SHIP SHOAL: SAND RESOURCE SYNTHESIS REPORT

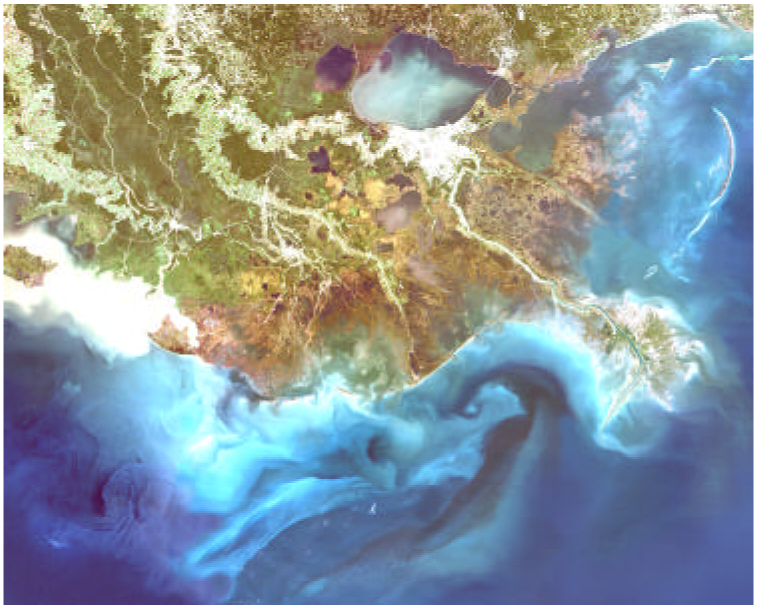

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

INTRODUCTION

A subsiding delta plain and regional absolute sea-level rise have collectively made the Mississippi River delta of southern Louisiana the site of the highest relative sea-level rise rates (RSLR) in the Gulf of Mexico basin (Penland et al., 1989). A consequence of the high RSLR rates, in conjunction with lower delta plain sediment starvation imparted by upstream damming and diversions, is an average long-term coastal erosion rate of 4.2 m yr^{-1} (Williams et al., 1991) and land loss of as much as 25 km^2 yr^{-1} (Britsch et al., 1993). Coastal deterioration of this magnitude suggests a dire future for coastal Louisiana.

Much attention is currently focused on the coastal change and habitat loss of southern Louisiana. Several state- and federally-funded programs (e.g., Coastal Wetlands Planning Protection Restoration Act (CWPPRA) and Coast 2050) are currently active and directed toward coastal ecosystem restoration in south Louisiana. Current Gulfside shoreline solutions to this problem include beach nourishment and barrier-island restoration. However, the success of these initiatives requires large volumes of texturally appropriate sediment and consequently, are feasible only if sand supply is sufficient and environmental impacts of removing this sediment minimal. A recently completed Coast 2050 project by the U.S. Geological Survey (Coastal Marine Geology Program) and University of New Orleans Coastal Research Laboratory, in conjunction with the U.S. Army Corp of Engineers, identified a relatively limited supply of high-quality sand resources on the inner-continental shelf of the Barataria Barrier Shoreline Feasibility Study (Fig 1). This survey concluded that there is not a sufficient quantity of nearshore sand resources to satisfy the needs of planned and proposed CWPPRA barrier shoreline projects and the proposed Coast 2050 Barataria Barrier Shoreline restoration project. As a consequence, large marine sand bodies such as Ship Shoal must be evaluated and integrated into the CWPPRA and Coast 2050 barrier-shoreline restoration programs. Therefore, shoreline restoration and

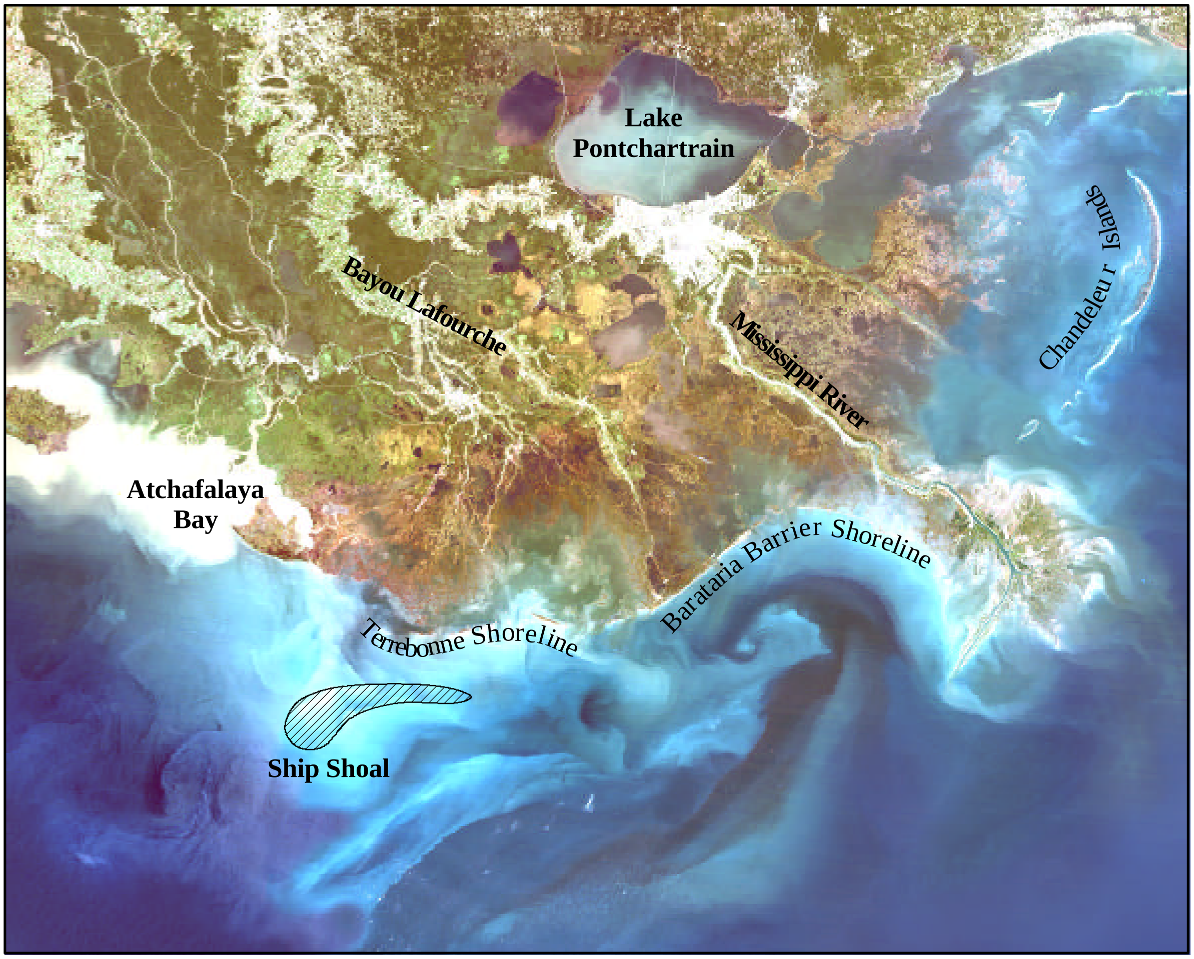


Figure 1. Satellite image showing features of south-central Louisiana that are discussed in the text.

