Combining Remote Sensing, GIS and Visualization Methods for Efficient Sand Source Exploration in Florida Coastal Waters

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Abstract

The types of geologic models that can be used for sand resource exploration in modern nearshore and shallow marine environments were discussed by Zarillo (2000). The process for evaluating shallow marine sand and gravel resources outlined in this paper includes a description of methods for analyzing geophysical and geotechnical data in three-dimensional format. In this paper emphasis is placed on data analysis methods using combined geophysical remote sensing methods, geologic visualization, and Geographical Information System (GIS) technology. Case studies from several locations in Florida coastal waters are reviewed.

Introduction

The availability of beach quality sand from nearby sediment resources of the inner continental shelf is a key element for successful beach renourishment to mitigate eroding segments of the Florida Coast. High resolution continuous seismic reflection profiling combined with sediment cores for ground truthing has been the workhorse for evaluating the lateral and vertical extent of shallow marine sand resources. Previous technology reviews presented at the National Beach Technology Conference and in other technical publications described the application of geologic models for interpretation of geophysical and geologic data for sand resources (Zarillo, 2000, Zarillo and Bacchus, 1991). Furthermore, recent surveys of sediment resources by the U.S. Minerals Management Service and state geologic surveys have identified the potential of significant sand resources in Federal waters of the U.S. Continental Shelf. In order to fully evaluate the potential for marine sand resources for beach nourishment and take full advantage of the geologic models of marine sedimentation and high-resolution remote sensing methods now common in sand source studies, it is necessary to apply the latest data processing and visualization technology. This is particularly true in Florida shallow marine environments where sand resources are limited and substantially different in their geologic occurrence compared to more terrigenous influenced sedimentary environments in coastal states to the north.

Analysis of Geophysical Records

New thresholds in computing and remote sensing technology were crossed in the 1990's with the arrival of very high resolution acoustic survey systems and the ability to process large data sets at low cost through advanced desktop computing. Digital processing of data using several software systems is now possible and essential even for projects of limited scope and budget.

Common Acoustic Signatures

Recognition of beach quality sand deposits of limited vertical extent and horizontal extent can be a challenge even in high-resolution digital seismic records. A catalog of acoustic signatures of the typical thin deposits of sand on the Florida carbonate platform is shown in Figures 1 though 4. These examples are from high resolution single beam acoustic sub-bottom profiling systems including the EdgeTech ™ CHIRP profiler. and the Datasonics™ CAP 6000. Specifications and typical applications of these systems can be found at http://www.edgetech.com/subbottom.html and http://www.benthos.com/. For sand exploration the frequency content of the transmitted acoustic pulse is usually selectable in the range of 400Hz to 12kHz. The frequency is tuned to the local sediment conditions to optimize resolution and penetration. Higher pulse frequency ranges up to 20 kHz are more suitable for high-resolution cable route surveys.

The sub-bottom acoustic signature reviewed here can be considered an end member of a continuum beginning with a veneer of sand overlying a lithified carbonate surface to well defined sand bodies having a distinctive topographic expression. Bodies of clean sand from inlet associated shoals are reshaped in the littoral environment and eventually become detached from the shoreface with rising sea level at the millennium time scale (Heron and Moslow, 1991). In depositional environments along the east coast of the US and in some portions of the Gulf coast shoreface connected and shoreface detached linear sand bodies are a primary target for recovering beach quality sand. Figure 1 shows the typical acoustic signature that might be observed in a survey of these shelf sand bodies. The crest area of a sand ridge is usually constructed from clean sand, whereas the trough areas well off the ridge are typically a mixture of sand, silt, and clay. A model of sand ridge stratigraphy and examples from the inner continental shelf of Florida are given in Zarillo (2000).

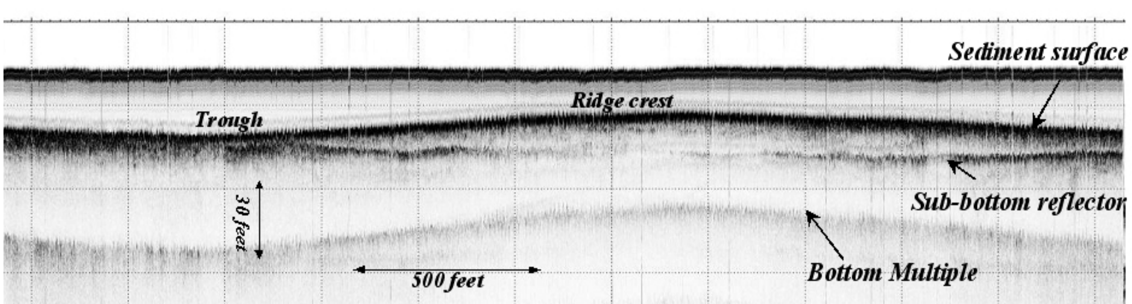


Figure 1. Acoustic profile across an inner shelf sand ridge. Data acquired using an EdgeTech CHIRP profiling system at 500 – 2.7 kHz

Holocene modern sediments of the inner continental shelf of Florida consist of a thin overburden or veneer resting on a pre-Holocene carbonate surface. This underlying carbonate surface may be only a few feet below the modern topographic surface in some areas. Figure 2 is an example of a sub-bottom record from New Pass in Lee County, Florida where the overburden of unconsolidated sand is only 3 to 8 feet thick above a semi-consolidated carbonate surface. Here the veneering sand over a shallow carbonate surface is derived from the ebb-shoal deposits of New Pass. The acoustic records define the backscatter from a nearly continuous reflector not more than 5 to 8 feet below the topographic surface. The low amplitude of backscatter above the reflector indicates unconsolidated sediment. Core samples from this area indicated a fine carbonate rich sand above the reflector (Figure 3). However in, this case the volume of sand estimated from sub-bottom records was deemed too low to be recoverable (SEA, Inc. 2000).

