FINAL REPORT

RECONNAISSANCE OFFSHORE SAND SEARCH (ROSS) OF THE FLORIDA SOUTHWEST GULF COAST

Prepared for
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Bureau of Beaches and Coastal Systems
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Preface

This is the final report for the Reconnaissance Offshore Sand Search Project conducted for the Florida Department of Environmental Protection, Bureau of Beaches and Coastal Systems Contract No. BS016 by URS Corporation and Coastal Planning and Engineering Inc. The proper citation for this report is:

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In January of 2001 The Florida Department of Environmental Protection (FDEP) Office of Beaches and Coastal Systems (OBCS) contracted with URS Corporation to develop an online queriable database and Internet map viewer for compiling and disseminating available coastal and nearshore data. The project was titled the "Reconnaissance Level Regional Sand Search for the Florida Panhandle". This project was eventually referred to as "Sandpan" which is derived from sand and panhandle

The project involved gathering together into one central enterprise database the relevant data from historical, present and future studies conducted in the Panhandle region of the Florida Gulf Coast. Granulametric, geophysical, and spatial data were included, as well as an annotated bibliography of all references related to nearshore and coastal processes which are instrumental in locating and characterizing sand sources for use in the overall context of the Florida coastal management plan. This data is instrumental in minimizing the cost of initial data searches needed for each nourishment project undertaken by FDEP contractors.

In February of 2003, the OBCS, at that time renamed the Bureau of Beaches and Wetland Resources (BBWR), again contracted with URS to continue development of the database and online components of the Sandpan database project with Florida's southwest Gulf Coast as the project area. One benefit of this new project was the teaming of URS with Coastal Planning and Engineering (CPE) of Boca Raton, Florida. With this addition of a more project-focused coastal engineering firm, the Sandpan reconnaissance framework could be more focused at the individual beach nourishment project level. With the union of these two fundamental ways of searching and viewing the available data, it was determined by BBWR that Sandpan needed to be expanded to include the new classes of data that can be of value in engineering beach nourishment operations. This new database and associated Web site is called the "Reconnaissance Offshore Sand Search" or ROSS (Figure 1-1).

2.1 LEGACY DATA: THE SEARCH PROCESS

Using the same approach that was used during the original Sandpan project, URS and CPE conducted an exhaustive literature search for relevant applicable data. This included all previous reports, core logs, sediment sampling data, isopach maps and other geotechnical, geophysical, bathymetric or sedimentological data available that specifically identifies or studies the distribution of offshore sand resources of the Florida Southwest Gulf coast. This information was obtained from the BBCS, the Florida Geological Survey, the University of Florida, the University of South Florida, the Florida State University, the U.S. Army Corp of Engineers, the U. S. Geological Survey, the Minerals Management Service, and previous studies conducted by various consultants contracting with the BBCS.

As of this report date, forty-eight new projects have been entered into ROSS for the Southwest Sand Search. These include theses, dissertations, Government reports and Consultant reports. This has increased the database by approximately 3800 sand samples, 800 cores and over 1200 miles of geophysical data in the form of sub-bottom profile images. Also, following the lessons learned during Sandpan, old paper rolls, which were subject to deterioration, were retrieved and scanned to a digital format for preservation.

2.2 DATA SELECTION PROCESS FOR ROSS

With the need to focus on data which enhances the database without diminishing storage capacity, and therefore slowing down the search and retrieval process, URS and CPE developed a Data Acquisition and Entry Plan. This plan was used as the framework for deciding what data will be incorporated into ROSS and what data will be archived outside of the database for the Southwest project. An example of this selection process could include data from a previous study of a borrow site. If there were a series of cores taken from a site that was subsequently developed, storing all the sample data from these cores may be unnecessary. Taking a representative sample of the cores which adequately describes the area would be adequate. Storing only this data would save space, as well as limit the return hits from the database, consequently speeding up the query process. For geophysical records like sidescan sonar, only mosaics created from these records are stored. The original individual records will be kept in an electronic archive, but they will not be in the database or on the associated ftp site.

2.3 THE DATABASE

2.3.1 Data Types

Two basic types of data are stored in the database. The first is tabular data used to store information about sediment properties. The original Sandpan database schema consisted of thirteen data tables that include three associated look-up tables. These tables contained data related to the sediment sample itself. Included were fields for sediment grain size, texture, mineralogy, both Munsell and descriptive color, organic content, shell content, heavy mineral content, collection method, location information, core layer information, the analytical methods used in analysis, and both Wentworth and USC classification schemes. Project information like project name, managing agency, contact names, project date, driller and collection methods are also included. Several other geologic parameters like sphericity, angularity, and gradation have also been recorded.

The new ROSS database schema is an expansion of the Sandpan schema and currently includes thirty data tables of which sixteen are look-up tables. The database has been expanded and enhanced to allow for more comprehensive search and comparison functions than previously available. Several new tables were added so that searches could be structured that would return data on descriptive properties of sediment layers found within cores. Included are tables, which store layer structure, lithology, and textural qualifiers. The capabilities for using descriptive information about sediment and sediment layer properties have been enhanced by adopting the U.S. Army Corps of Engineers standard core description procedures for characterizing sediments and core layers.

With the addition of the more project-focused analysis that includes storing data on core layers, the expanded database now contains these column headings:

AGENCY_ID
AGENCY_NAME
ANALYTICAL_METHOD_ID
ANALYTICAL_METHOD_NAME
ANALYTICAL_METHOD_DESCRIPTION
ANGULARITY_ID
ANGULARITY
PK_BIBSUMMARY
AUTHOR
AUTHOR_LAST_NAME
AUTHOR_INITIALS
TITLE
KEYWORDS
PAPER_YEAR
ABSTRACT
PUBLISHER
CALCULATION_METHOD_ID
CALCULATION_METHOD_NAME
CALCULATION_METHOD_DESCRIPTION
COLLECTION_METHOD_ID
COLLECTION_METHOD
COLLECTION_METHOD_DESCRIPTION
COLOR_DESCRIPTOR_ID
COLOR_DESCRIPTOR
COLOR_MATRIX_ID
CT_COLOR_TONE_ID
CD_DESCRIPTOR_ID
COLOR_TONE_ID
COLOR_TONE
COLOR_ID
COLOR
CONTACT_ID
CONTACT_NAME
CONTACT_PHONE
CORE_LAYER_QUALIFIER_ID
CL_CORE_LAYER_ID
STX_SOIL_TEXTURE_ID
SD_SOIL_DESCRIPTOR_ID
ST_SOIL_TYPE_ID
L_LITHOLOGY_ID
S_SORTING_ID
QUALIFIER
CORE_LAYER_ID
CORE_CORE_ID
LS_LAYER_STRUCTURE_ID
USCS_USCS_CLASSIFICATION_ID
CMTX_COLOR_MATRIX_ID
BOTTOM_OF_LAYER_INTERVAL
TOP_OF_LAYER_INTERVAL
MUNSELL_HUE_WET
MUNSELL_VALUE_WET
MUNSELL_CHROMA_WET
CORE_LAYER_COMMENTS
CORE_LAYER_IDENTIFIER

COL_COLOR_ID
COLOR_TONE_ID
CM_COLLECTION_METHOD_ID
PRJ_PROJECT_ID
DRL_DRILLER_ID
COLLECTION_DATE
CORE_TOP_ELEVATION
CORE_LENGTH
CORE_DIAMETER
X_COORD
Y_COORD
STATE_X
STATE_Y
STATE_ZONE
LONGITUDE
LATITUDE
LORAN_X
LORAN_Y
PENETRATION_DEPTH
RECOVERED_LENGTH
DIRECTION
OVERBURDEN
DEPTH_RX
GROUNDWATER_ELEVATION
PERCENT_RECOVERED
CORE_IDENTIFIER
DRILLER_ID
DRILLER_NAME
DRILL_TYPE
AGN_AGENCY_ID
GUEST_NAME
PK_GUESTBOOK
GUEST_ORG
GUEST_EMAIL
GUEST_DATE_VISIT
GUEST_COMMENT
GUEST_EMAIL_UPDATE
LAB_ID
LAB_NAME
CORE_ID
LAYER_STRUCTURE
LAYER_STRUCTURE
LITHOLOGY
HUE
VALUE
CHROMA
CMTX_COLOR_MATRIX_ID
PROJECT_ID
AGN_AGENCY_ID_POSSESSING
AGN_AGENCY_ID_MANAGING
CON_CONTACT_ID
PROJECT_NAME
PROJECT_DATE
PROJECT_LOCATION
HORIZONTAL_COORDINATE_SYSTEM
HORIZONTAL_DATUM
VERTICAL_DATUM
PROJECTION
SAMPLE_ID
PRJ_PROJECT_ID
LAB_LAB_ID
AM_ANALYTICAL_METHOD
SLU_SPHERICITY_ID
ALU_ANGULARITY_ID
CM_COLLECTION_METHOD_ID
USCS_USCS_CLASSIFICATION_ID
CMTX_COLOR_MATRIX_ID
MUNSELL_HUE_DRY
MUNSELL_VALUE_DRY
MUNSELL_CHROMA_DRY
MUNSELL_HUE_WET
MUNSELL_VALUE_WET
MUNSELL_HUE_WASHED
MUNSELL_VALUE_WASHED
MUNSELL_CHROMA_WASHED
MUNSELL_HUE_UNKNOWN
MUNSELL_VALUE_UNKNOWN
MUNSELL_CHROMA_UNKNOWN

LAB_ADDRESS
LAYER_STRUCTURE_ID
SAMPLE_DATE
SAMPLE_COMMENTS
ANALYSIS_DATE
LAB_REMARKS
X_COORD
Y_COORD
STATE_X
STATE_Y
STATE_ZONE
LORAN_X
LORAN_Y
LONGITUDE
LATITUDE
RANGE_MONUMENT
RM_TRANSECT_LOCATION
TOP_OF_SAMPLE_INTERVAL
BOTTOM_OF_SAMPLE_INTERVAL
GRAB_ELEVATION
MEAN
MEDIAN
STD
SKEWNESS
KURTOSIS
MEAN_ORIGINAL
MEDIAN_ORIGINAL
STD_ORIGINAL
SKEWNESS_ORIGINAL
KURTOSIS_ORIGINAL
CALC_CALC_METHOD_ID_MEAN
CALC_CALC_METHOD_ID_MEDIAN
CALC_CALC_METHOD_ID_STD
CALC_CALC_METHOD_ID_SKEW
CALC_CALC_METHOD_ID_KURT
PCT_FINES
PCT_PAN_FRACTION
PCT_CARBONATE
PCT_SHELL_FRAGMENTS

SAMPLE_IDENTIFIER
CARBONATE_DISSOLVED
HEAVY_MINERALS_DISSOLVED
ORGANICS_REMOVED
SHELL_FRAGMENTS_REMOVED
PHI
USCS_COBBLE
USCS_COARSE_GRAVEL
USCS_FINE_GRAVEL
USCS_COARSE_SAND
USCS_MEDIUM_SAND
USCS_FINE_SAND
USCS_SILT
USCS_CLAY
WW_BOULDER
WW_COBBLE
WW_GRAVEL
WW_PEBBLE
WW_VERY_COARSE_SAND
WW_COARSE_SAND
WW_MEDIUM_SAND
WW_FINE_SAND
WW_VERY_FINE_SAND
WW_SILT
WW_CLAY
WW_COLLOID
SAMP_SAMPLE_ID
CL_CORELAYER_ID
VIRTUAL_SAMPLE
PK_SITEINFO
SITE_QUESTION
SITE_INFO
USERMAN
USERMAN_LOCATION
COLUMN_NAME
ALIAS
DESCRIPTION
DISPLAY_ORDER
DISPLAY_YN

PCT_HEAVY_MINERALS	PHI_RANGE
PCT_ORGANICS \	SOIL_TYPE
SAMPLE_DATA_YN	SORTING_ID
CORE_DATA_YN	SORTING
DISPLAY_GROUP	STANDARD_DEVIATION
SOIL_DESCRIPTOR_ID	SPHERICITY_ID
SOIL_DESCRIPTOR	SPHERICITY
SOIL_TEXTURE_ID	USCS_CLASSIFICATION_ID
OIL_TEXTURE	CLASSIFICATION_NAME
SOIL_TYPE_ID	CLASSIFICATION_DESCRIPTION

The second type of data stored in the database is spatial data. Spatial features along with their accompanying attributes reside in the ORACLE relational database as Spatial Database Engine (SDE) layers. These spatial features are stored much like any other data types as a string of characters or as a number. This enables the end user to optimize the abilities of this corporate database management system to manipulate large datasets and relate them to a geographic location on the earth.

Important issues that users need to understand are the restrictions and caveats involved with any of the data sets. To accomplish this goal, metadata (or data about the data) have been created for each data set and each spatial layer. These metadata conform to the Federal Geographic Data Committee (FGDC) requirements. The FGDC coordinates the development of the National Spatial Data Infrastructure (NSDI). The NSDI encompasses policies, standards, and procedures for organizations to cooperatively produce and share geographic data. The 17 federal agencies that make up the FGDC are developing the NSDI in cooperation with organizations from state, local and tribal governments, the academic community, and the private sector. For more information, see www.fgdc.gov.

2.3.2 Accessing the Database

Access to the ORACLE database is possible using one of three methods. The most direct is to click on the Query Builder link found on the ROSS homepage (Figure 2-1). This link will take you directly to the online Enhanced Query Builder page (Figure 2-2).

The Enhanced Query Builder is a custom-built application that allows the user to create Structured Query Language (SQL) statements. These SQL statements access real-time data from the ORACLE relational database. Unique WHERE clause statements may be constructed by the user that are added to an SQL statement one criteria at a time. These SQL statements are what tell the computer to retrieve all the data for which the set of conditions are true. These statements may be set to return data from all of the thirty tables residing in the ROSS database. Once the query is executed, the data matching the search criteria are returned on the Sand Sample Query Results page.

At the bottom of the Sand Sample Query Results page there are three other options provided to the user. These are accessed by clicking on one of the three buttons found at the bottom of this page. These will enable the user to either “Download Data”, in a Tab delimited format, “Go

Back" to the Enhanced Query Builder to perform another query, or spatially "View in ArcIMS" the data that was returned by the query. A worked example of this can be found in Appendix 1.

The second way to access the ROSS database is through the online Internet Map Service (IMS) which is accessible through the ROSS homepage ArcIMS link. The IMS site was initially developed using the ESRI "out of the box" ArcIMS software.

Figure 2-3 is a screen capture of the on-line mapping page within the ROSS Web site. On the left side of the image are folders, which contain the many different "layers" with which the user may interact. These layers are the spatial representations of the tabular data residing in the Oracle database. Most of these layers have been created especially for this project, with data generated by this project. However, some of these layers, including the Artificial Reefs, Sea Grass Beds, and others, were downloaded from other sites and incorporated in the ROSS on-line mapping. This illustrates the versatility of on-line mapping. Designers can combine data and information accessed over the Internet with local data for display, query, and analysis. For instance, environmental issues in potential renourishment areas are a concern. As an on-line search of state government spatial data repositories was conducted many shapefiles dealing with environmental issues were found at the Florida Geographic Data Library (FGDL). These shapefiles were subsequently downloaded from the FGDL site, re-projected and added to the ROSS site.

The third way to access data residing in the ROSS database is to download the data directly to the users own workstation. By using the Downloads link on the ROSS homepage the user is taken to a location where all the data residing in the database is available for quick and easy download (Figure 2-4).

This data is stored as SDE layers in both spatial and tabular format. Spatial data is in shapefile format therefore allowing the user to add these to their own Geographic Information System (GIS), combining them with other shapefiles that the user may have developed or received from other sources. Shapefiles contain data from a relational database management system (RDBMS). The RDBMS may be pulled out of the shapefile as a stand-alone portable format to be used with the ArcView software on a local machine. Downloading the tabular data is accomplished through the Enhanced Query Builder. This data may be downloaded in a Tab delimited format compatible with several analytical and graphing software packages. The user may download all or part of the data.

By design, the ROSS site currently does not include tools used for composite statistical analysis. The reason is that the BBCS does not desire to constrain the design professional to any particular suite of analytical products. The intent of this project web site is to allow the user to view the data spatially over the Web, to be able to query the data on several different levels and to download this data to their own workstation for advanced analysis.

2.4 DATA ENTRY

To accommodate the various entities that will supply data for inclusion into the ROSS database, two separate data entry tools will be made available. The first is a purpose-built Microsoft Access front end and the second is the commercially available software gINT.

The Microsoft Access front end is a customized data entry form that makes use of a user-friendly graphical user interface or GUI. From the main page of the front end the user will be able to access the appropriate page for data input (Figure 2-5).

A PROJECT INFORMATION page includes places to enter pertinent information on the project (Figure 2-6). This includes Project name, location, managing agency, and contacts.

Project level parameters are also defined. These parameters are entered in fields that define the projection information and horizontal and vertical datums. There is a Grade Scale field that allows the user to select which of three grain size-recording measures were used, phi, millimeter, or sieve size. For example by choosing phi, as shown in Figure 2-6, the user then checks the appropriate boxes for the phi values used. This information will later determine, in the Add a Sample page data entry form, which fields will be available for data entry. This acts as a quality control feature to help eliminate incorrect data entries.

Once Project Information is recorded, the user may proceed to enter data. If there have been cores collected in the project the user needs to click on the CORES button on the main page of the front end, pulling up the Core Entry page. Here data relative to the collection location, elevation, penetration, recovery and other detailed information of the core is entered (Figure 2-7).

After data on the core is entered, information on the actual core layers may be added. This is a new feature of the *enhanced* ROSS database. In the old Sandpan design, only the core location information was stored. With the ROSS design the user may add data describing the core layers themselves. Click on the Add Layer Information For This Core button and the Core Layer Information page appears (Figure 2-8). On this page a user will be able to enter layer structure, composition, texture, lithology and sediment type. There is also a comments field for use in adding any other information the user finds pertinent.

The next step in entering data is to input individual sample information. This data entry tool recognizes two Sample types, Samples from a Core and Grab Samples. To enter information about a Core Sample, click the Add Sample To This Core button on the Core Entry form. To enter information about Grab Samples, click the Grab Samples button on the Main Page. The Sample Entry Page (Figure 2-9) is used for adding data related to the individual sample. Included are fields for all data columns residing in the database relating to sediment samples. On the bottom portion of the page is a series of boxes of which some are shaded out.

The open boxes with values beside them are the same ones set as the phi ranges on the Project Information page. When the user originally set up the project and chose the phi sizes, these were then transferred to this page, therefore only allowing data to be input into the correct fields. This eliminates the likelihood of the user placing data values in the wrong category.

The second data entry tool has been chosen because of its multi-faceted abilities. This is the commercially available gINT software. The data output formats for core logs and various other engineering and geological tools from the gINT software have been adopted by the Jacksonville District Army Corps of Engineers (ACOE). The developers of gINT have taken the database table structure created for the ROSS database and incorporate it into a commercially available software for contractors. Contractors will then be able to input data into this structure and deliver it to BBCS for almost seamless entry into the ROSS DATABASE. This software will eventually be able to create ACOE formatted core logs using the data retrieved from ROSS.

2.5 OTHER FEATURES AND TOOLS

2.5.1 The Annotated Bibliography

Another feature of the ROSS Web site is the searchable Annotated Bibliography (Figure 2-10). There are currently over 800 references in the database covering topics on sediments found on the continental shelf, sedimentary processes, sea level curves and fluctuations, and the resulting changes in the shoreline over the last 12,000 years.

A large portion of these references are theses, dissertations and reports not as readily accessible. The Annotated Bibliography page is designed so the user can search by the Author's last name, title of the paper or key word(s). There may also be an accompanying summary or abstract of the paper provided, copyrights permitting.

Web Site (http://ross.urs-tally.com)

The ROSS Web site is the means to an end. By navigating through the Web site, all the ROSS data, on-line interactive mapping, query builders to access the database, data downloads, reports, shapefiles and the annotated bibliography are available at the touch of a button. There is a New Users page with frequently asked questions that may help in understanding the functions of this Web site. New questions and answers will be posted as they are received and answered.

The ROSS database and Internet Map Service were created to provide a wide variety of users online access to both spatial and tabular data. This site will enable BBCS staff, coastal engineers, the academic community and the general public the ability to view and download all relevant data from historical, current and future studies conducted around the state of Florida.

The ROSS Web site was designed with three intentions. The first is to allow users to view data spatially over the web and be able to download this data in both tabular and shapefile format to a personal workstation for advanced analysis. The second is to give the coastal engineering community the ability to cut the cost of an initial design and permitting phase of a beach nourishment project. By compiling all the available data together in one easy to use location, more detailed evaluations of sand deposits needed for these projects may be conducted. Finally, the database has located and digitally preserved a large portion of data that once resided in perishable formats.

3. Section 3THREE Geological Model For Southwest Florida

3.1 INTRODUCTION

One step in initiating a reconnaissance search for potential offshore sand resources is to review both the general characteristics of offshore sand bodies near replenishment sites and known processes controlling the formation of these sedimentary features. The current measurable distance from shore to search for potential sand sources is two to three miles. This reasonable distance continues to increase as the requirements for beach nourishment sand increase and the variety of equipment used to economically develop the resources continues to develop. Our knowledge of shelf sand deposits is also expanding. At this time there is a vast amount of information for most locations off the Florida coast. We have synthesized this into both a summary overview and a very detailed compendium. The overview is presented in this report section and the lengthier, detailed compendium is given as Appendix 2.

3.2 PHYSICAL SETTING OF THE WEST FLORIDA COAST

The area covered by this report extends from Pasco County in the north to Collier County in the south. Coastal orientation is generally from the NW-SE but there are three major offsets at Indian Rocks (Pinellas County), Sanibel Island (Lee County) and Cape Romano (Collier County) (Figure 3-1). Coasts are characterized by extensive salt marshes along the open Gulf shoreline both north and south of the sandy Gulf beaches. Only those beaches facing the open Gulf and the contiguous shelf/shoreface environments are considered in this summary.

The southwest Florida barrier/inlet system is a mixed energy coastal system that is morphologically diverse as a result of a complicated interaction between relatively small tidal ranges (<1 m) and a mean wave height of 30-50 cm. Davis (1997) describes this coast as having the most diverse morphology of any barrier island system in the world, containing about 29 barrier islands and 34 tidal inlets along approximately 300 km of shore. The geomorphological framework of the central west coast is summarized by Davis and Barnard (2003) as having both wave-dominated and mixed energy (*e.g.* drumstick) barrier island morphologies with islands ranging from 2 km to more than 30 km in length. Inlets range from tide-dominated through mixed energy to wave-dominated. Washover deposits are common along this coastal reach.

Meteorological conditions over this area include summer prevailing winds from the south-southeast with low to moderate velocities and occasional occurrence of extreme storm events (hurricanes). During recent years, there have been several tropical storms and hurricanes that affected this coast. Winter cold fronts are common from November to March. When a cold front approaches, the barometric pressure falls and winds prevail from the southwest. When the front passes, there is an abrupt shift in wind direction accompanied by a rapidly rising barometric pressure and strong winds are from the northwest and north. (Stone, 1998; Davis and Barnard, 2003). The wave climate is mild with mean annual wave heights fluctuating from 0.3 to 0.5 m with short mean wave periods ranging from four to five seconds (Davis *et al*., 2003; Stone, 1998). Net littoral drift is from north to south. Net littoral drift rates range from 30,000 to 75,000 y^3/yr (*e.g.* Taylor, 2002); greater rates are observed where the coastal orientation increases the obliquity of northern waves (*e.g.* Sand Key and Sanibel Island). Drift and current reversals are commonly observed downdrift of tidal inlets due to wave refraction-diffraction patterns along ebb shoals. This phenomenon is particularly true for large tide-dominated inlets that have large and well-developed ebb tidal shoals.

In order to provide a basis for discussion of specific geological and geomorphological information, the coast of southwest Florida was divided into three different coastal segments (Davis and Barnard, 2003; Hine *et al*., 2003): (1) the Northern Coastal Segment consisting of Pinellas County barrier islands and Tampa Bay, delimited to the north by Anclote Key and to the south by Egmont Key, (2) the Central Coastal Segment, consisting of Manatee, Sarasota and Charlotte Counties from Anna Maria Island to the Peace River Estuary, and (3) the Southern Coastal Segment consisting of Lee and Collier Counties from Venice Inlet to Cape Romano.

3.3 NORTHERN COASTAL SEGMENT (PINELLAS COUNTY AND TAMPA BAY)

The Northern Coastal Segment is bounded by Anclote Key to the north and by Egmont Key to the south. A prominent feature in the northern coastal segment is Tampa Bay, the largest estuary in the state of Florida covering approximately 2590 km^2 (1,000 square miles) (Figure 3-2). The opening of Tampa Bay is about 4 km long and is delimited by Mullet Key to the north and Anna Maria Island to the south. Just north of Tampa Bay lies the boundary between the barrier island coast and the low-energy Big Bend coast that is dominated by open coastal marshes. Along the barrier islands prominent features include the change in orientation of the shoreline at Sand Key and the presence of bay-mouth barriers (*e.g.* Egmont Key) that were built by ebb shoal aggradations in the late Holocene (Stott and Davis, 2003).

3.4 CENTRAL COASTAL SEGMENT (MANATEE, SARASOTA AND CHARLOTTE COUNTIES)

The Central Coastal Segment extends from Anna Maria Island to Charlotte Harbor (Boca Grande Pass) (Figure 3-3). The Sarasota County and Charlotte County coasts are thinly mantled with loose, unconsolidated sand (the unconsolidated deposits generally thickening from south to north) that overlie eroded limestones (Campbell, 1985). The top of the limestone lies at approximate mean sea level in northwestern Sarasota County (in the vicinity of Longboat Key) but dips to more than 30 m (100 ft) depths in the southern-most part of Sarasota County and throughout Charlotte County (Campbell, 1985). A geologically younger limestone is found near sea level throughout southern Sarasota County (Campbell, 1985).

Anna Maria Island and Siesta Key are typical drumstick barrier islands whereas Longboat Key and Lido Key are elongated, wave-dominated barriers. Anna Maria Island maintains a characteristic drumstick barrier island shape with a wide updrift side and narrow downdrift segment. On its northern margin, Passage Key, the island is delimited by a large tidal inlet and ebb-tidal shoal, which provide sediment and wave shelter and promotes the drumstick shape.

Longboat Key and Lido Key are two elongated, wave-dominated barriers that occur south of Anna Maria Island. Siesta Key, a drumstick barrier, is located downdrift of Lido Key. An interesting feature of Siesta Key, in relation to the rest of Sarasota County, is an extensive rock outcrop at Point O' Rocks where it forms a prominent disjunctive rock surface for about 1.6 km along the beach.

3.5 SOUTHERN COASTAL SEGMENT (LEE COUNTY AND COLLIER COUNTY)

The southern part of the study area along the central west coast of Florida displays landforms that are characteristic of a sedimentary shore. This part of the coast features coastal barriers, estuaries, lagoons, inlets, wetlands, swamps, and inherited paleokarst (Figure 3-4). Most of the southern shelf is thinly mantled by loose, unconsolidated sand (the unconsolidated deposits generally thickening from less than a meter to several meters from south to north) that overlie eroded as well as marl and lime mud deposits (McCoy, 1962). Bedrock exposures along Lee and Collier counties are thus of younger age than the hardgrounds occurring north of Tampa Bay.

The southern study area is part of the same larger sedimentary continuum (extending from Anclote Key southwards to Cape Romano) that lies at the center of an ancient carbonate platform that faces seaward to an enormous sediment ramp. This ancient carbonate platform forms the proximal portion of the West Florida shelf-slope system (WFS) and exerts large-scale control on coastal geomorphology, the availability of sediments, and wave energy (Hine *et al*., 2003). Coastal geomorphology varies from drumstick shaped barriers (*e.g.* North Captiva Island) to barrier-spits (*e.g.* Captiva and Sanibel Islands) to long-and-narrow wave-dominated barriers (*e.g.* Longboat Key). In the northern part of this coastal segment, shoreline orientation changes dramatically from approximately north-south to east-west at Sanibel Island, a giant barrier spit (Figure 3-4). This barrier island coast transitions to a mangrove coast at Cape Romano in the southern part of this coastal segment.

Sedimentary accumulations have produced a significant dislocation at the southern boundary of the study area (Cape Romano) which has several implications for interpretation of local morphodynamics. Cape Romano marks the southern end of the quartz-sand dominated Gulf Barrier Island Chain; the siliciclastic to carbonate transition occurs rather abruptly around latitude 25°30' (Campbell, 1988; Sussko and Davis, 1992) where the mangrove coast (Ten Thousand Islands) begins near the northwestern margin of Florida Bay. The low wave energy regime of this coastal segment allows for the construction of ebb-tidal deltas, which store moderate quantities of sand (Davis *et al.*, 1993; Hine *et al*., 2003). Flood-tidal deltas along this coastal segment are relatively inactive due to small tidal ranges, sheltered lagoons, and ebb-dominated inlets (Davis and Klay, 1989; Finkl, 1994).

In order to describe many of the major sand deposits across the study area it is necessary to consider how long ago they formed and the relative relationships between earlier and later deposits. The geological time scale is commonly used for this purpose. On this scale history is divided into a number of intervals of variable durations. These intervals are given names and are arranged in a hierarchy that allows for sub-intervals. Long ago, before absolute dating techniques were developed, this system allowed discussion of processes and deposits according to their relative sense. Figure 3-5 shows the portion of the geological time scale that is used in this section of the report. This display shows both the names of the time intervals and the actual range of dates that define them.

Regional History of the Shoreline

It is useful to note that the underlying antecedent topography of the limestone surfaces, as well as their hardground exposures, significantly influence the orientation and geographic location of barrier islands and sand ridges along the west coast of Florida (Evans *et. al.* 1985, Hine *et. al.* 1986 and Locker *et. al.* 2003). The latter researchers in particular report a strong positive correlation between increased underlying bedrock gradients and increased sediment thickness. That is, thicker sediments occur over more steeply inclined basal surfaces and flatter basal gradients correlate with thinner sediment accumulations (Figure 3-6).

This suggests a direct control of antecedent topography where Holocene sediments preferably accumulated in areas where steeper bedrock anchored the littoral and shelf sands. Historical shoreline data for recently evolved coastal barriers and stratigraphic data based on core logs from older barriers indicate that they formed in response to a gentle wave climate that transported sediments onshore to shallow water where they shoaled upward to intertidal and supratidal levels (Locker *et al.*, 2003). The present coastal barriers thus probably formed within the last few thousand years (Holocene) close to their present location in association with antecedent topography comprised by shallow Miocene limestone bedrock (Evans *et al.*, 1985).

The barrier islands are relatively young having formed over the last 3000 years when the rates of sea level rise were not more than 0.04 cm yr^{-1} (Stapor *et al.*, 1988). The rate of sea level rise during the Holocene played a major role in barrier island development along this coast. During the early Holocene (*e.g.* 10,000 to 12,000 years ago) when rates of sea-level rise were greater than 1 cm yr^{-1}, they prohibited the development of stable barrier islands. Because this coast was devoid of major sediment supplies during this period of rapid sea-level rise, large coastal sand bodies were not developed or preserved on the shelf above the carbonate platform. The coastal morphology that we observe today began to develop about 3,000 years ago when favorable conditions that included declining rates of sea-level rise that stabilized to nearly today's rates (0.02 to 0.06 cm yr^{-1}). The oldest subaerial sediment accumulations on the barrier islands were dated at 3,000 YBP by Stapor *et al*. (1988) but Holocene sediments beneath the barrier islands were dated from 4,200 to 4,500 YBP by Davis and Kuhn (1985). Because sea level fluctuated around present eustatic conditions during the late Holocene (Fairbridge, 1961), sand bodies landward (beach ridges) and seaward (inner shelf sand ridges) of the present coastline developed during the last 4,000 years of the Holocene. These sediments generally do not exceed 8 m in thickness and thin from the barriers to the offshore. Holocene sediments lie unconformably on top of pre-Holocene strata. Most of the Pleistocene record is absent on the inner shelf except for restricted areas where thin layers of Pleistocene clay have been mapped *(e.g.* Davis and Kuhn, 1985). According to Hine *et al*. (2001) the pre-barrier history of this area is characterized by multiple incursions and excursions of sea level preserved in a wide range of estuarine to open marine sequences as expressed through the interpretation of vibracores.

Regional investigations conducted by the US Geological Survey (Hine *et al.*, 2001) show that most of the barrier islands originated at or near their present location as subtidal shoals, evolving into supratidal barriers. Their stratigraphy thus can be viewed in a relatively simple stratigraphic model characterized by initial upward shoaling, aggradation and then, in some cases, progradation.

Today, important variables that control barrier-island development include the availability of sediment and the interaction of wave and tidal energy. Modern morphodynamics of the barrier/inlet system are strongly influenced by anthropogenic activities such as stabilization of inlets, construction of causeways, coastal structures (*e.g.* jetties, groins) and general coastal constructions. The tidal range in this area is small (less than 1 m) leading to limited tidal prisms and frequent inlet closures and migrations. Exceptions are made for some coastal inlets that have relatively large tidal prisms and large ebb shoals due to the large area occupied by the backbarrier water bodies that feed them (*e.g.* mouth of Tampa Bay and Charlotte Harbor estuaries). At the mouth of Tampa Bay, for example, the Egmont ebb-tidal delta (also known as the Tampa Bay ebb-tidal delta), is a huge sedimentary complex that stores about 305,000,000 m^3 of sediment. This deposit is the second largest coastal sedimentary body in the open Gulf of Mexico (Stott and Davis, 2003) (the first is the Mississippi Delta).

Regional History of Shelf Sand Deposits

The formation of useful offshore sand deposits and other deposits has been strongly influenced by processes that have affected the entire study area, often modified by regional effects. The regional considerations include broad views of the formation of the present shelf surface as a consequence of processes in operation over geologically significant durations that are on the order of millions of years. Although it is well to consider these large scale processes, the relative importance of these historical factors tends to increase inversely with distance back in time.

At the broadest scale the entire Florida platform can be considered. The whole region that is now Florida and its adjoining continental shelves became submerged about 125 million years ago (mid-Cretaceous). Prior to this it was a coastal plain that was part of the super-continent Pangaea which began to break-up due to continental drift. Since becoming submerged the Florida platform has collected a thick sequence of carbonate and evaporite sedimentary deposits. These deposits generally formed in relatively shallow waters as sea levels varied and the shoreline migrated back and forth over the platform. The time-scales and magnitudes of these sea level fluctuations were variable. Overall, the Florida platform has been subsiding as the sediments were deposited as evidenced by the fact that most are of shallow water origin.

The details of most of the very ancient sea level variations are relatively unimportant with respect to the sand deposits on the present continental shelf and shoreface. There is a more detailed description of these ancient processes in Appendix II. However, the sea level variations that occurred during the most (geologically) recent ice ages are significant because the global ocean level changed as much as 120 meters on a time scale of approximately 100 thousand years. The most recent of these sea-level cycles began about 125,000 years ago with sea level falling from a relative high stand that was close to or slightly above its present elevation. This fall, which generally corresponded to a major advance of the northern hemisphere continental ice sheets, was uneven in its rate and reached a maximum that was 120 m below the present elevation about 18,000 years ago. During this time nearly the entire west Florida shelf was dry land. Since that time sea level has risen, again at a variable rate, coming close to its present elevation about 6,000 years ago. This means that the shoreline moved (transgressed) across the entire width of the West Florida shelf over this relatively brief period of geological time (Balsillie and Donoghue, 2004).

The sedimentary deposits of the West Florida shelf and shoreface have been strongly influenced by two major factors. First, the whole of the Florida peninsula is predominantly comprised of sediments that were chemically or bio-chemically derived. There is relatively little quartz sand and other granular sediments compared to other continental shelves adjoining land areas with alluvial rivers. The consequence is that the sedimentary environments surrounding the peninsular portions of Florida are relatively sediment-starved. The second factor is that sand-size sediment settles rapidly, requiring vigorous wave and current action to move it. Sand moves readily in the surf zones adjacent to beaches, but it is much less mobile beyond the shoreface which nominally corresponds to a water depth less than about 40 ft. There is enough hydrodynamic power at most deeper depths to rework sand deposits but the deposits themselves are most often the result of nearshore processes when sea level was lower.

Two outstanding characteristics of the WFS are the breadth and low gradient inherited from the underlying carbonate ramp system. The average gradient of the shelf is 0.4 m/km (Ginsburg and James, 1974). Several important topographic features have controlled sedimentation, besides the broad regional nature of the ramp. The western Florida coast and inner shelves are dominated by two large estuarine systems: Tampa Bay and Charlotte Harbor. Both of these drowned river-valley systems appear to occupy local structural depressions, perhaps resulting from concentrated dissolution of underlying limestones within the platform

Concentration of surface runoff into large, distinct basins allows for transport of upland sediments onto the shelf during sea-level lowstands, where they are reworked during subsequent high stands. Hebert (1985) reports that seismic data reveal a 30-m deep by 5-km-wide buried channel that can be traced approximately 40 km seaward from the present coastline at Tampa Bay.

Sediment grain size remains relatively coarse well out onto the outer shelf and upper slope (at depths of 500 m) (Hine, 1997). Sediment grain size is coarsest between depths of 75 and 100 m, becoming finer both landward and seaward (Blake and Doyle, 1983); muds and oozes occur in water depths greater than 800 m (Mullins *et al.,* 1988). In addition, the WFS is a mixed siliciclastic-carbonate system with a quartz-sand belt (Figure 3-7) that was introduced onto the Florida Platform after the closure of the Suwannee Straits in the late Paleogene (~25 mya). In general, facies boundaries trend parallel to the bathymetry (Doyle, 1981). Siliciclastic sediments are being introduced to the upper slope off northwestern Florida by the Loop Current, which periodically carries muds from the Mississippi River (Walker, 1984).

The quartz-sand belt at the coastline makes up the barrier-island system and underlies the marine-marsh system (Figure 3-7). The sedimentary wedge is not very thick (less than 10 m) and thins seaward (Sussko and Davis, 1992). In some areas, the quartz-carbonate boundary lies within a few hundred meters of the beach. The quartz-sand facies pinches out where limestone bedrock is exposed. Much of the shelf has exposed hardbottom but mixtures of quartz sand and carbonates occur in the form of inner shelf sand ridges (NOAA, 1985; Hine, 1997).

The dominant carbonate constituents within the quartz-sand belt (inner shelf) are mollusks (Figure 3-7). Scattered coral occur on exposed rocky surfaces in shallow water, and calcareous green algae (Halimeda, Udotea and Penicillis) in seagress beds. None of these organisms produce an identifiable component in the surrounding sediments. South of Cape Romano, quartz content drops from 80% to 2% on the inner shelf toward Florida Bay, a well-known carbonate sediment-producing environment that represents the bank-interior facies of the south Florida carbonate platform (Sussko and Davis, 1992).. This reduction in quartz content is because littoral drift is from north to south and the content of siliciclastics in the drift decrease with distance southwards from the Tampa Bay area. There is a shift from a quartz-dominated drift environment along the central-west coast to a carbonate-dominated coastal environment south of Cape Romano. The carbonate environment extends southwards into Florida Bay and eastwards to the Keys. The result of this is that this area runs out of quartz in the littoral drift materials south of Cape Romano because the provenance of the quartz is to the north.

The middle shelf is characterized by a thin molluscan-sand sheet, about 1m thick, where hardbottoms (exposed bedrock or relict reef) do not exist (Figure 3-7). Molluscan sands occur beyond the outer shelf; however, coralline-algal sands and ooids form identifiable facies belts with the outer shelf. The ooids are in water depths ranging from 80 to 100 m, but they are also found in shallow waters 2 to 5 m deep, indicating that they are autochthonous deposits formed when sea level was lower (Kump and Hine, 1986). These coated grains formed in shallow-water, wave-dominated environments during the last sea-level low stand and during early phases of the following rise. The molluscan sands and corraline-algal sands are probably younger than the ooids, having formed after sea level had risen and created open-shelf conditions (Reading, 1978). The algal sands probably dominate in areas where hardbottoms and/or rocky highs (relict reefs?) are more abundant (Hine, 1997).

Today, active areas of carbonate sedimentation are restricted to the southern and southwestern parts of the WFS (Florida Keys). These areas persist as broad, extensive carbonate platforms as a result of: (1) long-term residence in tropical to subtropical climatic zones, (2) separation from a siliciclastic-sediment source (the southeastern U.S. continental mainland) by an open seaway (Bahamas) or by distance (southern Florida), and (3) the absence of persistent environmental stress (*i.e.* nutrient overload from upwelling, etc.).

Prominent Offshore Sand Resource Types

Sand resources along the southwest coast of Florida (southeastern part of the WFS) fall within four broad categories: (1) sand ridges (2) ebb-tidal shoals (3) shoreface sands, and (4) infilled depressions.

3.6 SAND RIDGES

Sand ridges generally occur in water depths from 8 to 21 m (25 to 70 feet) and are associated with modern shelf processes and relict geological and geomorphological controls (*e.g.* bedrock slope). The ridges off the southwest coast may be associated with cuspate forelands and sedimentary headlands, or with reworked paleo ebb-tidal shoals and barriers. The ridges are obliquely oriented to the coast although shore-parallel and shore-transverse ridges occur in restricted locations (Figure 3-8). The presence of sand ridges on the shelf has been appreciated as singularities for some time, but new studies emphasize the widespread occurrence of sand ridge fields that greatly enhance the potential for locating multiple good-quality borrow sites on ridges (*e.g.* Gelfenbaum *et al.*, 1995; Dyer and Huntley, 1999; Locker, 2003; Benedet *et al.*, 2004; van der Meer *et al.*, 2005; Jones *et al.*, 2005). Multiple sand ridge fields occupy different parts of the WFS and although the sand ridges display similarities, there are notable differences in orientation, morphology, and composition. Due to limited thickness (1 to 2 m), it was initially thought that sand ridges off the southwest coast could not provide sufficient volumes to support projected beach nourishment requirements. Today, however, exploitation of thinner ridges is feasible using hopper dredges that are specifically designed to dredge long shallow cuts. Suction cutterhead dredges, on the other hand, are appropriate for deeper cuts and are not recommended for dredging sand ridges thinner than 2 m and therefore would not generally be cost effective for the dredging of sand ridges off the southwest Florida coast.

The shoreline-oblique (30-50º) inner shelf sand ridges offshore from Sand Key, for example, unconformably overlie Miocene limestones of the Arcadia Formation that in turn is also partly overlain by a thin veneer of mixed carbonate and siliciclastic sands and gravels (Edwards *et al.,* 2003; Locker *et al*., 2003). These sand ridges have been investigated previously as sources of sand for beach nourishment (Gelfenbaum *et al.,* 1995). Ridge orientation, spacing and alignment, which seem to be less well-defined offshore from major ebb-shoal systems (*e.g.* ridges near the Egmont ebb-tidal shoal), tend to be shore parallel to slightly shore oblique in wave dominated areas and offshore from sedimentary headlands. Shore transverse ridges occur exclusively offshore Anna Maria Island and Longboat Key. Generally, the troughs between successive sand ridges are hardgrounds comprised by Miocene to Pliocene limestones or very thin (less than 1 m) layers of coarse shell fragments mixed with siliciclastic sands. Ridge relief tends to be subdued in shallow waters, attributed to waves that tend to flatten the ridges according to Jones *et al*. (2005). Ridge orientation seems to be controlled by interactions between wave and tide-induced currents when ridge fields occur offshore from major tidal inlets and changes in shoreline orientations at sedimentary headlands (Figure 3-8).

Grain-size and compositional variations along this portion of the WFS show a cross-shelf gradation between beach and nearshore siliciclastic sand and the carbonate shelf sediment. In general terms, carbonate percentage increases with distance offshore but the facies transition is irregular in shape and closely linked to the morphology of the inner shelf (Gelfenbaum *et al*., 1995; Brooks *et al*., 2003; Locker *et al*., 2003). Most of the unconsolidated sediments on the inner shelf are concentrated in low-relief ridges with older strata exposed in intervening troughs (Locker *et al.,* 2003). The sand ridges unconformably overlie the underlying Miocene and Pliocene bedrock (hardbottoms). The series of low-relief ridges along this coast are smaller in length and width to ridges found on continental shelves of the eastern United States (*e.g.* Duane *et al.,* 1972), eastern Canada (*e.g.* Hoogendorn and Dalrymple, 1986), and Europe (*e.g.* Dyer and Huntley, 1999).

The sand ridges are generally shoreface-detached (except for transverse ridges offshore Anna Maria Island) and sediment starved. They are part of an active seafloor environment (not relict sediments). Evidence suggesting that these are active sand bodies includes: (1) relatively young AMS ^{14}C dates (< 1600 YBP) from foraminifera in the shallow subsurface (1.6 m below seafloor), (2) sediment textural boundaries and development of small bedforms in an area of constant and extensive bioturbation, (3) morphological asymmetry of sand ridges, and (4) exceedance of critical threshold velocity of sediment transport (based on current meter data) (Harrison *et al*., 2003) by storm-induced bottom flow. However, the time scale of formation or migration of these features is thought to be on the order of centuries to millennia (Caballeria *et al.*, 2003). Compositionally, the sand ridges contain a mixed siliciclastic - carbonate sand facies that dominates the surface and shallow subsurface (to -1.6 m) (Edwards *et al*., 2003). The carbonate content ranges from 7.1% to 51.8%, with the remainder being quartz. Mean grain size ranges from 0.09 mm to 0.8 mm. Composition of sand ridge sediments is variable and the decision to exploit one ridge over another generally depends on the composition of beaches to be renourished.

3.7 EBB TIDAL SHOALS

Ebb-tidal shoals are large reservoirs of sand along the southwest coast. For decades, ebb-tidal shoals and associated sandy deposits have been exploited for beach nourishment projects in the region. These shoals exhibit a range of shapes and forms that are morphodynamic responses to balances between wave and tidal forcing. There are 34 inlets along the west coast of Florida (Figure 3-9). Sand volumes stored in west coast inlets constitute an important source of clean sand for beach nourishment. Because ebb-tidal shoals accumulate sediments that are transported alongshore by longshore currents in the surf zone, they are generally composed of beach-compatible sediments. Due to high energy conditions of their natural environment, which is subject to the constant action of currents and tides, ebb-tidal shoals generally contain sands that are useful (devoid of fines and organic materials) for beach nourishment. Tidal shoals generally occur in shallower water which limits the use of hopper dredges that require a deeper draft for safe navigation. Fortunately the ebb shoals generally contain thicker sediment packages that can be successfully explored using cutterhead dredges. When the shoals occur at large distances from a project area (e.g. Cape Romano Shoals), a combination of cutterhead dredges and storage and delivery barges (scows) may be an appropriate dredging method.

Many of the large ebb-tidal shoals in the area (like those offshore the mouth of Tampa Bay and the entrance of Charlotte Harbor, Figure 3-10) are tide-dominated and store large volumes of sand not significantly influenced by waves. Due to the nature of these large tide-dominated sand bodies, they are poor sediment bypassers and constitute permanent sinks of littoral drift sediments. On the other hand, inlets offshore of small tidal inlets with smaller tidal prisms are predominantly wave-influenced and are better sediment bypassers. Figure 3-11 shows Blind Pass. This is a wave dominated inlet shown here after having closed naturally. Due to small tidal prisms, wave-dominated inlets tend to periodically close. When open, these types of inlets contain smaller ebb-tidal shoals and are a less suitable sand source than their larger counterparts (tide dominated and mixed-energy inlets). (Photo provided by the Lee County Government – Robert Neal). Approximate sand volumes stored in ebb shoals of these 34 tidal inlets were quantified by Hine *et al*. (1986) and Dean and O'Brien (1987).

3.8 NEARSHORE SAND BODIES

Shoreface sands, which occur at relatively shallow depths (*i.e.* 3 to 8 m), are generally thin and discontinuous along this coast. They have been exploited to advantage for beach nourishment projects. These nearshore sand bodies include blanket sand deposits that extend from the surf zone to offshore exposure of bedrock (hardground) or the beginning of sand ridge fields. They are of limited extent on the WFS because this coast is sediment starved with extensive nearshore hardgrounds (bedrock exposures). Although rare, there are some sand deposits that blanket shallow (3 to 10 m) waters that may be explored for coastal restoration. Nearshore sedimentary covers are, however, more common on offshore barrier islands that lie adjacent to major tide-dominated inlet systems. Figures 3-12 and 3-13 show representative shelf cross-sections by Locker *et al*. (2003), of the northern and southern coastal segments respectively. These figures show, for example, that nearshore sand blankets of 1 to 4 m in thickness occur offshore Anclote Key, Mullet Key, Treasure Island, and Anna Maria Island. These kinds of nearshore sand bodies also occur offshore Gasparilla Island and Cayo Costa (remnants of the Boca Grande - Charlotte Harbor ebb-tidal shoal). These were used in the Anna Maria Nourishment Project (2002) and are scheduled for the 2005 emergency restoration project for the same island. In Figure 3-12, representative stratigraphic cross-sections (A, F, and J) of the northern coastal segments show contrasting seabed conditions with bedrock exposures and Holocene sedimentary deposits (shaded) presenting the distinction between Holocene sediments (shaded) and underlying hardbottoms). Cross-section J shows ebb-tidal sands covering the inner shelf while cross-section F (Sand Key) shows bedrock exposures that dominate the seafloor between successive sand dunes and ridges. Figure 3-13 shows representative stratigraphic cross-sections (K, O, and R) of the southern coastal segments (see cross-section index, upper left hand corner) showing contrasting seabed conditions with bedrock exposures and Holocene sedimentary deposits (shaded) presenting the distinction between Holocene sediments (shaded) and underlying hardbottoms). Cross-section K shows Tampa Bay ebb-tidal sands covering the inner shelf while cross-sections O (Siesta Key) and R (Manasota Key) show bedrock exposures that dominate the seafloor between successive sand dunes and ridges. (From Locker *et al*., 2003).

3.9 INFILLED CHANNELS AND DEPRESSIONS

The WFS includes various types of depressional or negative topographic features that are incised into the karst (bedrock) surface and some surficial marls. Some of these depressions underlie sand ridges. Figure 3-14 is of a seismic cross-section of a sand ridge located about 8 km (5 miles) offshore Naples Beach in Collier County. This low-relief ridge is delimited by solution holes in its landward and seaward margins These solution holes were formed when the WFS was exposed to surface (subaerial) geomorphic processes during low stands of sea level. Clayey sediments infill the solution hole whereas sand and shelly sands make up the sand ridge. (From Benedet *et al.,* 2004). Small streams and some larger rivers cut into the karstified surface and persisted as valleys until sea level rose and they were infilled with recent marine and terrigenous muds. In contrast to the sand ridges, sediments infilling karst depressions are generally fine-grained muds and marls that are not suitable for beach nourishment projects.

Deposits that have been previously investigated as potentially beach-compatible sediments include infilled karst depressions on bedrock surfaces. Some of these infilled solution holes were investigated in Collier County (Coastal Engineering Consultants-Alpine, 2000) but vibracore samples contained fine-grained sediments with rubble fragments (silts and clays and rock) that are unsuitable for beach nourishment.

3.10 SUBMARINE PHYSIOGRAPHIC PROVINCES ON THE WEST FLORIDA SHELF

The West Florida Shelf (WFS) is the submerged western flank of the Florida Platform, a distally steepened carbonate ramp that extends 250 km into the Gulf of Mexico from the barrier island shoreline on the west coast of the subaerial peninsula. The low-gradient, low-energy inner shelf of the WFS is starved of sediment input by fluvial sources. The seafloor of the WFS is thus characterized by extensive exposure of Miocene to Quaternary limestone bedrock that is interspersed by thin veneers of coarse carbonate sands and finer-grained siliciclastic (quartz-dominated) sediments that range from a few centimeters thick to more than 4 m (Edwards *et al.*, 2003; Locker *et al.*, 2003). Brooks *et al.* (2003) recognize nine lithofacies on the WFS: limestone gravels, lime muds, organic muddy sand, olive grey sand, muddy sand, shelly sand, well-sorted sand, and black (phosphoritic) sand. Of these, only well-sorted sands are relevant to offshore searches for beach-quality sands in sand ridges.

Figure 3-15 shows subdivision of the shore and WFS in terms of eleven primary physiographic units. The WFS beyond the state-federal offshore boundary is undifferentiated in terms of bottom classification because, at the present time, sand resources in the area are not required. Seafloor classification units on the inner WFS (landward of the state-federal boundary) are subdivided for purposes of marine sand searches and comprehension of marine sand resources. These delineations provide a first cut in the interpretation of bottom types.

The onshore and nearshore units include barrier islands, sand sheets, bars, and deltas that are included in the previously noted mapping units and their percent of the total area mapped: Barrier Island Platform Sediments (19%), Ebb-tidal Delta Complexes (4.7%), Rock Platform - Sand Sheet Complex (20.7%), Shoreface-Attached Sand Sheets (9%), and Transverse Bars (0.4%) (Figure 3-15). Barrier islands along the west coast of Florida are perched on top of underlying pre-modern rocks that control coastal morphology as described by Riggs *et al.* (1995) and Locker *et al.* (2001). Barrier Island Platform Sediments, including the perched barrier islands themselves and back bays, make up the shore. The barrier island platforms are fronted by Shoreface-Attached Sand Sheets, Transverse Bars, and cut through by passes, inlets, and paleo river channels (*e.g.* Tampa Bay estuary) (Figure 3-15). Ebb-tidal shoals and paleo deltas (*e.g.* entrance to Tampa Bay) occur alongshore in association with variously-sized navigational entrances, inlets and passes. The Shoreface-Attached Sand Sheets are most extensive off Pasco and Pinellas counties but extend alongshore to Collier County. The Transverse Bars mapping unit is restricted to the area immediately offshore Anna Maria Island, on the southern margin of the Tampa Bay ebb-tidal delta complex.

Near the coast (less than 5 km offshore), less than 50% of the WFS contains rock exposure in the form of scarped hardgrounds, due to shorefacing, with extensive sediment veneers that accumulate in a range of deposits that include ebb-tidal deltas, sand sheets, bar systems, and ridge fields. Nearshore deposits have been traditionally exploited as sand sources for beach nourishment activities. Ridge fields and sand waves are recently identified sand sources that have great potential for supplying beach-quality sands for nourishment of eroded shores. The sand waves rest unconformably on the limestone bedrock and are themselves covered by an array of small to very large 2D subaqueous dunes (Ashley, 1990). Undifferentiated mainland units are comprised by Pleistocene terraces viz. Pamlico Terrace (6.6 m), Penholoway Terrace (21.3 m), and the Wicomico Terrace (30.5 m) (Edwards *et al.*, 2003), as seen for example on the Pinellas County peninsula. More than 5 km offshore (*i.e.* water depth greater than 8 m), the WFS seafloor is comprised by greater than 50% rock exposure as hardgrounds (Obrochta *et al.*, 2003), as mapped in the Rock Platform-Sand Sheet Complex. Sand bodies mantle portions of the limestone bedrock surface (rock platform) but they tend to be relatively thin (<< 4m thick) and discontinuous. Rather than occurring as waves or dunes (see Ridge Fields section of Table 3-1), the surficial sediments accumulate as thin, sediment-starved, sheets that are interspersed over the bedrock platform.

Recognition of shoreface-detached ridge fields as a potential sand resource on the WFS drives attempts to identify environments of deposition and their relationship to submarine physiographic provinces. In order to subdivide the WFS into discernable units within a hierarchy, the inner continental shelf is interpreted in terms of morphological properties that comprehend rock units and sedimentary systems, as shown in Figure 3-15 and summarized in Table 3-1. Recognition of these physiographic provinces in a spatial context facilitates understanding of coastal morphodynamics by providing a rational basis for delimiting sections of seafloor that are distinct from other areas. Delineation of characteristic seafloor patterns provides a nexus between sand search protocols and exploration models (Finkl *et al*., 1997, 2003, 2004, 2005; Andrews *et al*., 2002) that feed the ROSS database.

For purposes of sand search investigations, the submarine portion of the Florida Platform is divided into the following physiographic provinces: WFS, Ridge Fields, Shoreface - Attached Sand Sheets, Transverse Bars, Barrier Island Platform Sands, and Ebb-Tidal Delta Complexes (Figure 3-15).

Because nearshore and onshore sediments have been exploited for beach nourishment (*e.g.* Finkl *et al*., 1997, 2003) and are relatively well known, attention is focused on the distinct groups of ridge fields that are identified here (from north to south) as the: Anclote Ridge Field (offshore Pasco and Pinellas counties), Sand Key Ridge Field (offshore Pinellas County), Sarasota Ridge Field (offshore Manatee and Sarasota counties), Manasota Ridge Field (offshore Sarasota and Charlotte counties), Captiva Ridge Field (offshore Lee County), and Collier Ridge Field (offshore Collier County). These ridge fields occur offshore from Shoreface-Attached Sand Sheets and Rock Platform - Sand Sheet Complex mapping units with their seaward margins often extending into federal waters. The intervening limestone bedrock areas (hardgrounds) often contain extensive carbonate gravel deposits (*e.g.* up to 90% shell fragments) where the swale grain size average greater than 1 F . Salient morphometries are summarized in Table 3-1.

The Anclote Ridge Field (defined here), which contains about 32 x 10^5 hectares, lies offshore southern Pasco and northern Pinellas counties on the northern portion of the west-central Florida coast. These well developed ridges range up to 1 km wide and 14 km in length. Their slightly variable azimuths average about 290° 3 to 20 km from shore.

The Sand Key Ridge Field (defined here), containing about 27 x 10^5 hectares and lying offshore from the Indian Rocks headland in Pinellas County, contains well-developed sand waves that range up to 1.5 km wide by 10 km long by 4 m high. Nearshore ridges have an average azimuth of about 330° whereas those farther offshore average about 310° (Edwards *et al*., 2003; Harrison *et al.*, 2003).

The Sarasota Ridge Field (defined here), containing approximately 94 x 10^5 hectares and lying offshore the lengths of Manatee and Sarasota counties, is the most extensive ridge field on the west-central coast. This large ridge field is comprised by poorly developed sand waves that are interspersed by extensive hardgrounds. The sand waves range up to 4 km wide by 10 km long by 4 m high with variable azimuths ranging from 200° to 230°. Calcium carbonate content on the southeast side of the ridges ranges from 20% to 60% (Twichell *et al*., 2003).

The well-developed Manasota Ridge Field (defined here), containing about 30 x 10^5 hectares and lying offshore the boundary between Sarasota and Manatee counties, contains well-developed ridges that range up to 1 km wide by 6 km long. The ridges have an average azimuth of about 345° about 3 to 13 km offshore (Finkl *et al*., 2006).

The Captiva Ridge Field, comprising about 31 x 10^5 hectares, contains well-developed ridges that range up to 1.3 km in width by 7 km in length. Their average azimuth is about 345° 5 to 25 km from shore (Finkl *et al*., 2006).

The Collier Ridge Field, lying offshore Collier County and containing about 22 x 10^5 hectares (the smallest ridge field mapped along the west-central Florida coast Table 3-1), displays well-developed sand ridges that range up to 1 km wide by 5 km long. The average azimuth is about 240° 8 to 20 km from shore. There may be additional ridges closer to shore but there is a data gap in the bathymetry (see Figure 3-15).

The ridge fields, which collectively occupy about 239,000 hectares, account for about 46% of the mapped area in Figure 3-15. Of the ridge fields, the Sarasota Ridge Field is the largest (39.5%) and the Collier Ridge Field is the smallest (9.3%). The other ridge fields account for similar percents of the total ridge field area viz. Sand Key Ridge Field (11.5%), Manasota Ridge Field (12.9%), and Captiva Ridge Field (13.3%). Estimated sand resources contained in the ridge fields can be determined by assuming that the ridges occupy about one-third of the ridge field area (the intervening areas of seafloor are rock outcrops or thinly veneered bedrock) and average about 2 m in thickness. Based on these assumptions of reconnaissance data in the literature, the ridge fields would have the following volumes: Anclote Ridge Field (194 x 10^6 m^3), Sand Key Ridge Field (164 x 10^6 m^3), Sarasota Ridge Field (566 x 10^6 m^3), Manasota Ridge Field (185 x 10^6 m^3), Captiva Ridge Field (191 x 10^6 m^3), and the Collier Ridge Field (132 x 10^6 m^3). Cumulative potential sand resource volumes (not usable volumes measured as sand reserves) thus accrue to about 1.4 x 10^9 m^3. Detailed surveys are required to prove out the nature of these potential sand volumes. Nevertheless, they constitute a significant sand resource for beach nourishment along the west coast of Florida.

4. Section 4 FOUR Using Ross In Comprehensive Marine Sand Searches

There are no universal or comprehensive guidelines defining the best possible method of conducting a marine sand search investigation, but several guidelines for specific geographic regions have been developed (*e.g.* Finkl, Andrews, and Benedet, 2003; Finkl *et al.*, 1997, 2004; Benedet *et al.*, 2004; Finkl and Khalil, 2005a,b). The lack of general guidelines occurs because sand searches are site specific and they must be geared to specific geographic environments that retain similar shelf-sediment histories. Continental shelves, such as the West Florida Shelf, are drowned coastal plains and the characteristics of those plains are largely fashioned by terrestrial regimes of the hinterlands that reach the coast. Because sand searches must be geared or tailored to geological conditions in the area of the study, approaches to conducting the search must be compatible with the specific geographic parameters of that region. This means that exploration methodologies must be capable of resolving required detection limits that are determined by deposit configuration in different geographic areas. The same search techniques would not be deployed, by way of an extreme example, in the search for sand ridges on the WFS as would be required for the detection of infilled sediment troughs (inter-reefal sand bodies) that commonly occur along the southeast Florida coast. Even though marine sand searches must be oriented to the detection of specific geologic features, there are specialized approaches developed for the southwest coast of Florida (e.g. Finkl, Andrews and Benedet, 2003; Finkl et al., 2003; 2004 and Benedet et al., 2004).

These general procedures consist of sequential tasks that are conducted in a phase-wise manner, as enumerated on Figure 4-1. This flow diagram illustrates systematic approaches to offshore sand searches, based on ten major steps that incorporate a range of subset activities that are restrained by local circumstances. Each task is meant to direct the course of subsequent actions so that sand searches proceed following a logical strategy that produces an efficient exploration methodology. The sequence of investigation boils down to ten essential steps that involve: (1) literature reviews and analyses of prior data, (2) development of action plans that incorporate the creation of digital (GIS) databases of prior data, (3) reconnaissance (geological) geotechnical and geophysical surveys (if needed), (4) identification of target area, (5) detailed geophysical surveys, (6) detailed geotechnical investigation, (7) evaluation of geophysical and geotechnical data, (8) hazard, natural resources (seagrasses, hardbottoms, etc.) and archaeological assessment survey, (9) selection of borrow area, , and (10) preparation of reports and other final deliverables. The ROSS system provides enough information to address Phases 1 and 2. It also contains an extensive annotated bibliography to assist in the literature search. The investigator must augment this with the most recent and location-specific published and grey literature sources to compile a complete review. In some areas, where sufficient information is available, the data available in ROSS may provide enough information to substantially decrease survey needs during Phases 3 and 4 by reducing the area to be surveyed in preliminary reconnaissance investigations. These investigations, which traditionally covered relatively large expanses of the seabed, can now be simplified and abbreviated to verify the data. Subsequent phases are still needed to verify legacy data due to: (1) the dynamic nature of sand ridges, ebb shoals and nearshore sand bodies on the WFS, (2) advances in survey technology (accuracy and resolution), and (3) permitting requirements (*e.g.* cultural resources clearance).

In order to optimize resources, including time and effort, it is convenient to conduct detailed cultural resource surveys subsequent to definition of final borrow area boundaries so that only the area to be dredged is 'cleared'. ROSS contains several data coverages that can assist this effort. There are ranges of sub-tasks within each of these main phases of work and the whole process may take up to several months to complete depending on project size, location, amount of previous work completed (assuming that the data collected is adequate, appropriate, accurate, and relevant), available funding, weather conditions (especially sea state), *etc.* The availability of a comprehensive GIS database helps to optimize such investigations and significantly reduces costs and time involved with initial data compilation and analysis.

These guidelines are briefly summarized in terms of tasks to be completed within ten main phases. The descriptions indicate general strategies that logically work toward completion of phases so that future work can build on prior accomplishments that, to a certain degree, direct the course of subsequent actions.

4.1 PHASE I: REVIEW OF ROSS DATABASE AND PUBLISHED LITERATURE

The first phase of marine sand searches involves literature searches and design of the exploration program. In this phase, the ROSS system plays a major role in the marine sand search process. In the past, this initial data background check was sometimes overlooked because it was considered to be too time consuming or possibly even irrelevant as the data was old, or in a different format from today's conventions or use. Experience (CPE, 1992, 1999b; Andrews *et al*., 2002, 2004; Finkl, Khalil and Spadoni, 2002; Finkl, Andrews and Benedet, 2003; Finkl *et al*., 2003, 2004; Benedet *et al*., 2004) has shown that this phase is crucial to re-evaluation of prior knowledge, to the development of conceptual models of sedimentary environments, and to guide the planning of future survey options. Thus, the purpose of literature (data) review is to familiarize survey planners with local environmental conditions and to flag any special conditions that require avoidance or focused attention. Unfamiliarity with the peculiarities of local environments or geomorphological features holds potential for obtaining less than desirable results. Tasks proposed for the sand search are therefore adjusted to local conditions in the appropriate manner.

Thorough, comprehensive reviews of historical, technical, and scientific literature should include geological, geomorphological, and geophysical information or data. Basic literature sources that should be perused in terms of general geologic framework and coastal processes include books and primary scientific and engineering journals (*e.g. Journal of Coastal Research; Marine Geology; Journal of Sedimentary Research; Marine Resources and Geotechnology*) and conference proceedings (*e.g.* 'Coastal Sediments' sponsored by the American Society of Civil Engineers, ASCE). These data are always evolving as most of these publications are monthly and bimonthly and should be checked in early stages of marine sand searches. Particularly important in the west coast of Florida is the series of papers and reports available from the *USGS West Coast of Florida Studies* (see Hine *et al*., 2001) and its associated graduate theses and peer-reviewed journal publications.

The gray literature includes a vast range of materials that are produced on an irregular basis in the form of special reports that include but are not limited to: consulting reports prepared for government agencies such as the Florida Department of Environmental protection (FDEP), Florida Geological Survey (FGS), U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), and private consultants. These data, particularly individual consulting reports, are often hard to access. Fortunately for the west coast of Florida, all data developed by coastal consultants is archived at FDEP and is readily available in the ROSS database. Reports from governmental agencies such as the USGS, USACE, and FGS are also collected by the FDEP.

Offshore geotechnical literature and geotechnical data including geological maps, bathymetric maps, seismic cross sections, geotechnical data, both geological and geophysical borehole logs, within an approximate 10-km radius of the project area and adjacent sites should be consulted, analyzed, and reviewed. The intent of this phase is to initiate development of a flexible reconnaissance survey plan for preliminary geotechnical investigation. This plan should be geared to the identification of potential sites for probable borrow areas by eliminating locations that are unsuitable for any reason.

4.2 PHASE II: PREPARATION OF A SYSTEMATIC ACTION PLAN

Development of a systematic action plan builds on the results of Phase I tasks and involves reconnaissance geological and geophysical surveys that are guided by interpretation of spatio-temporal information contained in GIS databases. The ROSS system provides readily available data in GIS format thus eliminating the transition between analog data to GIS environments normally required during this phase. Data derived from bathymetric, seismic, and limited vibracore surveys are used to map bottom types and to differentiate areas with potential for containing usable sediments by using GIS spatial queries. Seismic sub-bottom profiles provide useful information where underlying bedrock restricts thickness and lateral extent of inner shelf sand bodies. Use of this information in real-time mode via an interactive GIS platform onboard a survey vessel, for example, provides ready access to archival and legacy data that can assist the decision-making process for modification of surveys on the fly. Potential targets can thus often be defined on the basis of bathymetry, image roughness of the seabed surface, sedimentary structures and sediment composition. Delineation of potential target areas thus excludes all other areas as being unsuitable due to poor quality of sediments or absence of them (*i.e.* in the case of exposed bedrock). The purpose of subsequent phases and tasks is then to work toward eventual exploitation of targeted sand sources.

4.3 PHASE III: RECONNAISSANCE GEOLOGICAL AND GEOPHYSICAL SURVEY

This phase of work normally includes several integrated tasks that focus on regional bathymetric surveys, seismic investigation, and preliminary surface – subsurface sampling using grab samples and jet probes (*e.g.* Finkl and Benedet, 2005) to verify historical data and sand deposit location. After reviewing the existing information, supplemental geotechnical investigations are normally conducted to obtain sediment data that helps evaluate potential sand sources and determine the availability of adequate sand volumes in the areas delimited using historic data sources. In some areas, the ROSS system may provide enough legacy data to significantly reduce or eliminate survey needs of this phase.

In situations where reconnaissance data is required, the investigations normally include positioning by DGPS, bathymetric surveys (using digital fathometers), surface sediment sampling, jet probes and seismic survey – sub-bottom profiling (using a sub-bottom profiler such as chirp sonar). Reconnaissance surveys are normally conducted along widely spaced tracklines of about 300 to 1000 m grid spacing. Preliminary sampling with grab samples and jet probes may be collected for initial evaluation, verification of historical data and delineation of potential sites where detailed surveys could be undertaken. Retrieval of sediment samples also facilitates calibration of seismic records and thereby increases the interpretive value of geophysical data (*e.g.* Griffiths and King, 1981) for locating potentially usable sand.

4.4 PHASE IV: IDENTIFICATION OF POTENTIAL TARGET AREAS FOR DETAILED EXPLORATION

As a result of the reconnaissance survey (Phase III), a base-map should depict potential target areas with detailed survey plans with proposed tracklines and sampling locations. Prepared on a suitable scale this kind of information is then presented to the sponsoring agencies for discussion and approval. It should be noted that changes and adjustments to the basic or initial plans are anticipated on the basis of the field data and analysis conducted during the Phases I thru III (Figure 4-1). In some cases, additional surveys in Phase III may not be necessary because potential target areas were successfully identified on the basis of geophysical and geotechnical data provided by the ROSS system and analyzed in Phases I and II. This situation may occur in areas that have been extensively explored previously or where there is a plethora of recent data that contains information useful to sand searches.

4.5 PHASE V: DETAILED GEOPHYSICAL SURVEY

This phase of work provides detailed geophysical investigations that include bathymetric surveys, and sub-bottom profiling (seismic). Basic literature about these survey procedures and requirements can be found in Wolf and Brinker, (1994), Yilmaz, and Doherty, (2000), Baker and Young (1999), Baldwin and Hempel (1986), Blondel and Murton (1997), Griffiths and King (1981), Dragoset and Evans (1997), Gorman, Morang and Larson (1998), Hunt (1984), Langeraar, (1984), Morang, Larson, and Gorman, (1997), Verma (1986), Worthington, Makin, and Hatton (1986). Detailed surveys typically follow trackline grid spacing on the order of 300 m or less. This level of detail normally provides sufficient details for defining potential borrow sites, but in some specialized cases that are geologically complex, closer grid spacing may be used.

Planning survey tracklines is a crucial part of any successful geophysical survey, which requires incorporation of scientific information (derived from the literature) and bathymetric data (from NOAA charts and bathymetric data collected during Phase II) (*e.g.* Hemsley, 1981). When the compiled base-map (which results from Phases I & II) is completed, the area selected for detailed study is earmarked for closely-spaced tracklines. The most satisfactory results are generally obtained by running geophysical (especially seismic) surveys in a pattern that is orthogonal to the prevailing offshore geologic structures or surficial topography. If the prevailing offshore geology is not parallel to the shore, the survey lines should be positionally adjusted to best image the terrain. For offshore areas where little is known about the surficial geology, an alternative procedure is to run survey lines in a zigzag pattern approximately perpendicular to the coast. Planning of track-lines is site-specific and should not be constrained by these broad suggestions and general recommendations.

The following components of a comprehensive geophysical survey should include accurate navigational positioning, detailed bathymetric survey, and seismic stratigraphic survey. A basic requirement for detailed high-resolution seismic survey, subbottom profiling, of delineated borrow areas is accurate navigational positioning or position control. DGPS is the primary positioning system currently used for hydrographic surveys. DGPS correctors can be obtained either through the U.S. Coast Guard (USCG), Maritime DGPS Service, or other differential services, provided they meet accuracy requirements.

Echosounders and digital fathometers, are used for bathymetric survey based calibrations and corrections mentioned for the earlier phase work. A detailed bathymetric map should be prepared using a suitable isobath interval. Bathymetric surveys are required for many studies of geology and geomorphology in coastal waters (Morang, Larson and Gorman, 1997a, b), including offshore sand searches in attempts to define target areas that may eventually become borrows. Fathometers or echo sounders are most often used to measure water depths offshore. The distance between the sound source and the reflector (seafloor) is computed as velocity of sound in water divided by one half of the two-way travel time. It has been observed that even with the best efforts at equipment calibration and data processing, the maximum practicable achievable accuracy for nearshore depth surveys is about ±0.15 m (USACE, 1991). Errors in acoustic depth determination are caused by salient complicating factors or processes that include:

a) Differences in the velocity of sound in near-surface water (about 1500 m/sec) that varies with water density, which in turn is a function of temperature, depth, and salinity.
b) Changes in the vessel's draft as fuel and water are depleted during the survey require boat-specific correction that is carried out by performing depth checks.
c) Waves cause the survey vessel to pitch up and down and the seafloor is recorded as a wavy surface. Transducers and receivers are now installed on heave-compensating mounts to obtain the true seafloor. Post survey data processing is the most common means of removing the wave signals.