renourishment projects within Louisiana are now confronted with finding and investigating more distally located offshore continental-shelf sand deposits. Additionally, exploitation of these potentially valuable resources will likely require the development of efficient and innovative dredging methodologies and nearshore sediment-delivery systems.

PURPOSE OF REPORT

This report focuses on the Ship Shoal area of the central Louisiana inner-continental shelf (Figs. 1 and 2). Ship Shoal has been the focus of numerous studies and previously suggested as a viable sediment source for barrier shoreline beach, dune, and back-barrier restoration projects along coastal Louisiana (e.g. Penland et al., 1989; Ramsey and Penland, 1991). The purpose of this report is to provide to a synthesis of current geologic knowledge about Ship Shoal, as well as address the suitability and feasibility of using Ship Shoal sediment for beach nourishment and restoration along Louisiana's rapidly deteriorating barrier shorelines.

REGIONAL GEOLOGIC FRAMEWORK

The geomorphologic and shallow stratigraphic framework of the Mississippi River delta plain and Louisiana inner-continental shelf is the product of fluvial and marine depositional processes that have been operative for at least the last 7,000 years (Frazier, 1967). During this time the Mississippi River and associated distributaries have been the primary conduits delivering sediments to the region. Current models describe the Holocene history (~ last 10 ky) of the Mississippi River delta as a multi-stage process reflecting the complex interplay between changing rates of sea-level rise and sediment dispersal paths (Frazier 1967; Penland and Boyd, 1985; Penland et al., 1988). Deltaic growth is an episodic process, fluctuating between periods of seaward progradation of deltaic depocenters (regressive deposition) and the landward retreat of the deltaic coastline as depocenters are abandoned, reworked, and inundated by marine waters (transgressive deposition).

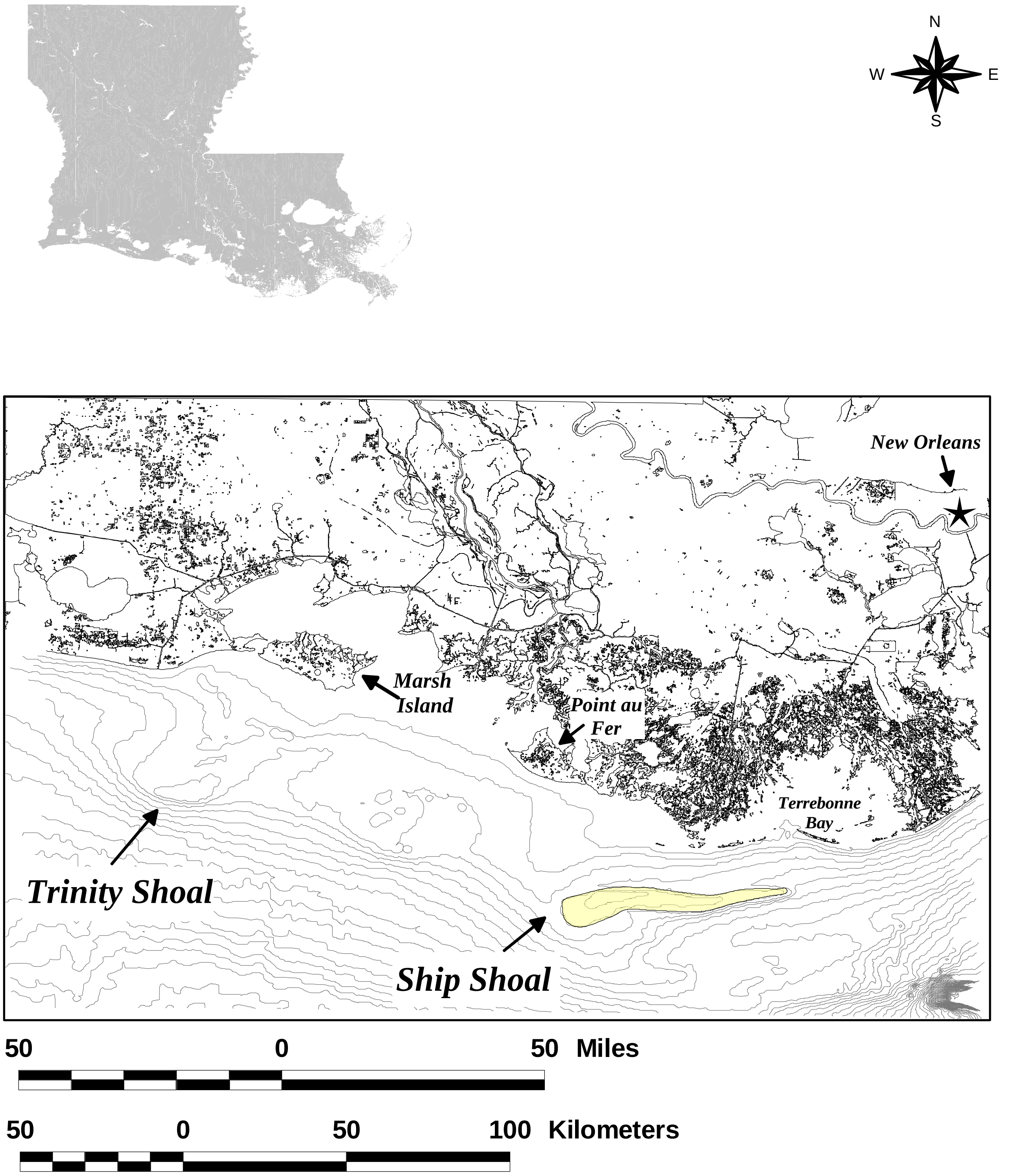


Figure 2. Regional map of south-central Louisiana coastline and inner-continental shelf. Ship Shoal is the easternmost shoal of a series of coast-parallel offshore shoals that are the transgressed remnants of earlier-formed deltaic headlands. Shoreline data from LOSCO (2000); bathymetric data from LOSCO (1999).

