A GEOLOGICAL INVESTIGATION OF SAND RESOURCES IN THE OFFSHORE AREA ALONG FLORIDA'S CENTRAL-EAST COAST

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FINAL SUMMARY REPORT

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Background

The Minerals Management Service of the U.S. Department of Interior (MMS) and the Florida Geological Survey (FGS) entered into a multi-year cooperative agreement (Cooperative Agreement #14-35-0001-330757/State of Florida Organization Code 3705 0204 829) in 1994 with the goal of characterizing the beach restoration potential of sands located in Federal waters off the central east coast of Florida. This includes the area underlying Federal waters out to ten miles offshore of southern Brevard, Indian River, St. Lucie and Martin Counties (Figure 1).

The MMS is responsible for management of all economic resources located in Federal waters off of the nation's coastline. The agency also collects, accounts for, and disburses revenues from Federal offshore mineral leases and from onshore mineral leases on Federal and Native American lands.

This cooperative agreement was funded through the International Activities and Marine Minerals Division (INTERMAR) of the MMS, which provides policy direction and guidance for the development of marine mineral resources on the Outer Continental Shelf. The purpose of this cooperative agreement is to identify sand deposits in Federal waters suitable for beach nourishment and wetlands protection projects. Information derived from this study will assist the MMS in making decisions concerning the future use of these deposits. Additionally, identifying offshore sand deposits now expedites the placement of sands on beaches impacted by future hurricanes or winter storms.

Summary of Tasks

Following is a summary report of all tasks accomplished during the course of this project in addition to a partial volumetric estimate of offshore sands identified during this investigation that are suitable for beach restoration. Portions of the accompanying text first appeared in earlier annual reports to the MMS. A more detailed discussion can be found in the Years 1-4 Annual Reports.

Year 1 tasks included the compilation of an annotated bibliography describing previously completed work in the study area, along with the initiation of an onshore push-core program designed to establish a baseline characterization of beach sands in the study area. Results of tasks completed during Year 1 of this investigation are summarized in "A Geological Investigation of the Offshore Area along Florida's Central East Coast, Annual report to the MMS-Year 1" (Hoenstine et al., 1995) delivered to the MMS in October 1995. FGS Open File Report #69, "A Geological Investigation of the Offshore Area Along Florida's Central East Coast, Year 1" (Freedenberg et al., 1995a) also summarizes the Year 1 results of this investigation. In October 1995, an interim report "A Geological Investigation of the Offshore Area Along Florida's East Coast, Interim Report to the U.S. Department of Interior, Minerals Management Service" (Freedenberg et al., 1995), was published describing a bottom sediment grab sampling program which was conducted in Federal waters in the northern part of the study area.

Year 2 activities were summarized in "Annual report to the U.S. Department of the Interior Minerals Management Service, Year 2, A Geological Investigation of the Offshore area along Florida's Central East Coast." (Freedenberg et al., 1997a). Additionally, an abstract summarizing this data " New Perspectives in Locating Sand for Beach Restoration in Florida- An Interim Report" (Freedenberg et al., 1997b) was published by the Geological Society of America, Southeastern Section. Year 2 tasks included the collection, description and analysis of additional push cores in southern Brevard County. These data were reprocessed and interpreted. A grab-sampling program was also initiated. Bottom sediment grab samples were collected and analyzed. Grab sample locations were chosen based on interpretation of the seismic data. Results of the grab sample analyses were used to pick sampling locations for a follow-on vibracore program.

Year 3 activities were summarized in "Annual Report to the United States Department of Interior Minerals Management Service, Year 3, A Geological Investigation of the Offshore Area Along Florida's Central East coast, Part 2" (Freedenberg et al., 1999). Part 1 served as an executive summary detailing tasks accomplished and a compilation of analytical results. Part 2 of this document consisted of Appendices containing the supporting data collected during Year 3 of the study. Tasks accomplished during Year 3 include the collection of subsurface acoustic profile data, analysis of previously collected push cores, grab sampling and vibracore collection.