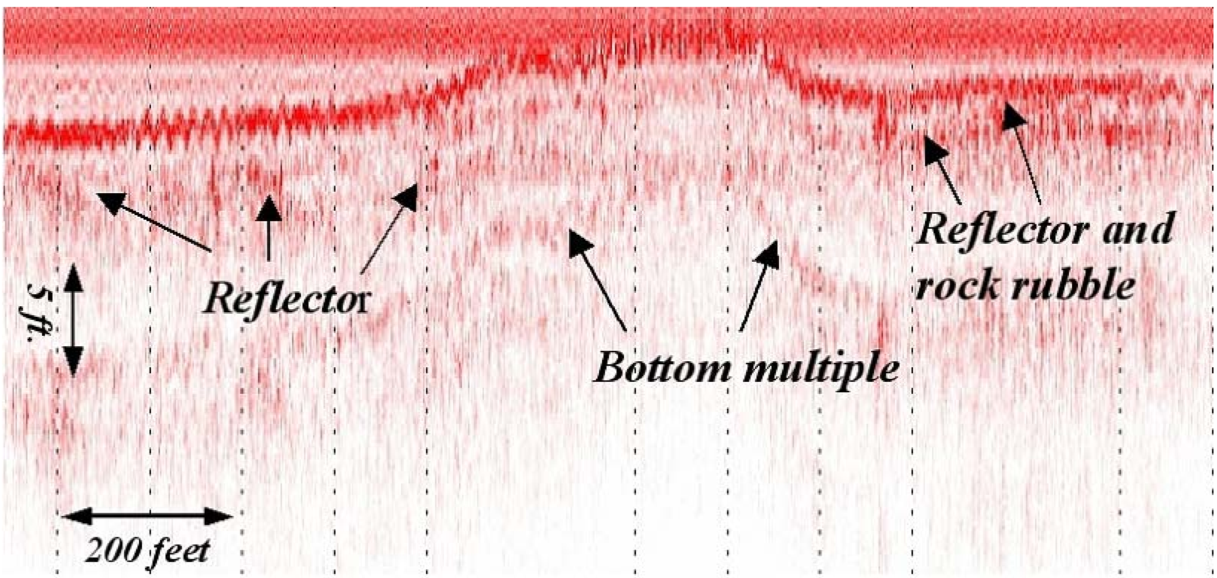


Figure 2. Acoustic profile across the outer ebb shoal of New Pass in Lee County. Florida. Data acquired with Datasonics 6000 profiling system with a frequency range of 600 Hz – 11 kHz

Figure 4 is an example of acoustic backscatter from a strong sub-bottom reflector corresponding to the late Pleistocene Anastasia Formation offshore of the Highland Beach area Palm Beach County, Florida. Offshore the elevation of the reflector increases until it merges with the topographic surface to form the rock reef approximately 1 mile offshore. Figure 5 shows coral rock fragments corresponding to the acoustic reflector from the lower portion of a core boring situated along one of the acoustic survey track lines. A similar acoustic of a relatively thin sand accumulation over carbonate is shown in Figure 6 from the nearshore areas of North Palm Beach County, FL. An accumulation of fragmented acoustic backscatter occurs above multiple sub-bottom reflectors.

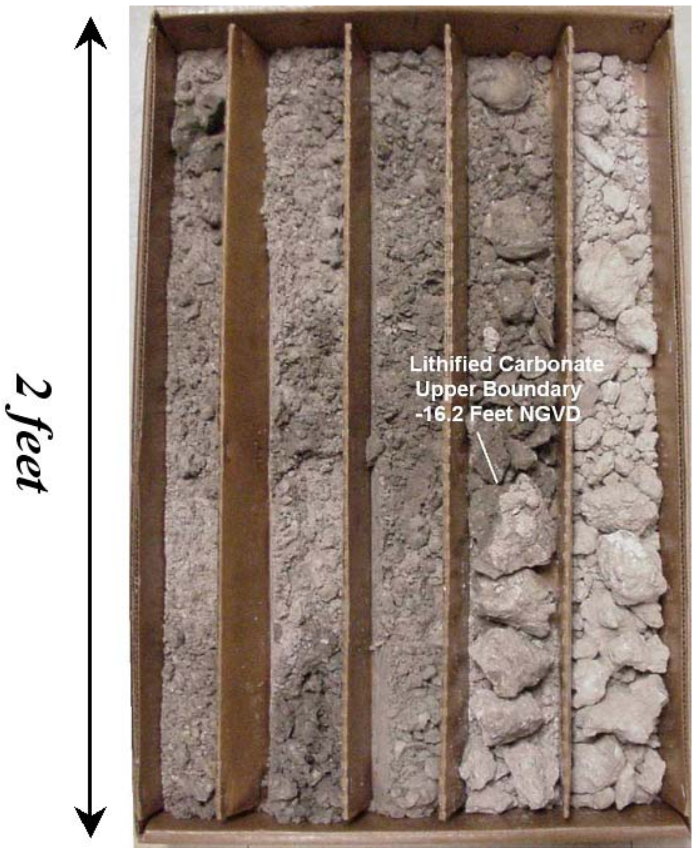


Figure 3. Boundary between unconsolidated fine sand and carbonate rock fragments corresponding to the acoustic reflector shown in Figure 2.