When conducting a seismic survey using a subbottom profiler, (e.g. 3.5 kHz high-resolution profilers, mini-sparker, uniboomer, chirp, etc.) a chirp subbottom profiler is preferred for proper depth-penetration and better resolution.

However, this equipment comes in a variety of configurations and these have their own methods for settings and operation. Considerable planning is needed to select the proper equipment, operation mode and survey trackline layout. Furthermore, instrumentation continually evolves so the plan needs to include a search for, and evaluation of, the newest equipment. Seismic stratigraphy should be developed on the basis of subbottom profiles thus obtained. Detailed surveys typically follow trackline grid spacing on the order of 300 m or less. This level of detail normally provides sufficient resolution for defining potential borrow sites, but in some specialized cases that are geologically complex closer grid spacing may be used.

In the third phase, a comprehensive geotechnical field survey is planned, executed, and analyzed. Preliminary maps based on this information can then be developed.

Successful sand searches rely on sonar imagery of the seafloor and sectional depth views along tracklines that show sedimentary layering. Seismic reflection profiling, calibrated to sand searches using vibracore data, is crucial to the delineation of potential sand bodies in terms of depth and lateral extent. Sonar surveys provide useful proxy data that can be interpreted in terms of smoothness or roughness of the seabed, information that is useful for differentiating rock outcrop from unconsolidated sediments.

In geophysical surveys, the distance between the sound source and the reflector is computed as velocity of sound in that medium (rock, sediment, or water) divided by one-half of the two-way travel time. This measurement is converted to an equivalent depth and recorded digitally or printed on a strip chart. A recent development that is extremely valuable to interpretation of bottom-sediment grain size is a signal-processing unit that can be interfaced with an echo sounder and used to indicate the size of seafloor sediments in terms of Wentworth or other general classification schemes (ASTM, 1994; Morang, Larson and Gorman, 1997a, b). This is accomplished by measuring two independent variables, viz. roughness and hardness, from acoustic signals and interpreting these data in terms of sediment type.

The basic principles of sub-bottom seismic profiling and acoustic depth sounding are essentially the same. A lower frequency and higher power signal (to penetrate the seafloor) is employed in subbottom seismic devices. The transmission of the waves through earth materials depends on properties such as density and composition. The signal is reflected from interfaces between sediment layers of different acoustical impedance (Sheriff and Geldart, 1982). Coarse sand and gravel, glacial till and highly organic sediments are often difficult to penetrate with conventional subbottom profilers, resulting in poor records with data gaps. Digital signal processing of multi-channel data can sometimes provide useful data despite poor signal penetration.

Seismic reflection profiles are roughly analogous to geologic cross-sections of subbottom materials because acoustic characteristics are usually related to lithology (Verma, 1986). Reflections may appear on the seismic record due to subtle changes in acoustic impedance that are associated with minor lithological differences between under- and overlying materials. Conversely, significant lithologic differences may not be recorded because of similar acoustic impedance values between bounding units, due to minimal thickness of stratigraphic units, or because reflectors are masked by gas (Sheriff and Geldart, 1982). Because of these complicating factors that can mislead interpretation of the seismic record, seismic stratigraphy should always be considered tentative until supported or verified by direct lithologic evidence from core samples.

The two most important parameters of sub-bottom seismic reflection systems are vertical resolution, *i.e.* the ability to differentiate closely spaced reflectors, and depth of penetration (*e.g.* Parkes and Hatton, 1986). The dominant frequency of acoustic pulses increases signal attenuation and consequently, decreases the effective penetration. In response to resolution of this problem, it is common to simultaneously deploy two seismic reflection systems during a survey. By combining results from one system that maximizes high-resolution capabilities with those of another system that is capable of greater depth penetration, it is possible to retrieve high-resolution data to greater depths than would normally be possible with a single seismic reflection system.

The Chirp system has advantage over single frequency (3.5 kHz) sub-bottom profilers (or pingers as they are commonly called) and boomer systems in sediment delineation because the reflectors are more discrete and less susceptible to ringing from both vessel and ambient noise. The full wave rectified reflection horizons are cleaner and more distinct than the half wave rectified reflections produced by the older analog systems.

All the data collected in Phase V should be incorporated into the GIS database (ROSS) and compared with complimentary legacy data.

4.6 PHASE VI: DETAILED GEOTECHNICAL INVESTIGATION

Detailed sampling using vibracores is an expensive procedure that involves significant effort and deployment of large vessels containing hoisting equipment and storage facilities for cores. Descriptions of vibracoring procedures and requirements can be found in Lee and Clausner (1979), Edgington and Robbins (1991), Larson, Morang and Gorman (1997), Finkl and Khalil (2005b). Costs for 20 ft vibracores often settle in the range of $5,000 to $7,000 which includes five to seven sediment samples per core depending on location and logistics. Descriptions of cores and analysis of selected sediment parameters adds additional laboratory fees to the total cost, making vibracoring a procedure that should be carefully planned to avoid wasted efforts. Potential vibracore sites should be judiciously selected to achieve the level of information and confidence needed for finding the target area, delineating borrow areas and for qualitative and quantitative evaluation of sand deposits (Finkl and Khalil, 2005b). Vibracore information is most beneficially employed in conjunction with subbottom data to gain maximum interpretive benefit of stratigraphic composition and sedimentary variation. Acoustic reflectors often can be identified on the basis of vibracoring, which, in effect, links or calibrates seismic reflection patterns to specific sediment types. Generally, vibracore sites should be spread throughout the survey area on a rectangular grid but preferably, in an alternative pattern that crosses the prevailing trend of the offshore geology. The standard accepted spacing between the core-sites is usually about 300 m. The minimum accepted recovery from each core is at least 80% and in at least three attempts or trials. Core recovery is sometimes problematical, especially where there are contrasting materials that are stratigraphically juxtaposed with sands vs. shell hash layers vs. carbonate rock clasts.

4.7 PHASE VII: EVALUATION OF GEOTECHNICAL DATA

Vibracores obtained in Phase VI are normally split longitudinally into two halves, with each portion labeled and dated for future reference. One half of the split core should be photographed and kept as an archive, the archived portion being cut into sections (not longer than 1.5-m) that are also labeled and dated. The archived core sections should be properly wrapped in clear plastic to avoid contamination from other core materials.

The other half of the split core should be sub-sampled for laboratory analyses for the development of visual lithologs (boring logs) of the cores on the basis of USCS designation (ASTM D2487-92, 1994). This procedure is accomplished in a standard format providing details of visual sedimentological properties followed by sampling. One representative sample for grain size analysis should be obtained from each horizon or layer (in a core) subject to a minimum of three samples from one core. Grain size and other physical parameters are analyzed either by mechanical sieving or by settling tube as per ASTM standard (ASTM D421/422). The Unified Soil Classification Scheme should be used to describe sedimentary materials and layering within the core.

A log is prepared for each core describing the sediments by layer including layer width, sediment color, texture, and presence of clay, mud, sand or shell and any other identifying features. Grain size analysis will be performed on approximately three or four sediment samples per core. Samples will be obtained from distinct layers in the sediment record, or periodically through the core record. This grain size analysis will be conducted for sand samples in accordance with the American Society for Testing and Materials (ASTM), Standard Material Designation D422-63 for partial size analysis of soils. Mechanical sieving will be accomplished using calibrated sieves, with a gradation of half phi intervals, per U.S. Army Corps of Engineers standards. Grain-size distribution curves will be prepared for each vibracore. The core logs, and raw sedimentological data will be developed into a GIS database and be available for electronic transfer to the State. In the end of the process all vibracore information (geographical location, logs, gradation analysis tables, sediment distribution curves and core photographs) should be stored in individual pdf files that can be made readily available from the ROSS system in the form of download menus or hyperlinks.

All necessary calibrations and other related tests that are considered necessary for the accuracy of the data and survey should be performed as part of this task group. Similarly, all necessary corrections usually carried out as standard operating procedures for reconnaissance surveys should include ascertaining tide and water levels. Once the sedimentary grain-size parameters, and other qualifiers relevant to the suitability as beach sediments are established, potential borrow areas can be delineated.

4.8 PHASE VIII: HAZARD, NATURAL RESOURCES AND ARCHAEOLOGICAL ASSESSMENT SURVEY

Once a potential borrow area has been identified, a cultural resources study is conducted using an underwater magnetometer, detailed seismic, sidescan sonar and bathymetric surveys in compliance with local, state and federal government regulatory requirements. Detailed geophysical data from the archeological surveys should also be integrated into the borrow area design data giving more certainty on sand deposits within the proposed cuts and to avoid duplicate efforts.

The purpose of the magnetometer survey is to determine if there are any metallic objects in the borrow area which may be of historic value, such as shipwreck artifacts. The magnetometer investigations are also useful in identifying non-historical metallic objects that may interfere with the dredging process such as abandoned engine blocks, pipelines, metal cable, *etc.* The results of the survey are documented by a professional archeologist and reported to the State Division of Archaeology. If needed, the borrow area should be revised and buffers should be implemented to avoid objects of potential historical value.

Cultural resource surveys (*e.g.* Kidder, 1996; Green, 2004; Watts and Finkl, 2004a, b, c, d) should be conducted when required for permitting purposes. These kinds of surveys are often necessary to ascertain the presence of drowned habitation sites of paleoindians (paleoanthropological and archeological term referring to Native American cultures prior to 8,000 BC) or other cultural groups and also provide excellent datasets for refinement of borrow area design cuts. Underwater archaeology is an important endeavor because it attempts to reconstruct where and how ancient peoples settled on coastal plains, now drowned to become continental shelf, or sometimes referred to as exposed continental shelf, and when they began to access and procure near-coastal and marine resources. In addition to the detection of Pleistocene settlements on exposed continental shelves when sea level was lowered during glacial cycles, there are important cultural remains on the seafloor that are related to contemporary society. Many of these artifacts (*e.g.* anchors, cables) have no cultural significance, but they can be harmful to dredges. Other cultural features such as buried pipelines and fiber optic cables require identification prior to dredging for definition of setbacks.

Due to the level of detail that is required for cultural surveys, sidescan sonar and magnetometer surveys are conducted on a close line spacing (~30 m). Normally, for such surveys the specifications and guidelines are provided by the permitting agency. Sidescan sonar surveys, which are conducted for identification of surface structures and hazards including debris, pipelines, shipwrecks, normally using dual-frequency sidescan sonar, are normally accompanied by a magnetometer survey (using either a Proton or Cesium Magnetometer). Generally, 100% swath coverage is needed for a sidescan sonar survey. This survey is normally done under the supervision of a professional marine archaeologist.

Natural resources are also a major concern. Off the southwest coast of Florida, environmental concerns mainly tend to focus on the presence of hardgrounds. Information that includes shapefiles from the Florida Geographic Data Library (FGDL) like the seagrass beds, Salt Marshes, Tidal Flats, Artificial Reefs and Aquatic Preserve Boundaries and side-scan sonar mapping are used to ascertain the occurrence of sensitive environments. If they are detected, they are delineated and avoided in sand searches and development of potential borrow sites.

4.9 PHASE IX: BORROW AREA SELECTION AND CALCULATION OF SAND VOLUME

Finally, the selection of potential borrow areas requires re-evaluation of all geotechnical and geophysical data obtained during Phases I through VIII, including updates or additions to prior surveys, and determination of outer limits of borrow areas. Geological cross-sections, compiled on the basis of sub-bottom data and vibracore logs, should be produced showing the sand layers and the proposed depths of cut. Isopachous maps for sediment thicknesses should be prepared to show the stratigraphic position of target sands and layers that should be avoided due to their unsuitability.

Because the depth, location, and orientation of borrow areas affects the adjacent shoreline, a thorough impact study should be conducted not only for borrow-site environmental assessment but for physical impact-assessment. These kinds of studies tend to focus on induced changes to wave propagation patterns and coastal circulation patterns for different depths of sediment removal (*e.g.* Bender and Dean, 2003).

The cost of dredging potential borrow areas can be a crucial consideration, especially where long haul or pump distances from borrow site to project area are concerned. The cost of dredging sediments from the inner part of the WFS is affected by the following major factors: type of sediment, distance from the borrow area to the barrier island, length and width of the barrier island to be restored, depth of water and depth of dredging in the borrow area, depth of water adjacent to the barrier island and thickness of the dredge cut.

The type of sediment determines dredge horsepower requirements, which in turn affects the cost of dredging. The distance from the borrow area to the extreme limits of the beach restoration project also affects project cost and equipment selection. When dredging with pumping distances up to 10 km, a cutterhead dredge (including the ocean-going dustpan) is the most efficient method. These dredges have 10,000 to 15,000 horsepower, which can pump non-cohesive sediments over these distances. When the distance from the borrow area to the barrier island exceeds 12 to 16 km, hopper dredges become more efficient in transporting the sediment. Thickness of cut in borrow areas also affects equipment selection and productivity. For cutterhead dredges to be productive, the cut must be at least 1 to 2 m thick. For cuts less than 2 m, cutterhead dredges can still operate but at less than optimum efficiency. For shallow cuts, hopper dredges and the ocean-going dustpan are more efficient because they excavate sediments in layers. If an insufficient number of cores are present in the borrow area, dredging contractors often add significant contingency fees to account for unknown or unfavorable conditions that might be encountered. Once a borrow area is selected, it may be worthwhile to go back for an additional round of vibracoring to effectively define sediment variability. Additional vibracoring with spacing no greater than 200 m apart may provide greater confidence in sedimentary conditions to reduce significantly dredging costs. Better estimates of sediment volumes by grain size for % sand (D_{50}, D_{85}) or % silt, shells, gravels, *etc.* may also reduce or offset dredging costs. Generally, it is reasonable to assume that the costs of conducting a very detailed and comprehensive marine sand source investigation is insignificant when compared with the potential for cost savings during dredging that may result.

4.10 PHASE X: DEVELOPMENT OF GEOTECHNICAL REPORT

The last phase of a sand search involves the preparation of final reports, appendices and digital data deliverables. As far as general guidelines are concerned, this final phase is perhaps the most important because a poorly prepared or presented report, wastes a great deal of effort. In the same way, if the datasets created are not incorporated into a digital database (ROSS) information will be lost and future duplicate efforts in the same area may be conducted by uninformed groups. It is thus essential that reporting procedures be followed using correct formats and styles. It is expected that final sand search reports will document the techniques, methods, analyses, and results. It should be common practice on the inner WFS that all newly generated data in marine sand searches be submitted in a digital format that can be incorporated into ROSS with minimal effort.

4.11 FINAL CONSIDERATIONS

Comprehensive reviews of previous offshore sand searches and legacy data is now facilitated by the existence of a comprehensive offshore marine sand search database (ROSS). Careful analysis of these legacy vibracore data, for example, should provide clear directives to the survey of target areas with the most potential for locating usable sand sources and significantly optimizing future sand search efforts. Selection of potential borrow areas, the ultimate goal of offshore sand searches, depends on adherence to established search protocols that are tempered by practical adjustments to local conditions.

Offshore sand resources along the west coast of Florida occur in three main depositional settings: (1) offshore sand ridges, (2) nearshore ebb shoals and (3) nearshore sand sheets. Bathymetrically positive features known as sand ridges that have been used in many nourishment projects along this coast and are the most prominent offshore sand deposit. These offshore sand ridge sands are offshore "mounds of sand" anchored in Hardbottom that are generally composed of mixtures of silicates (quartz) and carbonates (shell fragments, shell hash). Generally silt content increases with penetration depth and rock fragments are encountered in the boundary between the ridge's sandy sediments and the underlying hardbottom but sediment thickness and specific composition varies between ridges within the same field and between ridges located in different geographic locations along the SW Florida coast.

To search for beach quality sand on these sand ridges, a logical sequencing of investigation that differs from those applied along the east and panhandle coasts of Florida is necessary. A logical sequence of offshore sand searches targeting sand ridges along the SW Florida coast should adopt the following steps:

5.1 REVIEW OF HISTORICAL DATA

Using the ROSS database, the investigator can download historical datasets containing seabed relief information, geotechnical data (vibracores, jet probes, sand samples) and geophysical data (sidescan and seismic) to identify initial target areas for more detailed investigations. The gray scale shaded relief image available from ROSS can be used to identify offshore sand ridges occurring near a project area. The geotechnical and geophysical layers can then be turned on to see if any of the sediment data overlie ridges of interest. These data may provide initial information regarding deposit thickness and sediment textural properties. After target ridges are identified and data availability checked, the investigator can design a reconnaissance survey plan.

5.2 RECONNAISSANCE SURVEY PLAN

The reconnaissance survey plan should focus on obtaining better definition of sand ridge geomorphology and sediment characteristics. Commonly, a few offshore sand ridges (*i.e.* more than 5) are selected based on the analysis discussed in Section 5.1. These will be narrowed down to one or two ridges where the final borrow areas will be defined during future detailed field investigations.

The bathymetric data which is used to define the sand ridges of interest in Section 5.1 consists of historical NOAA-NOS data that can be 30 years old or older. Because some sand ridges may migrate and change shape over time, an updated bathymetric survey is a requirement for reconnaissance investigations prior to any seabed sampling. A reconnaissance seismic survey may also be conducted simultaneously with the bathymetric survey to allow for identification of sediment thickness. An experienced geologist/geophysicist can effectively map the sub-bottom hardbottom surface using seismic records obtained from chirp systems (*i.e.* the Edgetech 512i) to obtain information about sediment thickness. Undesirable materials such as rubble layers or presence of fine-grained sediments can also be mapped in the seismic records if calibration data (*i.e.* historical vibracores) are available. The spacing between lines in the reconnaissance surveys depends on the survey area but generally ranges from 1000 to 2000 ft but it can be more or less depending the objective of the investigation.

Traditionally sand quality and thickness in individual ridges may be investigated during preliminary sampling surveys using surface samples and jet probes. Because vibracores are more expensive and time-consuming they are traditionally reserved for detailed phases of an offshore investigation when the search area has been narrowed using other methods.

Sand quality and thickness in individual ridges may be investigated during preliminary sampling surveys using surface samples, jet probes or widely spaced vibracores. Surface grab samples can be deceiving because they only represent sedimentary characteristics of a few inches on the top of the ridges (generally sediment transported by modern processes) and do not show the characteristics of sediments lying below the ridge surface. Jet probes are a cost-effective method to investigate sediment thickness in the ridges. They also provide an indication of sediment quality in under-layers. However, the sediment samples extracted from jet probes are usually disturbed by the water jet and silt content may be underestimated.

One important consideration is that sand quality in the surface of the ridges as indicated by surface samples and widely spaced jet probes may not always be the most adequate procedure to select ridges for further investigation during reconnaissance efforts. Many times it was found that relict sediments underlying the ridge surface contains much cleaner sandy sediments (less shell and rubble fragments and lighter color) than surface sediments. This is because modern sedimentation processes linking the upper layers of sedimentation in a ridge may be significantly different from relict sedimentation processes that originated the ridge and are linked to deeper subsurface layers. Thus it is suggested that during reconnaissance investigations on offshore sand ridges on the SW coast of Florida, consideration is given to obtain at least one undisturbed sample (vibracore) on each offshore sand ridge to supplement jet probe and surface sample data.

Because the reconnaissance sampling plan should be designed to target the crests of the main sand ridges, spacing between samples varies with the size of the area, the total volume targeted, and the project budget.

5.3 DETAILED SURVEY PLAN AND PRELIMINARY BORROW AREA DESIGN

Following analysis of the data collected in during the reconnaissance survey plan, Section 5.2, a plan to conduct detailed investigations over a smaller area should be prepared. This detailed investigation plan aims at obtaining enough information to define the quality and quantity of sand in the study area and map the vertical and horizontal continuity of the sand layers. This level of investigation also provides enough information to identify layers of undesirable sediments within the study area that should be avoided during borrow area design. The detailed investigations usually consist of detailed bathymetry, sidescan and seismic surveys at spacings generally ranging from 200 to 300 ft with vibracores obtained at 1000 ft centers. Analysis of the information obtained in these detailed surveys allows for preliminary design of the offshore borrow area and mapping of surface features (*i.e.* environmental resources and possible obstructions to dredging) that occur in or near the borrow. Tools to assist in visualization of deposit morphology and sediment thickness and characteristics of sand borrow areas include geological cross-sections and fence diagrams, 3D isopach maps and bathymetric maps, color-coded interpretation of seismic records, *etc.*

Although these detailed investigations allow for preliminary borrow area design, they are usually adequate to meet the requirements of borrow area design. It must be appreciated that characteristics of mineral reserves such as offshore sand are geologically well known sites that are subject to sources of error directly linked to spatial and temporal variability of natural environments.

5.4 CULTURAL RESOURCE INVESTIGATIONS

Once the limits of the borrow area are defined, detailed geophysical investigations with 98 ft (30 m) line spacing should be used to investigate the presence of cultural resources within proposed borrow limits. The cultural resource surveys generally consist of magnetometer, sidescan and seismic surveys. Because these investigations must be conducted at 98 ft (30 m) intervals, the geophysical investigations discussed in Section 5.3 are generally conducted in multiples of 98 ft (30) m *viz.,* 196 ft (60) or 294 ft (90 m) so the cultural resource investigation can make use of data and lay additional tracklines between the lines previously run. Optimally, the cultural resource investigations are conducted using the same type of geophysical equipment as discussed in Section 5.3, so borrow area design can be refined using the additional data obtained. If any significant cultural resources (*i.e.* shipwrecks, large cultural artifacts *etc.*) are mapped within the limits of the proposed borrow area, the borrow design has to be modified to avoid disturbing the mapped features. This is usually done by adding 200 ft no-dredge buffers around the cultural resource feature or by modifying margins of the borrow area (when the cultural resource features occur near the borders of the borrow).

5.5 BORROW AREA IMPACT ANALYSIS (ENVIRONMENTAL INVESTIGATION AND NUMERICAL MODELING)

Data from the detailed survey plan and preliminary borrow area design (Section 5.3) and the cultural resource investigations (Section 5.4) may also be used to map any sensitive environmental resource (*e.g.* hardbottoms) occurring near the proposed borrow site. If sensitive environmental resources appear too close to the proposed dredge site, the borrow area design is modified.

In addition to cultural resource and environmental consideration, there is a need to evaluate whether the proposed borrow sites will significantly affect the nearshore wave climate and cause additional erosion of adjacent beaches. This evaluation can be done using a range of numerical models that simulate wave transformation over the borrow sites and can also simulate wave-induced currents, sediment transport, shoreline change and beach morphology change. Several wave models evaluate borrow area impacts on nearshore wave climates. In order to properly evaluate borrow area impact on nearshore waves, spectral wave models that incorporate most of the relevant physical processes of wave transformation (*e.g.* wave refraction, bottom friction and to a lesser extent diffraction) are recommended. While proposed borrows may induce changes in the nearshore wave climate, these changes may not necessarily cause additional erosion of adjacent beaches. To evaluate whether the impacts of borrow areas on nearshore waves is significant in terms of beach erosion and deposition patterns, shoreline change models or beach morphology change models can be used. These models can be either empiric (*i.e.* sediment transport is calculated based on the output of a wave transformation model that feeds empirical sediment transport formulas) or process-based (output from a wave transformation model is used to calculate wave-induced currents and these are in turn used to calculate bed-load and suspended load sediment transport). Simulations are run for scenarios with and without the proposed dredging. By comparing the with/without dredging scenarios, the investigator can evaluate the impact of dredging on the beach deposition and erosion patterns. If numerical modeling indicates that significant undesirable impacts are expect on adjacent beaches due to borrow area dredging, borrow area design modifications may be required.

5.6 FINAL BORROW AREA DESIGN

The final borrow area design, and the borrow area plans and specifications are prepared when all the concerns regarding the sediment quality within the borrow area, the cultural resource potential, the environmental consideration and the physical considerations are addressed. The final borrow area design shape and cut depths may differ significantly from the design prepared at the end of the survey plan and borrow area design (Section 5.3) due to the implementation of no-dredge buffers that reduce negative impacts from dredging.

This section describes potential sand resource areas along the southwest Gulf coast of Florida that require further investigation to provide sandy sediments for the restoration of critically eroded beaches along the SW Coast of Florida. Geological and geophysical data plus bathymetric imagery in the ROSS database formed the basis for selecting recommended investigation areas.

Discussion of sand resources on the continental shelf off the southwest coast of Florida is based on three coastal segments: (1) the Northern Coastal Segment consists of Pinellas County barrier islands and Tampa Bay (*i.e.* from Anclote Key to Egmont Key), (2) the Central Coastal Segment comprised by Manatee, Sarasota and Charlotte Counties (*i.e.* from Anna Maria Island to the Peace River Estuary), and (3) the Southern Coastal Segment in Lee and Collier Counties (*i.e.* from Venice Inlet to Cape Romano).

A total of five areas of potential sand resources have been designated within these three coastal segments (Figure 6-1). These areas each include sub-areas that have been selected for further analysis using the data and information residing in the ROSS database. This analysis will make use of the geophysical data along with vibracore, jet probe and grab sample information where available. The outcome of this analysis will show what is known about the sand resources in each of these Areas as well as to determine areas with insufficient data that warrant further data gathering efforts.

The process for this analysis will be the same for each of the 9 sub-areas selected. This includes using the data and information residing in the ROSS database. By turning on the different Layers on the IMS site, utilizing the images on the associated ftp site and accessing the data in the Oracle database through the Enhanced Query Builder (EQB). This analysis will follow 5 steps by showing; 1) the location of the potential sand source Areas, 2) the location of the geophysical tracklines, 3) the geophysical images (from the ftp site), 4) the vibracore and/or jet probe and grab sample locations and 5) the data pertaining to each core layer or sand sample from the Oracle database.

6.1 NORTHERN COASTAL SEGMENT

6.1.1 Area 1 – Sand Resources in Pinellas County

North of Tampa Bay, along the coast of Pinellas County, several beaches are designated as critically eroded by the Florida Department of Environmental Protection (FDEP) viz. Bellair Beach, Bellair Shores, Indian Rocks Beach, Indian Shores, Redington Shores, North Redington Beach, Madeira Beach, Treasure Island, Uphan Beach, and St. Petersburg Beach. Nourishment projects in this area have used mostly sandy sediments from ebb-shoals in the past. The Egmont Key ebb-tidal delta, for example, was extensively used in the past and may still supply quality sand for future renourishments. A number of offshore sand ridges on the Pinellas County inner shelf represent additional sand resources that have potential for beach nourishment (Figure 6-2).

Review of the ROSS database indicates that few offshore sand search investigations have been conducted in this shelf area (Figure 6-2). A regional study by the U.S. Geological Survey in the Central Coastal Segment provides the main source of information regarding sand ridges in this coastal segment. A seabed image created from NOAA bathymetry (available from the ROSS database) indicates that there are numerous sand ridges that warrant further geophysical and geotechnical investigation. Based on interpretation of the 3D bathymetric image which is shown in Figure 6-2 (ridge axes shown by white lines), about thirty (30) sand ridges were identified on the seabed extending from Clearwater Pass to John's Pass (about 12 miles alongshore) to about 8 miles offshore. Some of the larger ridges (2.5 miles long by 0.5 miles wide by 9 ft thick) contain large volumes of sandy sediments.

Two locations within Area 1 have been selected for analysis. These are Area 1A and Area 1B (Figure 6-3). One trackline crosses each of these features (Figure 6-4). For Area 1A, trackline 2D, between timestamp 2320 and 2300 and for Area 1B trackline 1C at timestamp 1356.

Area 1A

Figure 6-5 shows the sub-bottom image for Area 1A. On this image, three sand ridges are visible (circled). Three vibracores from the USGS Inner West-Central Florida Continental Shelf study are located close to these features (Figure 6-6). The data from these cores is presented in Table 6-1. Core COE 94-1 shows mostly fine quartz sand to a depth of 8 feet with increasing shell and carbonate to a depth of 10.5 feet. Core COE 94-2 shows mostly fine to medium quartz sand to a depth of 6 feet and core COE 94-3 shows mostly quartz sand to 4.6 feet increasing in carbonate deeper in the core. Also from the same study, one grab sample, J-17, is found in the area (Figure 6-7). This sample has a mean grain size of 0.64 phi which corresponds to medium sand using the Unified Soils Classification System (USCS).

Area 1B

Figure 6-8 shows a sub-bottom profile for Area 1B with a prominent sand ridge (circled). Four vibracores from the USGS Inner West-Central Florida Continental Shelf study are found in the vicinity of this feature (Figure 6-9). These are COE 94 – 11, COE 94 – 12, COE 94 – 14 and COE - 94 – 17. Data from these cores, listed in Table 6-2, shows core COE 94 – 11 contains mostly quartz sand to a depth of 3 feet, core COE 94 – 12 has mostly fine to medium quartz sand to a depth of 4.9 feet increasing in carbonate gravel content to 5.9 feet. Core COE 94 – 14 has mostly fine to medium quartz sand to a depth of 2.6 feet and core COE 94 – 17 is made up of mostly fine quartz sand to a depth of 7.2 feet. Two grab samples from the USGS Inner West-Central Florida Continental Shelf study are also found in the vicinity. These are J-46 and J-47 (Figure 6-10) and have mean grain sizes of 2.18 and 1.97 phi respectively corresponding to fine sand using the USCS.

A reconnaissance level investigation is recommended to study offshore sand ridges (ridge axes marked by white lines in Figure 6-2) with widely spaced bathymetric tracklines and 1 to 4 vibracores per sand ridge. Due to the lack of legacy data in this offshore area, reconnaissance jet probes should supplement vibracores to further investigate the sand resource potential. A bathymetric survey should precede sampling of sand ridges in order to accurately locate present sand ridge location (the NOAA bathymetric data is decades old). Sediment samples should be obtained from the main ridge axes.

6.2 CENTRAL COASTAL SEGMENT

6.2.1 Area 2 - Sand Resources in Manatee County and Northern Sarasota County

South of Tampa Bay, beaches on Anna Maria Island (Manatee County) and Longboat Key (Manatee and Sarasota Counties) are designated as critically eroded areas by the FDEP. These barrier islands have active beach nourishment programs that maintain a relatively stable beach configuration by means of periodic nourishment supplemented by coastal structures. Nourishment projects on Anna Maria Island use sand from transverse bars offshore the northern margin of the island and from the south lobe of the Passage Key ebb-tidal delta. Although these deltaic sand resources may provide sand for a few future nourishment cycles, it is also important to identify other sand resources for the long-term. Longboat Key also used white sands from the Passage Key ebb-tidal delta in the most recent nourishment project combined with offshore sands that were coarser and darker in color.

Several offshore sand ridges occur near the outer lobe of the Passage Key ebb-tidal delta and offshore from Anna Maria Island and Longboat Key. These ridges, lying unconformably on karstified bedrock, contain mixed carbonate (fragments of shells) and siliciclastic sediments. Many of these ridges have been used for beach nourishment in the past. Although this seabed area was investigated during previous offshore sand searches, several prominent offshore sand ridges were not considered for further, detailed studies, based on limited information provided by widely scattered jet probes and surface samples and availability of other nearby sand resources. Because there is an increasing need for good quality nourishment sand in this coastal segment, additional investigation is recommended for initially excluded offshore sand ridges and outer lobes of Passage Key ebb-tidal delta. These investigations should be based on analysis and interpretation of the ROSS database in order to avoid duplicative efforts and should consist of reconnaissance bathymetric surveys and widely spaced vibracores (1 to 4 vibracores per sand ridge). Bathymetric surveys should precede vibracore surveys in order to accurately locate ridge crests, determine local relief, and ascertain the main ridge axes for coring. Interpretation of historic bathymetric data (NOAA-NOS bathymetry) identified about 24 offshore ridges that require further investigation. Ridge crests and pertinent historical data are shown in Figure 6-11. Ridges that were extensively studied by prior vibracore surveys are not selected for further investigation (Figure 6-11).

Two locations within Area 2 have been selected for analysis. These are Area 2A and Area 2B (Figure 6-12). One trackline crosses Area 2A (Figure 6-13). This is line 1 between timestamp 1908 and 1948, and 2 tracklines are used to show the feature in 2B (Figure 6-13). These are line 2 at timestamp 738 and line 13 at timestamp 356.

Area 2A

Figure 6-14 shows the sub-bottom image for Area 2A. On this image, the width of this ebb delta is shown (red oval). Two vibracores from the USGS Inner West-Central Florida Continental Shelf study, USGS 95 16 and USGS 95-51B and 4 jet probes from the Longboat Key White Sand Search Investigations numbers LBK – 25, LBK – 26, LBK – 34 and LBK – 35 are located on this feature (Figure 6-15). Data from these cores and probes is found in Table 6-3. Information from core USGS 95-16 reveals mostly quartz sand to a depth of 6.3 feet and core USGS 95-51B shows a thin (0.6 ft) covering of mostly shelly sand changing to mostly quartz sand from 0.6 to 2.3 feet. The jet probes are distributed across the entire feature. The data from these probes shows the make-up of this feature is mostly fine sand to depths up to 17 feet. LBK-25 shows evidence of a layer of rock fragments close to shore. Data from the Longboat Key White Sand Search Investigations lists three grab samples, J-58, J-62 and N-3 that are located in the area (Figure 6-16). These samples show a mean grain size of 2.91, 2.72 and 2.81 phi respectively which corresponds to medium sand using the USCS (Table 6-3).

Area 2B

Figures 6-17 and 6-18 show two sub-bottom profile images for Area 2B. Line 2 runs north/south across the uppermost portion of this feature and Line 13 runs east-west across the lower, thinner portion. Both of these images show the feature (red oval). Three jetprobes have been taken in the vicinity of this feature. These are LBK-15, LBK-17 and LBK-20 from the Longboat Key White

Sand Search Investigations (Figure 6-19). Data from these cores, listed in Table 6-4, shows the feature to be mostly fine sand to a depth of 6-7 feet changing to mostly rock below that. One grab sample from the Inner West-Central Florida Continental Shelf study, N-40, is located on the upper portion of the feature (Figure 6-20). This sample has a mean grain size of 3.29 phi corresponding to fine sand using the USCS (Table 6-4).

Area 3 - Sand Resources in Southern Sarasota County and Charlotte County

A large ridge field remains relatively unexplored in the southern part of Sarasota County and throughout Charlotte County. These ridges are potential sand resources for FDEP-designated critical erosion areas at Siesta Key, Venice Beach, Englewood Beach, Knight Island, Bocilla Island, and Little Gasparilla. Previous beach nourishment projects used the northern lobe of the Boca Grande Pass and offshore ridges as borrow areas in this area.

The ridges, which are readily identified on 3D imagery created from historical bathymetric data, are oriented mostly in a NW-SE direction and occur from 2 to 8 miles offshore. Reconnaissance seismic work conducted under the SW ROSS contract in this area (see Figure 6-21 for location of reconnaissance seismic tracklines) indicated that relatively thick sediment packages comprise these ridges. Because limited sand search investigations have been conducted in this area, reconnaissance survey using a few (1 to 4) vibracores per ridge may not require supplementation by jet probes.

As part of the Reconnaissance Offshore Sand Search (ROSS) of the Florida Southwest Gulf Coast (this report) it was discovered after an exhaustive literature search that this area was significantly lacking in data. A result of this was to task CPE with the collection of reconnaissance level geophysical data in this area. This task resulted in approximately 80 nautical miles of geophysical data that has been annotated to show sand ridges and prominent reflectors. Many of these lines will be used for the analysis purposes of this section. Data obtained during the ROSS fieldwork (Figure 6-21) can initially be used to identify ridge crest location for preparation of a sampling plan. Additional bathymetric and seismic survey data should be obtained to delimit lateral and vertical extent of sand ridges. Visual inspection of NOAA bathymetric data identified about 30 large offshore sand ridges. Most ridges are 1 to 2 miles long but a few extended more than 4 miles (Figure 6-21). About 60 vibracores (2 vibracores per sand ridge), possibly supplemented by jet probes, should provide sufficient information to evaluate the sand resource potential of this area. The location of the recommended study area, existing historical data, and axes of the main sand ridge are illustrated in Figure 6-21.

Three locations within Area 3 have been selected for analysis. These are labeled Area 3A, 3B and Area 3C (Figure 6-22). Several tracklines cross sand ridges in these areas (Figure 6-23). In Area 3A there are 3 tracklines from the Bellows N 1994 cruise (Locker et al.), Line 1 at timestamp 126, Line 4 at timestamp 6 and Line 18 at timestamp 2232. Line 14-1 and Line 14-2 from the Southwest Gulf Coast Regional Sand Search project will also be shown. In Area 3B Line 10 from the Southwest Gulf Coast Regional Sand Search project will be looked at and for Area 3C 4 lines from the Southwest Gulf Coast Regional Sand Search project are shown. These are Lines 26B, 27, 30 and 31.

<u>Area 3A</u>

Figures 6-24 through 6-26 show the sub-bottom images for Area 1A from the 1994 Bellows cruise. Each of these images shows sand ridges (red oval). Figures 6-27 and 6-28 from the Southwest Gulf Coast Regional Sand Search project also show sand ridges. In all of these images except for Line 1, the direction of travel is perpendicular to the ridges. Line 1 intercepts the very end of the ridge at an oblique angle.

There are six grab samples found in this vicinity (Figure 6-29). Five are from the City of Venice Beach Nourishment Project, Environmental Study and are M-2, M-3, M-5, M-11 and M-12. Mean grainsize in phi are 0.98, 0.22, 0.32, 0.32 and 0.41 respectively. One grab sample from the Inner West-Central Florida Continental Shelf study, N-19 has a mean grain size in phi of 0.-62. These means correspond to medium sand using the USCS (see Table 6-5).

Area 3B

Figures 6-30 and 6-31 show the geophysical images from Lines 10-1 and 10-2 which cross the sand ridges. The images show the ridges, labeled 1 through 5. These images have also been annotated to show the lateral and vertical extent of the sand bodies and also the denser reflectors beneath the sand.

There are no vibracores, jet probes or grab samples in this vicinity.

Area 3C

Figures 6-32 through 6-35 shows the sub-bottom profiles for Area 3C. As with the previous images from the ROSS cruise, these tracklines are perpendicular to the ridges. These images have also been annotated to show the sand bodies and the more dense reflectors beneath them.

There are no vibracores, jet probes or grab samples in this vicinity.

6.3 SOUTHERN COASTAL SEGMENT

6.3.1 Area 4 – Sand Resources in Lee County

Several beaches, identified as critical erosion areas by the FDEP, occur on Gasparilla Island, Captiva Island, Sanibel Island, Estero Island, and Lovers Key. These beaches have been nourished in the past using a combination of sand resources from offshore sand ridges and nearshore ebb-tidal deltas. Beaches occurring to the north of Lee County may benefit from the exploration of potential large volumes of sand stored offshore from Boca Grande Pass. Clean white-colored sandy sediments from a sand ridge located adjacent to the outer lobe of this ebb-tidal delta were recently used to nourish Captiva Island.

Several shore-oblique sand ridges offshore Captiva and Sanibel Islands exist from 2.5 to about 14 miles offshore. Some of these ridges were previously dredged to nourish Captiva, Sanibel and Estero Islands (see ridges that are densely vibracored in Figure 6-36). Similar to the Manatee-North Sarasota Area (Study Area 2), screening of sand ridges was previously based on the analysis of limited surface samples and jet probes. As a consequence, sedimentary properties in some sand ridges may be unknown. Some ridges were investigated by detailed vibracore survey to define borrow areas for dredging (Figure 6-36) but many ridges still remain relatively unexplored. Due to the increasing needs of good quality sand along this coastal segment, further investigations of the relatively unexplored ridges are recommended.

Interpretation of NOAA bathymetry identified about 28 ridges for further investigation as seen in Figure 6-36. White lines in Figure 6-36 indicate the main axes of ridges that are recommended for further investigation. The axes of sand ridges that were studied in prior vibracore surveys were not digitized and are excluded from further consideration. In order to asses sand resources in this area, we recommend a reconnaissance investigation with widely spaced geophysical lines (to locate current ridge crests and determine dimensions) and one to four vibracores per ridge.

Two locations within Area 4 have been selected for analysis. These are Area 4A and Area 4B (Figure 6-37). Although there is no geophysical data for these two areas, it is possible to get an understanding of the make up of the sand contained in these ridges from jet probe and grab sample data.

Data contained in the ROSS database shows there are 3 jet probes taken on sand ridges in Area 4A (Figure 6-38). These are from the Captiva and Sanibel Islands Renourishment Project and are named CIJP-00-8, CIJP-00-11 and CIJP-00-12. Data from these probes, found in Table 6-6, shows these ridges are made up of fine to medium sand to a depth of approximately 6 feet.

Two jet probes, JP22-1 and JP23-1, from the Estero Island and Lovers Key Offshore Sand Source Investigation were taken in Area 4B (Figure 6-39). Data from these probes (Table 6-7) shows that JP22-1 is mostly silty sand to a depth of approximately 5 feet, and JP23-1, is mostly sand to a depth of about 2 feet.

Three grab samples, EI 27, EI 29 and EI 30, from the same study (Figure 6-39), show mean grain sizes of 0.76, 0.67 and 0.82 phi respectively (Table 6-7). These means correspond to medium sand using the classification of the USCS.

6.3.2 Area 5 – Sand Resources in Collier County

Critically eroded areas in Collier County, as identified by the FDEP, mostly occur in the City of Naples and on Marco Island. Most previous sand search investigations on the inner shelf offshore Collier County suggested that offshore sand sources are extremely limited. As a result, the proposed borrow area for the next Collier County renourishment project is a sand ridge commonly known as "Tom's Hill", located about 30 miles to the north in Federal Waters. Although prior studies suggested that sand resources are scarce, some areas remain unexplored. Depositional areas interpreted from NOAA bathymetry and the ROSS database are discussed as follows.

Historic reconnaissance sampling data indicates that some deposits located further offshore Marco Island in the south part of the County may contain relatively thick (*i.e.* greater than 10 ft) sediment accumulations that require further investigation (see ridge lines in Figure 6-40). Low-relief sand ridges located offshore from the City of Naples have been explored in detail in previous sand search efforts (see vibracores in the center of Figure 6-40) and are not recommended for additional investigation. Previous investigations suggested that the Cape Romano Shoals are potential sand resources for nourishment of Collier County beaches. These shoals, however, were not considered for recent renourishment projects because they: (1) are located in shallow water (*i.e.* less than 3 ft in some areas) which makes dredging difficult and expensive due to restricted access and (2) contain finer-grained sediments than sand resources further offshore. Although these shoals are not now economically attractive as sand resources, they may become viable in future as the need for sand increases. Additionally, it is possible that portions of the Cape Romano shoal complex may be located in deeper water and found to contain coarser sediments. This hypothesis, however, requires further investigation. Because relatively large quantities of sand are stored in the Capri and Big Marco Pass ebb-tidal delta complex, these areas may be able to supply nourishment needs in southern Collier County for the next few renourishment cycles.

Two areas in Area 5 have been selected that need further investigation. These are labeled Area 5A and Area 5B (Figure 6- 41). Area 5A is located between the 20 ft and 30 ft isobaths. As can be seen on Figure 6-40, there is a county-wide segment of the inner-shelf (about 2.5 miles wide) where no bathymetric data is available. Some sand ridges may occur in this area. Bathymetric investigations to fill this data gap are strongly recommended. Because historic bathymetric coverage is also poor in the southern part of the county, near the Cape Romano Shoals, this area is also recommended for bathymetric survey (Figure 6-40). Area 5B is located southwest of Cape Romano (Figure 6-41). In this area, additional reconnaissance vibracores are recommended for ridge areas located offshore of Marco Island (white lines in Figure 6-40). Selection of sediment ridges for additional sampling with reconnaissance vibracores over the rest of the inner continental shelf should be conducted only after the new bathymetric data is obtained, processed, and analyzed.

6.4 POTENTIAL SAND RESOURCE VOLUMES WITHIN PROPOSED INVESTIGATION AREAS

Definitions of mineral reserves, resources, and certainty of assessment, as adopted by the U.S. Bureau of Mines and U.S. Geological Survey in 1980 (SME, 2005) used in the definition of the sand resources are presented in this document. As a regional resource assessment study this inner shelf area was evaluated in terms of the likelihood of the occurrence of sand deposits (resources) within known geomorphological features (*e.g.* offshore ridges). The likelihood of occurrence is not an accurate measure of the resources themselves but a probabilistic statement within a range of error.

A *resource* is a concentration of naturally occurring material in or on the Earth's crust in such form that economic extraction is now feasible or at some time in the future. A *reserve*, on the other hand is the portion of the resource that can be economically and legally extracted at the time of determination. Volumes presented in this section are *potential sand resource volumes* contained within large areas of the seabed. Actual sand reserve volumes (*i.e.* dredgable borrow areas) will be significantly smaller than the volumes calculated during regional sand resource assessment studies. Information in the ROSS database allows for definition of sand resources. Further detailed geophysical, geotechnical and environmental studies will determine the final sand reserves (borrow areas) that can be economically and legally dredged.

During this regional sand resource assessment study, five investigation areas covering a large expanse of the seabed were delineated for further investigation. The five investigation areas combined occupy 535,000 acres of the seabed. One hundred and twenty four (124) potential sand deposits that have limited or no geotechnical and geophysical investigation were identified within these five areas. About 500 million cy of sandy sediments are potentially available in these resource areas when a flat cut of 3 ft is assumed. Summarized data for the sand resource areas is presented in Table 6-8.

6.5 FINAL CONSIDERATIONS

Based on the analysis and interpretation of historical bathymetric and geological data in the ROSS database, five areas along the southwest coast of Florida were selected for geotechnical and geophysical investigations. The areas are strategically located near FDEP-identified critically eroded areas and are potential long-term sand resources for the maintenance of these eroding beaches. Within each of these areas, sub-areas have been selected for current data review. These reviews make use of data in the ROSS database that includes bathymetry, geophysical data and granulometry.

Reconnaissance investigations are recommended for future study from new bathymetric surveys (to update decades old NOAA bathymetry) and seismic surveys to identify ridge dimensions and crest locations. Widely spaced vibracores (*i.e.* 1 to 4 vibracores per ridge) can be used to characterize sediment thickness and textural properties. These additional investigations should provide sufficient information to evaluate areas that may be able to provide long-term sand resources along the southwest coast of Florida and provide a framework for future, more detailed, borrow area design studies.

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Appendix I

Working Example Using The ROSS Query Builder

Appendix II

West Coast Of Florida – Geology, Evolution, Geomorphology And Sand Resources

Appendix III

Glossary

TABLES

Table 3-1 Submarine Physiographic Units on the Inner West Florida Shelf Along the Central West Coast of Florida

Physiographic Province	Morphometry	Description	Comments/Source
West Florida Shelf (WFS)	Distally steepened carbonate ramp that extends 250 km into the Gulf from the barrier island shoreline, 1:2000 (< 20-m isobath) to 1:5000 (> 20-m isobath) gradient, carbonate and siliciclastic veneer a few cm to 4 m thick.	Low energy, low gradient, microtidal, sediment-starved inner continental shelf with coarse carbonate sediments, finer-grained quarts-dominated sediments, and limestone bedrock (hardbottom).	Doyle and Sparks (1980), Hine *et al.* (2003, Obrochta *et al.* (2003), Locker *et al.* (2003), Brooks *et al.* (2003)
< 5 km offshore (Shoreface, nearshore zone, < 8 m isobath)	< 50% of WFS is hardbottom, shorefacing, scarped hardbottoms, 330-0° azimuth, LR < 4 m, 2-4 m km^{-1} gradient in nearshore zone, gradients steepest near ebb-tidal deltas (> 4 m km^{-1}) isobaths parallel to shore.	Shoreface connected sand sheets, sand ridges, sand waves, bars overlying limestone bedrock (hardbottom).	Obrochta *et al.* (2003), Locker *et al.* (2003), Brooks *et al.* (2003)
> 5 km offshore (Inner Shelf, > 8 m isobath)	> 50% of WFS is hardbottom, < 1:5000 gradient, complex isobaths.	Complex patterns of shoreface detached sand ridges, gravel troughs, sand sheets, hardbottoms.	Obrochta *et al.* (2003), Locker *et al.* (2003),
Ridge Fields			
Anclote	Ridges 0.5 to 1 km wide, 1-14 km long, 290° azimuth, 3 to 20 km from shore.	Well developed ridges.	This work
Sand Key	Ridges 1.0-1.5 km wide, 1-10 km long, LR 1-4 m, 330° azimuth < 5 km from shore, 310° azimuth > 5 km from shore.	Well developed ridges.	Ashley (1990), Edwards *et al.* (2003), Hafen, (2001), Harrison *et al.* (2003)
Sarasota	Ridges 1-4 km wide, 3-10 km long, LR 1-4 m, 200° to 230° azimuth, $CaCO_3$ 20-60% SE side of ridges.	Poorly developed ridges, extensive hardgrounds.	Twichell *et al.* (2003)
Manasota	Ridges, 0.5 to 1 km wide, 1-6 km long, 345° azimuth, 3 to 13 km from shore.	Well developed ridges.	Finkl, Andrews & Benedet (2006)
Captiva	Ridges, 0.5 to 1.3 km wide, 1-7 km long, 345° azimuth, 5 to 25 km from shore.	Well developed ridges.	Finkl, Andrews & Benedet (2006)
Collier	Ridges, 0.2 to 1 km wide, 1-5 km long, 345° azimuth north segment, 240° azimuth south segment, 8 to 20 km from	Well developed ridges, there may be additional ridges closer to the shore but data is lacking.	This work

Physiographic Province	Morphometry	Description	Comments/Source
	shore.		
Rock Platform – Sand Sheet Complex	Flat lying and scarped limestone rock outcrop starting in 5-8 m water depth, LR 4 m, > 1 m undercuts (ledges), mean grain sizes range from -1.4F (2.9 mm) to 5 F (0.03 mm, coarse silt) but most fall between 0F (coarse sand) and 3F (fine sand).	Hardgrounds (phosphate-rich, mixed carbonate-siliciclastic lithofacies from Miocene to Quaternary in age, with variable sedimentary cover, thin discontinuous sedimentary veneer.	Brooks *et al*. (21003), Edwards *et al*. (2003), Locker *et al*. (2003)
Shoreface-Attached Sand Sheets	Relatively flat sand sheets, generally 0.5 to 5 km wide but up to 10 km near Anclote Key, <4 m thick.	Sandy sediments interspersed by hardgrounds, sand thickness decrease towards the offshore from the modern beach.	This work
Transverse Bars	Extend 3 km along coast, 4 km in cross-shore direction, come within 75 m of shoreline, average wavelength 75-120 m, 2.0 m amplitude.	Well-sorted fine quartz sand < 10% $CaCO_3$ in bars overlying basal 0.5 m fine sand with shells, troughs poorly sorted $CaCO_3$ gravel (> 90% shell fragments).	Gelfenbaum and Brooks (2003)
Barrier Island Platforms Sands	Platforms 1 to 7 km wide, up to 10 m thick.	Perched barrier islands, siliciclastic sediments.	Locker et al. (2003), Riggs *et al*. (1995), Stapor (1991)
Ebb-Tidal Delta Complexes	Anclote Pass, Hurricane Pass, Clearwater Pass, John's Pass, Blind Pass, Bunces Pass, Egmont Channel, Southwest Channel, Passage Key Inlet, Longbaot Pass, New Pass, Big Sarasota Pass, Midnight Pass (closed), Venice Inlet, *etc.*	Modern and relict deltas.	Davis *et al*. (2003)

Table 6-1 AREA 1A							
Sand Query ResultsProject Name	Core Identifier	Core Top Elevation	Core Layer Identifier	Bottom of Layer Interval	Top of Layer Interval	Core Layer Color	Core Layer Qualifiers
Inner West-Central Florida Continental Shelf	COE-94-1(2)	28.2	COE-94-1(2).1	8	0	TAN	mostly Fine Quartz Sand; trace Shell
Inner West-Central Florida Continental Shelf	COE-94-1(2)	28.2	COE-94-1(2).2	9.5	8		mostly Shelly Sand; little Fine Sand
Inner West-Central Florida Continental Shelf	COE-94-1(2)	28.2	COE-94-1(2).3	10.5	9.5		mostly Carbonate Granule; little Sand
Inner West-Central Florida Continental Shelf	COE-94-2(2)	23.5	COE-94-2(2).1	6.1	0	GRAY	mostly Fine To Medium Quartz Sand; trace Shell
Inner West-Central Florida Continental Shelf	COE-94-3(2)	23.4	COE-94-3(2).1	4.6	0	GRAY	mostly Quartz Sand
Inner West-Central Florida Continental Shelf	COE-94-3(2)	23.4	COE-94-3(2).2	5.3	4.6		mostly Carbonate Granule; little Fine Sand

Sand Query ResultsProject Name	Collection Method	Sample Identifier	Bottom Of Sample Interval	Mean	PCT Fines
Inner West-Central Florida Continental Shelf	Grab Sample	J-17		0.64	0.64

Table 6-2 AREA 1B							
Sand Query ResultsProject Name	Core Identifier	Core Top Elevation	Core Layer Identifier	Bottom of Layer Interval	Top of Layer Interval	Core Layer Color	Core Layer Qualifiers
WEST-CENTRAL FLORIDA COASTAL STUDIE	COE-94-11(2)	-14	11A	3	0	DARK GR/	mostly Quartz Sand
WEST-CENTRAL FLORIDA COASTAL STUDIE	COE-94-12	-19.8	12A	4.9	0	TAN	mostly Fine To Medium Quartz Sand
WEST-CENTRAL FLORIDA COASTAL STUDIE	COE-94-12	-19.8	12B	5.9	4.9		mostly Carbonate Gravel
WEST-CENTRAL FLORIDA COASTAL STUDIE	COE-94-14	-11.8	14A	2.6	0	DARK GRA	mostly Fine To Medium Quartz Sand
WEST-CENTRAL FLORIDA COASTAL STUDIE	COE-94-17(2)	-10.7	17A	7.2	0	GRAY	mostly Fine Quartz Sand

Sand Query ResultsProject Name	Collection Method	Sample Identifier	Bottom Of Sample Interval	Mean	PCT Fines
Inner West-Central Florida Continental Shelf	Grab Sample	J-46		2.18	1.34
Inner West-Central Florida Continental Shelf	Grab Sample	J-47		1.97	9.36

Table 6-3 AREA 2A									
Sand Query ResultsProject Name	Collection Method	Core Identifier	Core Top Elevation	Core Layer Identifier	Bottom of Layer Interval	Top of Layer Interval	Core Layer Qualifiers	Sample Identifier	Mean
Inner West-Central Florida Continental Shelf	Vibracore	USGS-95-16	26	USGS-95-16	6.3	0	mostly Quartz Sand		
Inner West-Central Florida Continental Shelf	Vibracore	USGS-95-51B	26	USGS-95-51B.1	0.6	0	mostly Shelly Sand		
Inner West-Central Florida Continental Shelf	Vibracore	USGS-95-51B	26	USGS-95-51B.2	2.6	0.6	mostly Quartz Sand		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-25	-25	25-1	0.7	0	mostly Silt		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-25	-25	25-2	2	0.7	mostly Fine Sand		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-25	-25	25-3	3	2	mostly Rock Fragments		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-25	-25	25-4	12	3	mostly Sand; some Silt		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-26	-26	26-1	7	0	mostly Fine Sand		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-34	-28	34-1	17	0	mostly Fine Sand	LBK-34MID	2.02
Longboat Key White Sand Search Investigations	Jet Probe	LBK-35	-26	35-1	17	0	mostly Fine Sand	LBK-35MID	2.58

Sand Query ResultsProject Name	Collection Method	Sample Identifier	Bottom Of Sample Interval	Mean	PCT Fines
Inner West-Central Florida Continental Shelf	Grab Sample	J-58		2.91	4.21
Inner West-Central Florida Continental Shelf	Grab Sample	J-62		2.72	1.47
Inner West-Central Florida Continental Shelf	Grab Sample	N-3		2.81	1.13

Table 6-4 AREA 2B									
Sand Query ResultsProject Name	Collection Method	Core Identifier	Core Top Elevation	Core Layer	Bottom of Layer	Top of Layer	Core Layer Qualifiers	Sample Identifier	Mean
Longboat Key White Sand Search Investigations	Jet Probe	LBK-15	-41.2	15-1	6	0	mostly Fine Sand	LBK-15MID	2.99
Longboat Key White Sand Search Investigations	Jet Probe	LBK-15	-41.2	15-2	7	6	mostly Rock Fragments		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-15	-41.2	15-3	8	7	mostly Fine Sand		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-15	-41.2	15-4	9	8	mostly Rock		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-17	-39	17-1	7	0	mostly Fine Sand; little Shell Hash	LBK-17MID	2.47
Longboat Key White Sand Search Investigations	Jet Probe	LBK-17	-39	17-2	8	7	mostly Rock		
Longboat Key White Sand Search Investigations	Jet Probe	LBK-20	-35.2	20-1	6	0	mostly Fine Sand	LBK-20MID	3.07
Longboat Key White Sand Search Investigations	Jet Probe	LBK-20	-35.2	20-2	7	6	mostly Rock		

Sand Query ResultsProject Name	Collection Method	Sample Identifier	Bottom Of Sample Interval	Mean	PCT Fines
Inner West-Central Florida Continental Shelf	Grab Sample	N-40		3.29	5.05

Table 6-5 AREA 3A					
Sand Query ResultsProject Name	Collection Method	Sample Identifier	Bottom Of Sample Interval	Mean	PCT Fines
City of Venice Beach Nourishment Project, Environmental Study	Grab Sample	M-2	0.5	0.98	1.23
City of Venice Beach Nourishment Project, Environmental Study	Grab Sample	M-3	0.5	0.22	1.39
City of Venice Beach Nourishment Project, Environmental Study		M-5	0.5	0.32	6.55
City of Venice Beach Nourishment Project, Environmental Study	Grab Sample	M-11	0.5	0.32	1.11
City of Venice Beach Nourishment Project, Environmental Study	Grab Sample	M-12	0.5	0.41	1.01
Inner West-Central Florida Continental Shelf	Grab Sample	N-19		-0.62	1.18

Table 6-6 AREA 4A										
Sand Query Results Project Name	Core Identifier	Core Top Elevation	Core Layer Identifier	Bottom of Layer Interval	Top of Layer Interval	Core Layer Munsell	Sample Identifier	Top Of Sample Interval	Bottom Of Sample Interval	Mean
Captiva and Sanibel Islands Renourishment Project	CIJP-00-12	-29.1	12A	6	0	5Y 6/1	CIJP-00-12 BOT	0	6	1.16
Captiva and Sanibel Islands Renourishment Project	CIJP-00-12	-29.1	12A	6	0	5Y 6/1	CIJP-00-12 MID	0	3	1.06
Captiva and Sanibel Islands Renourishment Project	CIJP-00-12	-29.1	12A	6	0	5Y 6/1	CIJP-00-12 TOP	0	0.5	0.93
Captiva and Sanibel Islands Renourishment Project	CIJP-00-11	-27.2	11A	5	0	5Y 5/1	CIJP-00-11 BOT	0	5	1.58
Captiva and Sanibel Islands Renourishment Project	CIJP-00-11	-27.2	11A	5	0	5Y 5/1	CIJP-00-11 MID	0	2.5	0.88
Captiva and Sanibel Islands Renourishment Project	CIJP-00-11	-27.2	11A	5	0	5Y 5/1	CIJP-00-11 TOP	0	0.5	0.53
Captiva and Sanibel Islands Renourishment Project	CIJP-00-08	-24	8A	6	0	5Y 7/1	CIJP-00-08 TOP	0	0.5	2.48
Captiva and Sanibel Islands Renourishment Project	CIJP-00-08	-24	8B	10	6	5Y 7/1	CIJP-00-08 BOT	0	10	2.55
Captiva and Sanibel Islands Renourishment Project	CIJP-00-08	-24	8A	6	0	5Y 7/1	CIJP-00-08 BOT	0	10	2.55
Captiva and Sanibel Islands Renourishment Project	CIJP-00-08	-24	8A	6	0	5Y 7/1	CIJP-00-08 MID	0	5	2.44

Table 6-7 AREA 4B												
Sand Query ResultsProject Name	Core Identifier	Core Top Elevation	Core Layer Identifier	Bottom of Layer Interval	Top of Layer Interval	Core Layer Qualifiers	Sample Identifier	Top Of Sample Interval	Bottom Of Sample Interval	Grab Elevation	Sample Munsell (Dry)	Mean
Estero Island and Lovers Key Offshore Sand Source Investigation	EST-JP-22	-30	JP22-1	5	0	mostly Silty Sand	JP#22 TOP	0	0.5	-30	5Y 7/1	2.53
Estero Island and Lovers Key Offshore Sand Source Investigation	EST-JP-22	-30	JP22-1	5	0	mostly Silty Sand	JP#22 MID	0	2.5	-32	5Y 6/1	1.14
Estero Island and Lovers Key Offshore Sand Source Investigation	EST-JP-22	-30	JP22-1	5	0	mostly Silty Sand	JP#22 BOTT	0	5	-34	5Y 6/1	0.72
Estero Island and Lovers Key Offshore Sand Source Investigation	EST-JP-23	-34.5	JP23-1	2	0	mostly Sand	JP#23 TOP	0	0.5	-34.5	5Y 5/1	0.72
Estero Island and Lovers Key Offshore Sand Source Investigation	EST-JP-23	-34.5	JP23-1	2	0	mostly Sand	JP#23 MID	0	1	-35.5	5Y 5/1	0.83
Estero Island and Lovers Key Offshore Sand Source Investigation	EST-JP-23	-34.5	JP23-1	2	0	mostly Sand	JP#23 BOTT	0	2	-36.5	5Y 5/1	0.78
Estero Island and Lovers Key Offshore Sand Source Investigation							EI#27			-32.5	5Y 5/1	0.76
Estero Island and Lovers Key Offshore Sand Source Investigation							EI#29			-32	5Y 5/1	0.67
Estero Island and Lovers Key Offshore Sand Source Investigation							EI#30			-31.5	5Y 6/1	0.82

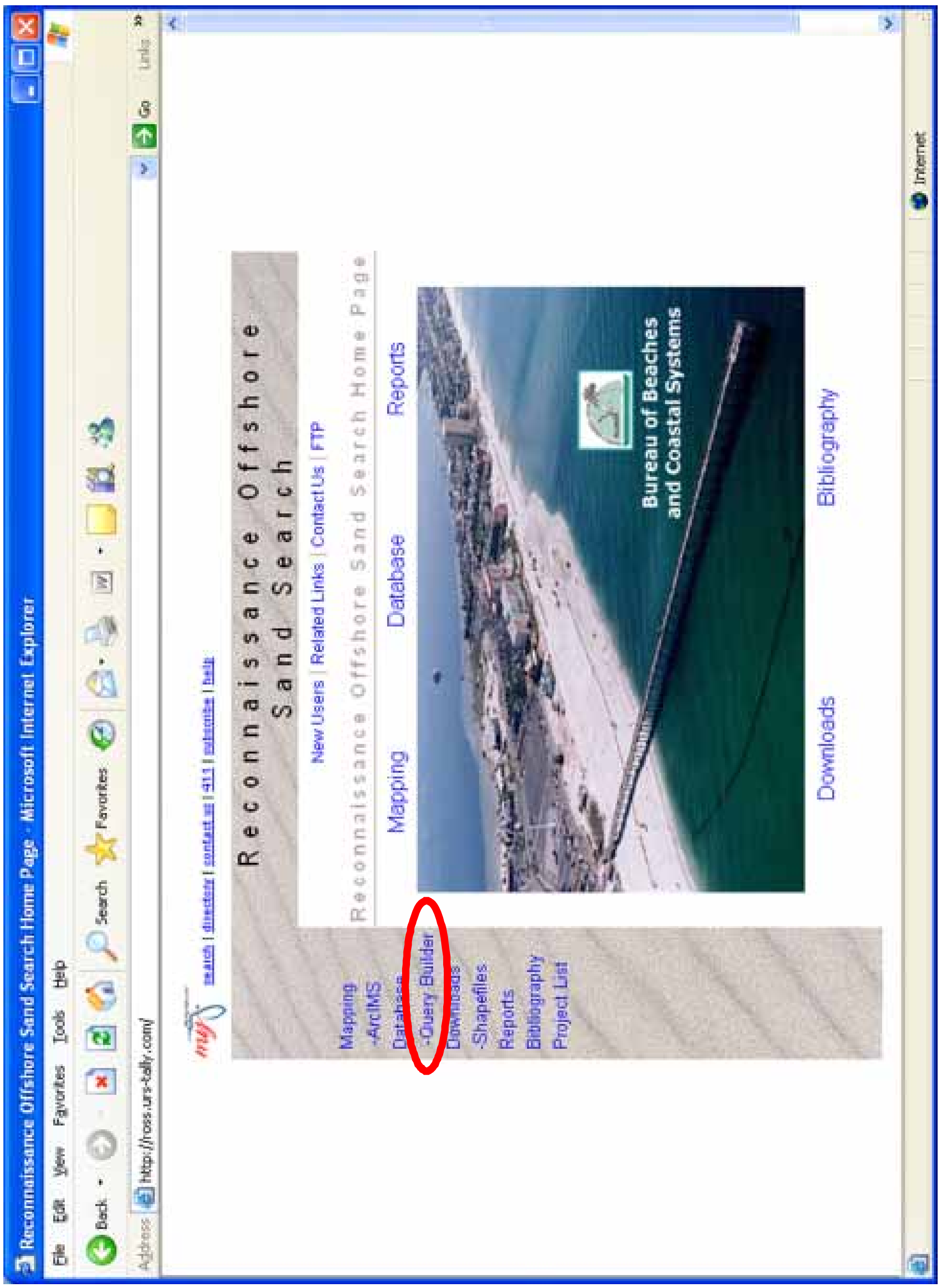
Table 6-8. Potential sand resource volumes estimated within five regional study areas along the southwest coast of Florida.

	Number of Potential Sand Ridges	Total Area (acres)	Potential Sand Resource Volume (cy) (3 ft cut)	Potential Sand Resource Volume (cy) (6 ft cut)	Potential Sand Resource Volume (cy) (9 ft cut)
Area 1	30	23,640	114,420,000	228,830,000	343,250,000
Area 2	24	25,442	123,140,000	246,280,000	369,410,000
Area 3	30	25,330	122,600,000	245,200,000	367,800,000
Area 4	28	21300	103,030,000	206,070,000	309,100,000
Area 5	12	8,400	40,640,000	81,290,000	121,930,000
Total	*124*	*104,112*	*503,830,000*	*1,007,670,000*	*1,511,490,000*

Figures

Figure 1-1. The ROSS Home Page

Figure 2-1. Link to the Enhanced Query Builder



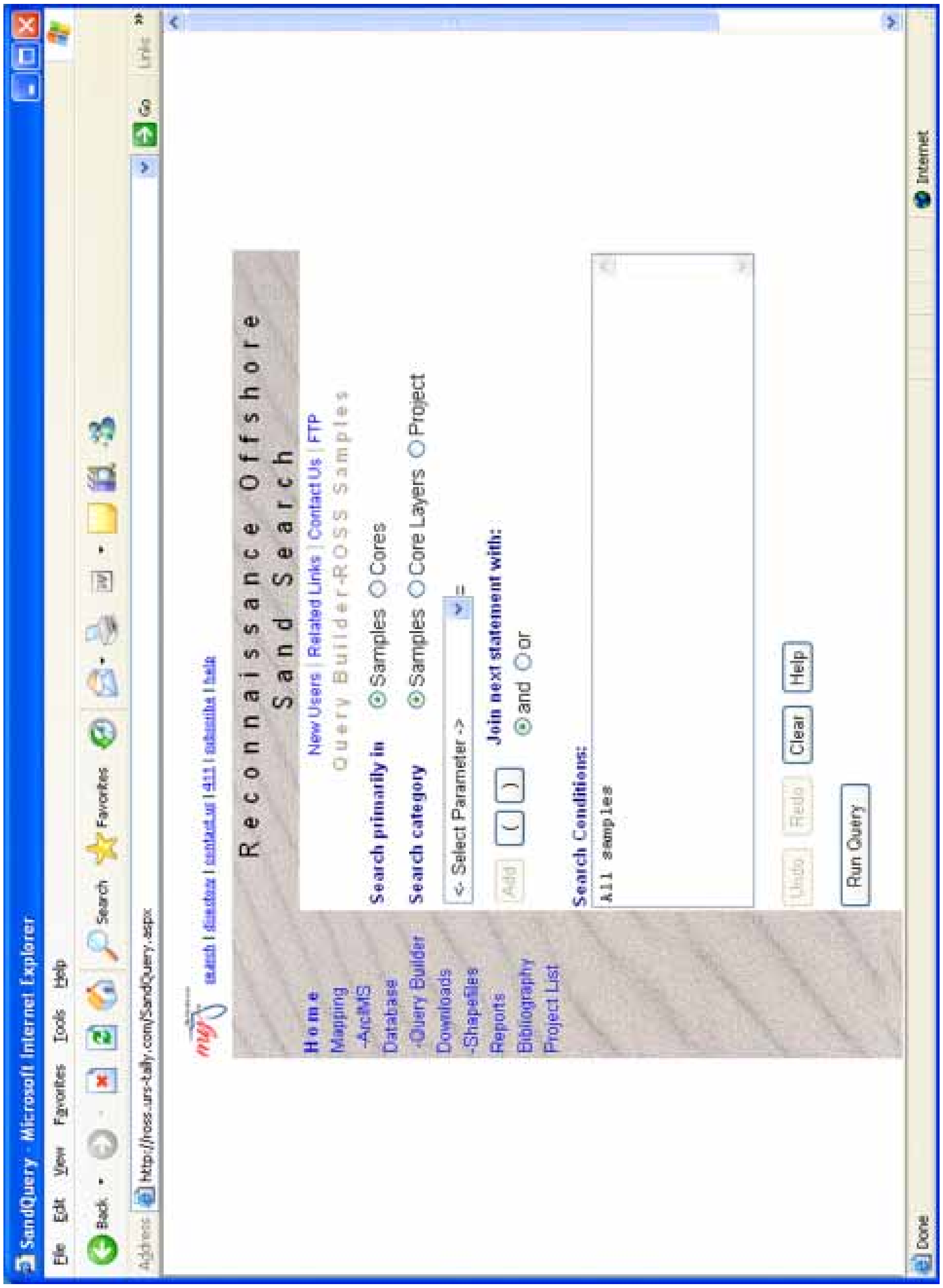
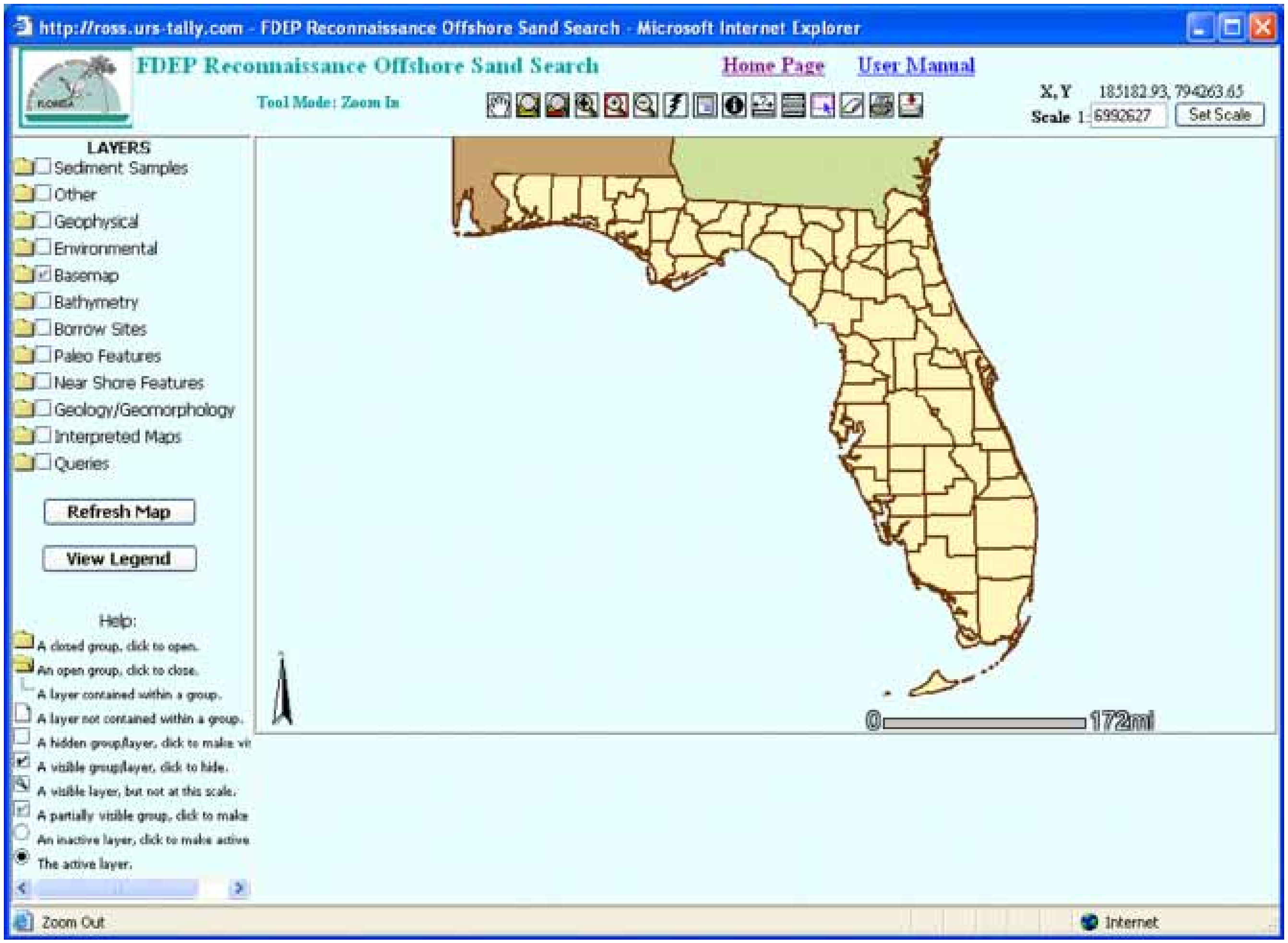


Figure 2-2. The Enhanced Query Builder.