Progress during Year 4 was documented in the report "A Geological Investigation of the Offshore Areas Along Florida's Central East Coast, Year 4 Annual Report to the United States Department of Interior Minerals Management Service" (Freedenberg et al., 2000a) This report included the description and analysis of bottom grab samples and vibracores collected off of Indian River, St. Lucie and Martin Counties. Findings from this report were summarized in a publication "Proceedings 2000 National Conference on Beach Preservation Technology" (Freedenberg et al., 2000b).

Additional vibracores were collected off of Indian River and St. Lucie Counties after the Year 4 annual report was issued. The descriptions of and results obtained from granulometric analysis of these vibracores are described in Appendix I of this report.

Central East Coast Geology

Various authors have described the onshore geology of Florida's central east coast counties. Applin and Applin (1944) describes the regional subsurface stratigraphy of Florida and southern Georgia. Brown et al., (1962) examined the water resources of Brevard County while Duncan et al., (1994), discussed the geologic framework of the lower Floridan aquifer system in Brevard County. Davis (1997) provides a readable account of modern perspectives in Florida geology. The following account borrows from Davis.

High foredunes are locally developed on barrier islands in the area of investigation. It is these foredunes which prevent overwash and landward migration during routine tidal and acute storm events. Maintenance of these foredunes through restoration and/or stabilization is vital to maintaining beach integrity in the study area.

Sediment transport in the study area is generally to the south but littoral drift may be locally reversed forming closed circulation cells. Cell formation could be caused by variations in sub sea bathymetry which serve to focus wave energy (Mehta and Brooks, 1973). Littoral cells would cause areas of convergent sand supply supporting beach ridge growth. Accompanying these convergent sand supply areas are divergent areas where erosion predominates. Stauble and DaCosta (1987) along with Stapor and May

(1983) support the existence of local littoral circulation cells while Dean and O'Brien (1987) focus on the general southward direction of littoral transport in the study area.

The shorefront areas of Brevard, Indian River, St. Lucie and Martin Counties all lie on the Atlantic Coastal Plain. Mixed lithology, quartz-carbonate sand, and barrier islands typify the coast of all four counties. All indurated sediments in the study area are generically assigned to the Anastasia Formation. It is likely that, while the Anastasia is generally regarded as Pleistocene in age, it also includes recently cemented (Holocene) beach rock. When examining an Anastasia specimen, there is no convenient way of knowing if the rock was cemented within the last 100 years or is a much older relic. The Anastasia underlies all modern beach sediments in the study area.

Underlying the unconsolidated surface sediments and the indurated Anastasia sediments in the study area are siliclastic Plio-Pleistocene sediments which in turn overlie the Neogene Hawthorn Group. The lithology of the Hawthorn group is extremely diverse, including clay, sand, limestone, silt-sized dolomite and phosphorites. This lithologic variability is evidence of repeated sea-level fluctuations on an expansive shallow water shelf (Compton, 1997). Local stratigraphic studies (Hoenstine, 1984, Scott, 1988, Weedman et al., 1995) suggest a Late Oligocene to Early Pliocene age for the Hawthorn Group sediments.

The Eocene Ocala Limestone, along with the Avon Park Formation and Oldsmar Limestone are found below the Hawthorn Group. These sediments were laid down on a widespread shallow carbonate platform that existed from Late Cretaceous to Eocene time. The Paleocene in the area of investigation is represented by the Cedar Keys formation, which consists of a limestone-dolomite sequence. Insufficient control makes the definitive differentiation of sub-Cedar Key sediments in the study area problematic.

Project Design

Stand-alone tasks performed in this scope of work included the assembly of an annotated bibliography describing previous work along the Central East Coast and the acquisition of 46 ten-foot push cores along the beach to characterize native beach sediments. Initial offshore evaluation was accomplished using a subsurface acoustic profiler to acquire approximately 1200 line-miles of seismic data. Eighty-seven bottom grab samples were collected from areas found to be favorable for sand deposition based on the interpretation of acoustic profile data. A total of 38 reconnaissance vibracores were also collected from those locations where seismic data and grab samples suggested sand of sufficient quality and volume for beach restoration.

