an open coast mangrove system."

He places its north end on Anclote Key which lies immediately north of Three Rooker Bar, the northern end of our study area. He places the south end at Cape Romano, which is the southern end of our study area on the southwest coast of Florida. He notes that the number of islands changes occasionally with new inlets opening and closing and that the coast has general north-south trend. There is locally a great range in shoreline orientation with individual islands, like Sanibel Island, exhibiting over a 90 degree range in orientation (Davis (1994)).

Additionally, Davis (1994) found that the beaches of the study area:

> *"...are quite variable on size and shape but are predictable in their composition and texture. The size and morphology of the beaches tend to reflect the availability of sediments and the local processes. Because there is quite a bit of range in the availability of sediment and because long stretches of the beaches along many of the barriers have been modified by man, there may be considerable local differences in beach development."*

and that:

> *"Steepness of the beach face ranges widely due to the wide range of composition. The very shelly gravel beaches are quite steep in comparison to those dominated by fine sand."*

From the 1990s and later, the United States Geological Survey (USGS) conducted the West-Central Florida Coastal Studies Project (Hine, *et al.,* 2001). As they describe it, "…the west-central coast of Florida, extending from Anclote Key on the north to Cape Romano on the south and facing the Gulf of Mexico, is an estuarine, barrier-island, inner-shelf system of marked contrasts, contradictions, and unique characteristics." They examined "…the northern half of the barrier chain from Anclote Key, the northernmost barrier island in the chain, to the mainland beach/headland at Venice, FL."

In that study the USGS found that:

> *"…this barrier inlet system, although quite varied in all respects, actually displays many common attributes in the development of its individual barrier islands and tidal inlets. Their stratigraphy can be viewed in a fairly simple stratigraphic model characterized by initial upward shoaling, aggradation and then, in some cases, progradation."*

They further state that:

> *"…it is impossible to predict where the coastline will be in the coming few years, decades, or longer. We cannot predict with any meaningful accuracy the weather, tropical storm activity, and climate changes in those time frames, so any specific predictions as to shoreline position, inlet behavior, barrier- island morphology, and resulting impact on human activity and property is meaningless. However, based upon our understanding of the recent past and certain geologic facts such as the lack of any new inputs of sand into the system, we can conclude that areas of critical coastal erosion will continue to be areas of concern. The lack of a major tropical storm striking this area since the mid 1920's coupled with the enormous growth in development since that time should remind all citizens of the potential for major destruction should the study area receive a direct hit."*

Morton and Peterson, (2003) report that the region from Venice inlet south to Cape Romano:

> *"…consists of sandy beaches and narrow barrier islands. Two prominent physiographic features are the headlands at Venice and Naples where the Gulf shore and mainland meet. The headlands are composed of Tertiary sandstone and limestone, which resist erosion. The coasts north and south of the headlands are characterized by barrier islands of variable dimensions separated by tidal inlets of variable dimensions (Davis, 1994). The sand that makes up the beaches and barriers overlies a hard limestone platform that forms the adjacent continental shelf (Locker et al., 1999a). The limestone is exposed on the shelf or covered by a thin veneer of sand and shell. The beach sand typically contains abundant broken shell material as a result of high production of mollusks in the clear warm water of the Gulf of Mexico and an absence of rivers that would supply additional sand. Shells and broken pieces of rock are also concentrated on some beaches by the offshore dredging and hydraulic pumping associated with beach nourishment projects, which are common along this coastal region."*

Hoffmeister and Multer (1968) and Hoffmeister (1974) discuss the geology and origin of the Florida Keys. Randazzo and Halley (1997) provide a concise analysis of their evolution.

Clark (1990) provides a comprehensive analysis of the beaches of the Florida Keys. He found that sandy beaches exist within the lower portion of the middle Keys and in the lower Keys fronting on both the Florida Straits and the Gulf of Mexico. He states that:

> *"Beach and dune formation in the keys is not common, and compared to the Florida peninsula, there is very little quartz sand on the Keys. The sand of the Keys beaches is of carbonate origin derived from the erosion of limestone, from aragonite particles precipitated from seawater, and from the fragmented remains of corals, cast-off shells, and calcareous algae."*

He found that the beaches had an average width of 50 feet (ft) (15.24 m).

PROJECT DESCRIPTION

The Bureau of Beaches and Coastal Systems (BBCS) of the Florida Department of Environmental Protection (FDEP) selected locations at approximately 1,000 foot (304.8 meters (m)) intervals for the purposes of beach monitoring and management which are an established reference feature in the study area. In this study the beach sampled was adjacent to every fifth location, where practicable. This resulted in a planned sample location spacing of approximately one mile (1.6 km). The planned sampling interval locally varied from this for points immediately adjacent to physically limiting geographic features such as inlets and the mouths of harbors and bays. The planned sampling interval also varied, on occasion, where it was determined from a review of online photo imagery and field observations that no beach existed at a proposed sampling location. Additionally, there were a few intended sampling locations where beach access could not be arranged. The beach sample locations used in this study are shown in Figure 1. Table 2 and Table 4 tie beach monument location points and latitude and longitude to beach sampling locations.

FIELD PROCEDURES

Beach sample collection by county

In planning the sample protocol, it was intended that at each sampling location samples would be collected from the swash zone, the beach berm, mid-beach and back beach. An idealized beach profile illustrating these locations is provided as Figure 2. Swash samples were collected just landward of the point waves reached at the time of sampling. Beach berm samples were collected if there was a distinct crest followed by a distinct fall in elevation landward of the swash sample point. Mid-beach samples were taken on wide beaches approximately midway between the swash sample point and the back beach sample point. Back beach samples were collected at the seaward base of the dune. If no dune was present a sampling point was picked just short of where the beach was vegetated. Very few locations were found where all four sample points were present. Due to the width of the beaches visited, swash zone, mid-beach and back beach samples were only collected at a few scattered locations while at most others only swash and back beach samples were obtained. At some locations, where the beach was extremely narrow, only samples from a single point on the beach were collected. At a few locations, where no beach was present, no samples were taken. GPS readings were obtained for each of the sampling points within each location. 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) above mean sea level (MSL). At each sampling point within an individual sampling location, four individual duplicate samples, each totaling approximately two ounces (oz) (56.7 grams (gm)) of sediment, were obtained for sieve analysis. To eliminate the influence of aeolian winnowing of fines at the sediment surface, samples were obtained by collecting sediments from an approximate depth of 6 to 12 inches (15.2 centimeters (cm) to 30.4 cm) below the beach surface.

Phelps *et al*., (2009), discuss a simple alphanumeric scheme utilized to identify loose sediment samples. All beach samples discussed in this report are identified with a two letter code for the county, followed by consecutive beach location numbers, 01, 02, 03, 04, etc., and completed by a one or two letter designation indicating the sample's placement on the beach profile. 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 at the first sample location in Pinellas County in the swash zone would be delineated as PI-01-SS. The samples collected from locations on the southwest coast of Florida were numbered from northwest to southeast. The samples collected from locations in the Florida Keys archipelago were numbered from northeast to southwest.

Access to the beach was primarily obtained through the use of an all terrain utility vehicle (UTV) or by driving a truck by road as close to individual locations as possible and walking onto the beach. Portions of the beaches in Collier County, courtesy of Collier County staff, were directly accessed by the use of a four wheel drive sport utility vehicle. Offshore islands not accessible by land were accessed by motor vessel. In two of those circumstances, at Cayo Costa State Park on La Costa Island and on Keewaydin Island in the Rookery Bay National Estuarine Research Reserve, all terrain vehicles were provided upon arrival on the islands. Other locations, most notably on Three Rooker Bar, Caladesi Island, Shell Key Preserve, North Captiva Island, Big Hickory Island, Little Marco Island, Kice Island, Cape Romano and some of the islands east of Key West, were accessed by nosing a boat onto the beach and wading in through the shallow surf.

Upon arrival at a sampling location, the following procedure was adhered to:

- Sample points were typically marked using survey flags, caution triangles and/or "traffic cones".

- Photographs were taken illustrating the sample points as marked. These photographs were shot from opposite directions down the length of the beach. Occasionally, at locations where the beach was unusually wide, photos were also taken across the width of beach.

- GPS coordinates of all sampling points were recorded in the field book and the coordinates of the back beach sampling point, or in the case of sampling locations with a single sample point that individual sample point, were entered into the memory of a hand held, Garmin Etrex, GPS unit. The unit is typically accurate to approximately 15 ft (4.57 ms).

- Sampling holes were dug at each sample point and four individual bags of two ounce (56.7 gm) sample were collected at a depth of between 6 to 12 inches (15.2 cm to 30.4 cm) below land surface.

- Sampling holes were then back filled.

Pinellas County

Beach samples from Pinellas County were collected on October 7, 8 and 9, 2009, on November 3 and 4, 2009 and on December 1, 2009. A total of 50 beach sampling locations were identified, and 101 beach samples were collected. Table 4 ties monument points to beach sampling locations. While it was intended that at each sampling location surface samples were to be collected from the swash zone, the beach berm, mid-beach and back beach, this was only possible at two sites. At 11 locations, where no discernible beach berm was noted, only swash zone, mid-beach and back beach samples were obtained. An example of this is provided in Figure 3. At 26 locations, the beach was so narrow that only samples from the swash zone and back beach were obtained. An example of this is provided in Figure 4. At eight locations, where the beach was extremely narrow, only a single sample was obtained. An example of this is shown in Figure 5. Additionally, at three sites, PI-16, PI-49 and PI-50, no samples were acquired. No access could be obtained for PI-16. PI-49 and PI-50 were not sampled as they faced on Tampa Bay rather than the Gulf of Mexico.

Hillsborough County

Samples from the beaches of Egmont Key, the only reach of beach in Hillsborough County, were collected on November 4, 2009. A total of five beach samples were collected from three sampling locations. Table 4 ties monument points to beach sampling locations. Due to the narrowness of the beach, at two locations only swash zone and back beach samples were collected and at the third location only a single sample was collected.

Manatee County

Samples from the beaches of Manatee County were collected on December 2, 2009. A total of 24 beach samples were collected from 15 sample locations (Figure 1). Table 4 ties monument points to beach sampling locations. Due to the narrowness of the beach, only swash zone and back beach samples were collected at ten locations and only single samples were collected at four other locations. At one location, MN-10, no sample was collected as no access could be obtained.

Sarasota County

Samples from the beaches of Sarasota County were collected on December 2, 3, 15 and 16, 2009 and on January 28, 2010. A total of 65 beach samples were collected from a total of 39 sampling locations (Figure 1). Table 4 ties monument points to beach sampling locations. Due to the narrowness of the beach, only swash zone, mid-beach and back beach samples were collected from seven locations and from 14 locations only swash zone and back beach samples were collected. At 16 locations only a single sample was collected. Additionally, at two locations, SA-11 and SA-15, where no beach was present, no samples were taken.

Charlotte County

Samples from the beaches of Charlotte County were collected on December 15, 16 and 17, 2009, and on January 12, 2010. A total of 25 beach samples were collected from 15 sampling locations (Figure 1). Table 4 ties monument points to beach sampling locations. At two locations, swash zone, mid-beach and back beach samples were acquired. At six locations, due to the narrowness of the beach, only swash zone and back beach samples were collected. At seven locations, where the beach was extremely narrow, only a single sample was collected.

Lee County

Samples from the beaches of Lee County were collected on November 7 and 8, 2009, on January 12, 13 and 14, 2010 and on January 28, 2010. A total of 98 beach samples were collected from a total of 55 sampling locations (Figure 1). Table 4 ties monument points to beach sampling locations. At only one location, swash zone, berm, mid-beach and back beach samples were obtained. Due to the narrowness of the beach, at eight locations only swash zone, mid-beach and back beach samples were obtained and only swash zone and back beach samples were collected at 24 locations. At 22 locations, where the beach was extremely narrow, only a single sample was collected.

Collier County

Samples from the beaches of Collier County were collected on November 5 and 6, 2009, and on January 26 and 27, 2010. A total of 70 beach samples were collected from a total of 47 sampling locations (Figure 1). Table 4 ties monument points to beach sampling locations. At three locations, only swash zone, mid-beach and back beach samples were collected. Due to the narrowness of the beach, only swash zone and back beach samples were collected at 21 locations. At 19 locations, where the beach was extremely narrow, only a single sample was collected. At three locations, CR-42, CR-44 and CR-45, no samples were collected as no beach was present.

Monroe County (the Florida Keys)

Samples from the beaches of Monroe County were collected on April 14 through April 17, 2010. Beaches are not present in the upper Keys of Monroe County. A total of 32 beach samples were collected from a total of 30 sampling locations (Figure 1) in the middle and lower Keys. As the occurrence of both islands and beaches upon those islands is scattered within the archipelago, separation between sample points often exceeded one mile. No samples were obtained from the islands west of Key West in the far western portion of the Florida Keys archipelago. Table 4 ties monument points to beach sampling locations. Due to the narrowness of the beach, only swash zone and back beach samples were collected at four locations. At 24 locations, where the beach was extremely narrow, only a single sample was collected. At two locations, MO-13 and MO-17 no samples were collected as no beach was present.

Photographs of the beach locations visited and the samples collected are provided in Appendix A. Also included in Appendix A are sample descriptions as well as granulometric analyses and photo micrographs of selected samples.

LABORATORY ANALYSIS

Sediment sample processing

The sieve nest used in sample processing by the FGS is delineated in Table 5 and depicted in Figure 6. All grain size distribution analyses were conducted using general guidelines of the American Society for Testing and Materials (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 (0.63 millimeter (mm) or 4 phi) sieve, oven dried and reweighed with the weight loss being assigned to the fine fraction. The sample was then dry sieved with the portion of the pan fraction obtained during dry sieving also assigned to the fine fraction. The sample was then digested with a 4 Molar hydrochloric acid solution, rinsed with deionized water, oven dried, reweighed and resieved.

The cumulative grain size distribution curves reflect the total grain size distribution (GSD) of the sample. The weight of the fine fraction (weight loss from wet sieving and weight of the pan fraction combined) was assigned to the less than 4 phi fraction. Separate GSD's were determined for the carbonate and non-carbonate fractions of each sample along with the combined GSD of the entire sample. The grain size distribution curves are provided with analysis (Excel spreadsheet). A link is provided in the grain size analysis column in the index of beach samples.

A set of four individual samples were collected at every sampling point. Sample #1 of a set, to be granulometrically processed, was processed as described above. The results of their granulometric analyses are provided in Appendix A. Sample #2 of those sets, subsequent to being dried, was described and photographed. These data can be accessed via the index under the photo page column. Sample #3 of those sets was dried and 10 percent of those samples were processed, like sample #1, for the purpose of quality control. If not processed it was retained as an archive sample. Sample #4 was held as a backup sample and, if not utilized, retained as an archive sample. Those sample sets not selected for processing were described, photographed and retained for processing in the future.

Grain size distribution (GSD) curves

Separate GSD curves were made for the non-carbonate fractions of each sample processed by the FGS along with a combined GSD of the entire sample. These curves can be found in Appendix A.

Sediment processing quality control

As a quality control check, duplicate samples were processed separately for approximately ten percent of all beach samples processed. A total of 23 duplicate samples were processed from Pinellas, Hillsborough, Manatee, Charlotte, Lee, Collier, and Monroe Counties. Graphical comparisons of initial and duplicate samples can be found in Appendix B. Using the Mann-Whitney Test (equivalent to the Wicoxon Test) to compare the distribution medians and Levene's Test, Conover (1999), to compare the variances, at a 95 percent confidence level, there was no significant difference found between the distributions of the first and duplicate samples for either of the two tests.