Figure 2-3. The ROSS ARCIMS page.



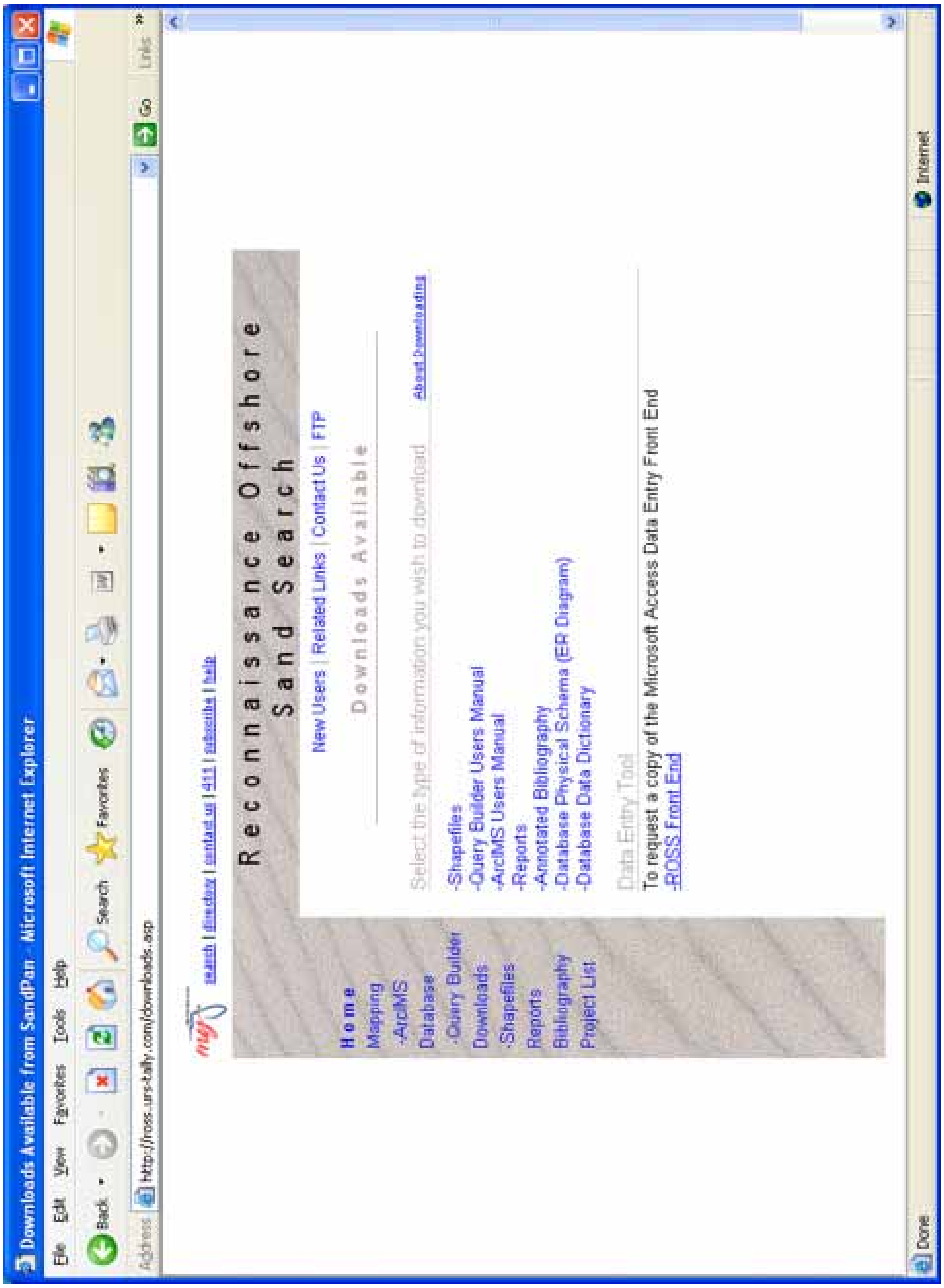


Figure 2-4. The ROSS Downloads page.

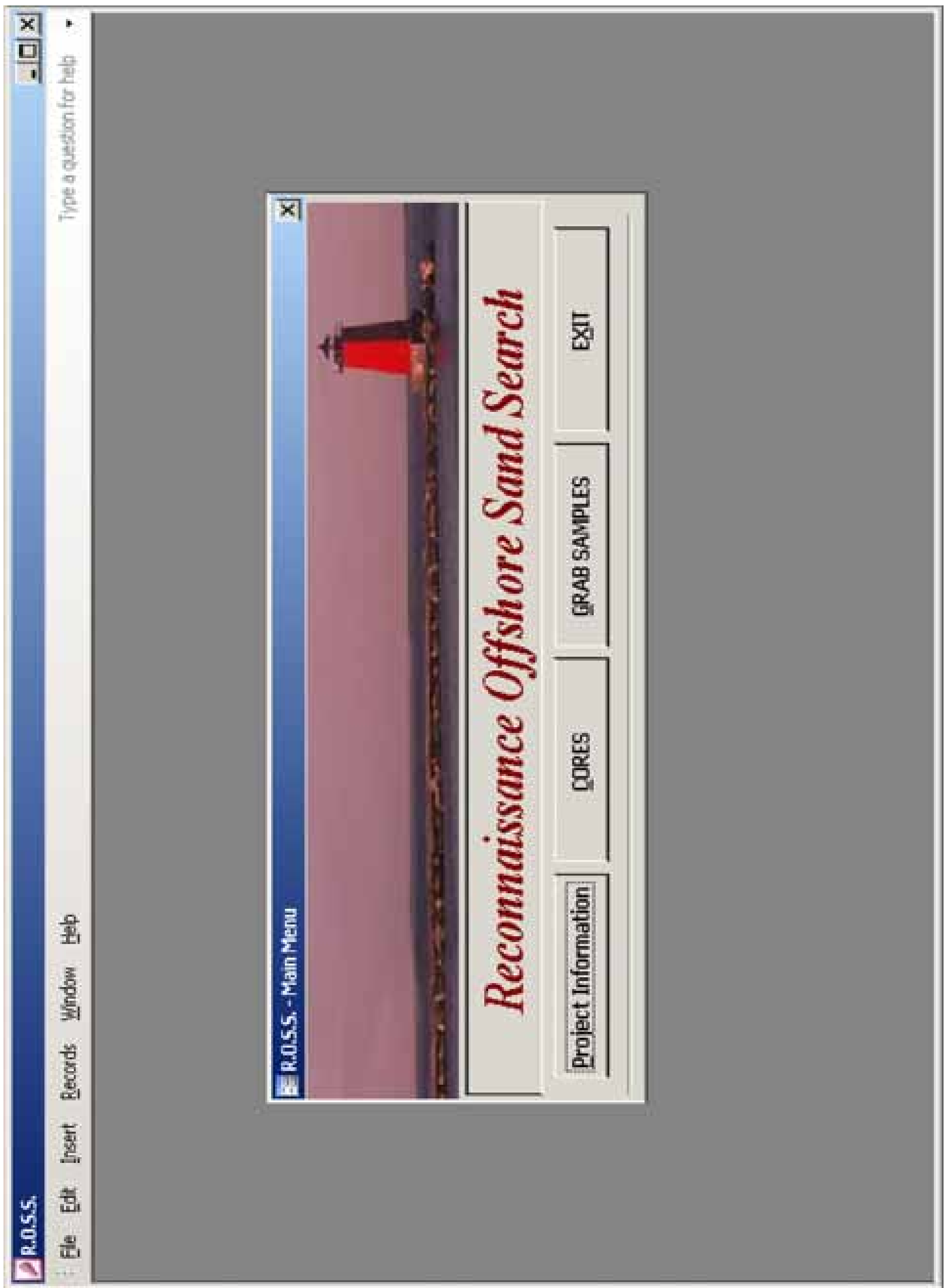


Figure 2-5. The Access Front End page.

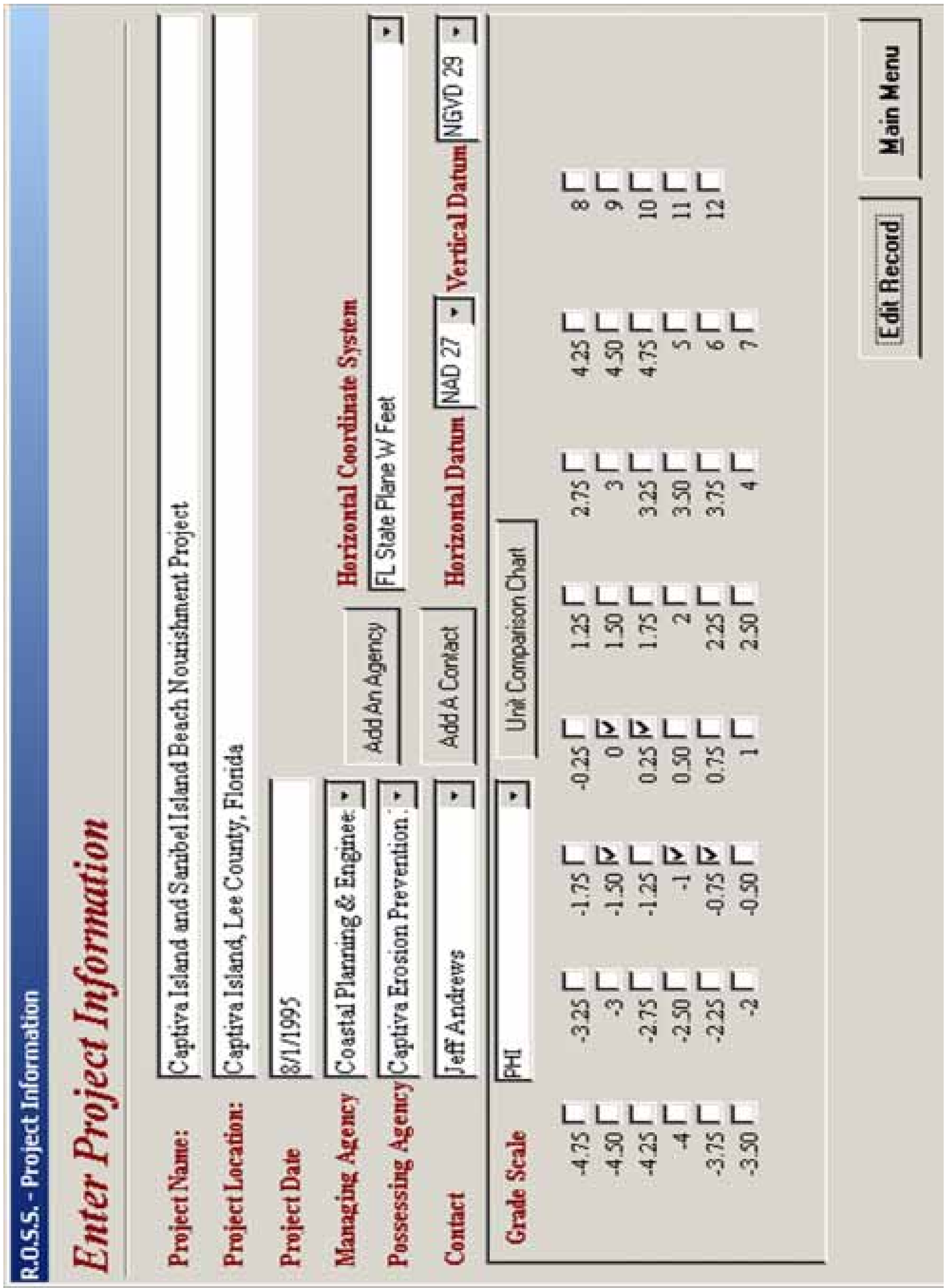


Figure 2-6. The Project Information page.

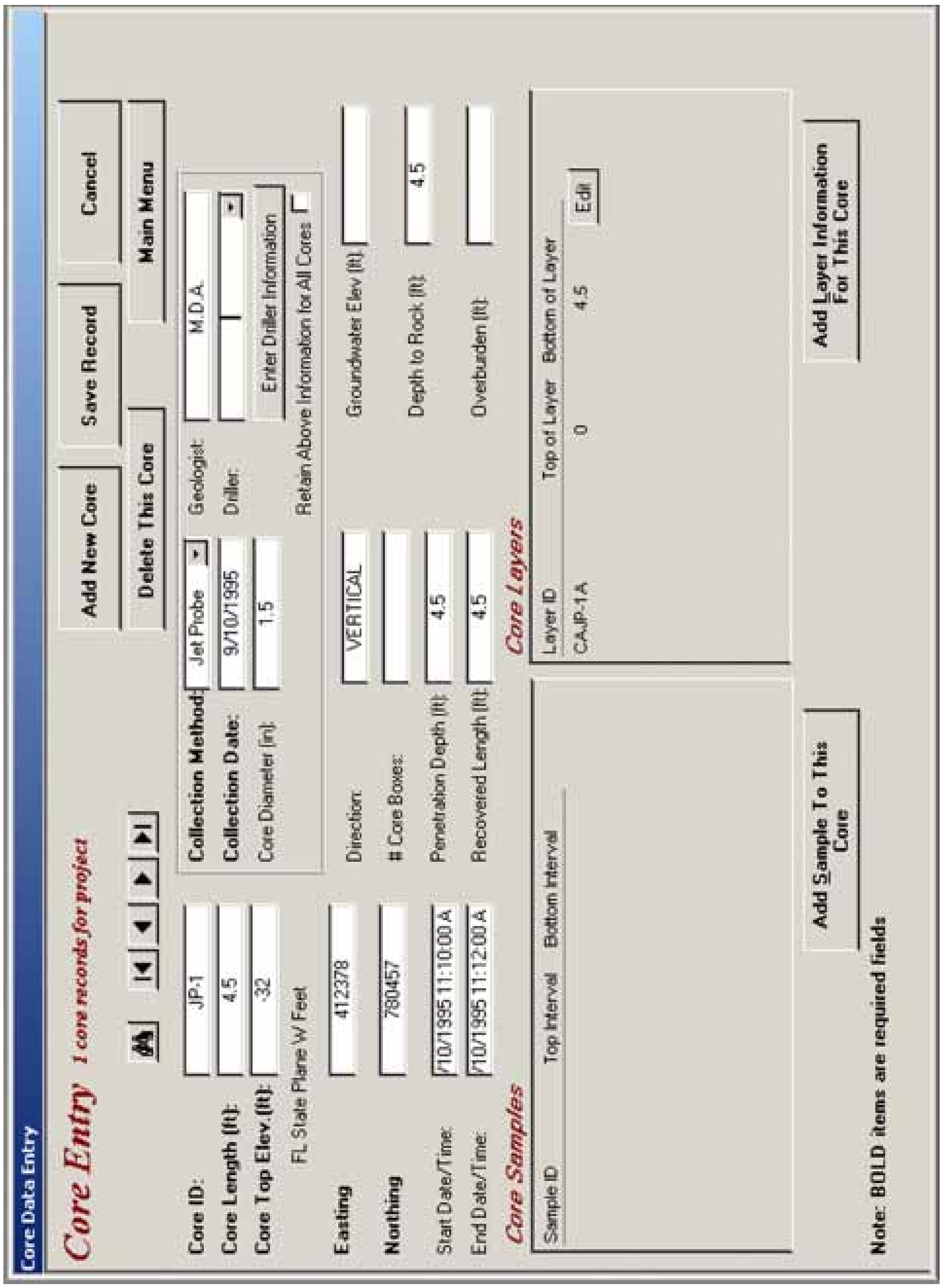


Figure 2-7. The Core Entry page.

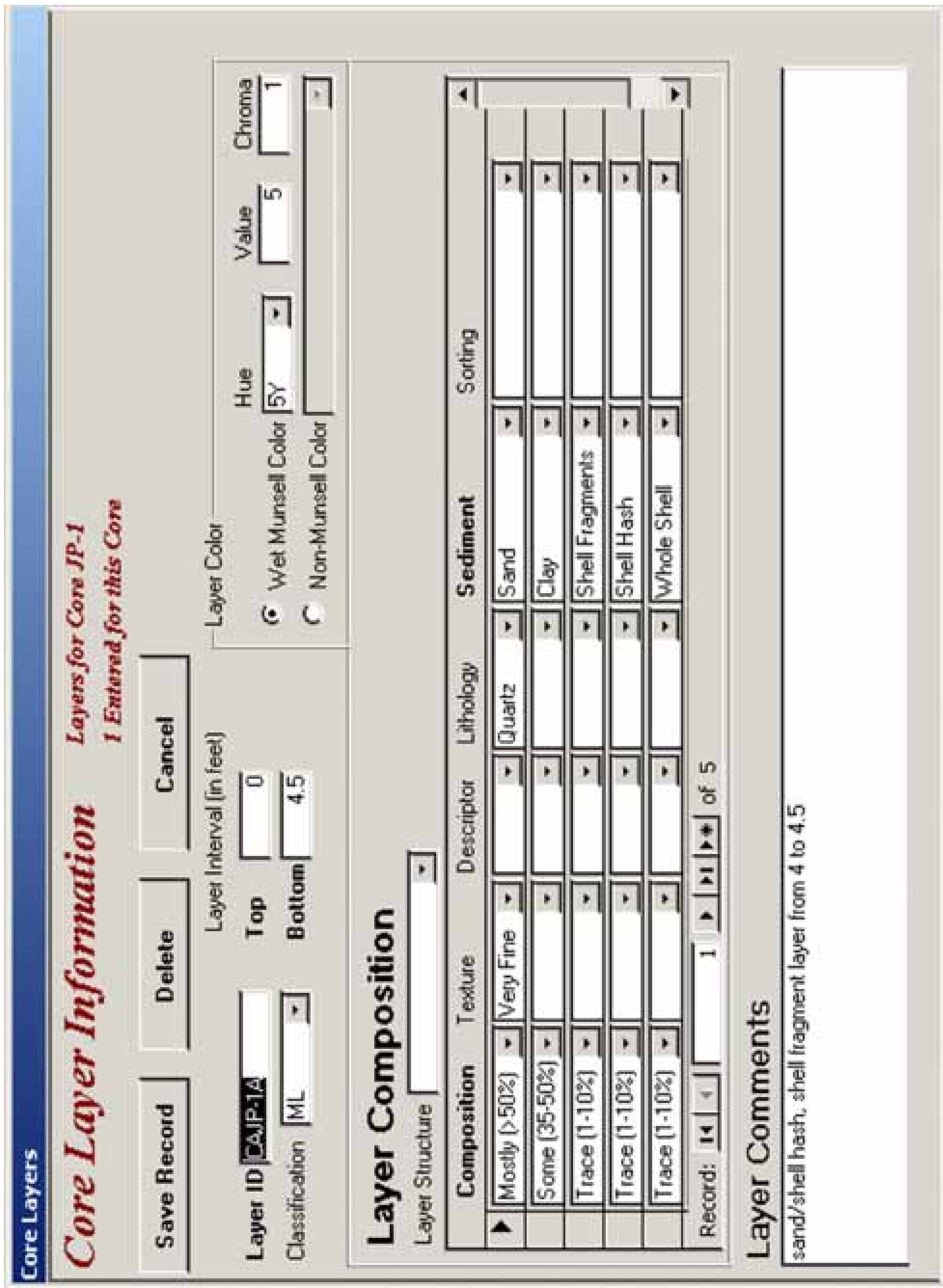


Figure 2-8. The Core Layers Information page.

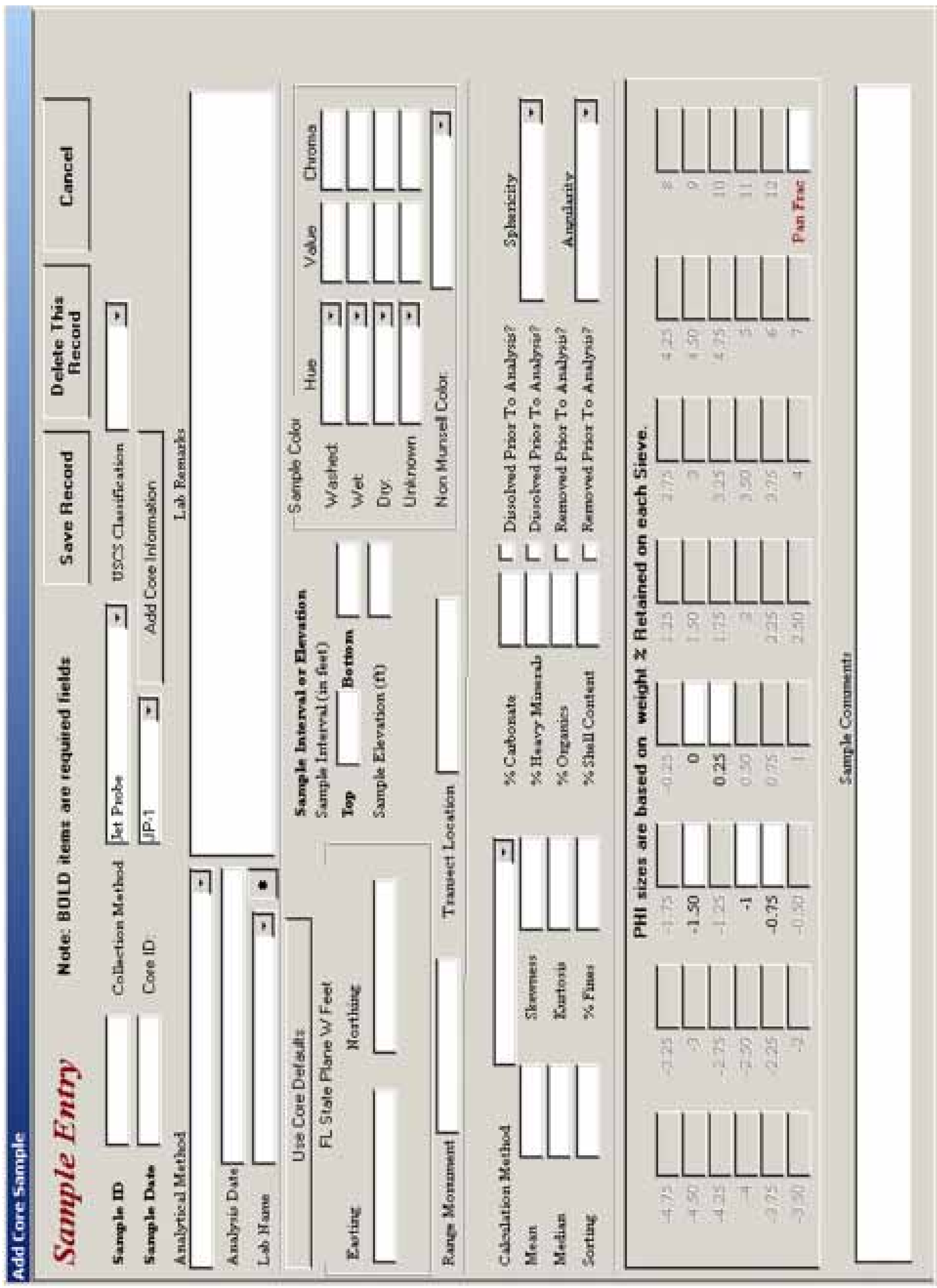


Figure 2-9. The Add Samples page.

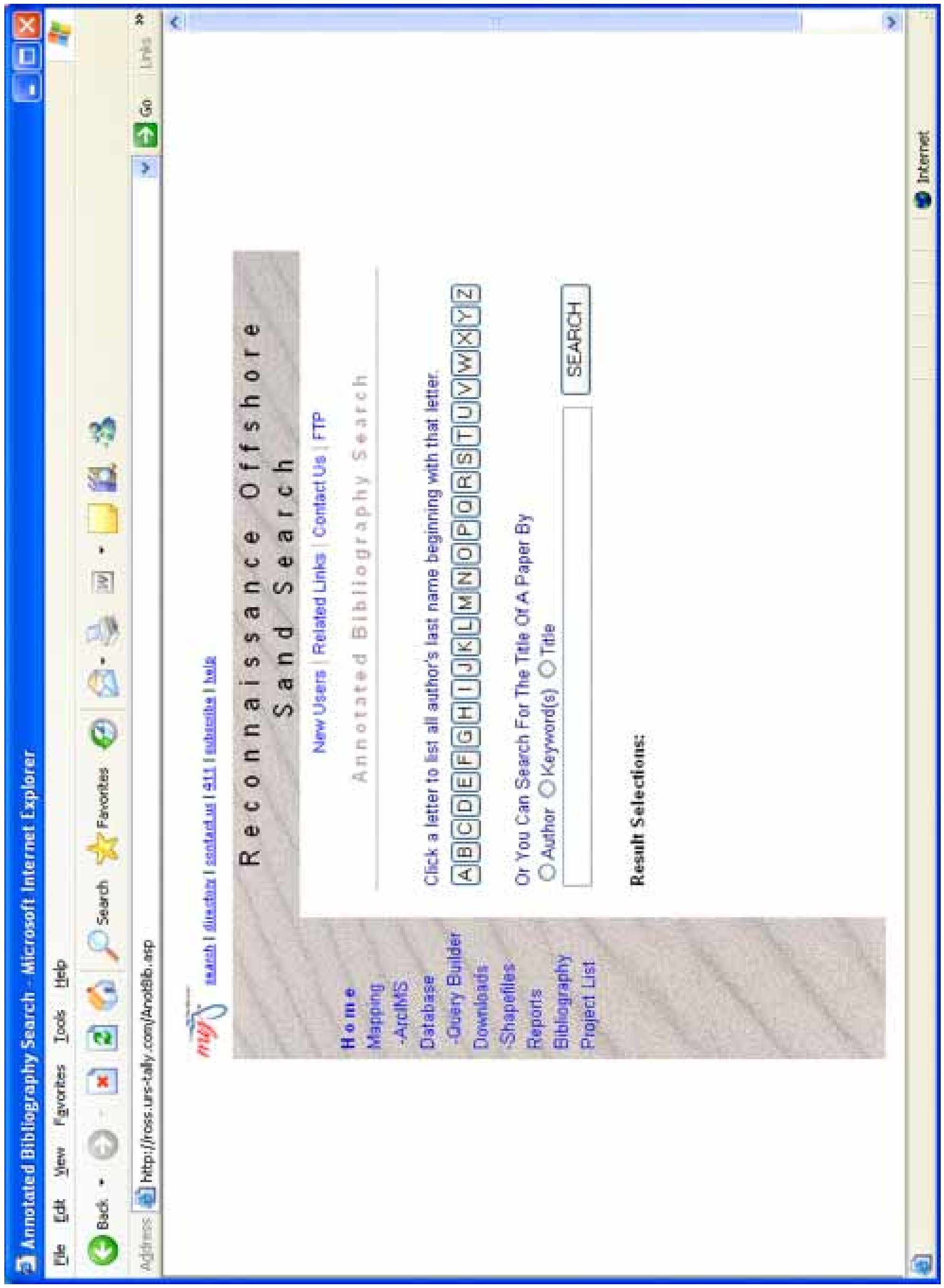


Figure 2-10. The Annotated Bibliography page.

Figure 3-1. Study area map from ROSS – enhanced with ArcView showing area from Anclote Key to Cape Romano..

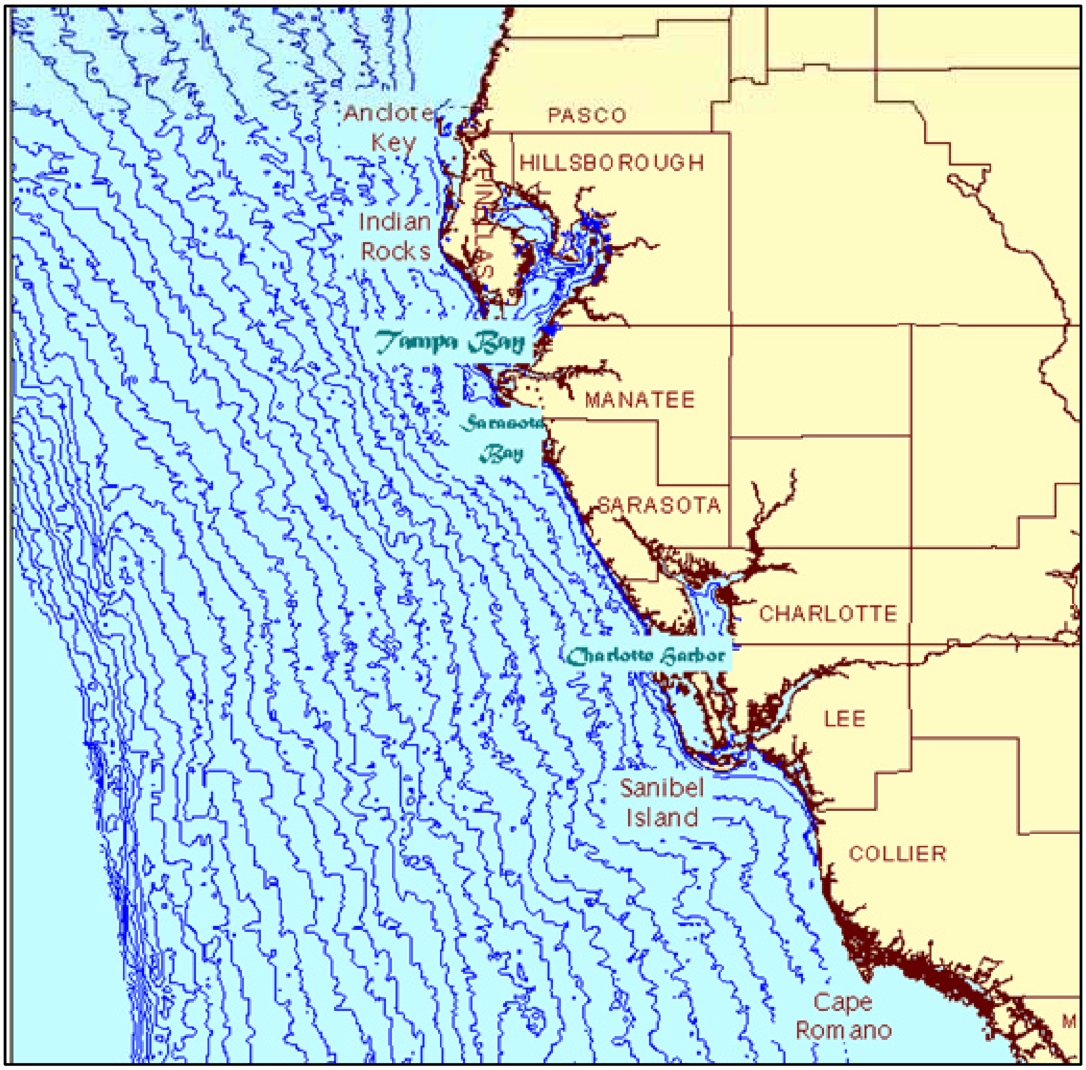


Figure 3-2. Detailed map of Northern Coastal Segment (Pinellas County & Tampa Bay) with bathymetry. Data from ROSS enhanced with ArcView.

Figure 3-3. Detailed map of the Central Coastal Segment (Manatee, Sarasota and Charlotte counties) with bathymetry. Data from ROSS enhanced with ArcView.

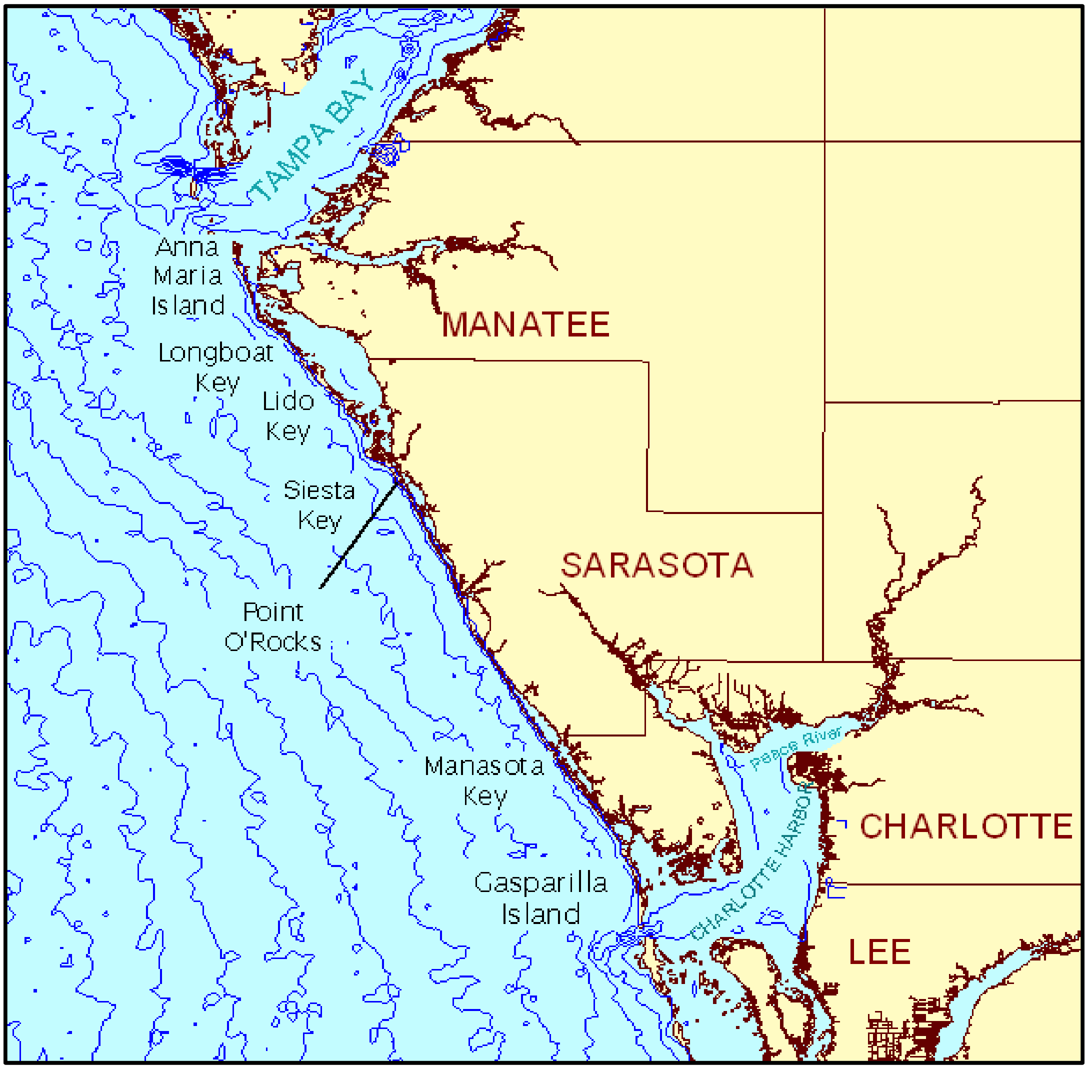


Figure 3-4. Detailed map of the Southern Coastal Segment (Sarasota Arch – South Florida Basin Region) with bathymetry. Data from ROSS enhanced with ArcView.

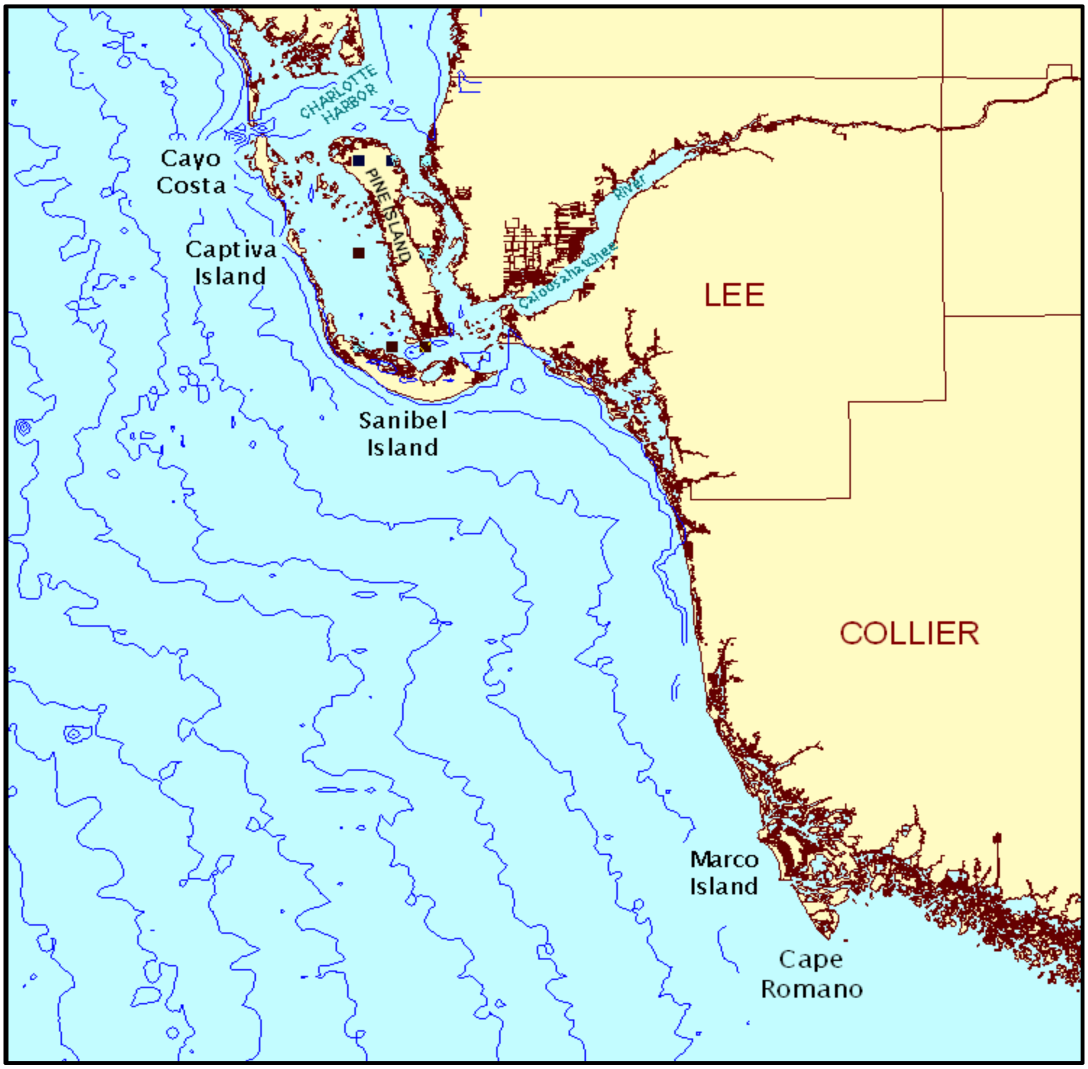


Figure 3-5. Geologic Time Scale.

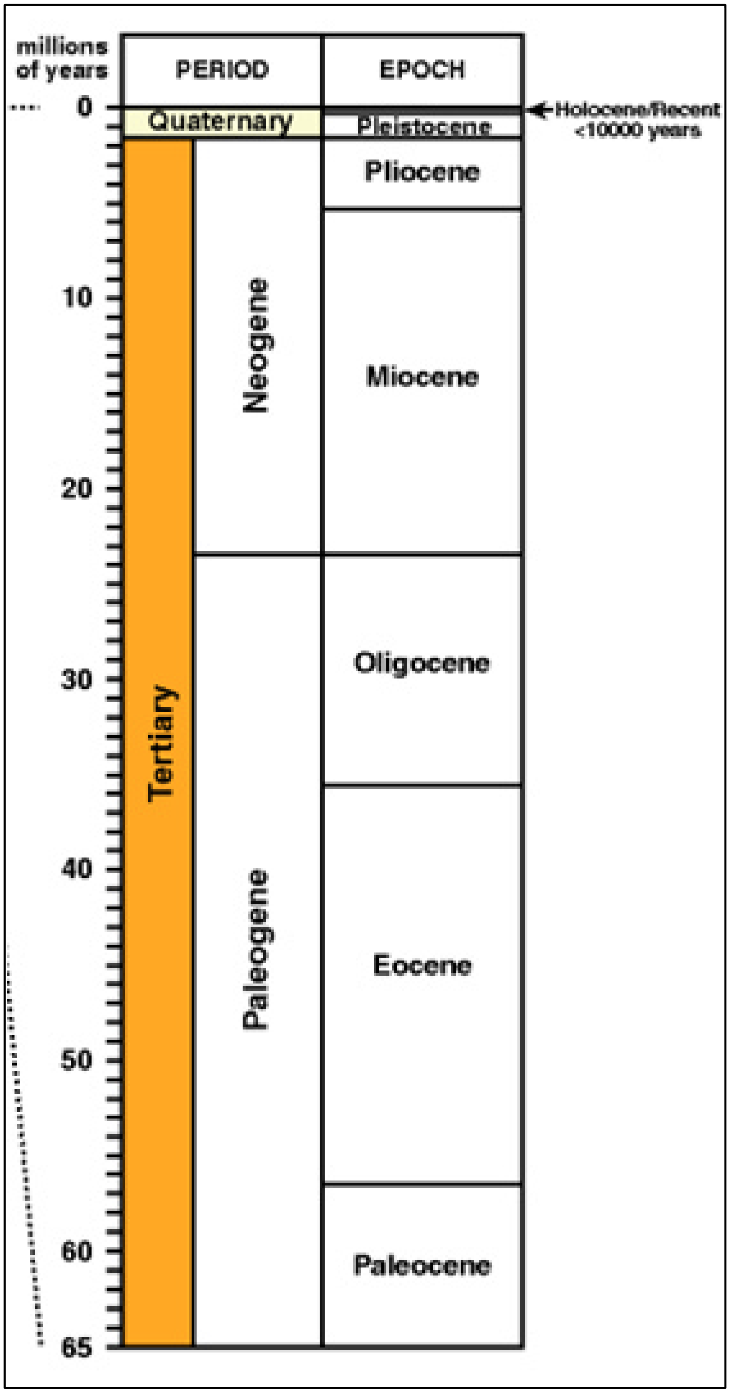


Figure 3-6. Data used by Locker *et al.* to illustrate the correlation between sediment thickness and bedrock gradient as presented.

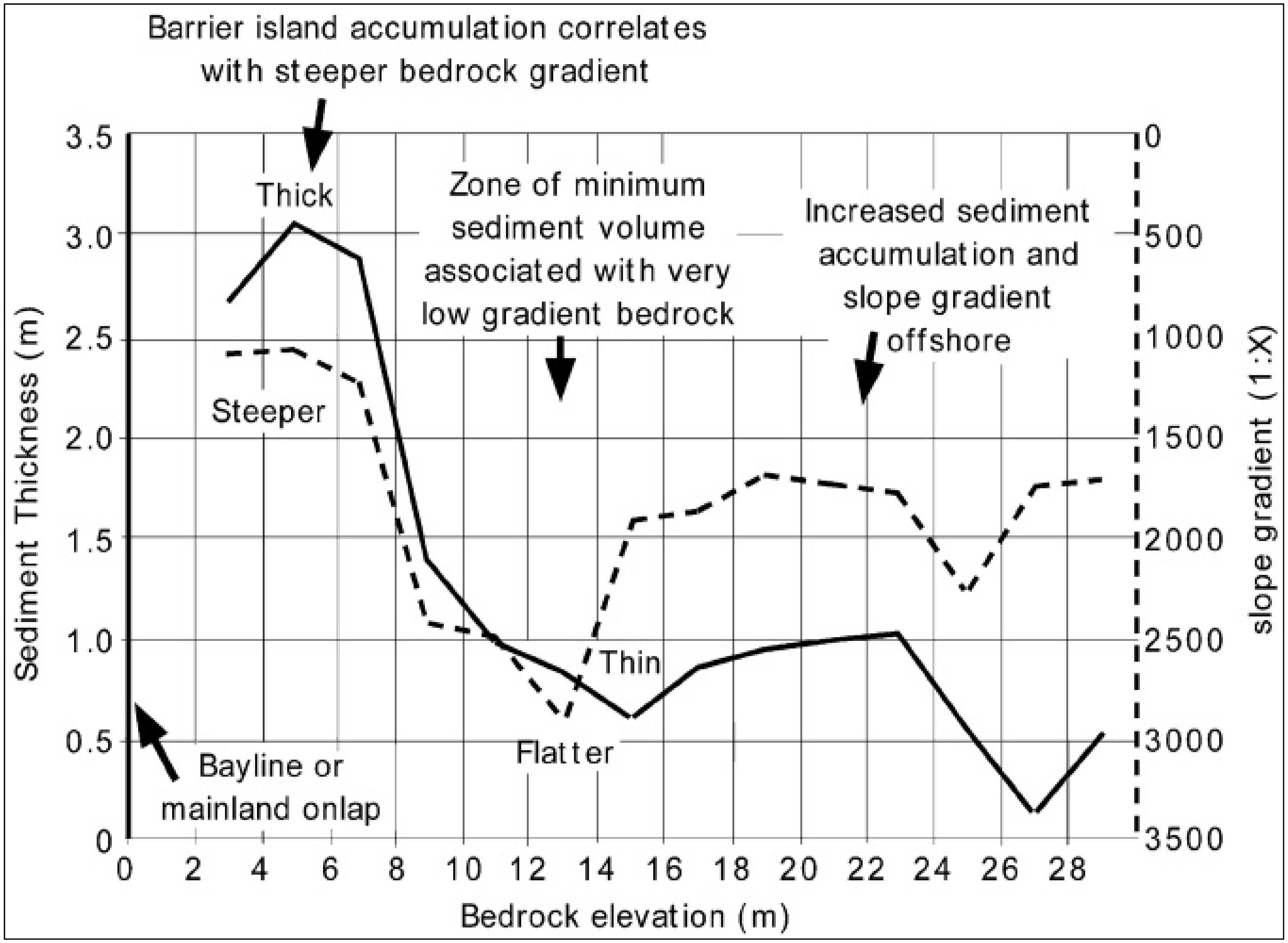


Figure 3-7. Generalized sediment facies map of the WFS, showing inner quartz sand belt and seaward carbonate belts, each dominated by a different carbonate sediment type. Facies belts parallel general bathymetric trends. (From Hine, 1997, and Reading, 1978).

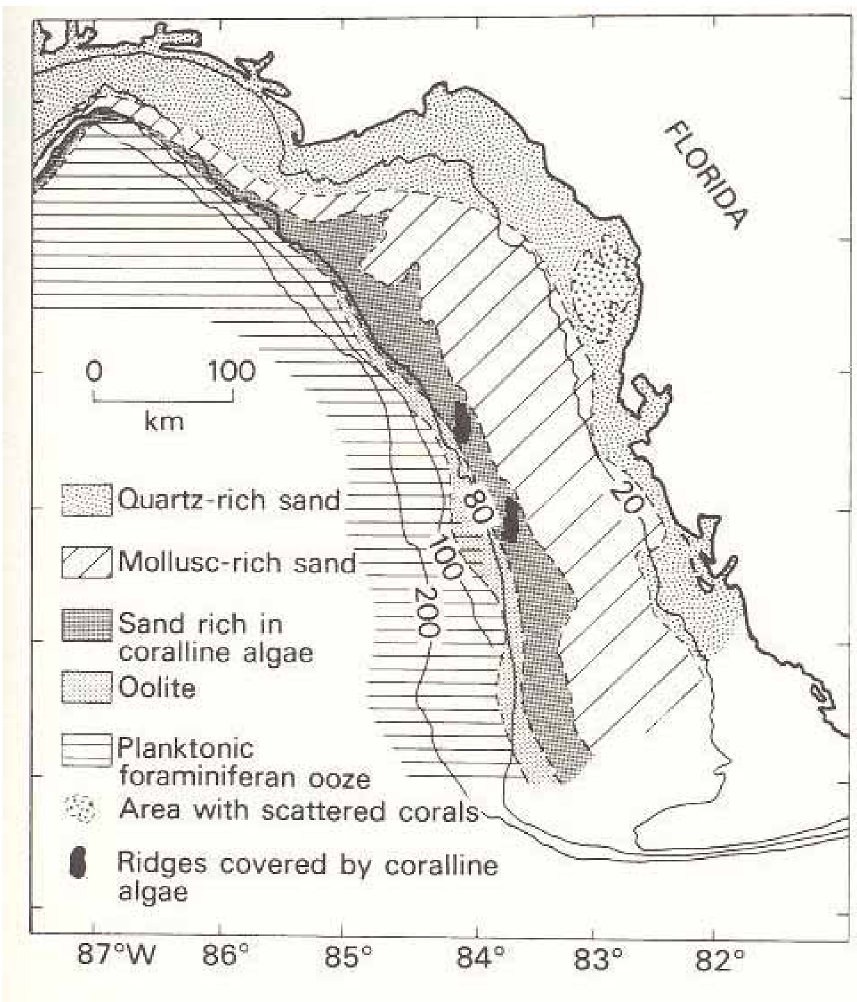


Figure 3-8. General sand ridge orientation interpreted from bathymetric data. Note the major ridge-realignment which occurs offshore Tampa Bay and at Indian Rocks Beach (From Locker *et al*., 2003).

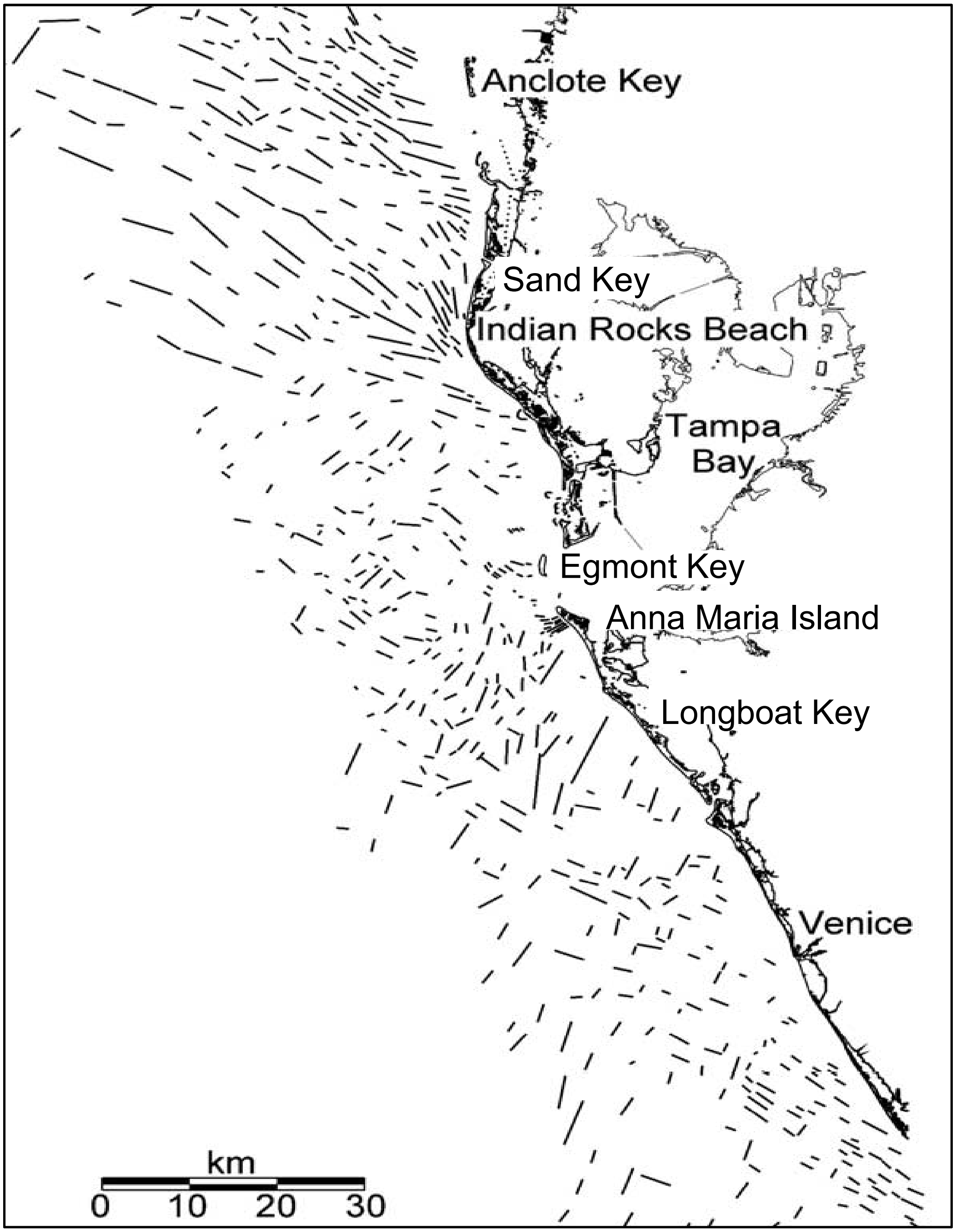
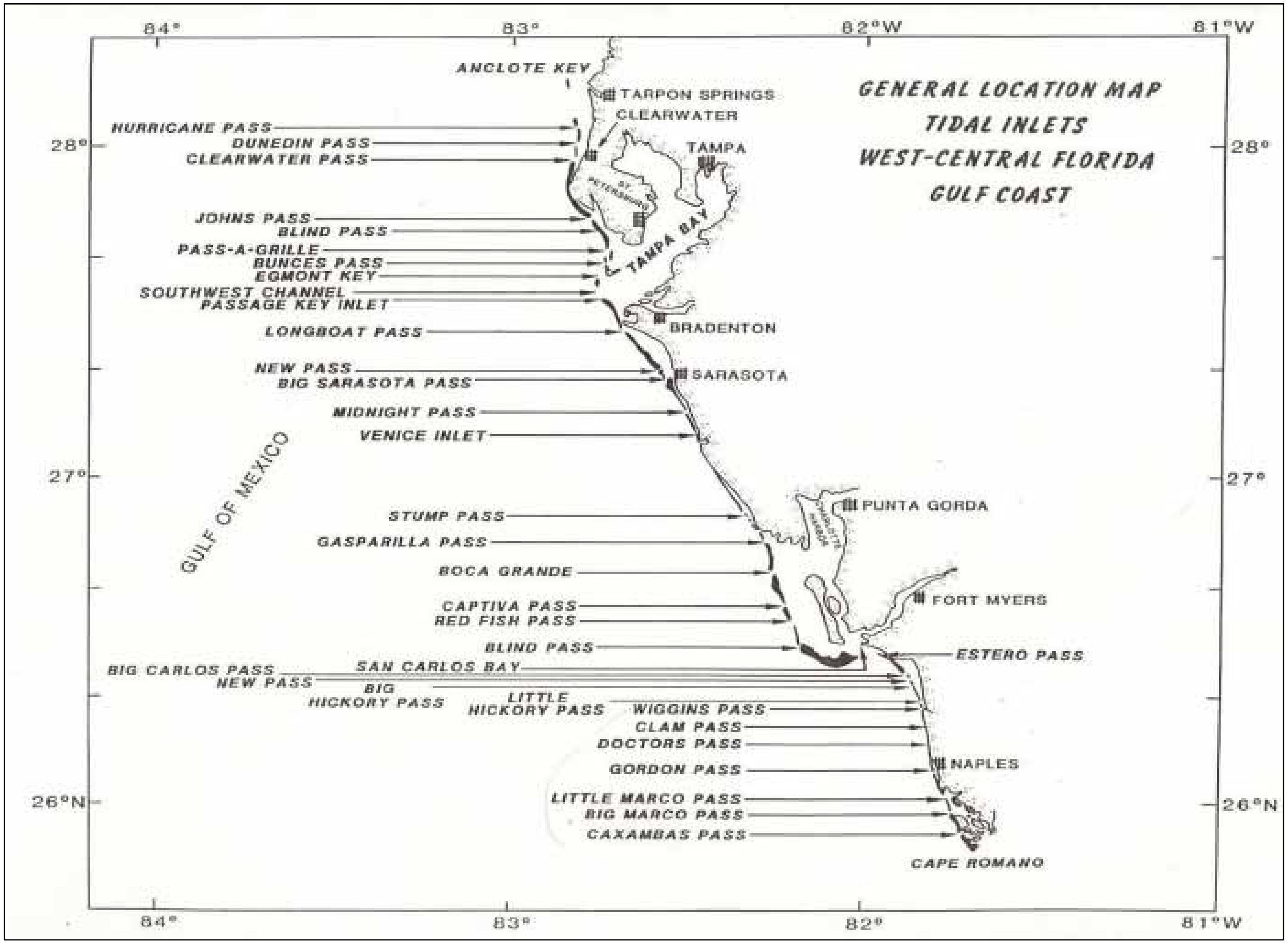


Figure 3-9. Tidal inlets along the central west coast of Florida. (from Hine *et al.*, 1986).



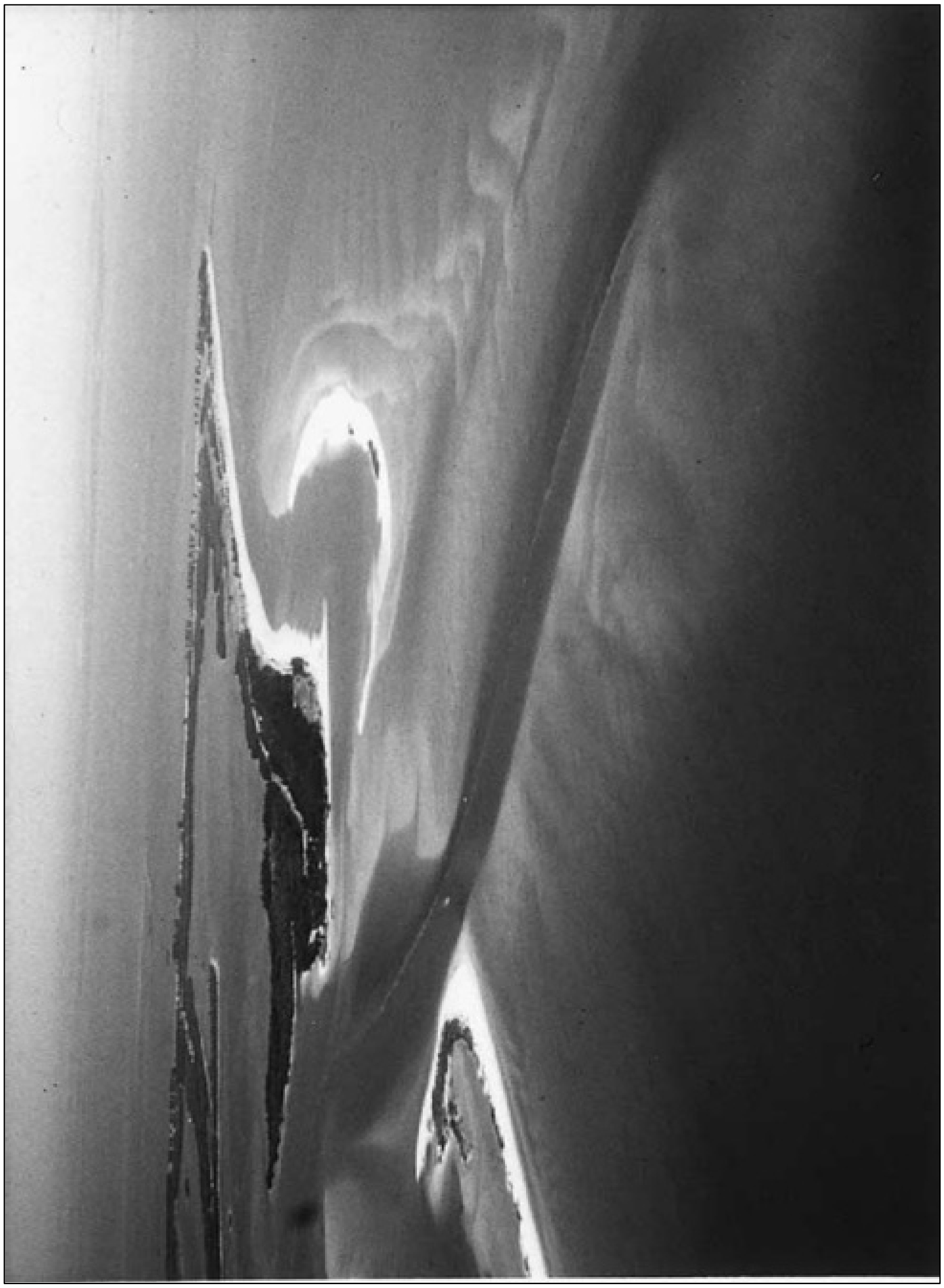


Figure 3-10. Bunces Pass, one of the inlets that connects Tampa Bay to the Gulf of Mexico, is an example of a tide-dominated inlet with a well developed ebb tidal shoal. (From Davis *et al.*, 2003).

Figure 3-11. Blind Pass, a wave-dominated inlet.
(Photo provided by the Lee County Government – Robert Neal).

Figure 3-12. Representative stratigraphic cross-sections (A, F, and J) of the northern coastal segments. (From Locker *et al*., 2003).

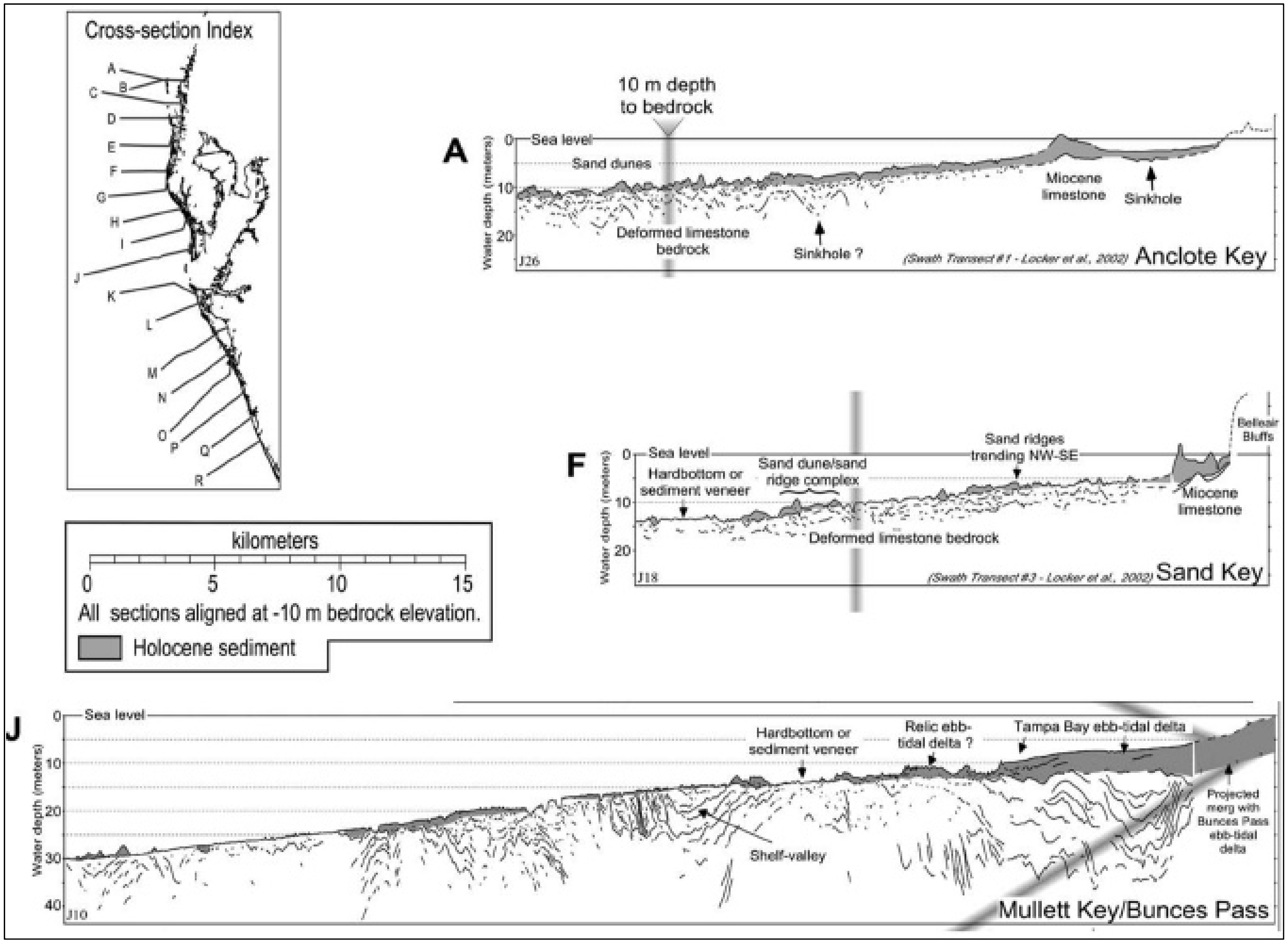


Figure 3-13. Representative stratigraphic cross-sections (K, O, and R) of the southern coastal segments. (From Locker *et al.*, 2003).

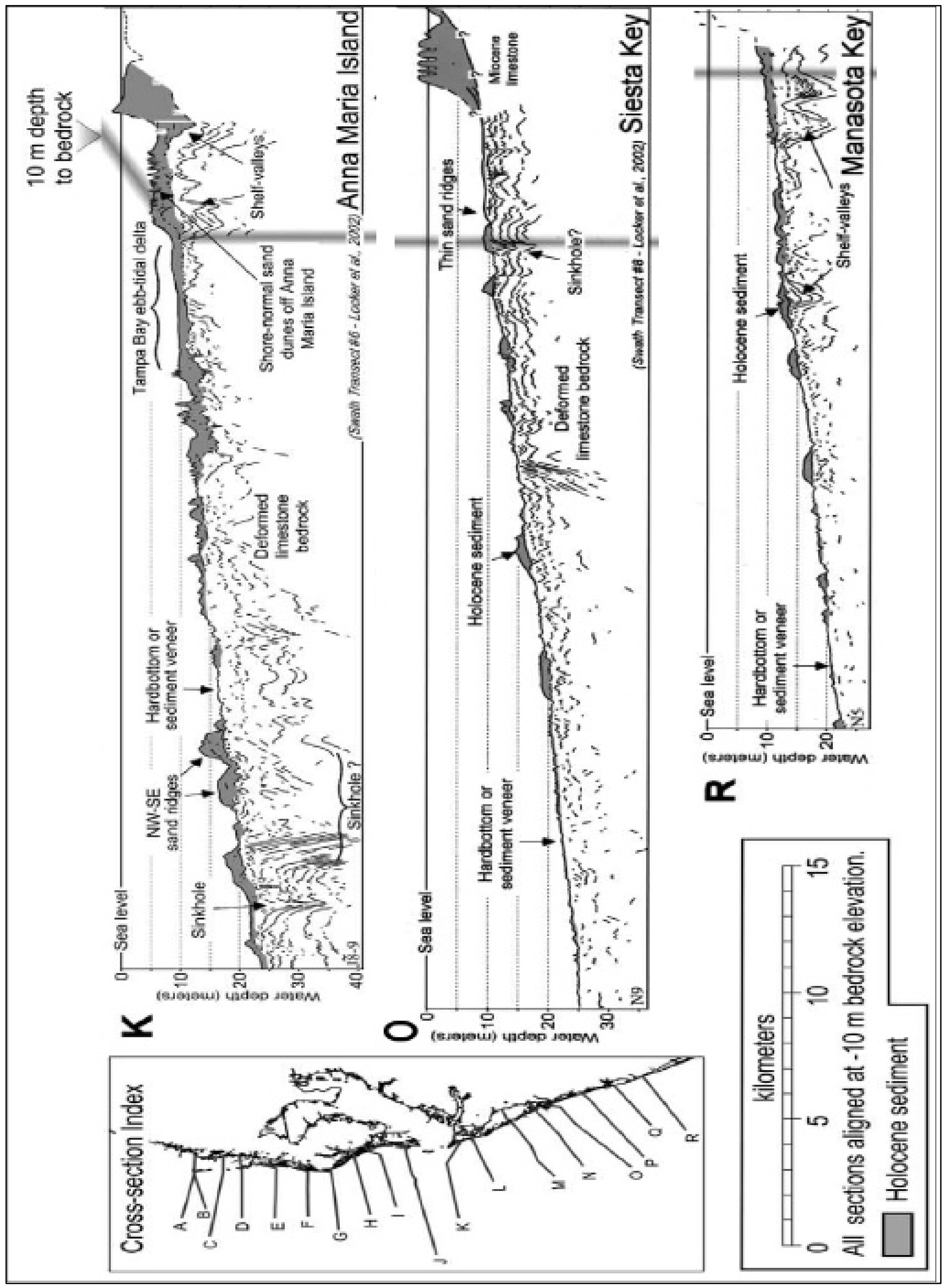


Figure 3-14. Seismic cross-section of a sand ridge located about 8 km (5 miles) offshore Naples Beach in Collier County. (From Benedet *et al.*, 2004).

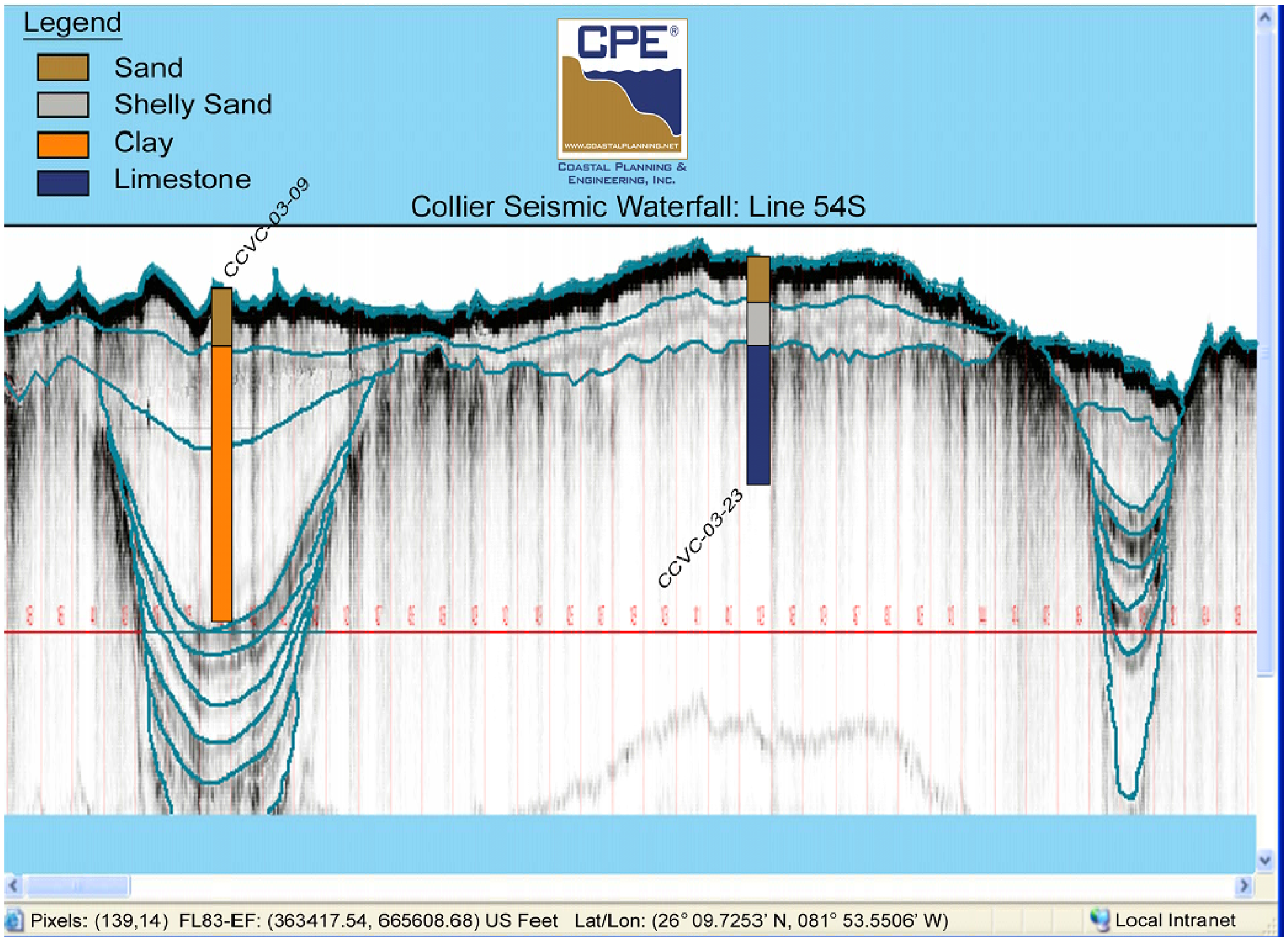


Figure 3-15. Subdivision of the shore and WFS in terms of eleven primary physiographic units.