Regressive depositional episodes are characterized by the seaward advance of distributaries, resulting in the construction of deltaic headlands and a progressively more seaward-located coastline. Deltaic headlands are however subject to marine processes such as wave and tidal currents that disperse sediment laterally and contribute toward the construction and nourishment of flanking beaches, beach ridges, and chenier plains. In the Ship Shoal area the most recent phase of constructional deposition is primarily attributed to progradation of the Maringouin deltaic complex (Fig. 3; Frazier, 1967). Distributary pathways are, however, ephemeral; seaward progradation results in lengthened distributary networks a reduction in their gradient, and ultimately, abandonment of the active distributary networks in favor of shorter, more hydraulically efficient routes. Distributary switching is a naturally occurring event and a fundamental process that has contributed to the overall geomorphology and geographic extent of the modern Mississippi River delta plain.

Distributary abandonment, coupled with the combined effects of substrate subsidence and absolute sea-level rise (collectively called relative sea-level rise), results in erosional headland retreat and the landward migration of the shoreline as earlier deposited sediment is reworked and redistributed by marine processes. Regressive deposition is recognized as an important contributing process to the vertically stacked and laterally offset deltaic depocenters preserved within the shallow Holocene stratigraphic framework of the Mississippi River delta plain and adjacent continental shelf (e.g. Scruton, 1960; Coleman and Gagliano, 1966; Frazier, 1967). Penland et al. (1981) and Penland and Boyd (1981) emphasized however the role and significance of transgressive events in the stratigraphic architecture of the deltaic system, and presented a conceptual model that accounts for the genesis of transgressive stratigraphy. Their three-stage model depicts the evolution of an active deltaic headland to an inner-shelf shoal

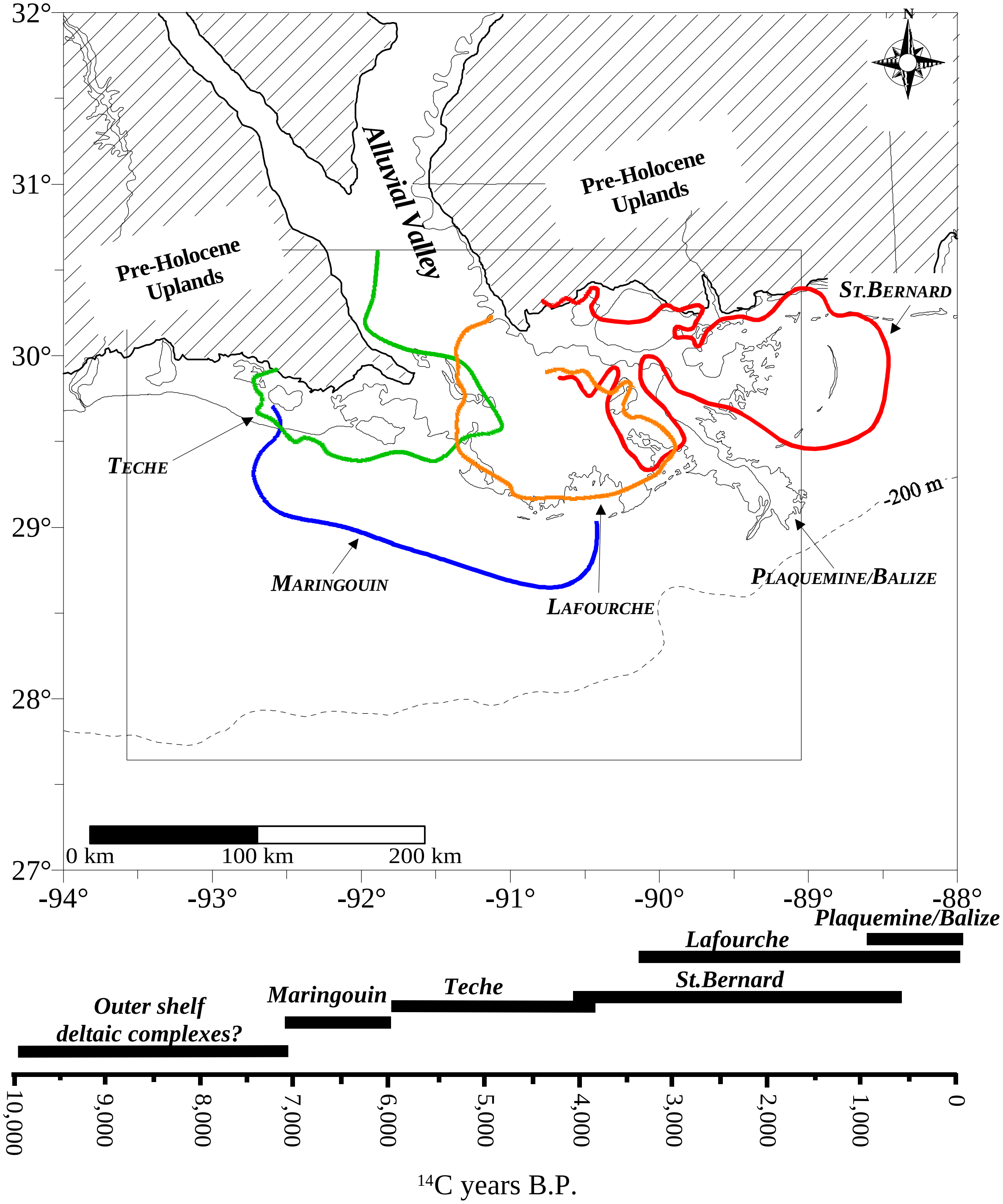


Figure 3. Geographic distribution and proposed chronology for Holocene delta complexes of the Mississippi River (modified from Frazier, 1967).

through processes of marine reworking and relative sea-level rise.

Transgressive deposition begins when marine processes transform an abandoned deltaic depocenter into a stage-1 erosional headland with flanking headland barriers and recurved spits built by longshore drift of headland sand sources (Figs. 4 and 5). A limited sediment supply from the abandoned distributaries coupled with continued relative sea-level rise and shoreface erosion eventually, leads to separation of the stage-1 barrier shoreline from the mainland and formation of a stage-2, barrier-island arc. The final stage occurs during transgressive submergence of the barrier-island arc as ongoing relative sea-level rise and storm processes prevent the barrier-island arc from maintaining subaerial integrity. Eventually, complete submergence and marine reworking generates a sand-rich marine shoal that is detached from the deltaic coastline and isolated on the inner shelf (Figs. 4 and 5).