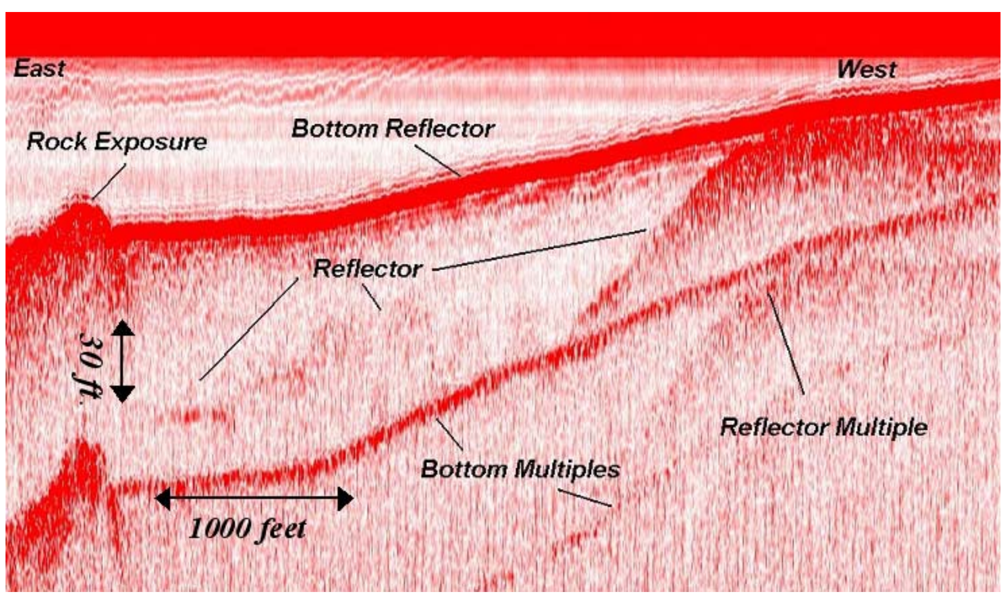
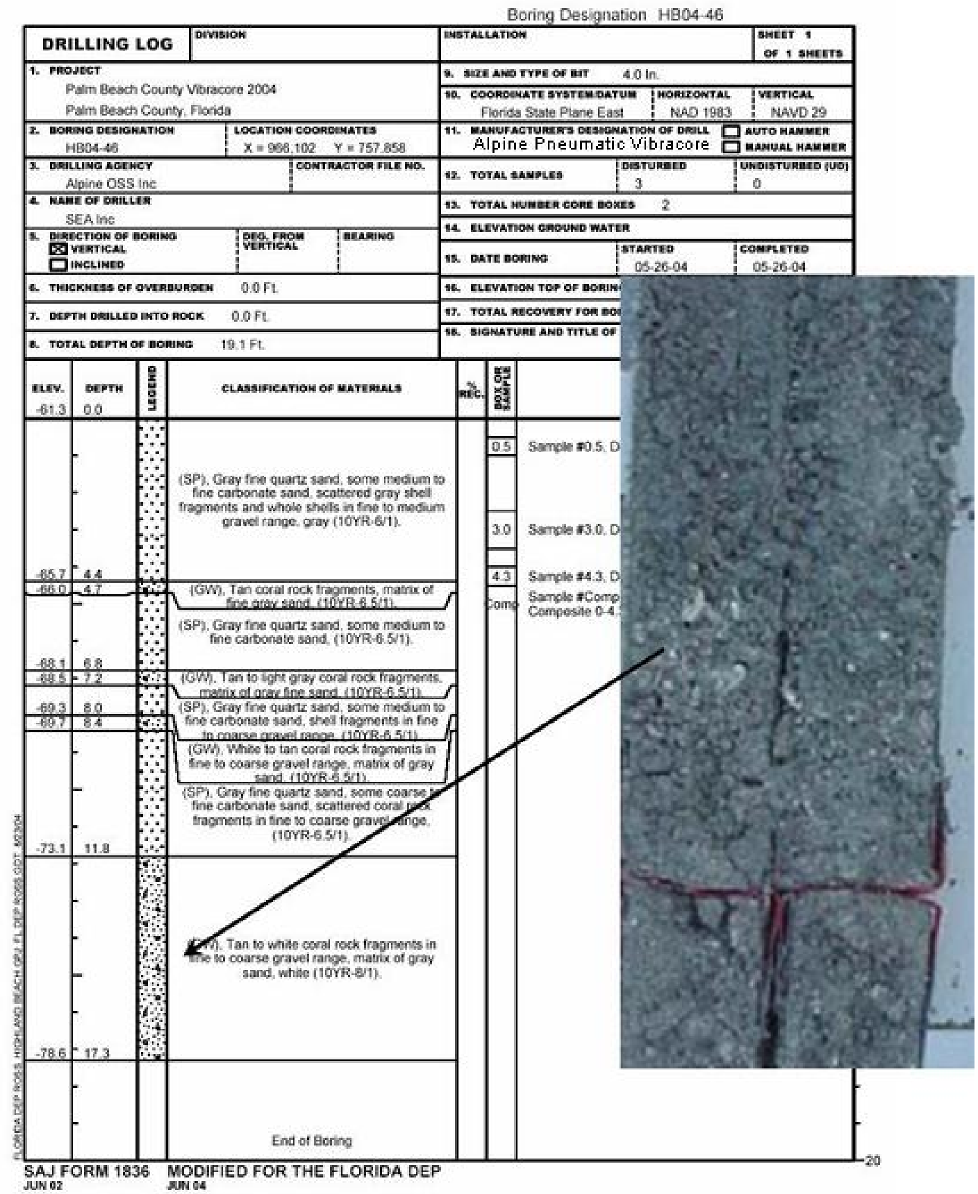


Figure 4. Sub-bottom acoustic profile from the Highland Beach area of Palm Beach County. Data acquired using an EdgeTech™ CHIRP profiling system at 500 Hz – 2.7 kHz,