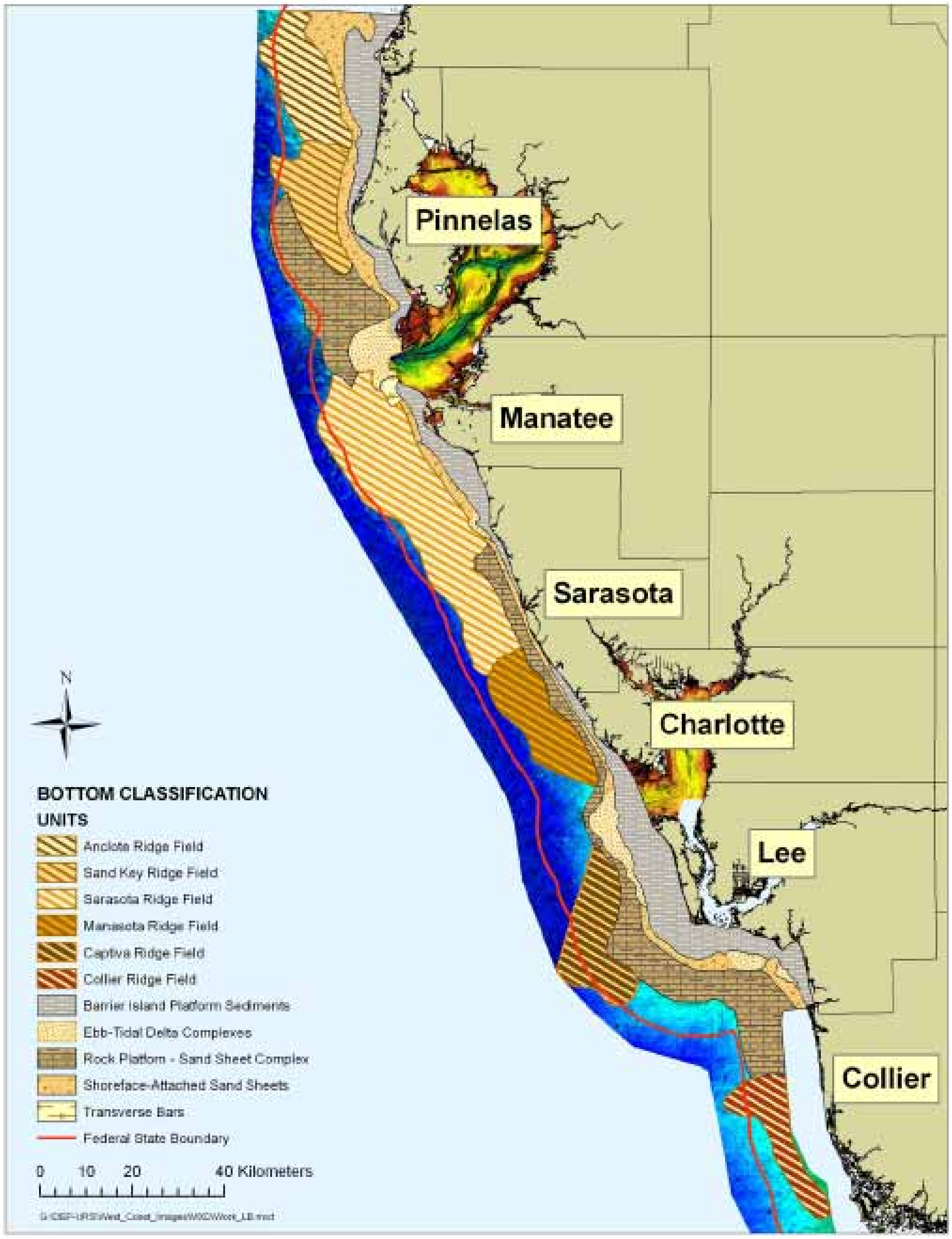


Figure 4-1. Flow diagram showing systematic approaches to offshore sand searches.

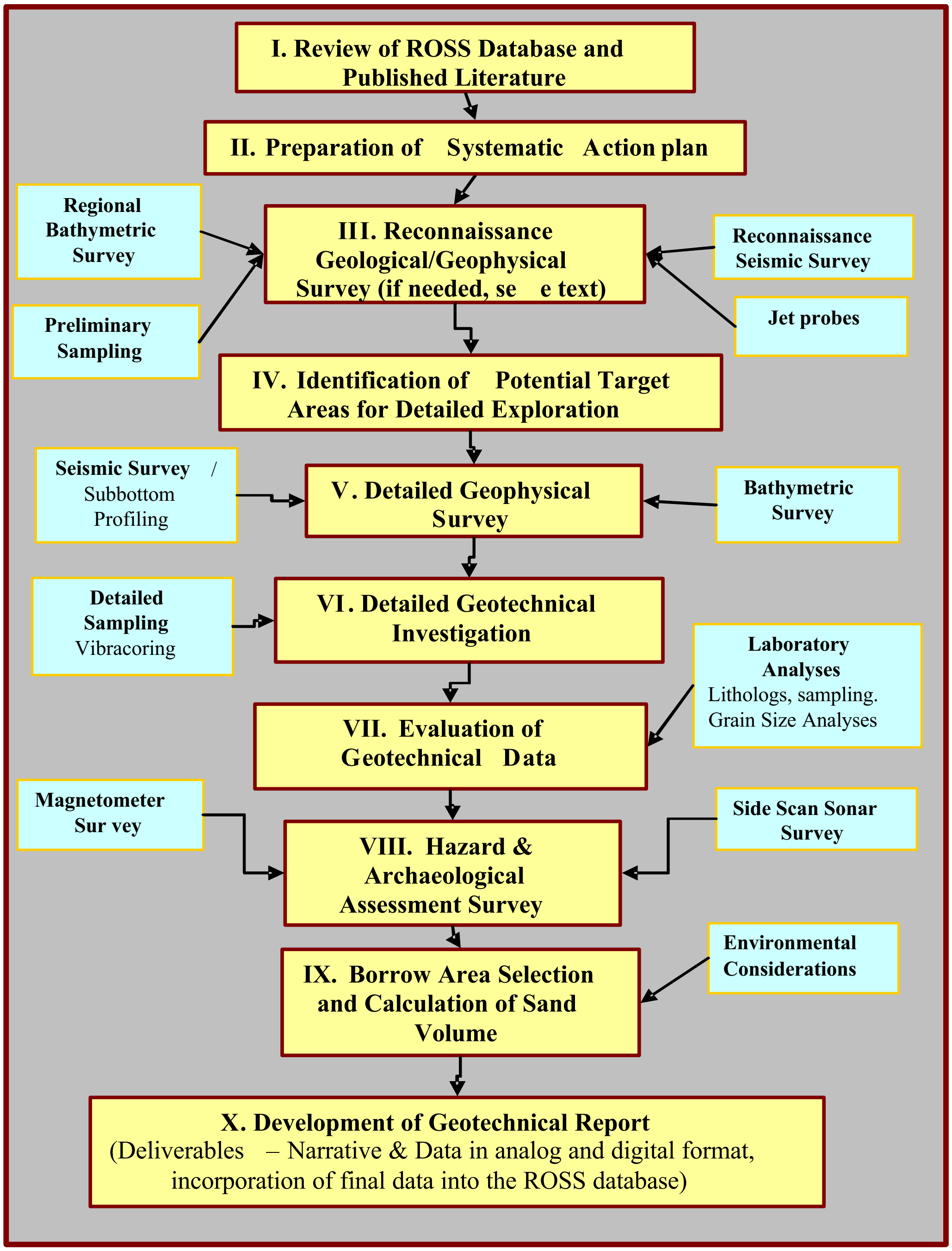


Figure 6-1. Potential Borrow Areas

Figure 6-2. Potential sand targets occurring in sand ridges (ridge axis marked by white lines) and historical data available for Pinellas County (Study Area 1).

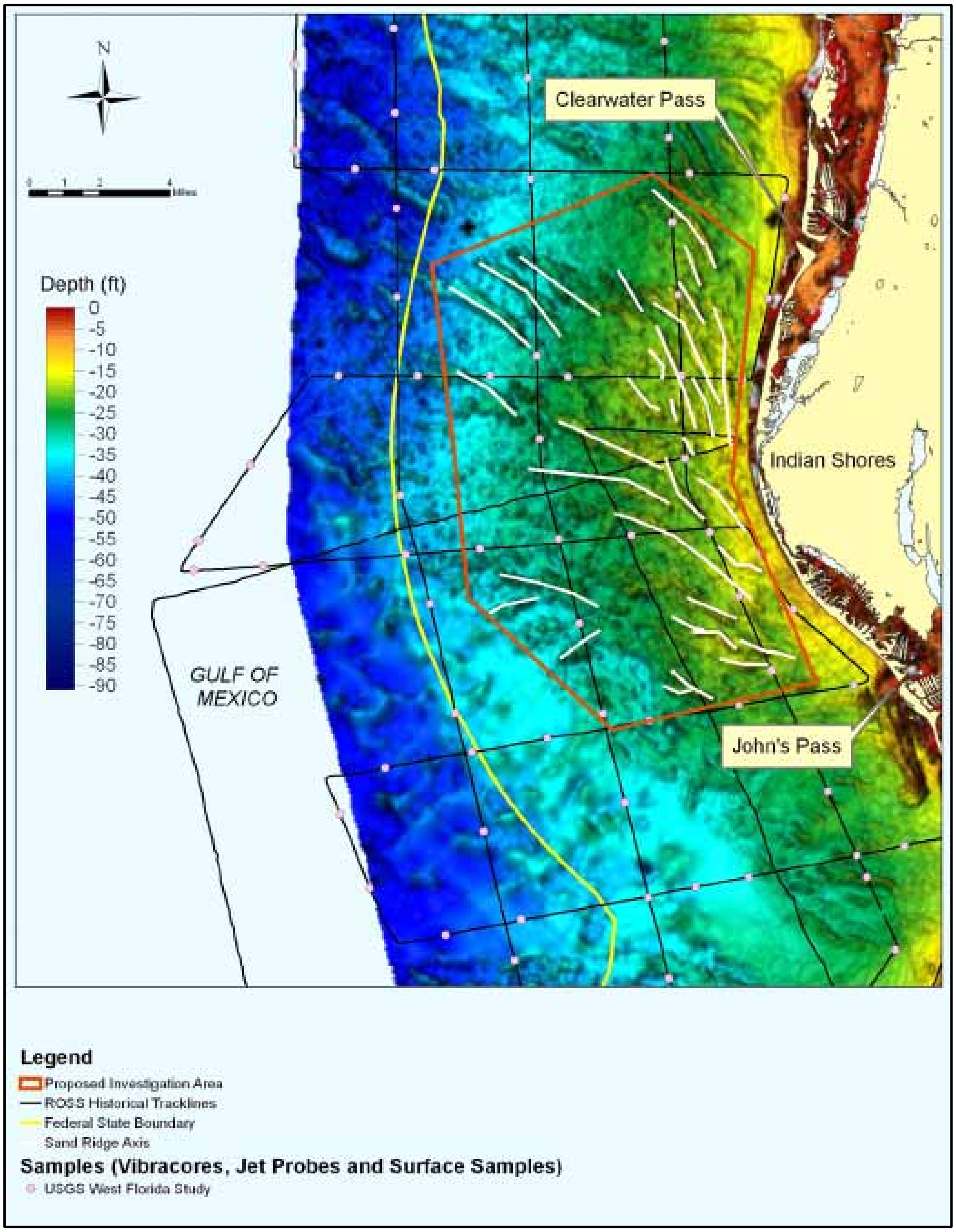
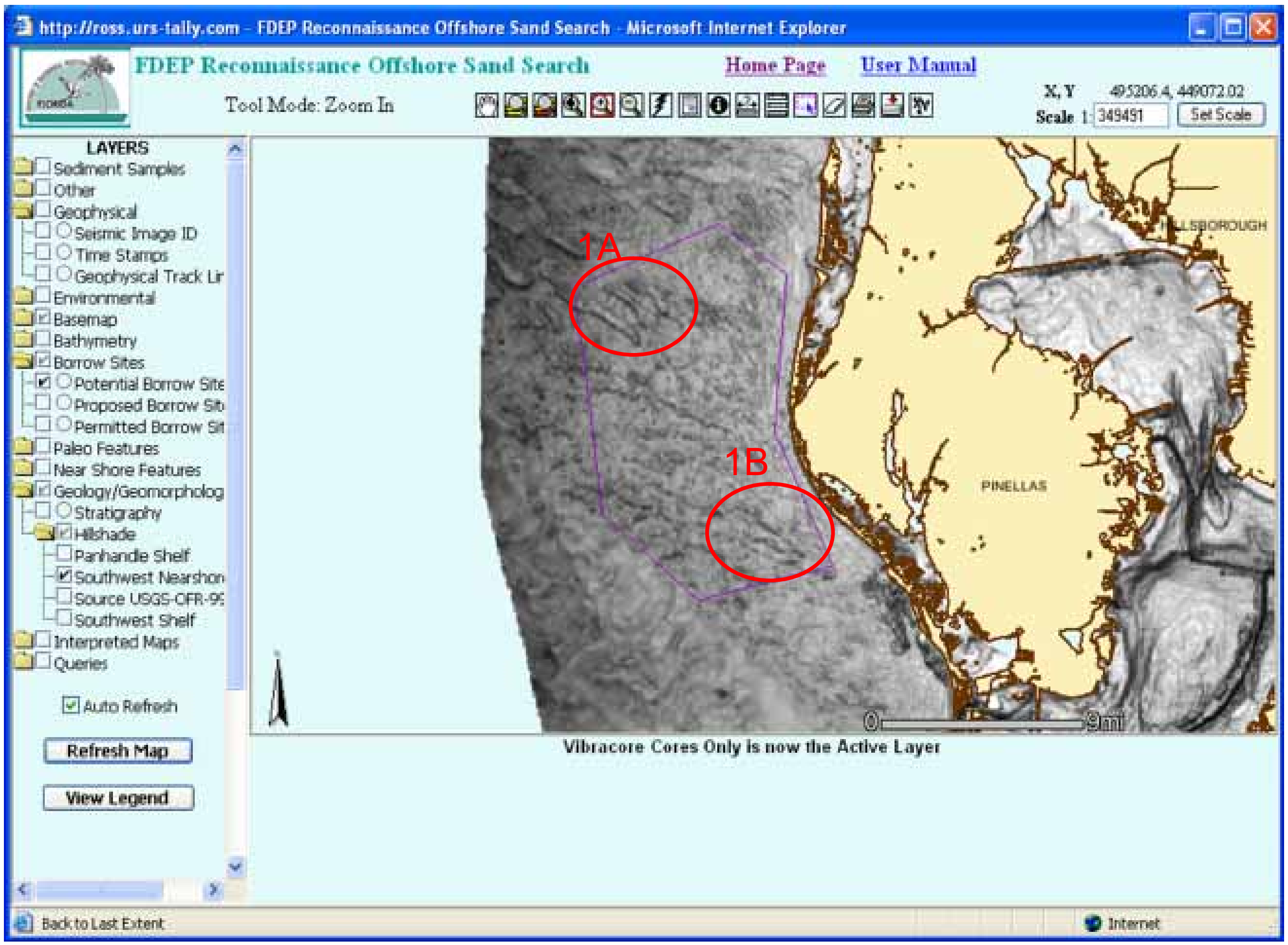


Figure 6-3. Area 1 showing areas 1A and 1B (circled) for future data acquisition.



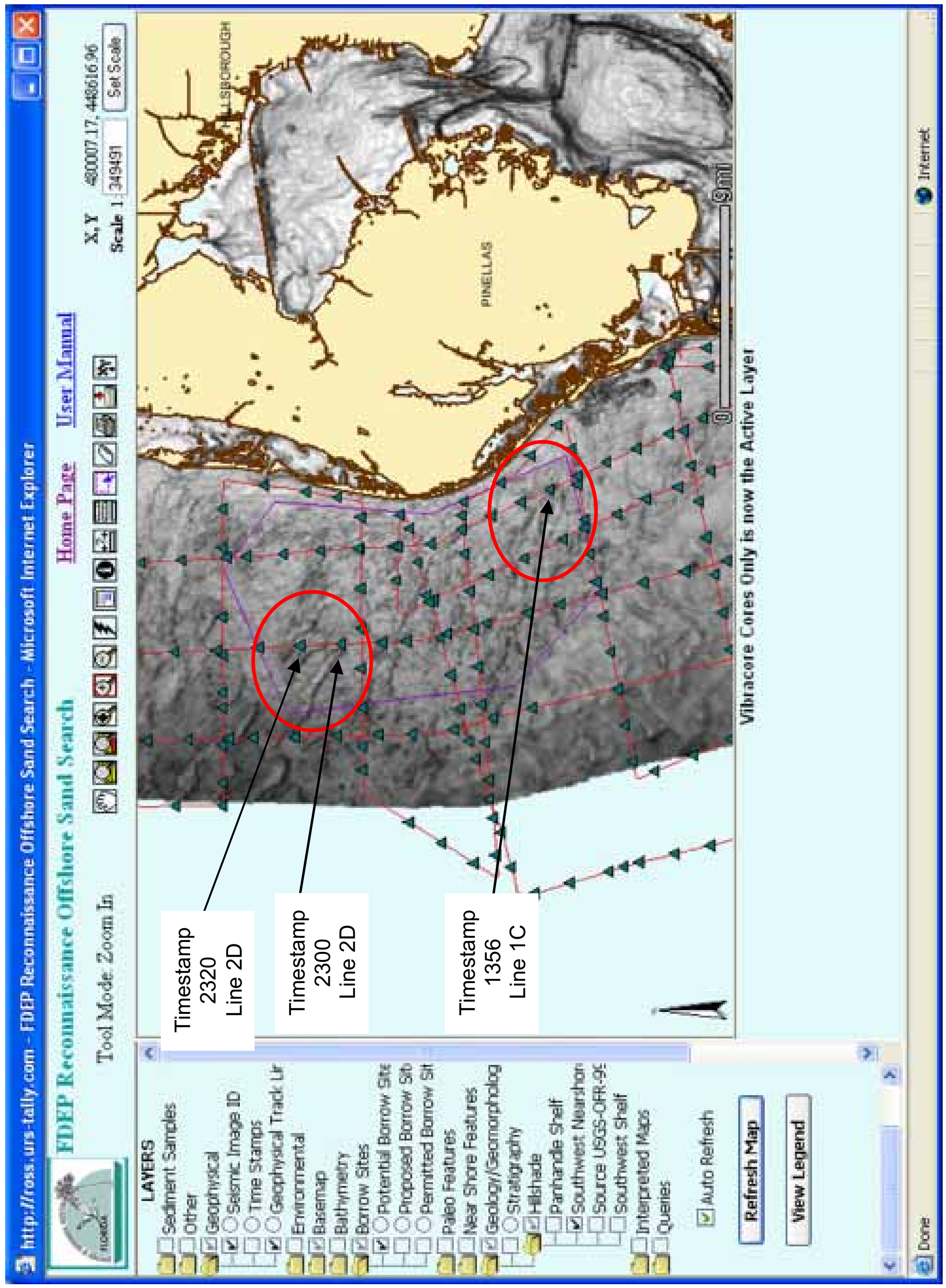
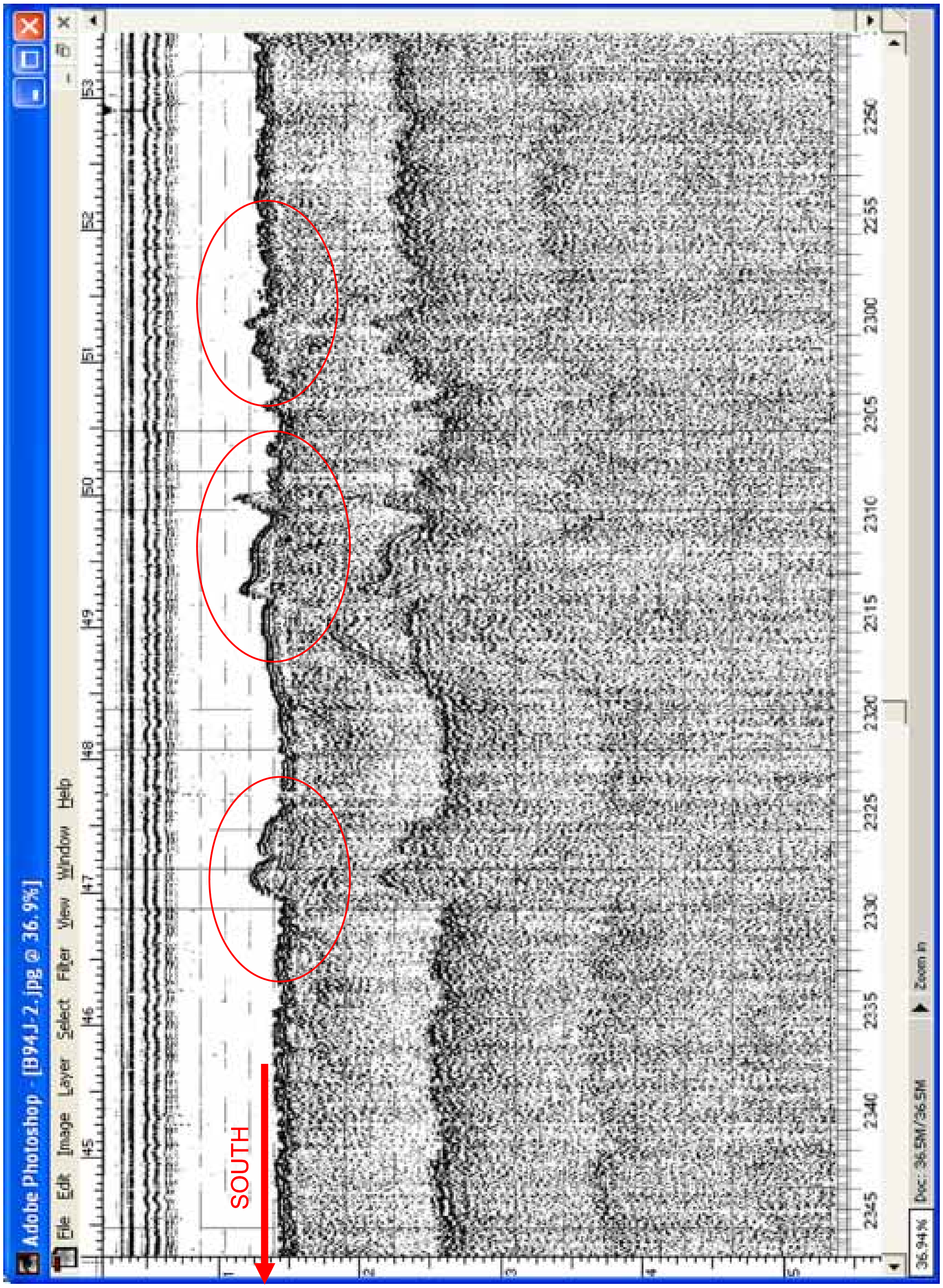


Figure 6-4. Area 1 geophysical image location.

Figure 6-5. Area 1A, line 2D showing series of sand ridges.



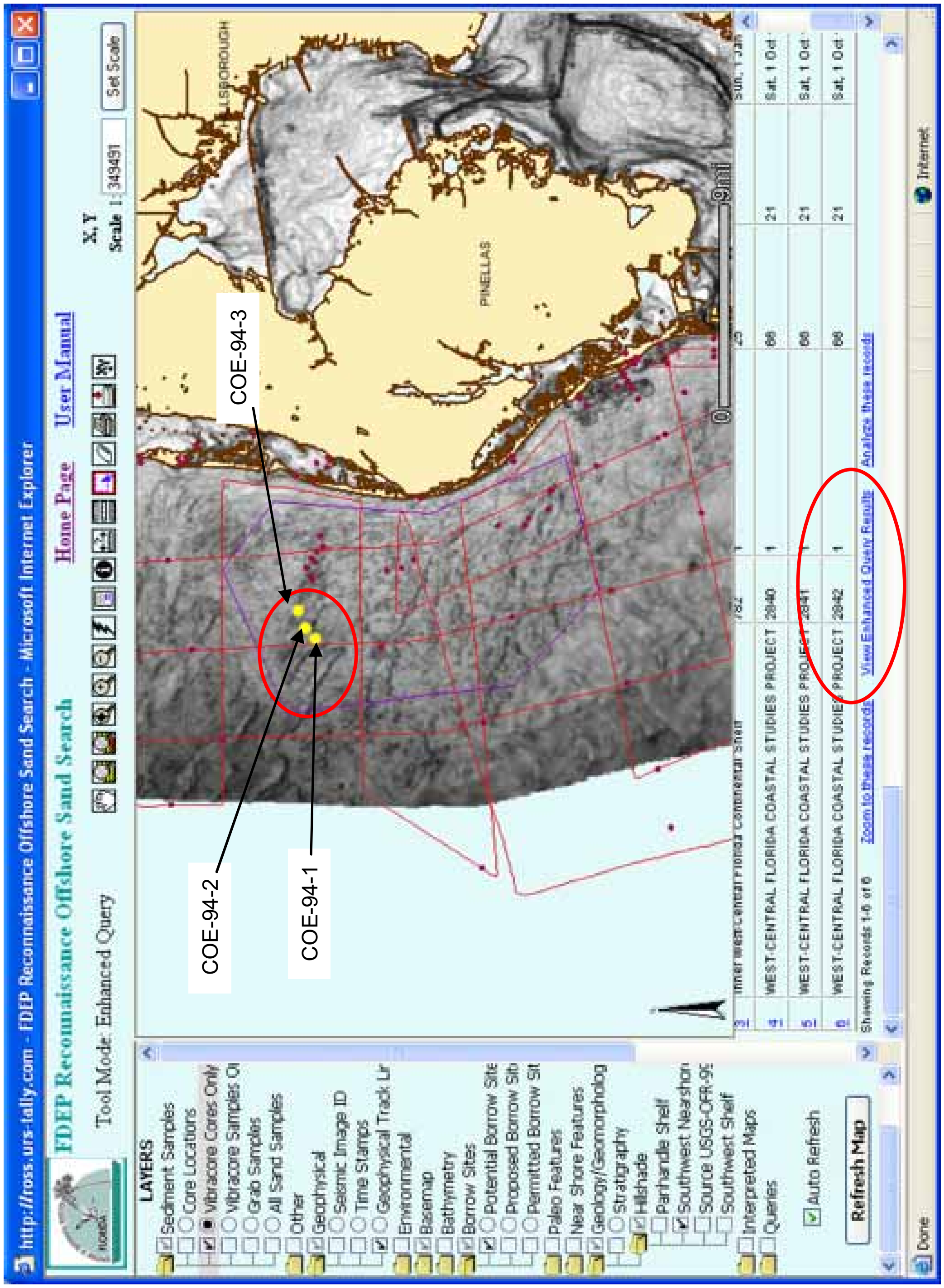
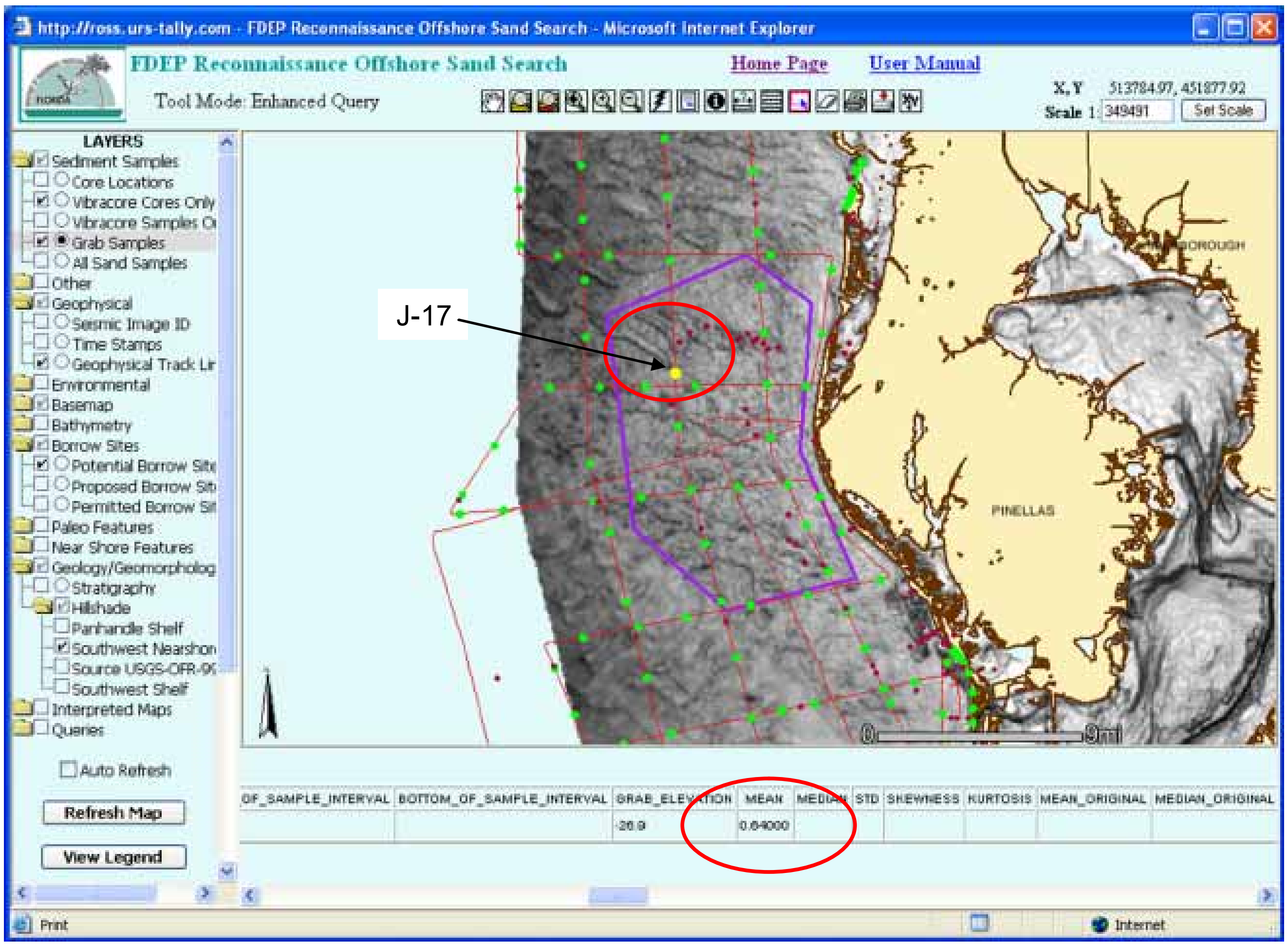


Figure 6-6. Area 1A, Location of vibracores in relation to geophysical data.

Figure 6-7. Grab sample location in Area 1A. Sample mean grainsize is 0.64 phi, corresponding to Medium Sand.



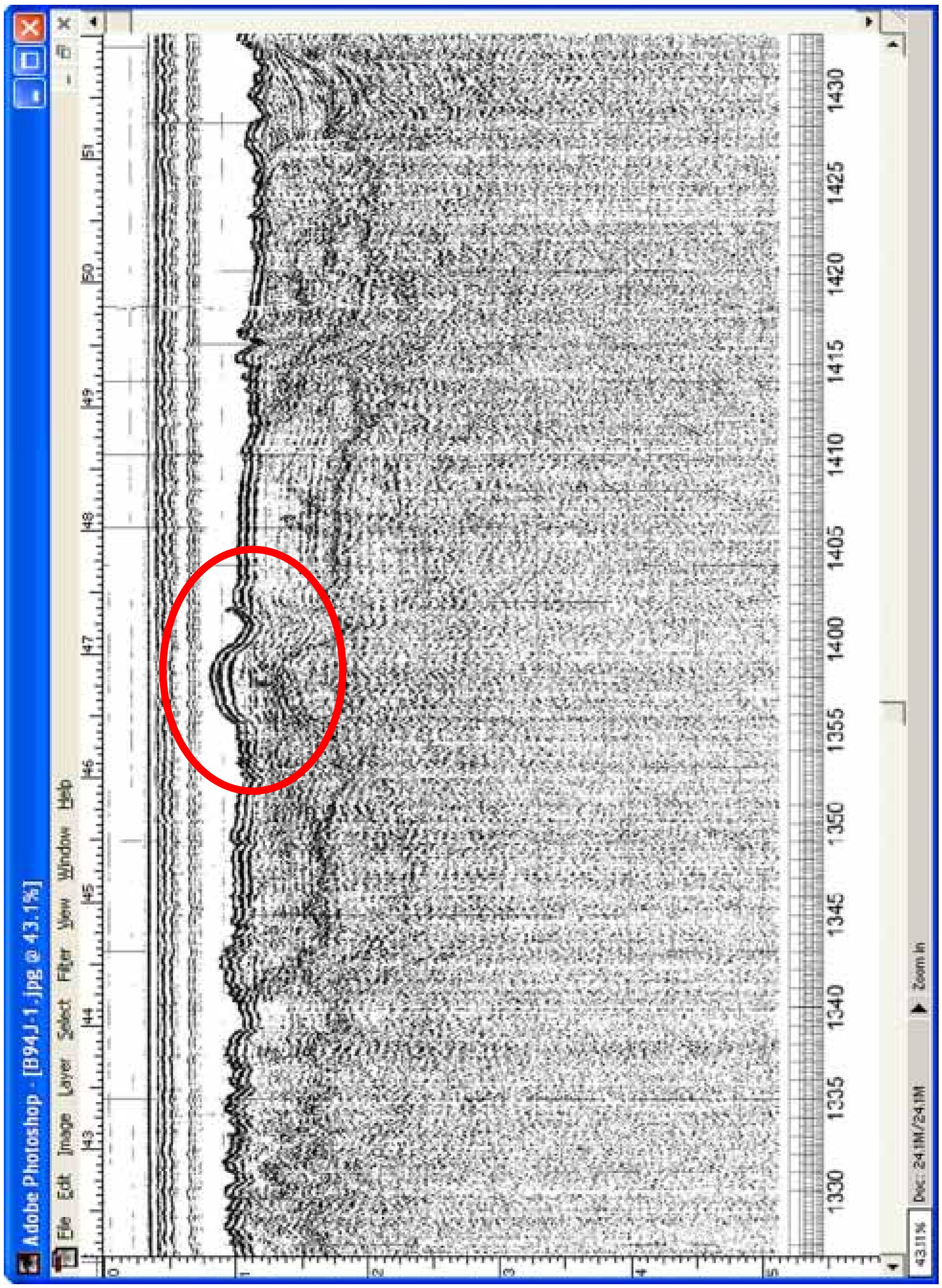


Figure 6-8. Area 1B geophysical image for trackline 1C showing sand ridge.

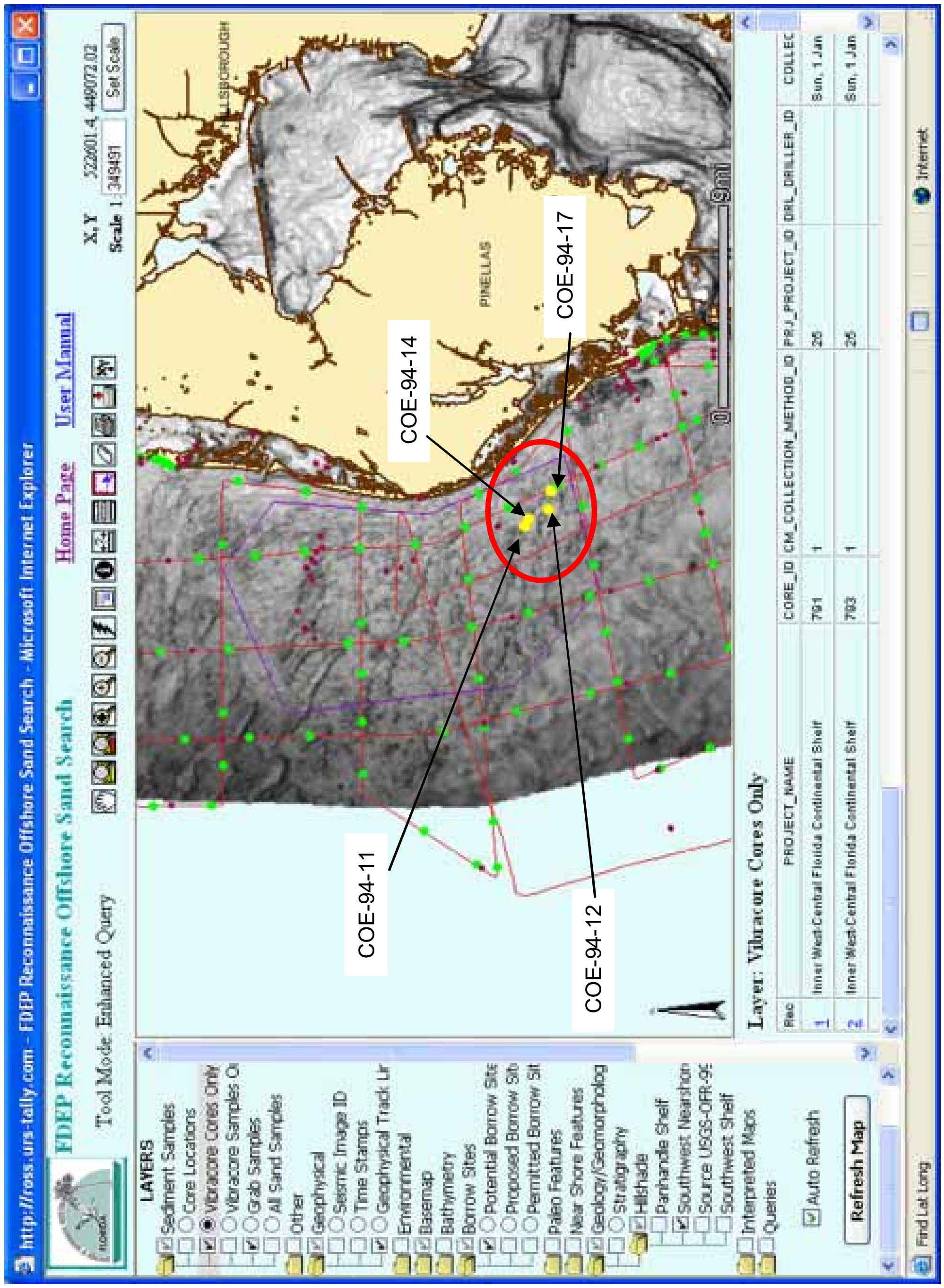


Figure 6-9. Area 1B, Location of vibracores in relation to geophysical data.

Figure 6-10. Area 1B, location of 2 grab samples in relation to geophysical data. Mean grain sizes for samples J-46 and J-47 are 2.18 and 1.97 phi respectively. These correspond to fine sand.

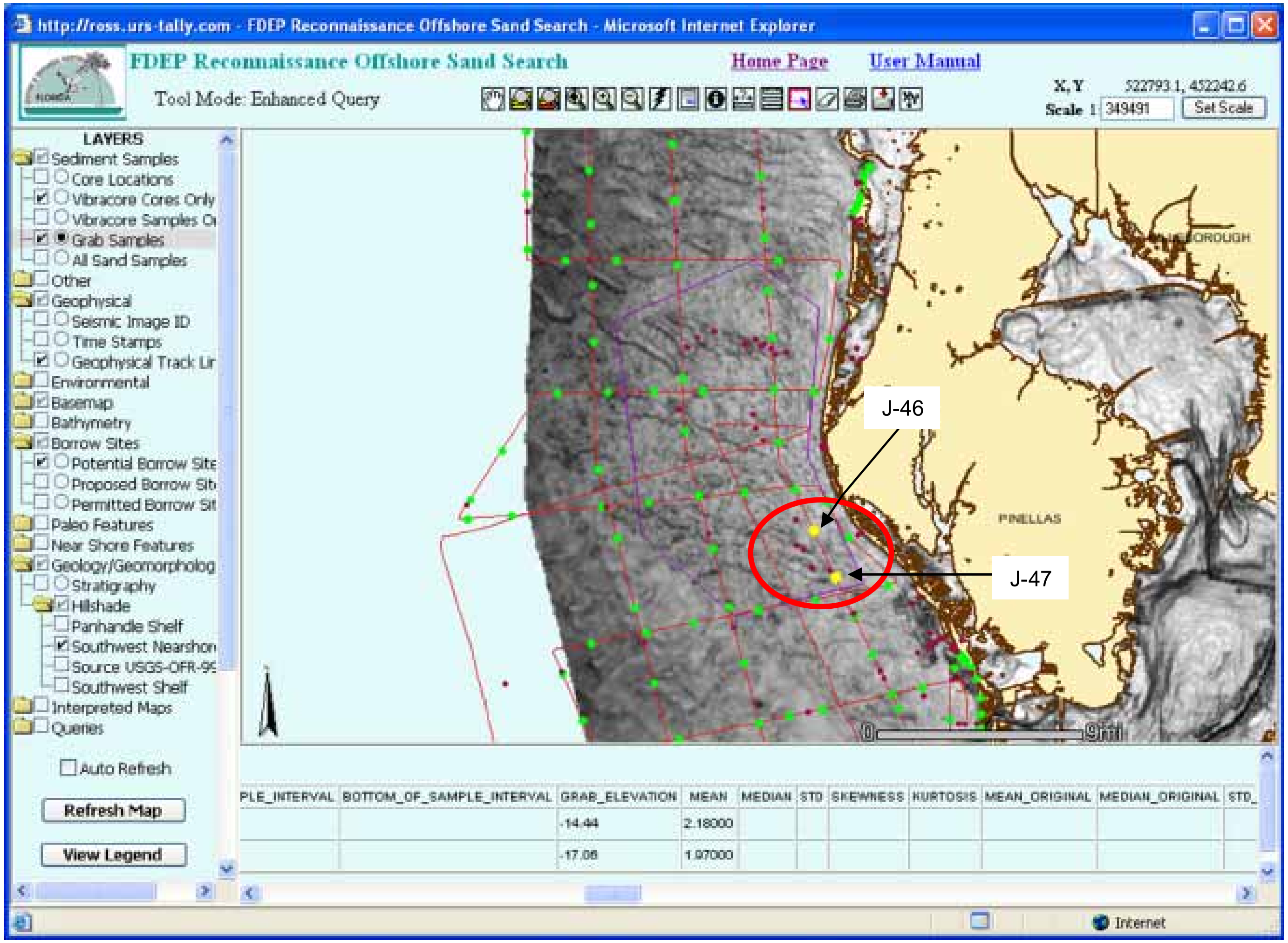
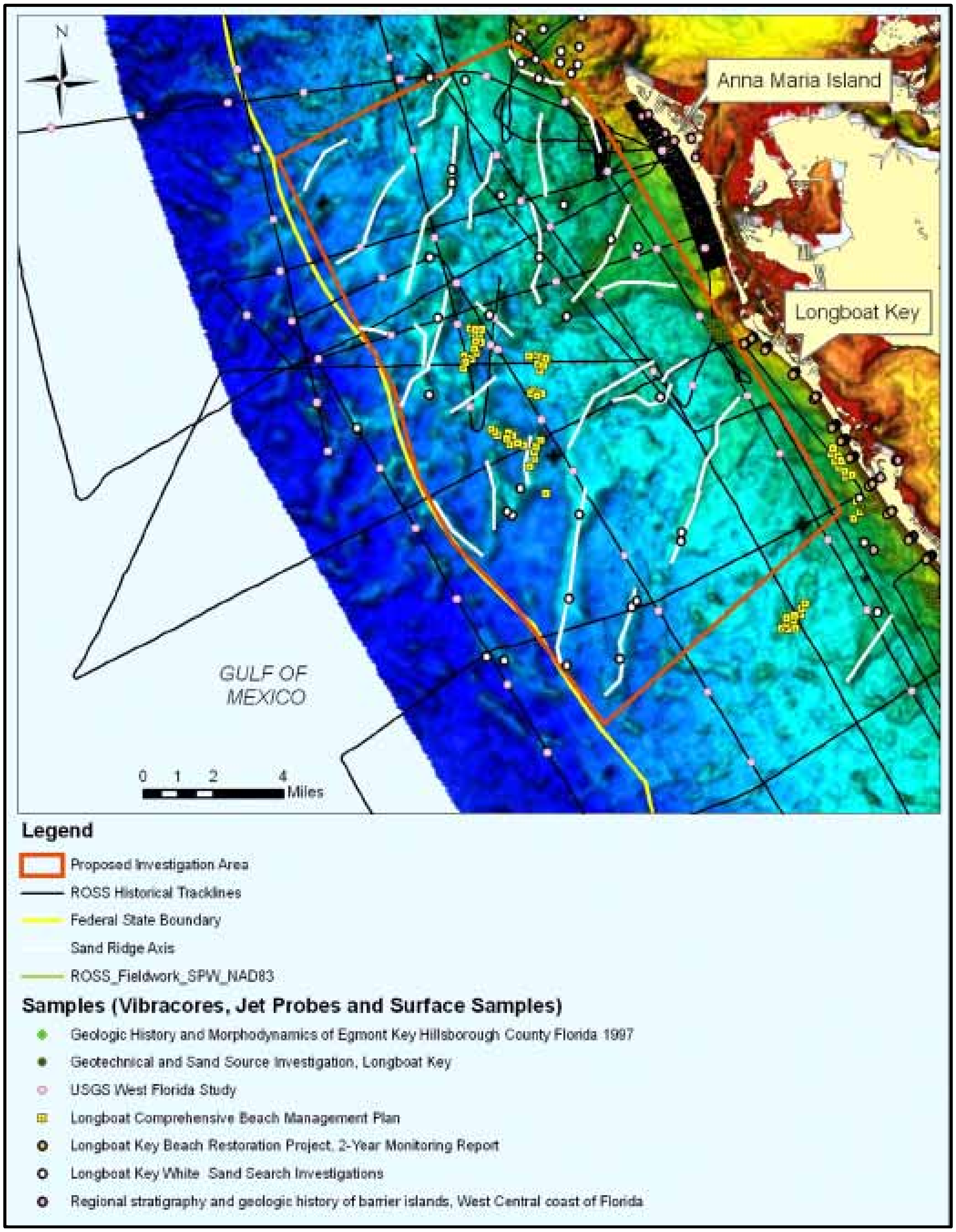


Figure 6-11. Potential sand targets occurring in sand ridges (ridge axis marked by white lines) and historical data Available for Central Coastal Segment, Manatee County and Northern Sarasota County (Study Area 2).



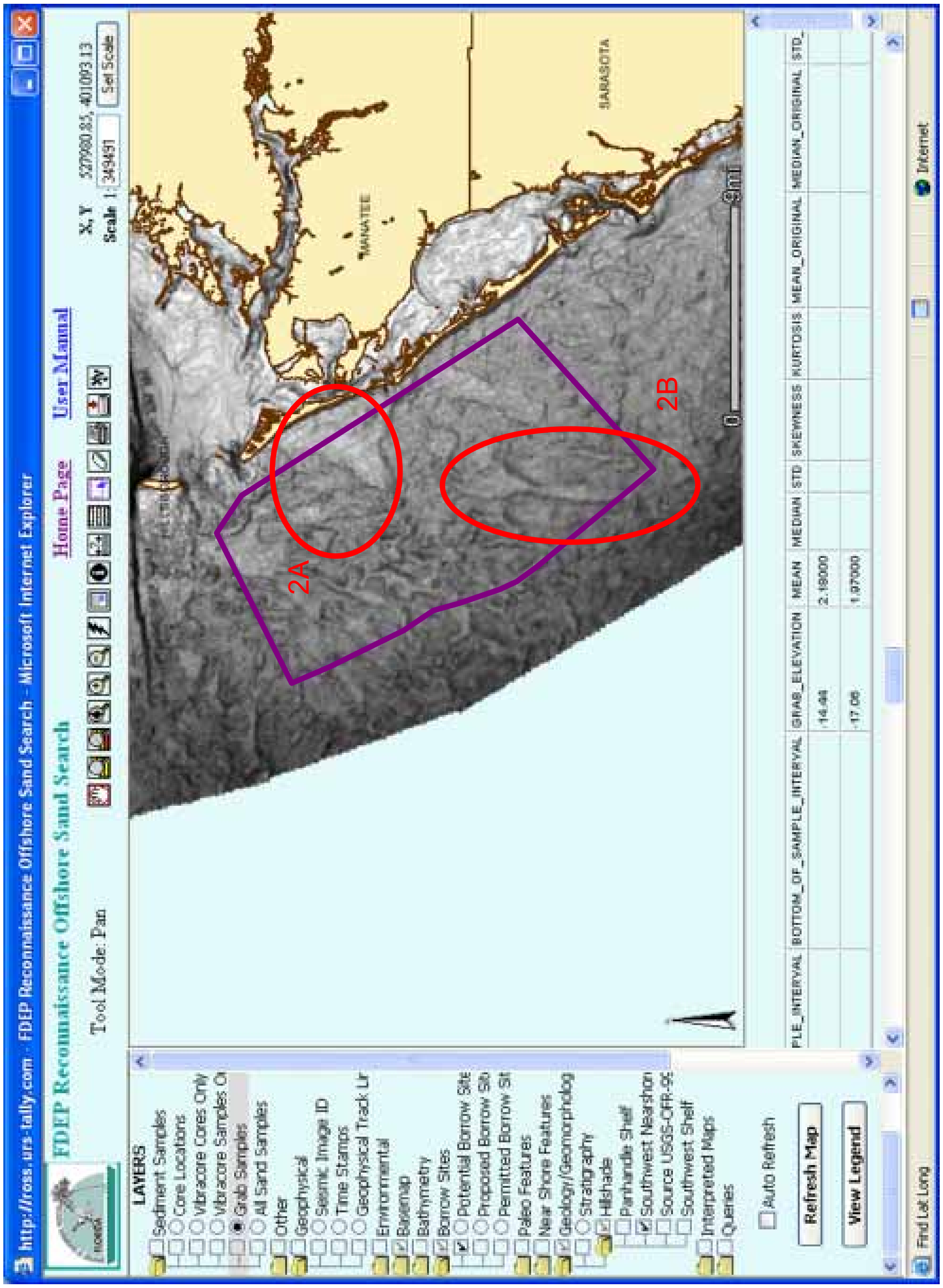


Figure 6-12. Area 2 showing areas 2A and 2B (circled) for future data acquisition.

Figure 6-13. Area 2 Geophysical image location.

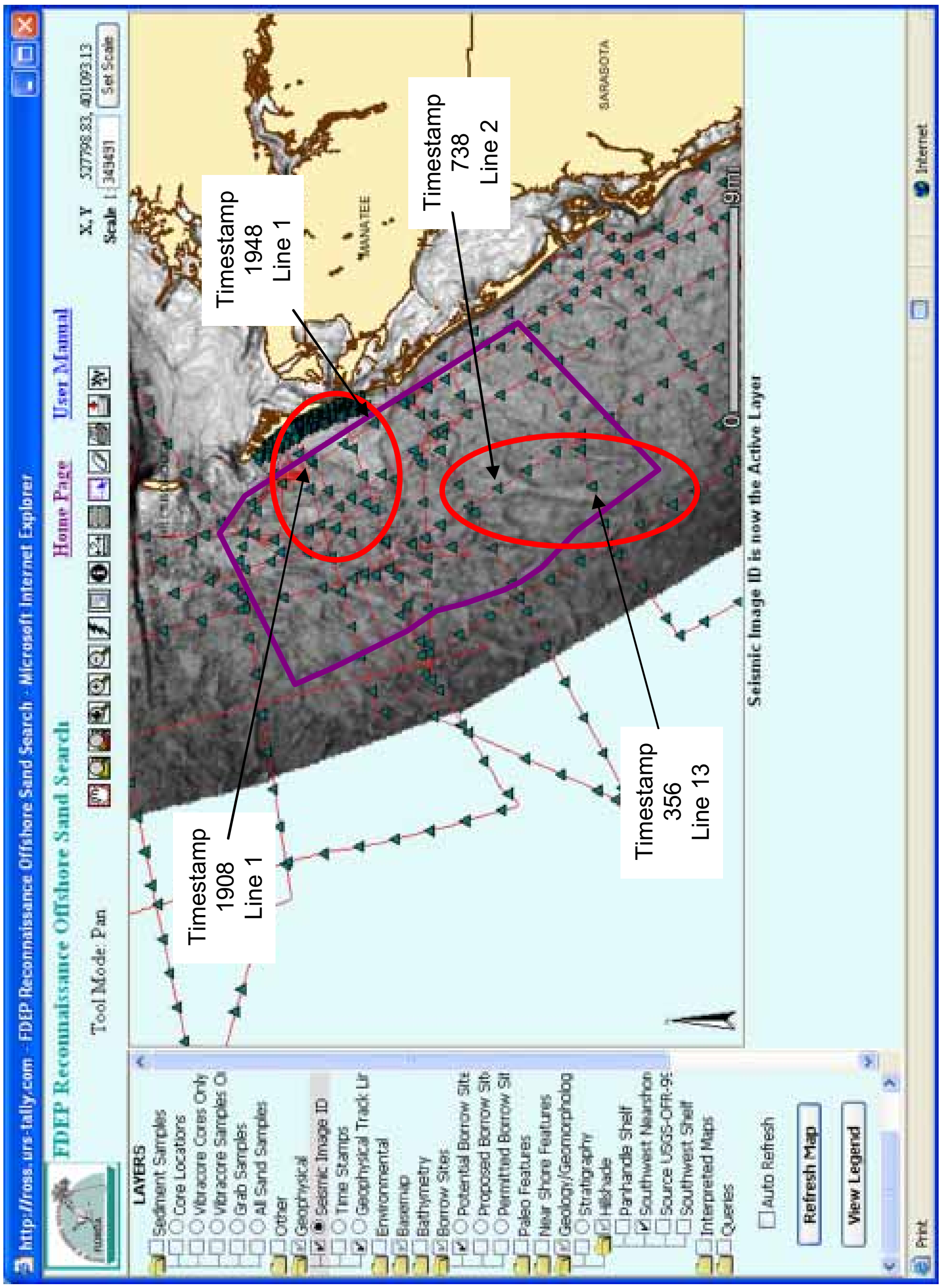


Figure 6-14. Geophysical image for trackline 1 Transgressive ebb delta.
Oval shows location of feature in Area 2A.

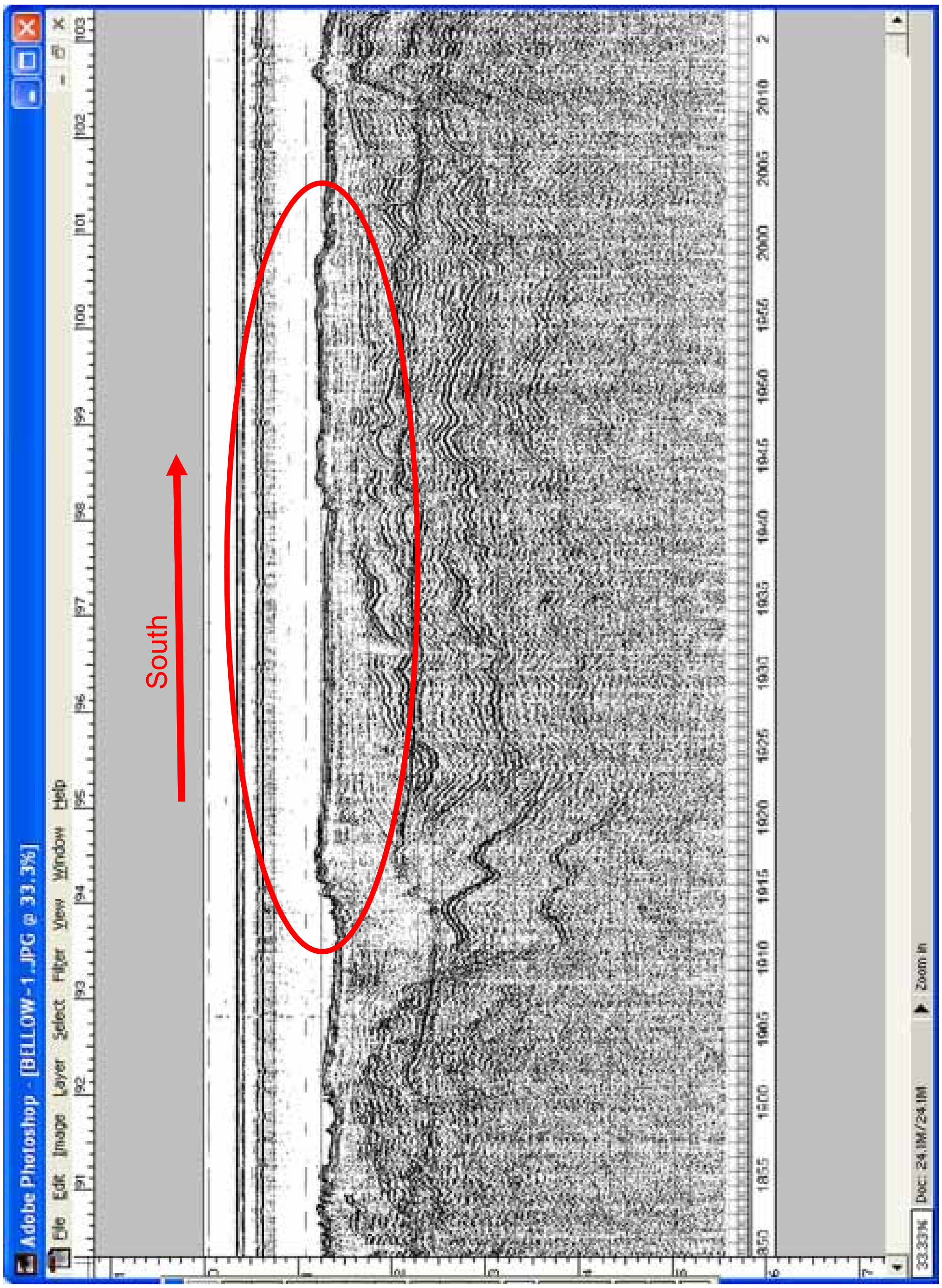
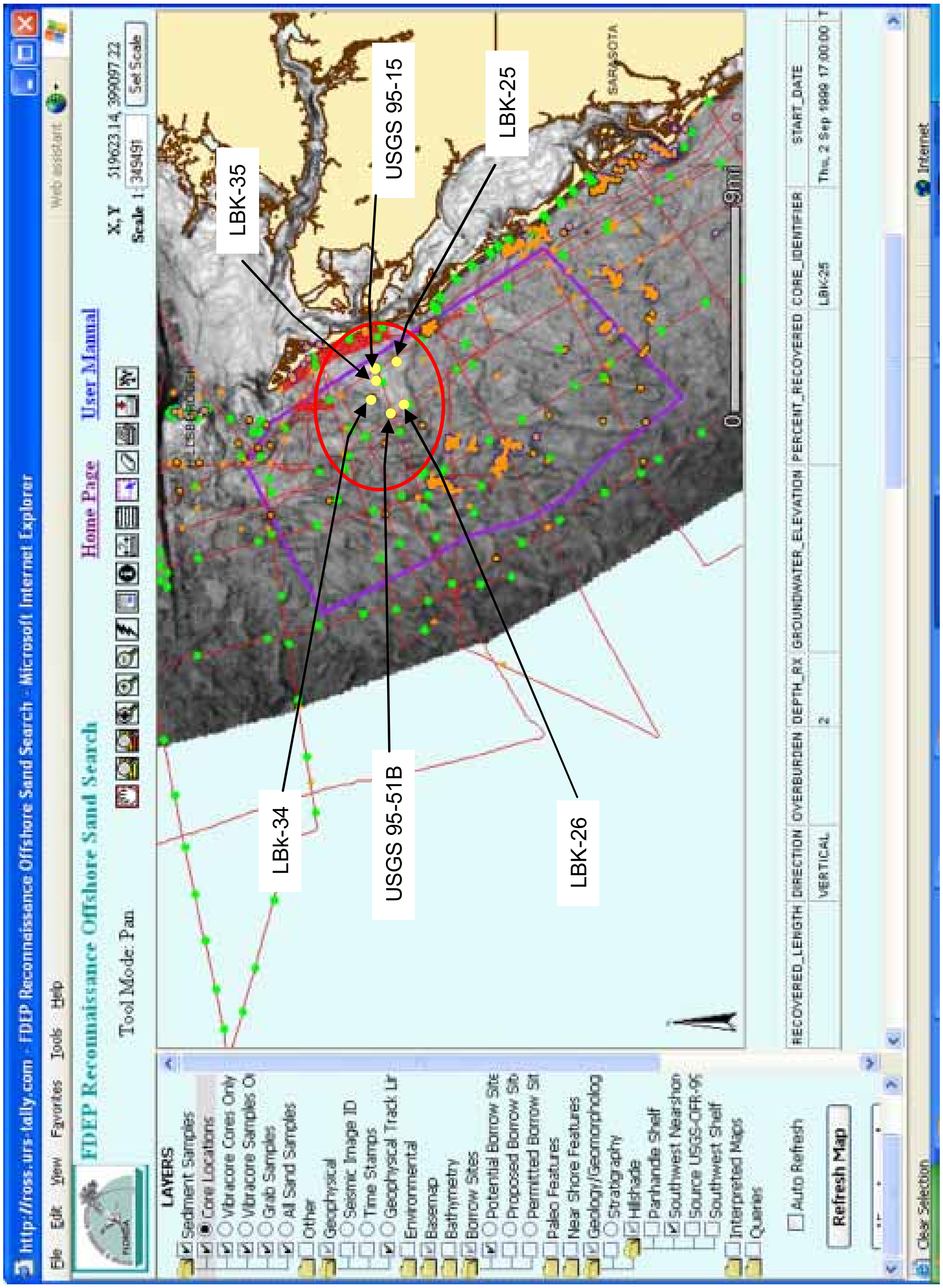


Figure 6-15. Area 2A, Location of vibracores in relation to geophysical data.



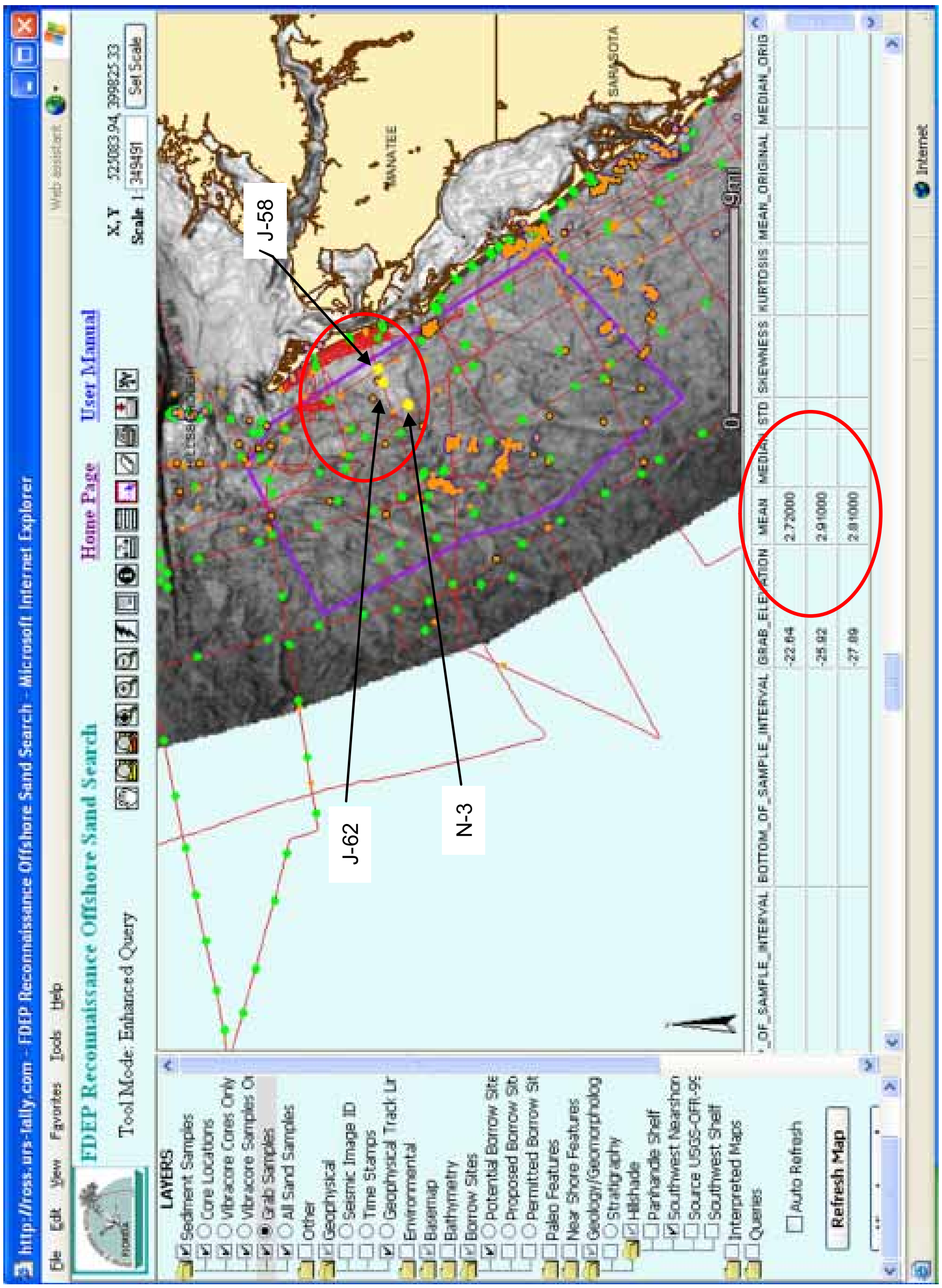
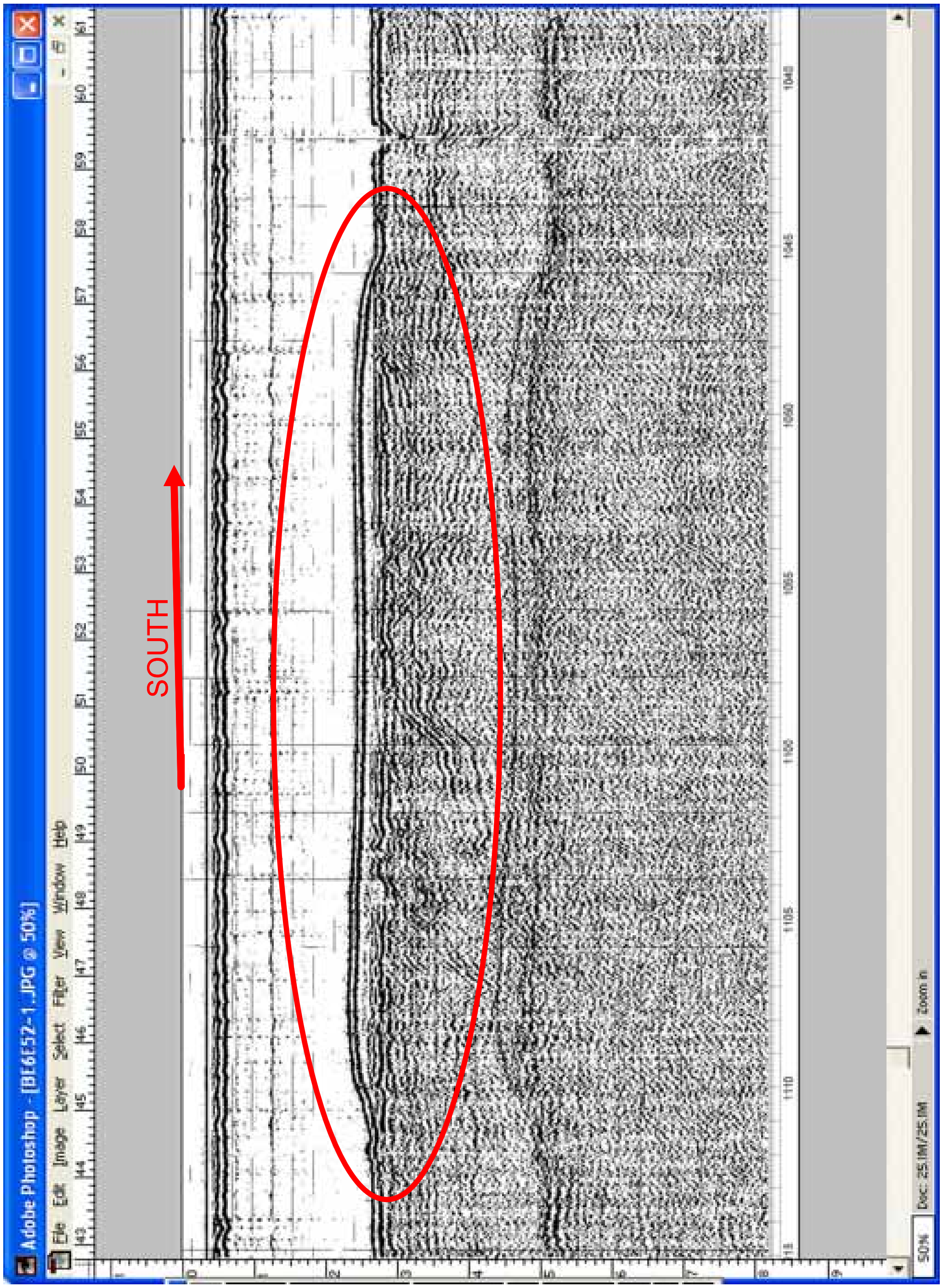


Figure 6-16. Area 2A, location of grab samples in relation to geophysical data. Mean grain sizes for the three samples are, J-58 = 2.91, J-62 = 2.72 and N-3 = 2.81 phi. These correspond to fine sand.

Figure 6-17. Area 2B geophysical image for trackline 2 showing sand feature (oval).



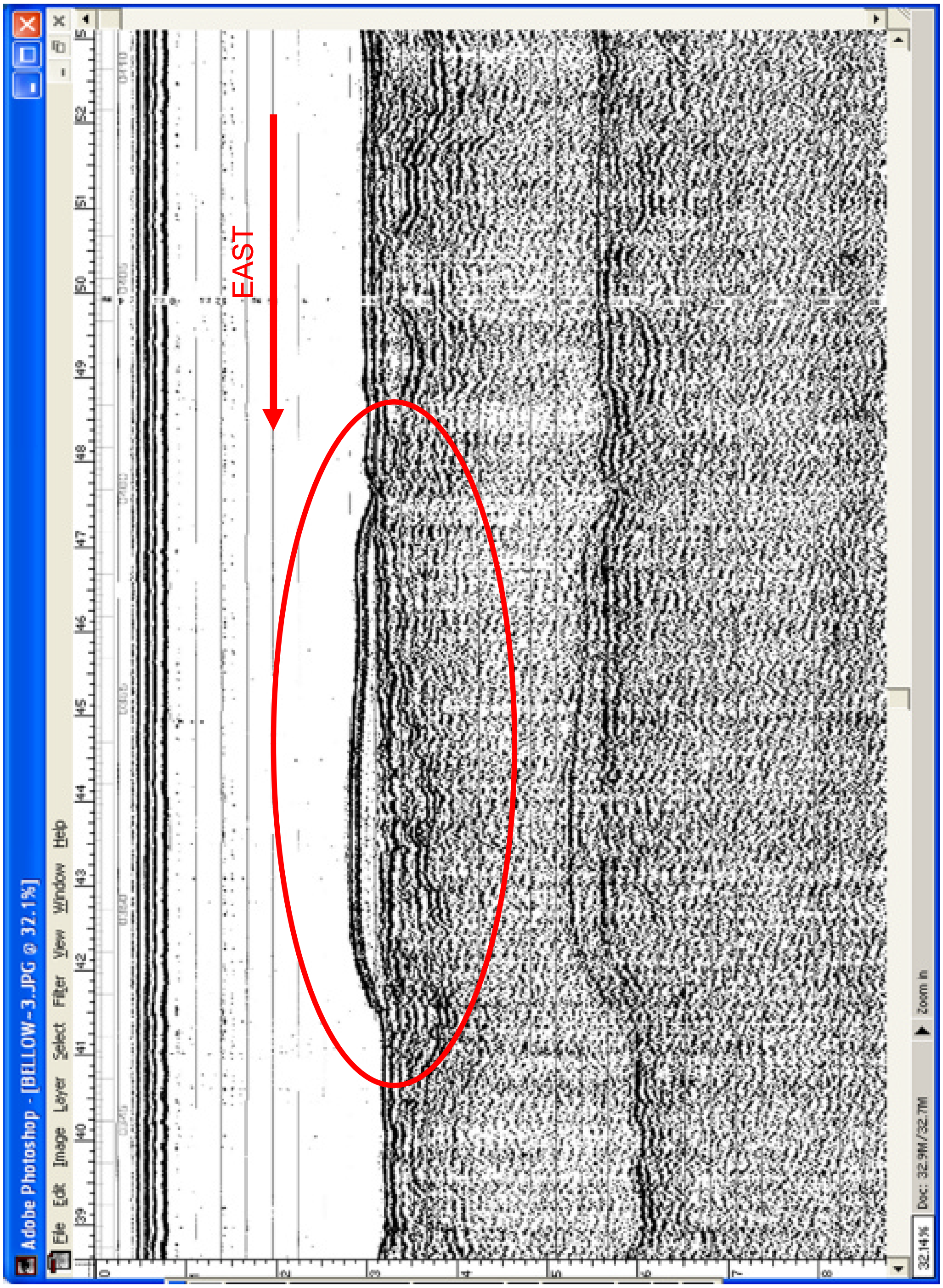


Figure 6-18. Area 2B geophysical image for trackline 13 showing sand feature (oval).