BEACH REACHES OF THE SOUTHWEST COAST OF FLORIDA

Table 1 lists the beach reaches of the southwest Florida coast from Pinellas County through Collier County. In that table, individual reaches are tied to their respective set of sampling locations.

It should be noted that inlets and passes, throughout history, periodically open and close such that what was once one island might be two or more. The Sanibel Island, Captiva Island, and North Captiva Island group is an example of this. Conversely, what were formerly two islands may become one. The reach of beach between Big Sarasota Pass and Venice Inlet, referred to as Siesta/Casey Key, and the reach of beach between Stump Pass and Gasparilla Pass, referred to as Knight Island/Don Pedro Island, are examples of this.

The FDEP BBCS (2008), Strategic Beach Management Plan for the Southwest Gulf Coast Region was extensively consulted and used to establish the timeline of recent beach replenishment and the construction of engineering structures on the beach reaches in this portion of the study area. Additionally, a historical database of beach replenishment projects, compiled by the Western Carolina University Program for the Study of Developed Shorelines (PSDS) (2009) was also consulted. Table 6 lists the boundaries of known metropolitan areas as well as federal, state, and county lands discussed in this report when they relate to sampling locations.

Figures 7 through 12, progressively from north to south, geographically tie grain size and carbonate percentage curves to long stretches of coastline. Shading across the displayed curves delineate where inlets occur and where the sampling interval exceeds one mile (1.6 km).

Three Rooker Bar and Honeymoon Island

Geographic setting

Three Rooker Bar, as shown in Figure 1, is the northernmost of the barrier islands offshore of Pinellas County which lies entirely within its borders. USGS (2010a) describes Three Rooker Bar as "…a small semicircular island that has emerged within the last decade". It is separated to the north and south by open water from Anclote Key and Honeymoon Island respectively. Three Rooker Bar is approximately 1.5 miles (2.41 km) long and at its widest is roughly 500 ft (152.4 m) wide. It is undeveloped and only accessible by boat.

USGS (2010b) states that: “Honeymoon Island is entirely within the Honeymoon Island State Recreation Area. A causeway was constructed in 1966 to connect the island to the mainland. In the late 1960's the southern half of the island was filled and leveled in preparation for development.” Honeymoon Island is separated from Caladesi Island to the south by Hurricane Pass. Prior to the hurricane of 1921, which created Hurricane Pass, they formed one continuous island. Honeymoon Island is approximately 1,000 ft (304.8 m) wide at its widest point and approximately 4 miles long (7.4 km) with beach along that entire length. While Honeymoon Island is connected to the mainland by the Dunedin Causeway and bridge, it is essentially undeveloped except for its most eastern portions adjacent to the causeway. Both Three Rooker Bar and Honeymoon Island are geographically separated from the mainland to the east by St. Joseph Sound.

Beach history in brief

In 1969, approximately 1,440,000 cubic yards (cy) (1.866 million cubic ms (million m^3)) of sand was placed on the beach at Honeymoon Island and a groin field constructed as well. In 1989 additional beach renourishment was performed with 230,000 cy (175,848 m^3) of sand placed. In 2000 and 2007, material from maintenance dredging, approximately 12,500 cy (9,557 cubic ms (m^3) and 130,000 cy (99,393 m^3), respectively, were placed on the beach as well. Between those two dates, approximately 12,000 cy (9,175 m^3) of additional sand was placed.

Data Analysis

Within this reach of beach, eight locations (PI-01 through PI-08), as delineated in Table 1 and shown in Figure 1, were sampled and 11 samples collected. Three locations lie on Three Rooker Bar and five locations lie on Honeymoon Island. Swash zone and back beach samples were obtained from three locations, PI-02 on Three Rooker Bar and PI-04 and PI-07 on Honeymoon Island. Samples from single points on the beach were obtained from locations PI-01 and PI-03 on Three Rooker Bar and locations PI-05, PI-06 and PI-08 on Honeymoon Island.

Carbonate material averaged 0.9 percent in the three samples (from locations Pl-01 through Pl-03) processed from Three Rooker Bar. The mean grain size before carbonate digestion was 0.178 mm (2.489 phi). The mean grain size after carbonate digestion was 0.178 mm (2.493 phi). As shown in Figure 7, the sediments down the length of the island’s beaches are almost entirely non-carbonate and uniformly fine grained.

Carbonate material averaged 5.0 percent of the five samples (from locations Pl-04 through Pl-08) processed from Honeymoon Island. The mean grain size before carbonate digestion was 0.184 mm (2.439 phi). The mean grain size after carbonate digestion was 0.174 mm (2.525 phi). As shown in Figure 7, the percentage of carbonate material increases across the middle section of the island’s beaches and decreases again at the south end. As was the case on Three Rooker Bar to the north, the sediments on Honeymoon Island are uniformly fine grained.

Photographs, as well as the granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of the inlet between Three Rooker Bar and Honeymoon Island and north and south of Hurricane Pass can be found in Appendix C. In both cases, virtually no difference can be seen between the sediments on either side of the inlets.

Caladesi Island and Clearwater Beach Island

Geographic setting

Caladesi Island and Clearwater Beach Island, as shown in Figure 1, are two barrier islands which lie off the coast of northern Pinellas County. Caladesi Island, the northernmost of the pair, is separated to the north from Honeymoon Island by Hurricane Pass and to the south from Clearwater Beach by Dunedin Pass (USGS, 2010b). This island, Caladesi Island State Park, is considered to be a classic example of a drumstick barrier island, (Locker *et al.,* 1999b). It is accessible only by boat and is undeveloped. The island is approximately two miles (3.2 km) long and one mile (1.6 km) wide at its widest point.

The southernmost of the pair, Clearwater Beach Island, is separated by Clearwater Pass from Sand Key to the south. Unlike Caladesi Island, Clearwater Beach Island is extensively developed. These islands are separated from the mainland of Pinellas County to the east by Old Clearwater Bay and Clearwater Harbor which lie respectively north and south of the causeway and bridge connecting Clearwater Beach to the mainland. The island is approximately 3.5 miles (5.6 km) long and a third of a mile (0.5 km) wide.

Beach history in brief

Concerning Clearwater Beach Island is developed with both residential and resort properties. As development proceeded, numerous hard structures on the beaches, such as groins and bulkheads, were constructed. Due to the construction of high-value properties proximal to the beach erosion has become a critical problem (USGS, 2010b). In 1950 approximately 150,000 cy (114,683 m^3) and in 1951 approximately 200,000 cy (152,911 m^3) of sand were placed on the beaches of this island. Subsequently, in 1981 and 1984, an additional approximately 180,000 cy (137,620 m^3) and 80,000 cy (61,164 m^3) of sand were placed on the island. The shoreline adjacent to Clearwater Pass has been armored with concrete bulkheads and, in 1986; private property interests constructed five rubble mound groins there as well. This construction is reported to have stabilized pocket beaches which have been maintained by those interests.

Data analysis

Within this reach of beach, out of eight locations (PI-09 through PI-16), as delineated in Table 1 and shown in Figure 1, seven locations were sampled and 15 samples collected. As shown in Figure 1, three locations lie on Caladesi Island and five locations lie on Clearwater Beach Island. Swash zone, mid-beach and back beach samples were obtained from two locations, PI-14 and PI-15, on Clearwater Beach Island. Swash zone and back beach samples were obtained from two locations, PI-09 and PI-10, on Caladesi Island and two locations, PI-12 and PI-13, on Clearwater Beach Island. Only samples from a single point on the beach were obtained from location PI-11 on Clearwater Beach Island. Location PI-16 was not sampled as no access could be obtained to determine if any beach was present.

Carbonate material averaged 6.1 percent of the three samples, from locations PI-09 through PI-11, processed from Caladesi Island. The mean grain size before carbonate digestion was 0.194 mm (2.364 phi). The mean grain size after carbonate digestion was 0.186 mm (2.430 phi). As shown in Figure 7, the percentage of carbonate material and mean grain size, starting from the midpoint location of the island's sample set, both increase southward. As was the case on Three Rooker Bar and Honeymoon Island to the north, the sediments are still relatively fine grained.

Carbonate material averaged 9.4 percent of the four samples, from locations PI-12 through PI-15, processed from Clearwater Beach Island. The mean grain size before carbonate digestion was 0.225 mm (2.150 phi). The mean grain size after carbonate digestion was 0.208 mm (2.269 phi). As shown in Figure 7, the percentage of carbonate material and mean grain size both decline southward until the last sample point before Clearwater Pass where both increase.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Hurricane Pass between Honeymoon Island and Caladesi Island, north and south of Dunedin Pass between Caladesi Island and Clearwater Beach Island, and north and south of Clearwater Pass between Clearwater Beach Island and Sand Key can be found in Appendix C. In the first case, as was previously noted, virtually no difference can be seen between the sediments on either side of Hurricane Pass. The curves in the second case, indicate that the sediments coarsen slightly at and south of Dunedin Pass. The curves in the third case show that the sediments coarsen south of Clearwater Pass. Comparison of the pre- and post-carbonate digestion curves show that the those coarser sediments are substantially carbonate and form a significant tail to the pre-carbonate digestion's primary peaks which are sourced in the non-carbonate fraction.

Sand Key

Geographic setting

Sand Key is a barrier island which lies off the coast of central Pinellas County. This island, as shown in Figure 1, is separated to the north from Clearwater Beach Island by Clearwater Pass and to the south from Treasure Island by Johns Pass. In the north, the island is separated from the mainland to the east by the Intracoastal Waterway. Progressing south, it is separated from the mainland to the east by the Intracoastal Waterway and Boca Ciega Bay. Sand Key is developed and at approximately 14 miles (22.5 km) in length is the longest continuous section of beach in Pinellas County. It is arcuate, concave to the mainland, and, while it varies substantially in width throughout its length, it is approximately 0.5 miles (0.8 km) wide at its widest point. Davis, (1994) states that:

> *"The longest barrier spit (in the study area) is Sand Key in Pinellas County. This double spit emanates from the headland at Indian Rocks where Pleistocene bluffs of Pamlico have served as source materials. The barrier is presently separated from the mainland by the Intracoastal Waterway at the headland but is 1.24-2.49 miles (2-4 km) from the mainland at each end. Because of the shoreline orientation of Sand Key, it experiences net littoral drift away from the headland to both the north and to the south with considerable erosion in the Indian Rocks area."*

Beach history in brief

Sand Key is quite developed and many beach nourishment projects have been performed upon it. Beach erosion in some areas has left high value properties both devoid of beaches and lacking in storm protection. (USGS, 2010c). Records indicate that beach restoration and nourishment have been conducted throughout the island with the exception of the area adjacent to the Town of Belleair Shores, Redington Beach and Madeira Beach where a groin field was constructed in the late 1950's. In 1973 approximately 126,000 cy (96,334 m^3) and in 1977 186,000 cy (142,207 m^3) of beach compatible dredge material was placed on the north end of Sand Key adjacent to the Pass. Additionally, between 1981 and 1984 approximately one million cubic yards (cy) of beach compatible dredged material was placed in the same area. Restoration projects continued between 1988 and 1998. In 1988, beach renourishment was conducted on the middle portion of the island and approximately 539,150 cy (412,210 m^3) was placed. While there are some inconsistencies in the record regarding volumes, it appears that in 1990, 1992, 1999 and 2006, beach renourishment on the northern and middle portions of the island was conducted and 1.3 million cy (0.9939 million m^3), 0.85 million cy (0.65 million m^3), 2.6 million cy (1.98 million m^3) and 1.7 million cy (1.3 million m^3) were placed, respectively. The sediment sources for all these replenishment projects were dredged material incidental to channel maintenance in the area.

Data analysis

Within this reach of beach, 16 locations (PI-17 through PI-32), as delineated in Table 1 and shown in Figure 1, were sampled. From those locations, 33 samples were collected. Swash zone, mid-beach and back beach samples were obtained from two locations, PI-17 and PI-18. Swash zone and back beach samples were obtained from 13 locations, PI-19 and PI-20 as well as PI-22 through PI-32. Only samples from a single point on the beach were obtained from PI-21.

Carbonate material averaged 36.7 percent of the 16 samples (from locations PI-17 through PI-32) processed from Sand Key. The mean grain size before carbonate digestion was 0.375 mm (1.413 phi). The mean grain size after carbonate digestion was 0.188 mm (2.408 phi). As shown in Figure 7, the percentage of carbonate material and mean grain size both initially rise from the immediate vicinity of Clearwater Pass and then decline southward to Johns Pass. Additionally, the character of the curves from Sand Key is more uniform than those seen to the south.

Photographs, as well as granulometric analysis of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Clearwater Pass between Clearwater Beach Island and Sand Key and north and south of Johns Pass between Sand Key and Treasure Island can be found in Appendix C. As was noted above the curves comparing grain size north and south of Clearwater Pass indicate that the sediments coarsen south of Clearwater Pass. Comparison of the pre- and post-carbonate digestion curves show that those coarser sediments are substantially carbonate and form a significant tail to the pre-carbonate digestion's primary peaks which are sourced in the non-carbonate fraction. The sediments also coarsen south of Johns Pass. The carbonate fraction, in the sample south of Johns Pass, produces a distinct, albeit, broad secondary peak in the pre-carbonate digestion curves.

Treasure Island and Long Key

Geographic setting

These two islands, as shown in Figure 1, lie off the coast of central and southern Pinellas County. The islands comprising this reach are separated from the mainland to the east by Boca Ciega Bay and the Intracoastal Waterway. Both of these islands are extensively developed.

The northernmost of these two barrier islands, Treasure Island, is separated to the north from Sand Key by Johns Pass and to the south from Long Key by Blind Pass. Treasure Island is described in Locker *et al.* (1999c) as a "…drumstick barrier that has been completely developed…." The island is approximately 3.3 miles long and 0.5 miles (0.8 km) wide at its widest point.

Long Key is separated to the south from Shell Key Shoal by Pass-a-Grille Channel. It is arcuate, concave to the Gulf of Mexico, approximately four miles (6.4 km) long and 0.5 miles (0.8 km) wide at its widest point.

Beach history in brief

The earliest recorded renourishment of Treasure Island occurred in 1964 with the placement of 10,000 cy (7,646 m^3) of sand. The island's beaches were replenished again in 1966 and 1968 with the placement of over 120,000 cy (91,747 m^3) of sand. Short segments of Treasure Island's shoreline were subsequently renourished every three to five years from 1969 to 2006. Approximately 2.87 million cy (2.194 million m^3) of sand were placed during this period using sediment from the dredging of Blind Pass, Pass-a-Grille and the Egmont Channel as well as an offshore borrow area.

Long Key is developed, with large condominium and hotels built quite close to the beach. It has been greatly affected by recent beach erosion. Beach nourishment projects have been performed in several areas in response to rapid beach erosion (USGS, 2010d). Segments of the Long Key's shoreline have been renourished at least every five years since 1980. Between 1979 and 2006, approximately 1.68 million cy (1.28 million m^3) of sand were placed.

Data analysis

Within this reach of beach, five locations (PI-33 through PI-37) and five locations (PI-38 through PI-42), as delineated in Table 1 and shown in Figure 1, were sampled from Treasure Island and Long Key respectively. A total of 27 samples, 14 samples from Treasure Island and 13 samples from Long Key were collected.