Boring Designation HB04-46

DRILLING LOG | DIVISION | INSTALLATION | SHEET 1 OF 1 SHEETS

1. PROJECT
Palm Beach County Vibracore 2004
Palm Beach County, Florida

2. BORING DESIGNATION: HB04-46 | LOCATION COORDINATES: X = 966,102 Y = 757,858

3. DRILLING AGENCY: Alpine OSS Inc | CONTRACTOR FILE NO.

4. NAME OF DRILLER: SEA Inc

5. DIRECTION OF BORING: ☒ VERTICAL ☐ INCLINED | DEG. FROM VERTICAL | BEARING

6. THICKNESS OF OVERBURDEN: 0.0 Ft.

7. DEPTH DRILLED INTO ROCK: 0.0 Ft.

8. TOTAL DEPTH OF BORING: 19.1 Ft.

9. SIZE AND TYPE OF BIT: 4.0 In.

10. COORDINATE SYSTEM/DATUM: Florida State Plane East | HORIZONTAL: NAD 1983 | VERTICAL: NAVD 29

11. MANUFACTURER'S DESIGNATION OF DRILL: Alpine Pneumatic Vibracore | ☐ AUTO HAMMER ☐ MANUAL HAMMER

12. TOTAL SAMPLES | DISTURBED: 3 | UNDISTURBED (UD): 0

13. TOTAL NUMBER CORE BOXES: 2

14. ELEVATION GROUND WATER

15. DATE BORING | STARTED: 05-26-04 | COMPLETED: 05-26-04

16. ELEVATION TOP OF BORIN…

17. TOTAL RECOVERY FOR BO…

18. SIGNATURE AND TITLE OF…

ELEV.	DEPTH	CLASSIFICATION OF MATERIALS	BOX OR SAMPLE	
-61.3	0.0			
-65.7	4.4	(SP), Gray fine quartz sand, some medium to fine carbonate sand, scattered gray shell fragments and whole shells in fine to medium gravel range, gray (10YR-6/1).	0.5 / 3.0 / 4.3	Sample #0.5, D… / Sample #3.0, D… / Sample #4.3, D…
-66.0	4.7	(GW), Tan coral rock fragments, matrix of fine gray sand, (10YR-6.5/1).	Comp…	Sample #Comp… Composite 0-4.…
-68.1	6.8	(SP), Gray fine quartz sand, some medium to fine carbonate sand, (10YR-6.5/1).		
-68.5	7.2	(GW), Tan to light gray coral rock fragments, matrix of gray fine sand, (10YR-6.5/1).		
-69.3	8.0	(SP), Gray fine quartz sand, some medium to fine carbonate sand, shell fragments in fine to coarse gravel range, (10YR-6.5/1).		
-69.7	8.4	(GW), White to tan coral rock fragments in fine to coarse gravel range, matrix of gray sand, (10YR-6.5/1).		
-73.1	11.8	(SP), Gray fine quartz sand, some coarse to fine carbonate sand, scattered coral rock fragments in fine to coarse gravel range, (10YR-6.5/1).		
-78.6	17.3	(GW), Tan to white coral rock fragments in fine to coarse gravel range, matrix of gray sand, white (10YR-8/1).		
		End of Boring		

SAJ FORM 1836 JUN 02 MODIFIED FOR THE FLORIDA DEP JUN 04

FLORIDA DEP ROSS HIGHLAND BEACH.GPJ FL DEP ROSS.GDT 8/23/04

Figure 5. Coral rock fragments in the lower sections of a core boring obtained in a water depth of -62 ft. in the Highland Beach area of Palm Beach County.

Figure 6 exemplifies a sub-bottom record that includes acoustic backscatter from rock rubble strewn through the sediment overburden as well as a strong acoustic reflector that represents a continuous lithified surface well below the topographic surface. It is important to recognize the acoustic signature of rock fragments in acoustic records in order to exclude rock debris from beach fill projects. This record is from north Palm Beach County, Florida where the sediment overburden is relatively thin over a shallow trough defined by the underlying carbonate surface that eventually extends to the surface as a series of rock outcrops approximately 7,000 feet offshore.

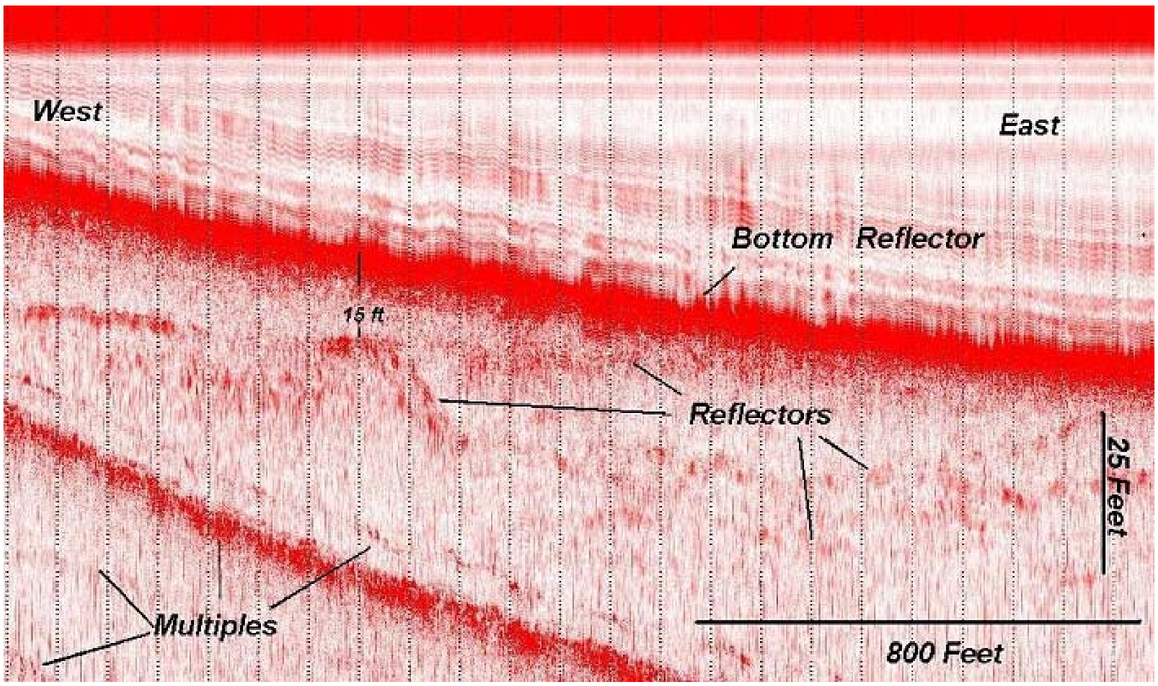


Figure 6. Sub-bottom acoustic profile from the Singer Island area of Palm Beach County. Data acquired using an EdgeTech^{TM} CHIRP profiling system at 500 – 2.7 kHz.

Combining Remote Sensing, Visualization, and GIS Technology for Optimal Analysis

The combination of acoustic seismic stratigraphy records and direct geologic sampling with geographical information systems (GIS) and other 3D visualization methods is a powerful tool for assessing shallow sand resources that may contain beach quality sand. Traditional methods for mapping large sand bodies have limited value in Florida since nearshore sand resources in many areas are not necessarily found in well-defined sand bodies having a strong topographic expression. Often sand resources are dispersed and must be explored and recovered in a patchwork of borrow cuts having irregular geometry and vertical dimensions. Thus, GIS technology having the capability of 3D analysis and combining several types of data as distinct image and feature themes into one visualization package is an optimal method for analysis.

Analysis of seismic stratigraphy from the acoustic properties of sub-bottom records outlined in the previous section begins with extraction of the horizontal and vertical position of important sources of acoustic backscatter. Desktop software available at relatively low cost provides a method of both enhancement and digitization of seismic profiles in the industry standard SEGY (Society of Exploration Geophysicists) format. Sub-surface data collected along survey track lines along with simultaneous topographic data can be conveniently displayed as a series of themes in standard GIS software such as Arcview™ or ArcInfo™ . For instance, Figure 7 shows a screen capture of survey track lines from the Highland Beach area of south Palm Beach County along which both topographic and sub-bottom acoustic data sets were collected. The track lines are displayed as feature themes whereas the background is an image theme depicting the results of a topographic LIDAR survey of Palm Beach County water to depths of approximately 70 feet.