SHIP SHOAL: LOCATION AND MORPHOLOGY

Ship Shoal is the easternmost and largest of a group of inner-shelf shoals that have developed on the Louisiana continental shelf as a result of deltaic abandonment and marine transgression (Figs. 2 and 6). The shoal is an asymmetric, landward-skewed sedimentary body approximately 50-km long, marking the minimum seaward extent of early to mid-Holocene Maringouin deltaic deposition. Widths across the central part of the shoal range between 4 and 8 km, whereas on the eastern and western ends shoal width ranges between 5 and 10 km (Fig. 6). Relative to the surrounding shelf, relief of the shoal varies from between approximately 7 m on the western end to approximately 5 m in the central and eastern portions of the shoal; water depths above the shoal range between approximately 3 m over the western end to 8 m on the eastern-edge (Figs. 6 and 7).

A 15- to 20-km wide platform lies seaward of Ship Shoal and forms the base of Ship Shoal between the 12- and 20-m isobaths (Fig. 6). Approximately 25-km seaward of Ship Shoal

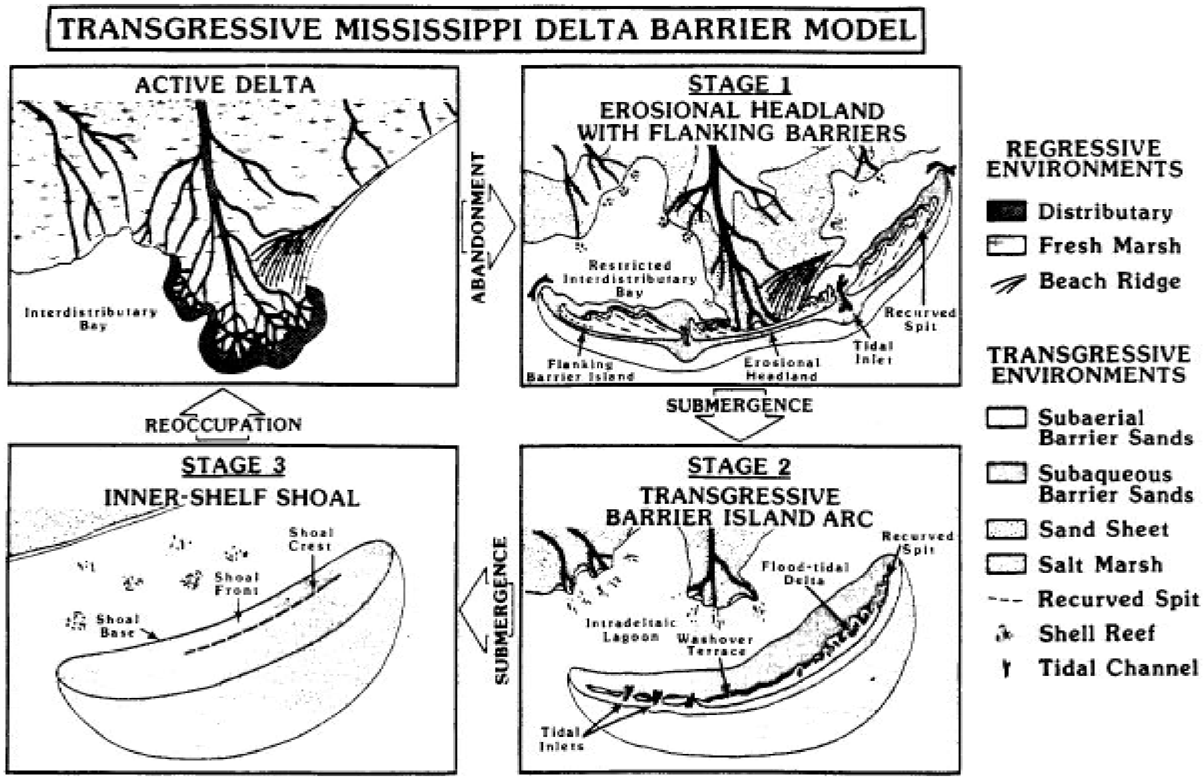


Figure 4. Plan view of a three-stage conceptual model illustrating the construction of transgressive stratigraphic intervals within the Mississippi River deltaic framework. Evolution of deltaic headlands to an inner-shelf shoal progresses from stage 1: erosional headland and flanking barriers to stage 2: transgressive barrier-island arc to stage 3: inner-shelf shoals (modified from Penland et al., 1988).