On Treasure Island, the swash zone, berm, mid-beach and back beach samples were obtained from two locations, PI-34 and PI-35. Swash zone, mid-beach and back beach samples were obtained from one location, PI-37. Swash zone and back beach samples were obtained from location PI-33. Only samples from a single point on the beach were collected from location PI-36.

On Long Key, the swash zone, mid-beach and back beach samples were obtained from three locations, PI-38, PI-39 and PI-41. Swash zone and back beach samples were obtained from two locations, PI-40 and PI-42.

Carbonate material averaged 40.9 percent of the five samples (PI-38 through PI-37) processed from Treasure Island. The mean grain size before carbonate digestion was 0.481 mm (1.057 phi). The mean grain size after carbonate digestion was 0.210 mm (2.252 phi). The sample from location PI-37 was not analyzed after digestion due to the abundance of carbonate material it contained. As shown in Figure 7, the percentage of carbonate material and mean grain size both increase southward to Blind Pass.

Carbonate material averaged 32.7 percent of the five samples (from locations PI-33 through PI-42) processed from Long Key. The mean grain size before carbonate digestion was 0.351 mm (1.509 phi). The mean grain size after carbonate digestion was 0.185 mm (2.433 phi). As shown in Figure 7, the percentage of carbonate material and mean grain size both decrease along the beaches extending from the immediate vicinity of Blind Pass southward to the midpoint of the island's beaches. Both parameters then increase to Pass-a-Grille Channel.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Johns Pass between Sand Key and Treasure Island, north and south of Blind Pass between Treasure Island and Long Key and north and south of Pass-a-Grille Channel between Long Key and Shell Key Shoal can be found in Appendix C.

The sediments coarsen significantly so in the carbonate fraction south of Johns Pass, and south of both Blind Pass and Pass-a-Grille Channel as well. As previously discussed the carbonate fraction, in the sample furthest south of Johns Pass, produces a distinct, albeit, broad secondary peak in the pre-carbonate digestion curve.

Comparison of the pre- and post-carbonate digestion curves from the sample furthest north of Blind Pass shows that the single fine grained peak expressed is composed primarily of non-carbonate material. Conversely, the pre-carbonate digestion curve for the adjacent sample, lying immediately north of Blind Pass, shows a single strong broad peak of coarse sediments that are composed entirely of carbonate material. The curves from the samples south of Blind Pass show bimodal pre-carbonate digestion curves. wherein the fine grained peaks are far more distinct and primarily non-carbonate in nature.

The curves from the samples south of Pass-a-Grille Channel show multimodal peaks in pre-carbonate digestion curves. The fine grained are from the non-carbonate sediment fraction while the coarse grained peaks are from the carbonate sediment fraction.

Shell Key Shoal and Mullet Key

Geographic setting

These barrier two islands, as shown in Figure 1, lie off the coast of southern Pinellas County. The islands comprising this reach are separated from the mainland to the east by Tampa Bay. Davis, (1994) describes them as "…barriers that have a distinctly wave-dominated plan but they also have some tidal influence in the form of flood-tidal spits."

Shell Key Shoal, formerly known as Bunce Key and Shell Island, was once two separate islands but has formed one continuous island since approximately 1994. It is entirely undeveloped. Shell Key Shoal is separated to the north from Long Key by Pass-a-Grille Channel and from Mullet Key to the south by Bunces Pass.

Mullet Key, a county park, is lightly developed. The USGS (2010e) reports that it "…is one of the few sections along this coast that appears to be accreting sand. Recent surveys indicate that Mullet Key is accreting sand on its northern point." Mullet Key is the southernmost barrier island of Pinellas County.

Mullet Key is separated from Egmont Key by Egmont Channel. It is approximately 1.7 miles (2.7 km) long and 400 ft (121.9 m) wide at its widest point.

Beach history in brief

The first recorded instance of beach replenishment on Mullet Key was in 1964 with the placement of 140,000 cy (107,038 m^3) of sand. In 1973, approximately 0.7 million cy (0.5 million m^3) of sand, from the dredging of Egmont Channel, was placed on the south end of Mullet Key. In 1977 and 2006 over 0.35 million cy (0.27 million m^3) of additional sand, from the dredging of Tampa Harbor, was placed in the same area.

Data analysis

Within this reach of beach, as shown on Figure 1, three locations (PI-43 through PI-45) from Shell Key Shoal and three locations (Pl-46 through Pl-48), from Mullet Key were sampled. Eight samples were collected from Shell Key Shoal and seven samples were collected from Mullet Key.

On Shell Key Shoal, the swash zone, mid-beach and back beach samples were obtained from two locations, PI-44 and PI-45. Swash zone and back beach samples were obtained from one location, PI-43.

On Mullet Key, the swash zone, mid-beach and back beach samples were obtained from one location, PI-47. Swash zone and back beach samples were obtained from two locations, PI-46 and Pl-48.

Carbonate material averaged 52.0 percent of the three samples (from locations Pl-43 through Pl-45) processed from Shell Key Shoal. The mean grain size before carbonate digestion was 0.369 mm (1.440 phi). The mean grain size after carbonate digestion was 0.200 mm (2.320 phi). As shown in Figure 7, the percentage of carbonate material and mean grain size both initially start high immediately south of Pass-a-Grille Channel then decline southward.

Carbonate material averaged 7.5 percent of the three samples (from locations Pl-46 through Pl-48) processed from Mullet Key. The mean grain size before carbonate digestion was 0.327 mm (1.613 phi). The mean grain size after carbonate digestion was 0.155 mm (2.691 phi). As shown in Figure 7, the percentage of carbonate material and mean grain size both continue to decline from Shell Key Shoal southward to a minor peak upward at the last sample point before Egmont Channel.

Photographs, as well as the granulometric analyses results from samples collected and processed, from these two islands are provided in Appendix A. Curves comparing grain size north and south of Pass-a-Grille Channel between Shell Key Shoal and Long Key, north and south of Bunces Pass between Shell Key Shoal and Mullet Key and north and south of Egmont Channel between Mullet Key and Egmont Key can be found in Appendix C.

As was noted above, the curves from the samples south of Pass-a-Grille Channel show multimodal peaks in their pre-carbonate digestion curves. The fine grained and coarse grained peaks are from non-carbonate and carbonate sediments, respectively.

The pre-carbonate digestion curves from the samples furthest north of Bunces Pass are bimodal with the fine grained and coarse grained peaks also coming from non-carbonate and carbonate sediments, respectively. A comparison of the pre- and post-carbonate digestion curves for the samples obtained immediately north and south of Bunces Inlet shows that the samples are relatively fine grained and primarily non-carbonate. The curves from the samples furthest south of Bunces Pass indicate that the sediments in that sample are composed exclusively of fine grained carbonate material.

The curves from the sample furthest north of Egmont Channel show the sediment sample to be unimodal, fine grained and a comparison of the pre- and post-carbonate digestion curves indicate that the sediments are predominately non-carbonate in nature. The curves from the samples obtained immediately north and south of Egmont Channel are bimodal with their fine grained and coarse grained peaks also appearing to come from non-carbonate and carbonate sediments, respectively. The curves from the sample furthest south of Egmont Pass are broad and indicate that the coarser fraction of the sediments in that sample is composed of carbonate material.

Egmont Key

Geographic setting

Egmont Key lies in the mouth of Tampa Bay and is separated from Mullet Key to the north by the Egmont Channel and from Anna Maria Island to the south by the Southwest Channel and Passage Key Inlet. It lies perpendicular in orientation to these two channel sets. Egmont Key consists of Egmont Key State Park and Egmont Key National Wildlife Refuge. It is essentially undeveloped and contains the only Gulf of Mexico beaches in Hillsborough County. The Key is approximately 1.2 miles (2.0 km) long and, at its widest point, is 1640 ft (500 m) wide. Kling (1997) describes it as the "…vegetated supratidal portion of the Egmont ebb-tidal delta."

Beach history in brief

The erosional history of Egmont Key is discussed at length in Kling (1997) and in Stott and Davis (2003). The USGS (USGS, 2010e) reports that: "Egmont Key has seen high rates of erosion within the last decade. Erosion has decreased the size of the island from about 500 to less than 300 acres." Stott and Davis (2003) conclude that over the past century the island has lost approximately 40 percent of its area with more than 523,180 cy (400,000 m^3) of sediment having been lost to the deep channels on either end of the island.

In 2006, approximately 1.0 million cy (0.7646 million m^3) of sand were placed on the island's beach and near shore area.

Data analysis

Within this reach of beach, three locations (HL-01 through HL-03), as delineated in Table 1 and shown in Figure 1, were sampled. Five samples were collected.

On Egmont Key, the swash zone and back beach samples were obtained from two locations, Hl-01 and Hl-03. Only samples from a single point on the beach were obtained from one location, HL-02.

Carbonate material averaged 0.9 percent of the three samples (from locations HL-01 through HL-03) processed from Egmont Key. The mean grain size before carbonate digestion was 0.287 mm (1.802 phi). The mean grain size after carbonate digestion was 0.215 mm (2.216 phi). As shown in Figure 7, mean grain size trends finer southward along the beaches of Egmont Key. The sediments are almost entirely non-carbonate.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Egmont Channel between Mullet Key and Egmont Key and north and south of the Southwest Channel and Passage Key Inlet, between Egmont Key and Anna Maria Island can be found in Appendix C.

As discussed above, curves from the sample furthest north of Egmont Channel show the sediment sample to be unimodal, fine grained. A comparison of the pre- and post-carbonate digestion curves indicate that the sediments are predominately non-carbonate in nature. The curves from the samples obtained immediately north and south of Egmont Channel show that the sediments are bimodal with their fine grained and coarse grained peaks coming from their non-carbonate and carbonate sediment fractions, respectively. The curves from the sample furthest south of Egmont Pass are broad and indicate that the coarser fraction of the sediments in that sample is composed of carbonate material.

The peaks on the curves from the sample furthest north of the Southwest Channel and Passage Key Inlet are broad. A comparison of its pre- and post-carbonate digestion curves indicate that the coarser sediments in that sample are composed of carbonate material. The curves from the samples obtained immediately north and south of the Southwest Channel and Passage Key Inlet show those samples' sediments to be a homogenous, relatively fine grained mixture of carbonate and non-carbonate sediments. The peaks on the curves from the sample furthest south of the Southwest Channel and Passage Key Inlet are narrow and indicate that the sediments are relatively fine grained with the minor coarser fraction of sediments in that sample being composed of carbonate material.

Anna Maria Island

Geographic setting

Anna Maria Island is the northernmost barrier island of Manatee County. It is the first barrier island immediately south of the mouth of Tampa Bay. It is completely developed, primarily with residential and small tourist facilities (Locker *et al.,*1999d). The island is approximately 6.2 miles (12.0 km) long and, being slightly arcuate, is concave to the Gulf. It is separated from Egmont Key to the northwest by the Southwest Channel, also known as Passage Key Inlet, from the mainland by Tampa Bay to the northeast, Ana Maria Sound to the east and Sarasota Bay to the southeast and from Longboat Key to the southeast by Longboat Pass. Pekala (1996), reports that it "…has a characteristic drumstick shape with a minimum width of 0.1 km (328 ft) near the south end and a maximum width of 2 km (1.2 miles) near the north end."

Beach history in brief

The erosional history of Anna Maria Island is discussed in Pekala (1996) where it is both noted that erosion problems on the island's Gulf of Mexico shore have been of concern since before 1947 and that the earliest, albeit ineffectual, beach replenishment project took place in 1963. At that time a quantity of sand, whose volume is now unknown, from Sarasota Pass was placed on the island. While there seems to be some uncertainty in the records regarding exact volumes involved, in 1993, 2002 and 2006, beach restoration projects were completed with over 6.1 million cy (4.7 million m^3) of sand being placed on the island's beaches.

Data analysis

Within this reach of beach, nine locations (MN-01 through MN-09), as delineated in Table 1 and shown in Figure 1, were sampled and 15 samples collected. Swash zone and back beach samples were obtained from six locations, MN-02 through MN-06 and MN-09, on Anna Maria Island. Only samples from single points on the beach were obtained from the remaining three locations, MN-01, MN-07, and MN-08.

Carbonate material averaged 23.2 percent of the samples processed from Anna Maria Island. The mean grain size before carbonate digestion was 0.331 mm (1.597 phi). The mean grain size after carbonate digestion was 0.207 mm (2.272 phi). As shown in Figure 8, both carbonate percentage and mean grain size increase in the middle portion of the island's beaches from lows at either end.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Passage Key Inlet between Egmont Key and Anna Maria Island and north and south of Longboat Pass between Anna Maria Island and Longboat Key can be found in Appendix C.

As was noted above, the peaks on the curves from the sample furthest north of Passage Key Inlet are broad and a comparison of its pre- and post-carbonate digestion curves indicates that the coarser sediments in that sample are composed of carbonate material. The curves from the samples obtained immediately north and south of Passage Key Inlet show those samples' sediments to be a homogenous, relatively fine grained mixture of carbonate and non-carbonate sediments. The peaks on the curves from the sample furthest south of Passage Key Inlet are narrow and indicate that the sediments are relatively fine grained with the minor coarser fraction of sediments in that sample being composed of carbonate material.

The curves from the samples north and immediately south of Long Pass show that the sediments are unimodal in distribution. The peaks on the curves from those samples are narrow and indicate sediments in that sample are composed primarily of relatively fine grained, non-carbonate material. What carbonate material they contain is a minor coarser grained fraction. The curves from the sample furthest south of Long Pass show the sediments are bimodal in distribution. A comparison of the pre- and post-carbonate digestion curves indicates that their fine grained and coarse grained peaks come from non-carbonate and carbonate sediments, respectively.

Longboat Key

Geographic setting

Longboat Key, an approximately 10 miles (16.1 km) long linear barrier island, has beach along its entire expanse. Its width varies from a maximum of approximately one mile (1.609 km) to 500 ft (152.4 m). Locker, *et al.* (1999e) states that "The island is now a wave dominated barrier although the southern portion was a drumstick barrier when it was separated from the northern portion." Davis (1994) includes it in a discussion of islands with "…a very complex pattern of multiple beach ridge systems with a range of orientations and which are spread along much of the length of the island."

Longboat Key is separated from Anna Maria Island, to the northwest, by Longboat Pass. It is separated from Lido Key, to the southeast, by New Pass. It is separated from the mainland to the east by Sarasota Bay. Longboat Key lies in both Manatee and Sarasota counties and is roughly bisected by the county line.

Beach history in brief

The earliest known occurrence of beach renourishment on Longboat Key is thought to have occurred in 1963 or 1964, the date is uncertain. Approximately 2,700 cy (2,064 m^3) of sand was placed on the beach. In 1978, approximately 101,480 cy (77,587 m^3) of additional sand was placed. Over 6.3 million cy (4.817 million m^3) of sand were placed on the beach from 1982 through 2006. While most of this sand came from the dredging of Longboat Pass and New Pass, some was taken from a borrow area offshore.

Data analysis

Within this reach of beach, 12 locations (MN-10 through MN-15 and SA-01 through SA-06), as delineated in Table 1 and shown in Figure 1, were identified. Eleven locations were sampled and 19 samples collected.

Swash zone, mid-beach and back beach samples were obtained from location SA-04. Swash zone and back beach samples were obtained from six locations, MN-12 through MN-15, SA-01, and SA-05. Only samples from single points on the beach were obtained from four locations, MN-11, SA-02, SA-03 and SA-06. No sample was collected at location MN-10.