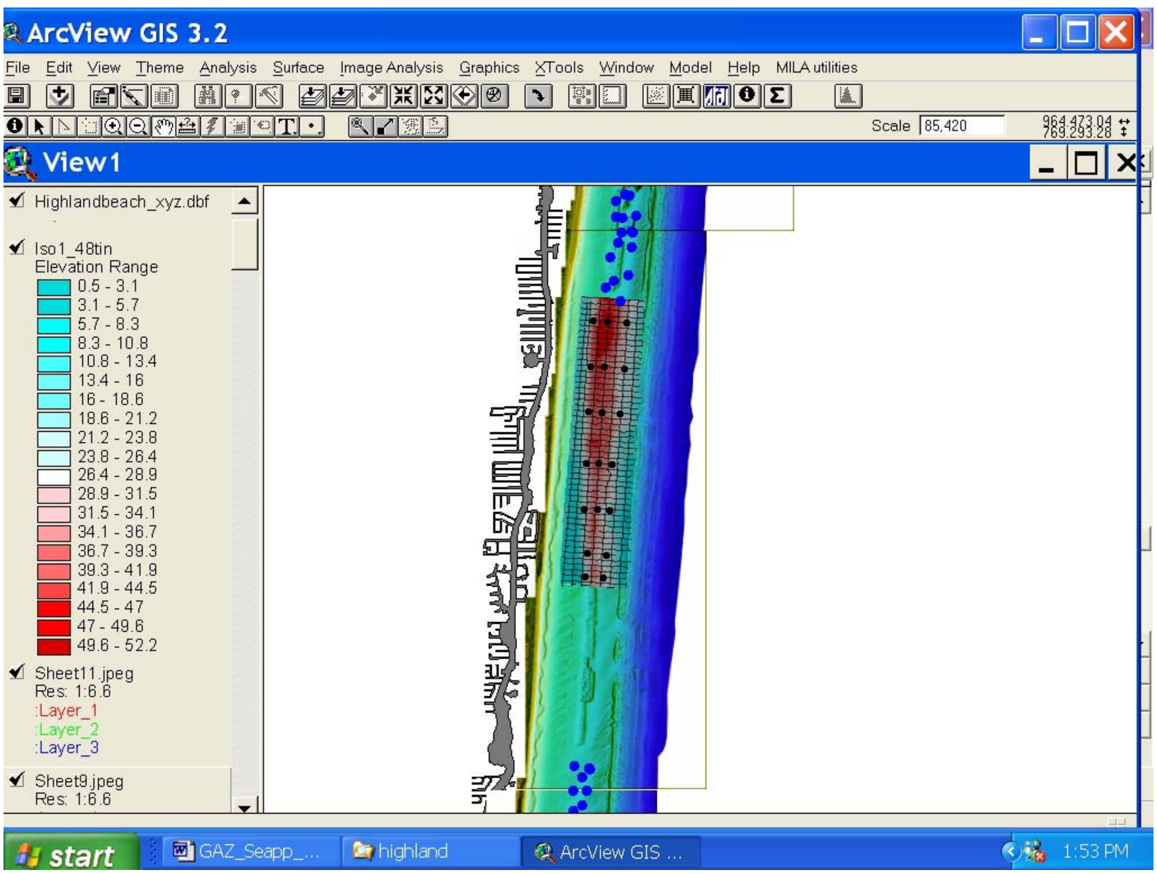


Figure 7. Screen capture of ArcView™ GIS themes in the Highland Beach areas of Palm Beach County. Shown are survey track lines (line theme) sediment isopach data (grid theme), core locations, (point theme) and LIDAR bathymetric data (image analysis theme) in the background provided by Palm Beach County ERM.

Once the various types of data sets are included in the GIS project files, the spatial and three dimensional analysis capabilities of GIS can be used to extract useful information for further analysis of sand resources. For instance Figure 8 illustrates a perspective view from the northeast of the relative positions of the bathymetric surface and rock surface defined by a prominent sub-bottom reflector in the Highland Beach area of Palm Beach County. The three-dimensional analysis capabilities of GIS software allow calculations of sediment volume contained between the bounding surfaces shown in Figure 8. Figure 9 illustrates the isopach or sediment thickness between the bathymetric and acoustic surfaces in this case. The calculation is completed by computing the difference in the interpolated grid data used to generate the image of the two surfaces. These data are accessible through the menus that guide the use of the GIS software.