Push Cores

Push cores were collected to provide a baseline documentation of beach sediment character. A total of 46 push cores (17 in Brevard, 14 in Indian River, 9 in St. Lucie and 6 in Martin Counties) were collected at arbitrarily chosen locations along the shoreline. All cores were described and their grain size distribution was determined (Appendix I). The percent carbonate content for each sample was also measured.

The push cores were collected by beveling the end of a ten foot length of two-inch Schedule 40 PVC and driving it into the beach sediment with a hammer. All push cores were driven to a depth of ten feet below ground surface or until refusal. One half of each core was archived at the FGS core storage facility, while the second half was used for sample description and grain size analysis. All cores were split lengthwise, described lithologically, and sampled for granulometric analyses. The locations of all cores collected in the study area during the course of this study are shown on the accompanying map (Figure 2). Results of the lithologic and granulometric characterization of push cores are summarized in Annual Reports 2 and 3. Additional granulometric analyses were performed on those intervals containing larger amounts of heavy minerals. The results of these analyses are included in the respective Annual Reports.

Initial sample analysis consisted of drying the sample and providing a visual description of texture and lithology. Grain size analyses were conducted in accordance with ASTM standard D-442 (ASTM, 1989). All samples were weighed and wet sieved through a 62.5 μ screen. The weight of the fines removed during wet sieving was recorded. The retained fraction was dried and passed through a 4mm screen which removed the gravel sized material. The weight of the gravel-sized fraction was then recorded.

The sand fraction (the portion left behind after wet sieving and gravel separation) was then weighed and passed through a stack of 0.25 ϕ screens with openings ranging from –2 ϕ to 4 ϕ. Weight percent collected on each screen was calculated and graphed. These values represent the total weight of the complete sample fraction. Graphical and statistical parameters were determined for each sampling distribution. Note – granulometric results were calculated using retaining sieve sizes rather than midpoint of adjacent sieves. This conforms with granulometric protocol established for the FGS/MMS/Continental Shelf Associates (CSA) environmental study conducted in the study area during the years 2002 – 2003.

After initial sieving, the split obtained for each size fraction was dissolved in hydrochloric acid in order to remove any carbonate material present. After removal of carbonate material, the sample was again wet sieved, dried, and dry sieved. The weight of sediment remaining on each pan was recorded and graphed. These values are considered to represent the silica fraction in each sample.

The carbonate fraction for each sample was determined by subtracting the silica fraction from the total fraction for each sample run. The grain size distribution of the carbonate material was calculated and graphed.

All sample description and granulometric data is presented in Appendix I of this report as well as in earlier annual reports to the MMS.

Geospatial data illustrating the distribution of carbonate sands in the study area is presented on the accompanying ArcView and HTML displays.

Seismic Data

Approximately 1200 line-miles of subsurface acoustic profile data were recorded during the course of this study. All data was acquired in Federal waters off of Brevard, Indian River, St. Lucie and Martin Counties. The seismic program consisted of 164 east-west (dip) lines and three north-south (strike) lines. The strike lines were between 36 and 41 miles in length. Dip lines averaged five to seven miles in length. Average production rate was 20-25 line-miles per day.

Data was collected aboard the United States Geological Survey Research Vessel *Gilbert* and the Florida Geological Survey Research Vessel *Geoquest*. Signal energy for the survey was provided by a Huntec boomer sled towed approximately 30 feet behind the research vessel. A ten station ITI streamer cable was used for signal detection. In an effort to improve signal resolution and provide repetitive imaging of the same depth point, only signals from the five adjacent geophones closest to the research vessel were activated during this shooting program. Figure 4 illustrates the shooting geometry used in this survey.