Carbonate material averaged 33.8 percent of the samples processed from locations MN-11 through MN-15 lying on the north end of Longboat Key in Manatee County. The mean grain size before carbonate digestion was 0.297 mm (1.754 phi). The mean grain size after carbonate digestion was 0.211 mm (2.246 phi). Carbonate material averaged 32.1 percent of the samples processed from locations SA-01 through SA-06 lying on the south end of Longboat Key in Sarasota County. The mean grain size before carbonate digestion was 0.337 mm (1.570 phi). The mean grain size after carbonate digestion was 0.201 mm (2.317 phi). Carbonate material averaged 32.9 percent of all of the samples processed from Longboat Key. The mean grain size before carbonate digestion was 0.303 mm (1.721 phi). The mean grain size after carbonate digestion was 0.202 mm (2.310 phi). As shown in Figure 8, there is considerable variation in carbonate percentage and mean grain size from north to south down the length of this island's beaches. Carbonate percentages, in particular, vary from less than 5 percent to greater than 70 percent. Both carbonate percentages and mean grain size increase three times in tandem peaks both from lows adjacent to the passes at either end of the island and from lows between the peaks.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Longboat Pass between Anna Maria Island and Longboat Key and north and south of New Pass between Longboat Key and Lido Key can be found in Appendix C.

As noted above, the curves from the samples north and immediately south of Long Pass show that the sediments are unimodal in distribution. The peaks on the curves from those samples are narrow and indicate the sediments are composed primarily of fine grained non-carbonate material. The carbonate material they contain is a minor, coarser grained, fraction. The curves from the sample furthest south of Long Pass show the sediments are bimodal in distribution. A comparison of the pre- and post-carbonate digestion curves indicates that their fine grained and coarse grained peaks come from non-carbonate and carbonate sediments, respectively.

The pre-carbonate digestion curves from the sample furthest north of New Pass show the sediments to be bimodal in distribution. The fine grained and coarse grained peaks are from non-carbonate and carbonate sediments, respectively. The curves from the samples immediately north of and those south of New Pass show the sediments to be unimodal in distribution. The peaks on the curves from those samples are narrow. A comparison of their pre- and post-carbonate digestion curves indicates that the sediments in those samples are composed primarily of fine grained, non-carbonate material, with what carbonate material they contain being in the coarser grained fraction.

Lido Key and Siesta/Casey Key

Geographic setting

Lido Key is separated from Anna Maria Island to the north by New Pass, from the mainland to east by Sarasota Bay, and from Siesta/Casey Key to the south by Big Pass. Lido Key is approximately 2.5 miles (4.0 km) long and developed. Like Shell Key Shoal and Mullet Key, Davis (1994) describes Lido Key as a barrier with "… a distinctly wave-dominated plan" which also has "…some tidal influence in the form of flood-tidal spits."

Siesta/Casey Key, to the south of Lido Key, is separated from the mainland to the east and Manasota Key to the south by Sarasota Bay and Venice Inlet respectively. Siesta Key is a "drumstick" barrier island on its north end (Davis, 1994) while Casey Key, to which it is joined, is a wave dominated linear barrier island which is, throughout much of its length, quite narrow. Siesta Key is approximately 1.24 miles (2.0 km) wide at its widest point while Casey Key narrows, in some stretches, to less than 328 ft (100 ms) wide. These two islands were formerly separated by Midnight Pass, an unstable inlet that closed in 1983. The former inlet lies in the vicinity of sampling location SA-17. The combined island is approximately 16 miles (25.8 km) long and substantially developed.

Beach history in brief

According to USGS (2010f), "Lido Key was formed artificially in the 1920's when a series of small mangrove islands were filled with dredge material from New Pass." The earliest well documented occurrence of beach restoration on Lido Key was in 1964 when approximately 121,000 cy (92,511 m^3) of sand was placed on the beach. Over 2.45 million cy (1.873 million m^3) of sand were placed on the island's beaches from 1970 through 2003. While most of this sand came from the dredging of New Pass, some was taken from a borrow area offshore. In 2007, approximately 0.85 million cy (0.6499 million m^3) of sand from an offshore borrow site was placed on the beach south of Point O' Rocks in the middle portion of Siesta/Casey Key.

Data analysis

Within this reach of beach, 19 locations (SA-07 through SA-25), as delineated in Table 1 and shown in Figure 1, were identified and 17 locations sampled, four from Lido Key and 13 from Siesta/Casey Key. Ten samples were collected from Lido Key and 23 samples were collected from Siesta/Casey Key.

On Lido Key swash zone, mid-beach and back beach samples were obtained from three locations, SA-08 through SA-10. Only samples from a single point on the beach were obtained from one location, SA-07.

Carbonate material averaged 33.5 percent of the samples processed from Lido Key. The mean grain size before carbonate digestion was 0.329 mm (1.602 phi). The mean grain size after carbonate digestion was 0.174 mm (2.527 phi). As shown in Figure 8, both carbonate percentage and mean grain size increase from the adjacent island's proximal samples, peak and then decline. Carbonate percentages along the island vary from less than 10 percent to greater than 55 percent.

Swash zone, mid-beach and back beach samples were obtained from two locations, SA-12 and SA-13 on Siesta/Casey Key. Swash zone and back beach samples were obtained from six locations, SA-14, SA-17, SA-18, and SA-23 through SA-25. Only samples from single points on the beach were obtained from five locations, SA-16 and SA-19 through SA-22. No samples were collected from two locations, SA-11 and SA-15, where no beach was present.

Carbonate material averaged 56.1 percent of the samples processed from Siesta/Casey Key. The mean grain size before carbonate digestion was 0.574 mm (0.800 phi). The mean grain size after carbonate digestion was 0.241 mm (2.053 phi). The samples from locations SA-17 and SA-20 were not analyzed after digestion due to the abundance of carbonate material they contained. As shown in Figure 8, from north to south, there is an abrupt change in carbonate percentage and mean grain size which appears to coincide with the location of Midnight Pass, the inlet that formerly divided this island. North and south of the length of beach that runs from SA-16 through SA-18, the region of the former inlet, carbonate percentages increase from less than 10 percent to greater than 70 percent. Mean grain size significantly coarsens south of that length of beach as well.

Photographs and granulometric analyses of those samples collected and processed are provided in Appendix A. Curves comparing grain size north and south of New Pass between Longboat Key and Lido Key, north and south of Big Pass between Lido Key and Siesta Key, north and south of the former inlet, Midnight Pass, and north and south of Venice Inlet between Casey Key and Manasota Key can be found in Appendix C.

As was noted above, the pre-carbonate digestion curves from the sample furthest north of New Pass show the sediments to be bimodal in distribution with the fine grained and coarse grained peaks coming from non-carbonate and carbonate sediments, respectively. The curves from the samples immediately north of and those south of New Pass show that sediments to be unimodal in distribution. The peaks on the curves from those samples are narrow. A comparison of their pre- and post-carbonate digestion curves indicates that the sediments in those samples are composed primarily of fine grained non-carbonate material, with what carbonate material they contain being in the coarser grained fraction.

The pre-carbonate digestion curves from the samples north of Big Pass show single fine grained peaks with significant tails of coarse grained material. Comparison with the post-carbonate digestion curves shows that the tail is composed of carbonate material. Conversely the curves from the samples south of Big Pass only show a single fine grained peak without any extraneous coarse grained material.

The pre-carbonate digestion curves from SA-14, the sample furthest north of the location of the former inlet, Midnight Pass, shows a single, narrow, fine grained peak that is substantially composed of non-carbonate material. The remaining curves on the pre-carbonate digestion graph individually show broader multiple peak responses to a mixture of coarser grained material. The curves for samples SA-16, SA-18 and SA-19 resolve to single peaks shifted to the finer end of the spectrum on the post-carbonate digestion graph. The sample from SA-17 shows no curve on the post-carbonate digestion graph as it was composed entirely of carbonate sediments.

The pre- and post-carbonate digestion curves from the samples north of Venice Inlet are distinctly different in character. This is attributed to a strong dichotomy in grain sizes between their carbonate and non-carbonate fractions. A comparison of the pre- and post-carbonate digestion curves from the samples south of Venice Inlet show that these sediments are entirely carbonate.

Manasota Key

Geographic setting

Manasota Key is separated from Siesta/Casey Key, to the north, by Venice Inlet. It is approximately 20 miles (32.19 km) long. The island is approximately 1.25 miles (2.01 km) wide at its widest on its north end and narrows to less than 500 ft (152.4 m) wide on its south end. The northern middle and southern parts of the key are separated from the mainland to the east by the Intracoastal Waterway, Lemon Bay and further south by the Intracoastal Waterway. The southern end of the key is separated from Knight Island/Don Pedro Island by Stump Pass. Davis (1994) describes it as a long narrow barrier which "…extends about 15.5 miles (25 km) from the broad Miocene headland area near Venice." He states that "…Manasota Key represents a combination of longshore drift and wave-dominated morphology that has resulted in this unique barrier on this coast."

The development of Manasota Key is mixed with extensive development on the north end, and minimal to moderate development further south. Stump Pass Beach State Park lies on its southern end.

Beach history in brief

The first recorded replenishment of the beaches on Manasota Key occurred on its north end in 1963. That area was again replenished in 1975 and 1980. No estimates of the volume of sand placed are available. The northern end of Manasota Key, in Sarasota County, was replenished in 1994 and 1996 with an approximately 1.8 million cy (1.4 million m^3) of sand obtained from offshore borrow sites. Additionally, approximately 0.9 million cy (0.7 million m^3) of sand was placed in 2005 using sand from five offshore borrow sites. The southern end of Manasota Key, in Charlotte County, was replenished in 2003 and 2006 with approximately 100,000 cy (76,455 m^3) and 148,000 cy (113,154 m^3) of sand respectively obtained from the dredging of Stump Pass.

Data analysis

Within this reach of beach, 19 locations (SA-26 through SA-39 and CH-01 through CH-05), as delineated in Table 1 and shown in Figure 1, were identified and sampled. A total of 28 samples were collected. Swash zone, mid-beach and back beach samples were obtained from location SA-27. Swash zone and back beach samples were collected from seven locations, SA-26, SA-29, SA-32 through SA-35 and CH-02. Only samples from single points on the beach were obtained from 11 locations, SA-28, SA-30 and SA-31, SA-36 through SA-39, CH-01, and CH-03 through CH-05.

Carbonate material averaged 49.1 percent of the samples processed from the north end of Manasota Key in Sarasota County. The mean grain size before carbonate digestion was 0.446 mm (1.165 phi). The mean grain size after carbonate digestion was 0.317 mm (1.659 phi). Carbonate material averaged 42.3 percent of the samples processed from the south end of Manasota Key in Charlotte County. The mean grain size before carbonate digestion was 0.490 mm (1.029 phi). The mean grain size after carbonate digestion was 0.347 mm (1.529 phi). Carbonate material averaged 47.3 percent of all of the samples processed from Manasota Key. The mean grain size before carbonate digestion was 0.458 mm (1.128 phi). The mean grain size after carbonate digestion was 0.326 mm (1.617 phi). The samples from locations SA-26, SA-27 and SA-30 were not analyzed after digestion due to the abundance of carbonate material they contained. As shown in Figure 9, between locations SA-30 and SA-31, there is an abrupt drop in carbonate percentage and mean grain size. Carbonate percentages decline from a value of greater than 80 percent to less than 30 percent. Between locations SA-35 and SA-36, there is an increase in carbonate percentage and mean grain size. Carbonate percentages increase from a value of less than 30 percent to greater than 55 percent.

Photographs, as well as granulometric analysis, of the samples collected and processed are provided in Appendix A. Curves comparing grain size north and south of Venice Inlet, between Siesta/Casey Key and Manasota Key, and north and south of Stump Pass between Manasota Key and Knight Island can be found in Appendix C.

As noted above, the pre- and post-carbonate digestion curves from the samples north of Venice Inlet are distinctly different in character. This is attributed to a strong dichotomy in grain sizes between their carbonate and non-carbonate fractions. A comparison of the pre- and post-carbonate digestion curves from the samples south of Venice Inlet show that these sediments are entirely carbonate.

The pre- and post-carbonate digestion curves from the sample furthest north of Stump Pass show those sediments to be coarser than those immediately adjacent to and furthest to the south of Stump Pass. Comparison of both curve sets for all the samples displayed shows that their carbonate fractions are coarser than their non-carbonate fractions.

Knight Island/Don Pedro Island

Geographic setting

Knight Island/Don Pedro Island is separated from Manasota Island to the north by Stump Pass, from the mainland to the east first by the Intracoastal Waterway then by Placida Harbor and from Gasparilla Island to the south by Gasparilla Pass. The island is approximately four miles (6.44 km) long and varies in width from approximately 0.5 miles (0.8 km) to 1,000 ft (304.8 m) wide. Except for Don Pedro State Park in the middle portion of it, the island is developed, albeit more substantially so, on its southern end.

Beach history in brief

The beaches of Knight Island/Don Pedro Island were replenished from 1995 through 2006 in four projects with approximately 1.27 million cy (0.97 million m^3) of sand obtained from the dredging of Stump Pass.

Data analysis

Within this reach of beach, eight locations (CH-06 through CH-13), as delineated in Table 1 and shown in Figure 1, were identified. All eight locations were sampled and 14 samples were collected.

Swash zone, mid-beach and back beach samples were obtained from CH-08. Swash zone and back beach samples were obtained from four locations, CH-07, CH-09, CH-10 and CH-12. Only samples from single points on the beach were obtained from three locations, CH-06, CH-11 and CH-13.

Carbonate material averaged 28.5 percent of the samples processed. The mean grain size before carbonate digestion was 0.324 mm (1.624 phi). The mean grain size after carbonate digestion was 0.244 mm (2.036 phi). As shown in Figure 9, carbonate percentage and mean grain size curves peak from the first sample location south of Stump Pass and then trend downward to sample point CH-13 which is just north of Gasparilla Pass. Carbonate percentages range from greater than 40 percent to less than 10 percent.

Photographs, as well as granulometric analysis, of the samples collected and processed are provided in Appendix A. Curves comparing grain size north and south of Stump Pass between Manasota Key and Knight Island/Don Pedro Island and north and south of Gasparilla Pass between Knight Island /Don Perdro Island and Gasparilla Island can be found in Appendix C.

As noted above, the pre- and post-carbonate digestion curves from the sample furthest north of Stump Pass show those sediments to be coarser than those immediately adjacent and furthest to the south. Comparison of both curve sets for all the samples shows that their carbonate fractions are coarser than their non-carbonate fractions.

The pre-carbonate digestion curves from samples north and south of Gasparilla Pass show single, fine grained, peaks. The pre-carbonate digestion curve for the sample immediately south of the pass shows a significant tail of coarse grained material. Comparison with the post-carbonate digestion curves shows the tail is composed of carbonate material.

Gasparilla Island

Geographic setting

Gasparilla Island is separated from Manasota Key to the north by Stump Pass, from the mainland to the east by Gasparilla Sound and Charlotte Harbor, and from Cayo Costa Island to the south by Boca Grande Pass. Gasparilla Island, except for a short section at Gasparilla State Park near its southern tip, is developed. The island is approximately eight miles (12.9 km) long and varies in width from approximately one mile (1.61 km) to less than 1,000 ft (304.8 m) wide.

Beach history in brief

In 1981, 1993 and 1997 over 264,000 cy of sand from maintenance dredging of Boca Grande Pass was placed on the southern end of Gasparilla Island. In 2007, the south end of Gasprilla was replenished with an additional 0.92 million cy (0.70 million m^3) of sand from the dredging of Boca Grande Pass.