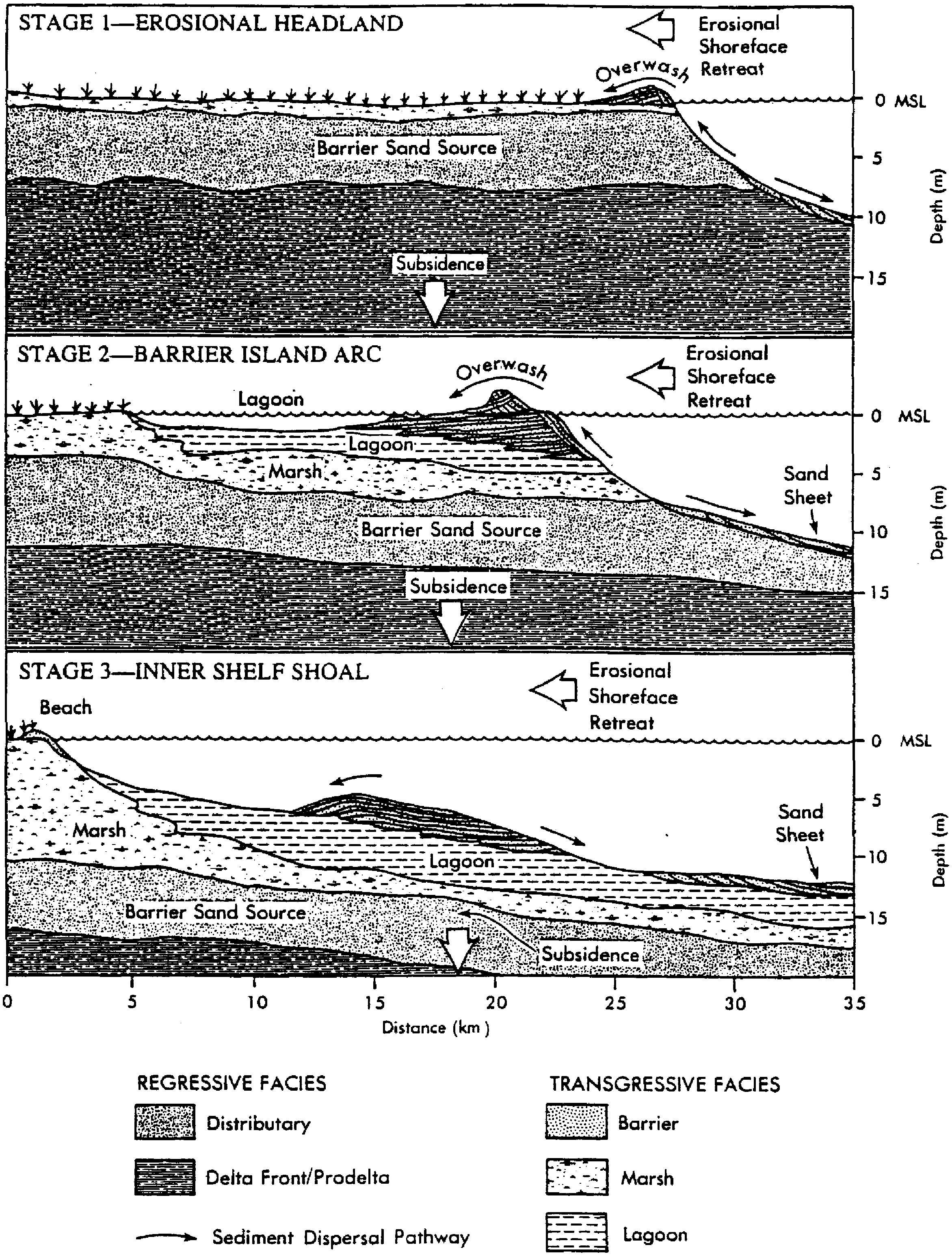


Figure 5. Cross sectional view of a stratigraphic framework illustrating the development of sand-rich shoals on the inner continental shelf from an abandoned deltaic headland (from Penland et al., 1985).

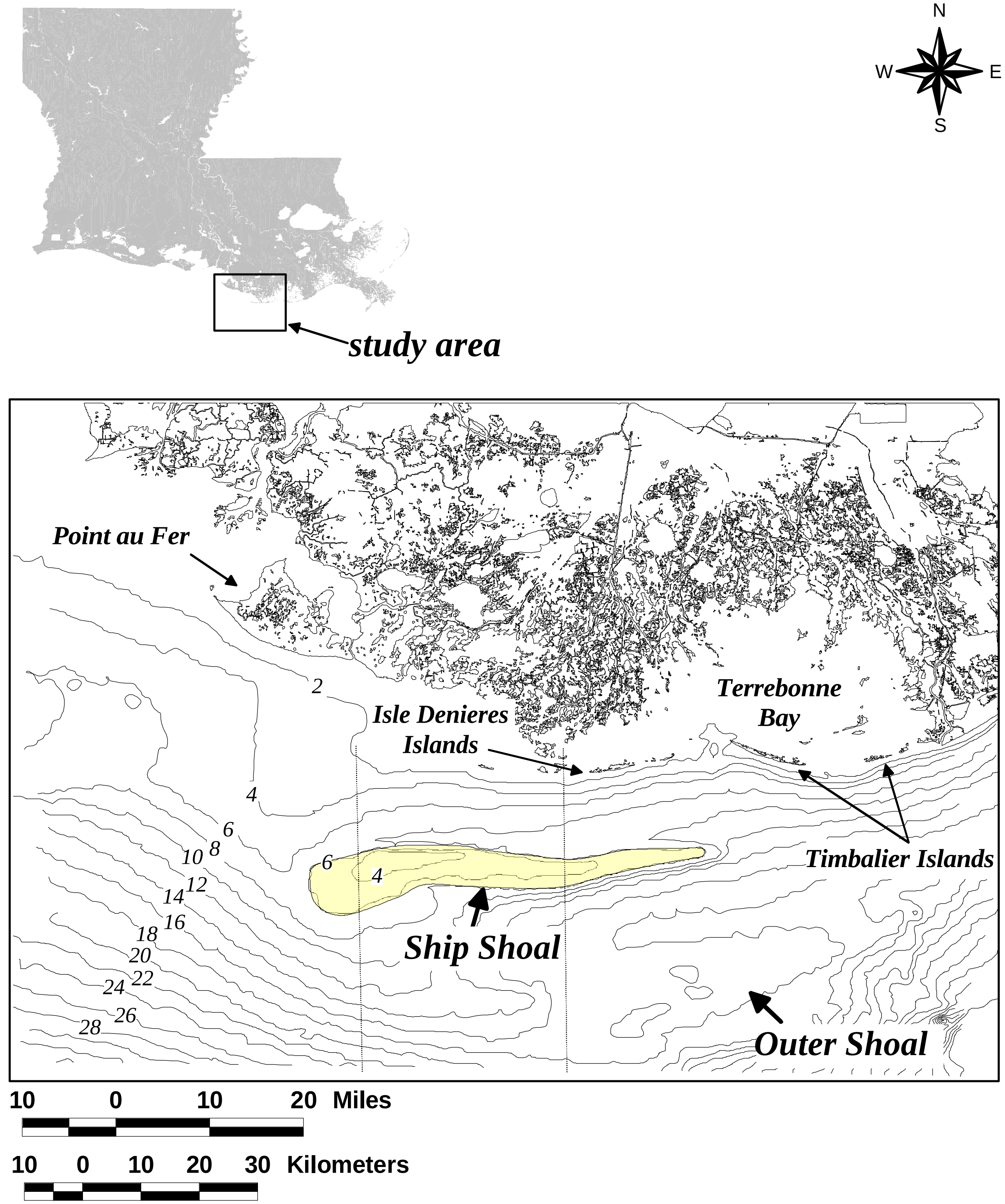


Figure 6. Detailed bathymetric map of the Ship Shoal area. Dashed lines across Ship Shoal mark location of cross sections displayed in figure 7. Contour interval every two meters. Shoreline data from LOSCO (2000). Bathymetric data from LOSCO (1999).