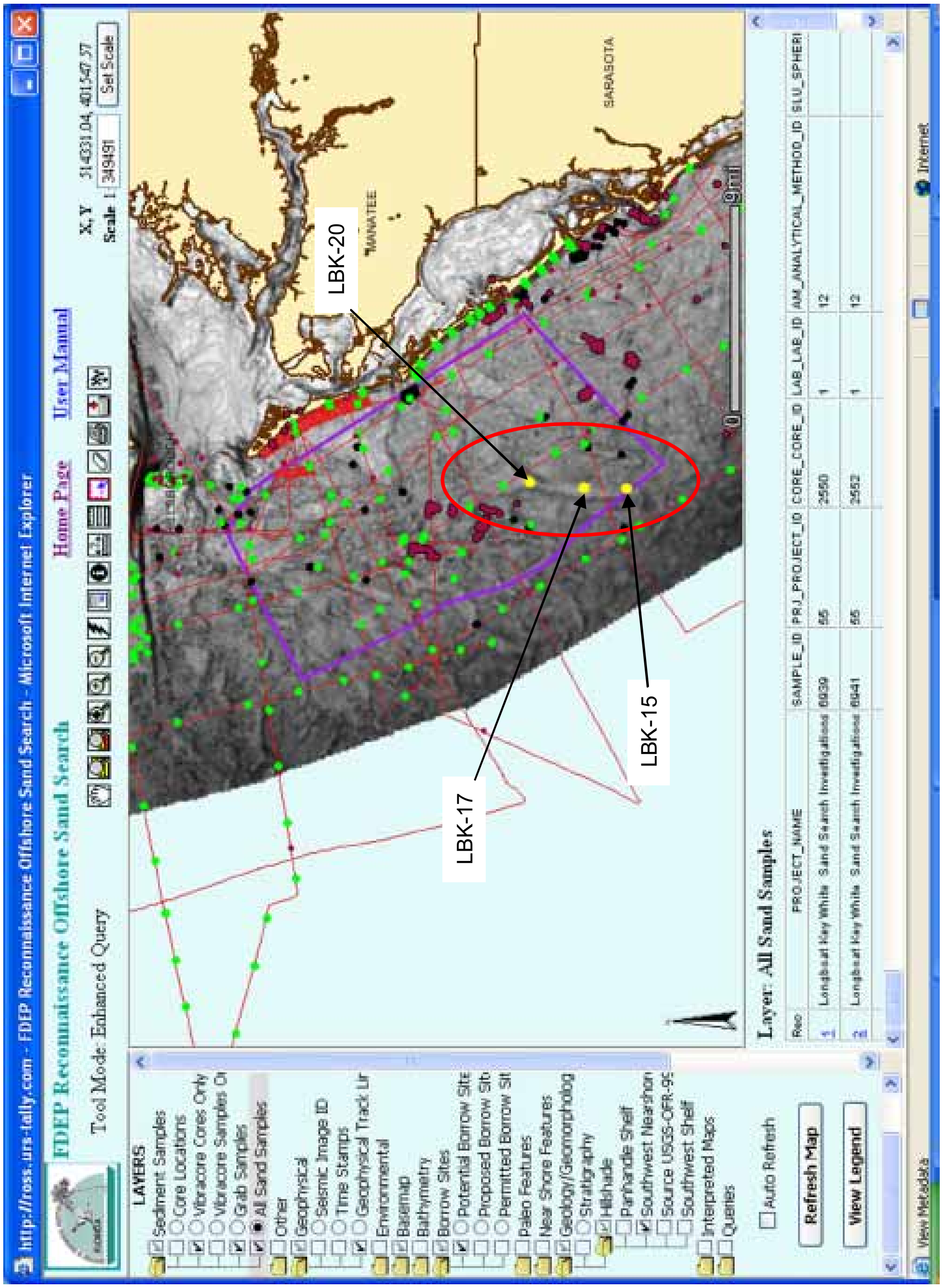


Figure 6-19. Area 2B location of vibracores in relation to geophysical data.

Figure 6-20. Area 2B location of grab sample in relation to geophysical data. Mean grain size of sample N-40 is 3.29 phi. This corresponds to fine sand.

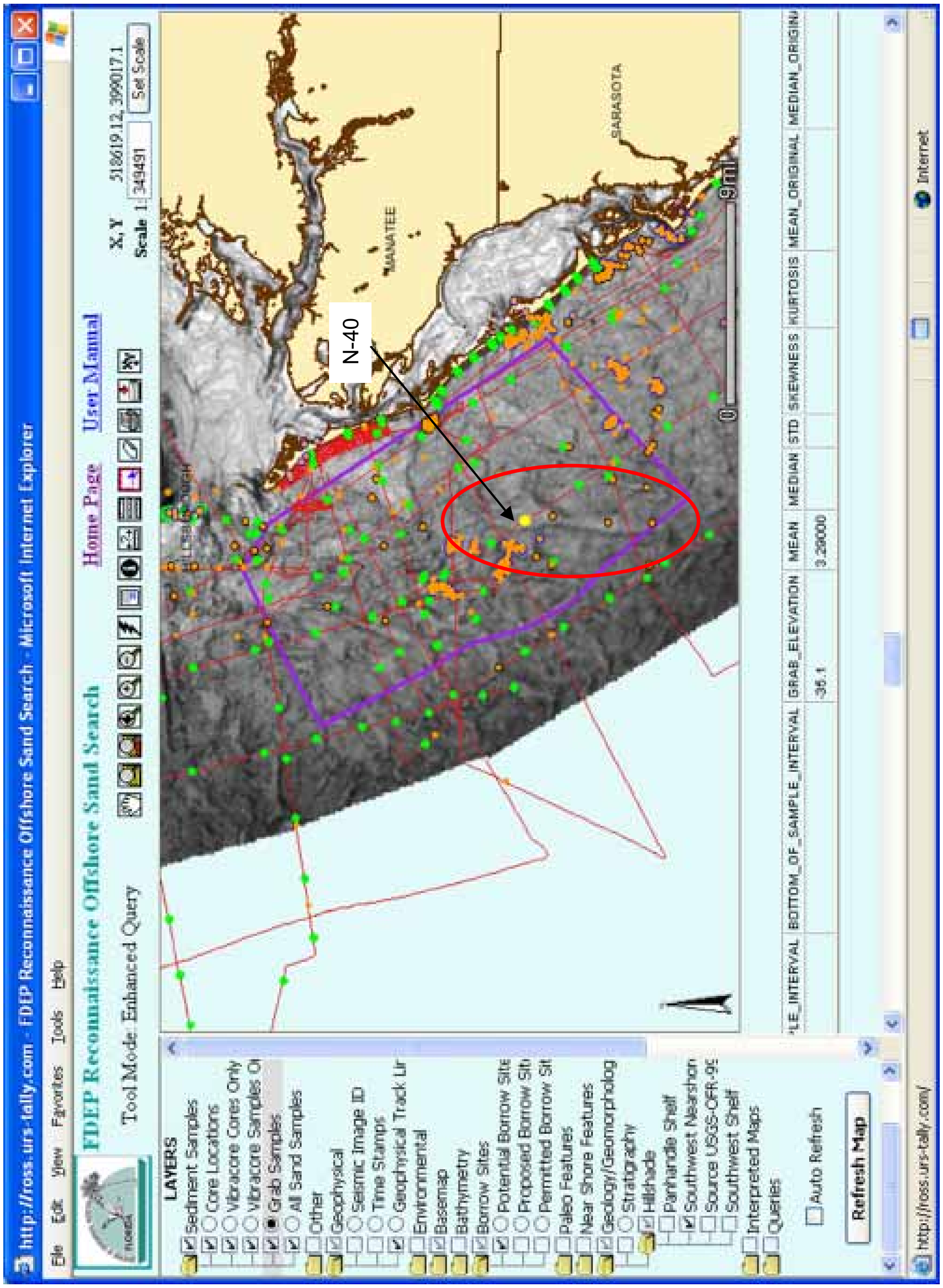


Figure 6-21. Potential sand targets occurring in sand ridges (ridge axis marked by white lines) and historical data available for Central Coastal Segment, Southern Sarasota and Charlotte Counties (Study Area 3).

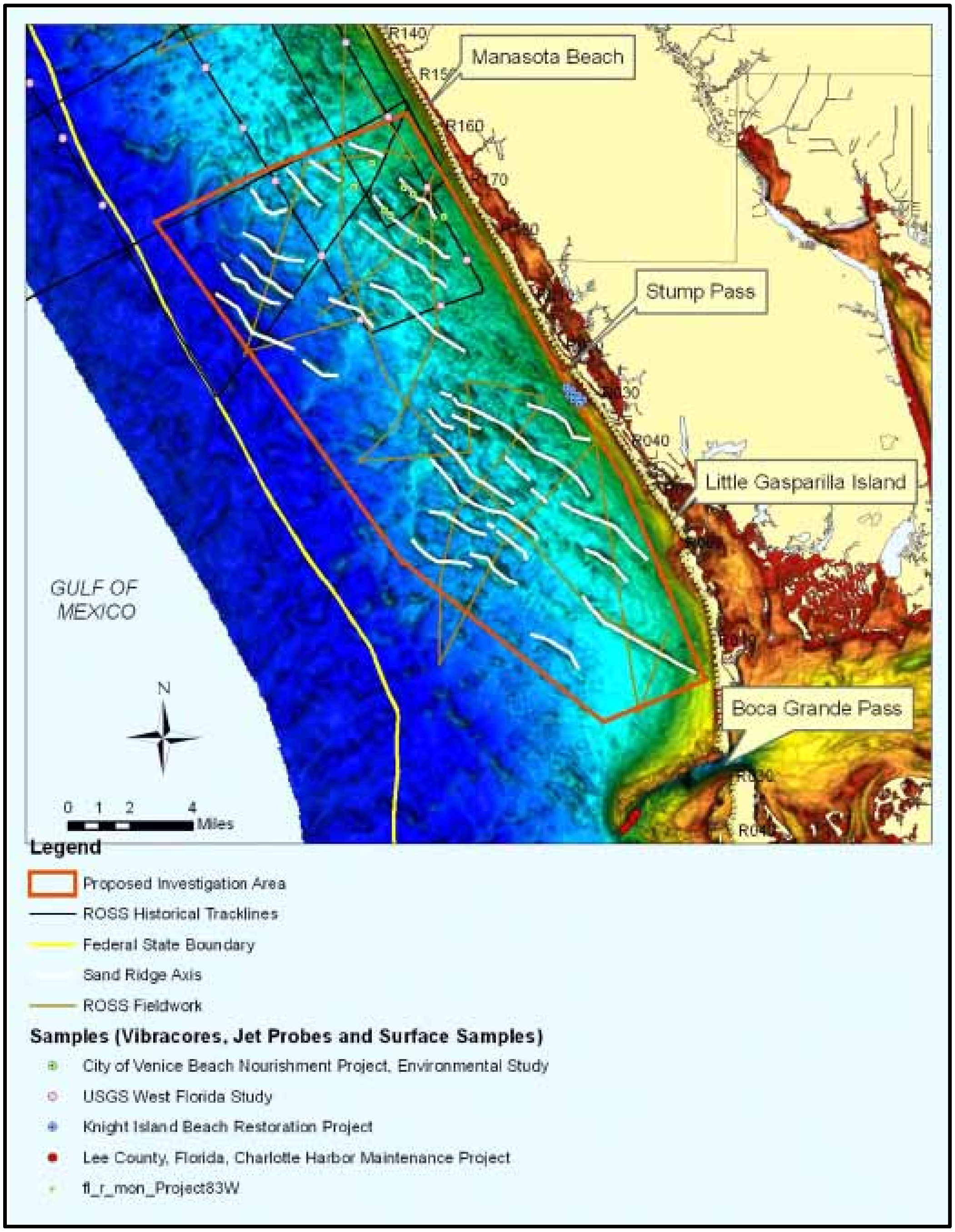
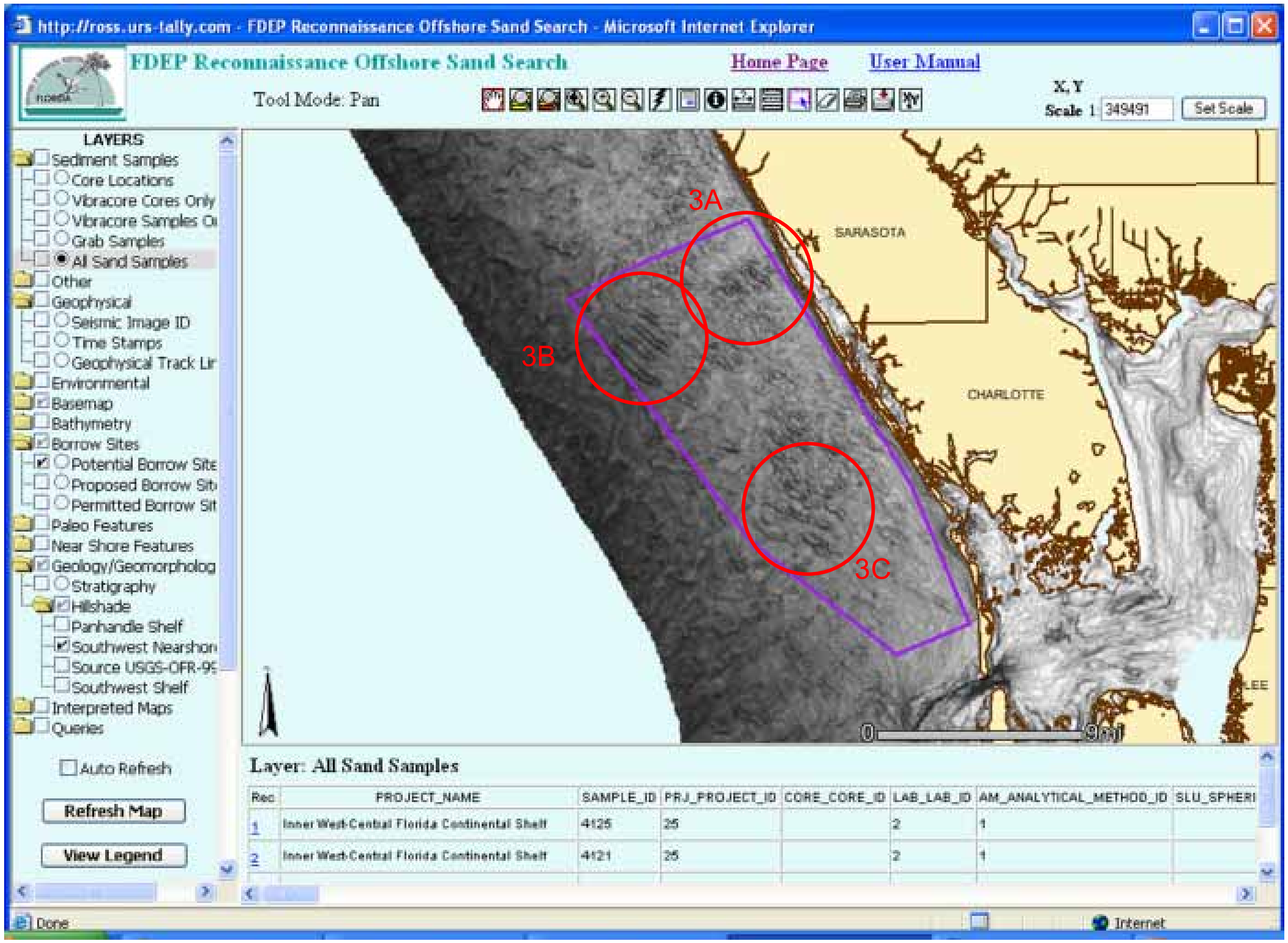


Figure 6-22. Area 3 showing areas 3A, 3B and 3C (circled) for future data acquisition.



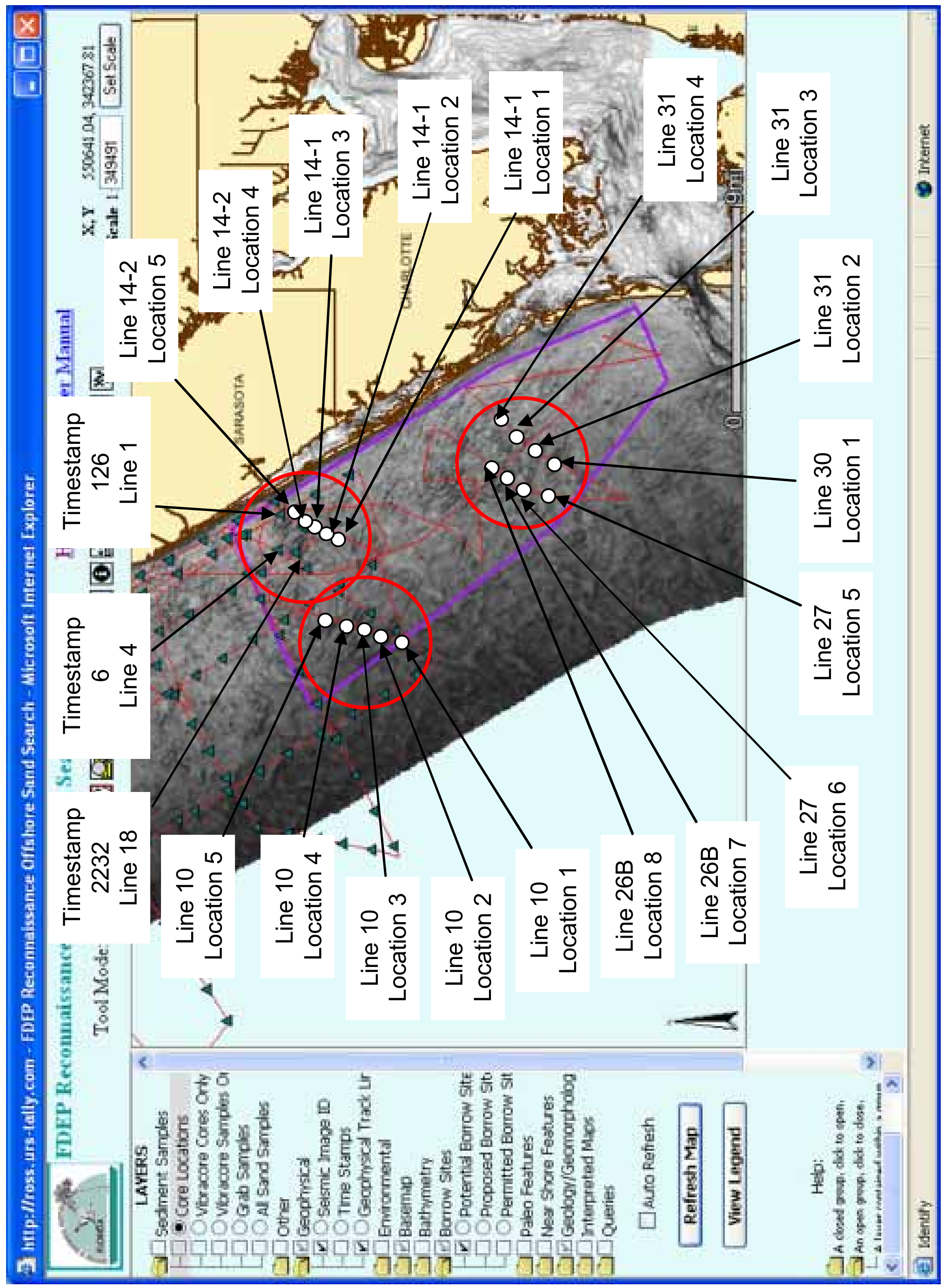


Figure 6-23. Area 3 geophysical image locations.

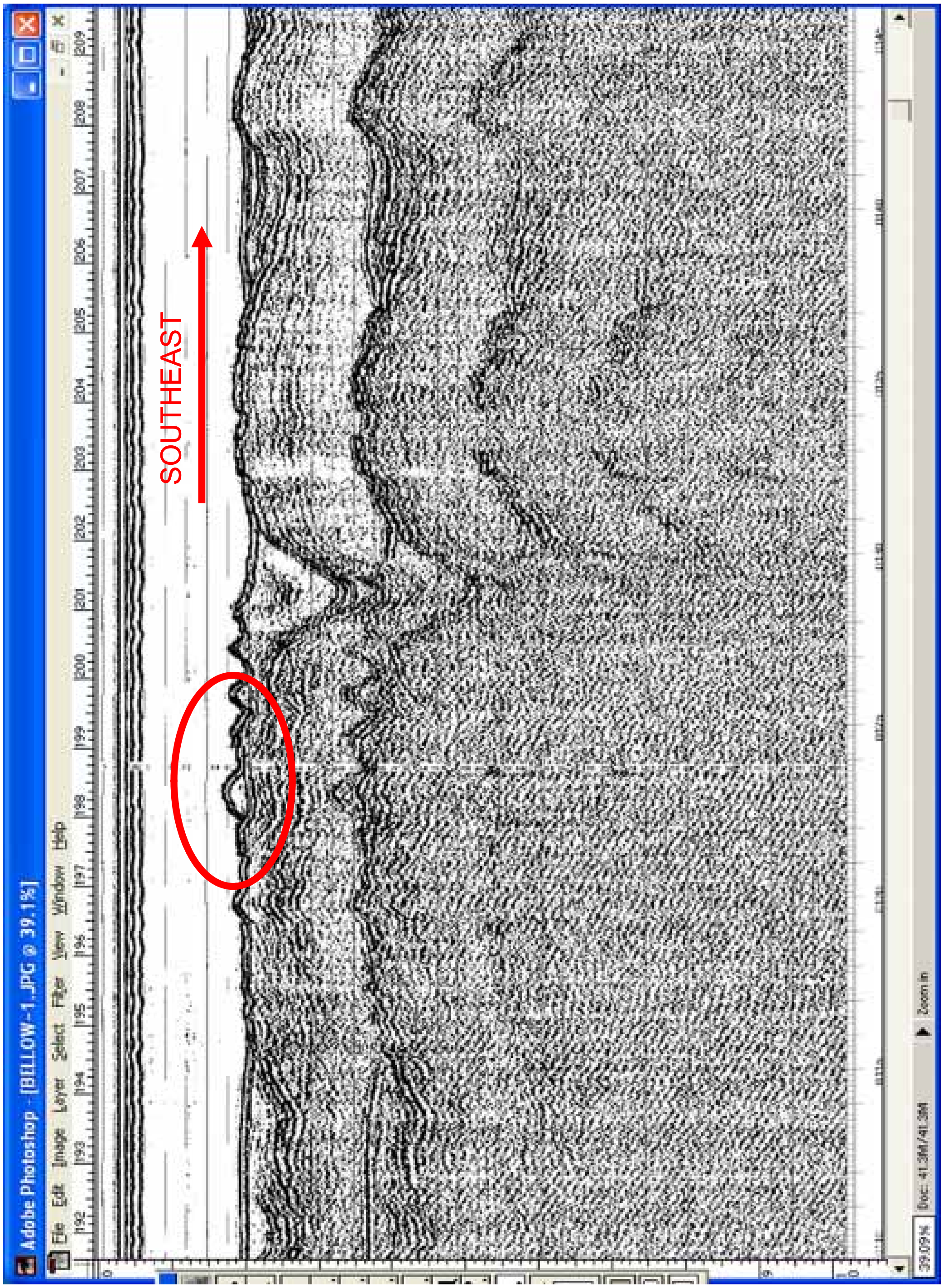


Figure 6-24. Area 3A geophysical image for trackline 1 showing sand ridge.

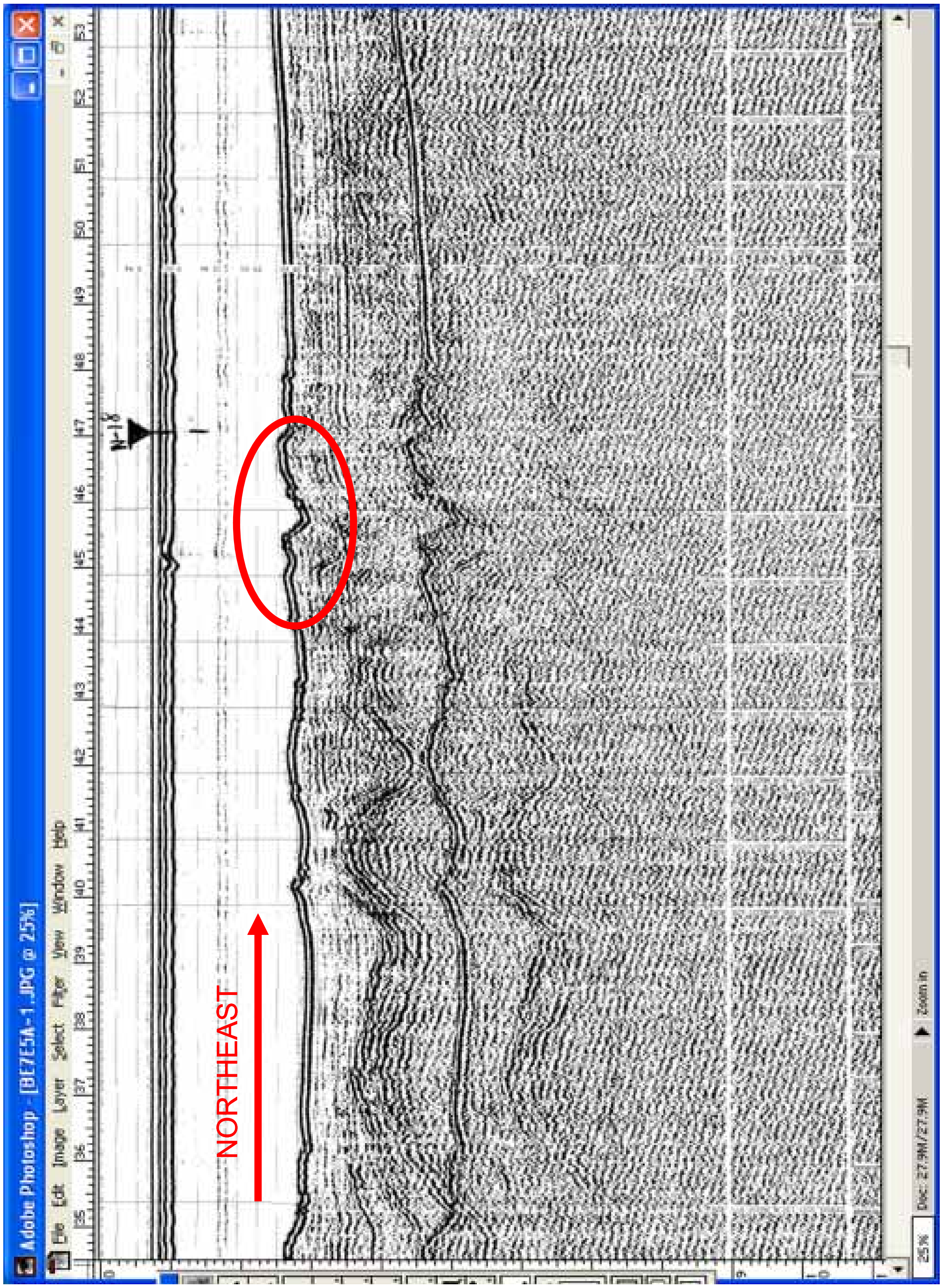


Figure 6-25. Area 3A geophysical image for trackline 4 showing sand ridges.

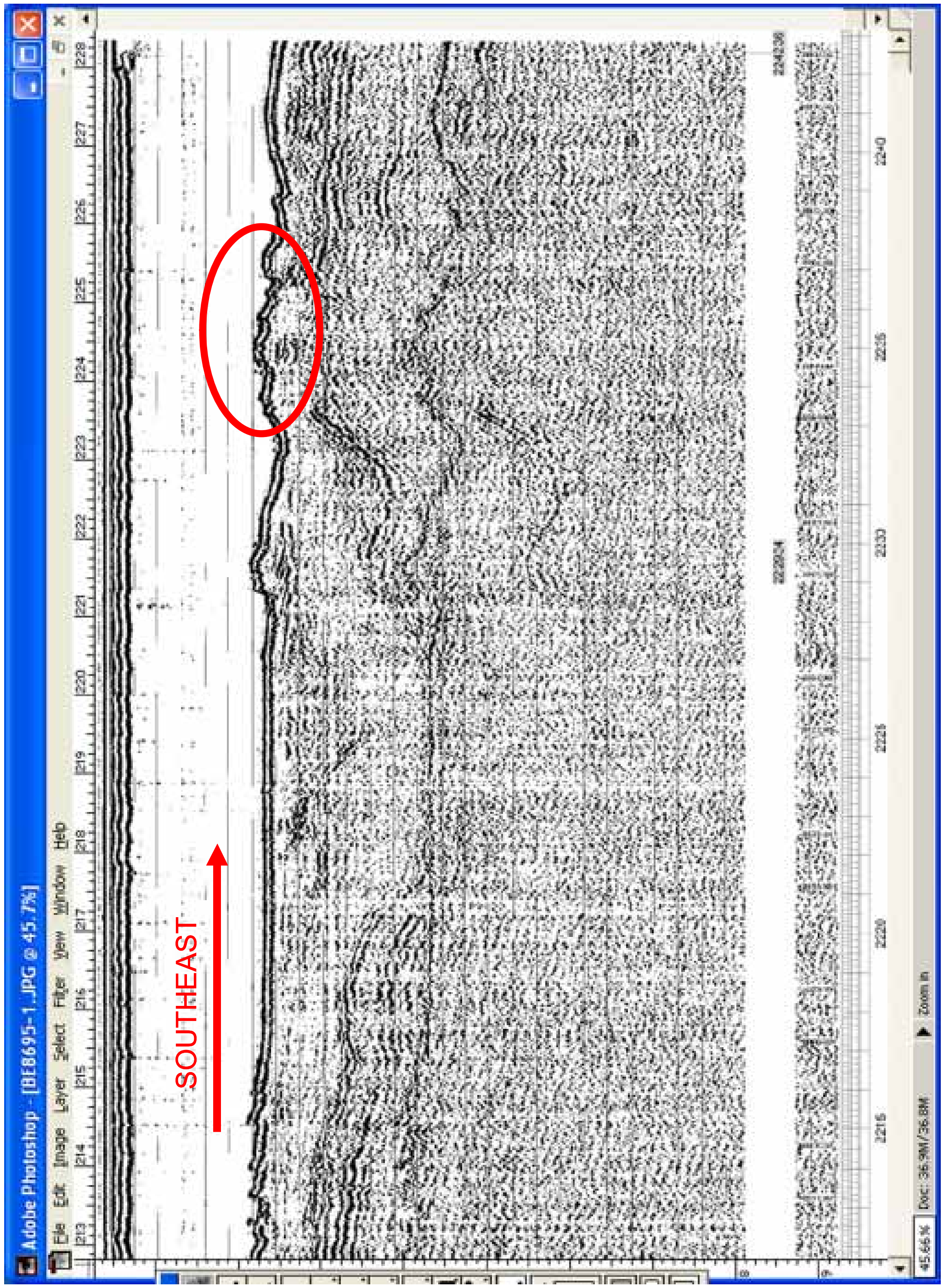
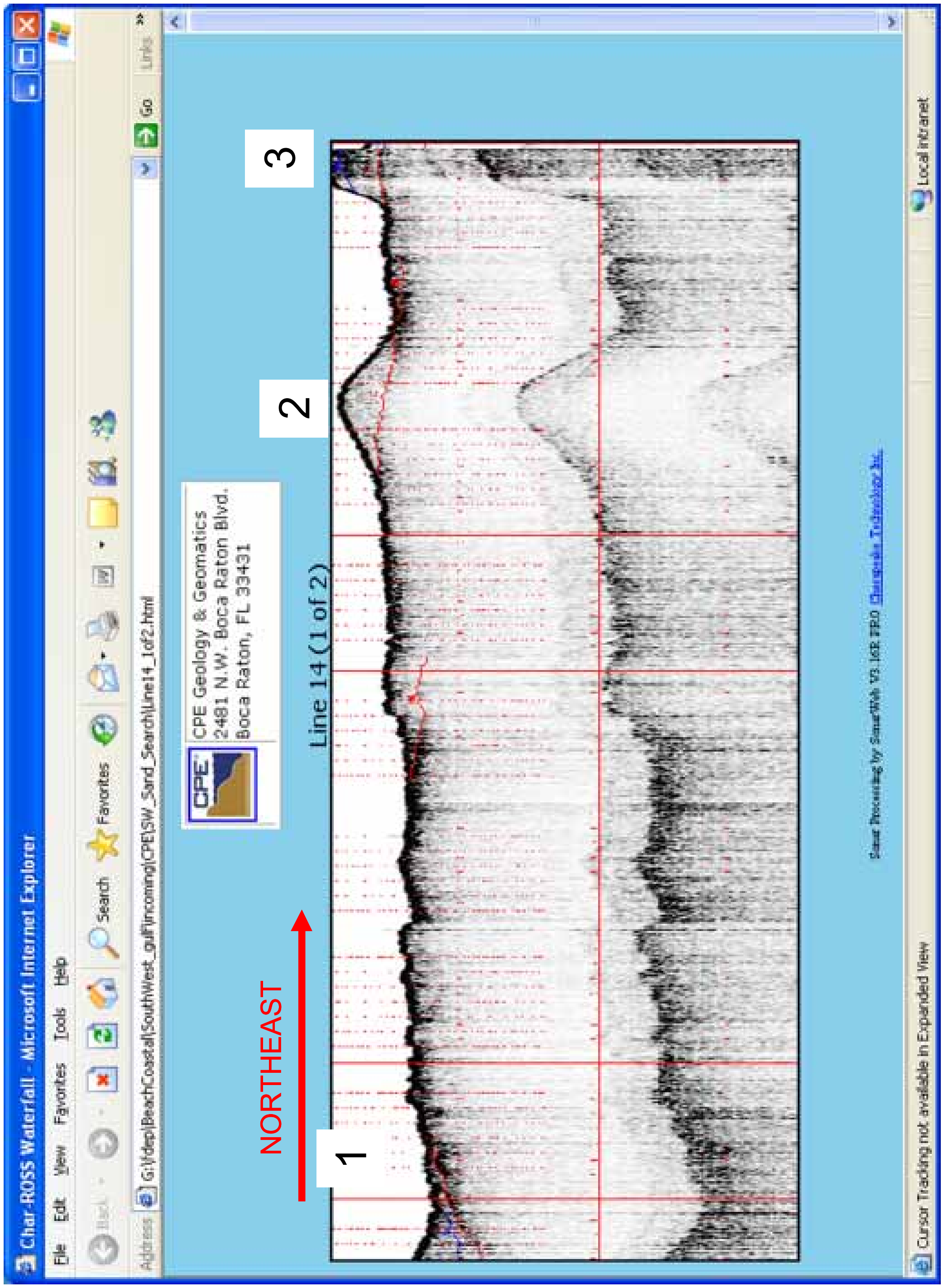


Figure 6-26. Area 3A geophysical image for trackline 18 showing sand ridge.

Figure 6-27. Area 3A geophysical image for line 14-1 locations 1, 2 and 3 on Figure 6-23.



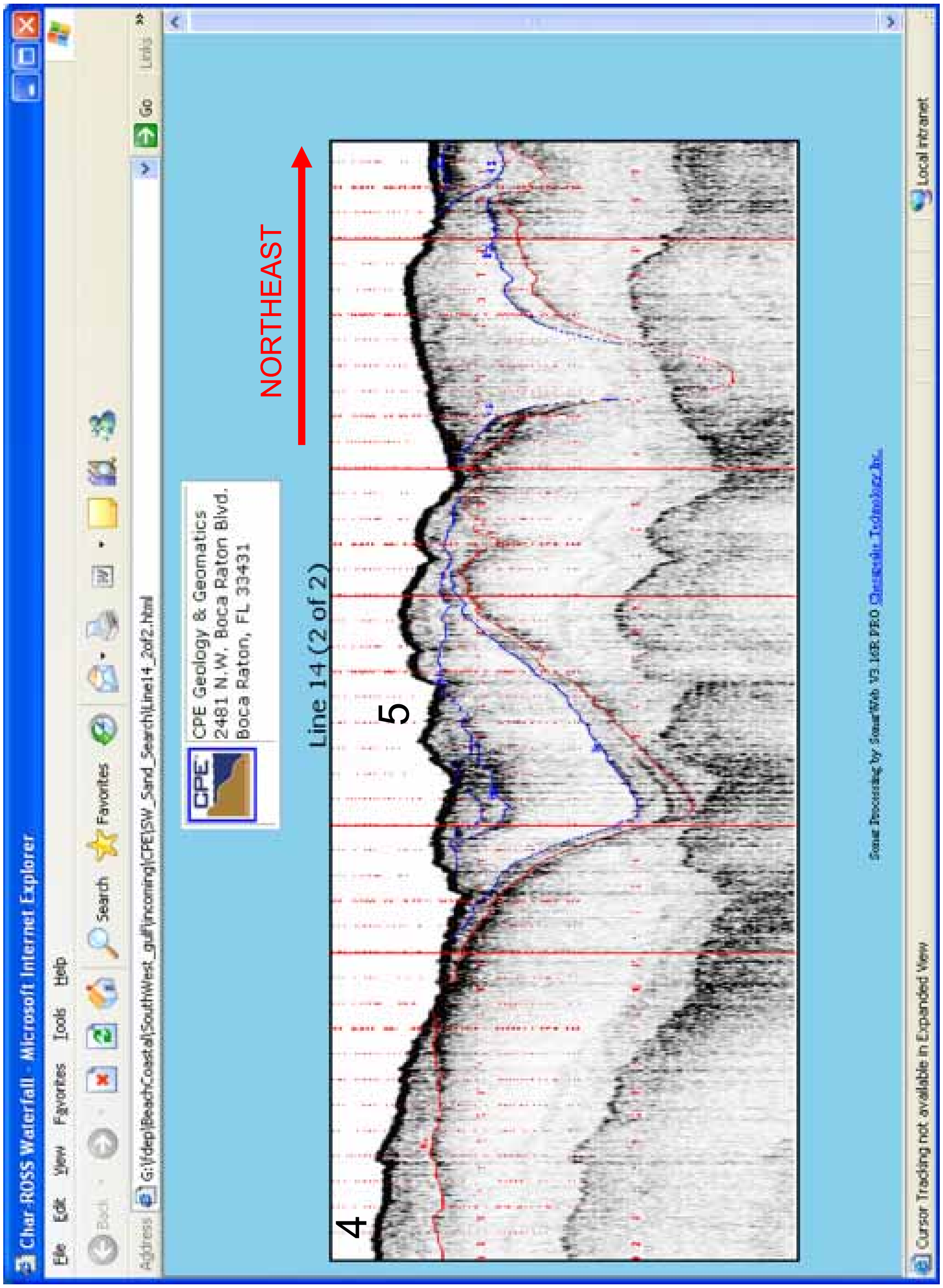


Figure 6-28. Area 3A geophysical image for line 14-2 locations 4 and 5 on Figure 6-23.

Figure 6-29. Area 3A location of grab samples in relation to geophysical data. Mean grain size for the samples are; M-2 = 0.98, M-3 = 0.22, M-5 = 0.32, M-11 = 0.32, M-12 = 0.41 and N-19 = -0.62 phi. These values correspond to medium sand.

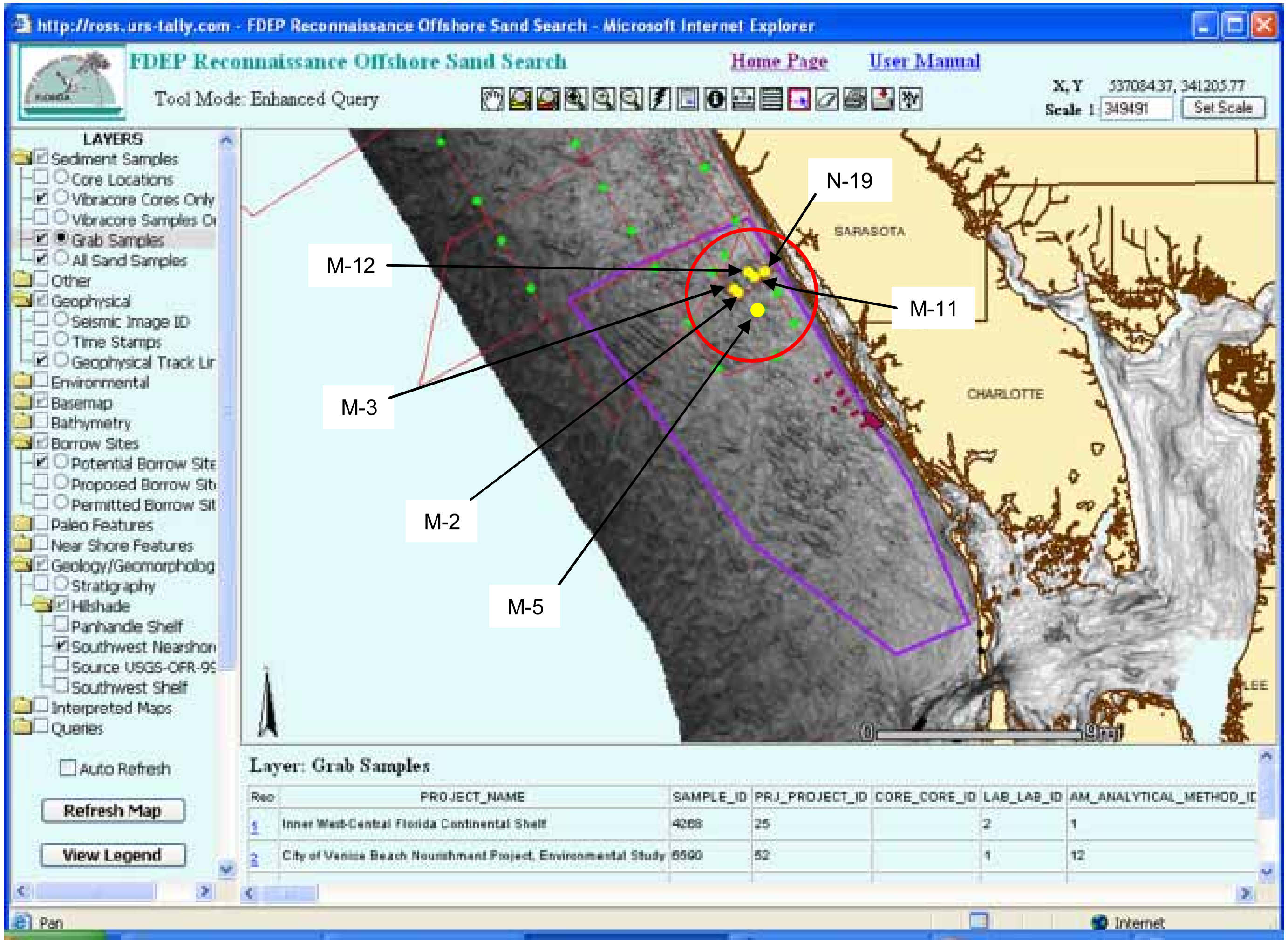


Figure 6-30. Area 3B line 10-1 locations 3, 4 and 5 on map Figure 6-23.

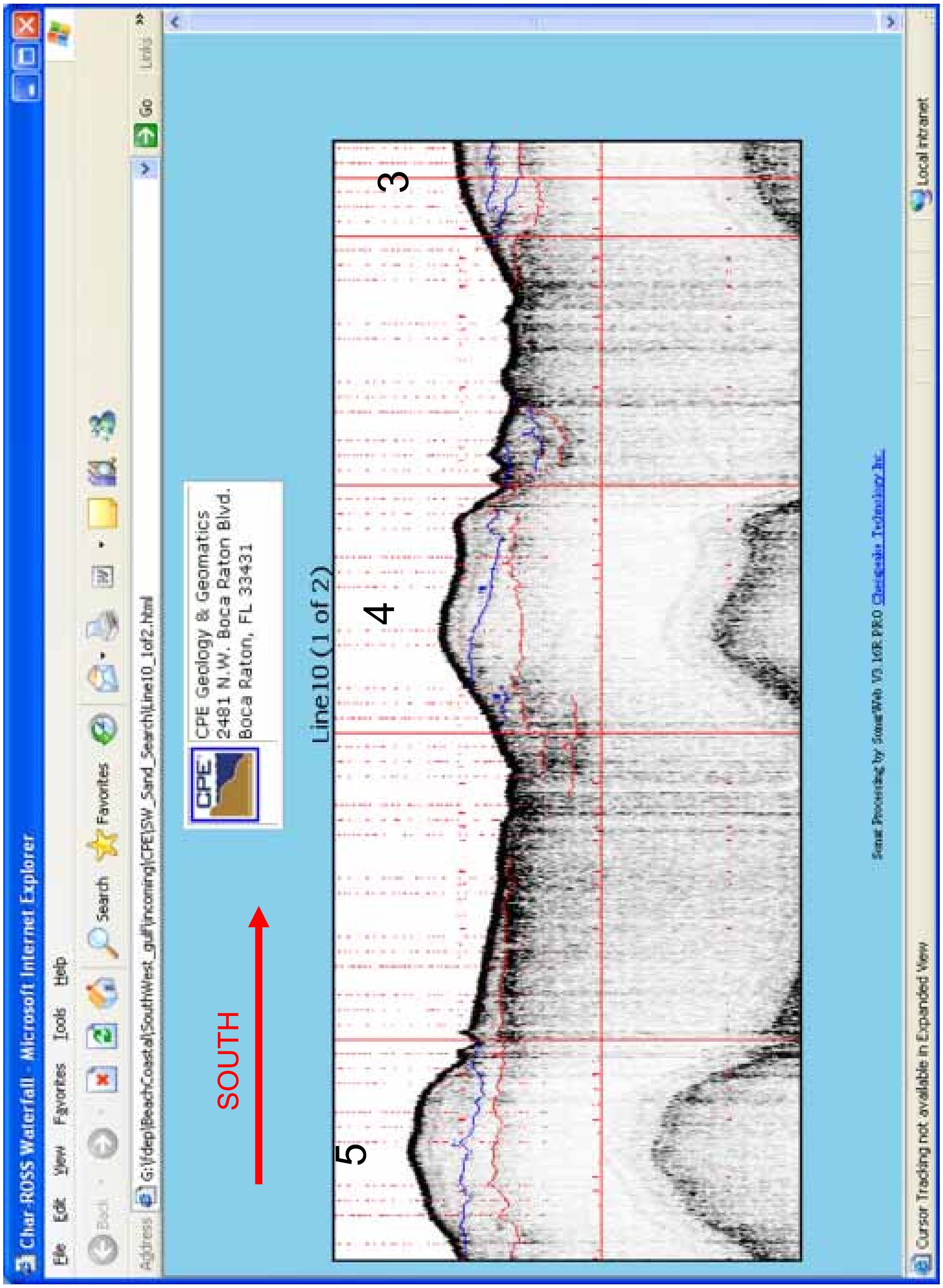
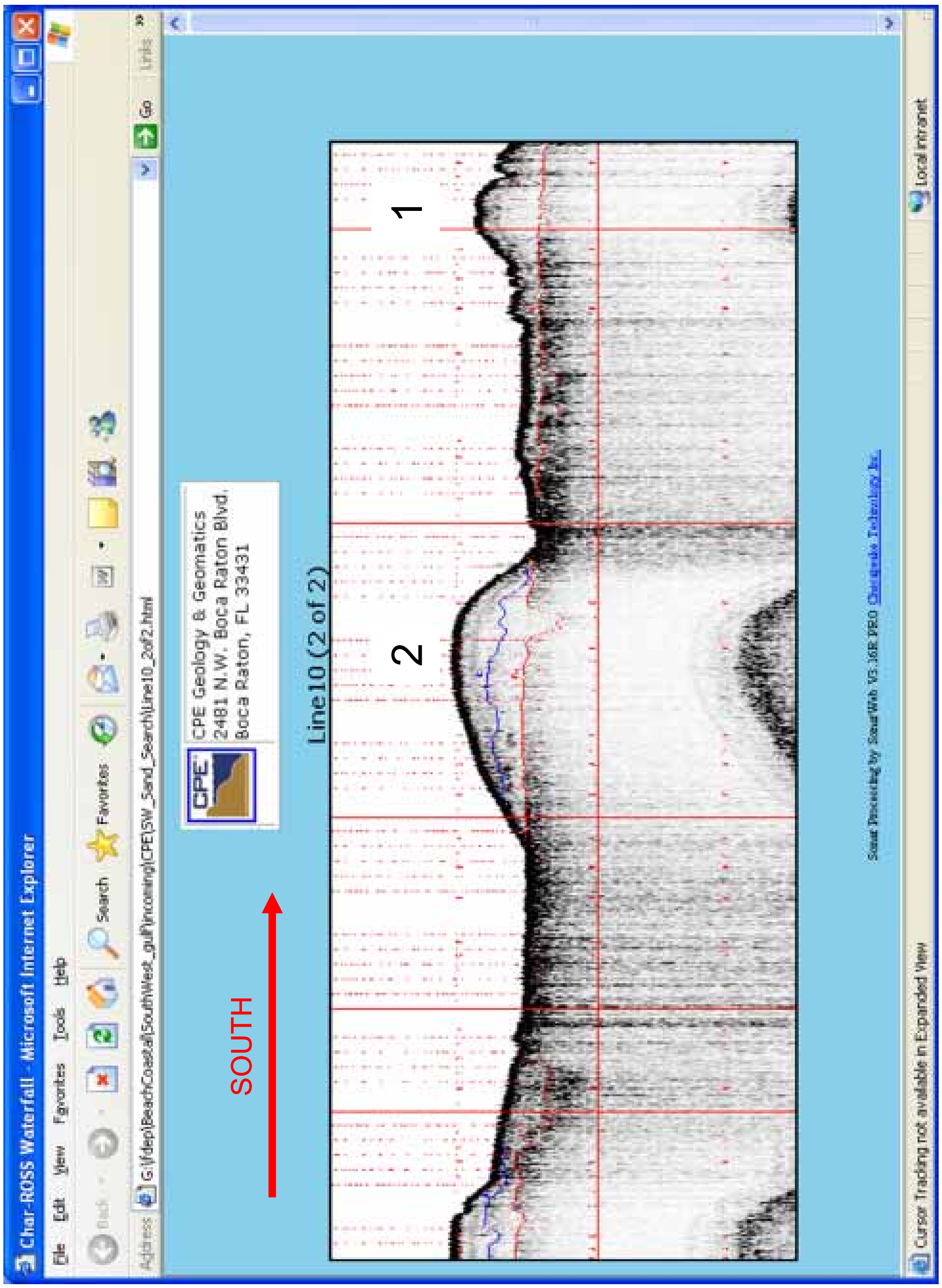


Figure 6-31. Area 3B line 10-2 locations 2 and 1 on map Figure 6-23.



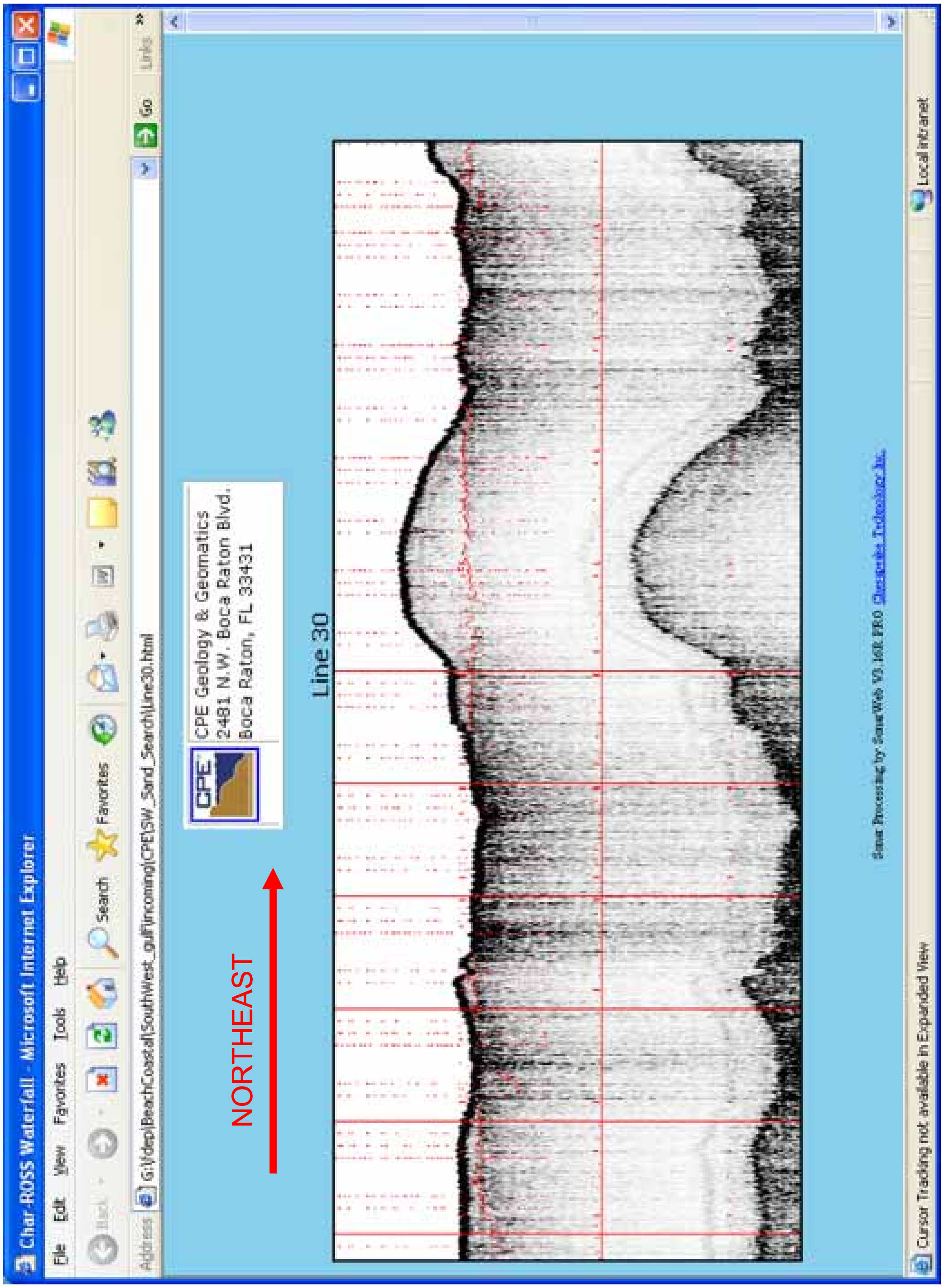
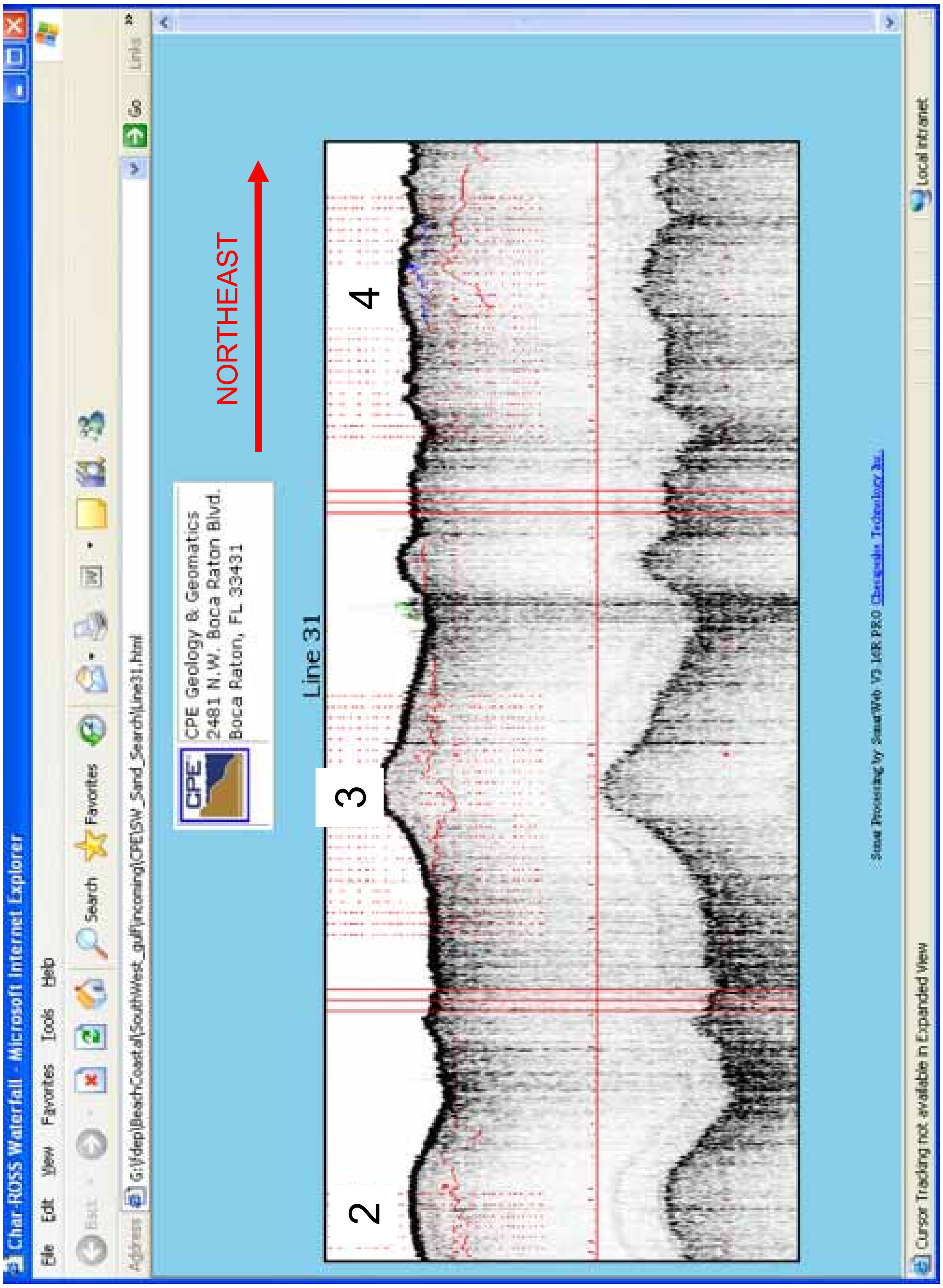


Figure 6-32. Area 3C line 30 location 1 on map Figure 6-23.

Figure 6-33. Area 3C line 31 locations 2, 3 and 4 on map Figure 6-23.



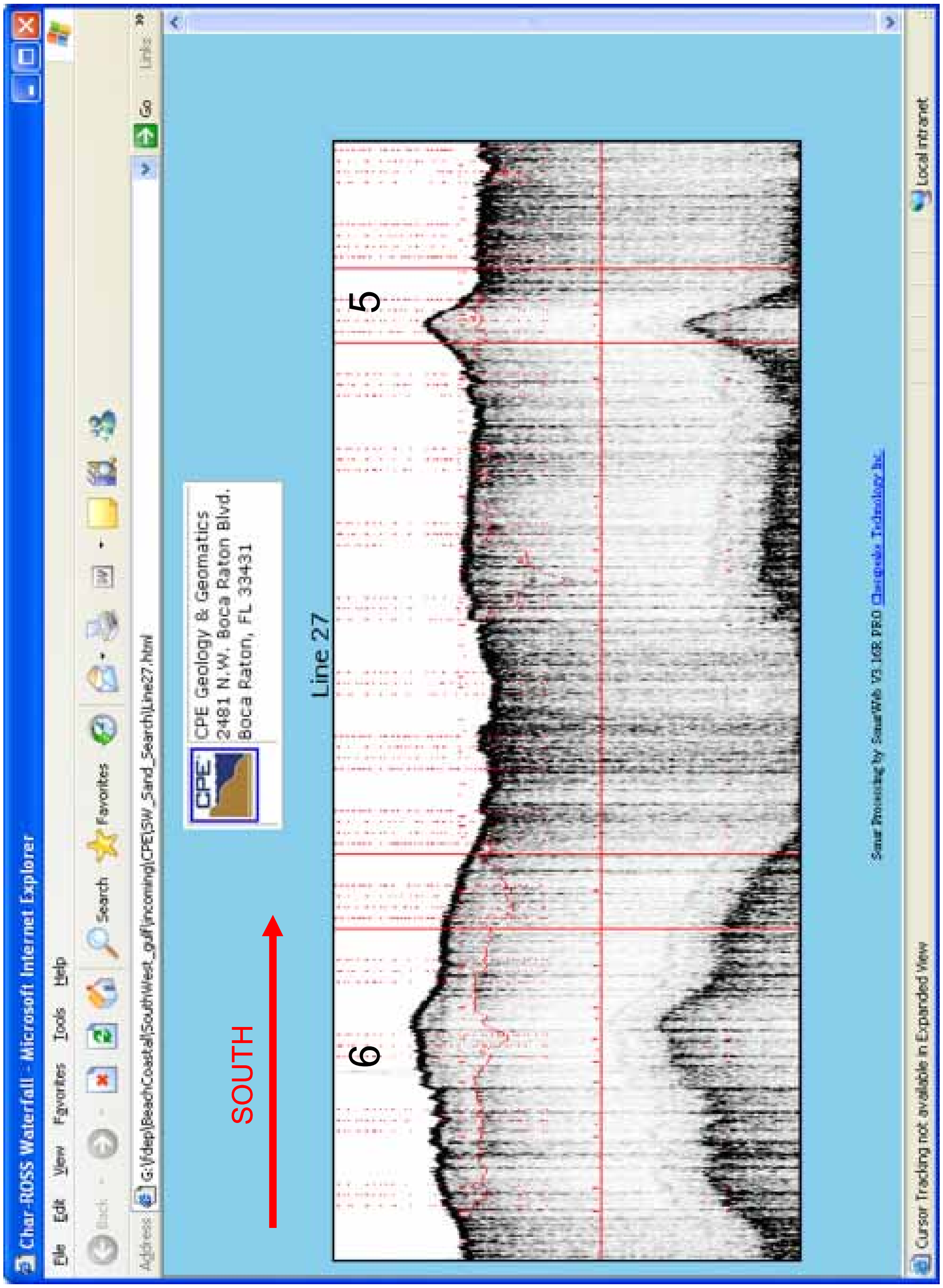


Figure 6-34. Area 3C line 27 locations 5 and 6 on map Figure 6-23.

Figure 6-35. Area 3C line 26B locations 7 and 8 on map Figure 6-23.

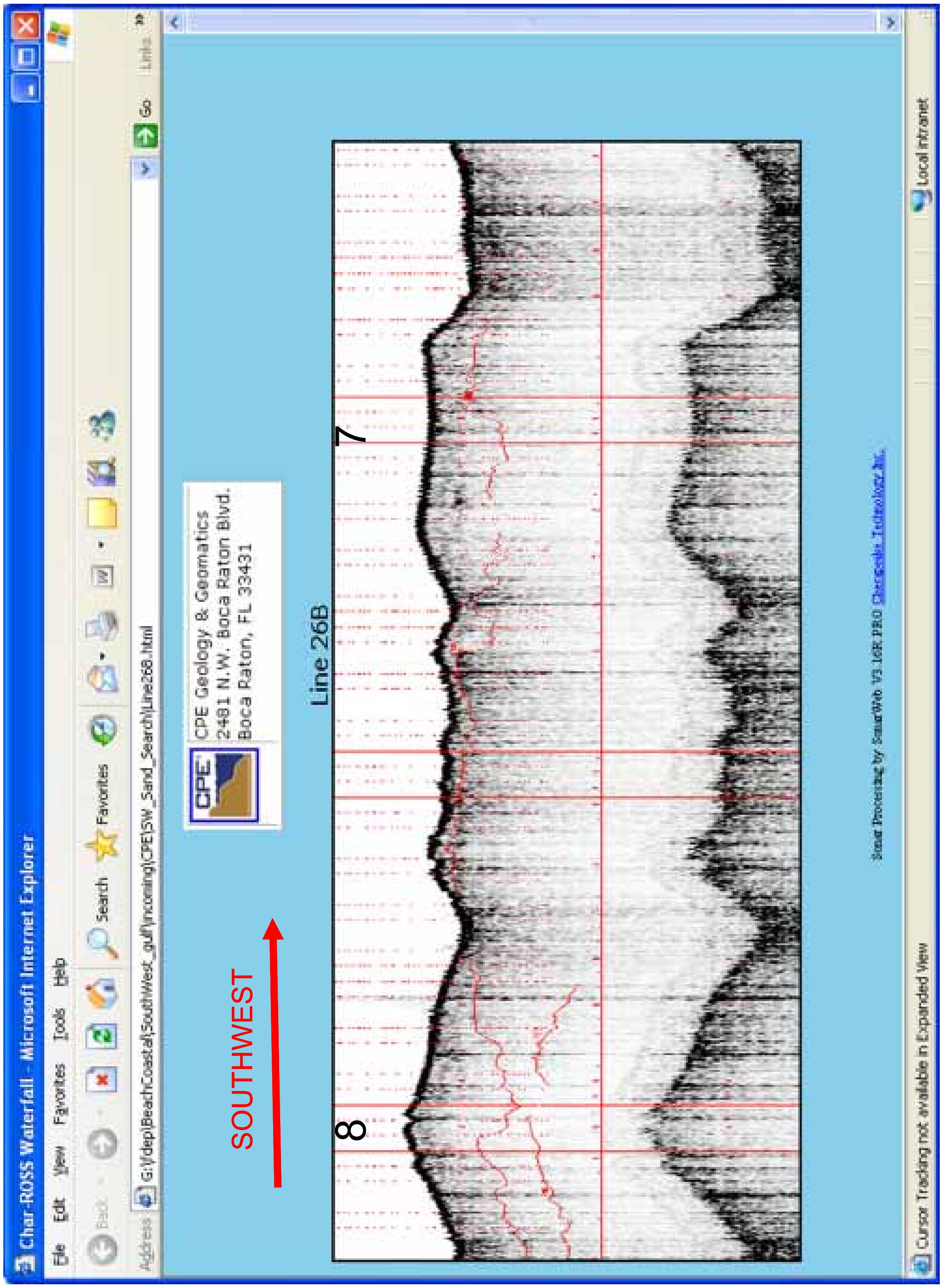
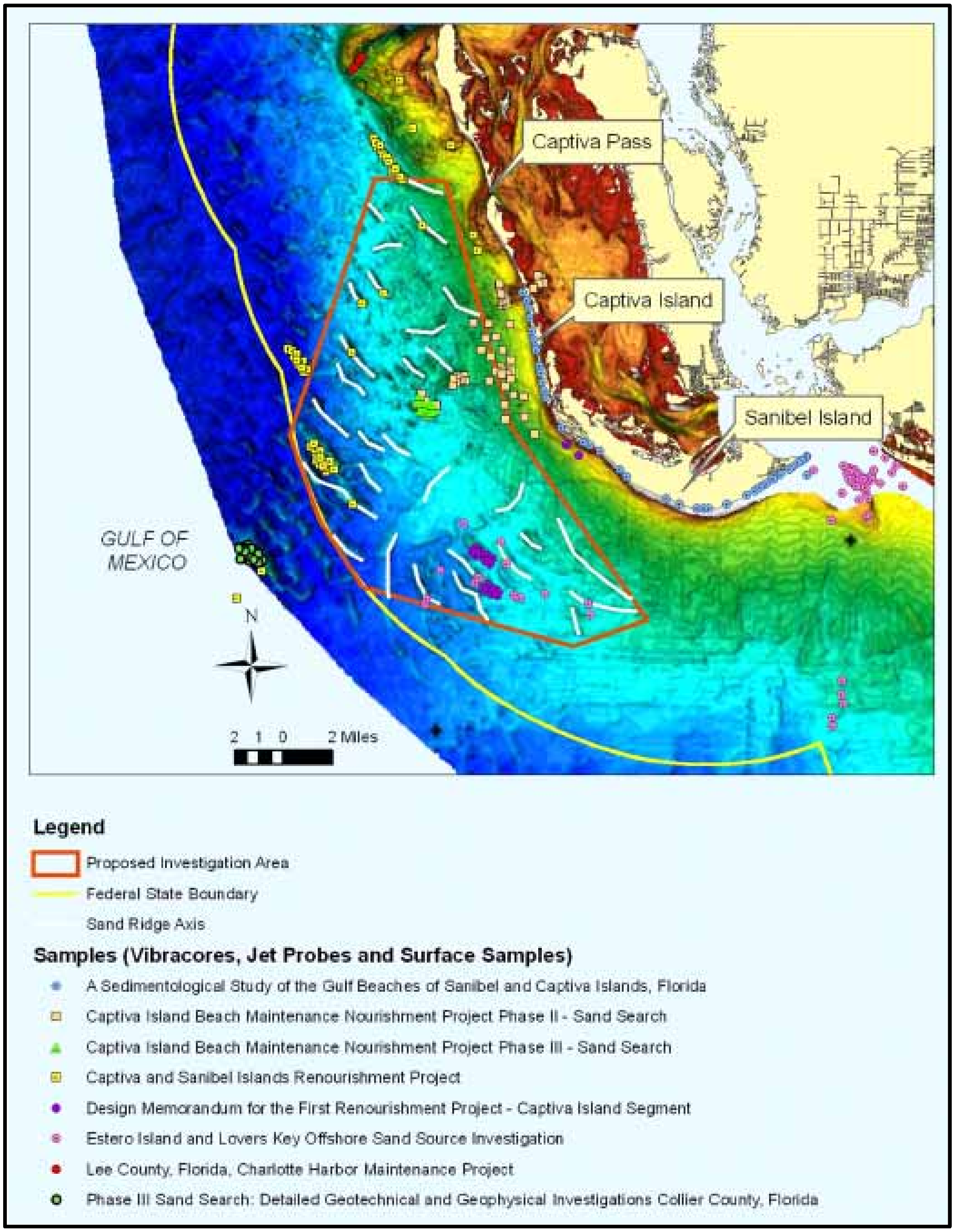


Figure 6-36. Potential sand targets occurring in sand ridges (ridge axis marked by white lines) and historical data available for Southern Coastal Segment, Lee County (Study Area 4).



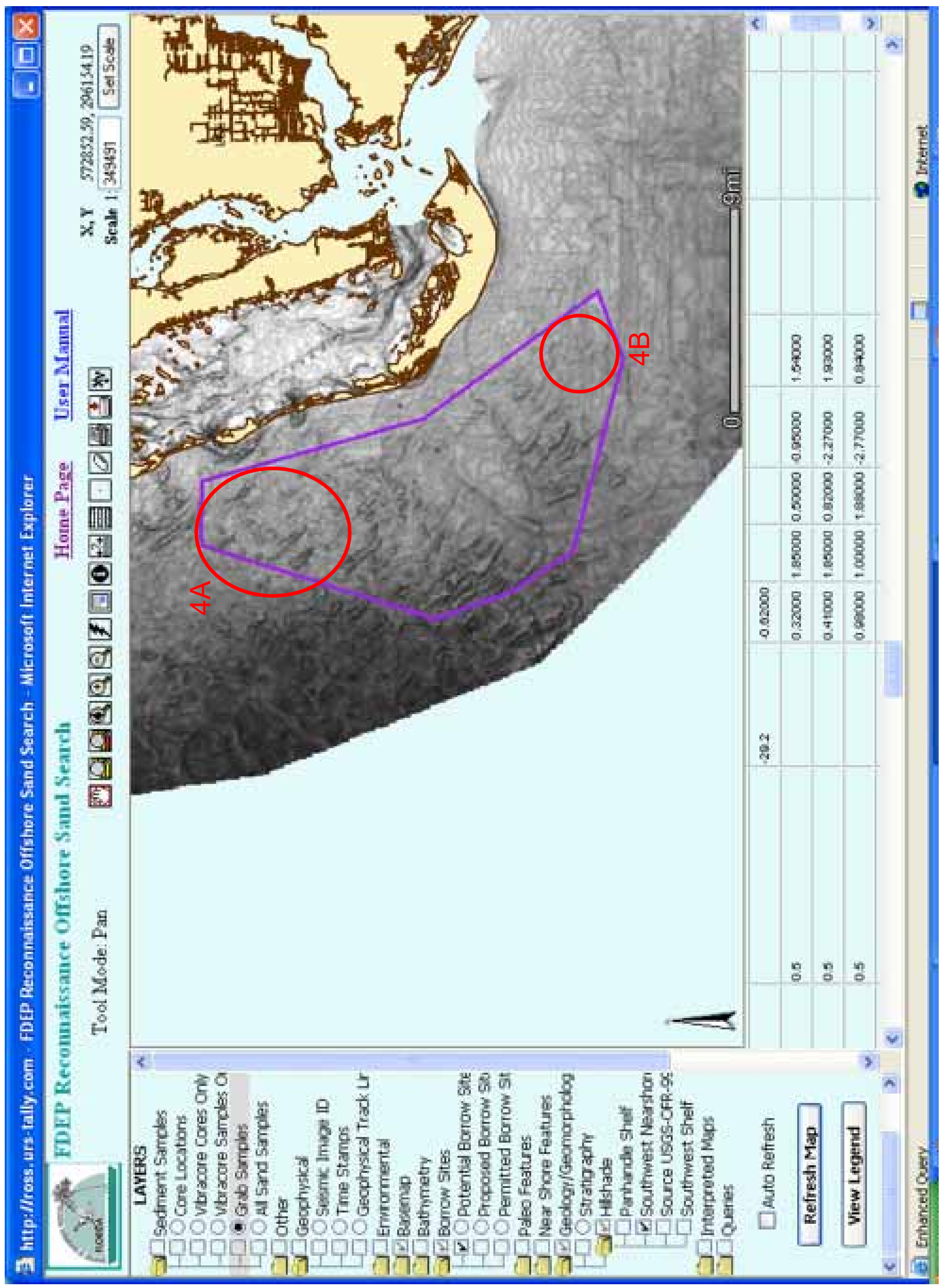


Figure 6-37. Area 4 showing areas 4A and 4B (circled) for future data acquisition.

Figure 6-38. Area 4A (red oval) showing locations of jet probes.