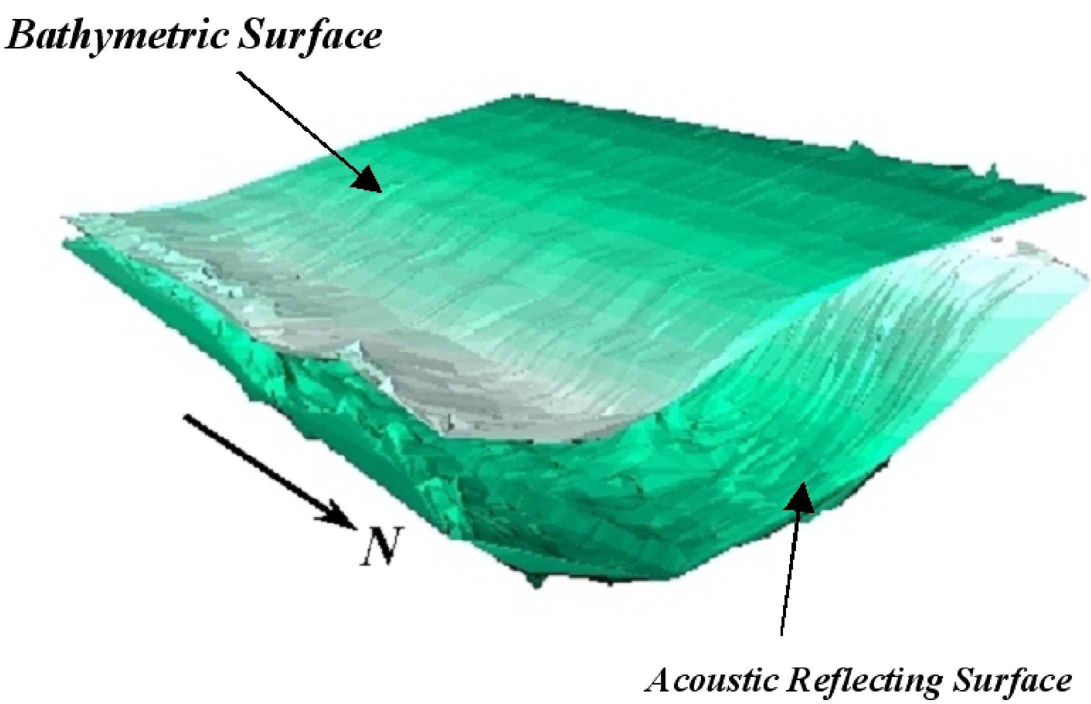


Figure 8. Perspective view of surfaces interpolated in GIS from topographic and acoustic data collected in the Highland Beach area of Palm Beach County, FL. (Vertical exaggeration. 30x).

Although standard desktop GIS software like Acrview™ or ArcInfo™ along with digital terrain model (DTM) software are useful for visualizing three-dimensional surfaces and gridded data they lack the capability of directly analyzing geotechnical and sedimentologic data required to evaluate sediment quality. For this purpose it is necessary to be able to combine analysis performed with geologic software platforms like Rockware™ with GIS project files. Figure 10 is an example of a geologic fence diagram constructed from core boring data in the Briny Breezes area of Palm Beach County. Analyses of geologic and sedimentologic data developed using geotechnical software can often be exported to GIS shape files and combined with survey data within GIS project files. Figure 11 shows the fence diagram in the form of a 3D GIS shape file combined with the interpolated data that represent the topographic and sub-bottom reflector surfaces constructed from acoustic survey data. This combination allows better three-dimensional resolution of beach quality sand resources and more precise location of rock rubble that can contaminate beach fill construction.

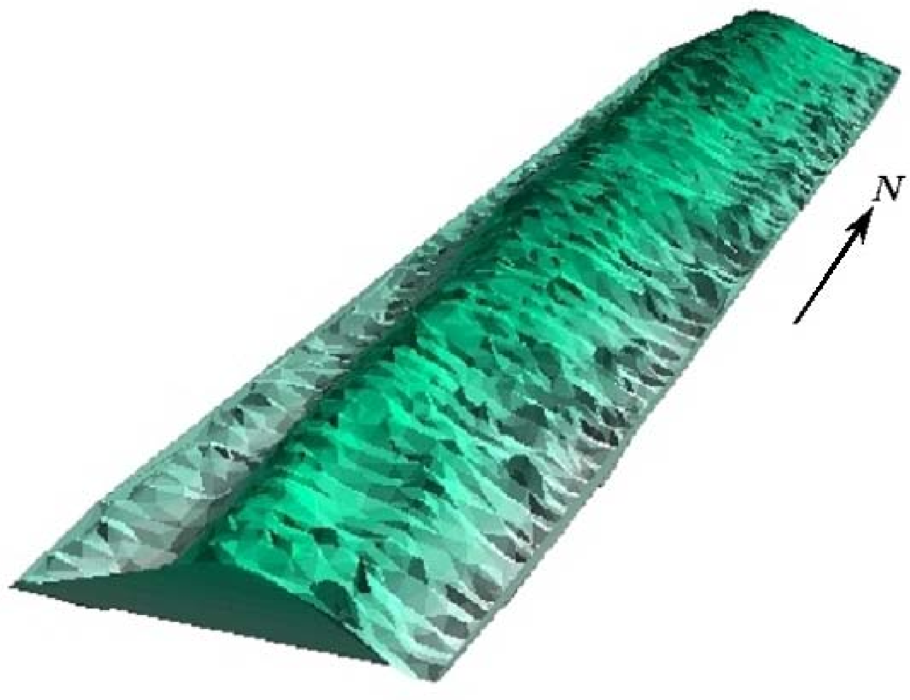


Figure 9. Perspective view from the southeast of the isopach or sediment volume between the bathymetric and sub-bottom bounding surfaces shown in Figure 8. (Vertical exaggeration 30x).

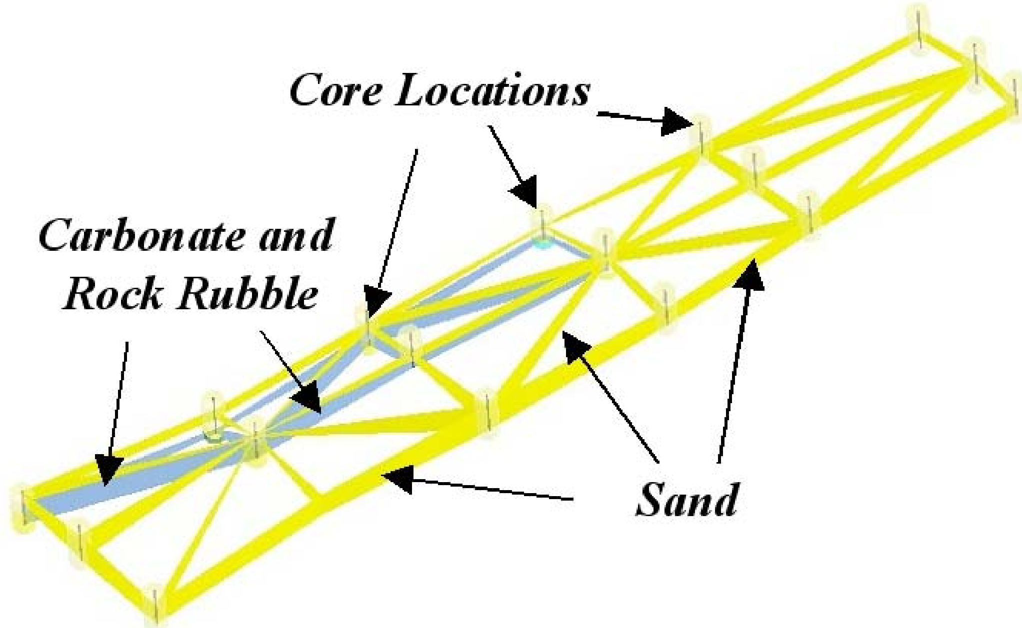


Figure 10. Geologic fence diagram showing the major nearshore stratigraphic units in the Briny Breezes area of south Palm Beach County, Florida. (Vertical exaggeration 20x).