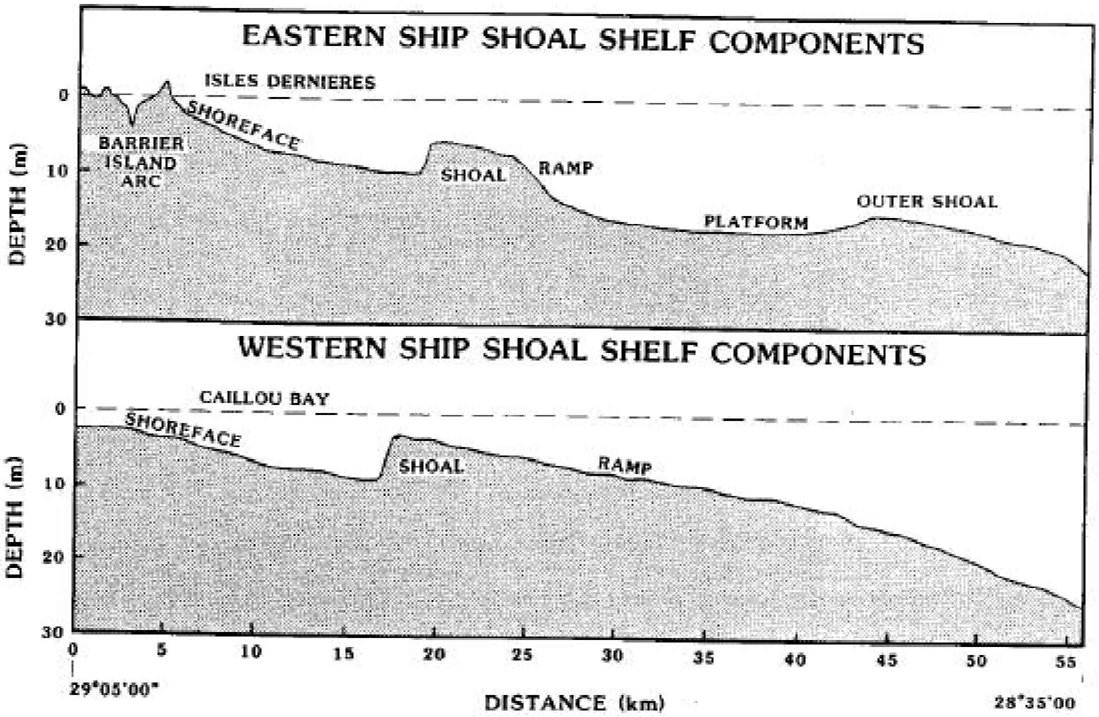


Figure 7. Bathymetric profiles illustrating the primary geomorphologic components of eastern and western Ship shoal (modified from Penland et al., 1986).

on the seaward edge of this platform is another shore-parallel shoal with an inner-shelf relief of only 1 to 2 m and water depths of approximately 12 to 15 m above its crest. This feature, termed the Outer Shoal (Penland et al., 1988) is approximately 35-km long and 5 to 10-km wide. The platform and Outer shoal are best defined on the inner shelf, offshore of the western end of Ship Shoal.

Toward the west along the crest of the shoal there is a reduction in the seaward slope of the shoal and an increase in the landward slope (Figs. 6). This variation in shoal-crest asymmetry and westward orientation occurs concurrently with a decrease in water depth over the crest and an increase in shoal relief. This westward trending increase of the landward-directed crest slopes and water depths reflects the influence of a nearshore protuberance defined by a 6-m bathymetric protuberance extending southeast out of the Calliou Bay and Point Au Fer areas (Fig. 6). The Calliou Bay protuberance, Ship Shoal, and the seaward platform constitute the shelf components of the easternmost portion of the transgressed Maringouin delta. Bathymetric profiles extending across the shoal illustrate the geomorphic components across the western and eastern components of the shoals-platforms complex (Fig. 7).

The landward asymmetry of Ship shoal as well as seafloor bathymetric change (List et al., 1994) suggest that Ship shoal is migrating north-northwest onto the Calliou Bay platform. Sea-floor change analysis conducted for the time period 1880’s to 1930’s indicates the landward edge of Ship Shoal accreted 42.5 x 10^6 m^3 of sediment. For the analysis period between 1930 and 1980 the landward edge accreted 43.3 x 10^6 m^3 and the seaward slope eroded 62.1 x 10^6 m^3. Accretion along the landward edge was most likely the result of redeposition of sediment that had been moved from the seaward face of the shoal. The deficit between eroded and accreted material is likely attributable to offshore-onshore transport and dispersal of sediment that has been reworked by storm events impacting the shelf.

SHIP SHOAL: GEOLOGIC FRAMEWORK

Available Geologic Data

Numerous researchers have previously investigated the sedimentology, stratigraphy, and morphology of Ship Shoal (e.g. Kraweic, 1960; Frazier, 1974; Penland et al., 1981; Penland and Boyd, 1981). A variety of methods, including vibracores, surface grab samples, and high-resolution seismic profiling have been utilized in these investigations. Figures 8 and 9 show the distribution of high-resolution seismic profiles and vibracores collected around Ship Shoal in the 1980's by the Louisiana Geological Survey; these datasets were used in this report to verify the conclusions of previous workers and construct new diagrams and maps displaying the stratigraphy and morphology of Ship Shoal. These vibracore and high-resolution seismic profiles are archived at the University of New Orleans Coastal Research Laboratory.

High-resolution seismic data available for the Ship Shoal area was collected with a Datasonics 3.5-khz subbottom profiler and an Ocean Research Equipment Geopulse system. The subbottom profiler is a high-frequency system that offers high resolution (~0.5 m) within shallow sediments, however penetration depth is limited to the approximately upper 15 m of stratigraphy. Alternatively, the Geopulse system has poorer resolution in the upper stratigraphy but a penetration depth generally in excess of 25 m. Typically, both of these high-resolution seismic profiles are available in the Ship Shoal area along any single seismic track line.

Vibracores used in this study were collected, through contracts with the Louisiana Geological Survey, between 1983 and 1993 by Alpine Ocean Seismic Surveys. Each vibracore was 7.5 cm in diameter and 10- to 12-m long. Along the eastern end of Ship Shoal, five 6-m long vibracores were taken in the year 2001 from the U.S. Geological Survey *R/V Gilbert*. Most of the vibracores used in this report were described in detail and analyzed for grain-size