The sled-mounted Huntec boomer signal source was towed at an approximate speed of four knots and fired four times per second. The boomer creates a bubble pulse by using a rapidly moving electromagnetically controlled plate. A power supply (originally capacitive discharge, later switching) is used to create a current which moves the plate. As the plate is manipulated, cavitations cause bubble formation. The source signal frequency is dependent on plate geometry and activation energy. The power supply used in this project was set to generate 135 joules. For this survey, the boomer was configured so that most of the source energy had a frequency of approximately 400 Hz. Field data were sampled and converted to a digital format. Signal amplitudes were sampled at a rate of 16,000 times per second (this process is commonly referred to analog-digital conversion or ADC) for a record length of 200 milliseconds (ms). This provided 3200 samples per shot record. Given the boat speed of four knots and shot intervals ranging form 250 ms to 1 second, it can be calculated that the seafloor was imaged at consecutive depth imaging points of approximately 1.5 feet. Shooting parameters were chosen in consultation with the USGS.

Most previous acoustic profiling programs have relied on analog signal recording and processing. During these analog acquisition programs, the equipment operator was obliged to pick recording and final display parameters as the data was being acquired. Analog data were processed as they were recorded and immediately printed onto a paper record. No provision was made for post processing. The paper record generated during the shooting was the only tool available to the interpreter.

During the digital recording program implemented during this study, all field records were archived on magnetic media and later transferred to DVD's for long term storage. All field data was converted to SEG-Y format and is available for general distribution. SEG-Y is a standard format for the exchange of seismic data and is readily manageable by all seismic processing programs. Various proprietary formats were in use before SEG-Y became the industry standard.

An ELICS Delph II System was used for digital data recording, processing and display. The ELICS system provided an integrated platform for the digital recording and processing of subsurface acoustic profile and seismic data. Data processing parameters were chosen so as to emphasize stratigraphic differences within the sea bottom sediment.

Post processing was performed on several lines using the Seismic Processing Workshop software package developed by Parallel Geophysical. Post processing gives the interpreter the option of choosing display parameters, which can either emphasize the stratigraphic or the structural features of the record. Digital signal processing allows the precise specification of processing parameters. Data record processing was carefully controlled using selected DSP techniques including spiking de-convolution for wavelet shaping, adjusting automatic gain control (AGC) strength to preserve dynamic range and application of a digital swell filter to smooth out repetitive wave action. These techniques are much more refined than their analog equivalents. Post processing was done to enhance stratigraphic features in the record. Areas favorable for sand accumulation were identified and further examined using grab samples.

One hundred and sixty four, five - to seven - mile long east-west (dip) lines were acquired at one half to one mile intervals throughout the study area. Two north-south lines were acquired in Brevard County while a single north-south line was acquired in Federal waters off of Indian River, St. Lucie and Martin Counties. Figure 3 presents the locations of subsurface acoustic profile tracklines acquired during the project

Interpretation Criteria

Resolution of the data is sufficiently high so that small scale facies mapping may be performed. An area of stratigraphic "onlap" has been identified off the southern portion of Brevard County. Onlap sequences are often accompanied by well developed basal transgressive sands which formed as a part of the beach pushed up before a rising sea. Such sands, if their occurrence can be confirmed, may represent viable sources of material suitable for shoreline restoration. Two vibracores were collected from this stratigraphic sequence and, unfortunately, neither of them was found to contain sands of sufficient quality for beach restoration.

Structural interpretation of subsurface acoustic profile data consisted solely of mapping bathymetric highs. Mapping of individual reflection horizons was not attempted.

Acoustic Profile Results

In the study area, it was found that occurrence of restoration quality sand accumulations is closely associated with the presence of bathymetric highs on the subsurface acoustic profile data. The testing of stratigraphic features was not as successful as collecting cores from the bathymetric highs. All vibracore locations, which were chosen based on stratigraphic character, had a high mud content. During the last three years of this project, a decision was made to maximize economic return on the information obtained from vibracore data. Collection of vibracores was, therefore, limited to locations coincident with bathymetric highs.

Grab Samples

Eighty seven grab samples were collected during this study (43 from locations off of Brevard, ten from locations off of Indian River, 14 from locations off of St. Lucie and 20 from locations off of Martin Counties). Grab sample locations were chosen based on subsurface acoustic profiler character. Reflection signatures in the vicinity of bathymetric highs were examined and those locations interpreted to have the largest aerial extent of sand development were sampled.