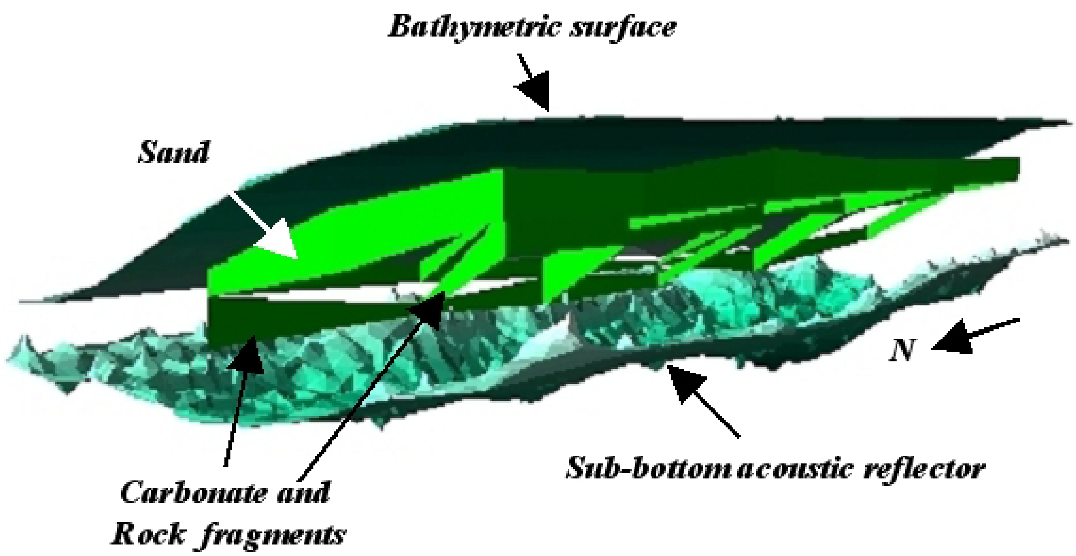


Figure 11. Combination of a 3D fence diagram GIS Shape file with the shape files depicting the bathymetric and sub-bottom acoustic reflector surfaces. (Vertical exaggeration 20x).

Once combined in this manner the distribution of beach quality sand and be better visualized. This allows a more precise calculation of the volume of recoverable beach quality sand. In this case the Briny Breezes survey area situated between the Palm Beach County shoreline and the rock reef outcrops approximately a mile offshore was shown to contain up to 9 million cubic yards of beach quality sand.

In a similar example combining the capabilities of GIS and geologic analysis software geophysical data were combined to assess the potential for recovering beach quality sand from the Sebastian Inlet in Brevard County, Florida. Here a sand trap was designed to accululate sand transported to the flood from the throat of Sebastian Inlet (Figure 12). Figure 13 shows a fence diagram of sub-bottom stratigraphy constructed using Rockware™ combined with the configuration of a sub-bottom acoustic reflector that

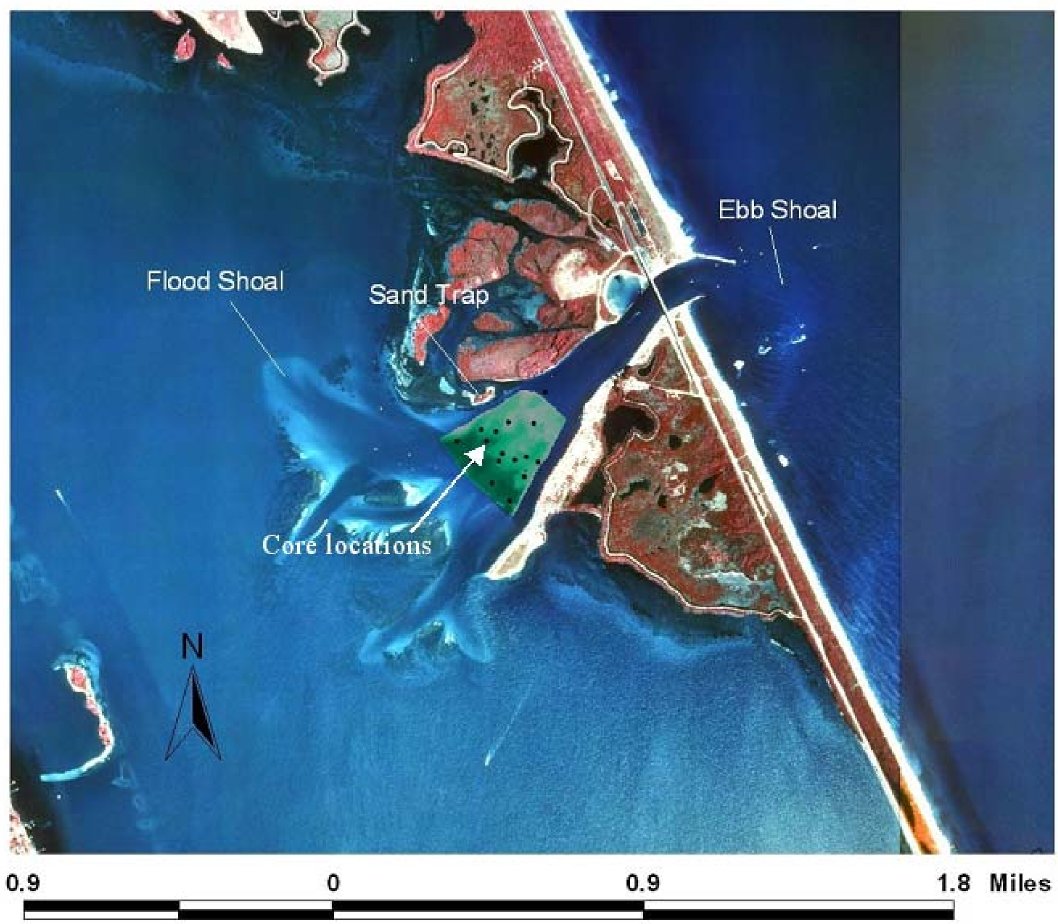


Figure 12. Location of the sediment trap to the west of Sebastian Inlet on the boundary between Brevard County and Indian River County, Florida.