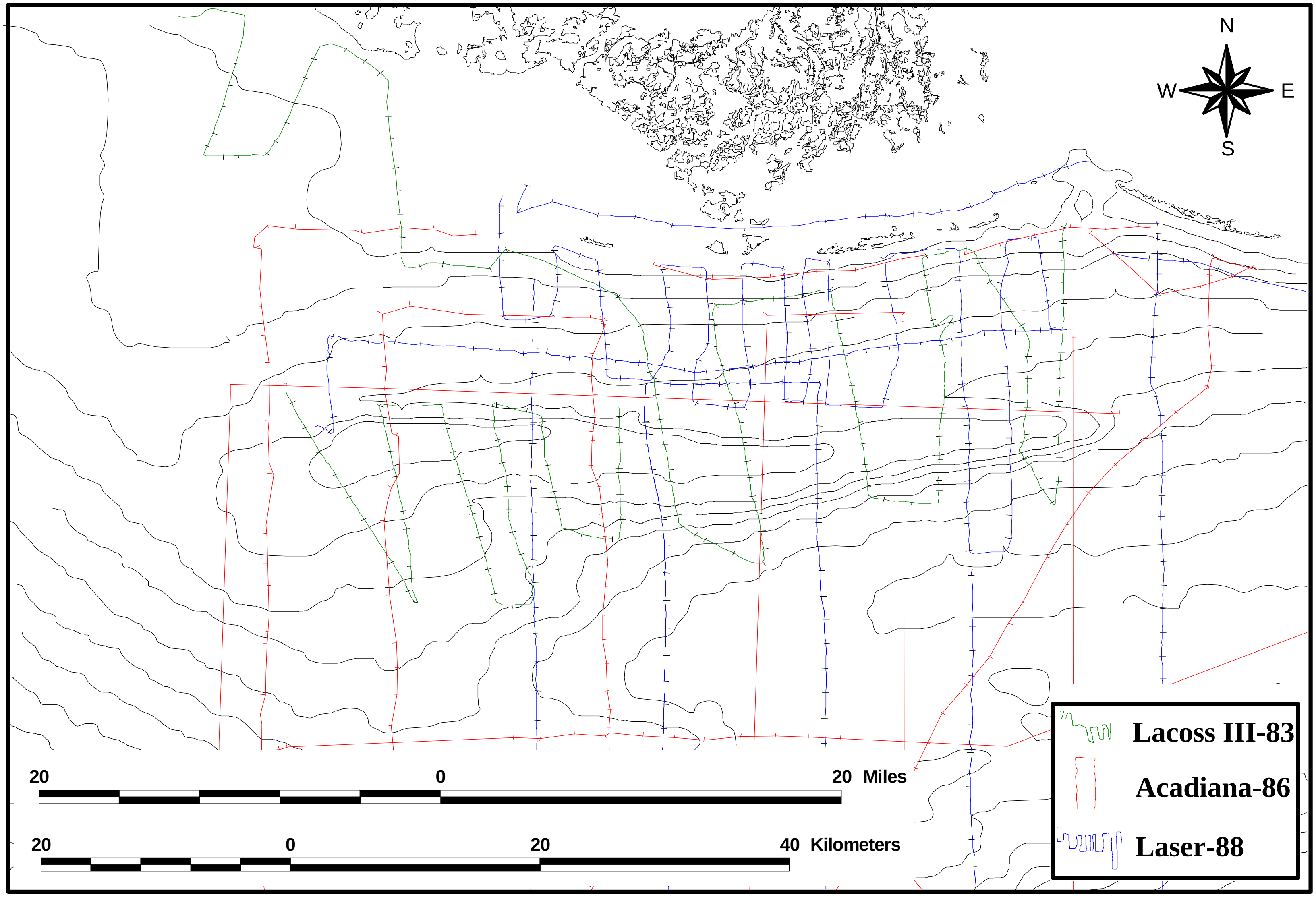


Figure 8. Distribution of high-resolution seismic coverage for the Ship Shoal area. These seismic surveys were acquired during the 1980's by the Louisiana Geological Survey and are currently archived at the University of New Orleans Coastal Research Laboratory.

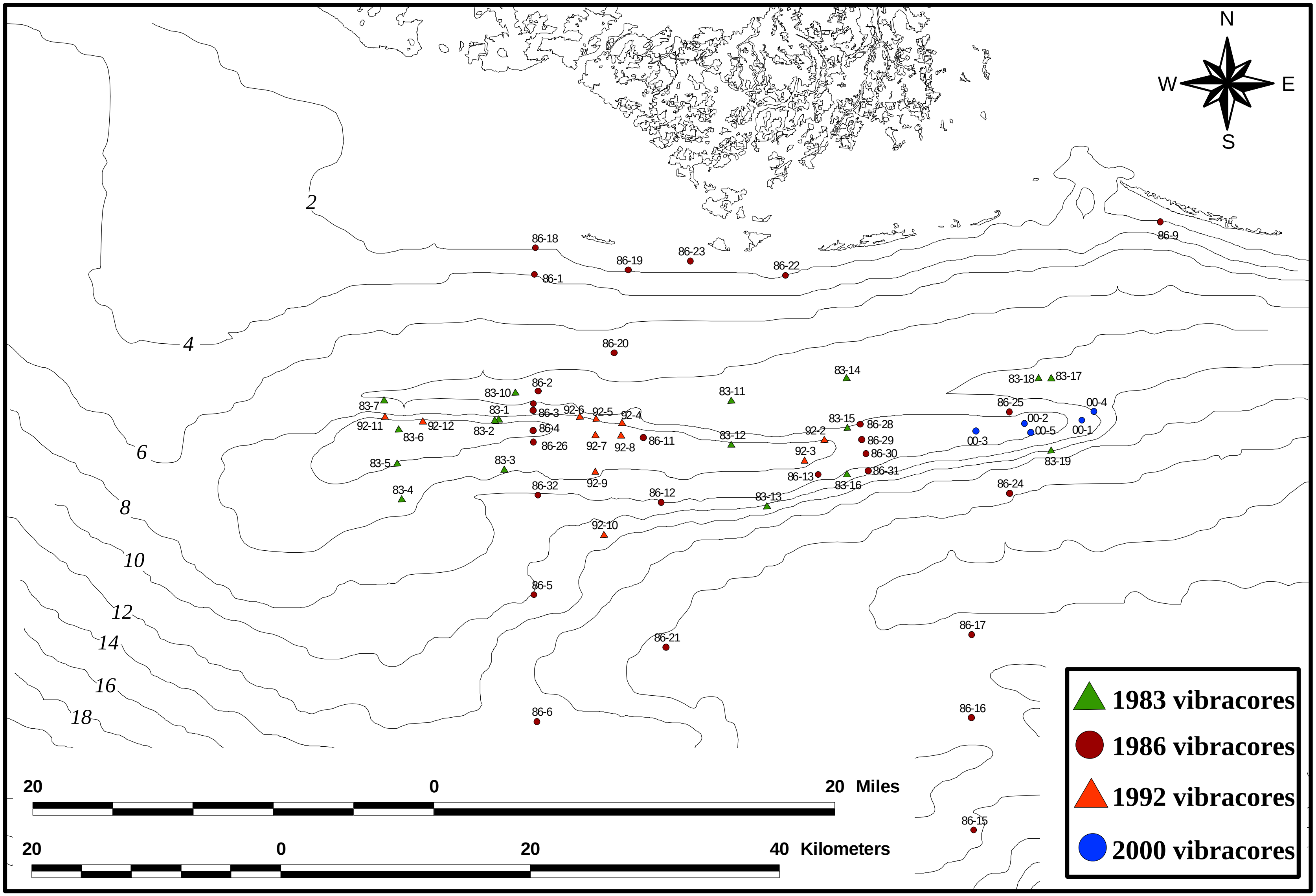


Figure 9. Distribution of vibracores for the Ship Shoal area. Vibracores were acquired during the 1980s by the Louisiana Geological Survey and currently archived at the University of New Orleans Coastal Research Laboratory.

distributions by Louisiana Geological Survey personnel now employed by UNO. Figure 10 and Table 1 display the grain-size classification scheme used throughout this text.