The grab samples were collected using the FGS 24' Carolina skiff. A six-inch Eckman dredge was used for sample retrieval. At numerous sample locations, multiple attempts were necessary for the recovery of an amount of sediment sufficient for bottom characterization. During recovery at many sites in Brevard County, the jaws of the dredge were repeatedly found to be propped open by shell material. This allowed much of the sand-sized material to escape from the dredge. Repeated sampling was necessary to recover the 100-200 grams necessary for sample description and granulometric analysis of sand sized material. All material recovered during successive dredging attempts was saved. The combination of samples collected in such a fashion may lead to exaggerated reporting of the coarser grain size fraction. Proposed grab sample locations were numbered consecutively and plotted on a map. For logistical reasons, the grab samples locations were not sampled in consecutive order during the field phase of the sampling program. The original numbering system, however, was preserved. The reader, therefore, will not find consecutive numbering of grab samples on the summary map. Grab sample locations were chosen to emphasize those areas showing potential for sand accumulation based on the interpretation of subsurface acoustic profile data. Grain size distribution and percent carbonate content were determined for all grab samples. The grab sample locations containing restoration quality sand development were identified for vibracoring and further examination. Figure 5 displays the locations of all grab samples collected during this study.

Reconnaissance Vibracores

Thirty-five vibracores were collected from locations coincident with restoration quality sand development as confirmed by previous grab sample collection. Ten of these vibracores were collected off of Brevard County, eight collected off of Indian River County, four were collected off of Martin County and 13 were collected off of St. Lucie County. Refusal was met at one location in Brevard County (VB-7) and one location in St. Lucie County (VSL-9) and one location in Martin County (VM-1). At each of these coring locations, the boat was moved approximately one quarter mile from the original location and a replacement vibracore was successfully collected. The locations for these cores were chosen based on the sand quality found in grab samples, which were collected during earlier phases of this project.

All vibracores were collected using the *Atlantic Twin,* a dedicated 90-foot catamaran survey vessel operated by Alpine Ocean Seismic Survey, Inc. The reports provided by the contractor are included as Appendix 2 in this document. All vibracores were 20 feet in length.

Granulometric analysis of vibracores collected reveals that many of the cores contained sands suitable for beach restoration material as promulgated by section 5J of the Florida Administrative Code (FAC) Chapter 62B-41.0007. This rule stipulates that restoration sand "…must be similar to that already existing on site in both coloration and grain size…" and "…in general, not contain greater that 5 percent fines (passing #200 sieve) or gravel exclusive of shell material (retained by #4 sieve) and be free of coarse gravel or cobbles." Informal conversations with Florida Department of Environmental Protection's (DEP) Beaches and Coastal Systems staff reveals that, on occasion, sands with as much as 10% fine sand content may be deemed acceptable for beach restoration use. A #200 sieve opening will pass 3.75 phi grains while a #4 sieve will pass grains of –2.25 phi size.

Digital photographs were taken of all vibracores and inserted into web pages accessed from either the Web Project or the Arcview Project. These web pages are organized and accessed as follows: an index page comprising the entire project area was created and divided into ten equal areas. Each of those areas contains cores with the labels hyperlinked to web pages containing the digital photographs. Excel spreadsheets describing the grain size distributions for individual intervals within the vibracores are, in turn, linked to the web pages.

It should be emphasized that the degree of lateral extent can not be firmly assigned to any of the sands found during this reconnaissance vibracoring program. Proper evaluation of sand suitability for beach restoration requires that an additional coring program be undertaken to delineate lateral extent of the individual sand bodies. Once aerial extent is determined, the economic viability of each individual sand body can be more accurately evaluated and environmental assessments can be carried out on those accumulations showing economic promise. Locations of reconnaissance vibracores collected during this study are displayed as Figure 6.

Development Vibracores

Based on the analysis of data collected during reconnaissance vibracoring, an area of prospective sand development was located off of St. Lucie County and a program of development vibracoring was initiated. The development vibracore program was designed to determine the depth and aerial extent of restoration quality sands in an accumulation identified during the reconnaissance phase of this project. Thirteen developmental locations were chosen and 20' vibracores were acquired from each of these locations. These vibracores were described and their grain size distribution and percentage carbonate content were determined. Figure 7 shows the locations of all development vibracores.