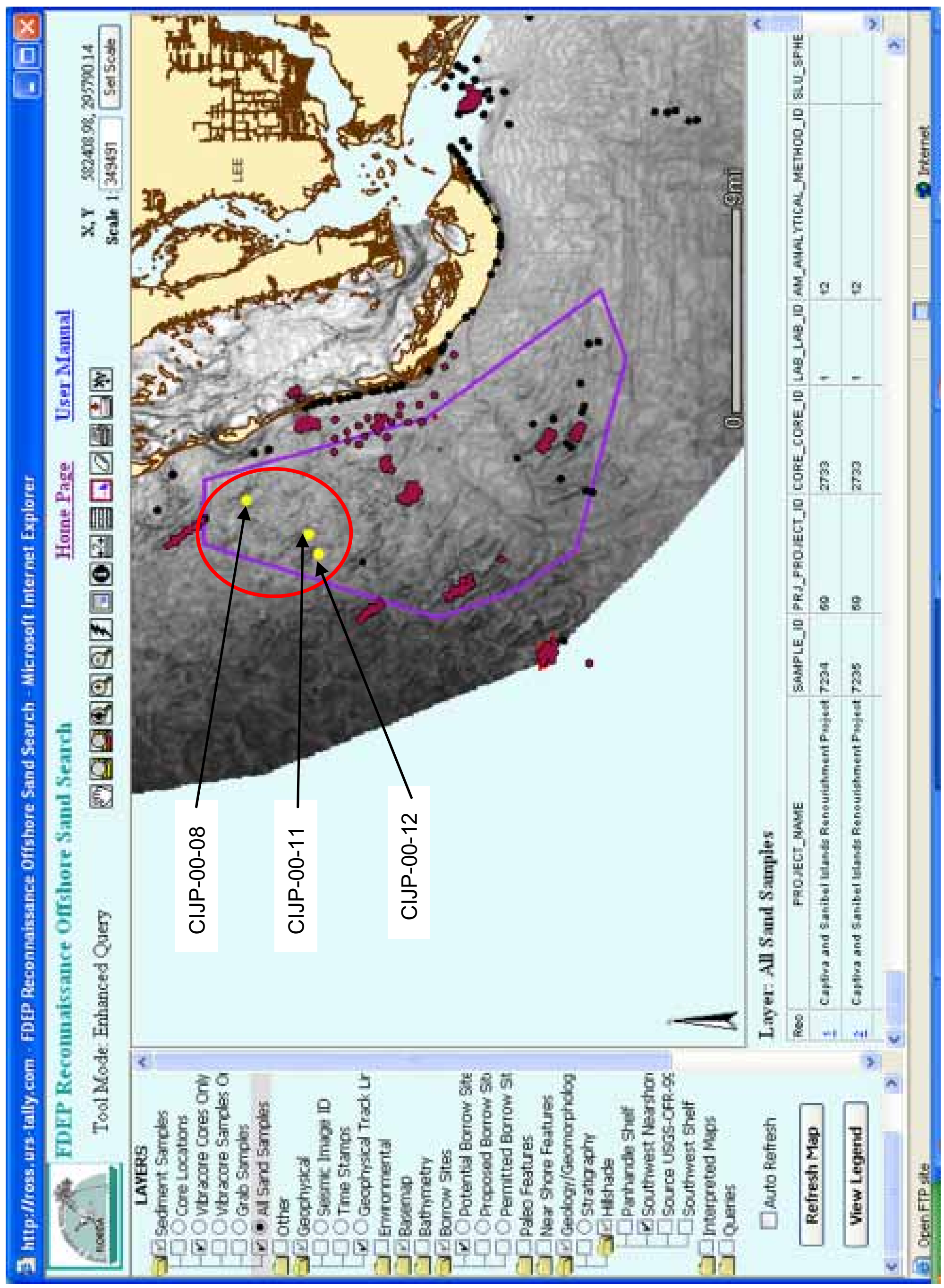


Figure 6-39. Area 4B (red oval) showing locations of jet probes (JP) and grab samples. Grab sample mean grain sizes are EI#27 = 0.76, EI#29 = 0.67 and EI#30 = 0.82 phi corresponding to medium sand.

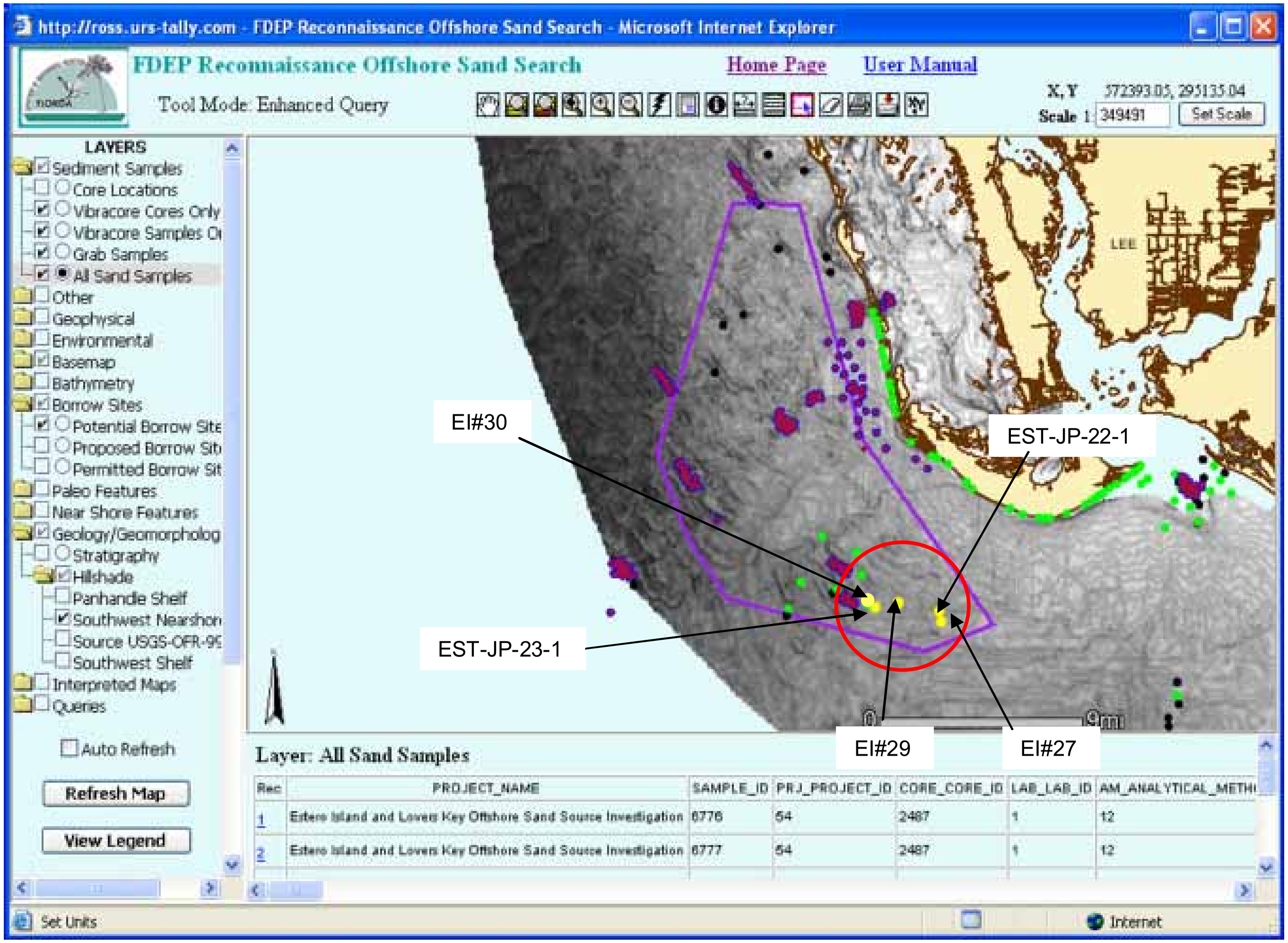


Figure 6-40. Potential sand targets occurring in sand ridges (ridge axis marked by white lines) and historical data available for Southern Coastal Segment, Collier County (Study Area 5).

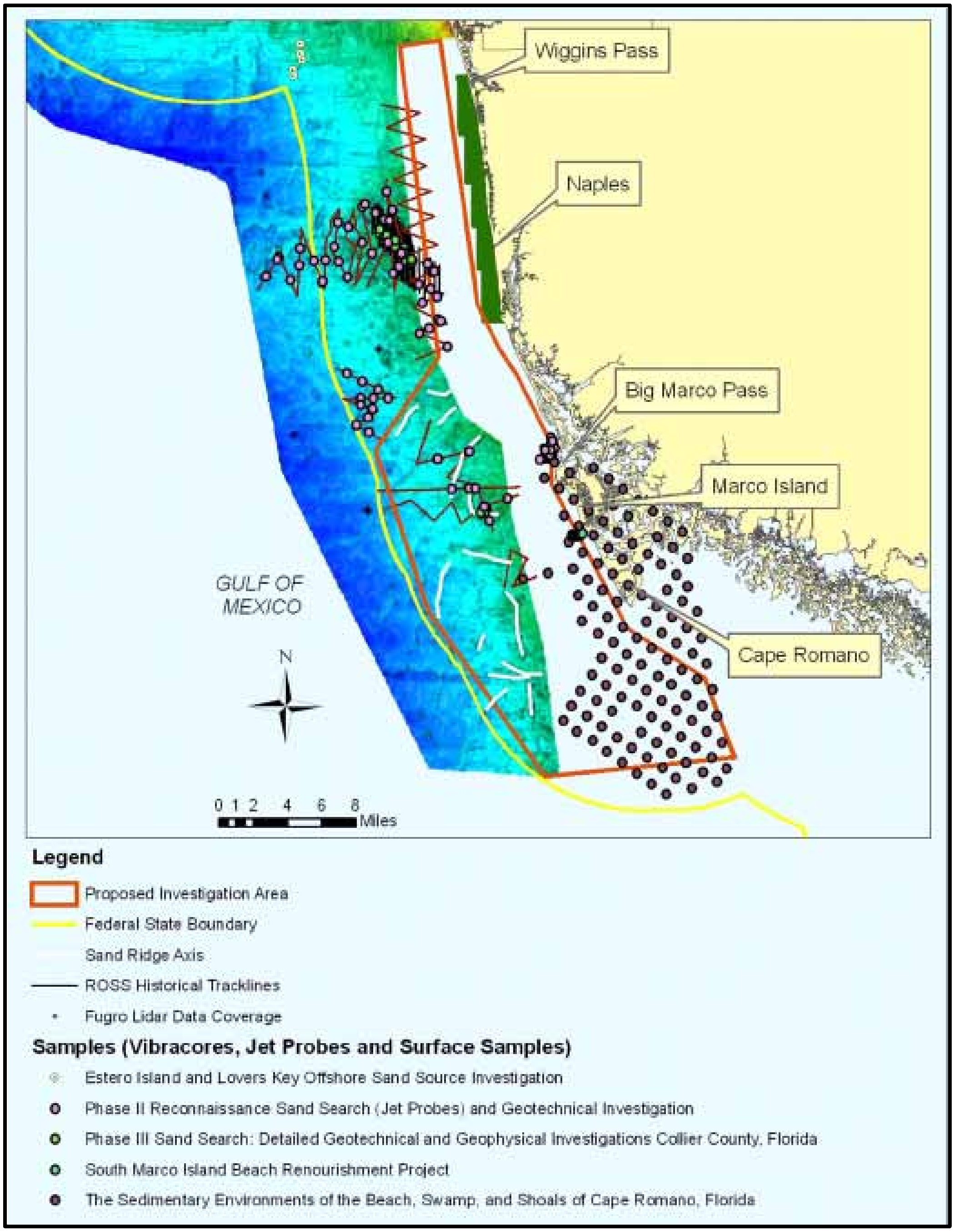
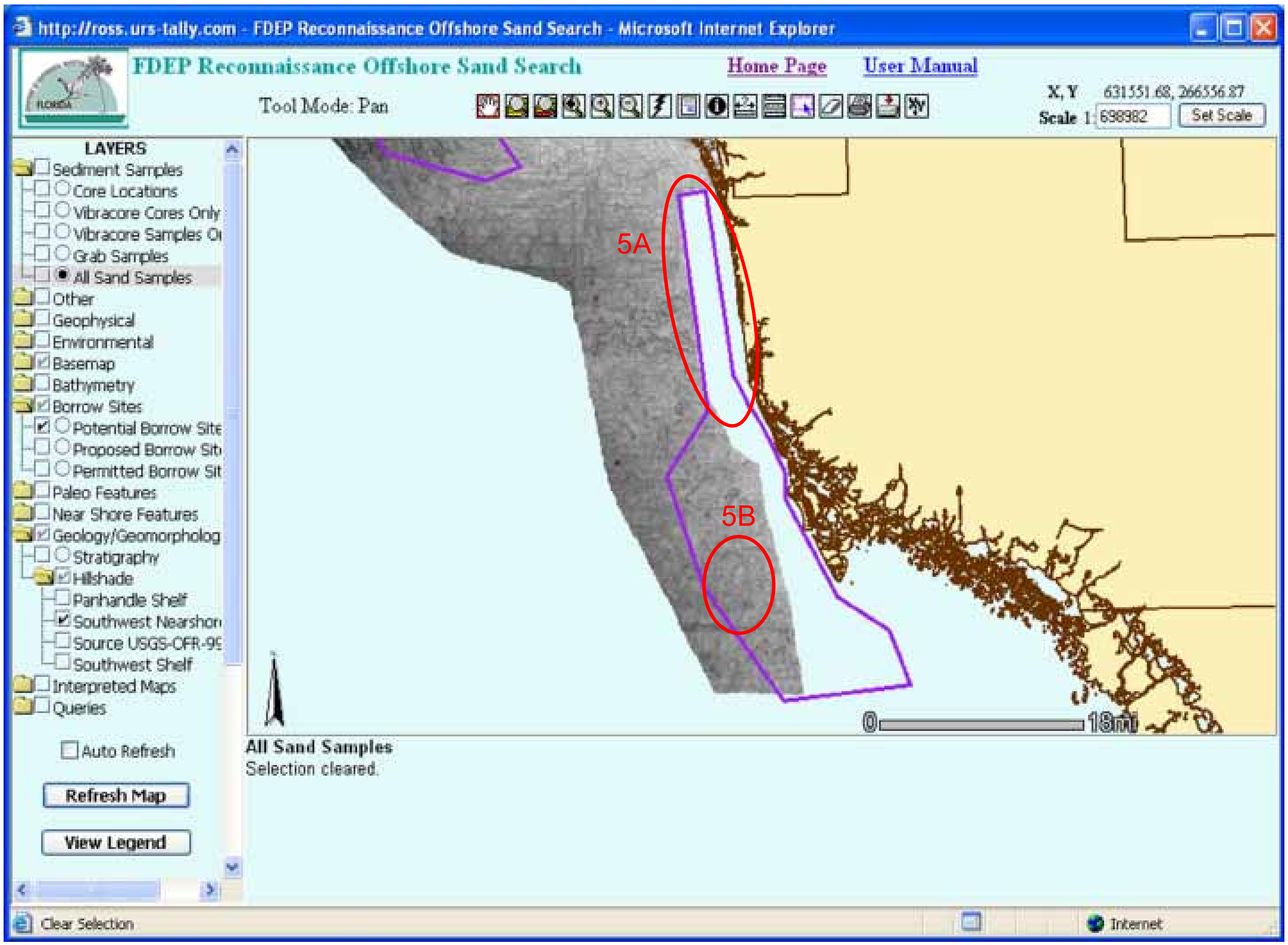


Figure 6-41. Area 5 showing areas 5A and 5B (circled) for future data acquisition.



APPENDIX I
Working Example Using the ROSS Query Builder

Example

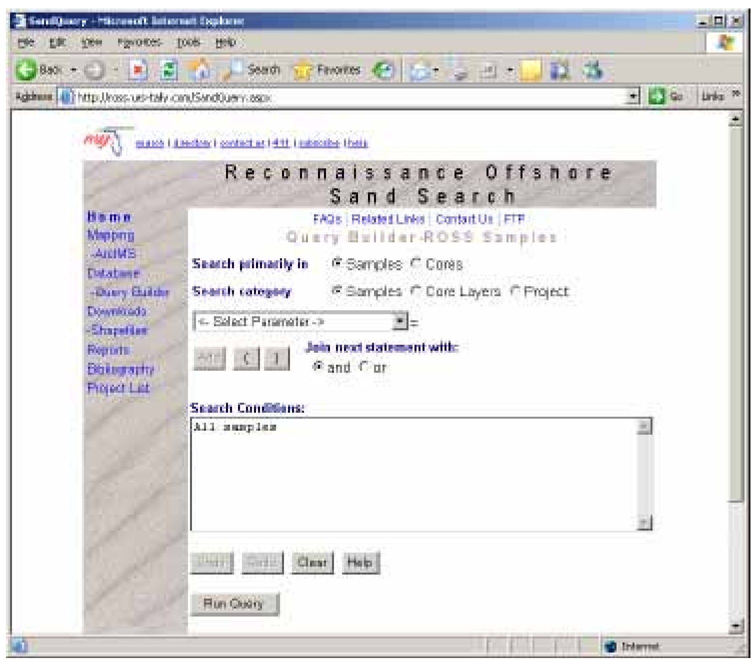
The following example demonstrates how a user can define certain criteria that will drill down through all of the Sample information in the ROSS database and return only those records that meet the criteria. The user shall learn how to build a Boolean query string to send to the ORACLE database. Then the user will see the sample data displayed spatially on the ROSS IMS site that matched the criteria set forth in the query.

Section 1 Defining Query Criteria

From the ROSS Homepage, click on the "Query Builder" link along the left side of the screen. This brings up the ROSS Query Builder page (Figure 1).

Figure 1

The Query Builder has been designed to allow you to focus on criteria that applies to either Cores or individual Samples. It works by allowing you to create a "where" clause that is added to an SQL (Structured Query Language) selection statement. This selection statement tells the database to retrieve rows where the conditions you have set are true.

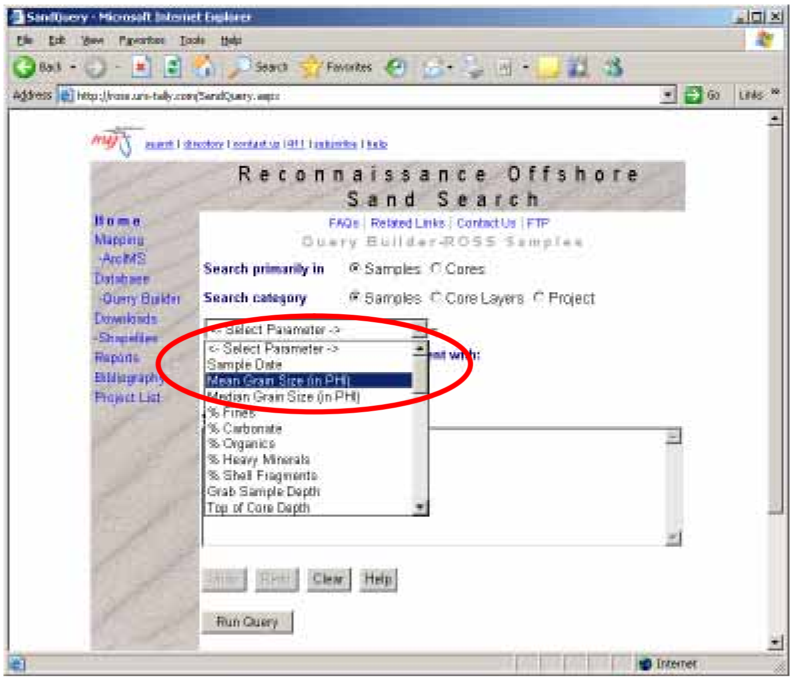


The query is made against one of two database views that join together data from several different database tables. Because of the structure of the database, you must specify whether the query should be run against the samples or core view. The sample view includes all data in the samples data, plus related data in the core table. The core view includes all data in the core table plus related data in the samples table. They appear to be very similar, but they are different representations of the data.

The query parameters are categorized into three different groups. The Sample group, which provides parameters associated with the samples table. The Cores group, which provides parameters associated with the cores and core layers tables, and the Project group, which provides parameters associated with the project table.

In this example, a query of the ROSS database will be designed to return all samples that that have a Mean Grain Size range of between –1 and 1 phi, with less than 5% Fines. The query will then be refined to select from this initial dataset those samples that are located within 6 feet of the seafloor and are in the vicinity of Captiva Island on the Florida southwest Gulf coast.

Figure 2

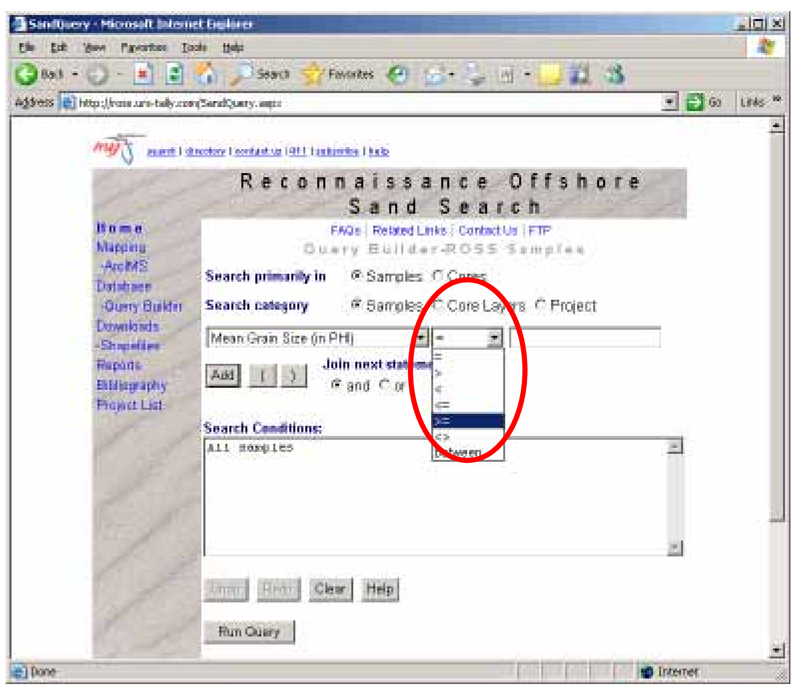


Step 1:

The first drop down box seen in Figure 2, contains various parameters that may be used to define search parameters.

Using the dropdown box shown in Figure 2, select "Mean Grain Size (in PHI)".

Figure 3

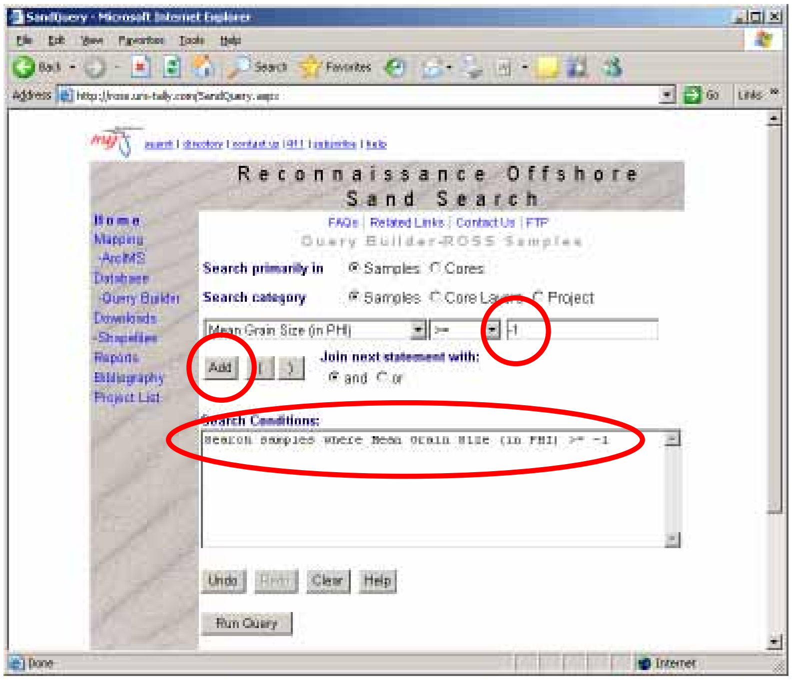


Step 2:

The 2nd drop down list shown in Figure 3, contains a series of operators. These are used to set the equality or inequality of the query statement.

For this example, select the ">=" operator to establish the greater than or equal to search criteria.

Figure 4



Step 3:

Type "–1" into the text box shown circled in Figure 4.

Click the "Add" button.

You should now see the first condition added to the text field labeled "Search Conditions".

Figure 5

Step 4:

Select the "<=" operator from the 2nd drop down list (Figure 5).

Type "1" in the text box.

Click the "Add" button.

You should now see that the second condition has been added using the default "AND" operator, to the text field labeled "Search Conditions".

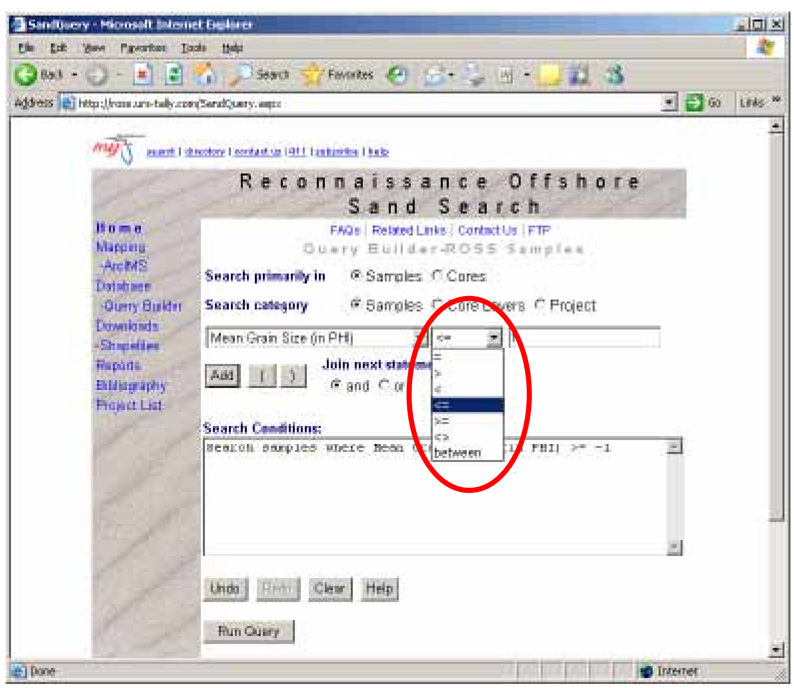
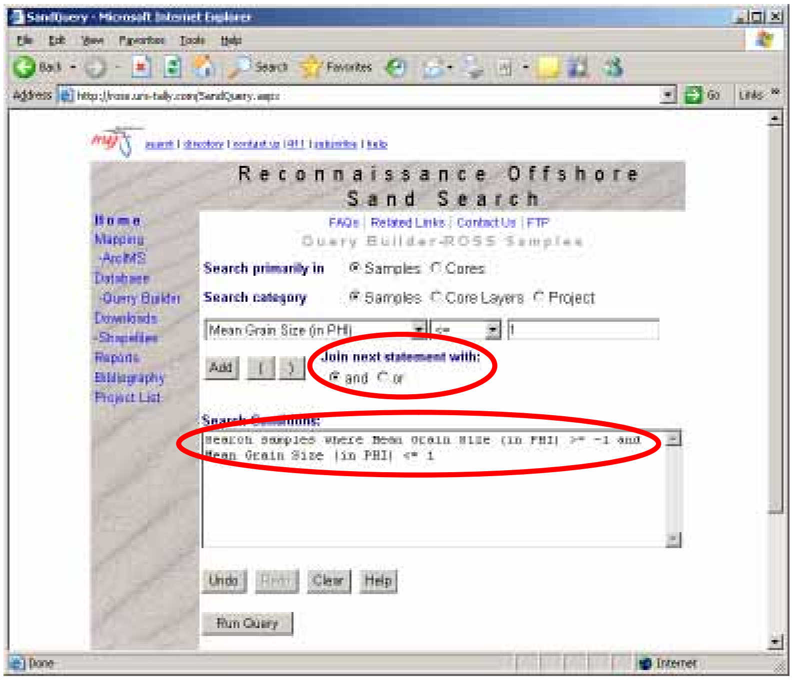


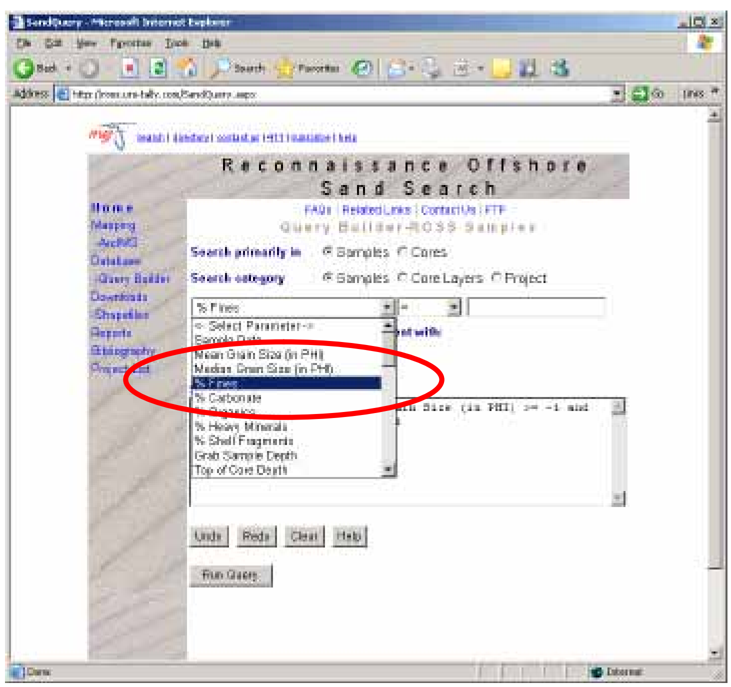
Figure 6.



Step 5:

The second criteria has now been added using the join operator "AND". Selecting the "AND" operator tells the database to return all records that are both >= to -1 and <= 1 (eg. those records equal to or between this range).If the "OR" operator was chosen, this would return all records that are less than -1 (eg. -2, -3, etc.) and those greater than 1 (eg. 2, 3, etc.). Therefore to return the records in the phi range of interest, the "AND" operator is used.

Figure 7



Step 6:

The next step is to further limit the return hits by adding the % Fines criteria. Select the "% Fines" option from the 1st drop down list.

Note: Results will be returned for those samples that actually have a value in the % Fines column of the database (0 – 5%). If the % Fines field is blank, it will not show up in the query result set.

Figure 8

Step 7:

Next, select the less than operator (“<”) from the 2nd drop down list. Enter “5” in the text box to the right and click the “Add” button.

At this point the “Search Conditions” text field contains your third criteria for the initial search as seen below in Figure 9.

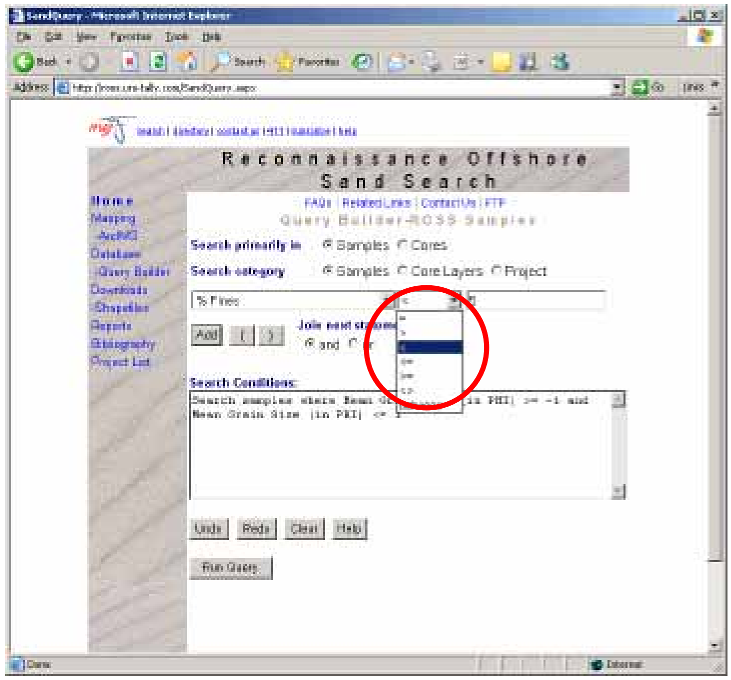
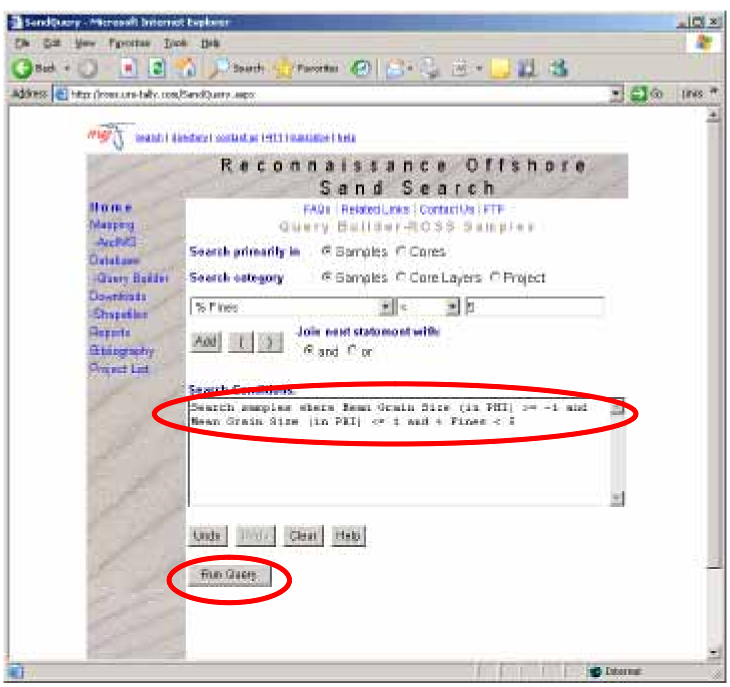


Figure 9



Step 8:

Click the “Run Query” button at the bottom of the screen (Figure 9) to send the query to the Oracle database.

Oracle is now searching all the records in the ROSS database. The records will be returned to the screen in table applet form.

The results of this query show that 507 samples matched the query conditions (Figure 10).

Step 9:

Once the information is returned to this screen, the user has three options: 1) to "Download" the data, 2) to "View Map" and 3) "Query Builder" to further refine the criteria. The third option will be discussed now and the first two options will be presented later in the text.

To refine this query to include only samples that are within 6 feet of the sea floor, click the "Query Builder" button as seen in Figure 10. By selecting this option, the user is returned to the Query Builder screen and allowed to add additional criteria to the original query.

Figure 10

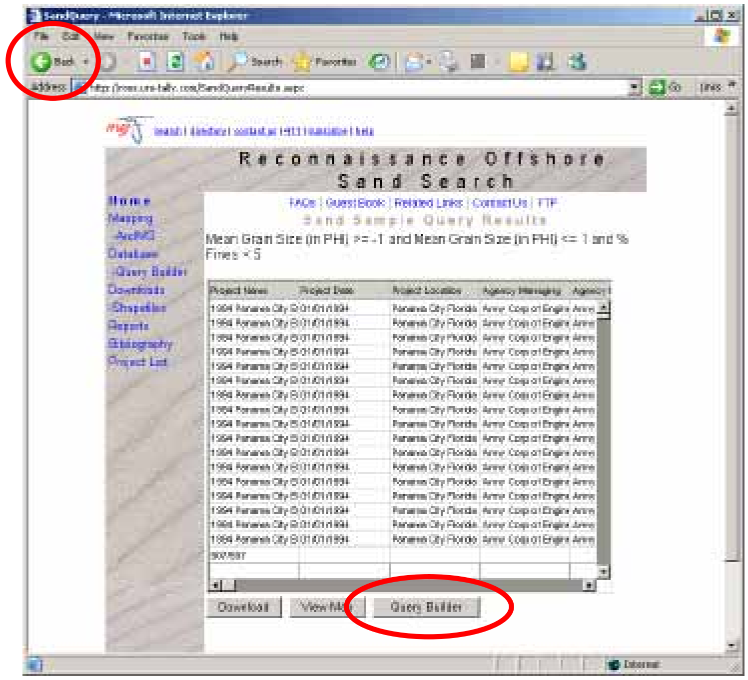
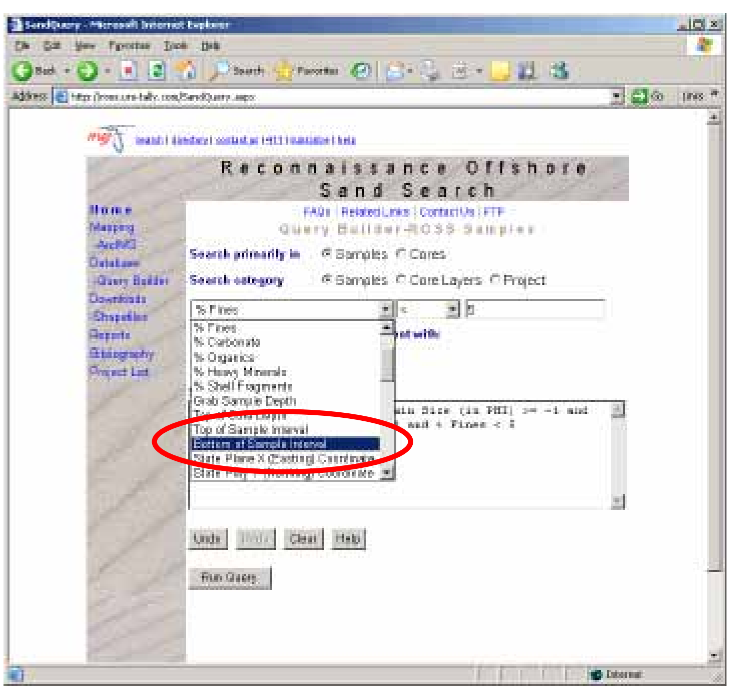


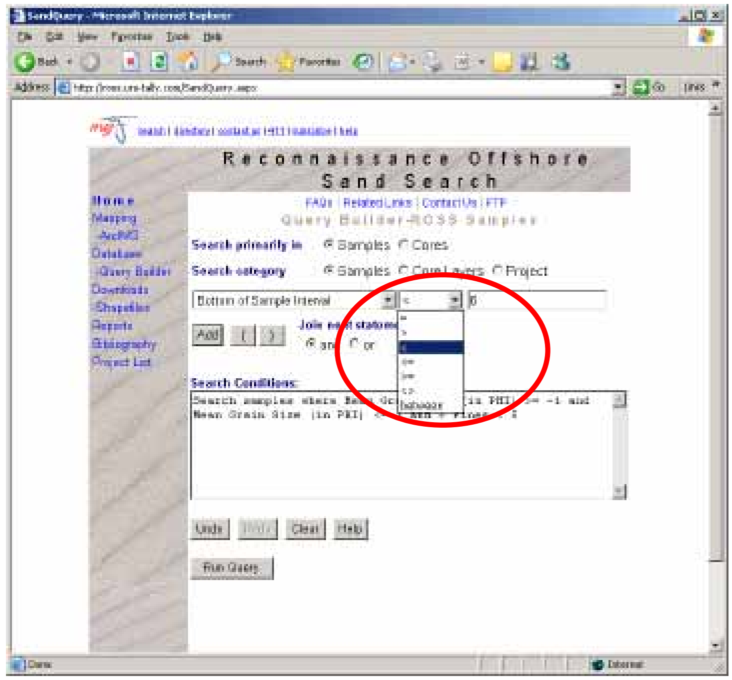
Figure 11



Step 10:

Using the first dropdown menu, select the "Bottom of Sample Interval" option as shown in Figure 11.

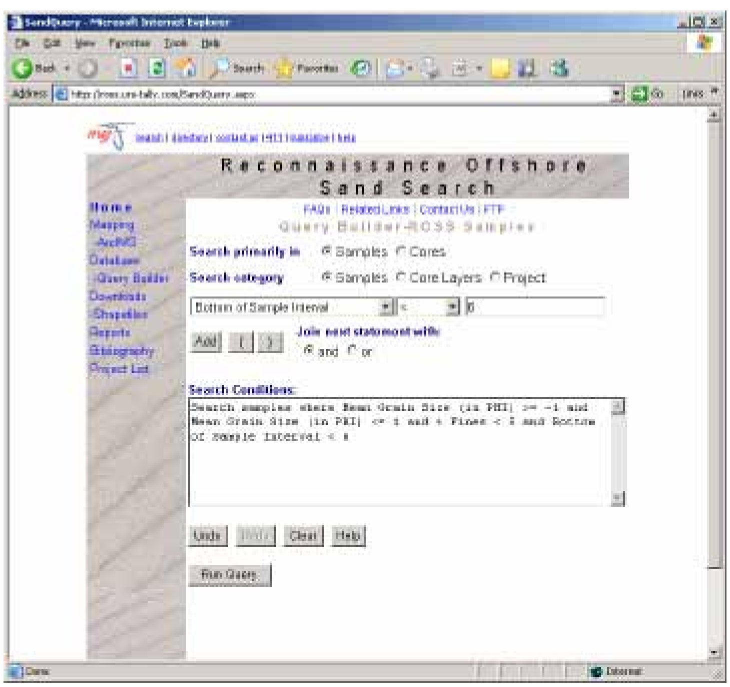
Figure 12



Step 11:

Select the "<" operator in the 2nd drop down box and replace the 5 with a 6 in the text box as shown in Figure 12.

Figure 13



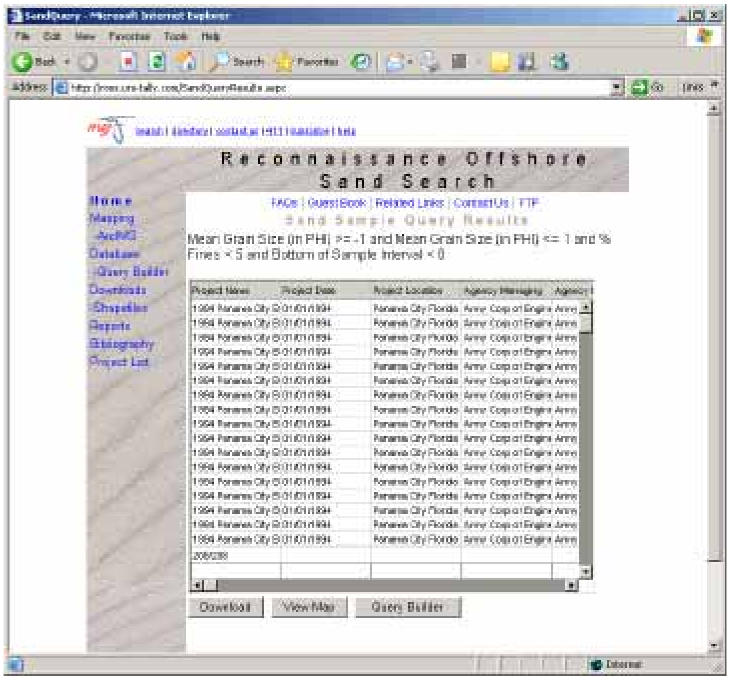
Step 12:

Click the "Add" button.

You will now see the example conditions added to the "Search Conditions" text field (Figure 13).

Click the "Run Query" button and this will return a subset of the original 507 samples that meet this additional condition. 208 of the initial 507 results are within 6 feet of the sea floor. (Figure 14 below).

Figure 14



For the last criteria of the original query we will select only samples that were taken in the vicinity of Captiva Island. Click the "Query Builder" button. You will be taken back to the Query Builder screen where we will now add the following criteria:

Figure 15

Step 13:

Change the "Search Category" to "Project" as shown in Figure 15.

The screen will refresh giving you a new set of values to search by in the drop down list. These values are determined by the Search Category that you select.

Using the 1st drop down box, select "Project Location".

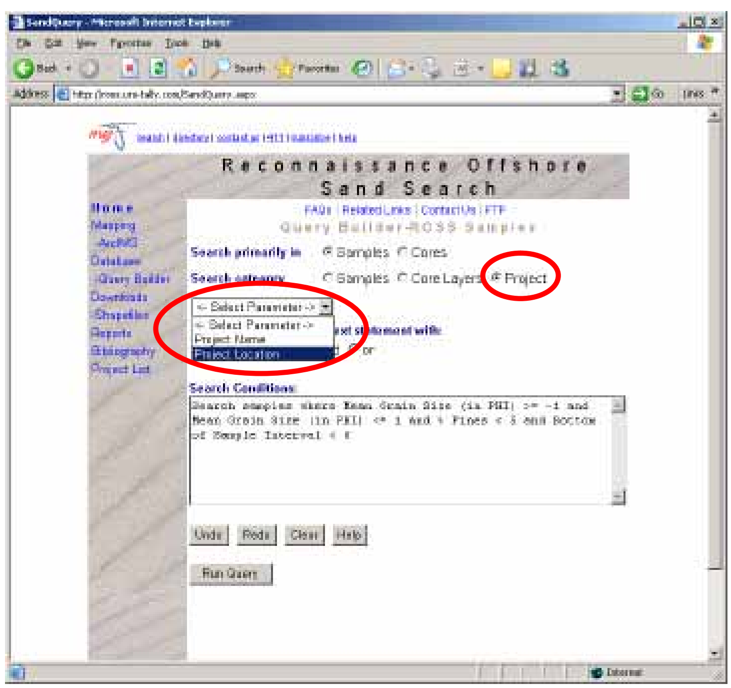
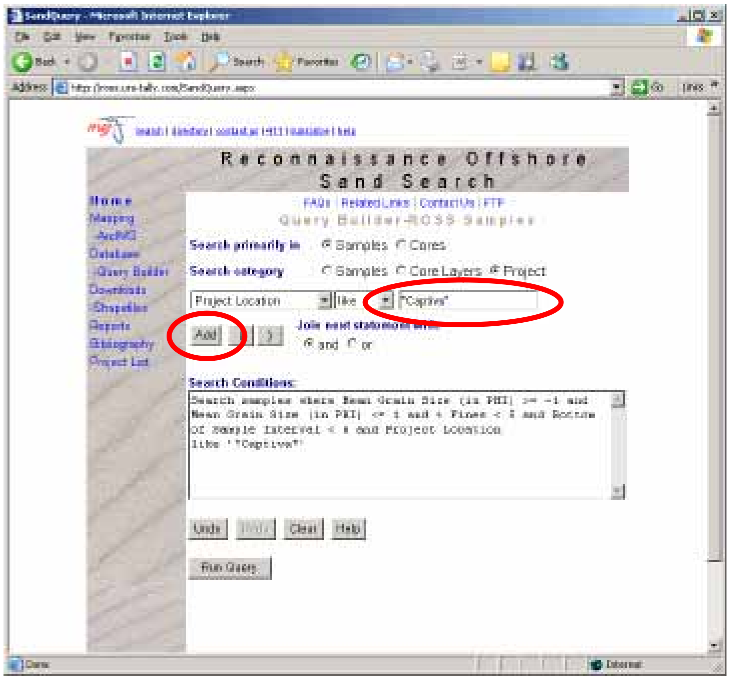


Figure 16



Step 14:

Using the 2nd drop down box, select "Like".

Type *Captiva* in the text box.

Click the "Add" button .

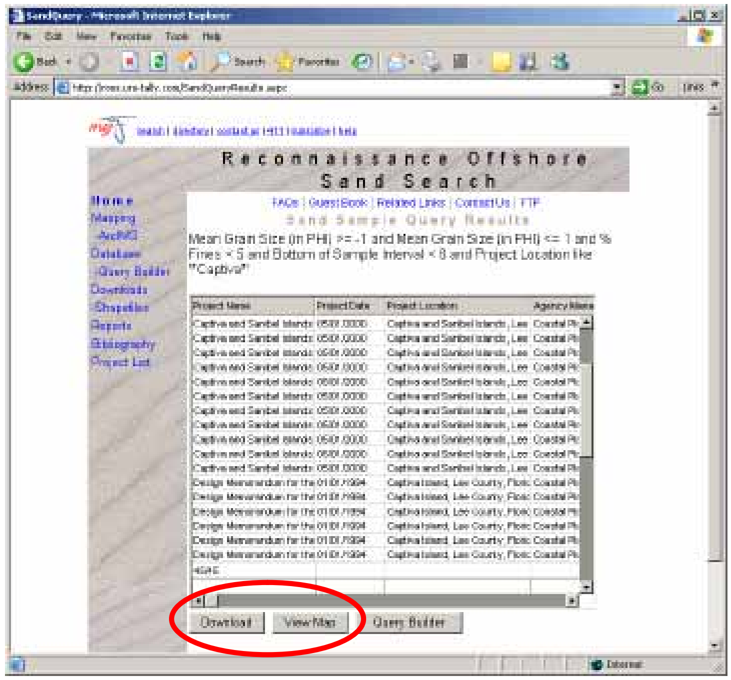
Click the "Run Query" button to see the results.

Note about wildcard characters: The asterisk (*) is considered a wildcard. The * is used twice in this example because we are searching for any projects that contains the word Captiva anywhere in the Project Location field. There are three ways that we could use the * and they would return different datasets.

- Captiva* => Returns Only Samples taken from Projects where the Location starts with the word Captiva.
- *Captiva => Returns Only Samples taken from Projects where the Location ends with the word Captiva.
- *Captiva* => Returns Only Samples taken from Projects where the Location contains the word Captiva.

You should now see that 45 of the initial 507 samples (as of this writing) are from a Project or Projects where the "Location" field in the database has specified the data was located in the vicinity of Captiva Island (Figure 17 on the following page).

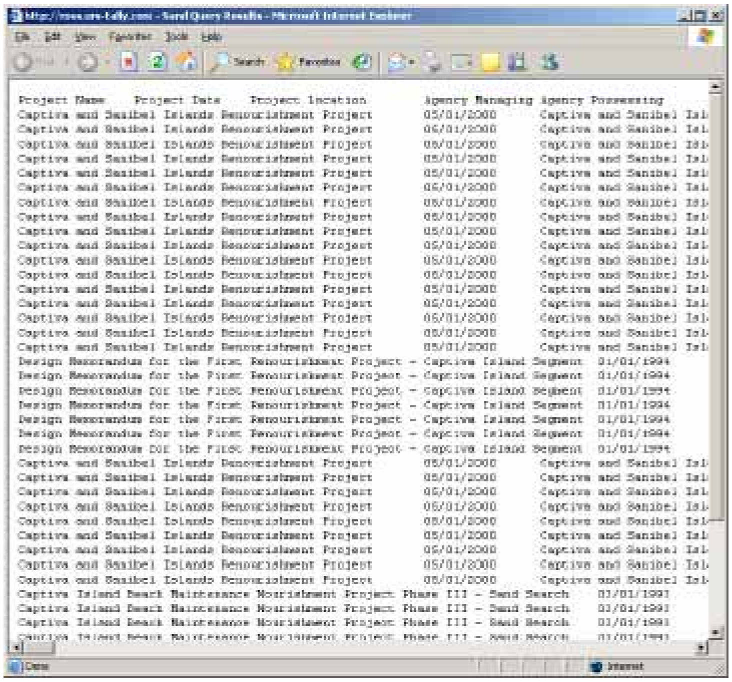
Figure 17



Now that we have refined our search result to only 45 Samples that meet our criteria, you can either download the results, in a Tab delimited format, to your local computer to perform more technical analysis by clicking the “Download” button. Or you can click the “View Map” button to see a spatial depiction of the samples location on a map.

Downloading Your Search Results

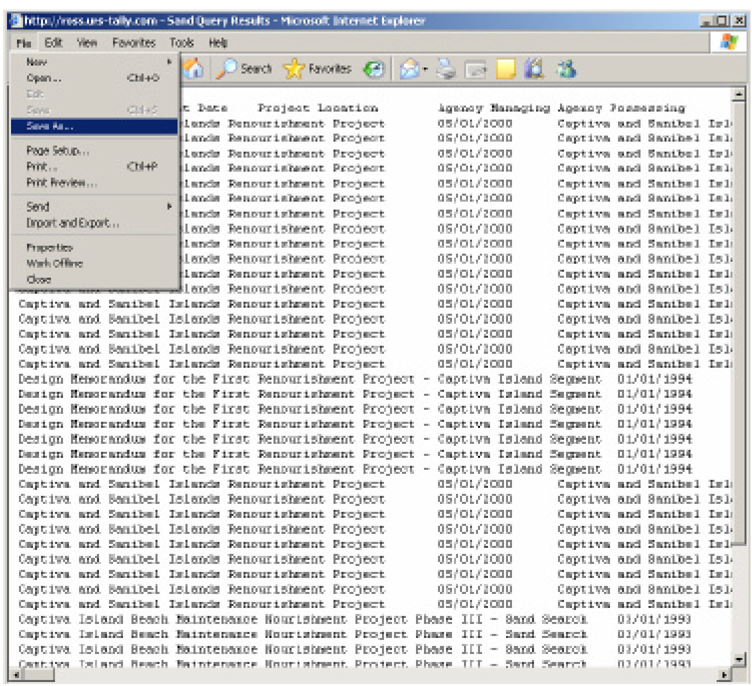
Figure 18



To download the results of your search, click the "Download" button shown in Figure 17.

A new window will appear that looks like Figure 18.

Figure 19

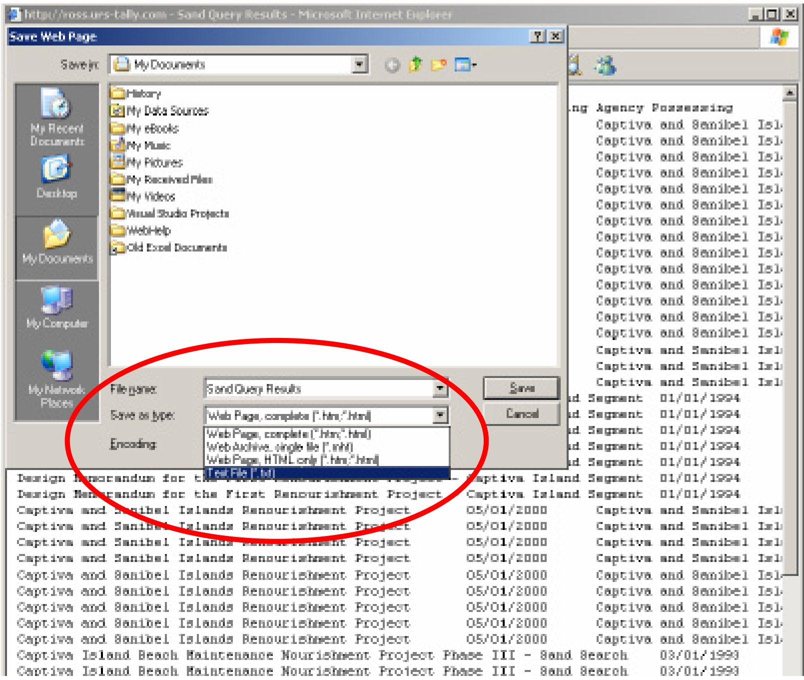


Click "File".

Click "Save As".

A standard Windows "Save File" dialog box will appear. Name your file then select the Save As Type as a "Text File (*.txt)" using the drop down menu as shown in Figure 20 below.

Figure 20

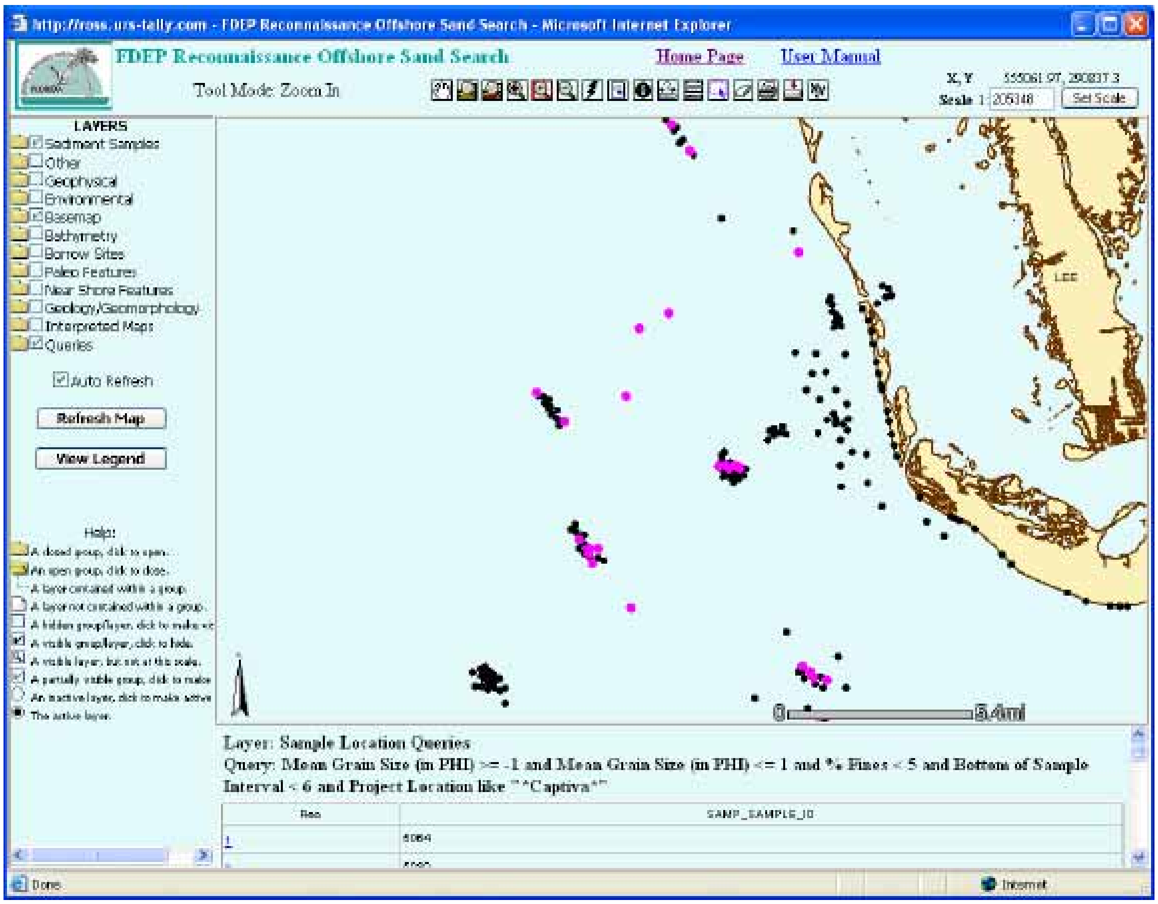


This will save the text that is displayed in the window as a tab-delimited text file that can be manipulated using Microsoft Excel or any other text editor.

Viewing Your Results On A Map

To view the physical location of the Samples your search returned, click the "View Map" button shown in Figure 17. You should now see another window pop up that looks like the one shown below (Figure 21). The Samples that meet your criteria will be highlighted to prominently stand out among all the cores/samples in that area.

Figure 21



APPENDIX II
WEST COAST OF FLORIDA – GEOLOGY, EVOLUTION, GEOMORPHOLOGY AND SAND RESOURCES

INTRODUCTION

Description of the geologic setting is central to comprehension of bedrock seafloor surfaces and the sediments sitting on them. The nature of sedimentary deposits determines sand quality and its potential use for beach nourishment. It is thus helpful to understand the general shelf environments because the distribution of beach-quality sands on the seabed is not random, but spatially well defined in terms of stratigraphy, grain composition, age of materials, and erosional-depositional events. This report summarizes the geological evolution of the West Florida Shelf (WFS) with emphasis on sand resources. Discussions include a regional description of the geological evolution of the Gulf of Mexico and the WFS, description of modern (Holocene) coastal geomorphology and associated coastal-marine processes. This report is focused on stratigraphy and geographical distribution of sedimentary deposits, and includes detailed discussions of shelf and coastal geomorphology, individual coastal segments, and assessment of sand resources. A final section recommends procedures and methods for conducting marine sand searches and identifies the role of the ROSS database within this methodology.

Study Area

The Gulf of Mexico is a Mediterranean-type sea that stretches more than 1770 km from west to east and c. 900 km from north to south with a surface area of about 1.5 x 10^6 km^2. This semi-enclosed ocean basin is bordered by the coast of the United States from Florida to Texas, and by the east coast of Mexico from Tamaulipas to Yucatán (Figure 1). The northern coast of Cuba funnels the Gulf into the Atlantic Ocean through the Straits of Florida (through which the Florida Current passes); the Gulf of Mexico is connected with the Caribbean Sea through the Yucatán Channel. The Bay of Campeche (Bahía de Campeche), Mexico, and Apalachee Bay, Florida, are the Gulf's largest reentrants. For the U.S. coastal segment, the total shoreline, including bays and lagoons, is over 27,000 km. This report considers the southeastern margin of the Gulf of Mexico, which is the seaward shelf area along the central west coast of Florida with a shoreline distance of about 350 km. Evolution of the western margin of the Florida Platform is considered in terms of alternating phases in its history that include a continental shelf (marine depositional environments and submarine landscapes formed from drowned coastal plains), a coastal plain (subaerial landscapes), and a variety of seascapes (land-sea boundary transition zones).

GEOLOGICAL EVOLUTION OF THE GULF OF MEXICO

The purpose of this introductory section is to provide a brief summary overview of the geological (structural and stratigraphic) evolution of the eastern Gulf of Mexico and in particular the WFS. This review highlights salient geological events and processes that

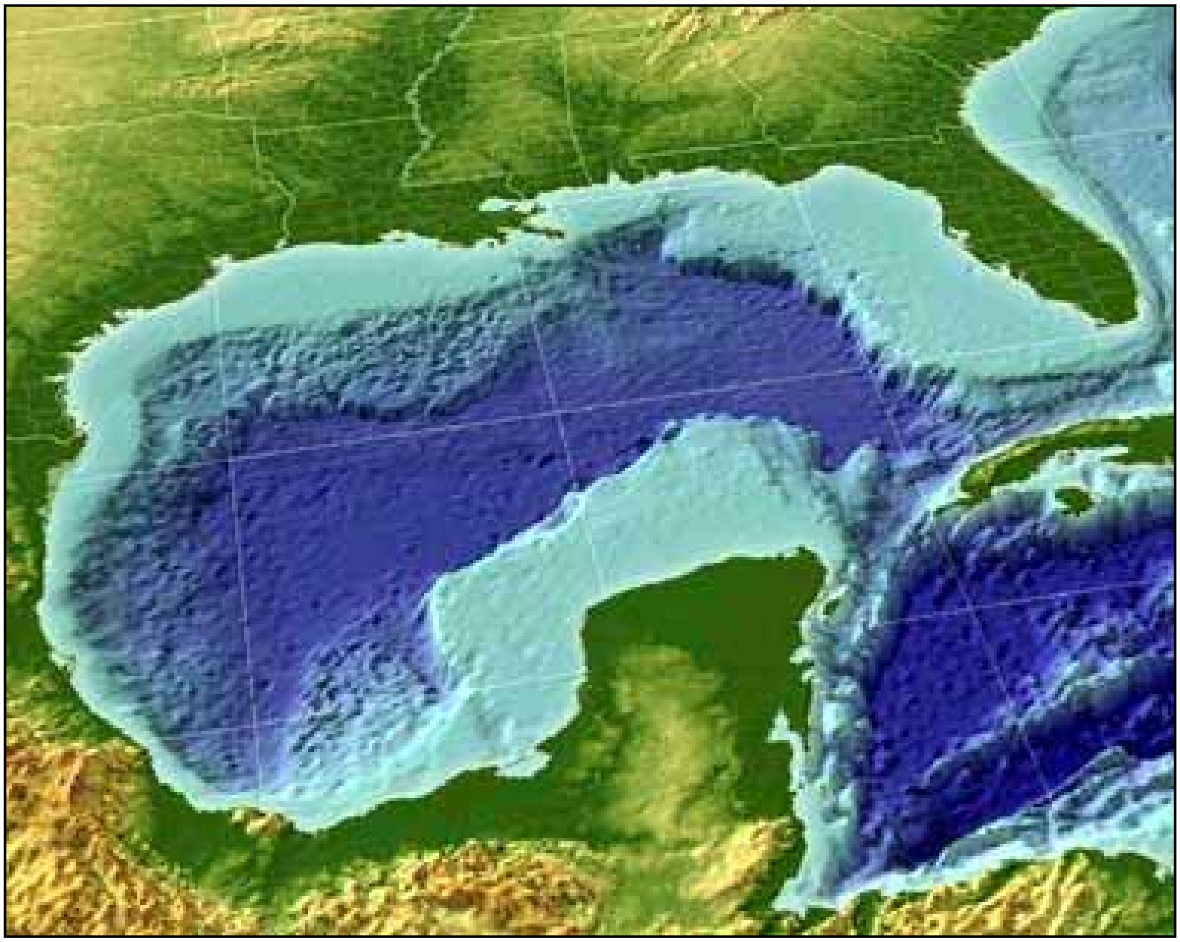


Figure 1. General configuration of the Gulf of Mexico basin showing landmasses (green to brown tones), continental shelves (light blue color), and oceanic deeps (dark blue colors). The West Florida Continental Shelf (WFS) in the eastern Gulf is about 220 km wide and comprises the submerged part of the Florida Platform.

led up to the present configuration and composition of the continental shelf that today forms the platform upon which lie sand deposits that are mostly nearshore unconsolidated Holocene deposits. Some of these sand deposits can provide valuable borrow sources for beach nourishment. A major purpose of the ROSS database is to assist in locating and evaluating these potential sand resources.

This review is initiated by major structural development of the basin in the Late Triassic (see Figure 3a for an abbreviated time scale starting about 200 million years ago) and culminates in description and explanation of the present (Holocene, last 10,000 years) shelf surface and sediments deposited thereon, as mainly reported in primary literature.

The drowned surface of the karstified Florida Peneplain is the rock platform that supports Holocene sediments. Highlights of the structural (geotectonic transform margin of the eastern Gulf of Mexico as described from regional gravity surveys by Hall *et al*., 1982) and stratigraphic framework of the Gulf of Mexico basin, sedimentation cycles, sea-level change, and surficial and subterranean processes that produce karst features are discussed with a view towards explaining the distribution of contemporary unconsolidated sediments on the WFS. To a degree, these control the exposure of very ancient (pre-Quaternary) sediments on the seafloor. Additionally, paleorelief influences the present configuration of the shoreline (mainland shore and barrier islands), estuaries, and sediment facies on the inner and outer shelf. Karstification is an important process, which affected portions of the continental shelf during sea-level low stands (when the shelf was a coastal plain surface). Karst depressions (dolines, cockpits, sink holes) became infilled with sediments (usually fine grained) after drowning by sea-level rise. A complicated pattern of surficial sediments on the WFS thus emerges from study of facies distribution patterns due to the exposure of bedrock surface as hardgrounds, presence of relict terrestrial deposits (drowned and reworked by marine processes), production of biogenic materials (coral and algae), chemical precipitates (ooids and phosphorites), and siliciclastic-carbonate transitions. Comprehensive summaries of seafloor characteristics, regional stratigraphic patterns, sediment dynamics, and siliciclastic-carbonate transitions are provided papers in a special issue of *Marine Geology* (notably those by Duncan *et al*., 2003; Harrison *et al*., 2003; Hine *et al*., 2003; Locker, *et al*., 2003; Obrochta, 2003). Holocene phases of sedimentation and coastal-marine reworking of relict sediments on the shelf are the main subjects of this report as they relate to offshore sand resources for beach nourishment activities along the central-west coast of Florida.

Origins and Geologic History of the Basin

The relatively simple, roughly circular structural basin of the Gulf of Mexico, approximately 1700 km in diameter, is filled in its deeper part with 10 to 15 km of sedimentary rocks that range in age from Late Triassic to Holocene (approximately 230 Ma [Mega annum = 1 million years] to present). Because little is known about the geologic history of the Gulf of Mexico basin before Late Triassic time (pre-Triassic rocks are known from only a few widely separated outcrop areas and wells), much of the geologic history of the basin during Paleozoic time (the time period preceding 230Ma) is inferred from the study of neighboring areas (*e.g.* Bornhauser, 1958; Donnely, 1975; Gore, 1992; Donnelly, 1975; Martin, 1975; Uchupi, 1975; Salvador, 1991). Some researchers postulate the presence of a basin in the area during most of Paleozoic time (600 to 230 Ma), but most evidence seems to indicate that Paleozoic rocks do not underlie most of the Gulf of Mexico basin and that the area was, at the end of Paleozoic time, part of a large supercontinent (Pangaea).

The present Gulf of Mexico basin, in any case, is believed to have originated in Late Triassic time as the result of rifting and formation of transform faults within the North American Plate when it began to crack and drift away from the African and South American plates. Rifting probably continued through Early and Middle Jurassic time with the formation of "stretched" or "transitional" continental crust throughout the central part of the basin (Hall *et al*., 1982) as it rotated from its source area. Periodic advance of the sea into the continental area from the west during late Middle Jurassic time resulted in the formation of the extensive salt deposits that are known today in the Gulf of Mexico basin.

The main drifting and rotating episode took place during the early Late Jurassic after the formation of the salt deposits when the Yucatan block moved southward and separated from the North American Plate and true oceanic crust formed in the central part of the basin.

The basin has been a stable geologic province since Late Jurassic time and may be characterized by persistent subsidence in its central part, probably due at first to thermal cooling and later to sediment loading as the basin filled with thick prograding clastic wedges along northwestern and northern margins, particularly during the Cenozoic. To the east, the stable Florida Platform (a coastal plain) was not covered by the sea until the latest Jurassic or the beginning of Cretaceous time. Carbonate platforms rimmed most of the basin during the Early Cretaceous. The Yucatan Platform on the southern margin of the Gulf of Mexico basin was emergent until the mid-Cretaceous. After both platforms were submerged, the formation of carbonates and evaporites dominated the geologic history of these two stable areas.

Today, the Gulf of Mexico is a small oceanic basin surrounded by continental landmasses (Figure 1). Due to their physical structure, the Gulf and the Caribbean Sea are sometimes combined and referred to as the 'American Mediterranean'. The basin is physiographically complex (Gardner, 2004). Uchupi (1975) divides the Gulf of Mexico into two distinct geographical provinces (terrigenous and carbonate) while Antoine (1972) recognizes seven physiographic zones. The scheme proposed by Antoine is presented here, with additional information derived from other sources. This summary thus focuses on Antoine's geographical province #3, the South Florida Continental Shelf and Slope of which the West Florida Continental Shelf (WFS) is a subprovince.

(1) Gulf of Mexico Basin

Structurally, the Gulf of Mexico basin is subdivided into the Sigsbee Deep and Abyssal Plain, the continental rise, and the Mississippi Cone. The continental rise, located between the Sigsbee Escarpment and the Sigsbee Abyssal Plain, is composed of sediments transported to the area from the north. The Sigsbee Abyssal Plain is a deep, flat portion of the Gulf seafloor that is located to the northwest of the Campeche Bank. In this relatively uniform area of the Gulf bottom, the Sigsbee Knolls and other small diapiric (salt) domes represent the only major topographical features. Composed of soft sediment, the Mississippi Cone extends southeast from the Mississippi Trough to eventually merge with other sediments in the central basin. The cone is bordered by the DeSoto Canyon to the east and the Mississippi Trough to the west, and has been described in detail by Ewing *et al*. (1958).

(2) Northeast Gulf of Mexico

This physiographic province extends east of the Mississippi Delta near Biloxi to the eastern side of Apalachee Bay where seafloor is characterized by soft sediments. West of the DeSoto Canyon, terrigenous (land-derived) sediments are thickly piled and infill remnants of the Gulf basin. In the eastern portion of the region, Mississippi-derived sediments cover the western edge of the Florida Carbonate Platform and a transition towards carbonate sediments begins. The Florida Escarpment separates the Florida Platform from the Gulf Basin and also forms the southeastern side of the DeSoto Canyon. In a region characterized by sediment deposition, the presence of the DeSoto Canyon is poorly understood. Some theories suggest that the canyon is the result of erosion caused by oceanic currents, possibly the Loop Current (Nowlin, 1971).

(3) South Florida Continental Shelf and Slope

A submerged (drowned) portion of the larger emergent Florida Peninsula. This part of the Gulf of Mexico extends along the coast from Apalachee Bay to the Straits of Florida and includes the Florida Keys and Dry Tortugas. A generalized progression towards carbonate sediments occurs from north to south ending in the thick carbonate sequences of the Florida Basin. Evidence suggests that this basin was at one time enclosed by a barrier reef system (*e.g*. Ewing *et al*., 1966; Sheridan *et al*., 1966; Oglesby *et al*., 1965; Antoine and Ewing, 1963). In the Straits of Florida, the Jordan Knoll appears to be composed of remnants from this ancient reef system. This reef may have once extended across the straits, joining the Florida reefs with those of northern Cuba.

(4) Campeche Bank

This extensive carbonate bank is located to the north of the Yucatan Peninsula (Ordonez, 1936) and extends from the Yucatan Straits in the east to the Tabasco-Campeche Basin in the west to include Arrecife Alacran. The region shows many similarities to the south Florida platform and some evidence suggests that the two ancient reef systems may have been continuous (Antoine and Ewing, 1963; Uchupi and Emery, 1968). Continental drift and erosional processes are both theorized to have played a role in the separation of the two geologically similar carbonate platforms.