Data analysis

Within this reach of beach, eight locations (CH-14 and CH-15 as well as LE-01 through LE-06), as delineated in Table 1 and shown in Figure 1, were identified. All eight locations were sampled and 17 samples were collected.

Swash zone, berm, mid-beach and back beach samples were taken from location LE-04. Swash zone, mid-beach and back beach samples were obtained from two locations LE-05 and LE-06. Swash zone and back beach samples were obtained from two locations, CH-14 and CH-15. Only samples from single points on the beach were obtained from three locations, LE-01 through LE-03.

Carbonate material averaged 27.8 percent of the samples processed from locations CH-14 and CH-15, which lie in Charlotte County. The mean grain size before carbonate digestion was 0.391 mm (1.353 phi). The mean grain size after carbonate digestion was 0.222 mm (2.170 phi). Carbonate material averaged 35.6 percent of the samples processed from locations LE-01 through LE-06 in Lee County. The mean grain size before carbonate digestion was 0.427 mm (1.228 phi). The mean grain size after carbonate digestion was 0.256 mm (1.968 phi). Carbonate material averaged 33.7 percent of all the samples processed from Gasparilla Island. The mean grain size before carbonate digestion was 0.418 mm (1.258 phi). The mean grain size after carbonate digestion was 0.247 mm (2.016 phi). As shown in Figure 9, carbonate percentage and mean grain size trend increase southward from the midpoint of this reach of beach. Carbonate percentages on the northern portion of this reach vary from greater than 40 percent to less than 15 percent, while on the southern portion of the reach they vary from greater than 45 percent to greater than 20 percent.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Gasparilla Pass between Knight Island /Don Pedro Island and Gasparilla Island and north and south of Boca Grande Pass between Gasparilla Island and La Costa Island can be found in Appendix C.

As noted above, the pre-carbonate digestion curves from the samples north and south of Gasparilla Pass show single fine grained peaks. The pre-carbonate digestion curve for the sample immediately south of the pass shows a significant tail of coarse grained material. Comparison with the post-carbonate digestion curves shows the tail is composed of carbonate material.

The pre-carbonate digestion curves from the samples from the north and south of Boca Grande Pass show that the sediments south of the pass are coarser than those to its north. The pre-carbonate digestion curves display a range of peaks with significant tails of coarse grained material. The greatest separation of peaks is between the curves from the samples immediately adjacent to the inlet with the samples north and south of the inlet being the finest and the coarsest, respectively. Comparison of the pre- and post-carbonate curves show that the carbonate fraction of northernmost and samples adjacent to the inlet is significantly coarser than the non-carbonate fraction and that the southernmost sample is entirely carbonate in composition. Comparison of the pre- and post-carbonate digestion curves also reveals that tails noted above are composed primarily of carbonate material.

La Costa Island

Geographic setting

Davis (1994) describes La Costa Island as a drumstick or mixed energy barrier that displays "…a very complex pattern of multiple beach ridge systems with a range of orientations and which are spread along much of the length of the island."

La Costa Island is separated from Gasparilla Island to the north by Boca Grande Pass and from the mainland to the northeast by Charlotte Harbor, to the east by Pelican and Primo Bays and to the southeast by Pine Island Sound. It is separated from North Captiva Island to the south by Captiva Pass. La Costa Island, except for numerous small in-holdings, consists entirely of Cayo Costa State Park. The island is approximately eight miles long. It varies in width from approximately one mile (1.61 km) to less than 500 ft (152.4 m) wide. It is accessible only by boat.

Beach history in brief

La Costa Island has been allowed to remain in a natural state with little or no modification of the beach environment.

Data analysis

Within this reach of beach, eight locations (LE-07 through LE-14), as delineated in Table 1 and shown in Figure 1, were identified. All eight locations were sampled and 11 samples were collected.

Swash zone, and back beach samples were obtained from three locations, LE-09, LE-10 and LE-12. Only samples from single points on the beach were obtained from locations, LE-07, LE-08, LE-11, LE-13 and, LE-14.

Carbonate material averaged 46.2 percent of the samples processed. The mean grain size before carbonate digestion was 0.563 mm (0.829 phi). The mean grain size after carbonate digestion was 0.262 mm (1.935 phi). The sample from location LE-08 was not analyzed after digestion due to the abundance of carbonate material it contained. As shown in Figure 10, both the percent carbonate and mean grain size curves peak at the north and south ends of this reach and dip in the middle. Carbonate percentage varies from greater than 90 percent to less than 20 percent.

Photographs and granulometric analyses of the samples collected and processed are provided in Appendix A. Curves comparing grain size north and south of Boca Grande Pass between Gasparilla Island and La Costa Island and north and south of Captiva Pass between La Coast Island and North Captiva Island can be found in Appendix C.

As noted above, the pre-carbonate digestion curves from the samples from the north and south of Boca Grande Pass show that the sediments south of the pass are coarser than those to its north. The pre-carbonate digestion curves display a range of peaks with significant tails of coarse grained material. The greatest separation of peaks is between the curves from the samples immediately adjacent to the inlet with the samples north and south being the finest and the coarsest, respectively. Comparison of the pre- and post-carbonate curves show that the carbonate fraction of northernmost and inlet adjacent samples is significantly coarser than the non-carbonate fraction and that the southernmost sample is entirely carbonate in composition. Comparison of the pre- and post-carbonate digestion curves also reveals the tails, noted above, are composed primarily of carbonate material.

A comparison of the pre and post-digestion curves from the samples north and south of Captiva Pass reveals that while their fine grained fractions are composed of non-carbonate their coarse grained fractions are composed of carbonate material. The samples from south of the inlet contain less carbonate than those to the north. Those to the north of the inlet display peaks with prominent coarse tails which are composed primarily of carbonate material.

North Captiva and Captiva Islands

Geographic setting

North Captiva Island is separated from La Costa Island to the north by Captiva Pass and from the mainland to the east by Pine Island Sound. Redfish Pass, created by a hurricane in 1921, separates it from Captiva Island to the south. North Captiva Island is developed only on its north end. It is approximately six miles (9.7 km) long, 0.25 miles (402 m) wide at its widest and narrows to less than 500 ft (152.4 m) wide near its southern end. It is accessible only by boat.

Captiva Island is separated from North Captiva Island to the north by Redfish Pass, from the mainland to the east by Pine Island Sound and from Sanibel Island to the south by Boca Ciega, also known as Blind Pass. The island is approximately five miles (8.1 km) long. It is 0.5 miles (0.8 km) wide at its widest and locally narrows to less than 500 ft (152.4 m) wide.

Beach history in brief

The first recorded beach restorations on Captiva Island were in 1961, 1962, 1963, 1965 and 1967. However, no volume estimates of sand placed are available. Later, beach restoration on the northern end of Captiva Island was accomplished in four projects from 1981 to 2006 with the placement of approximately 4.07 million cy (3.11 million m^3) of sand from the dredging of Redfish Pass and an offshore sand source.

Data analysis

Within this reach of beach, 11 locations (LE-15 through LE-25), as delineated in Table 1 and shown in Figure 1, were identified. All 11 locations, five on North Captiva and six on Captiva Island, were sampled. Six samples were collected on North Captiva Island and 12 samples were collected on Captiva Island.

Swash zone and back beach samples were obtained from only one location, LE-18 on North Captiva Island. Only samples from single points on the beach were obtained from the island's remaining four locations, LE-15 through LE-17 and LE-19.

Carbonate material averaged 43.4 percent of the samples processed from North Captiva Island. The mean grain size, before carbonate digestion, was 0.743 mm (0.428 phi). The mean grain size, after carbonate digestion, was 0.267 mm (1.907 phi). As shown in Figure 10, the percent carbonate and mean grain size curves both trend upward from location LE-16 southward. Both peak at location LE-19 just north of Redfish Pass. Percent carbonate varies from greater that 90 percent, at location LE-19, to less than 20 percent at location LE-16.

Swash zone, mid-beach and back beach samples were obtained from one location, LE-20 on Captiva Island. Swash zone, and back beach samples were obtained from four locations, LE-21, LE-22, LE-24 and LE-25. Only samples from a single point on the beach were obtained from one location, LE-23.

Carbonate material averaged 51.5 percent of the samples processed from Captiva Island. The mean grain size, before carbonate digestion, was 0.536 mm (0.899 phi). The mean grain size, after carbonate digestion, was 0.361 mm (1.469 phi). Percent carbonate and mean grain size both trend upward from location LE-25 southward. Percent carbonate continues to rise past location LE-25 just north of Boca Ciega. Percent carbonate varies from greater that 60 percent, at location LE-25, to greater than 20 percent at location LE-21.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Captiva Pass between La Costa Island and North Captiva Island, north and south of Redfish Pass between North Captiva Island and Captiva and north and south of Boca Ciega between Captiva Island and Sanibel Island can be found in Appendix C.

As noted above, a comparison of the pre- and post-digestion curves from the samples north and south Captiva Pass shows that the fine grained and coarse grained fractions are composed primarily of non-carbonate and carbonate material, respectively. The samples from south of the inlet contain less carbonate than those to the north. Those to the north of the inlet display peaks with prominent coarse tails which are composed primarily of carbonate material.

A distinct difference was noted between the pre- and post-digestion curves from the samples north and south of Redfish Pass. The fine grained end of the pre digestion curves are shallower compared to those of the post-carbonate digestion curves due to the presence of a wide spectrum of carbonate grain sizes. Examination of the post-carbonate digestion curves show that the non-carbonate fractions north of the pass are finer grained than those to the south.

Comparison of the pre- and post-carbonate digestion curves from the samples north and south of Boca Ciega shows that the coarser sediment fractions of these samples are composed of carbonate material. This is specifically apparent in the distinct shifting, to the finer end of the scale, of the primary peaks between the pre- and the post-carbonate digestion curves.

Sanibel Island

Geographic setting

Davis, (1994) states that:

> *"…Sanibel Island is the widest of the barriers on this coast. Sanibel has developed at a major dislocation in the coast…, As a result, the shoreline of this island displays a broad curve over about 90 degrees. Because of the dislocation of the coast, Sanibel has become a sediment sink in that the longshore transport in the north-to-south system is deposited here in the form of numerous sets of prograding beach ridges."*

Sanibel Island is approximately 12 miles (19.3 km) long and varies from approximately two miles (3.219 km) to less than a mile (1.609 km) wide. It is arcuate, concave to the mainland, and marks a major shift in the coast line to the east. Northwest to southeast trending on its northern end, the island hooks to the south southeastward until, on its eastern most point, it trends from the northeast to the southwest. Thus, from its north end, its beaches face initially southwest and proceed progressively more and more southward until, at the middle of the island's Gulf shore, they face south. From that point, they progressively face more and more southeastward. The island is separated from Captiva Island to the north by Boca Ciega, from the mainland to the north and northeast by Pine Island Sound and from Estero Island to the east by the mouth of San Carlos Bay. Sanibel Island is extensively developed.

Beach history in brief

In 1996 and 2006 approximately 237,100 cy (181,276 m^3) and 305,000 cy (233189 m^3) of sand, respectively, were placed on the northwest end of Sanibel Island.

Data analysis

Within this reach of beach, 14 locations (LE-26 through LE-39), as delineated in Table 1 and shown in Figure 1, were identified. All 14 locations were sampled and 29 samples were collected.

Swash zone, mid-beach and back beach samples were obtained from two locations, LE-30 and LE-31. Swash zone, berm and back beach samples were obtained from LE-28. Swash zone, and back beach samples were obtained from nine locations, LE-27, and LE-32 through LE-39. Only samples from single points on the beach were obtained from two locations, LE-26 and LE-29.

Carbonate material averaged 48.9 percent of the samples processed. The mean grain size, before carbonate digestion, was 0.432 mm (1.209 phi). The mean grain size, after carbonate digestion, was 0.204 mm (2.293 phi). The sample from location LE-31 was not analyzed after digestion due to the abundance of carbonate material it contained. As shown in Figure 11, both the percent carbonate and mean grain size curves peak in the middle portion of this reach with both declining significantly at its southern end. Carbonate percentage varies from less than 10 percent to greater than 85 percent across this reach.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Boca Ciega between Captiva Island and Sanibel Island and north and south of Matanzas Pass at the mouth of San Carlos Bay between Sanibel Island and Estero Island can be found in Appendix C.

As noted above, comparison of the pre- and post-carbonate digestion curves from the samples north and south of Boca Ciega shows that the coarser sediment fractions of these samples are composed of carbonate material. This is specifically apparent in the distinct shifting, to the finer end of the scale, of the primary peaks between the pre- to the post-carbonate digestion curves.

A comparison of the pre- and post-carbonate dissolution curves from the sediments north and south of Matanzas Pass at the mouth of San Carlos Bay show little differentiation between the samples. The curves are unimodal in distribution with narrow peaks and the sediments are fine grained.

Estero Island

Geographic setting

Estero Island is slightly arcuate, concave to the Gulf of Mexico, and approximately 7 miles (11.3 km) long. The island's width varies from approximately 0.5 miles (0.8 km) wide near its southern end to less than 500 ft (152.4 m) wide near its northern end. It is separated from Sanibel Island to the west by the mouth of San Carlos Bay (Matanzas Pass) and from the mainland to the north and east by the Intracoastal Waterway, an extensive mangrove estuary, and Ostego Bay. It is separated from Lovers Key to the south by Big Carlos Pass. The island is developed.

Beach history in brief

Periodic maintenance dredging of Matanzas Pass at the mouth of San Carlos Bay in 1986, 1998 and 2001, has been conducted. The dredged material was placed on the beaches of the north end of Estero Island. Volume estimates are not available.

Data analysis

Within this reach of beach, eight locations (LE-40 through LE-47), as delineated in Table 1 and shown in Figure 1, were identified. All eight locations were sampled and 16 samples were collected.

Swash zone, mid-beach and back beach samples were obtained from two locations, LE-45 and LE-47. Swash zone, and back beach samples were obtained from four locations, LE-41 through LE-44. Only samples from single points on the beach were obtained from two locations, LE-40 and LE-46.

Carbonate material averaged 8.8 percent of the samples processed. The mean grain size before carbonate digestion was 0.183 mm (2.452 phi). The mean grain size after carbonate digestion was 0.159 mm (2.650 phi). As shown in Figure 12, percent carbonate on this reach of beach is less than five percent on the northern half of the reach. Both the percent carbonate and mean grain size curves show increase through the southern half of the reach.

Photographs, as well as granulometric analyses of the samples collected and processed, are provided in Appendix A. Curves comparing grain size north and south of Matanzas Pass at the mouth of San Carlos Bay between Sanibel Island and Estero Island and north and south of Big Carlos Pass between Estero Island and Lovers Key can be found in Appendix C.

As discussed above, a comparison of the pre- and post-carbonate dissolution curves from the sediments north and south of Matanzas Pass at the mouth of San Carlos Bay show little differentiation between the samples. The curves are unimodal in distribution with narrow peaks and the sediments are fine grained.

A comparison of the pre- and post-carbonate dissolution curves from the sediments north and south of Big Carlos Pass shows a distinct difference between them. The sediments to the north are finer grained with their curves displaying single peaks on both curve sets. Their single peaks have minor tails that are not seen on the post-carbonate digestion curves. Those missing tails represent coarse grained carbonate material that has been removed. The samples to the south display a bimodal distribution on the pre-carbonate digestion curves with one broad and one narrow peak on each sample's curve and a single narrow peak on each sample's post-carbonate digestion curve. The coarse grained peaks seen in the carbonate pre-digestion curves are not seen on the post-carbonate digestion curve. The coarse grained fraction is thus shown to be composed of carbonate material. The fine grained peaks that occur on both the pre- and post-carbonate digestion curves are thus shown to be from non-carbonate material.