Correlates with the coquina of the Anastasia Formation. The fence diagram shows that the only significant volume of sand for potential recovery for beach restoration is in the west portion of the Sebastian Inlet sand trap. Figure 14 combines the 3D shape files of a fence diagram with the bathymetric surface and sub-bottom reflector generated in ArcView™ GIS. The 3D visualization of the rock surface, sand deposits, and the bathymetry in this figure reinforces the conclusion that sand resources are confined to the west segment of the Sebastian Inlet sand trap. Rock outcrops can be seen near the east boundary of the trap.

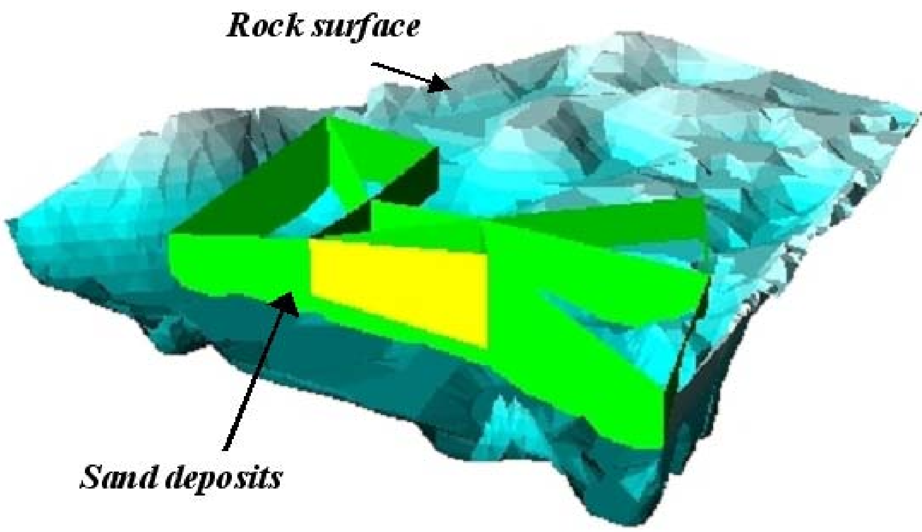


Figure 13. Combination of a 3D fence diagram GIS shape file with the shape files depicting the sub-bottom acoustic reflector correlating with the coquina rock surface below the Sebastian Inlet sand trap. (Vertical exaggeration 20x).

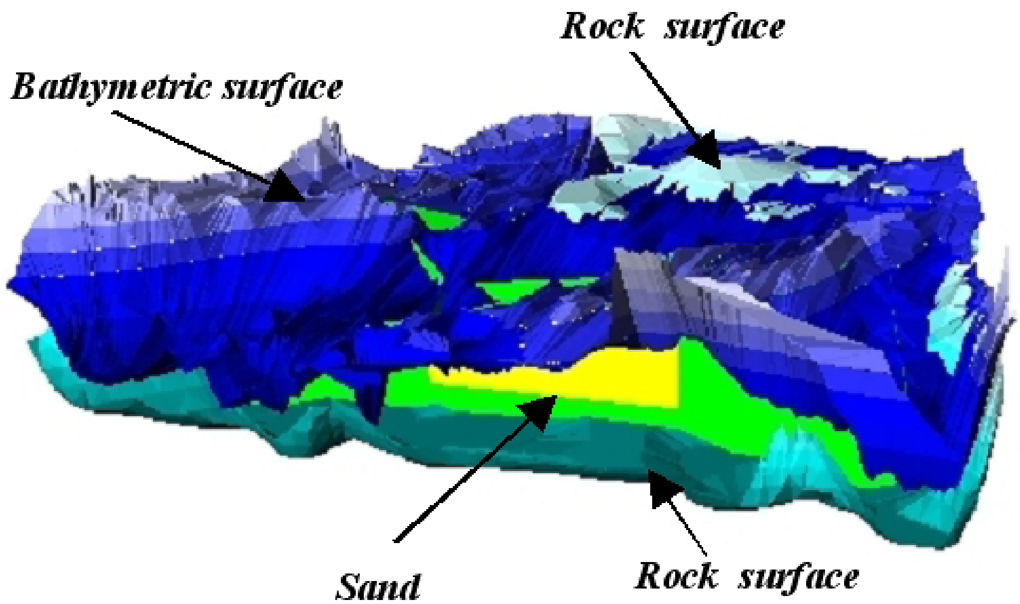


Figure 14. Combination of a 3D fence diagram GIS shape file with the shape files for the sub-bottom acoustic reflector and topographic surface within the Sebastian Inlet sand trap. (Vertical exaggeration 20x).

Summary

The availability of beach quality sand from nearby sediment resources of the inner continental shelf is a key element for successful beach renourishment to mitigate eroding segments of the Florida coast. High resolution continuous seismic reflection profiling combined with sediment cores for ground truth has been the workhorse for evaluating the lateral and vertical extent of shallow marine resources. In order to fully evaluate the potential for efficiently recovering shallow marine sand resources for beach nourishment and take full advantage of the geologic models of marine sedimentation it is necessary to apply the latest low cost data processing and visualization technology. This is particularly true in Florida shallow marine environments where sand resources are limited and substantially different in their geologic occurrence compared to more terrigenous influenced sedimentary environments in coastal states to the north. This paper described methods for combining acoustic seismic stratigraphy data and direct geologic sampling with geographical information systems and 3D visualization methods to assess shallow marine sand resources that may contain beach quality sand

Typical examples were given on how to recognize and quantify the signature of beach quality sand deposits of limited vertical extent and horizontal extent in high to very high-resolution digital seismic records. A catalog of acoustic signatures was provided that represent the typically thin deposits of sand on the Florida carbonate platform.

Acknowledgments

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References

McBride, R. A. and T. F. Moslow, 1991. Origin, evolution, and distribution of shoreface sand ridges, Atlantic inner shelf. USA. Marine Geology, 97:57-85.

Zarillo, G.A., 2000 Prospecting for Beach Quality Sand: Applying Geological Models. National Conference on Beach Preservation Technology '00, Florida Shore and Beach Association. Melbourne, FL.

Zarillo, G.A. and Bacchus, T.S., 1992. Application of Seismic Methods to Sand Source Studies for Beach Nourishment. In Handbook of Geophysical Exploration at Sea, CRC Press. Boca Raton, FL., pp. 241-258.