(5) Bay of Campeche

This isthmian embayment extends from the western edge of Campeche Bank to offshore regions just east of Veracruz (~96 degrees W). The Sierra Madre Oriental forms the south-southwestern border, and the associated coastal plain is similar to the Texas-Louisiana coast along the northern margin of the Gulf of Mexico. The bottom topography is typified by long ridges that extend parallel to the exterior of the basin. Upward migration of salt domes is theorized to cause complex bottom profiles (Worzel *et al*., 1968).

(6) Eastern Mexico Continental Shelf and Slope

This geological province spans the entire eastern shore of Mexico between Veracruz in the south to the Rio Grande in the north. The regional seafloor topography is characterized by sediment-covered folds that parallel the shore. Apparently created by sediment-covered evaporites, the folds seem to have impeded sediment transport from the Mexican coast to the Gulf Basin (Bryant *et al*., 1968). As sediment cover increases from south to north, so does the relative complexity of bottom structures.

(7) Northern Gulf of Mexico

The northern Gulf of Mexico extends from Alabama to the U.S.-Mexico border. North to south, the province extends from 300 km inland of the present day shoreline to the Sigsbee Escarpment. Sediments in the region are generally thick with the greatest sediment load provided by the Mississippi River. Widespread salt deposits are present throughout the region (Murray, 1961; Halbouty, 1967) and these structures create subsurface and emergent topographic features on the continental slope such as the Flower Garden Banks off the Texas/Louisiana coast and the pinnacles region offshore of the Mississippi/Alabama coast.

CONTINENTAL MARGINS OF THE EASTERN GULF OF MEXICO

Geological summaries of the WFS (see Antoine, 1972; Antoine *et al*., 1974; Ibrahim and Uchupi, 1982) note that the West Florida Platform is dominated by a structural basin that has subsided while accumulating a sedimentary pile of more than 4.6 km of shallow-water, primarily carbonate-evaporite sediments since Late Jurassic-Early Cretaceous time. Extending westward beneath the continental shelf to where it is truncated by a NW-SE trending transform fault, the Florida Escarpment formed the structural rim of the basin during Early Cretaceous time. It was capped by an algal barrier reef that restricted circulation sufficiently to support deposition of evaporites in the basin. The northern extension of the Florida Escarpment and associated Lower Cretaceous reef trend is approximated by the boundary between the Florida carbonate platform and the terrigenous clastic continental margin of the northern Gulf of Mexico. Reflection seismological profiles have contributed extensive evidence that helps to better understanding the nature of subsurface features in Florida. Major structural features of the WFS (Figure 2) include, from north to south the Apalachicola Basin, Middle Ground Arch, Tampa Basin, Sarasota Arch, and the South Florida Basin Region (Smith and Lord, 1997). The Middle Ground Arch (Figure 2), a broad positive seafloor feature, separates the Apalachicola Basin from the Tampa Basin. Lithologies associated with the Tampa Basin, Sarasota Arch, and South Florida Basin Region provide the foundation rocks of the WFS.

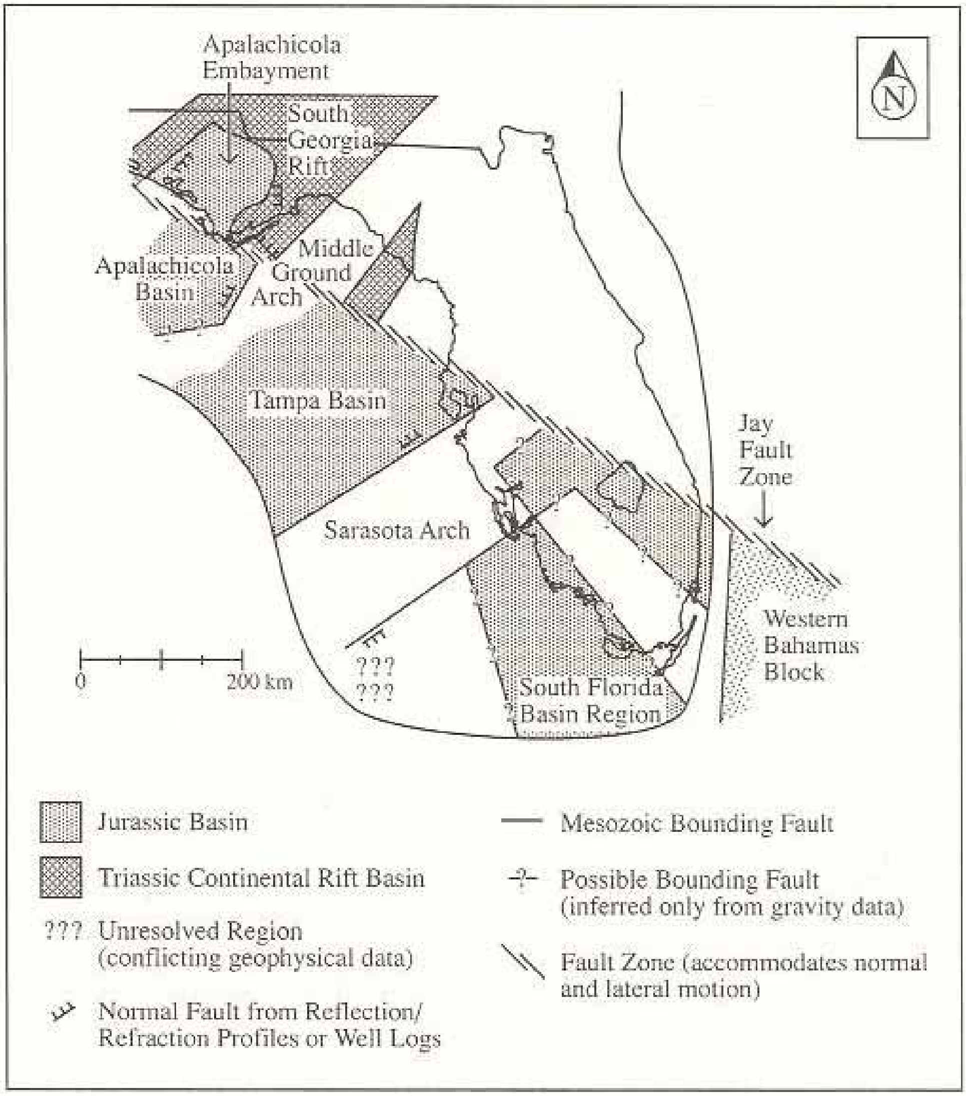


Figure 2. Major structural features of the West Florida Continental Shelf (WFS) showing primary fault zones (transform faults), rift basins, and blocks. (From Smith and Lord, 1997).

Carbonates of the Florida Platform represent integrated carbonate-evaporite-siliciclastic facies systems (Randazzo, 1997). These systems respond to low-stand, transgressive, and high-stand sea-level conditions (Handford and Loucks, 1993). The Florida Platform was located near the mid-Triassic equator and migrated northward (along with North America) during the Jurassic to the Oligocene. This platform evolved from a rimmed shelf in the Jurassic and Cretaceous to a carbonate ramp in the Paleogene, based on descriptions summarized by Handford and Loucks (1993). Episodes of cyclic sedimentation were repetitive cycles that involved shallowing upward alternations of carbonate and evaporite sedimentation. Sea level was higher during the Cretaceous and most of the Paleogene than at present (Figure 3a). Figure 3b shows worldwide (eustatic) fluctuations of sea level through the Neogene (Miocene and Pliocene) and Quaternary (Pleistocene and Holocene) where sea level was higher than present. Deposits associated with eustatic fluctuations are also shown in Figure 3, which reconstruct major stratigraphic units for the South Florida Basin including the Florida west coast (WFS). These eustatic fluctuations resulted in incursions of clastic sediments from the north and west during low stands, which became more frequent during the late Eocene and Oligocene. Although it is not known how most of this huge system was terminated, there are a number of processes that could shut down the widespread carbonate production on the Florida Platform. Such processes for example include: (1) eutrophication of seawater by nutrients from terrestrial runoff and coastal upwelling, (2) continental plate migration in colder climates, (3) burial by river deltas where siliciclastic sediments are shed from the eroding Appalachian Mountains, Piedmont, and continental interior, and (4) sea-level fluctuations (interacting eustatic and tectonic processes coupled with local subsidence to produce relative differences in sea level). According to analyses by Hine (1997), most likely a combination of these factors terminated the development of the gigacarbonate platform.

Today, active areas of carbonate sedimentation are restricted to the southern and southwestern parts of the WFS (Florida Keys). These areas persist as broad, extensive carbonate platforms as a result of: (1) long-term residence in tropical to subtropical climatic zones, (2) separation from a siliciclastic-sediment source (the southeastern U.S. continental mainland) by an open seaway (Bahamas) or by distance (southern Florida), and (3) the absence of persistent environmental stress (*i.e.* nutrient overload from upwelling, schizohaline waters).

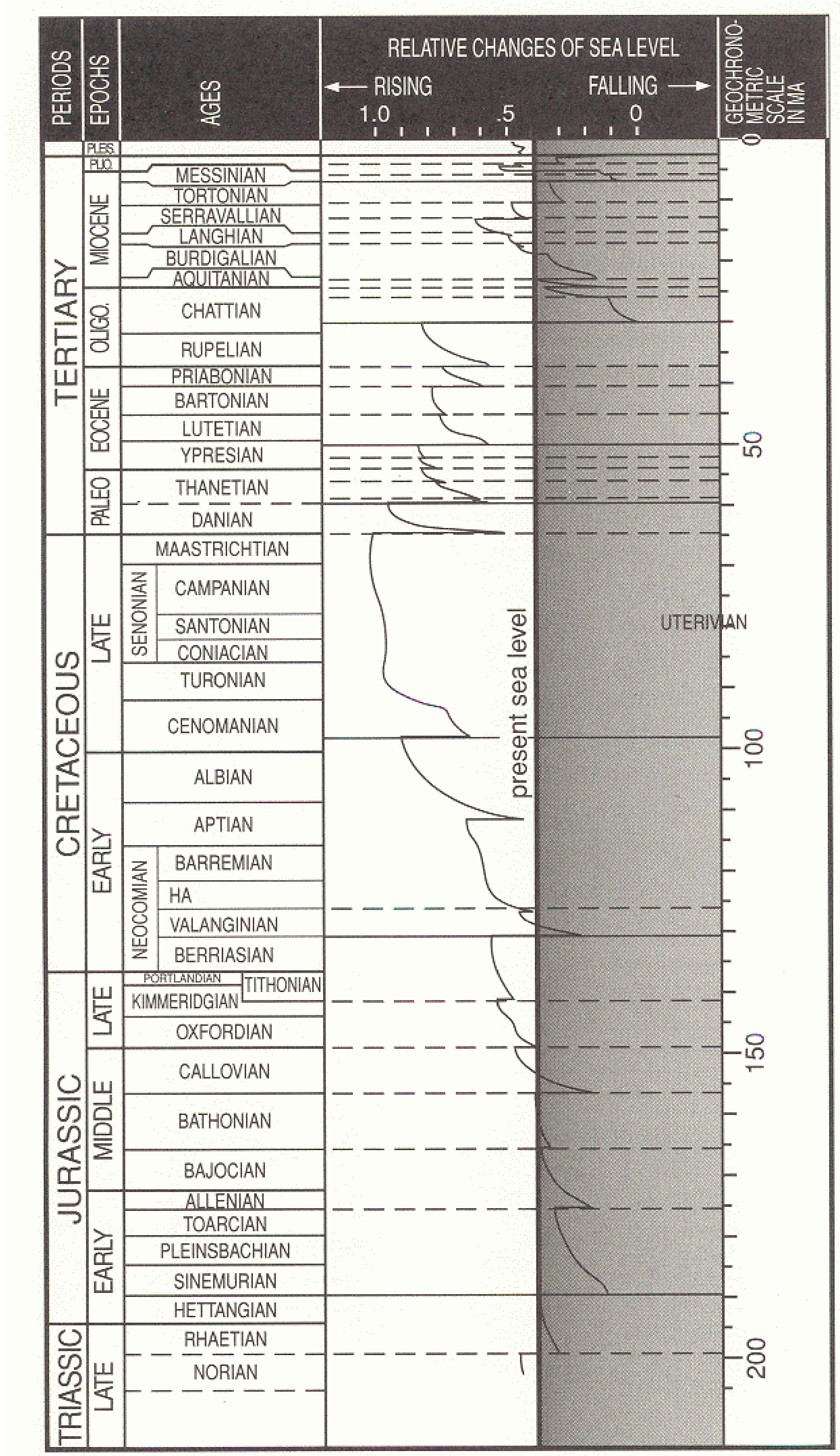


Figure 3a. Late Mesozoic and Cenozoic geochronologies and sea-level fluctuations based on magnetostratigraphy, biostratigraphy, and sequence chronostratigraphy. (From Randazzo, 1997, compiled from Haq *et al*., 1988).

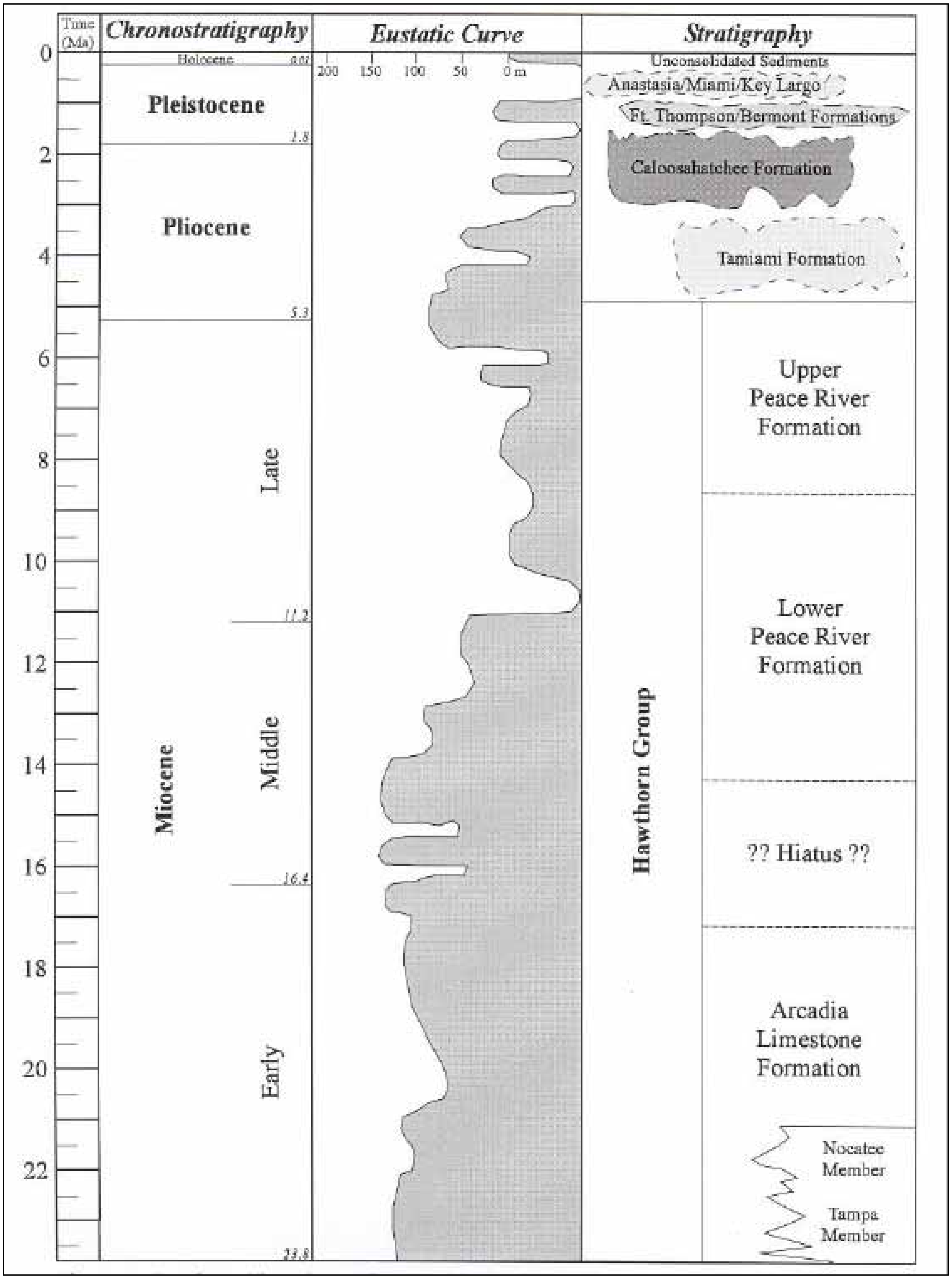


Figure 3b. Stratigraphic column for west-central Florida, including the WFS based on interpretation of chronostratigraphy, lithostratigraphy, and eustatic cycles compiled by Haq *et al*. (1988), Cunningham *et al*. (2001), and Duncan *et al*. (2003). (From Suthard (2005).

Two outstanding characteristics of the Quaternary and modern WFS are the breadth and low gradient inherited from the underlying carbonate ramp system. The average gradient of the shelf is 0.4 m/km (Ginsburg and James, 1974). Several important topographic features have controlled sedimentation, besides the broad regional nature of the ramp. The western Florida coast and inner shelves are dominated by two large estuarine systems: Tampa Bay and Charlotte Harbor. Both of these drowned river-valley systems appear to occupy local structural depressions, perhaps resulting from concentrated dissolution of underlying limestones with the platform. Evans and Hine (1991) have shown that prominent subsurface sinkholes and fold structures occur beneath Charlotte Harbor. Other studies of the Florida Platform also emphasize the importance of subsurface karst features (e.g. Snyder *et al*., 1989), folds and sag structures that are readily discernable in Paleogene strata beneath the east margin of the Florida Platform. Extensive, buried Miocene karstification and prominent collapse features are also known to occur along the outer shelf off southwestern Florida (Macurda, 1989). Perhaps low stands of sea level during the late Paleogene and early Neogene, accompanied by geothermal heat flow, as described by Kohout (1967), promoted accelerated fluid flow within the Florida Platform and caused extensive dissolution that produced the deformation seen in seismic profiles and eventually created the shallow basins of Tampa Bay and Charlotte Harbor. These two basins contain similar patterns in Holocene sediment deposition that are controlled by regional environmental factors (Brooks, 2004).

Concentration of surface runoff into large, distinct basins allows for transport of upland sediments onto the shelf during sea-level lowstands, where they are reworked during subsequent high stands. Hebert (1985) reports that seismic data reveal a 30-m by deep 5-km-wide buried channel that can be traced approximately 40 km seaward from the present coastline at Tampa Bay (see also discussion in Berman, 2005, and Suthard, 2005). This apparent westerly subaerial sediment transport accounts for the deposition of siliciclastic sediments (or reworked Miocene phosphorites) or more distal (westerly) parts of the underlying carbonate ramp (Hine, 1997).

Where Tertiary limestones have been exposed, the karst topography has had a dominant effect on coastal morphology (Hine *et al*., 1988). The inner shelf reveals aligned sinkholes and liner depressions etched in bedrock, formed by springs discharging freshwater that migrated landward in response to sea-level rise (Hine and Beklnap, 1986).

Facies changes are broader and more diffuse than on rimmed carbonate platforms because the WFS and the West Florida Slope constitute a ramp system (Reading, 1978). However, unlike carbonate ramp models (Read, 1985), sediment grain size remains relatively coarse well out onto the outer shelf and upper slope (at depths of 500 m) (Hine, 1997). Sediment grain size is coarsest between depths of 75 and 100 m, becoming finer both landward and seaward (Blake and Doyle, 1983); muds and oozes occur in water depths greater than 800 m (Mullins *et al.,* 1988). In addition, the WFS is a mixed siliciclastic-carbonate system with a quartz-sand belt (Figure 4) that was introduced onto the Florida Platform after the late Paleogene closure of the Suwanne Strait. In general, facies boundaries trend parallel to the bathymetry (Doyle, 1981). The quartz-sand facies is a second primary difference between the west Florida margin and the Campeche Bank;

siliciclastic sediments are being introduced to the upper slope off northwestern Florida by the Loop Current, which periodically carries muds from the Mississippi River (Walker, 1984).

The quartz-sand belt at the coastline makes up the barrier-island system and underlies the marine-marsh system (Figure 4). The sedimentary wedge is nowhere very thick (less than 10 m) and thins seaward (Sussko and Davis, 1992). In some areas, the quarts-carbonate boundary lies within a few hundred meters of the beach. The quartz-sand facies pinches out where Tertiary limestone bedrock is exposed. Much of the shelf has exposed hardbottom but admixtures of quartz sand and carbonates occur in the form of inner shelf sand ridges (NOAA, 1985; Hine, 1997).

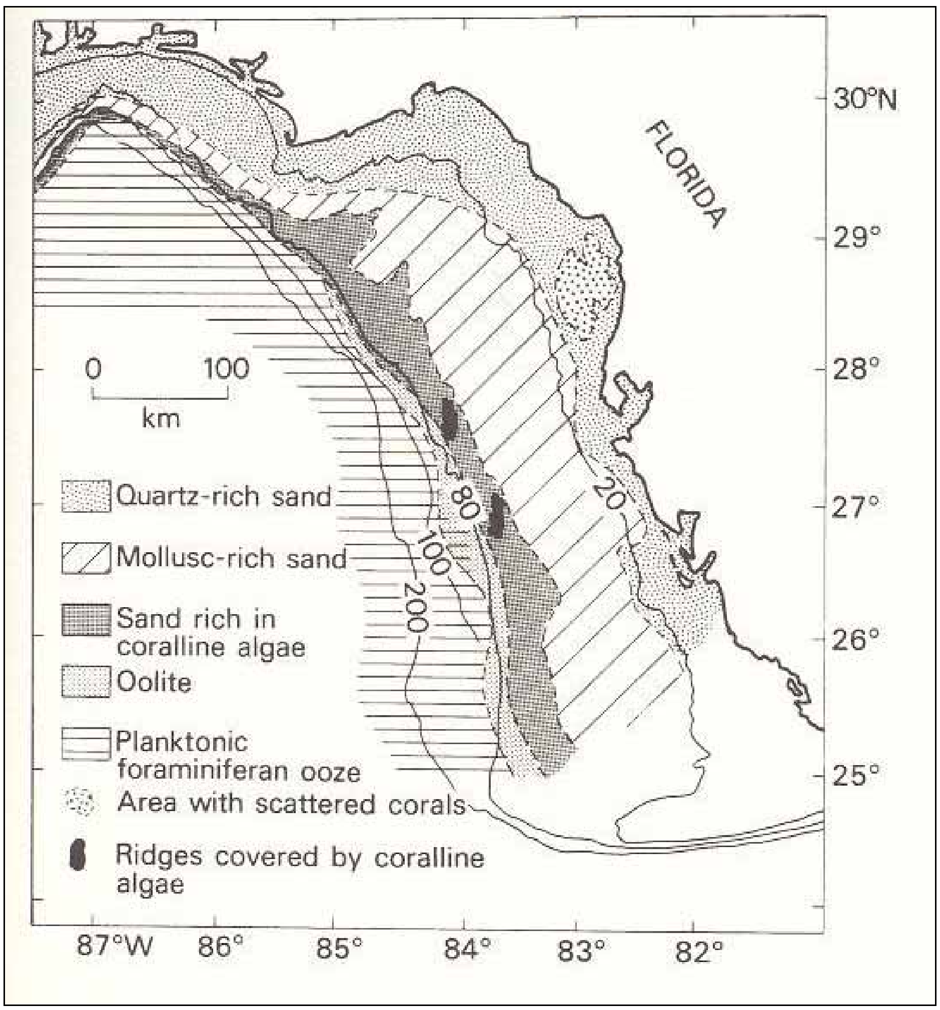


Figure 4. Generalized sediment facies map of the WFS, showing inner quartz sand belt and seaward carbonate belts, each dominated by a different carbonate sediment type. Facies belts parallel general bathymetric trends. (From Hine, 1997, and Reading, 1978).

The dominant carbonate constituents within the quartz-sand belt (inner shelf) are mollusks (Figure 4). Scattered coral occur on exposed rocky surfaces in shallow water, and calcareous green algae (Halimeda, Udotea, and Penicillis) in seagrass beds but none of these organisms produce an identifiable component in the surrounding sediments. South of Cape Romano, quartz content drops from 80% to 2% on the inner shelf toward Florida Bay, a well-known carbonate sediment-producing environment that represents the bank-interior facies of the south Florida carbonate platform (Sussko and Davis, 1992).

The middle shelf is characterized by a thin molluscan-sand sheet, about 1 m thick, where hardbottoms (exposed bedrock or relict reef) do not exist (Figure 4). Molluscan sands occur beyond the outer shelf; however, coralline-algal sands and ooids form identifiable facies belts with the outer shelf. The ooids are in water depths ranging from 80 to 100 m, but they are also found in shallow waters 2 to 5 m deep, indicating that they are autochthonous deposits formed when sea level was lower (Kump and Hine, 1986). These coated grains formed in shallow-water, wave-dominated environments during the last sea-level low stand and during early phases of the following rise. The molluscan sands and coralline-algal sands are probably younger than the ooids, having formed after sea level had risen and created open-shelf conditions (Reading, 1978). The algal sands probably dominate in areas where hardbottoms and/or rocky highs (relict reefs?) are more abundant (Hine, 1997).

The region of the outer shelf, shelf margin, and upper slope (200 – 600 m) is a broad area consisting of two facies belts: hardgrounds with algal ridges (200 – 400 m) and winnowed sands (400 – 600 m). A bioturbated pelagic-ooze facies extends from 600 m to the seaward margin of the West Florida Escarpment. Three types of Quaternary hardgrounds are recognized: (1) heavily bored, intraclastic, foraminiferal grainstones cemented by magnesium calcite, (2) deep-water coral framestones, and (3) gravel-sized rhodolith rudstones consisting of red-algae encrustations of skeletal fragments and intraclasts (Mullins *et al*., 1988). The winnowed sands contain calcite (from planktonic foraminifers), aragonite (from bivalves and gastropods, including pteropods), and magnesian calcite (from red algae, benthic foraminifers, echinoderms, and intergranular cement). The winnowed sands and hardground overlie oozes.

COASTAL PROCESSES AND GEOMORPHOLOGY

The southwest Florida barrier/inlet system is a mixed energy coastal system that is morphologically diverse as a result of a complicated interaction between relatively small tidal ranges (<1 m) and a mean wave height of 30-50 cm. Davis (1997) describes this coast as having the most diverse morphology of any barrier island system in the world containing about 29 barrier islands and 34 tidal inlets along about 300 km of shore (Figure 4). The geomorphological framework of the central west coast is summarized by Davis and Barnard (2003) as having both wave-dominated and mixed energy (*e.g.* drumstick) barrier island morphologies with islands ranging from 2 km to more than 30 km in length. Inlets range from tide-dominated through mixed energy to wave-dominated. Washover deposits are commonly verified along this coastal reach. Coastal orientation is generally from the NW-SE but there are three major dislocations at Indian Rocks (Pinellas County), Sanibel Island (Lee County) and Cape Romano (Collier County) (Figure 5).

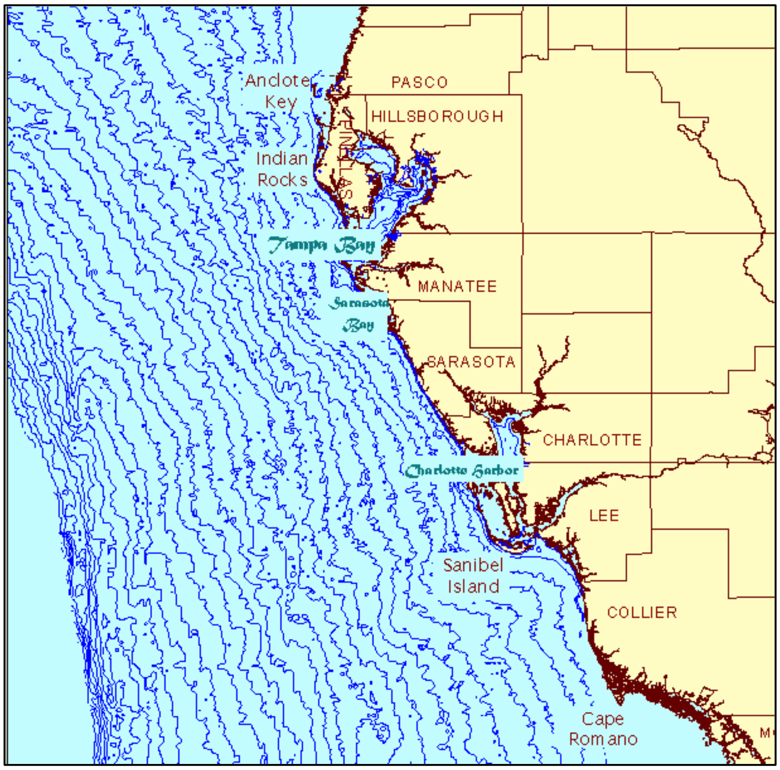


Figure 5. Study area map (from ROSS- enhanced with ArcView) showing area from Anclote Key to Cape Romano.

It is useful to note that the underlying antecedent topography of the Tertiary limestone surfaces, as well as their hardground exposures, significantly influence the orientation and geographic location of Holocene barrier islands and sand ridges along the west coast of Florida, as discussed by Evans *et al.* (1985), Hine *et al.* (1986) and Locker *et al*. (2003). The latter researchers in particular report a strong positive correlation between increased underlying bedrock gradients and increased sediment thickness. That is, thicker sediments occur over more steeply inclined basal surfaces and flatter basal gradients correlate with thinner sediment accumulations (Figure 6). This suggests a direct control of antecedent topography where Holocene sediments preferably accumulated in areas where steeper bedrock anchored the littoral and shelf sands. Historical shoreline data for recently evolved coastal barriers and stratigraphic data based on core logs from older barriers indicate that they formed in response to a gentle wave climate that transported sediments onshore to shallow water where they shoaled upward to intertidal and supratidal levels (Locker *et al.*, 2003). The present coastal barriers thus probably formed in the Holocene close to their present location in association with antecedent topography comprised by shallow Miocene limestone bedrock (Evans *et al.*, 1985). Today, important variables that control barrier-island development include the availability of sediment and the interaction of wave and tidal energy.

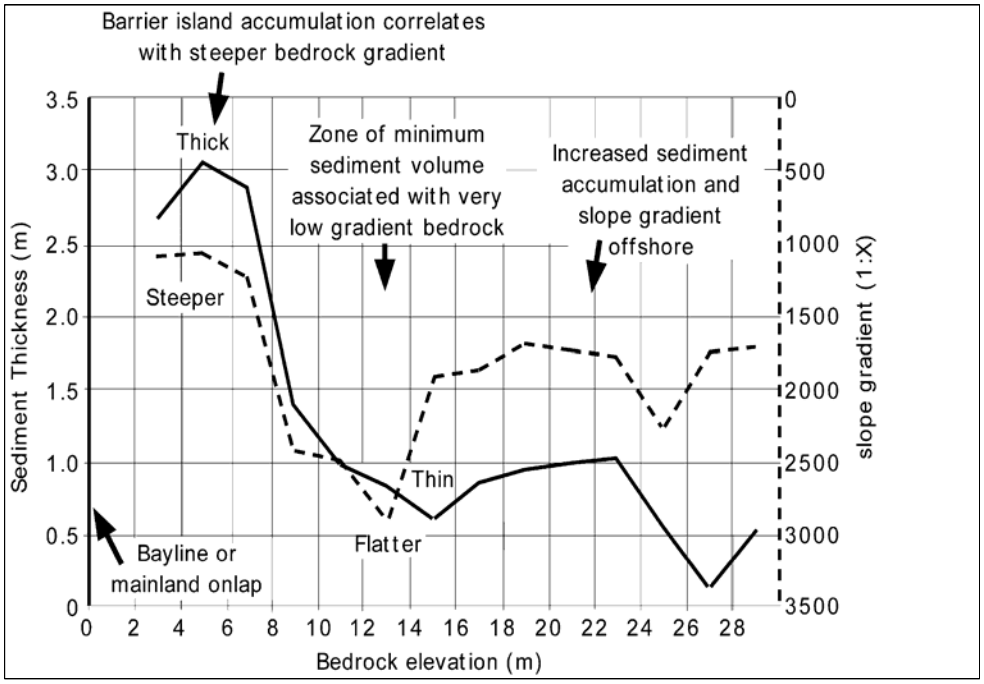


Figure 6. Data used by Locker *et al*. (2003) to illustrate the correlation between sediment thickness and bedrock gradient as presented.

Regional investigations conducted by the US Geological Survey (Hine *et al.*, 2001) show that most the barrier islands originated at or near their present location as subtidal shoals evolving to supratidal barriers. Their stratigraphy thus can be viewed in a relatively simple stratigraphic model characterized by initial upward shoaling, aggradation and then, in some cases, progradation.

The barrier islands are relatively young having formed over the last 3000 years when the rates of Holocene sea level rise were not more than 0.04 cm a^{-1} (Stapor *et al.*, 1988). The rate of sea level rise during the Holocene played a major role in Barrier island development along this coast. During the early Holocene (*e.g.* 10,000 to 12,000 years ago) when rates of sea-level rise were greater than 1 cm a^{-1}, they prohibited the development of stable barrier islands. Because this coast was devoid of major sediment supplies during this period of rapid sea-level rise, large coastal sand bodies were not developed or preserved on the shelf above the carbonate platform. The coastal morphology that we observe today began to develop about 3000 years ago when favorable conditions included declining rates of sea-level rise that stabilized to nearly today's rates (0.02 to 0.06 cm a^{-1}). The oldest subaerial sediment accumulations on the barrier islands were dated at 3,000 YBP by Stapor *et al*. (1988) but Holocene sediments beneath the barrier islands were dated from 4,200 to 4,500 YBP by Davis and Kuhn (1985). Because sea level fluctuated around present eustatic conditions during the late Holocene (Fairbridge, 1961), sand bodies landward (beach ridges) and seaward (inner shelf sand ridges) of the present coastline developed during the last 4,000 years of the Holocene. These sediments generally do not exceed 8 m in thickness and thin from the barriers to the offshore. Holocene sediments lay unconformably ontop of pre-Holocene strata. Most of the Pleistocene record is absent on the inner shelf except for restricted areas where thin layers of Pleistocene clay have been mapped *(e.g.* Davis and Kuhn, 1985). According to Hine *et al*. (2001) the pre-barrier history of this area is characterized by multiple incursions and excursions of sea level preserved in a wide range of estuarine to open marine sequences.

Modern morphodynamics of the barrier/inlet system are strongly influenced by anthropogenic activities such as stabilization of inlets, construction of causeways, coastal structures (*e.g.* jetties, groins) and general coastal constructions. The tidal range in this area is small (less than 1 m) leading to limited tidal prisms and frequent inlet closures and migrations. Exceptions are made for some coastal inlets that have relatively large tidal prisms and large ebb shoals due to the large area occupied by the back barrier water bodies that feed them (*e.g.* mouth of Tampa Bay and Charlotte Harbor estuaries). At the mouth of Tampa Bay, for example, the Egmont ebb-tidal delta (also known as the Tampa Bay ebb-tidal delta), is a huge sedimentary complex that stores about 305,000,000 m^3 of sediments. This deposit is the second largest coastal sedimentary body on open Gulf of Mexico (Stott and Davis, 2003) (the first is the Mississippi Delta).

Meteorological conditions predominant over this area include summer prevailing winds from the south-southeast with low to moderate velocities and occasional occurrence of summer extreme storm events (hurricanes). During recent years, there have been several tropical storms and hurricanes that affected this coast. The 2004 hurricane was a reminder of the vulnerability of this coast to extreme storm events when Hurricane Charley made landfall in the Punta Gorda region (Charlotte County). This major storm drastically affected coastal morphology for hundreds of kilometers to the south and north of the landfall area by opening new inlets (*e.g.* breach in North Captiva Island) and causing extensive overwash and damage to coastal infrastructure. H. Charley was in fact the first major hurricane to make landfall in southwest Florida since coastal development took place. Winter cold fronts are common from November to March along the study area. They are generally generated in Canada and move southward across the Great Plains. When the cold fronts move offshore from Texas and Louisiana and then head towards the east-southeast there is sufficient fetch to generate significant waves in this coast. When a cold front approaches, the barometric pressure begins to fall and winds are from the southwest as the front moves near the peninsula. When the front passes, there is an abrupt shift in wind direction accompanied by a rapidly rising barometric pressure and strong winds from the northwest and north. As the front moves across the peninsula toward the east coast, wind velocity decreases and barometric pressure levels out (Davis and Barnard, 2003).

Due to limited fetch in the Gulf of Mexico, the wave climate is mild with mean annual wave heights fluctuating from 0.3 to 0.5 m with short mean wave periods ranging from 4 to 5 seconds (Davis *et al*., 2003). Net littoral drift is from north to south given that the most frequent energetic wave events originate from cold fronts that generally move in the north to south direction. Net littoral drift rates range from 30,000 to 75,000 cy/yr (*e.g.* Taylor, 2002); greater rates are observed where the coastal orientation increases the obliquity of northern waves (*e.g.* Sand Key and Sanibel Island). Drift and current reversals are commonly observed downdrift of tidal inlets due to wave refraction-diffraction patterns along ebb shoals. This phenomenon is particularly true for large tide-dominated inlets that have large and well-developed ebb tidal shoals.

GEOLOGY AND GEOMORPHOLOGY OF COASTAL SEGMENTS

In order to provide a basis for cogent discussion of specific geological and geomorphological information, the coast of southwest Florida was divided in three different coastal segments that are subdivisions of the coastal stretch often referred to as the West-Central Barrier Chain (Davis and Barnard, 2003; Hine *et al*., 2003): (1) the Northern Coastal Segment consisting of Pinellas County barrier islands and Tampa Bay and delimited to the north by Anclote Key and to the south by Egmont Key, (2) The Central Coastal Segment, consisting of Manatee, Sarasota and Charlotte Counties from Anna Maria Island to the Peace River Estuary, and (3) the Southern Coastal Segment consisting of Lee and Collier Counties from Venice Inlet to Cape Romano. Summary descriptions of these coastal segments with emphasis on coastal geomorphology and shelf sand bodies are provided below. Note that more detailed studies of shelf morphology and continental shelf depositional systems in these coastal segments are summarized in *Marine Geology* (Volume 200, Numbers 1-4), providing insight and interpretation of the geologic framework and deposits for most of the WFS.

Northern Coastal Segment (Pinellas County and Tampa Bay)

This coastal segment is delimited to the north by Anclote Key and to the south by Egmont Key. A prominent feature in the northern coastal segment is Tampa Bay, the largest estuary in the state of Florida covering approximately 2590 km^2 (1,000 square miles). The opening of Tampa bay is about 4 km long and is delimited by Mullet Key to the north and Anna Maria Island to the south. Just north of Tampa bay lies the boundary between the barrier island coast and the low-energy Big Bend coast that is dominated by open coastal marshes. Along the barrier islands prominent features include the change in orientation of the shoreline at Sand Key and the presence of bay-mouth barriers (*e.g.* Egmont Key) that were built by ebb shoal aggradations in the late Holocene (Stott and Davis, 2003). Some of these islands are relatively young having formed in the last millennium. Figure 7.

Hardgrounds in this area are generally of Miocene age (Hawthorn group) consisting of two main formations, the Arcadia formation and the Peace River Formation (Scott, 1997). The Arcadia Formation (Early to mid Miocene) is a marine limestone/dolostone with thin beds of phosphatic quartz sands and clays (less than 1.5 m thick and limited lateral extend). The Peace River Formation (Middle-Upper Miocene) is mostly siliciclastic with interbebbed quartz sands, clays and carbonates. This formation contains large volumes of fluvio-deltaic sediments and very few marine carbonates in contrast to the older Arcadia Formation (Scott, 1997; Suthard, 2005). Rock outcrops on the northern part of Sand Key are comprised of Miocene exposures of the Arcadia Formation (Tampa member).

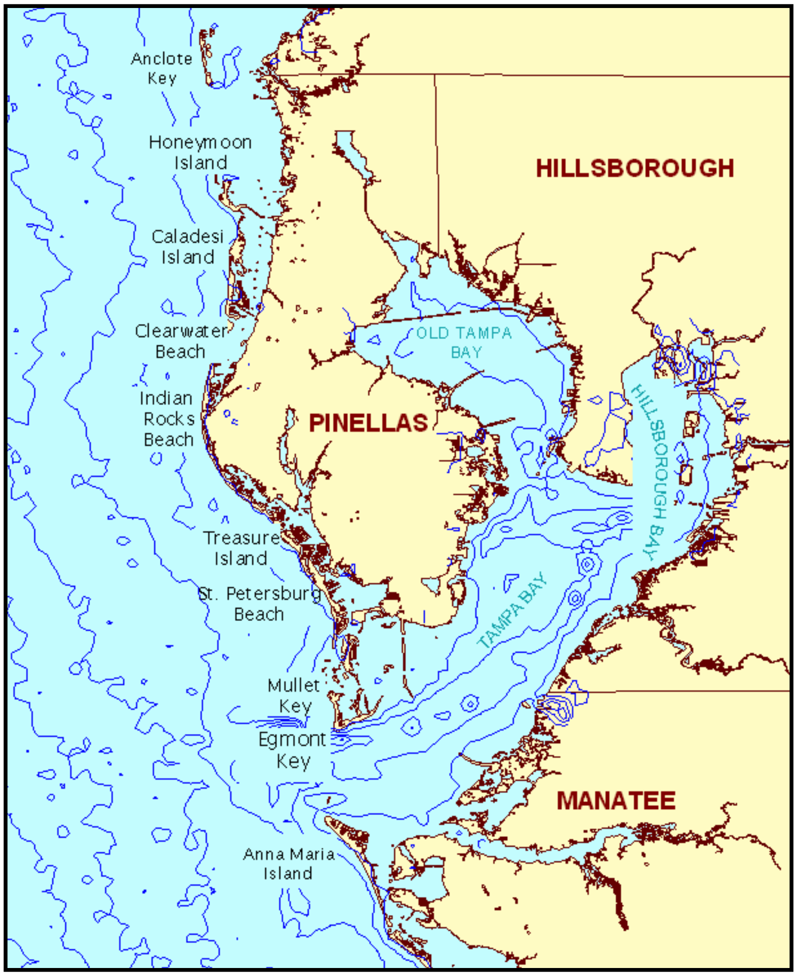


Figure 7. Detailed map of Northern Coastal Segment (Pinellas County & Tampa Bay) with bathymetry. Data from Ross, enhanced with ArcView

The inner shelf contains bedrock exposures (hardgrounds) of the Arcadia Formation that are unconformably overlain by Holocene sand ridges. The sand ridges have a general NW-SE orientation from Sand Key northward but assume a more perpendicular orientation (relative to the shoreline) offshore Treasure Island and Mullet Key. In the area influenced by the Tampa Bay ebb-tidal shoal, the ridges are not well developed and tend to exhibit chaotic orientation patterns (see discussion on sand ridges). Holocene sediments often blanket hardgrounds offshore Anclote Key, but the hardgrounds become exposed in troughs between ridges offshore Sand Key (Figure 8). Offshore Mullet Key, a thick Holocene package covers the inner shelf (north section of the Tampa Bay ebb tidal shoal)

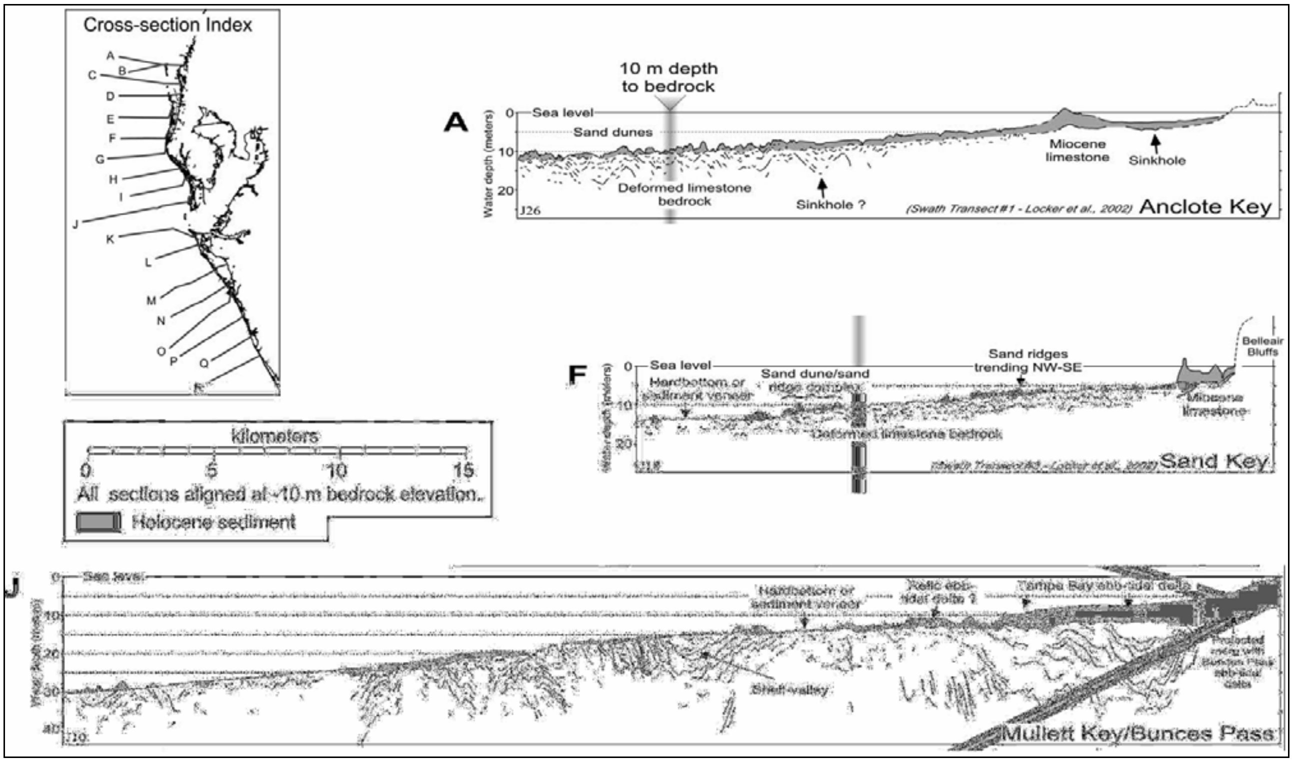


Figure 8. Representative stratigraphic cross-sections (A, F, and J) of the northern coastal segments showing contrasting seabed conditions with bedrock exposures and Holocene sedimentary deposits (shaded), presenting the distinction between Holocene sediments (shaded) and underlying hardbottoms). Cross-section J shows ebb-tidal sands covering the inner shelf while cross-section F (Sand Key) shows bedrock exposures that dominate the seafloor between successive sand dunes and ridges. (From Locker *et al*., 2003).

Central Coast and Shelf (Manatee, Sarasota and Charlotte Counties)

This coastal segment extends from Anna Maria Island to Charlotte Harbor (Boca Grande Pass) (Figure 9). The Sarasota County and Charlotte County coasts are thinly mantled with loose, free running sand (the unconsolidated deposits generally thickening from south to north) that overlie eroded limestones of the Arcadia and Peace River Formations (Campbell, 1985). The Arcadia Formation, a white to tan-colored quartz sandy limestone with a carbonate mud matrix of lower Miocene age (23 to 15.6 Ma) occurs as a near-subsurface layer throughout the area. The top of Arcadian limestone lies at approximate mean sea level in northwestern Sarasota County (in the vicinity of Longboat Key) but dips to more than 30 m (100 ft) depths in the southern-most part of Sarasota County and throughout Charlotte County (Campbell, 1985). The younger Peace River Formation (Middle to Upper Miocene – 16 to 5 Ma) is found near sea level throughout southern Sarasota County (Campbell, 1985).

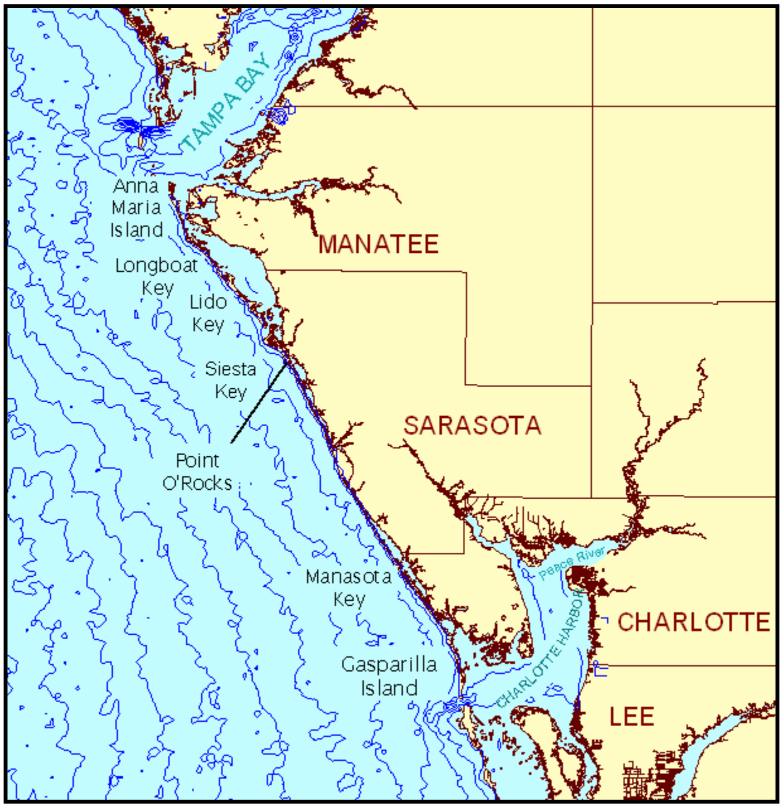


Figure 9. Detailed map of Central Coastal Segment (***Manatee, Sarasota and Charlotte Counties***) with bathymetry. Data from Ross, enhanced with ArcView.

Anna Maria Island and Siesta Key are typical drumstick barrier islands whereas Longboat Key and Lido Key are elongated wave dominated barriers. Anna Maria Island maintains a characteristic drumstick barrier island shape with a wide updrift side and narrow downdrift segment (Figure 10). The island is delimited by a large tidal inlet and ebb-tidal shoal on its northern margin (Passage Key) that provides sediment and wave shelter that promotes the drumstick shape. Large transverse bars (cross-shore bars) that occur on the inner shelf offshore Anna Maria Island have wavelengths of 60 to 120 m, local relief of 2 m, and extend 3 km offshore (Gelfenbaum and Brooks, 2003). These transverse bars are reported to migrate up to 20 m a^{-1} to the south by Gelfenbaum and Brooks (2003). Genesis and maintenance of these transverse bars remain contentious issues. Genetic interpretations of their development include convergent shoaling waves and resultant cross-shore circulation (Niedoroda and Tanner, 1970), a quasi-harmonic response of a sandy sea bed to alongshore tidal and wind-driven currents acting in association with waves (Falques *et al*., 1996), and alongshore tidal flow asymmetries (Barcilon and Lau, 1973). Sediments from these transverse bars were dredged for the nourishment of Anna Maria Island in 2002 (Figure 10).

Figure 10. North-south oblique aerial photograph (left image) showing the drumstick shape of Anna Maria Island. The landward boundary of the 2002 borrow area (arrow marking the borrow area edge) is located within the transverse bar field. The transverse bars and the 2002 borrows, shown in the right image (looking from west to east), abruptly terminate to the south in a relatively featureless nearshore.

Longboat Key and Lido Key are two elongated, wave-dominated barriers that occur south of Anna Maria Island. Siesta Key, a drumstick barrier, is located downdrift of Lido Key. An interesting feature of Siesta Key, in relation to the rest of Sarasota County, is an extensive rock outcrop at Point of Rocks where it forms a prominent disjunctive rock surface for about 1.6 km along the beach. The outcrop was initially thought to be part of the Anastasia Formation (Campbell, 1985) but recent studies by the US Geological Survey (Hine *et al*., 2001) indicate that the rock formation at Siesta Key is younger than the Pleistocene Anastasia Formation. The Siesta Key outcrops, modern Holocene formations 4000 years old, contain beach sediments that are attributed to a pre-existing barrier island that was lithified by fresh groundwater percolation. The mechanical resistance of this cocinoid limestone to wave and current erosion accounts for its prominent seaward projection. Stapor *et al.* (1988), using aerial photographs and field surveys to define several sets of beach ridge systems along Siesta Key, obtained radiocarbon dates of shells in the ridges to develop a chronology for island evolution that dates back to the mid Holocene. The oldest beach-ridge set, dated at 3000 YBP, occurs near the center of the island. Landward of Point of Rocks, radiocarbon dates range from 4300 to 1900 YBP in "beachrock" that extends from present mean sea level to -2.5 m (Spurgeon, 1997). South of Siesta Key, the coast is dominated by relatively narrow, elongated, wave-dominated barrier islands (i*.e*. Casey Key and Manasota Key, Knight Island and Don Pedro Island). Gasparilla Island, the last barrier of this coastal segment assumes a shape somewhat similar to typical drumstick morphology and is delimited to the south by Boca Grande Pass (main channel of the Peace River estuary).

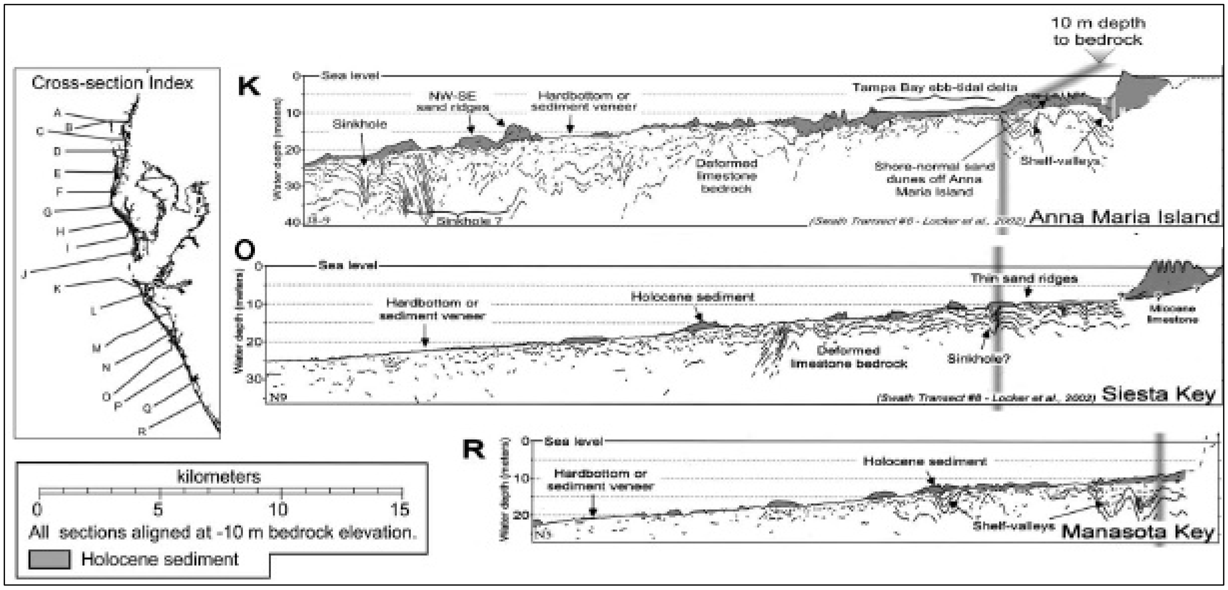


Figure 11. Representative stratigraphic cross-sections (K, O, and R) of the southern coastal segments (see cross-section index, upper left hand corner) showing contrasting seabed conditions with bedrock exposures and Holocene sedimentary deposits (shaded) presenting the distinction between Holocene sediments (shaded) and underlying hardbottoms). Cross-section K shows Tampa Bay ebb-tidal sands covering the inner shelf while cross-sections O (Siesta Key) and R (Manasota Key) show bedrock exposures that dominate the seafloor between successive sand dunes and ridges. (From Locker *et al*., 2003).

The inner shelf offshore Sarasota County is dominated by sand ridges that lie unconformably on top of Miocene hardbottoms (Arcadia and Peace River Formations) (Figures 11 and 12).

The sand ridges along this coastal segment have two general orientations (Figure 13). Shore oblique (NW-SE) sand ridges occur offshore Casey Key, Manasota Key and the southern part of Siesta Key whereas shore-transverse (SW-NE) ridges occur mostly offshore Anna Maria Island, Longboat Key, and Lido Key. Prominent shore parallel to shore-oblique sand ridges in water depths from 9 to 15 m occur offshore the mid section of Manasota Key to the end of this coastal segment. The ridge patterns offshore southern Sarasota County and northern Charlotte County are interrupted by a scoured depression in the shelf that may be represent a trace of the Peace River paleo-channel that incised the carbonate bedrock during lower sea-level stands. Several of these sand ridges were investigated in offshore marine sand searches and a few, containing beach-quality sediments, were dredged for coastal restoration (*e.g.* Finkl *et al*., 2003 and Benedet *et al.*, 2004; CPE, 1992, 1995, 1998, 1999 a and b) (Figure 14).

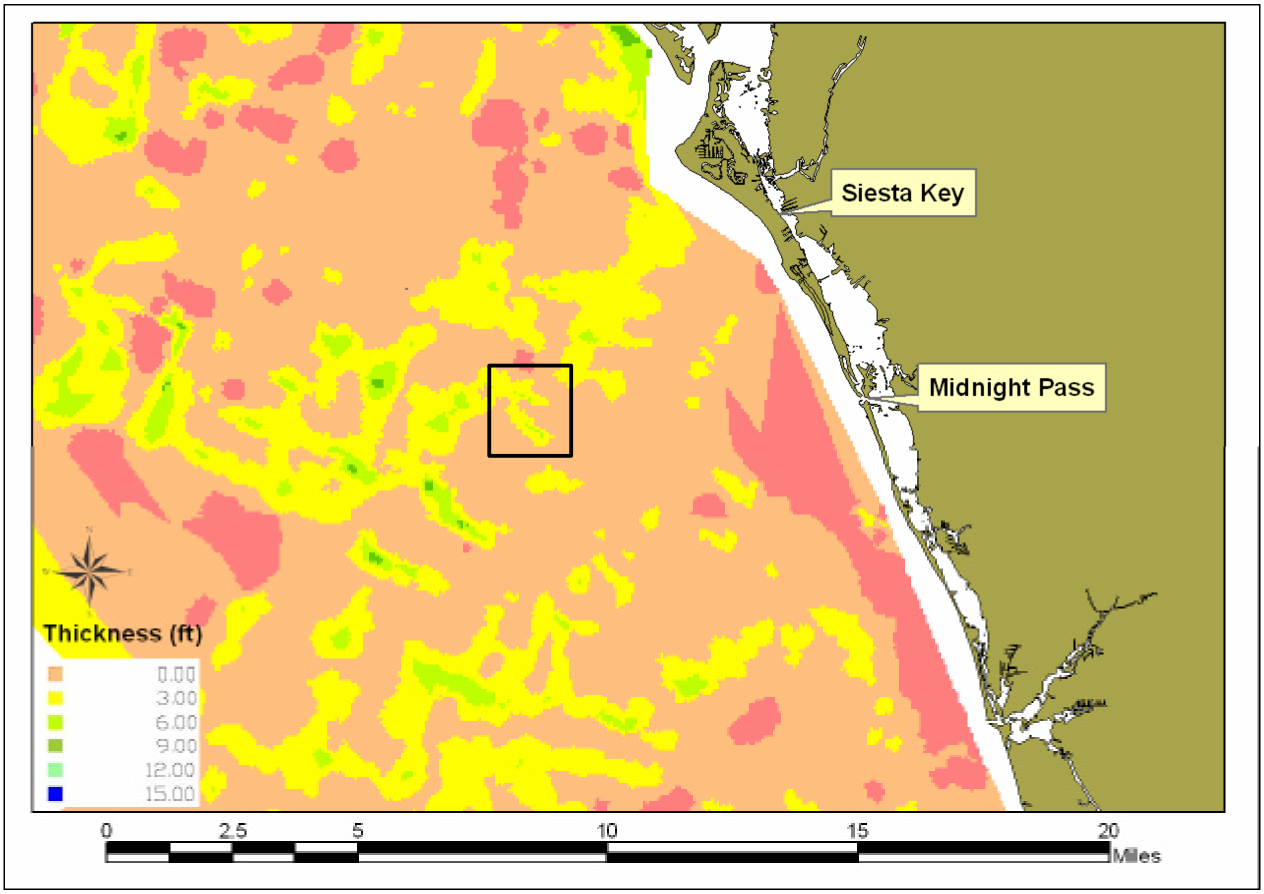


Figure 12. Sediment thickness on the seafloor off offshore central Sarasota County, Florida. The isopachs were calculated in customary units from bathymetry and seismic reflection profile data that was respectively obtained from NOAA and the U.S. Geological Survey. Sand thickness is greatest in sand ridges (3 to 12-foot isopachs). Miocene bedrocks are exposed on the shelf where pink and red shades are present (no sediment cover).

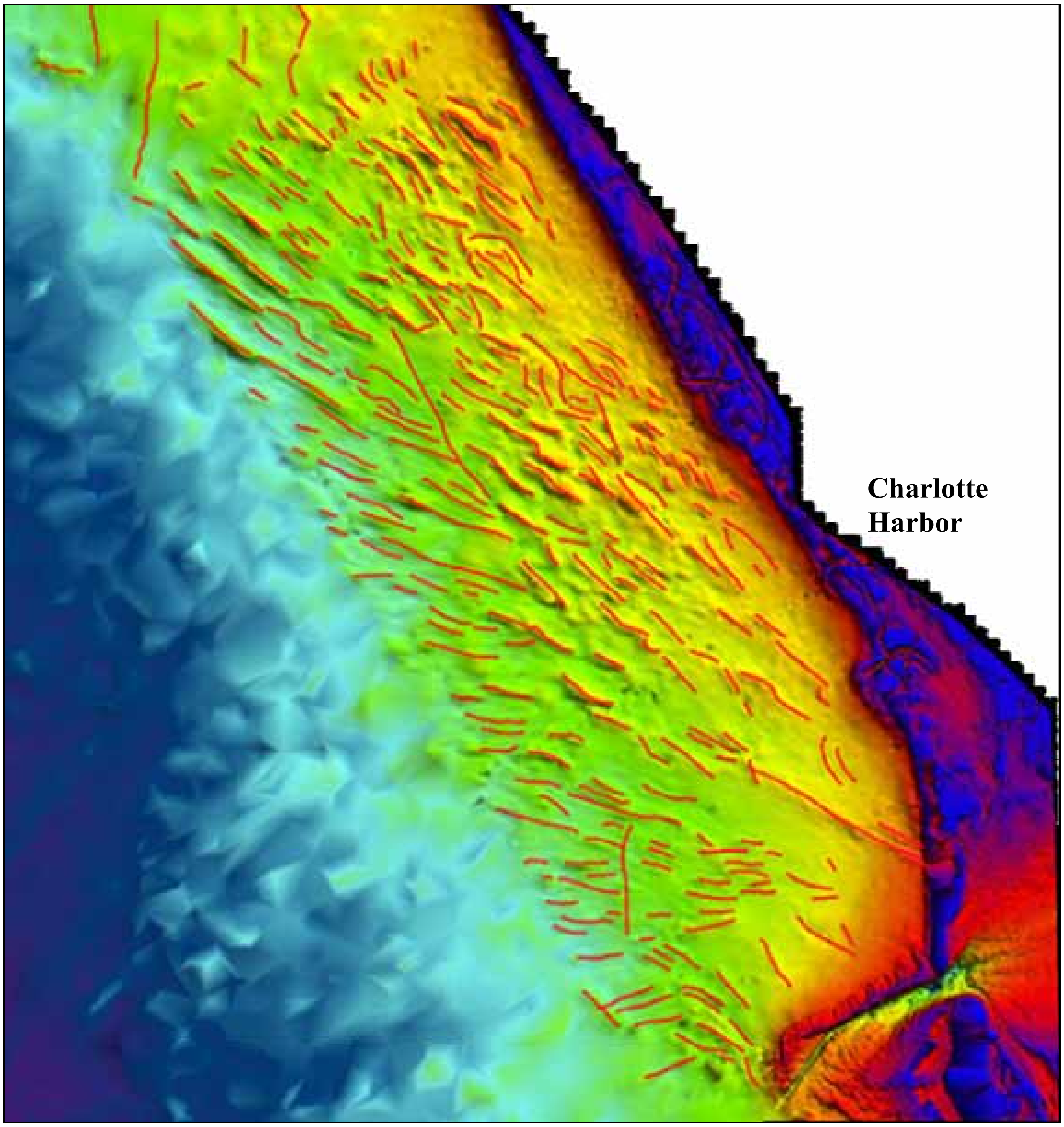


Figure 13. Sand ridge orientation offshore the southern part of the Central coastal segment.

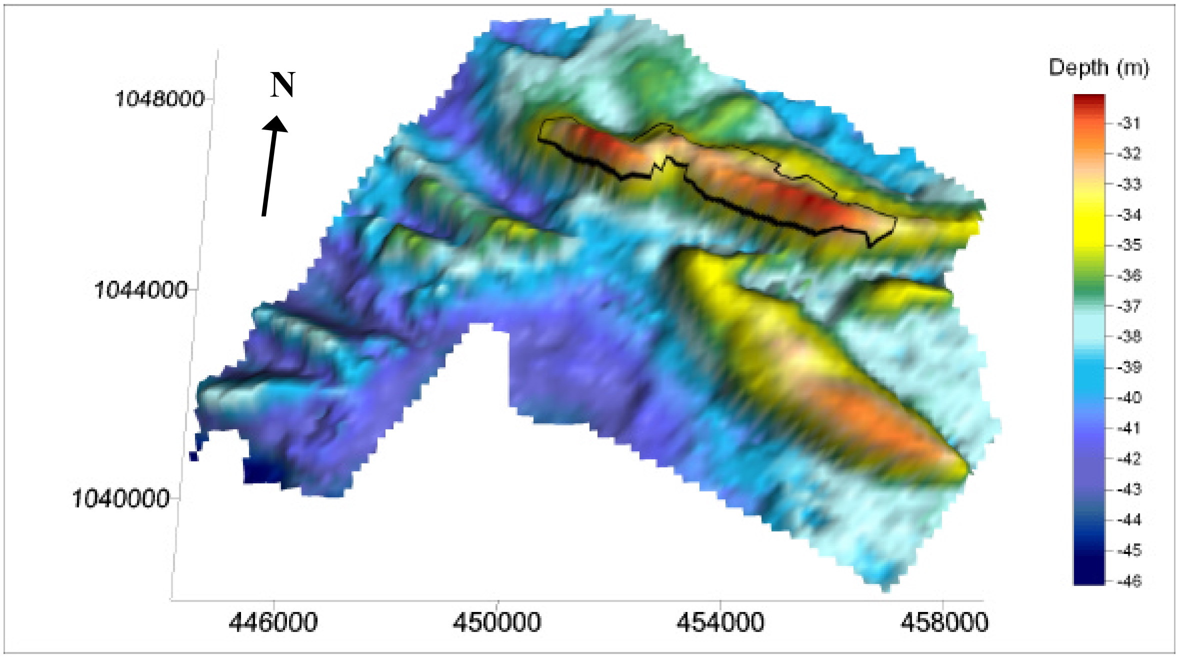


Figure 14. Digital elevation model (DEM) of sand ridges off Siesta Key. The black line enclosing part of the northern ridge defines a borrow area that will be used for the 2005 Siesta Key Renourishment Project. The large northwest-southeast trending sandy ridge lying to the south of the borrow area also rises 8 to 10 feet above the surrounding seafloor (elevations are in feet NGVD and coordinates displayed are in NAD 83 FL State Plane West).

Southern Coastal Segment (Lee County and Collier County)

The southern part of the study area along the central west coast of Florida displays landforms that are characteristic of a sedimentary shore. This part of the coast features coastal barriers, estuaries, lagoons, inlets, wetlands, swamps, and inherited paleokarst (Figure 15). Most of the southern shelf is thinly mantled by loose, free running sand (the unconsolidated deposits generally thickening from less than a meter to several meters from south to north) that overlie eroded limestones of the Peace River Formation (Upper Miocene) and the Tamiami Formation (Pliocene Series – 5.3 to 1.8 Ma) (Drew and Schromer, 1984) as well as marl and lime mud deposits (McCoy, 1962). Bedrock exposures along Lee and Collier counties are thus of younger age (Upper Miocene to lower Pliocene) than the hardgrounds occurring north of Tampa bay (Lower to mid Miocene).

The southern study area is part of the same larger sedimentary continuum (extending from Anclote Key southwards to Cape Romano) that lies at the center of an ancient carbonate platform that faces seaward to an enormous sediment ramp. This ancient carbonate platform forms the proximal portion of the west Florida shelf-slope system (WFS) and exerts large-scale control on coastal geomorphology, the availability of sediments, and wave energy (Hine *et al*., 2003). Coastal geomorphology varies from drumstick shaped barriers (*e.g.* North Captiva Island) to barrier-spits (*e.g.* Capita and Sanibel islands) to long-and-narrow wave-dominated barriers (*e.g.* Longboat Key).

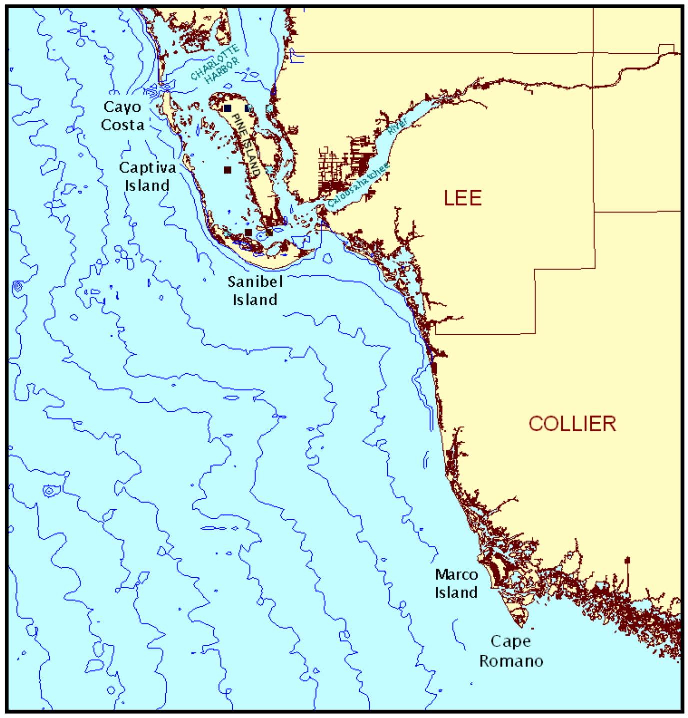


Figure 15. Detailed map of Southern Coastal Segment (*Sarasota Arch – South Florida Basin Region*) with bathymetry. Data from Ross, enhanced with ArcView

In the northern part of this coastal segment, shoreline orientation changes dramatically from more or less north-south to east-west at Sanibel Island (Figure 15), a giant barrier spit. This barrier island coast transitions to a mangrove coast at Cape Romano in the southern part of this coastal segment.

Quaternary sedimentary accumulation has produced a significant dislocation at the southern boundary of the study area (Cape Romano) which has several implications for interpretation of local morphodynamics. Cape Romano marks the southern end of the quartz-sand dominated Gulf Barrier Island Chain; the siliciclastic to carbonate transition occurs rather abruptly around latitude 25°30' (Campbell, 1988; Sussko and Davis, 1992) where the mangrove coast (Ten Thousand Islands) begins near the northwestern margin of Florida Bay. The low wave energy regime of this coastal segment allows for the construction of ebb-tidal deltas, which store moderate quantities of sand (Davis *et al.*, 1993; Hine *et al.*, 2003). Flood-tidal deltas along this coastal segment are relatively inactive due to small tidal ranges, sheltered lagoons, and ebb dominated inlets (Davis and Klay, 1989; Finkl, 1994).

Although this region is relatively sediment-starved, ebb-tidal deltas and offshore sand ridges provide a ready-made source of sand for beach nourishment (Finkl *et al.*, 2003; Benedet *et al.*, 2004). Salient inner shelf features include the large shore-parallel to shore-oblique sand ridge fields located offshore Sanibel Island. Oblique and less well-developed sand ridges occur offshore central Collier County whereas tidal sand ridges occur offshore Cape Romano. The ridge fields offshore Sanibel Island, referred to colloquially as Tom's Hills, extend continuously for more than 6 km and collectively store more than 75 x 10^6 m^3 of sandy sediments that are readily available for nourishment of adjacent beaches (Figure 16). The ridge deposits in this part of the WFS, similar to the ridges occurring to the north, are geologically young, having formed during the later part of the Holocene. Although these sands were undoubtedly reworked by nearshore waves and currents during the past-glacial (Holocene) flooding of the WFS, they are still being reworked. Modern inner-shelf dynamic processes, such as the action of undertow currents and storm wave activity, reshaped and reworked the sedimentary architecture of these deposits to induce the morphologies presently seen. The ridges are said to be relatively active and are not classified as relict sand bodies by many authors (*e.g*. Gelfenbaum and Brooks, 2003; Edwards et al., 2003; Twichell et al., 2003). Benedet *et al.* (2004) based on the stratigraphy and geographic location of the ridges, hypothesized that the ridge fields offshore Captiva and Sanibel Islands are associated with modern shelf processes (*e.g.* largely controlled by the change in shoreline orientation in the area). The ridges offshore Naples in central Collier County were attributed to re-working of former ebb-shoal deposits.