Lovers Key, Big Hickory and Little Hickory Islands

Geographic setting

Lovers Key lies entirely within Lovers Key State Park and is approximately two miles (3.2 km) long and less than 500 ft (152.4 m) wide at its widest point. It is separated from Estero Island to the north by Big Carlos Pass, from the mainland to the east by mangrove islands and Estero Bay and from Big Hickory Island to the south by a shallow inlet. It is undeveloped and only accessible by narrow foot bridges from the offices of the state park or by boat.

Big Hickory Island is approximately 1.5 miles (2.4 km) long and 0.5 miles (0.8 km) wide with approximately one mile (1.609 km) of beach. It is separated from Lovers Key to the north and Little Hickory Island to the south by shallow inlets. The island is separated from the mainland to the east by Estero Bay and is, except for its northern end, undeveloped. Its beach is only accessible by boat.

Little Hickory Island is approximately seven miles (11.3 km) long and less than a 0.25 miles (402 m) wide. It is separated by a shallow inlet from Big Hickory Island to the north. Its northern end is separated from the mainland to the east by Big Hickory Island and Estero Bay. Its middle portion is separated from the mainland to the east by Fish Trap Bay and Little Hickory Bay. Its southern end is separated from the mainland to the east and south by an extensive mangrove estuary and Wiggins Pass respectively. The island, except for the Barefoot Beach State Preserve on its southern end, is developed.

Beach history in brief

In October 2004, a beach renourishment project was conducted on Lovers Key which consisted of placing approximately 590,000 cy (0.4511 million m^3) of sand on the beach.

From 1984 to 2000, Collier County conducted periodic maintenance dredging to maintain the Wiggins Pass entrance channel. The dredged sand was placed on the beach of Little Hickory Island and the beach immediately south of the inlet.

In December 1995, approximately 217,000 cy (165,908 m^3) of sand was placed on Little Hickory Island using sand from the ebb shoal of New Pass. In 2004, additional beach nourishment was completed. The amount of sand placed in 2004 is uncertain. Either approximately 143,000 cy (109,331 m^3) of sand from the ebb shoal of Big Carlos Pass was placed in a single project or there were two projects consisting of the placement of 144,000 cy (110,096 m^3) and 127,290 cy (97,320 m^3).

Data analysis

Within this reach of beach, 12 locations (LE-48 through LE-55 and CR-01 through CR-04), as delineated in Table 1 and shown in Figure 1, were identified. Eleven locations were sampled and 16 samples were collected.

Swash zone, and back beach samples were obtained from five locations, CR-01, CR-03, LE-48, LE-54 and LE-55. Only samples from single points on the beach were obtained from six locations, LE-49, LE-50 through LE-53 and CR-02. One location, CR-04, was not sampled as no beach was present.

Carbonate material averaged 51.6 percent of the samples processed from the three locations, LE-48 through LE-50, on Lovers Key. The mean grain size before carbonate digestion was 0.548 mm (0.869 phi). The mean grain size after carbonate digestion was 0.160 mm (2.640 phi). As shown in Figure 12, both the percent carbonate and mean grain size curves peak at location LE-49 and then precipitously decline to the next location to the south, LE-50. Percent carbonate varies from greater than 75 percent to less than 15 percent.

Carbonate material averaged 29.8 percent of the samples processed from the two locations, LE-51 and LE-52, on Big Hickory Island. The mean grain size before carbonate digestion was 0.298 mm (1.747 phi). The mean grain size after carbonate digestion was 0.178 mm (2.488 phi). As shown in Figure 12, both percent carbonate and grain size increase southward along this island's beaches.

Carbonate material averaged 76.5 percent of the samples processed from the three locations, LE-53 through LE-55 on the northern portion of Little Hickory Island, which lie in Lee County. The mean grain size before carbonate digestion was 1.307 mm (-0.386 phi). The mean grain size after carbonate digestion was 0.213 mm (2.228 phi). Carbonate material averaged 53.4 percent of the samples processed from the three locations sampled, CR-01 through CR-03, on the southern portion of Little Hickory Island, which lie in Collier County. The mean grain size before carbonate digestion was 0.424 mm (1.240 phi). The mean grain size after carbonate digestion was 0.236 mm (2.086 phi). Carbonate material averaged 65.0 percent of all the samples processed from the island. The mean grain size before carbonate digestion, of all the samples processed from the island, was 0.914 mm (0.130 phi). The mean grain size after carbonate digestion, of all the samples processed from the island, was 0.219 mm (2.193 phi). As shown in Figure 12, both percent carbonate and grain size diminish southward along this island's beaches.

Photographs and granulometric analyses of the samples collected and processed are provided in Appendix A. Curves comparing grain size north and south of Big Carlos Pass between Estero Island and Lovers Key, north and south of New Pass between Lover's Key and Big Hickory Island, north and south of

Big Hickory Pass between Big Hickory and Little Hickory islands and north and south of Wiggins Pass between Little Hickory Island and the mainland to the south can be found in Appendix C.

As noted above, a comparison of the pre- and post-carbonate digestion curves from the sediments north and south of Big Carlos Pass shows a distinct difference between them. The sediment samples to the north are finer grained with their curves displaying single peaks on both curve sets. Their single peaks have minor tails that are not seen on the post-carbonate digestion curves. Those missing tails represent coarse grained carbonate material that has been digested. The samples to the south display a bimodial distribution on the pre-carbonate digestion curves with one broad and one narrow peak on each sample's curve and a single narrow peak on each sample's post-carbonate digestion curve. The coarse grained peaks seen in the carbonate pre-digestion curves are not seen on the post-carbonate digestion curve. The coarse grained fraction is composed of carbonate material. The fine grained peaks that occur on both the pre- and post-carbonate digestion curves are from non-carbonate material.

A comparison of the pre- and post-carbonate digestion curves from the sediment samples furthest north of and those proximal to and south of New Pass shows a distinct difference. The northernmost sediment sample, the sample shared with the Big Carlos Pass comparisons, displays a bimodial distribution on the pre-carbonate digestion curves with one broad and one narrow peak on the sample's curve and a single narrow peak on the sample's post-carbonate digestion curve. The missing peak on the post-carbonate digestion curve evidences coarse carbonate material. The retained peak on that curve evidences fine grained non-carbonate material and plots with the single peaks of the remaining three sediment samples.

The pre-carbonate digestion curves from the samples north and south Big Hickory Pass shows that all but the sample immediately south of the pass have distinct peaks at the fine grained end of the spectrum with long tails progressively more coarse grained. A comparison of the pre- and post-carbonate digestion curves from the sediment samples north and south of Big Hickory Pass reveals that the volume of the coarse carbonate fraction, as a percentage of each sample, increases southward and that there is a dramatic shift between the two in the peaks displayed by the sample immediately south of the pass. Its peak is substantially narrower and shifted to the fine grained end of the spectrum in the post-carbonate digestion curve. Comparison with the peaks on curves from the other samples, the two to the north of the pass and the one furthest south of the pass, shows the peaks on the post-digestion curve to be even narrower than the sample immediately south of the pass and further into the fine grained end of the spectrum.

The pre-carbonate digestion curves from the samples north and south Wiggins Pass shows those from the samples north of the pass to be multimodal in distribution and shifted to the coarse end of the spectrum while those south of the pass are unimodal, narrower in distribution and fine grained. A comparison of the pre- and post-carbonate digestion curves from the sediment samples north and south of Wiggins Pass shows that the digestion of carbonate material distinctly alters the curves for the samples north of the pass making them unimodal, narrower in distribution and concurrent with the peaks of the curves from the samples south of the pass.

Wiggins Pass to Gordons Pass

Geographic setting

This reach of mainland coastal beach is bounded on the north and south by Wiggins Pass and Gordons Pass, respectively, and divided by two additional inlets, Clam Pass and Doctors Pass. With the exception of Delnor-Wiggins Pass State Park just south of Wiggins Pass, and the area immediately north and south of Clam Pass, this expanse of mainland coastline is substantially developed all the way to Gordons Pass.

Beach history in brief

In 1960, the City of Naples modified Doctors Pass by channel dredging and jetty construction. In 1966, the pass was again dredged and the jetties were augmented with rock and sand from the dredging. Maintenance dredging has been conducted about every four years with dredged sand being placed on the beach or inshore zone south of the inlet. In 2005, approximately 60,000 cy (45,873 m^3) of dredged sand was placed in the near shore area south of the inlet.

From 1984 to 2000, Collier County conducted periodic maintenance dredging to maintain the Wiggins Pass entrance channel. The dredged sand was placed on the beach of Little Hickory Island and the beach immediately north of the inlet and at least 35,000 cy (26,759 m^3) of sand were placed on the beaches of Delnor-Wiggins State Park immediately to the south.

In 1983 and 1995, approximately 48,000 cy (36,699 m^3) and 42,000 cy (32,111 m^3) of sand, respectively, was placed on Vanderbilt Beach, which lies approximately midway between Wiggins Pass and Clam Pass. It is variously reported that in 1996 either approximately 91,000 cy (69,574 m^3), 760,000 cy (581,062 m^3), or 1,132,000 cy (865,476 m^3) of sand was placed on Vanderbilt Beach and Park Shores, just north of Doctors Pass, and over the expanse of beach between Doctors Pass and Gordons Pass. Additionally, between 1996 and 2003, approximately 78,000 cy (59,635 m^3) of truck-hauled sand was placed between Doctors Pass and Gordons Pass as well as approximately 5,000 cy (3,823 m^3) of inlet bypassed sand. In 2006, approximately 178,000 cy (136,091 m^3), 140,000 cy (107,038 m^3) and 355,000 cy (107038 m^3) of sand were placed in the areas of Vanderbilt Beach, Park Shores and between Doctors Pass and Gordons Pass respectively. Also, between 1996 and 2003, approximately 95,000 cy (72633 m^3) of inlet bypassed sand and approximately 75,500 cy (57,724 m^3) of truck-hauled sand was additionally placed on the beach between Doctors and Gordons Pass. Nourishment continued in May 2006 with the placement of 355,000 cy (271,417 m^3) of sand in the same area.

The initial dredging of the flood shoals of Clam Pass in 1999 and maintenance of the channel in 2002 and 2007 has resulted in the dredging of sediments, totaling approximately 22,000 cy (16,820 m^3), and the placing of beach restoration quality sand on the beaches to either side of Clam Pass.

Data analysis

Within this reach of beach, 17 locations (CR-05 through CR-21), as delineated in Table 1 and shown in Figure 1, were identified. All 17 locations were sampled and 29 samples were collected.

Swash zone and back beach samples were obtained from 12 locations, CR-05 through CR-13, CR-16 through CR-18. Only samples from single points on the beach were obtained from five locations, CR-14, CR-15 and CR-19 through CR-21.

Carbonate material averaged 33.6 percent of the samples processed from the six locations, CR-05 through CR-10, on the section between Wiggins Pass and Clam Pass. The mean grain size before carbonate digestion was 0.472 mm (1.083 phi). The mean grain size after carbonate digestion was 0.323 mm (1.628 phi). As shown in Figure 12, both percent carbonate and grain size increased southward along this segment's beaches. Percent carbonate increased from less than 15 percent to greater than 60 percent.

Carbonate material averaged 24.0 percent of the samples processed from the four locations, CR-11 through CR-14, on the section between Clam Pass and Doctors Pass. The mean grain size before carbonate digestion was 0.391 mm (1.354 phi). The mean grain size after carbonate digestion was 0.331 mm (1.593 phi). As shown in Figure 12, both percent carbonate and grain size decreased southward along this segment's beaches. Percent carbonate decreased from greater than 30 percent to less than 10 percent.

Carbonate material averaged 23.0 percent of the samples processed from seven locations, CR-15 through CR-21, on the section between Doctors Pass and Gordons Pass. The mean grain size before carbonate digestion was 0.377 mm (1.406 phi). The mean grain size after carbonate digestion was 0.320 mm (1.642 phi). As shown in Figure 12, grain size decreased southward along this segment's beaches. The percent carbonate curve decreases southward to the center of the segment then rises again at its southern end.

Photographs and granulometric analyses of the samples collected and processed are provided in Appendix A. Curves comparing grain size north and south of Wiggins Pass between Little Hickory Island and the mainland, north and south of Clam Pass, north and south of Doctors Pass and north and south of Gordons Pass between the mainland and Keewaydin Island can be found in Appendix C.

As noted above, the pre-carbonate digestion curves from the samples north and south Wiggins Pass shows those from the samples north of the pass are multimodal in distribution and shifted to the coarse end of the spectrum while those south of the pass are unimodal, narrower in distribution and finer grained. A comparison of the pre- and post-carbonate digestion curves from the sediment samples north and south of Wiggins Pass shows that the digestion of carbonate material distinctly alters the curves for the samples north of the pass making them unimodal, narrower in distribution and concurrent with the peaks of the curves from the samples south of the pass.

The curves from the samples north and south of Clam Pass are, with exception of the sample immediately south of the pass, broadly concurrent. The curves for the sample immediately south of the pass are shifted into the finer grained end of the spectrum. A comparison of the pre- and post-carbonate digestion curves shows that the carbonate fractions of the samples are coarser grained than the non-carbonate fractions.

The curves from the samples north and south of Doctors Pass show that those from the samples furthest north and closest to the pass to the south and those from the samples furthest south and closest to the pass to the north form two sets of broadly concurrent curves. The second set is shifted further to the finer grained end of the spectrum than the first.

A comparison of the pre- and post-carbonate digestion curves from the samples north and south of Gordons Pass reveals a concurrent, narrow, unimodal distribution skewed to the finer grained end of the spectrum with a significant tail of coarser grained material. A comparison of the pre- and post-carbonate digestion curves shows that the carbonate fractions of the samples comprise that tail.

Keewaydin Island

Geographic setting

Keewaydin Island is separated from the mainland to the north and east by Gordons Pass and an extensive mangrove estuary, respectively. The island is approximately nine miles (14.5 km) long and varies from approximately one mile (1.6 km) to 500 ft (152.4 m) wide. It is separated from Little Marco Island to the south by Little Marco Pass. It is accessible only by boat and is developed only on its northern end. The island consists of a long narrow beach strand fringed on its eastern shore by an extensive mangrove estuary. It is, except for the developed portion, part of the Rookery Bay National Estuarine Research Reserve.

Beach history in brief

In 1962, the U.S. Army Corps of Engineers dredged the channel at Gordons Pass and that maintenance dredging has been conducted by them about every seven years since. The beach quality dredged material was placed on the beach 300 ft (91.4 m) south of Gordons Pass extending approximately 4,000 ft (1,219 m) south onto Keewaydin Island. As a result, for the period between 1963 and 1985, approximately 3.327 million cy (2.544 million m^3) of sand were placed on the island.

Data analysis

Within this reach of beach, nine locations (CR-22 through CR-30), as delineated in Table 1 and shown in Figure 1, were identified. All nine locations were sampled and 11 samples were collected.

Swash zone, and back beach samples were obtained from two locations, CR-26 and CR-30. Only samples from single points on the beach were obtained from seven locations, CR-22 through CR-25 and CR-27 through CR-29.