A sand thickness isopach map was constructed and proven restoration quality sand reserves were calculated. The aerial extent and thickness of the sand source has not yet been fully evaluated and the eastern flank of the deposit has yet to be determined. All vibracores collected from the eastern flank of the deposit contained a full 20 feet of restoration quality sand. To date, approximately 23 million cubic yards (MCY) of beach quality material have been confirmed from this sand source. This figure can only increase as the eastern limit of sand development is fully delineated.

Additional Sand Sources

Table 1, "Preliminary Possible Sand Reserves off of the Central Florida East Coast" summarizes the location of additional possible sand sources in the study area. These sand sources should be considered as "possible" accumulations. The reserves are assigned based on sand developed in a single vibracore (indicated on Table). Aerial extent of these sand bodies was determined solely by subsurface acoustic profile character. Additional developmental vibracoring is necessary before the reserves assigned to these sand bodies can be moved to the "probable" or "confirmed" categories.

Table 1

Preliminary Identified Sand Reserves off of the Central Florida East Coast

County	Vibracores	Possible Reserves (mcy)
Brevard		
	VB-1	115.0
	VB-3	49.5
	VB 9,10	260.0
Indian River		
	VIR-3	100.0
	VIR-5	10.2
St. Lucie		
	VSL 4,5,6,7,8,10	247.8 (total)
	VSL 1,2	123.9
Martin		
	VM-4	82.6
	VM-1a,2	46.4

A tabulation of potential sand reserves by County follows:

Brevard County

Reconnaissance vibracoring off of Brevard County has revealed three possible sources of replenishment material (Year 3 Annual Report, Part 1, (Freedenberg et al., 1999)). These include 115 MCY of possible reserves associated with VB-1, 49.5 MCY of estimated reserves associated With VB-3 and 260 MCY of possible reserves associated with VB-9 and VB-10.

Indian River County

Reconnaissance Vibracore VIR-3 contained 17 feet of restoration quality sand. When the aerial extent of this deposit is projected on the basis of subsurface acoustic character, it is possible that as much as 100 MCY of sand may be associated with this accumulation. Additional developmental vibracoring should be performed to fully delineate the depth and lateral extent of this deposit.

Fifteen feet of restoration quality beach sand was found in vibrocore VIR-5. Based on geophysical mapping of aerial extent, it is possible that as much as 10.2 mcy of reserves may be associated with this location.

St. Lucie County

Abundant restoration quality sands have been confirmed in Federal waters off of St. Lucie County. Two areas with prominent deposits are associated with the St. Lucie Shoal complex. One of these areas was extensively sampled during a development vibracore program and found to contain approximately 23 MCY of restoration quality sand reserves. This accumulation is located off of the southern portion of St. Lucie County and is associated with the St. Lucie Shoal Complex. A sand isopach map for this deposit is included as Figure 8. It should be noted that the eastern limit of this deposit has not been delineated. The St. Lucie Shoal Complex may have as much as 247.8 MCY of recoverable reserves. An additional 123.2 MCY of sand may be associated with a deposit found in vibracores VSL-1 and VSL-2.

Martin County

The southern portion of Martin County contains a narrow shelf of insufficient width to contain significant sand deposits in Federal waters. The northern portion of the county contains a wider shelf but sands have been found to be darker in color than the sands in neighboring St. Lucie County to the north. Nevertheless, vibracores with significant sand development were collected in Martin County and 82.6 MCY of restoration quality sand may be associated with a deposit penetrated by VM-4 and 46.4 MCY may be associated with vibracores VM-1a and VM-2.

Mixed Lithology Sediments and Carbonate Content

The beaches in the study area have a mixed terrigenous-carbonate lithology. Carbonate content was determined for all samples analyzed in this study. The carbonate content in the topmost interval of the push cores and vibracores along with carbonate content of bottom grab samples was calculated and a contour map (Figure 9) was generated in order to illustrate distribution of carbonate material in the study area.