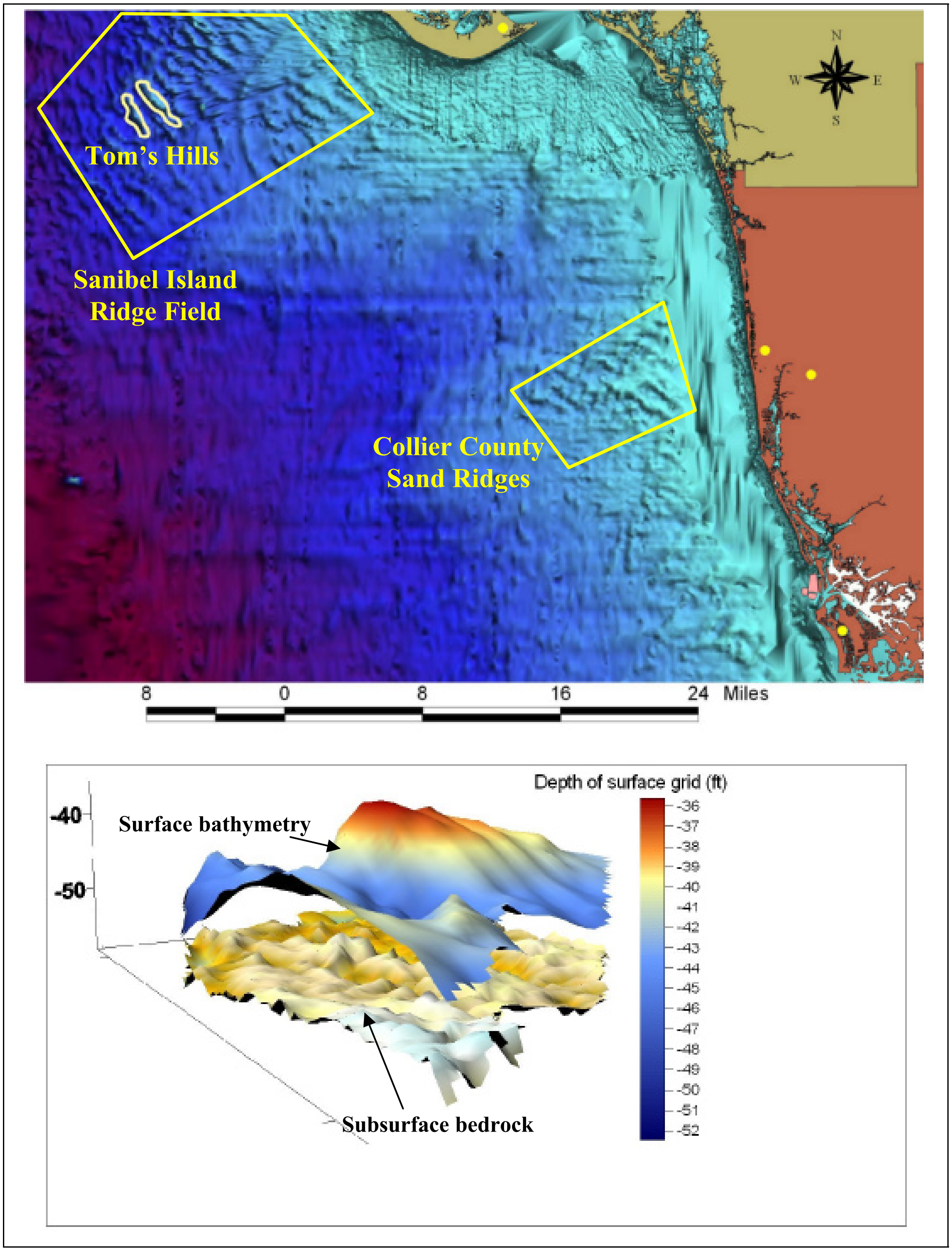


Figure 16. The top image is a digital terrain model (DEM) showing bathymetrically positive features (sand ridges) offshore southern Lee County and northern Collier County. Two ridges located offshore Sanibel Island, referred to as Tom's Hills, have been investigated in detail for beach nourishment (Finkl *et al*., 2003). The lower image is a graphic (exploded diagram) that shows a sand ridge in Tom's Hills where the ridge crest lies 4.5 m (15 ft) above the adjacent seafloor. The subsurface bedrock consists of karstified carbonate rocks probably of late Miocene to early Pliocene age.

Other commonly occurring features on the WFS include various types of depressional (negative topographic) features that are incised into the karst (bedrock) surface and some surficial marls. Some of these depressions underlie sand ridges (Figure 17). These solution holes were formed when the WFS was exposed to surface (subaerial) geomorphic processes during low stands of sea level, small streams and some larger rivers cut into the karstified surface and persisted as valleys until sea level rose and they were infilled with recent marine and terrigenous muds. In contrast to the sand ridges, sediments infilling karst depressions are generally fine-grained muds and marls that are not suitable for beach nourishment projects.

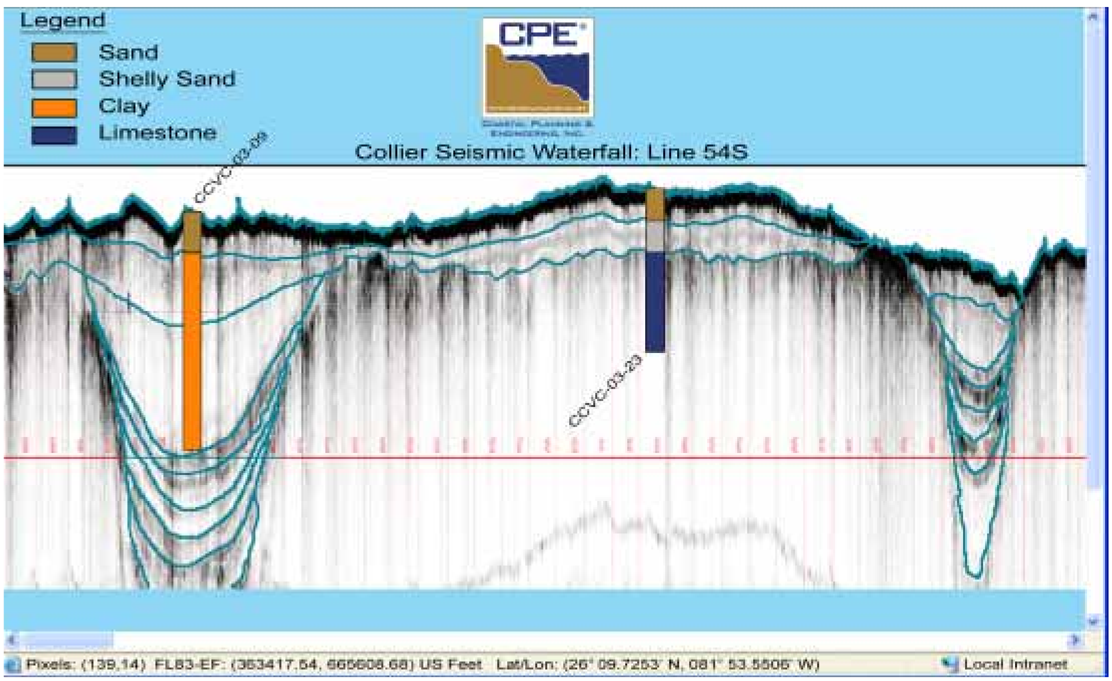


Figure 17. Seismic cross-section of a sand ridge located about 8 km (5 miles) offshore Naples Beach in Collier County. This low-relief ridge is delimited by solution holes in its landward and seaward margins. Clayey sediments infill the solution hole whereas sand and shelly sands make up the sand ridge. (From Benedet *et al.,* 2004).

INNER SHELF SAND BODIES FOR BEACH NOURISHMENT

Sand resources along the southwest coast of Florida (southeastern part of the WFS) fall within three broad categories: (1) sand ridges; (2) ebb-tidal shoals, and (3) shoreface sands. These categories may be further subdivided based on origin (provenance), chemical composition, granulometry, and hydrodynamics. Sand ridges generally occur in water depths from 8 to 21 m (25 to 70 feet) and are associated with modern shelf processes and relict geological and geomorphological controls (*e.g.* bedrock slope). The ridges off the southwest coast may be associated with cuspate forelands and sedimentary headlands, or with reworked paleo ebb-tidal shoals and barriers. The ridges are obliquely oriented to the coast although shore-parallel and shore-transverse ridges occur in restricted locations. Ebb-tidal shoals are large reservoirs of sand along the southwest coast. For decades, ebb-tidal shoals and associated sandy deposits have been exploited for beach nourishment projects in the region. These shoals exhibit a range of shapes and forms that are morphodynamic responses to balances between wave and tidal forcing. Shoreface sands, which occur at relatively shallow depths (*i.e.* 3 to 8 m, 10 to 25 ft), are generally thin and discontinuous along the coast. They have been exploited to advantage for beach nourishment projects. Additional deposits that have been previously investigated as potentially beach-compatible sediments include infilled karst depressions on Miocene and Pleistocene bedrock surfaces (hardgrounds). Some of these infilled solution holes were investigated in Collier County (Coastal Engineering Consultants-Alpine, 2000) but vibracore samples contained fine-grained sediments with rubble fragments (silts and clays and rock) that are unsuitable for beach nourishment. The three broad categories of marine sand resources indicated above are described in more detail in the following paragraphs.

Sand Ridges

The presence of sand ridges on the shelf has been appreciated as singularities for some time, but new studies emphasize the widespread occurrence of sand ridge fields that greatly enhances the potential for locating multiple good-quality borrow sites on ridges (*e.g.* Gelfenbaum *et al.*, 1995; Dyer and Huntley, 1999; Locker, 2003; Benedet *et al.*, 2004; van der Meer *et al.*, 2005; Jones *et al.*, 2005). Multiple sand ridge fields occupy different parts of the WFS and although the sand ridges display similarities, there are notable differences in orientation, morphology, and composition. Due to limited thickness (1 to 2 m), it was initially thought that sand ridges offshore the southwest coast could not provide sufficient volumes to support projected beach nourishment requirements. Today, however, exploitation of thinner ridges is feasible using hopper dredges that are specifically designed to dredge long shallow cuts. Suction cutterhead dredges, on the other hand, are appropriate for deeper cuts and are not recommended for dredging sand ridges thinner than 2 m and therefore would not generally be cost effective for the dredging of sand ridges off the southwest Florida coast.

The shoreline-oblique (30-50º) inner shelf sand ridges offshore Sand Key, for example, unconformably overlie Miocene limestones of the Arcadia Formation that in turn is also partly overlain by a thin veneer of mixed carbonate and siliciclastic sands and gravels (Edwards *et al.,* 2003; Locker *et al*., 2003). These sand ridges have been investigated previously as sources of sand for beach nourishment (Gelfenbaum *et al.,* 1995). Ridge orientation, spacing and alignment, which seem to be less well-defined offshore from major ebb-shoal systems (*e.g.* ridges near the Egmont ebb-tidal shoal), tend to be shore parallel to slightly shore oblique in wave dominated areas and offshore from sedimentary headlands. Shore transverse ridges occur exclusively offshore Anna Maria Island and Longboat Island. Generally, the troughs between successive sand ridges are hardgrounds comprised by Miocene to Pliocene limestones or very thin (less than 1 m) layers of coarse shell fragments mixed with siliciclastic sands. Ridge relief tends to be subdued in shallow waters, attributed to waves that tend to flatten the ridges according to Jones *et al*. (2005). Ridge orientation seems to be controlled by interactions between wave and tide-induced currents when ridge fields occur offshore from major tidal inlets and changes in shoreline orientations at sedimentary headlands (Figure 18).

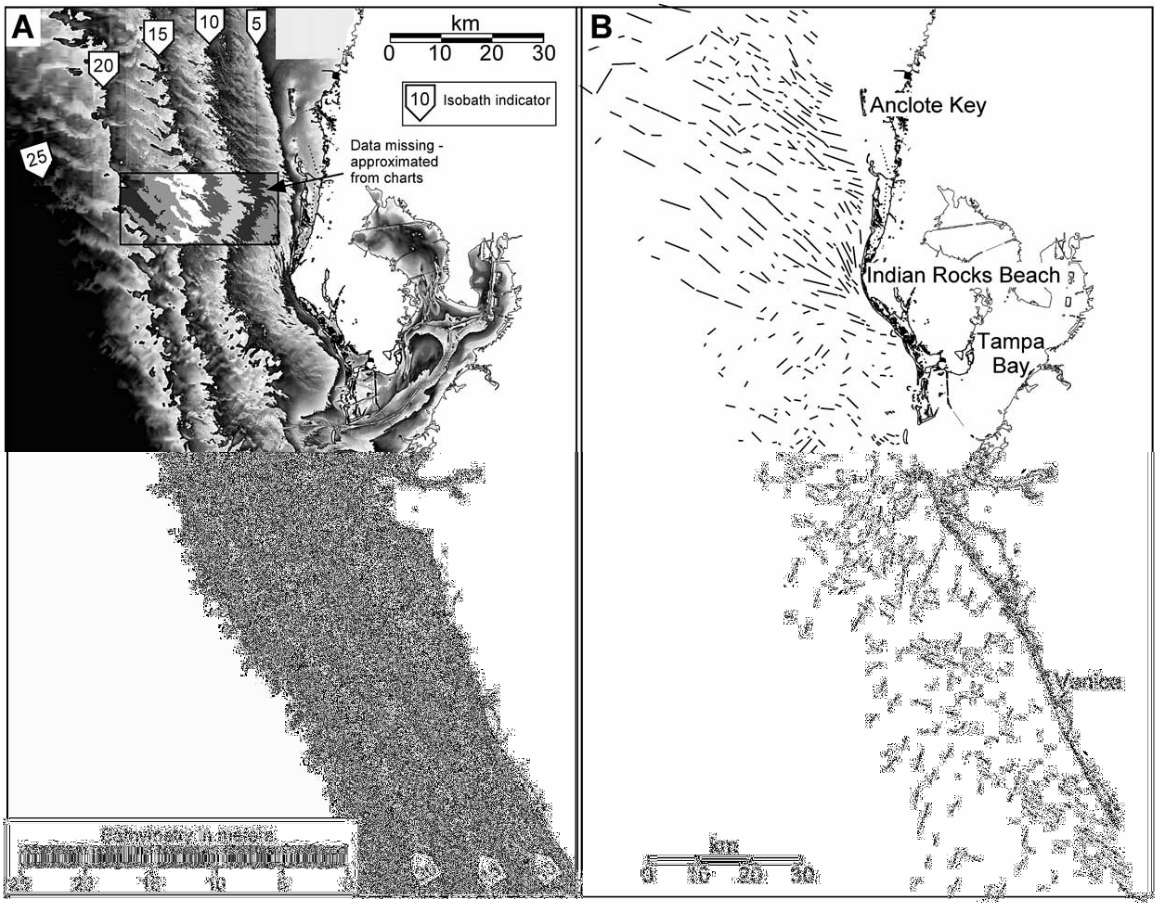


Figure 18. General sand ridge orientation (right figure) interpreted from bathymetric data (left image). A major ridge-realignment occurs offshore Tampa Bay and at Indian Rocks Beach. (From Locker et al., 2003)

Grain-size and compositional variations along this portion of the WFS show a cross-shelf gradation between beach and nearshore siliciclastic sand and the carbonate shelf sediment. In general terms, carbonate percentage increase with distance offshore but the facies transition is irregular in shape and closely linked to the morphology of the inner shelf (Gelfenbaum *et al*., 1995; Brooks *et al*., 2003; Locker *et al*., 2003). Most of the unconsolidated sediments on the inner shelf are concentrated in low-relief ridges with older strata exposed in intervening troughs (Locker *et al.,* 2003). The sand ridges unconformably overlie the underlying Miocene and Pliocene bedrock (hardbottoms). The series of low-relief ridges along this coast are smaller in length and width to ridges found on continental shelves of the eastern United States (*e.g.* Duane *et al.,* 1972), eastern Canada (*e.g.* Hoogendorn and Dalrymple, 1986), and Europe (*e.g.* Dyer and Huntley, 1999).

Sand Ridge Stratigraphy and Age

Stratigraphically, the sand ridges are separated from the underlying Tertiary carbonate strata by a Holocene ravinement surface (Twichell *et al*., 2003). The top of the oldest unit, the present hard rock seafloor, is Miocene to early Pliocene Hawthorn Group (Arcadia, Peace River and Tamiani formations). Depressions in these bedrock (hardbottom) units, which are related to karst topography, contain some Pleistocene strata immediately below the ravinement surface cut during the Holocene marine transgression. The youngest units are ridge sediments which are generally late Holocene in age (Twichell *et al.,* 2003). The ravinement surface separating ridge sands from older deposits is flat-lying with a thin discontinuous veneer of sediments in troughs between ridges. The flatness of the surface suggests that there has been minimal erosion of trough floors during the Holocene rise in sea level.

The sand ridges are generally shoreface-detached (except for transverse ridges offshore Anna Maria Island) and sediment starved. They are part of an active seafloor environment (not relict sediments). Evidences suggesting that these are active sand bodies includes: (1) relatively young AMS ^{14}C dates (< 1600 YBP) from foraminifera in the shallow subsurface (1.6 m below seafloor), (2) sediment textural boundaries and development of small bedforms in an area of constant and extensive bioturbation, (3) morphological asymmetry of sand ridges, and (4) exceedance of critical threshold velocity of sediment transport (based on current meter data) (Harrison *et al*., 2003) by storm-induced bottom flow. Compositionally, the sand ridges contain a mixed siliciclastic - carbonate sand facies that dominates the surface and shallow subsurface (to -1.6 m) (Edwards *et al*., 2003). The carbonate content ranges from 7.1% to 51.8%, with the remainder being quartz. Mean grain size ranges from 0.09 mm to 0.8 mm. Composition of sand ridge sediments is variable and the decision to exploit one ridge over another generally determines the composition of renourished beaches.

Benedet *et al.* (2004) and Finkl *et al.* (2003) verified a distinct differentiation in composition and stratigraphic sequence between the ridges offshore Sanibel Island and ridges offshore Naples Beach in Collier County. Vibracore samples from the ridges offshore Sanibel Island indicated that they contain sediments that are very similar to those occurring in the present beach-surf zones *viz.* mostly homogeneous siliciclastic sands with 10 to 30% carbonate content, 0.25 to 0.35 mm grain size with extremely low silt contents and a few scattered shell fragments. The Sanibel ridges also exhibit greater relief (*e.g.* 3 to 9 m) and lateral extent (3 to 6 km). On the other hand, the ridges located offshore from the City of Naples have lower relief (1-3 m) and limited lateral extent (generally less than 3 km) with generally fining upward sequences that include thin intercalations of mixed fines (clay-silt) plus whole shells. Basal sequences on the Naples ridges consist of shells and carbonate rock fragments mixed with silty sands, whereas upper layers consist of mostly finer-grained siliciclastic-carbonate sand mixtures. These different origins and compositions infer different evolutionary mechanisms of these ridge systems, as discussed by Benedet *et al*. (2004) and Finkl *et al*. (2004).

Evolution of Ridges and Reworking by Modern Shelf Processes

The shoreline-oblique (30º-50º), inner shelf sand ridges offshore southwest Florida occur in an environment that is underlain by limestone and covered by a thin veneer of mixed carbonate and siliciclastic sands and gravels (Edwards *et al.*, 2003; Locker *et al.*, 2003). The ridges tend to be thicker and more widely spaced with increasing water depth. This is similar to observations along the New Jersey coast (*e.g.* Stubblefield *et al.*, 1984).

Theories accounting for the modern formation of seabed sand ridges consider interacting systems of waves, currents and sediments and differential feedback mechanisms between them (termed morphodynamics).

Numerous theories have been posited to explain ridge formation offshore from sedimentary headlands (*e.g.* Duane *et al*., 1972) and shoreline re-orientations such as Sand Key and Sanibel Island. Huntley and Dyer (1999) classified these types of features as "headland banks" or "en echelon banks that formed along the retreat paths of headlands and spit growth (Figure 19). These researchers describe this type of bank formation in terms of spit growth and subsequent spit detachment from the headland as the coastline retreats (Figure 12). Castor (1972) later attributed the effects of currents and wave gradients to reshaping and fragmentation of these features to form multiple ridge systems.

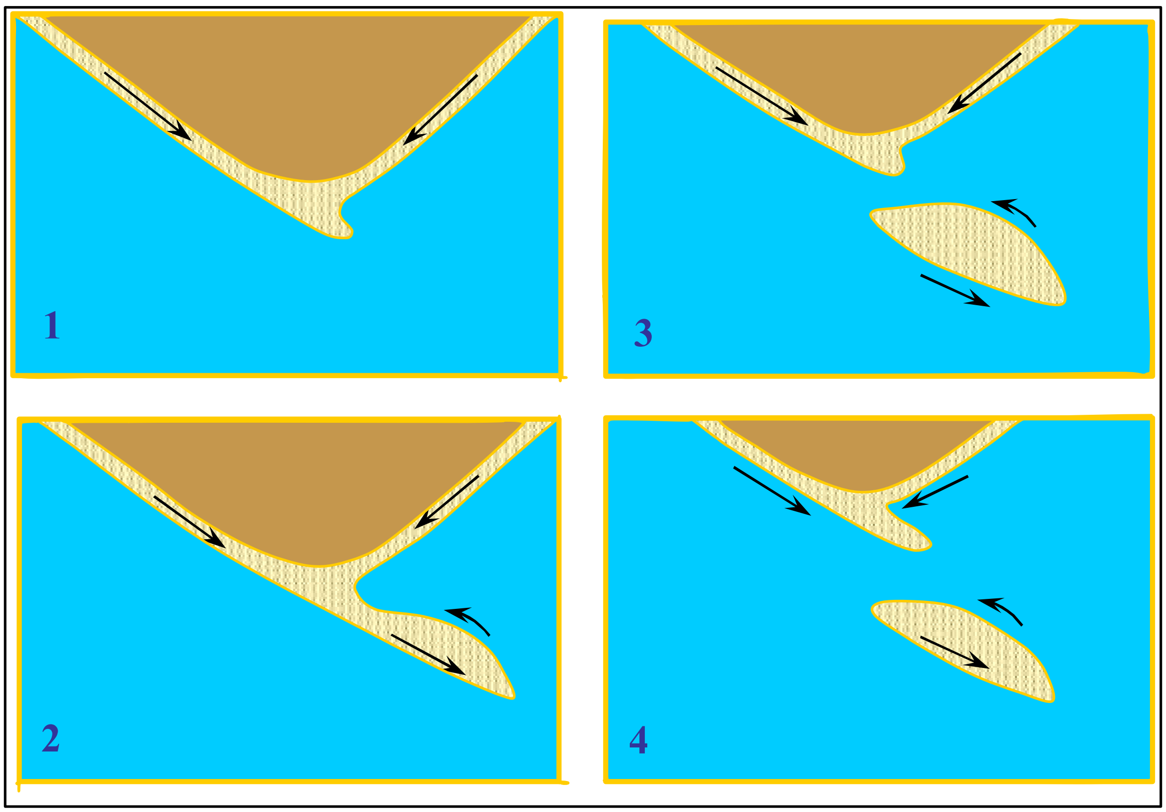


Figure 19. Simplified diagram to explain the formation of en-echelon banks (headland banks) (modified from Dyer and Huntley, 1999). Varying rates of shoreline recession, differential erosion, current vorticity, and gradients of wave energy and radiation stress generate more complex ridge distributions and shapes.

On the European shelf of the North Sea, sand banks that occur offshore from headlands have been linked to residual gyres, a process that invokes Coriolis forces to explain preferential accretion on one side of a headland (Pingree and Maddock, 1979). Jones *et al*. (2005), using 3D hydrodynamic models, verified that the location of sand banks did not necessarily coincide with the location of residual gyres. They instead linked the location of sand banks offshore of coastal headlands with flow patterns. That is, when flow speed is directed offshore with greater velocity near the headland area, these currents disperse and decrease in velocity just offshore of the headland where the banks are formed. Although these are attractive process-based hypotheses, more research is needed to ascertain whether the shoreline retreat model or the current vorticity model, or combinations of both, are responsible for the generation and maintenance of the sand ridges offshore sedimentary headlands (*e.g.* Sand Key and Sanibel Island) along the WFS. These hypotheses are presented on the basis of interpretations of the scientific literature, but they need to be verified in the field and in numerical modeling studies to ascertain their applicability to the study area.

Independent from evolutionary mechanisms, once a bed disturbance (sand ridge) is formed, the stability theories of Huthnance (1982) may help explain growth and maintenance even if the forces that originally generated the banks are no longer operative. Huthnance (1982) explained the growth and realignment of ridges by combining effects of cross-bank and along-bank flows (current refraction and bed friction). According to his theory, the along-crest component of currents will be reduced by the influence of friction-refraction turning the current vectors toward the ridge crest. In a cross-bank scheme, the flow speed is reduced on the downstream side of the bank due to friction over the ridge, thus inducing sediment to fall on the ridge area. For the WFS ridges, recent current meter data indicates that the critical threshold velocity of sediment transport is frequently exceeded (Harrison *et al.*, 2003); so that these sand ridges and bedforms are influenced by modern storm-induced bottom flows. The same authors (Harrison *et al*., 2003) also invoked the stability principles of Huthnance to explain sand ridge growth.

Other sedimentary ridges, occurring offshore straight shorelines may have different genesis and control mechanisms as indicated by their different geomorphology and stratigraphy. The ridges offshore Collier County, for example, exhibit stratigraphic sequences that resemble paleo inlet ebb-tidal shoal environments. That is, their genesis may be linked to the inlet retreat path model described by Mc Bride and Moslow (1991). Because ebb-shoals along this coast are relatively small and sediment supply is meager, the ridges are thinner and have less lateral extent than those described by Mc Bride and Moslow (1991). They do, however, contain a sedimentary package that describes a succession of bay-shoal sediments rich in shells and silt overlain by relatively clean, re-worked beach-marine sands on the top sequences.

Ebb Tidal Shoals

There are 34 inlets along the west coast of Florida (Figure 20). Sand volumes stored in west coast inlets constitute an important source of clean sand for beach nourishment. Because ebb-tidal shoals accumulate sediments that are transported alongshore by alongshore currents in the surf zone, they are generally composed of beach-compatible sediments. Due to high energy conditions of their natural environment, which is subject to the constant action of currents and tides, ebb-tidal shoals generally contain sands that are useful (devoid of fines and organic materials) for beach nourishment. Tidal shoals generally occur in shallower water which limits the use of hopper dredges that require a deeper draft for safe navigation. Fortunately the ebb shoals generally contain thicker sediment packages that can successfully explored using cutterhead dredges. When the shoals occur at large distance from a project area (e.g. Cape Romano Shoals) a combination of cutterhead dredges and storage and delivery barge (scows) may be an appropriate dredging method.

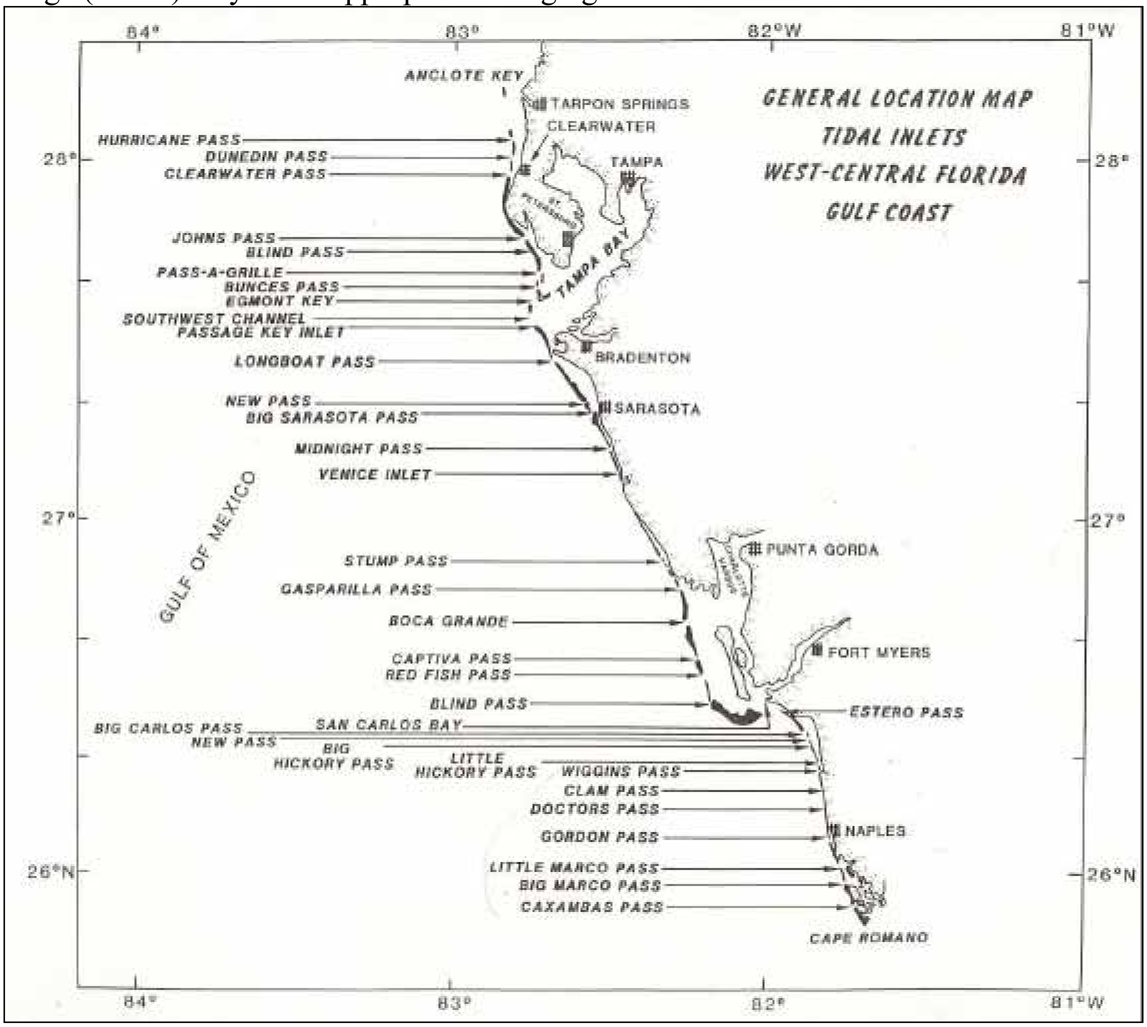


Figure 20. Tidal inlets along the central west coast of Florida. (From Hine *et al*., 1986).

Most of these inlets have been modified by engineering works including maintenance dredging to promote navigation conditions, sand extraction for beach restoration, and stabilization by coastal structures, inlet opening and closure, *etc*. Even though tide range is relatively small (less than 100 cm), low wave energy and large back bay (lagoonal) areas contribute to the opening and maintenance of tidal inlets. Additionally, low wave energy facilitates build up and maintenance of large ebb-tidal shoals that store large volumes of sand (Hine *et al*., 1986).

Many of the large ebb-tidal shoals in the area (*e.g.* those offshore Tampa Bay – Figure 22) mouth and the entrance of Charlotte Harbor) are tide-dominated and store large volumes of sand that is not significantly influenced by waves. Due to the nature of these large tide-dominated sand bodies, they are poor sediment bypassers and constitute permanent sinks of littoral drift sediments. In the other hand, inlets offshore of small tidal inlets with smaller tidal prisms are predominantly wave-influenced (Figure 23) and are better sediment bypassers. Johns Pass, Midnight Pass and Blind Pass (the two last are currently closed) are good examples of wave-dominated inlets. These inlets have well-developed flood-tidal shoals and relatively unstable cross-sectional areas when compared to their counterparts (large tide-dominated inlets). Because of their stable interaction and sediment sharing with adjacent shorelines, In smaller wave-dominated inlets, sand dredging mostly impacts the natural sediment bypassing mechanisms and not the wave refraction - diffraction patterns (because of their limited size and relief). On the other hand, dredging of large tide-dominated shoals has little impact on natural sediment bypassing mechanisms (little to no bypassing occurs in these systems) but more significant impacts on the wave field if large quantities are extracted due to the large dimensions and relief in these systems.

Figure 22. Bunces Pass, one of the inlets that connect Tampa Bay to the Gulf of Mexico, is an example of a tide-dominated inlet with a well developed ebb tidal shoal. (From Davis *et al.*, 2003).

Approximate sand volumes stored in ebb shoals of these 34 tidal inlets were quantified by Hine *et al*. (1986) and Dean and O'Brien (1987), who also estimated the impacts of inlets on coastal sediment budgets. This work was updated with site-specific inlet management plans and consulting reports by Balsille and Clark (2001). Their methodologies to estimate ebb-tidal shoal volumes included interpretation of aerial photographs, inspection of historical maps, analysis of documents, field investigations (bathymetric data), and literature reviews.

Figure 23. Blind Pass, a wave-dominated inlet, shown after having closed naturally. Due to small tidal prisms, wave-dominated inlets tend to periodically close. When open, these types of inlets contain smaller ebb-tidal shoals and are a less suitable sand source than their larger counterparts (tide-dominated and mixed-energy inlets). (Photo provided by the Lee County Government – Robert Neal).

It is important to consider that the ebb-tidal shoals are located in shallow-water coastal environments and are part of a natural sand bypassing system. Impacts that may occur due to the extraction of ebb-shoal sands include changes in wave propagation patterns (refraction and diffraction) and temporary interruption of natural sand bypassing. Both processes influence patterns of erosion and deposition of adjacent shorelines. Although negative impacts may occur, benefits accruing from sand extracting in ebb-tidal shoals many times exceed the potential for negative effects or negative impacts can be mitigated. It is recommended, however, that sand extraction from ebb-shoals should be evaluated on a case specific basis. Numerical models and comprehensive coastal sediment budgets can provide guidance to evaluate the potential for impact to the wave field and adjacent shorelines, as well as estimates of ebb-shoal recovery time scales after ebb-shoal dredging.

Nearshore Sand Bodies

Nearshore sand bodies include blanket sand deposits that extend from the surf zone to offshore exposure of bedrock (hardground) or the beginning of sand ridge fields. They are of limited extent on the WFS because this coast is sediment starved and there are extensive nearshore hardgrounds (bedrock exposures). Although rare, there are some sand deposits that blanket shallow (3 to 10 m) waters that may be explored for coastal restoration. Nearshore sedimentary covers are, however, more common on offshore barrier islands that lie adjacent to major tide-dominated inlet systems. Shelf cross-sections by Locker *et al*. (2003) (see Figures 8 and 11) show, for example, that nearshore sand blankets 1 to 4 m in thickness occur offshore Anclote Key, Mullet Key, Treasure Island, and Anna Maria Island (interpreted as remnants of the Tampa Bay ebb-tidal delta). Based on their interpretations, it is reasonable to assume that these kinds of nearshore sand bodies may also occur offshore Gasparilla Island and Cayo Costa (remnants of the Boca Grande - Charlotte Harbor ebb-tidal shoal). These nearshore sands were used in the Anna Maria Nourishment Project (2002) and are scheduled for the 2005 emergency restoration project for the same island.

THE ROSS DATABASE IN THE CONTEXT OF COMPREHENSIVE MARINE SAND SEARCHES

There are no universal or comprehensive guidelines regarding the best possible way to conduct a marine sand search investigation, but several guidelines for specific geographic regions have been developed (*e.g.* Finkl, Andrews, and Benedet, 2003; Finkl *et al.*, 1997, 2004; Benedet *et al.*, 2004; Finkl and Khalil, 2005). The lack of general guidelines occurs because sand searches are site specific and they must be geared to specific geographic environments that retain similar shelf-sediment histories. Continental shelves, such as the WFS, are drowned coastal plains and the characteristics of those plains are largely fashioned by terrestrial regimes of the hinterlands that reach the coast. Because sand searches must be geared or tailored to geological conditions in the area of the study, approaches to conducting the search must be compatible with the specific geographic parameters of that region. This means that exploration methodologies must be capable of resolving required detection limits that are determined by deposit configuration in different geographic areas. The same search techniques would not be deployed, by way of an extreme example, in the search for sand ridges on the WFS as would be required for the detection of infilled sediment troughs (inter-reefal sand bodies) that commonly occur along the southeast Florida coast. Even though marine sand searches must be oriented to the detection of specific geologic features, there are specialized approaches developed for the southwest coast of Florida (*e.g.* Finkl *et al*., 2003; 2004 and Benedet *et al*., 2004).

These general procedures consist of sequential tasks that are conducted in a phase-wise manner, as enumerated Figure 24. The sequence of investigation boils down to ten essential steps that involve: (1) literature reviews and analyses of prior data, (2) development of action plans that incorporate the creation of digital (GIS) databases of prior data, (3) reconnaissance geological (geotechnical) and geophysical surveys (if needed), (4) identification of target area, (5) detailed geophysical surveys, (6) detailed geotechnical investigation, (7) evaluation of geophysical and geotechnical data, (8) selection of borrow area, (9) hazard and archaeological assessment survey, and (10) preparation of reports and other final deliverables. The ROSS database provides enough information to address Phases 1 and 2. It also contains an extensive annotated bibliography to assist in the literature search. The investigator must augment this with the most recent and location-specific published and grey literature sources to compile a complete review. In some areas, where sufficient information data is available, the data available in the ROSS database may provide enough information to substantially decrease survey needs during Phases 3 and 4 by reducing the areas necessary to be surveyed in preliminary reconnaissance investigations. These investigations, which traditionally covered relatively large expanses of the seabed, can now be simplified and abbreviated to verify the data. Subsequent phases are still needed to verify legacy data due to: (1) the dynamic nature of sand ridges, ebb shoals and nearshore sand bodies on the WFS, (2) advances in survey technology (accuracy and resolution), and (3) permitting requirements (*e.g.* cultural resources clearance).

In order to optimize resources, including time and effort, it is convenient to conduct detailed cultural resource surveys subsequent to definition of final borrow area boundaries so that only the area to be dredged is 'cleared'. ROSS contains several data coverages that can assist this effort. There are ranges of sub-tasks within each of these main phases of work and the whole process may take up to several months to complete depending on project size, location, amount of previous work completed (assuming that the data collected is adequate, appropriate, accurate, and relevant), available funding, weather conditions (especially sea state), *etc.* The availability of a comprehensive GIS database helps to optimize such investigations and significantly reduce costs and time involved with initial data compilation and analysis.

These guidelines are briefly summarized in terms of tasks to be completed within ten main phases. The descriptions indicate general strategies that logically work toward completion of phases so that future work can build on prior accomplishments that, to a certain degree, direct the course of subsequent actions.

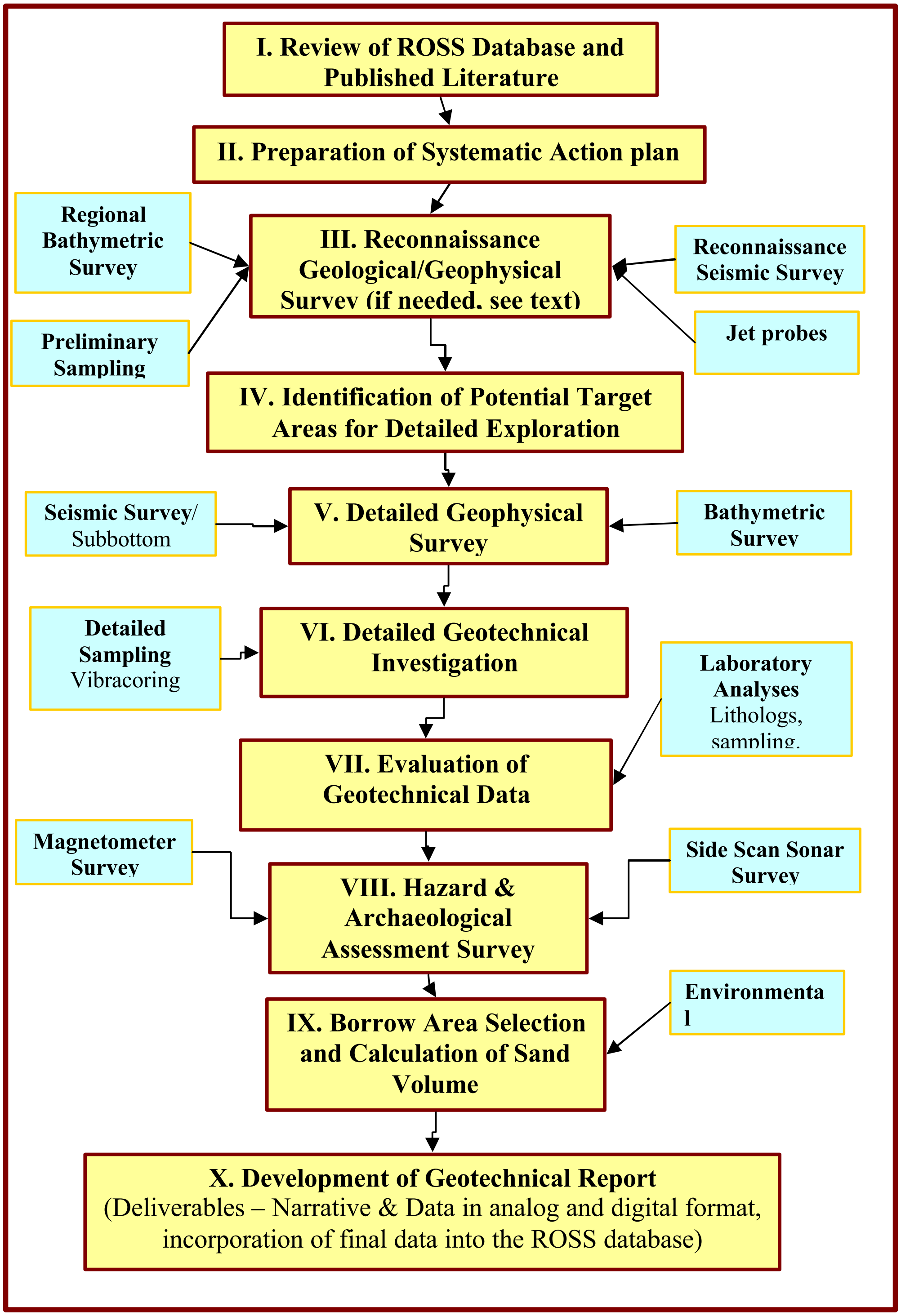


Figure 24. Flow diagram showing systematic approaches to offshore sand searches, based on ten major steps that incorporate a range of subset activities that are restrained by local circumstances. Each task is meant to direct the course of subsequent actions so that sand searches proceed following a logical strategy that produces an efficient exploration methodology.

Phase I: Review of Ross Database and Published Literature

The first phase of marine sand searches involves literature searches and design of the exploration program. This phase is where the ROSS database plays a major role in the marine sand search process. In the past, this initial data background check was sometimes overlooked because it was considered to be too time consuming or possibly even irrelevant as the data was old, in a different format from today's conventions or use, *etc.* Experience (CPE, 1992, 1999b; Andrews *et al*., 2002, 2004; Finkl *et al*., 2002, 2003, 2004; Benedet *et al*., 2004) has shown that this phase is crucial to re-evaluation of prior knowledge, to the development of conceptual models of sedimentary environments, and to guide the planning of future survey options. Thus, the purpose of literature (data) review is to familiarize survey planners with local environmental conditions and to flag any special conditions that require avoidance or focused attention. Unfamiliarity with peculiarities of local environments or geomorphological features holds potential for obtaining less than desirable results. Tasks proposed for the sand search are therefore adjusted to local conditions in the appropriate manner.

Thorough (comprehensive) reviews of historical, technical, and scientific literature should include geological, geomorphological, and geophysical information or data. Basic literature sources that should be perused in terms of general geologic framework and coastal processes include books and primary scientific and engineering journals (*e.g. Journal of Coastal Research; Marine Geology; Journal of Sedimentary Research; Marine Resources and Geotechnology*) and conference proceedings (*e.g.* 'Coastal Sediments' sponsored by the American Society of Civil Engineers, ASCE). These data are always evolving as most of these publications are monthly and bimonthly (except for conferences) and should be always checked in early stages of marine sand searches. Particularly important in the west coast of Florida is the series of papers and reports available from the *USGS West Coast of Florida Studies* (see Hine *et al*., 2001) and its associated graduate thesis and peer-reviewed journal publications.

The gray literature includes a vast range of materials that are produced on an irregular basis in the form of special reports that include but are not limited to: consulting reports prepared for government agencies such as the Florida Department of Environmental protection (FDEP), Florida Geological Survey (FGS), U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), and private consultants. These data, particularly individual consulting reports, are often hard to access. Fortunately for the west coast of Florida, all data developed by coastal consultants is archived at FDEP and is readily available in the ROSS database. Reports from governmental agencies such as the USGS, USACE, and FGS are also collected by the FDEP.

Offshore geotechnical literature and geotechnical data (geological maps, bathymetric maps, seismic cross sections, geotechnical data, both geological and geophysical borehole logs) within an approximate 10-km radius of the project area and adjacent sites should be consulted, analyzed, and reviewed. The intent of this phase is to initiate development of a flexible reconnaissance survey plan for preliminary geotechnical investigation. This plan should be geared to the identification of potential sites for probable borrow areas by eliminating locations that are unsuitable for any reason.

Phase II: Preparation of a Systematic Action Plan

Development of a systematic action plan builds on the results of Phase I tasks and involves reconnaissance geological and geophysical surveys that are guided by interpretation of spatio-temporal information contained in GIS databases. The ROSS database provides readily available data in GIS format thus eliminating the transition between analog data to GIS environments normally required during this Phase. Data derived from bathymetric, seismic, and limited vibracore surveys are used to map bottom types and to differentiate areas with potential for containing usable sediments by using GIS spatial queries. Seismic sub-bottom profiles provide useful information where underlying bedrock restricts thickness and lateral extent of inner shelf sand bodies. Use of this information in real-time mode via an interactive GIS platform onboard a survey vessel, for example, provides ready access to archival and legacy data that can assist the decision-making process for modification of surveys on the fly. Potential targets can thus often be defined on the basis of bathymetry (*e.g.* shoals, ridges, and mounds), image roughness of the seabed surface (smooth light-colored returns vs. rough dark-colored signals), sedimentary structures (*e.g.* ripples, waves) and sediment composition (historical vibracore and jet probe information). Delineation of potential target areas thus excludes all other areas as being unsuitable due to poor quality of sediments or absence of them (*i.e.* in the case of exposed bedrock). The purpose of subsequent phases and tasks is then to work toward eventual exploitation of targeted sand sources.

Phase III: Reconnaissance Geological and Geophysical Survey

This phase of work normally includes several integrated tasks that focus on regional bathymetric survey, seismic investigation, and preliminary surface – subsurface sampling using grab samples and jet probes (*e.g.* Finkl and Benedet, 2004) to verify historical data and sand deposit location. After reviewing the existing information, geotechnical investigations are normally conducted as supplemental to obtain sediment data that helps evaluate potential sand sources and determine the availability of adequate sand volumes in the areas delimited using historic data sources. In some areas, the ROSS database may provide enough legacy data to significantly reduce or eliminate survey needs of this phase.

In situations where reconnaissance data is required, the investigations normally include positioning by DGPS, bathymetric survey (using digital fathometers), surface sediment sampling, jet probes and seismic survey – sub-bottom profiling (using a sub-bottom profiler such as chirp sonar). Reconnaissance surveys are normally conducted along widely spaced tracklines (about 300 to 1000 m grid spacing). Preliminary sampling with grab samples and jet probes may be collected for initial evaluation, verification of historical data and delineation of potential sites where detailed surveys could be undertaken. Retrieval of sediment samples also facilitates calibration of seismic records and thereby increases the interpretive value of geophysical data (*e.g.* Griffiths and King, 1981) for locating potentially usable sand.

Phase IV: Identification of Potential Target Areas for Detailed Exploration

As a result of reconnaissance survey (Phase III), a base-map (prepared on suitable scale) should depict potential target areas with detailed survey plans with proposed tracklines and sampling locations. This kind of information is then presented to the sponsoring agencies for discussion and approval. It should be noted that changes and adjustments to the basic or initial plans are anticipated on the basis of the field data and analysis conducted during the Phases I thru III (Figure 24). In some cases, additional surveys in Phase III may not be necessary because potential target areas were successfully identified on the basis geophysical and geotechnical data provided by the ROSS database and analyzed in Phases I and II. This situation may occur in areas that have been extensively explored previously or where there is a plethora of recent data that contains information that is also useful to sand searches.

Phase V: Detailed Geophysical Survey

This phase of work provides detailed geophysical investigations that include bathymetric surveys, and sub-bottom profiling (seismic). Basic literature about these survey procedures and requirements can be found in Wolf and Brinker, (1994), Yilmaz, and Doherty, (2000), Baker and Young (1999), Baldwin and Hempel (1986), Blondel and Murton (1997), Griffiths and King (1981), Dragoset and Evans (1997), Gorman, Morang and Larson (1998), Hunt (1984), Langeraar, (1984), Morang, Larson, and Gorman, (1997), Verma (1986), Worthington, Makin, and Hatton (1986). Detailed surveys typically follow trackline grid spacing on the order of 300 m or less. This level of detail normally provides sufficient details for proving out potential borrows, but in some specialized cases that are geologically complex closer grid spacing may be used.

Planning survey tracklines is a crucial part of any successful geophysical survey, which requires incorporation of scientific information and bathymetric data (derived from Phases I thru IV). When the compiled base-maps are completed, the area selected for detailed study is earmarked for closely-spaced tracklines. The most satisfactory results are generally obtained by running geophysical (especially seismic) surveys in a pattern that is orthogonal to the prevailing offshore geologic structures or surficial topography. If the prevailing offshore geology is not parallel to the shore, the survey lines should be positionally adjusted to best image the terrain. Planning of track-lines is site-specific and should not be constrained by these broad suggestions and general recommendations.

The following components of a comprehensive geophysical survey should include accurate navigational positioning, detailed bathymetric survey, and seismic stratigraphic survey.

(1) **Navigational Positioning**. A basic requirement for detailed high-resolution seismic survey, subbottom profiling, of delineated borrow areas is accurate positioning or position control. DGPS is the primary positioning system currently used for hydrographic surveys. DGPS correctors can be obtained either through the U.S. Coast Guard (USCG),

Maritime DGPS Service, or other differential services, provided they meet accuracy requirements.

(2) **Detailed Bathymetric Survey**. Echosounders, digital fathometers, are used for bathymetric survey based calibrations and corrections mentioned for the earlier phase work. A detailed bathymetric map should be prepared using a suitable isobath interval. Bathymetric surveys are required for many studies of geology and geomorphology in coastal waters (Morang, Larson and Gorman, 1997a, b), including offshore sand searches in attempts to define target areas that may eventually become borrows. Fathometer or echo sounders are most often used to measure water depths offshore. The distance between the sound source and the reflector (seafloor) is computed as velocity of sound in water divided by one half of the two-way travel time. It has been observed that even with the best efforts at equipment calibration and data processing, the maximum practicable achievable accuracy for nearshore depth surveys is about ±0.15 m (USACE, 1991). Errors in acoustic depth determination are caused by salient complicating factors or processes that include:

(a) Differences in the velocity of sound in near-surface water (about 1500 m/sec) varies with water density, which in turn is a function of temperature, depth, and salinity.
(b) Changes in the vessel's draft as fuel and water are depleted during the survey require boat-specific correction that is carried out by performing depth checks.
(c) Waves cause the survey vessel to pitch up and down and the seafloor is recorded as a wavy surface. Transducers and receivers are now installed on heave-compensating mounts to obtain the true seafloor. Post survey data processing is the most common means of removing the wave signals.

An Innerspace digital survey grade Fathometer (Model 448 TDSR), an example of equipment commonly used for surveys of water depth is a self-contained, portable precision survey echo sound recorder. Capable of operating in depth ranges of 0.5 to about 170 m with a measuring accuracy of ± 0.03 m, its major feature is a completely solid-state high-resolution thermal printing technique. This system is often interfaced to the Coastal Oceanographic Hydrographic Navigation System to simultaneously store depth and location data. Transducers are usually mid-ship mounted at a known depth below the surface.

(3) **Detailed Seismic Survey**. When conducting a seismic survey using a subbottom profiler, (e.g. 3.5 kHz high-resolution profilers, mini-sparker, uniboomer, chirp, etc.) a chirp subbottom profiler is preferred for proper depth-penetration and better resolution.

However, this equipment comes in a variety of configuration and these have their own methods for settings and operation. Considerable planning is needed to select the proper equipment, operation mode and survey trackline layout. Furthermore, instrumentation continually evolves so the plan needs to include a search for, and evaluation of, the newest equipment. Seismic stratigraphy should be developed on the basis of subbottom profiles so obtained. Detailed surveys typically follow trackline grid spacing on the order of 300 m or less. This level of detail normally provides sufficient resolution for proving out potential borrows, but in some specialized cases that are geologically complex closer grid spacing may be used.

In the third phase, a comprehensive geotechnical field survey is planned, executed, and analyzed. Preliminary maps based on this information can then be developed.

Planning survey tracklines is a crucial part of any successful geophysical survey, which requires incorporation of scientific information (derived from the literature) and bathymetric data (from NOAA charts and bathymetric data collected during Phase II) (*e.g.* Hemsley, 1981). When the compiled base-map (which results from Phases I & II) is completed, the area selected for detailed study is earmarked for closely-spaced tracklines. The most satisfactory results are generally obtained by running geophysical (especially seismic) surveys in a pattern that is orthogonal to the prevailing offshore geologic structures or surficial topography. If the prevailing offshore geology is not parallel to the shore, the survey lines should be positionally adjusted to best image the terrain. For offshore areas where little is known about the surficial geology, an alternative procedure is to run survey lines in a zigzag pattern approximately perpendicular to the coast. Planning of track-lines is site-specific and should not be constrained by these broad suggestions and general recommendations.

Successful sand searches rely on sonar imagery of the seafloor and sectional depth views along tracklines that show sedimentary layering. Seismic reflection profiling, calibrated to sand searches using vibracore data, is crucial to the delineation of potential sand bodies in terms of depth and lateral extent. Sonar surveys provide useful proxy data that can be interpreted in terms of smoothness or roughness of the seabed, information that is useful for differentiating rock outcrop from unconsolidated sediments.

Seismic Survey/Sub-Bottom Profiling Using the Chirp Sonar System

In geophysical surveys, the distance between the sound source and the reflector is computed as velocity of sound in that medium (rock, sediment, or water) divided by one-half of the two-way travel time. This measurement is converted to an equivalent depth and recorded digitally or printed on strip chart. A recent development that is extremely valuable to interpretation of bottom-sediment grain size is a signal-processing unit that can be interfaced with an echo sounder and used to indicate the size seafloor sediments in terms of Wentworth or other general classification schemes (ASTM, 1994; Morang, Larson and Gorman, 1997a,b). This is accomplished by measuring two independent variables, viz. roughness and hardness, from acoustic signals and interpreting these data in terms of sediment type.

The basic principles of sub-bottom seismic profiling and acoustic depth sounding are essentially the same. A lower frequency and higher power signal (to penetrate the seafloor) is employed in subbottom seismic devices. The transmission of the waves through earth materials depends on properties such as density and composition. The signal is reflected from interfaces between sediment layers of different acoustical impedance (Sheriff and Geldart, 1982). Coarse sand and gravel, glacial till and highly organic sediments are often difficult to penetrate with conventional subbottom profilers, resulting in poor records with data gaps. Digital signal processing of multi-channel data can sometimes provide useful data despite poor signal penetration.

Seismic reflection profiles are roughly analogous to geological cross sections of subbottom materials because acoustic characteristics are usually related to lithology (Verma, 1986). Reflections may appear on the seismic record due to subtle changes in acoustic impedance that are associated with minor lithological differences between under- and overlying materials. Conversely, significant lithologic differences may not be recorded because of similar acoustic impedance values between bounding units, due to minimal thickness of stratigraphic units, or because reflectors are masked by gas (Sheriff and Geldart, 1982). Because of these complicating factors that can mislead interpretation of the seismic record, seismic stratigraphy should always be considered tentative until supported or verified by direct lithologic evidence from core samples.

The two most important parameters of sub-bottom seismic reflection systems are vertical resolution, *i.e.* the ability to differentiate closely spaced reflectors, and depth of penetration (*e.g.* Parkes and Hatton, 1986). The dominant frequency of acoustic pulses increases signal attenuation and consequently, decreases the effective penetration. In response to resolution of this problem, it is common to simultaneously deploy two seismic reflection systems during a survey. By combining results from one system that maximizes high-resolution capabilities with those of another system that is capable of greater depth penetration, it is possible to retrieve high-resolution data to greater depths than would normally be possible with a single seismic reflection system.

The major systems are briefly summarized as follows:

The X-STAR CHIRP 512i Sub-bottom Profiler is an example of equipment that is suitable for seismic surveys of unconsolidated sediments, which are accomplished by sending an acoustic signal through the seafloor and receiving reflecting acoustic signals in the form of a recording chart signature. The seismic record identifies the sediment surface and other layers or features within the sediment column. The X-STAR Full Spectrum Sonar is a versatile wideband FM sub-bottom profiler that generates cross-sectional images of the seabed and collects digital normal incidence reflection data over many frequency ranges. X-STAR transmits an FM pulse that is linearly swept over a full spectrum frequency range (also called a “chirp pulse”). The tapered waveform spectrum results in images that have virtually constant resolution with depth.

The Chirp system has advantage over single frequency (3.5 kHz) sub-bottom profilers (or pingers as they are commonly called) and boomer systems in sediment delineation because the reflectors are more discrete and less susceptible to ringing from both vessel and ambient noise. The full wave rectified reflection horizons are cleaner and more distinct than the half wave rectified reflections produced by the older analog systems.

An example of a composite approach that combines high-resolution data with acceptable depths of penetration in one unit is the X-STAR system, which includes a SB-0512 towfish that generates a FM pulse with amplitude and phase weighting in the frequency range of 500 Hz to 12 kHz to produce a beam width is that is about 4.5 to 6 m. This towfish, which contains four transmitters and four receive arrays, has deep Uniboom-type penetration. This towfish has a depth of penetration that is 15 m in coarse calcareous sands and more than 60 m in silt or clay. Vertical resolution varies from 15 to 40 cm, depending on the pulse frequency. Reflections measured by the system are displayed as shades of gray or color on a computer monitor and recorded simultaneously. As the seismic data is collected, an interface from the navigation computer combines with it and stores the data for replay and archiving. A typical hardcopy cross-sectional view of the sub-bottom can be produced in real time with a vertical scale across the record that represents approximately 2.5 m per scale division using a velocity of 1500 m per second. Because the velocity in upper (shallower) sand layers is higher, the record gives a conservative estimate of sand thickness.

All the data collected in Phase V should be incorporated into the GIS database (ROSS) and compared with complimentary legacy data.

Phase VI: Detailed Geotechnical Investigation

Detailed sampling using vibracores is an expensive procedure that involves significant effort and deployment of large vessels containing hoisting equipment and storage facilities for cores. Descriptions of vibracoring procedures and requirements can be found in Lee and Clausner (1979), Edgington and Robbins (1991), Larson, Morang and Gorman (1997), Finkl and Khalil (2004). Costs for 20 ft vibracores often settle in the range of $5,000 to $7,000 (including 5 to 7 sediment samples per core) per core depending on location and logistics. Description of cores (to produce reliable logs) and analysis of selected sediment parameters adds additional laboratory fees to the total cost, making vibracoring a procedure that should be carefully planned do avoid wasted efforts. Potential vibracore sites should be judiciously selected to achieve the level of information and confidence needed firstly for finding the target area (as in Phase II), secondly for delineating borrow areas and thirdly for qualitative and quantitative evaluation of sand deposits (Finkl and Khalil, 2004). Vibracore information is most beneficially employed in conjunction with subbottom data to gain maximum interpretive benefit of stratigraphic composition and sedimentary variation. Acoustic reflectors often can be identified on the basis of vibracoring, which in effect links or calibrates seismic reflection patterns to specific sediment types. Generally, vibracore-sites should be spread throughout the survey area on a rectangular grid but preferably, in an alternative pattern that crosses the prevailing trend of the offshore geology. The standard accepted spacing between the core-sites is usually about 300 m. The minimum accepted recovery from each core is at least 80% and in at least three attempts or trials. Core recovery is sometimes problematical in certain areas, especially where there are contrasting materials that are stratigraphically juxtaposed viz. sands vs. shell hash layers vs. carbonate rock clasts.

Phase VII: Evaluation of Geotechnical Data

Vibracores obtained in Phase VI are normally split longitudinally into two halves, with each portion legibly labeled and dated for future reference. One half of the split core should be photographed and kept as archive, the archived portion being cut into sections (not longer than 1.5-m) that are legibly labeled and dated. The archived core sections should be properly wrapped in clear plastic to avoid contamination from other core materials.

The other half of the split core should be sub-sampled for laboratory analyses that lead to development of visual lithologs (boring logs) of the cores on the basis of USCS designation (ASTM D2487-92, 1994). This procedure is accomplished in a standard format providing details of visual sedimentological properties followed by sampling. One representative sample for grain size analysis should be obtained from each horizon or layer (in a core) subject to a minimum of three samples from one core (7 m) is collected. Grain size and other physical parameters are analyzed either by mechanical sieving or by settling tube as per ASTM standard (ASTM D421/422). The Unified Soil Classification Scheme should be used to describe sedimentary materials and layering within the core.

A log is prepared for each core describing the sediments by layer including layer width, sediment color, texture, and presence of clay, mud, sand or shell and any other identifying features. Grain size analysis will be performed on approximately three or four sediment samples per core. Samples will be obtained from distinct layers in the sediment record, or periodically through the core record. This grain size analysis will be conducted for sand samples in accordance with the American Society for Testing and Materials (ASTM), Standard Material Designation D422-63 for partial size analysis of soils. Mechanical sieving will be accomplished using calibrated sieves, with a gradation of half phi intervals, per U.S. Army Corps of Engineers standards. Grain-size distribution curves will be prepared for each vibracore. The core logs, and raw sedimentological data will be developed into a GIS database and be available for electronic transfer to the State. In the end of the process all vibracore information (geographical location, logs, gradation analysis tables, sediment distribution curves and core photographs) should be stored in individual pdf files that can be made readily available from the GIS database (ROSS) in the form of download menus or hyperlinks.

In similar vain, all necessary calibrations and other related tests that are considered necessary for the accuracy of the data and survey should be performed as part of this task group. Similarly, all necessary corrections usually carried out as standard operating procedures for reconnaissance surveys should include ascertaining tide and water levels. Once the sedimentary grain-size parameters, and other qualifiers relevant to the suitability as beach sediments are established, potential borrow areas can be delineated.

Phase VIII: Hazard and Archaeological Assessment Survey

Once a potential borrow area has been identified, a cultural resources study is conducted using an underwater magnetometer, detailed seismic, sidescan sonar and bathymetry in compliance with local, state and federal government regulatory requirements. Detailed geophysical data from the archeological surveys should also be integrated into the borrow area design data giving more certainty on sand deposits within the proposed cuts and avoid duplicate efforts.

The purpose of the magnetometer survey is to determine if there are any metallic objects in the sand source (borrow area) which may be of historic value, such as shipwrecks artifacts. The magnetometer investigations are also useful in identifying non-historical metallic objects that may interfere with the dredging process such as abandoned engine blocks, pipelines, metal cable, *etc.* The results of the survey are documented by a professional archeologist and reported to the State Division of Archaeology. If needed, the borrow area should be revised and buffers should be implemented to avoid objects of potential historical value.

Cultural resource surveys (*e.g.* Kidder, 1996; Green, 2004; Watts and Finkl, 2004a, b, c, d) should be conducted when required for permitting purposes. These kinds of surveys are often necessary to ascertain the presence of drowned habitation sites of paleoindians (paleoanthropological and archeological term referring to Native American cultures prior to 8,000 BC) or other cultural groups and also provide excellent datasets for refinement of borrow area design cuts. Underwater archaeology (continental shelf archaeology) is an important endeavor because it attempts to reconstruct where and how ancient peoples settled on coastal plains (now drowned to become continental shelf, or sometimes referred to as exposed continental shelf) and when they began to access and procure near-coastal and marine resources. In addition to the detection of Pleistocene settlements on exposed continental shelves when sea level was lowered during glacial cycles, there are important cultural remains on the seafloor that are related to contemporary society. Many of these artifacts (*e.g.* anchors, cables) have no cultural significance, but they can be harmful to dredges. Other cultural features such as buried pipelines and fiber optic cables require identification prior to dredging for definition of setbacks.

Due to the level of detail that is required for cultural surveys, sidescan sonar and magnetometer surveys are conducted on a close line spacing (~30 m). Normally, for such surveys the specifications and guidelines are provided by the permitting agency. Sidescan sonar surveys (Figure 16), which are conducted for identification of surface structures and hazards (debris, pipelines, shipwrecks) normally using dual-frequency sidescan sonar, are normally accompanied by a magnetometer survey (using either Proton or Cesium Magnetometer). Generally, 100% swath coverage is needed for a sidescan sonar survey. This survey is normally done under the supervision of a professional marine archaeologist.

Phase IX: Borrow Area Selection and Calculation of Sand Volume

Finally, the selection of potential borrow areas requires re-evaluation of all geotechnical and geophysical data obtained during Phases I thru VIII, including updates or additions to prior surveys, and determination of outer limits of borrow areas. Geological cross-sections, compiled on the basis of sub-bottom data and vibracore logs, should be produced showing the sand layers and the proposed depths of cut. Isopachous maps for sediment thicknesses should be prepared to show the stratigraphic position of target sands and layers that should be avoided due to their unsuitability.

Because the depth, location, and orientation of borrow areas affects the adjacent shoreline, a thorough impact study should be conducted not only for borrow-site environmental assessment but for physical impact-assessment. These kinds of studies tend to focus on induced changes to wave propagation patterns and coastal circulation patterns for different depths of sediment removal (*e.g.* Bender and Dean, 2003).

The cost of dredging potential borrow areas can be a crucial consideration, especially where long haul or pump distances from borrow to project area are concerned. The cost of dredging sediments from the inner part of the WFS is affected by the following major factors: type of sediment, distance from the borrow area to the barrier island, length and width of the barrier island to be restored, depth of water and depth of dredging in the borrow area, depth of water adjacent to the barrier island, and thickness of the dredge cut.

The type of sediment determines dredge horsepower requirements, which in turn affects the cost of dredging. The distance from the borrow area to the extreme limits of the beach restoration project also affects project cost and equipment selection. When dredging with pumping distances up to 10 km, a cutterhead dredge (including the ocean-going dustpan) is the most efficient method. These dredges have 10,000 to 15,000 horsepower, which can pump non-cohesive sediments over these distances. When the distance from the borrow area to the barrier island exceeds 12 to 16 km, hopper dredges become more efficient in transporting the sediment. Thickness of cut in borrow areas also affects equipment selection and productivity. For cutterhead dredges to be productive, the cut must be at least 1 to 2 m thick. For cuts less than 2 m, cutterhead dredges can still operate but at less than optimum efficiency. For shallow cuts, hopper dredges and the ocean-going dustpan are more efficient because they excavate sediments in layers. If an insufficient number of cores are present in the borrow area, dredging contractors often add significant contingency fees to account for unknown or unfavorable conditions that might be encountered. Once a borrow area is selected, it may be worthwhile to go back for an additional round of vibracoring to effectively prove out sediment variability. Additional vibracoring with spacing no greater than 200 m apart may provide greater confidence in sedimentary conditions to reduce significantly dredging costs. Better estimates of sediment volumes by grain size for % sand (D_{50}, D_{85}) or % silt, shells, gravels, *etc.* may also reduce (offset) dredging costs. Generally, it is reasonable to assume that the costs of conducting a very detailed and comprehensive marine sand source investigation is insignificant when compared with the potential for cost savings during dredging that may result.

Phase X: Development of Geotechnical Report

The last phase of sand searches involves the preparation of final reports, appendices and digital data deliverables. As far as general guidelines are concerned, this final phase is perhaps the most important because if the report is poorly prepared or presented in an inappropriate manner, then a great deal of effort has been wasted. In the same way, if the datasets created are not incorporated into a digital GIS database (ROSS) it will get lost and future duplicate efforts in the same area may be conducted by uninformed groups. It is thus essential that reporting procedures be followed using correct formats and styles. It is expected that final sand search reports will document the techniques, methods, analyses, and results. It should be common practice on the inner WFS that all newly generated data in marine sand searches is submitted in a GIS format that can be incorporated into ROSS with minimal effort.

FINAL CONSIDERATIONS

Uncontrolled or free ranging sand searches that more or less indiscriminately cover broad areas of seafloor are costly enterprises that often produce few useful results. Experience has shown that best results are obtained from the judicious deployment of survey resources and careful selection of instrumentation within a procedural strategy that defines protocols for preliminary site selection, field survey, and data reduction. The ROSS database coupled with the general sand search methodology proposed in this document should be a point of reference for all future marine sand search efforts along the inner WFS. Well thought-out marine sand search investigations should be always pursued because they have potential to save millions of dollars during construction. It is thus worth reiterating that all newly generated data in marine sand searches along the southwest coast of Florida should be submitted to the FDEP in a GIS format that can be incorporated into ROSS.

Comprehensive reviews of previous offshore sand searches and legacy data is now facilitated by the existence of a comprehensive offshore marine sand search database (ROSS). Careful analysis of these legacy vibracore data, for example, should provide clear directives to the survey of target areas with the most potential for locating usable sand sources and significantly optimizing future sand search efforts. Selection of potential borrow areas, the ultimate goal of offshore sand searches, depends on adherence to established search protocols that are tempered by practical adjustments to local conditions.

APPENDIX III

GLOSSARY

Cockpit (conical karst, kegel karst, polygonal karst)
Cockpit karst is a special form of "Conekarst" in which the residual hills are chiefly hemispheroidal and surround closed, lobed, depressions known as dolines or "cockpits" each of which is drained to the aquifer by one or more sinkholes. The dolines have concave floors covered with a variable amount of rock rubble and soil, which has often been redistributed to form a flat floor as a result of repeated flooding.

Doline
A doline, sink or sinkhole is a closed depression draining underground in karst areas. It can be cylindrical, conical, bowl- or dish-shaped. The diameter ranges from a few to many hundreds of meters. The name doline comes from dolina, the Slovenian word meaning valley. So this was originally a colloquial Slovenian word that was used by geologists to describe rolling plains that have few surface streams and often no surface valleys. Instead, the landscape is pocked with sinkholes, often tens or hundreds of sinkholes per square kilometer. These sinkholes range from barely discernible shallow swales one to two meters wide to depressions hundreds of meters in depth and one or more kilometers in length.

Eustasy, Eustatic
Refers to global sea level and its variations. Changes in sea level result from movement of tectonic plates altering the volume of ocean basins, or when changes in climate affect the volume of water stored in glaciers and in polar icecaps. Eustasy affects positions of shorelines and processes of sedimentation. Eustasy is one of several terms that are used to describe the changing relationships between sea level and dry land. When the term "relative" is used, it connotes change that is not attributed to any specific cause. The term "eustasy" or "eustatic" refers to changes in the amount of water in the oceans, usually due to global climatic changes. The melting of glaciers at the end of ice ages is an example of eustatic sea level rise. When the Earth's climate cools, water is evaporated from the oceans and is precipitated on landmasses as permanent ice and snow. This causes sea levels to fall relative to a stable land mass.

Evaporite
A class of sedimentary minerals and sedimentary rocks that form by precipitation from evaporating aqueous fluid. Common evaporite minerals are halite, gypsum and anhydrite, which form as seawater evaporates, and the rocks limestone and dolostone. Evaporites are water-soluble, mineral sediments that result from the evaporation of saline water. Evaporites start to precipitate when their concentration in water reaches such a level that they can no longer exist as solutes. This supersaturation is usually the result of prolonged evaporation. Evaporite minerals are geologically important because they clearly are related to the environmental conditions that existed at the time of their deposition, namely an arid environment, such as coastal plain.

Facies, Sedimentary
A set of characteristics that distinguish a given section of sedimentary rock from nearby sections. Such characteristics include mineral content, grain size, shape, and density.

Hardground
As applied in benthic habitat classification and mapping the term involves the interplay and interdependence between marine geology, biology and physical oceanography. In southern Florida this colloquially refers to exposure of bedrock as opposed to the presence of living corals or coral-algal assemblages.

Karst, karstification
An area possessing surface topography resulting from the underground solution of subsurface limestone or dolomite that produces fissures, sinkholes, underground streams, and caverns.

Peneplain (erosion surface)
A land surface of regional scope worn down by erosion to a nearly flat or broadly undulating plain. The Florida peneplain is the eroded surface of the sedimentary platform that extends to the shelf break.

Physiography, physiographic
The study and classification of natural surface features of Earth on the basis of similarities in geologic structure and the history of geologic changes.

Provenance, sedimentary
The geographical area and environment from which sediments are derived.

Siliciclastic
Pertaining to clastic, non-carbonate rocks that are almost exclusively silicon-bearing, either as forms of quartz or as clays. Examples of Florida siliclastics are loose quartz sands, silts, or clays.

Sinkhole
Sinkholes, also known as sinks, dolines, and cenotes, are formed by the collapse of cave roofs and are a feature of landscapes that are based on limestone bedrock. The result is a depression in the surface topography. This may range anywhere from a small, gentle earth-lined depression, to a large, cliff-lined chasm. Most often there is a small area of rock exposure near or at the bottom of a sinkhole, and a patent opening into the cave below may or may not be visible.

Subsidence
The settling or sinking of the ground as a result of the loss of support from underlying soils or strata. This could be due to factors such as earthquakes, compaction, a decrease in groundwater, underground excavations or the settling of waste.