Carbonate material averaged 32.9 percent of the samples processed from nine locations, CR-22 through CR-30. The mean grain size before carbonate digestion was 0.399 mm (1.327 phi). The mean grain size after carbonate digestion was 0.216 mm (2.212 phi). As shown in Figure 12, the percent carbonate curve declines southward to the middle of the reach from which it trends upward and peaks. It then declines again toward the southern end of the reach. Mean grain size remains relatively constant southward to the middle of the reach where it peaks in tandem with percent carbonate. It then declines to the southern end of the reach.

Photographs and granulometric analyses of the samples collected and processed are provided in Appendix A. Curves comparing grain size north and south of Gordons Pass between the mainland and Keewaydin Island and north and south of Little Marco Pass between Keewaydin Island and Little Marco Island can be found in Appendix C.

As was discussed above, a comparison of the pre- and post-carbonate digestion curves from the samples north and south of Gordons Pass reveals a concurrent narrow unimodal distribution skewed to the finer grained end of the spectrum with a prominent tail of coarser grained material. A comparison of the pre- and post-carbonate digestion curves shows that the carbonate fraction of the samples comprise that tail.

As was the case with Gordons Pass, comparison of the pre- and post-carbonate digestion curves from the samples north and south of Little Marco Pass also reveal a concurrent, narrow, unimodal distribution skewed to the finer grained end of the spectrum with a significant tail of coarser grained material. A comparison of the pre- and post-carbonate digestion curves also shows that the carbonate fractions of the samples comprise that tail.

Little Marco and Marco Islands

Geographic setting

Little Marco Island is separated from Keewaydin Island by Little Marco Pass. The island is approximately 2.5 miles (4.02 km) long but only approximately one mile (1.61 km) of it fronts on the Gulf of Mexico. The portion that fronts on the Gulf of Mexico is approximately 0.5 miles (0.8 km) wide. It possesses a short, narrow beach strand separated from the mainland to the east by an extensive mangrove estuary and from Marco Island to the south by Capri Pass, a mangrove island, and Big Marco Pass.

Davis (1994) includes Marco Island in a discussion of drumstick or mixed-energy barrier islands. He states that it contains: "…a very complex pattern of multiple beach ridge systems with a range of orientations and which are spread along much of the length of the island." Marco Island is separated from the mainland to the east by an extensive mangrove estuary. It is separated from Kice Island of Cape Romano to the south by Caxambas Pass. The island is approximately two miles (3.2 km) wide and four miles (6.4 km) long and extensively developed.

Beach history in brief

Approximately 1,260,000 cy (963,339 m^3) and 1,959,299 cy (1.498 million m^3) of sand were placed on the northern and central portion of Marco Island in 1990 and 1991, respectively. In 1995, approximately

2,400 cy (1,835 m^3) of sand was placed as well. Additional sand was placed in 1998, but the volume is unknown. Since 2001, periodic nourishment in the same area, using sand from upland borrow sites and the dredging of Collier Creek, has been conducted. In 2004, approximately 520,000 cy (397,569 m^3) of sand was placed on the beach and in 2005, approximately 260,000 cy (198,784 m^3) of additional sand, dredged from the ebb shoal of Big Marco Pass/Capri Pass was placed on the beach as well. In 2006, approximately 180,000 cy (137,620 m^3) of beach quality sand dredged from the Caxambas Pass was placed on the beaches of South Marco Island.

Data analysis

Within this reach of beach, ten locations (CR-31 through CR-40), as delineated in Table 1 and shown in Figure 1, were identified. Nine locations were sampled and 17 samples were collected.

Samples from single points on the beach were obtained from two locations, CR-31 and CR-32, on Little Marco Island. Carbonate material averaged 8.3 percent of the samples processed from those two locations. The mean grain size before carbonate digestion was 0.181 mm (2.468 phi). The mean grain size after carbonate digestion was 0.158 mm (2.662 phi). As shown in Figure 12, both the carbonate percentage and mean grain size curves increase to the south on this island. Carbonate percentages are below 15 percent.

Swash zone, mid-beach and back beach samples were obtained from two locations, CR-37 and CR-38, on Marco Island. Swash zone, and back beach samples were obtained from four locations, CR-33, CR-34, CR-36 and CR-39. Only samples from a single point on the beach were obtained from one location, CR-35. One location, CR-40, was not sampled.

Carbonate material averaged 37.6 percent of the samples processed from eight locations, CR-33 through CR-40, on Marco Island. The mean grain size before carbonate digestion was 0.494 mm (1.018 phi). The mean grain size after carbonate digestion was 0.193 mm (2.372 phi). As shown in Figure 12, both the carbonate percentage and mean grain size curves increase to the south on this island. Carbonate percentages rise from less than 10 percent to greater than 60 percent.

Photographs and granulometric analyses of the samples collected and processed are provided in Appendix A. Curves comparing grain size north and south of Little Marco Pass between Keewaydin Island and Little Marco Island, north and south of Big Marco Pass/Capri Pass between Little Marco Island and Marco Island and north and south of Caxambas Pass between Marco Island and Kice Island can be found in Appendix C.

As noted above, a comparison of the pre- and post-carbonate digestion curves from the samples north and south of Little Marco Pass reveals a concurrent, narrow, unimodal distribution skewed to the finer grained end of the spectrum with a significant tail of coarser grained material. A comparison of the pre- and post-carbonate digestion curves shows that the carbonate fractions of the samples comprise that tail.

As was the case with Gordons Pass and Little Marco Pass, comparison of the pre- and post-carbonate digestion curves from the samples north and south of Big Marco/Capri Pass also reveal a concurrent, narrow, unimodal distribution skewed to the finer grained end of the spectrum with a tail of coarser grained material. A comparison of the pre- and post-carbonate digestion curves also shows that the carbonate fractions of the samples comprise that tail.

As was the case with Gordons Pass, Little Marco Pass, and Big Marco/Capri Pass comparison of the pre- and post-carbonate digestion curves from the samples north and south of Caxambas Pass also reveal a generally concurrent, narrow, unimodal distribution skewed to the finer grained end of the spectrum with a significant tail of coarser grained material in the curves for the samples from the north side of the Pass. A comparison of the pre- and post-carbonate digestion curves also shows that the carbonate fractions of the samples comprise that tail.

Kice and Morgan Islands of Cape Romano

Geographic setting

Kice Island is separated from Marco Island to the north by Caxambas Pass and from Morgan Island to the south by Blind Pass. Morgan Island forms the tip of Cape Romano. Both Kice Island and Morgan Island exhibit narrow, discontinuous beach strands approximately two miles (3.2 km) long and a mile (1.61 km) wide. They are separated from the mainland, to the east, by an extensive mangrove estuary. The final southernmost sample collected on the southwest coast of Florida was taken from an unnamed narrow arcuate island immediately south of Morgan Island. All of these islands are undeveloped and accessible only by boat.

Beach history in brief

The islands of Cape Romano have not been modified by beach renourishment activities and thus remain in a more or less natural state. Both Kice and Morgan Islands are experiencing ongoing erosion and shoreline retreat.

Data analysis

Within this reach of beach, seven locations, CR-41 through CR-47, as delineated in Table 1 and shown in Figure 1, were identified. Four locations were sampled and seven samples were collected.

Swash zone, mid-beach and back beach samples were obtained from one location, CR-43. Swash zone and back beach samples were obtained from one location, CR-41. Only samples from single points on the beach were obtained from two locations, CR-46 and CR-47. Three locations, CR-42, CR-44 and CR-45 were not sampled.

Carbonate material averaged 24.9 percent of the samples processed from the four locations, CR-41, CR-43, CR-46 and CR-47, in the Cape Romano Islands. The mean grain size before carbonate digestion was 0.420 mm (1.251 phi). The mean grain size after carbonate digestion was 0.198 mm (2.338 phi). As shown in Figure 12, samples taken from CR-41 and CR-43, obtained from Kice island, reveal carbonate percentages of less than 10 percent in CR-41, and less than 5 percent in CR-43. Samples from CR-46 and CR-47 were taken from the southernmost tip of Morgan Island and a small island immediately to its south. They reveal carbonate percentages greater than 30 percent and greater than 55 percent in samples CR-46 and CR-47, respectively.

Photographs and granulometric analysis of the samples collected and processed are provided in Appendix A. Curves comparing grain size north and south Caxambas Pass between Marco Island and Kice Island can be found in Appendix C.

As noted above, comparison of the pre- and post-carbonate digestion curves from the samples north and south of Caxambas Pass reveals a generally concurrent, narrow, unimodal distribution skewed to the finer grained end of the spectrum with a significant tail of coarser grained material in the curves for the samples from the north side of the Pass. A comparison of the pre- and post-carbonate digestion curves also shows that the carbonate fractions of the samples comprise that tail.

BEACH REACHES OF THE FLORIDA KEYS ARCHIPELAGO (MONROE COUNTY)

Table 1 lists the beach reaches of the Keys of Monroe County. In that table, individual reaches are tied to their respective set of sampling locations. Figure 1 shows the sample locations. The FDEP BBSC, (2008) Strategic Beach Management Plan for the Florida Keys Region and Clark, (1990) was extensively consulted and used to establish the timeline of recent beach replenishment and the construction of engineering structures on the beach reaches in this portion of the study area. Additionally, an historical database of beach replenishment projects, compiled by the Western Carolina University Program for the

Study of Developed Shorelines (PSDS) (2009) was also consulted. Table 6 lists the limits of known metropolitan areas as well as federal, state, and county lands discussed in this report with regard to sampling locations. For the purpose of this report, the Florida Keys archipelago has been broken down geographically into discussions of the middle and lower keys. Sample locations MO-01 through MO-11 lie in the middle keys while sample locations MO-12 through MO-30 lie in the lower keys. Figures 13 and 14 geographically tie grain size distribution comparison curves to the distribution of islands in the Keys that were identified for beach sampling. Figure 15 graphically displays changes in mean grain size, before digestion of carbonate material, as well as the percentage of carbonate material in the samples through the Florida Keys archipelago.

The middle Keys

Geographic setting

The islands of Matacumbe Key, Long Key, Little Crawl Key, and Fat Deer Key on which Coco Plum Beach and Key Colony Beach are located, and Vaca Key lie on the western end of what are known as the middle Keys of the Florida Keys archipelago. They typically exhibit very narrow, often patchy, beach strands facing on the Florida Straits. In 1990 the public beach on the southeast end of lower Matecumbe Key had "...2,200 ft (670.6 m) of fine grained sandy beach averaging 25 ft (7.6 m) wide." The public beach on Long Key had "...approximately 15,800 ft (4.8 km) of beach averaging 25 ft (7.62 m) in width", Little Crawl Key had "…1,200 ft (365.8 m) of beach averaging 15 ft (4.6 m) wide". Coco Plum Beach had "...7,500 ft (2.3 km) of fine sand beach averaging 25 ft (7.6 m) wide". Key Colony Beach had a "...4,550 ft (1.39 km) long and 50 ft (15.2 m) wide beach". Vaca Key had "...2,000 ft (609.6 m) of private beach averaging 15 ft (4.6 m) wide and 1,600 ft (487.7 m) of public beach averaging 25 ft (7.6 m) wide" (Clark, 1990). While no measurements of beach length and width were made as part of this study, it is clear that in the intervening 20 years since the Clark (1990) study, some alteration of both beach width and length has occurred.

Beach history in brief

In 2008, approximately 14,450 cy (11,048 m^3) of sand was placed on the beach at Curry Hammock State Park on Little Crawl Key. An addition, West Coco Plum Beach was created by dredge and fill in the 1950's.

Data analysis

The middle keys, as sampled, are comprised of lower Matacumbe Key (locations MO-01 through MO-03), Long Key (locations MO-04 through MO-06), Little Crawl Key (location MO-07), Coco Plum Beach/Key Colony Beach (locations MO-8 though MO-10) and Vaca Key (location MO-11). These locations are delineated in Table 1 and shown in Figure 1.

On lower Matacumbe Key, only samples from single points on the beach were collected from locations MO-01 through MO-03. Carbonate material averaged 98.1 percent of the three samples processed. The mean grain size was 0.524 mm (0.933 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve declines westward.

On Long Key, only samples from single points on the beach were obtained from three locations, MO-04, through MO-06. Carbonate material averaged 98.9 percent. The mean grain size was 0.374 mm (1.420 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve continues to decline westward.

On Little Crawl Key's single location, MO-07, only samples from a single point on the beach were obtained. Carbonate material was 1.7 percent of the sample. The mean grain size before carbonate digestion was 0.495 mm (1.015 phi). The mean grain size after carbonate digestion was 0.495 mm (1.015 phi). As shown in Figure 15, the mean grain size curve peaks at location MO-07 and then continues to decline westward. Both the peak in the mean grain size curve and the dip in the percent carbonate curve at MO-07 are attributed to past beach replenishment activities where sediments from outside the Keys were utilized.

Only samples from single points on the beach were collected from Coco Plum Beach/Key Colony Beach's three locations, MO-08 through MO-10. Carbonate material averaged 89.5 percent of the samples processed. The mean grain size was 0.457 mm (1.130 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve coarsens westward. The decline of the percent carbonate curve from 100 percent carbonate is attributed to past beach replenishment activities where sediments from outside the Keys were utilized.

Vaca Key swash zone and back beach samples were collected from one location, MO-11. Carbonate material averaged 94.6 percent of the samples processed. The mean grain size was 0.456 mm (1.133 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve coarsens westward. The decline of the percent carbonate curve from 100 percent carbonate and the fining of mean grain size seen at location MO-11 are attributed to past beach replenishment activities where sediments from sources outside of the Keys were used.

Photographs, as well as granulometric analysis, of the samples collected and processed are provided in Appendix A.

The lower Keys

Geographic setting

The islands of Little Duck Key, Ohio Key, Bahia Honda Key, Spanish Harbor Keys, Big Pine Key, Cook Island, Big Munson and Munson Islands, Sugarloaf Key and Key West lie on the western end of what are known as the Lower Keys of Florida Keys archipelago. As was the case in the Middle Keys they typically exhibit, patchy, very narrow beach strands facing on the Florida Straits. Clark (1990) states that the public beach on Little Duck Key "...has a 25 ft (7.6 m) wide, 825 ft (251.5 m) long public beach".

Clark found that Ohio Key had 1,600 ft (487.7 m) of narrow beach and that Bahia Honda Key has 7,400 ft (487.7 m) of beach with an average width of 60 ft (18.3 m). He noted that 1,000 ft (304.8 m) of beach existed at the Boy Scout Camp in the Spanish Harbor Keys.

He found that "Much of the straits shoreline of Big Pine Key is a coarse grained, sand perched, beach." At the time of his study, Long Beach on Big Pine Key extended "...for about 5,400 ft (1,646 m)" and that the beach on Cook Island was "…2,400 ft (731.5 m) long."

Clark found that Big Munson Island had "…500 ft (152.4 m) of pocket beach" and that Munson Island was "...completely surrounded by its sandy shore." His study also found that Sugarloaf Beach on Sugarloaf Key comprised "…3,000 ft (914.4 m) of sandy beach" and was "...a narrow, severely eroded, perched beach."

Key West is the western most island of our study area and in many ways is a case unto itself. Clark (1990) states that it is, "The best studied sandy shore line in Monroe County." It exhibited, at that time, shoreline retreats in some areas as high as 3 ft (0.9 m) per year. As previously stated, while no measurements of beach length and width were made as part of this study, it is clear that in the intervening 20 years since the Clark (1990) study, some alteration of both beach width and length has occurred.

Beach history in brief

Since the early 1970's, numerous attempts have been made to armor, build groins and fill eroding stretches of beach at Bahia Honda Key. This Key's beaches have been severely impacted by hurricanes in 1998 and 2005. The over-wash sediments from those storms were returned to the beaches.