Carbonate content of the samples was found to vary from 17.22% in grab sample IR-30 to 99.5% in grab sample SL-18. The percentage of carbonate material was found to uniformly increase in an offshore direction. This was found to be the primary trend in carbonate occurrences. Also, one would expect to find an increase in carbonate content in a southerly direction along the shoreline (further from the terrigenous source, thus, greater influence exerted by biogenic shell material). This was not seen in this study. Areas of high carbonate content were interspersed with areas of more modest content. This tends to suggest that processes other than long shore transport are responsible for the percentage of carbonate material in the bottom sediment.

Conclusions

- This report documents results of a multi-year cooperative agreement with the United States Department of Interior Minerals Management Service (MMS) designed to locate sands suitable for beach restoration in Federal waters off of the central Florida east coast (southern Brevard, Indian River, St. Lucie and Martin Counties).
- Subtasks completed during this study include:
  - An annotated bibliography was developed which summarized previous work done in the study area.
  - Forty-six ten-foot long push cores were collected at arbitrary intervals along the shoreline in order to characterize native beach sediment.
  - Approximately 1200 line-miles of subsurface acoustic profile data has been collected along the length of the study area.
  - Eighty-seven grab samples were collected from locations judged favorable for sand development on the basis of subsurface acoustic profile reflection character.
  - Thirty-eight reconnaissance vibracores were collected from locations where previous grab sampling showed high quality sand development.
  - Thirteen development vibracores were collected with the goal of delineating a prospective sand area off of southern St. Lucie County. This program partially delineated the sand deposit and additional vibracoring will be needed in order to determine the full extent of the deposit.
  - Annual reports have been issued for each year of the cooperative agreement. All reports are hyperlinked to this publication. This report will serve as the final document issued under this cooperative agreement.
- More than 23 MCY of restoration quality material has been confirmed from a Federal waters accumulation off of southern St. Lucie County.
- Additional areas of potential sand accumulation have been identified. Reserves have been assigned to these areas based upon the results of a single exploratory vibracore and the reflection character of subsurface acoustic profile data passing near the site. Additional development vibracoring should be performed at these sites in order to fully define the thickness and lateral extent of each sand deposit.

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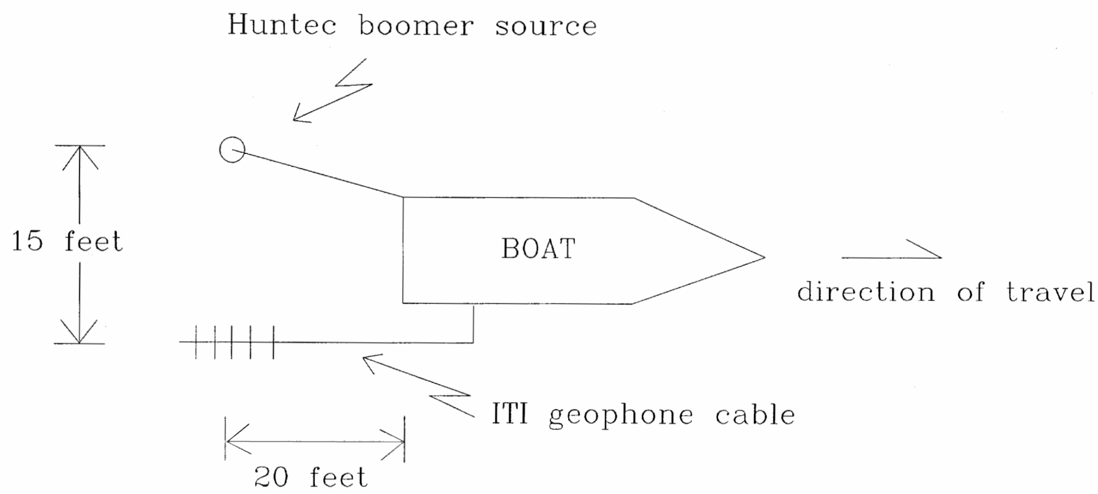

Figure 4. SHOOTING GEOMETRY