The first recorded instance of the replenishment of Smather's Beach on Key West was in 1960 with the placement of 30,000 cy (22,937 m^3) of sand. In 2000 and 2001, four groins were constructed to retain sand within the confines of the beach and 36,000 cy (27,524 m^3) of sand were placed. At least some of these sands were derived from crushed limerock and the importation of oolitic, aragonite sands from the Bahamas.

The beach at Fort Zachary Taylor Historic State Park on the southwest tip of Key West lies in an area built on dredge material from ship channel maintenance. Revetments, to protect the park, were constructed in 1964. In 1989, as part of a terminal groin and breakwater construction project, 10,000 cy (7, 646 m^3) of sand was placed on the beach. In 2007, in response to hurricane damage sustained in 1989, 1999 and 2005, additional sands were trucked in and placed on the beach.

Data analysis

The lower keys are comprised of Little Duck Key (location MO-12), Ohio Key (location MO-13), Bahia Honda Key (locations MO-14 through MO-16), Spanish Harbor Keys (locations MO-17 and MO-18), Long Beach on Big Pine Key (locations MO-19 though MO-21) Cook Island (location MO-22), Big Munson Island (locations MO-23 and MO-24), Munson Island (Location MO-25), Sugarloaf Key (locations MO-26 and MO-27 and Key West (locations MO-28 through MO-30). On Little Duck Key, Ohio Key, Bahia Honda Key, Spanish Harbor Keys, Long Beach on Big Pine Key, Cook Island, and Big Munson Island samples from single points on the beach were collected from locations MO-12, MO-14 through MO-16 and MO-18 through MO-24. Locations MO-13 and MO-17 were not sampled as no beach was present at those locations. All locations are delineated in Table 1 and shown in Figure 1.

Carbonate material was 99.6 percent of the single sample, MO-12, processed from Little Duck Key. The mean grain size was 0.790 mm (0.340 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve continues the trend of coarsening westward.

Carbonate material comprised 99.9 percent of the three samples, MO-14 through MO-16, collected from Bahia Honda Key. The mean grain size was 0.329 mm (1.605 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve shows that the sediments initially fine westward of Little Duck Key and then slightly coarsen.

Carbonate material averaged 100 percent of the single sample, MO-18, collected from the Spanish Harbor Keys. The mean grain size was 2.028 mm (-1.020 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve shows that the sediments have abruptly and significantly coarsened. Curves comparing the grain size spectrums of samples on the west end of Bahia Honda Key, MO-15 and MO-16, with those of samples from both the Spanish Harbor Keys, MO-18, and the east end of Big Pine Key, MO-19 and MO-20, can be found in Appendix C. These graphically display the abrupt change in grain size occurring between sample points MO-16 and MO-18, respectively, east and west of Bahia Honda Channel/Bogie Channel. The curves from MO-15 and MO-16 show peaks toward the fine grained end of the spectrum of grain sizes with MO-16 being the finer grained of the two. The curves from MO-18 and MO-19 are congruent. They show peaks shifted toward the coarse grained end of the spectrum and a pronounced rise at the extreme coarse grained end of the spectrum.

Carbonate material was 99.8 percent of the three samples, MO-19 through MO-21, collected from Long Beach on Big Pine Key. The mean grain size was 1.517 mm (-0.601 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve shows that the sediments have exhibited a trend of fining westward.

Carbonate material averaged 99.9 percent of the single sample, MO-22, collected from Cook Island. The mean grain size was 1.057 mm (-0.080 phi). Post-digestion analysis was not performed. As shown in Figure 14, the mean grain size curve shows that the sediments at this location have coarsened slightly and go counter to the general trend of fining westward.

Carbonate material averaged 99.9 percent of the two samples, MO-23 and MO-24, collected from Big Munson Island. The mean grain size was 1.113 mm (-0.154 phi). Post-digestion analysis was not performed. As shown in Figure 15, the mean grain size curve shows that the trend of fining westward concludes at MO-23.

On Munson Island, only samples from a single point on the beach were collected from location MO-25. Carbonate material averaged 53.4 percent of the sample. The mean grain size before carbonate digestion was 0.474 mm (1.078 phi). The mean grain size after carbonate digestion was 0.251 mm (1.994 phi). Both the peak in the mean grain size curve and the dip in the percent carbonate curve at MO-25 shown in Figure 15, are attributed to past beach replenishment activities where sediments from sources outside of the Keys were used.

On Sugarloaf Key, samples from single points on the beach were collected from locations MO-26 and MO-27. Carbonate material averaged 99.2 percent of the two samples collected. The mean grain size was 0.974 mm (0.038 phi). Post-digestion analyses were not performed.

On Key West, swash zone and back beach samples were collected from locations MO-28 and MO-29. At one location, MO-30, sample from a single point on the beach was obtained. Carbonate material averaged 34.9 percent of the three samples processed. The mean grain size before carbonate digestion was 0.433 mm (1.207 phi). The mean grain size after carbonate digestion was 0.413 mm (1.277 phi). Figure 15 graphically shows that the beach sediments of Key West appear to have been substantially affected by past beach replenishment activities. The sediments collected at MO-28 are less than 5 percent carbonate, a finding that is distinctly aberrant to this region of the Keys. This suggests sediments from sources outside of the Keys were used in beach replenishment.

Photographs, as well as granulometric analysis, of samples collected and processed are provided in Appendix A.

SUMMARY AND CONCLUSIONS

Appendix A provides photographs of beach conditions and descriptions, photographs and granulometric analysis of selected samples from each location. It also provides analysis of their color via the use of Munsell values. Color, generally from an aesthetic view point, is considered a secondary parameter of importance. Historically however, the political/economic ramifications of beach replenishment sediment color mismatches with *in situ* sediments can be considerable. Appendix B provides sediment sample quality control analyses. Table 7 provides a summary of beach sediment descriptions. Table 8 provides a summary of the average carbonate percentages and mean grain size for the various reaches. Figures 7 through 12 graphically display those changes with respect to geographical location along the southwest coast, while Figures 13 and 14 graphically display changes in the grain size distribution curves along the Florida Keys archipelago. Photomicrographs of 13 samples, illustrating variability in grain size and carbonate content, are provided in Appendix D. In addition, a PowerPoint presentation illustrating the study area and our findings is provided in Appendix E.

Figures 15 and 16 graphically display changes in mean grain size as well as the percentage of carbonate material in the samples through the length of Florida Keys archipelago and the southwest Coast, respectively. The nature of the changes in these curves define distinct regions along the coast of southwest Florida and the Florida Keys archipelago.

The beaches of the southwest coast of Florida

Based on analysis of the granulometric and carbonate percentage curves shown on Figure 16, the southwest coast of Florida can be divided into four regions. As seen in Figure 16, the first region is defined by the area bounded by sample locations PI-01 and PI-15. It includes the two reaches of Three Rooker Bar and Honeymoon Island, as well as Caladesi and Clearwater Beach Islands. It is thus bounded by the north end of Three Rooker Bar and Clearwater Pass. Proceeding southward from the north end of Three Rooker Bar at the Pinellas/Pasco County border, the carbonate fraction is low and the mean grain size is relatively fine. The reach comprising Three Rooker Bar displays the minimum carbonate percentages for the region. There is little to no separation between the pre- and post-carbonate curves until after location PI-15 at the southern boundary of the region is reached. Both the percent carbonate and, to a very minor degree, the mean grain size curves trend upward across the region from north to south.

The second region is defined by the area bounded by sample locations PI-17 and SA-14. This region includes the reaches of Sand Key, Treasure Island and Long Key, Shell Key Shoal and Mullet Key, Egmont Key, Anna Maria Island, Longboat Key, and the Siesta Key portion of the Lido Key and Siesta Key/Casey Key reach. It is bounded on the north end by Clearwater Pass and on the south end by the former inlet Midnight Pass. In this region, mean grain size and carbonate percentages both periodically peak together and then decline southward. Where mean grain size and carbonate percentages peak, there is a strong separation between the pre- and post-carbonate curves. This separation suggests that the carbonate fraction is coarser. Rapid lateral changes in carbonate percentage are strongly associated with Clearwater Pass, Johns Pass, Blind Pass, Pass-a-Grille, Bunces Pass, Longboat Pass, New Pass, Big Pass and the former location of Midnight Pass. The sediments of the Egmont Key reach between Egmont Inlet and the Southwest Channel/Passage Key Inlet are finer grained and lower in carbonate content compared to the reaches to its north and south. Carbonate percentages in the region range from less than 5 percent, at Egmont Key, and the southern margin of the Lido Key Siesta Key/Casey Key reach, to over 80 percent at Blind Pass on the southern margin of Treasure Island. As seen in Figure 16, the carbonate percentage and, to a lesser degree, the mean grain size curves strongly peak on the north end of Sand Key, broadly peak from the south end of Treasure Island through the north end of Mullet Key, the south end of Anna Maria Island and broadly across the south end of Longboat Key and the north end of Lido Key. Additionally, the curves from Sand Key, at the northern end of the region, are more uniform in character and contain less peaks than those from the southern portion of the region.

The third region is defined by the area bounded by sample locations SA-16 and LE-39. This region includes the south end of the Lido Key and Siesta Key/Casey Key reach and the reaches of Manasota Key, Knight Island/Don Pedro Island, Gasparilla Island, La Costa Island, North Captiva Island and Captiva Island, and Sanibel Island. It is bounded on the north end by where Midnight Pass formerly occurred and on the south end by Big Carlos Pass at the mouth of San Carlos Bay. As shown in Figure 16, carbonate percentages average significantly higher in this region than in the region to its north and marginally higher than in the region to its south. Carbonate percentages in the region range from less than 10 percent, on the south end of Sanibel Island, to over 90 percent on the north end of La Costa Island. As seen in Figure 16, the carbonate percentage and, to a lesser degree, the mean grain size curves broadly peak north and south of Venice Inlet, north and south of Stump Pass, south of Boca Grande Pass on the north end of La Costa Island, and from immediately north of Boca Ceiga to the middle of Sanibel Island. There is a broad minimum in the curves centered on Gasparilla Pass. Additionally, the curves from the Casey Key portion of the island that is Siesta Key/Casey Key extending to the northern portion of Manasota Key and from south end of Captiva Island and the northern portion of Sanibel Island are more uniform in character and contain less peaks than those from the middle portion of this region.

The fourth region is defined by the area bounded by sample locations LE-40 and CR-47. It includes the reaches of Estero Island, Lovers Key, Big Hickory and Little Hickory Islands, Wiggins Pass to Gordons Pass, Keewaydin Island, Little Marco and Marco Islands and Kice and Morgan Islands of Cape Romano. It is bounded on the north by Big Carlos Pass at the mouth of San Carlos Bay and on the south by the south end of Cape Romano. As seen in Figure 16, carbonate percentages average slightly lower in this region than in the region to its north. The carbonate percentage and, to a lesser degree, the mean grain size curves broadly peak on Little Hickory Island, north of Clam Pass, on the south end of Keewaydin Island, and north and south of Caxambas Pass. Between these peaks, there is less variability than in other regions.

Several general observations can be made regarding the southwest coast of Florida. As was the case on the east coast of Florida as seen in Phelps *et al.* (2009), Figure 16 shows that the mean grain size and carbonate percentage curves track well (where carbonate percentages increase so does mean grain size). In Figure 16, significant separation between the pre and post-carbonate mean grain size curves is noted where the carbonate percentage curve rises above 25 percent. While the ratio of carbonate material to non-carbonate material varies substantially, the general trend from north to south, shows the percentage of carbonate material within the samples, until location of the former inlet Midnight Pass is reached, to range from less than 5 to greater than 50 percent. After that point, there is an increase in carbonate percentage such that it ranges from less than 10 to greater than 90 percent until the southern terminus of Sanibel Island is reached. Once past that point, there is a decrease in carbonate percentage such that it ranges between less than 5 and greater than 75 percent. Broad changes in the orientation of the coast line at Sand Key and Sanibel Island are reflected in changes in both carbonate percentages and mean grain size.

Appendix C provides comparative grain size distribution curves across individual inlets, passes, and harbor mouths. As seen in these curve sets, the carbonate fraction present in the samples has a component that is typically coarser than what is present in the non-carbonate fraction. This agrees with the distinct bimodality found by Davis (1994) in beach sediment typical of the region, as shown in Figure 17. As seen in that figure, coarse shell and fine sand each form distinct peaks with little overlap. Comparison of the pre- and post-carbonate digestion curves for sample points adjacent to inlets, passes, and channels, provided in Appendix C, frequently show tails and even distinct peaks in the coarse grained end of the pre-carbonate digestion curves that are not present on the post-carbonate digestion curves. Peaks on the fine grained ends of both curve sets are present on both before and after carbonate digestion. Additionally, peaks on the pre-carbonate digestion curves can occasionally be seen to have shifted toward the finer end of the spectrum in the post-carbonate digestion curves.

The beaches of the Florida Keys archipelago

The natural beach sands of the Florida Keys archipelago sampled are all but exclusively carbonate (Clark, 1990). The curves displayed in Figure 15 define two individual regions not based, even in part, in carbonate percentages but solely on grain size. This is in direct contrast to what is seen on the east coast of Florida (Phelps *et al*., 2009) and on the southwest coast of Florida in this study. That being said, those beaches of the Florida Keys archipelago sampled for this report that show carbonate percentages significantly less than 100 percent, as seen on little Crawl Key, Munson Island and Key West, clearly appear to have been influenced by past replenishment activities wherein sediments not native to the Florida Keys archipelago are presumed to have been introduced.

The first region is defined by the area bounded by sample locations MO-01 through MO-16. The region begins in the middle of the geographic division of the Florida Keys archipelago called the middle Florida Keys. It extends marginally into the geographic division called the lower Florida Keys. The islands of Matacumbe Key, Long Key, Little Crawl Key, Fat Deer Key on which Coco Plum Beach/Key Colony Beach lies, Vaca Key, Little Duck Key, Ohio Key and Bahia Honda Key all lie in this region. As seen in Figure 15, it is characterized by a mean grain size curve which, when the influence of beach replenishment is recognized and discounted, generally fines westward but has one slight, apparently natural, peak on Little Duck Key. This peak can also be seen in the grain size distribution curves of Figures 13 and 14. It abruptly ends on Bahia Honda Key where, compared to the sediments of the Spanish Harbor Keys and those to the west of them, there is an abrupt shift in grain size. Appendix C graphically displays grain size curves for samples immediately east and west of this point of change.

The second region is defined by the area bounded by sample locations MO-17 through MO-30. The region begins west of the margin of the geographic division called the lower Florida Keys and extends through the length of that region. The islands of the Spanish Harbor Keys, Long Beach which lies on Big Pine Key, Cook Island, Big Munson Island, Munson Island, Sugarloaf Key and Key West all lie in this region. As seen in Figure 15, it is characterized by a mean grain size curve which, when compared to the sediments seen on the beaches of Bahia Honda Key, substantially and abruptly coarsens. This is due, primarily, to a significant change in fossil constituents within the samples. There is a change from sand size, well-weathered fossil fragments of mollusks and foraminifera to granule size gastropods and coral fragments at MO-18 through MO-20. Samples from MO-21 through MO-24 also contained coral fragments and gastropods; however, the amount and size observed was less. This change in fossil constituents is also reflected in the grain size distribution curves (as can be seen in Figure 14). The mean grain size curve in this region, again when the influence of beach replenishment is recognized and discounted, fines westward.

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