Surficial sedimentary character

Krawiec (1966) examined the textural character and mineralogy of Ship Shoal and the adjacent shelf with grab samples taken along south-trending transects of the western and eastern shoal (Fig 11). Compositional analysis and grain-size statistics indicated that Ship Shoal consists predominantly of fine-grained, quartz sand and is substantially more sand rich than adjacent parts of the shelf (Fig. 11). Krawiec (1966) concluded, on the basis of grain size, sorting, and bulk composition, that Ship Shoal formed from the deterioration of a barrier shoreline associated with a formerly active Mississippi River delta.

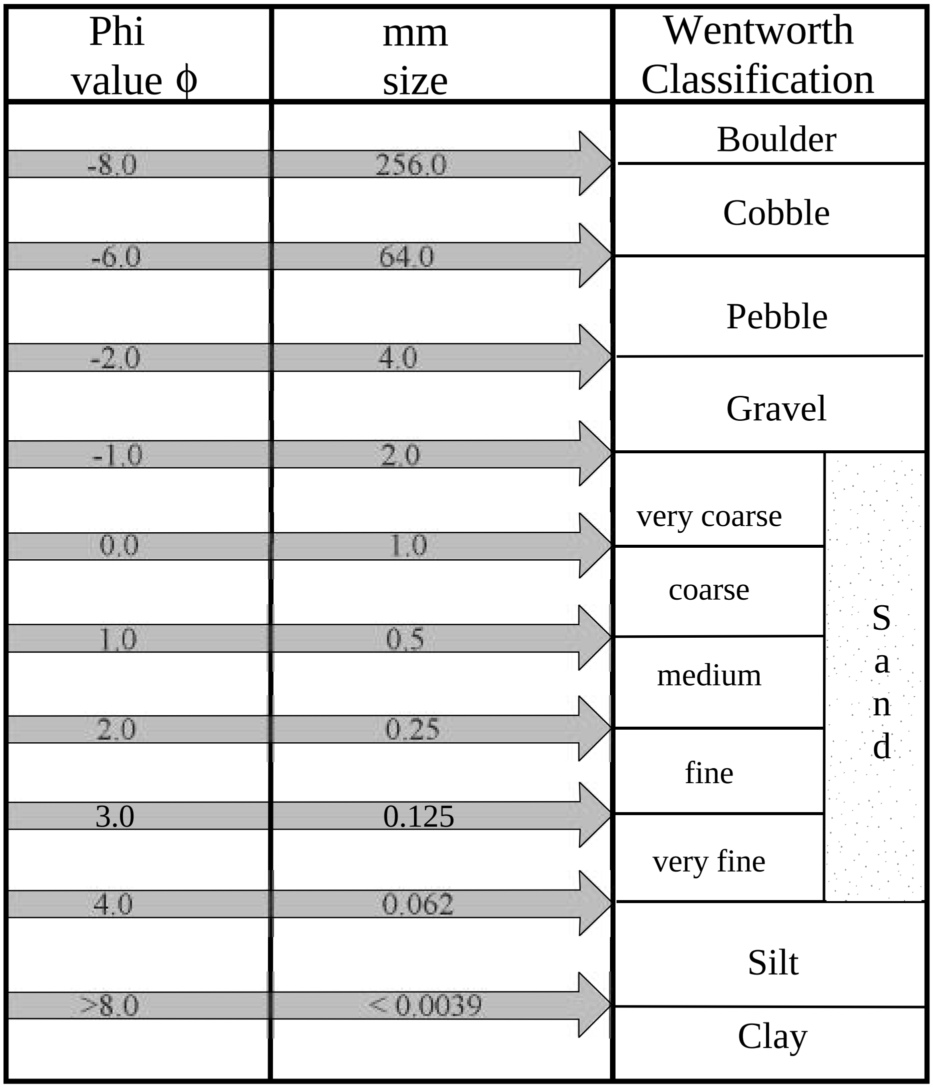
Cuomo (1984) investigated the surficial shoal sediments and concluded that grain size decreases from east to west along the shoal crest and toward the south away from the shoal crest; sorting also decreases away from the shoal crest. Cumo (1984) suggested that grain-size distributions for the shoal crest were similar to the well-sorted (0.28 - 0.44 ϕ units), fine to very-fine grained sand (2.7-3.9 ϕ) that is characteristic of beach environments.

Frazier (1974) mapped the subaqueous lithofacies in the Ship Shoal region on the basis of percent sand. Between the 7- to 8-m isobaths, Ship Shoal was indicated to contain between 75-100% sand. Locally, seaward protruding areas of the western shoal contained zones of between 75 - 100% and 50 - 75% sand. Much of the surrounding shelf was indicated to consist of silty clay.

Williams et al. (1989) combined previous datasets with their own to map seven major lithofacies in the Ship shoal area that were distinguished on the basis of sand content (Fig. 12). Quartz sand, consistent with the results of Krawiec (1966) and Mazullo (1986), was found to be

Very well sorted	< 0.35
Well sorted	0.35 – 0.50
Moderately well sorted	0.50 – 0.70
Moderately sorted	0.70 – 1.00
Poorly sorted	1.00 – 2.00
Very poorly sorted	2.00– 4.00
Extremely poorly sorted	> 4.00

Table 1. Measures of sorting used in grain-size analysis. Phi units represent a non-dimensional description of the measure of dispersion about the mean grain size; low values are representative of well-sorted sediments (modified from McManus, 1988).



Phi value ϕ	mm size	Wentworth Classification	
		Boulder	
-8.0	256.0		
		Cobble	
-6.0	64.0		
		Pebble	
-2.0	4.0		
		Gravel	
-1.0	2.0		
		very coarse	Sand
0.0	1.0		
		coarse	
1.0	0.5		
		medium	
2.0	0.25		
		fine	
3.0	0.125		
		very fine	
4.0	0.062		
		Silt	
>8.0	< 0.0039		
		Clay	

Figure 10. Diagram displaying the equivalence of the dimensionless phi grain-size scale, metric measurements, and the Wentworth grain-size classifications (modified from Hobson, 1979).

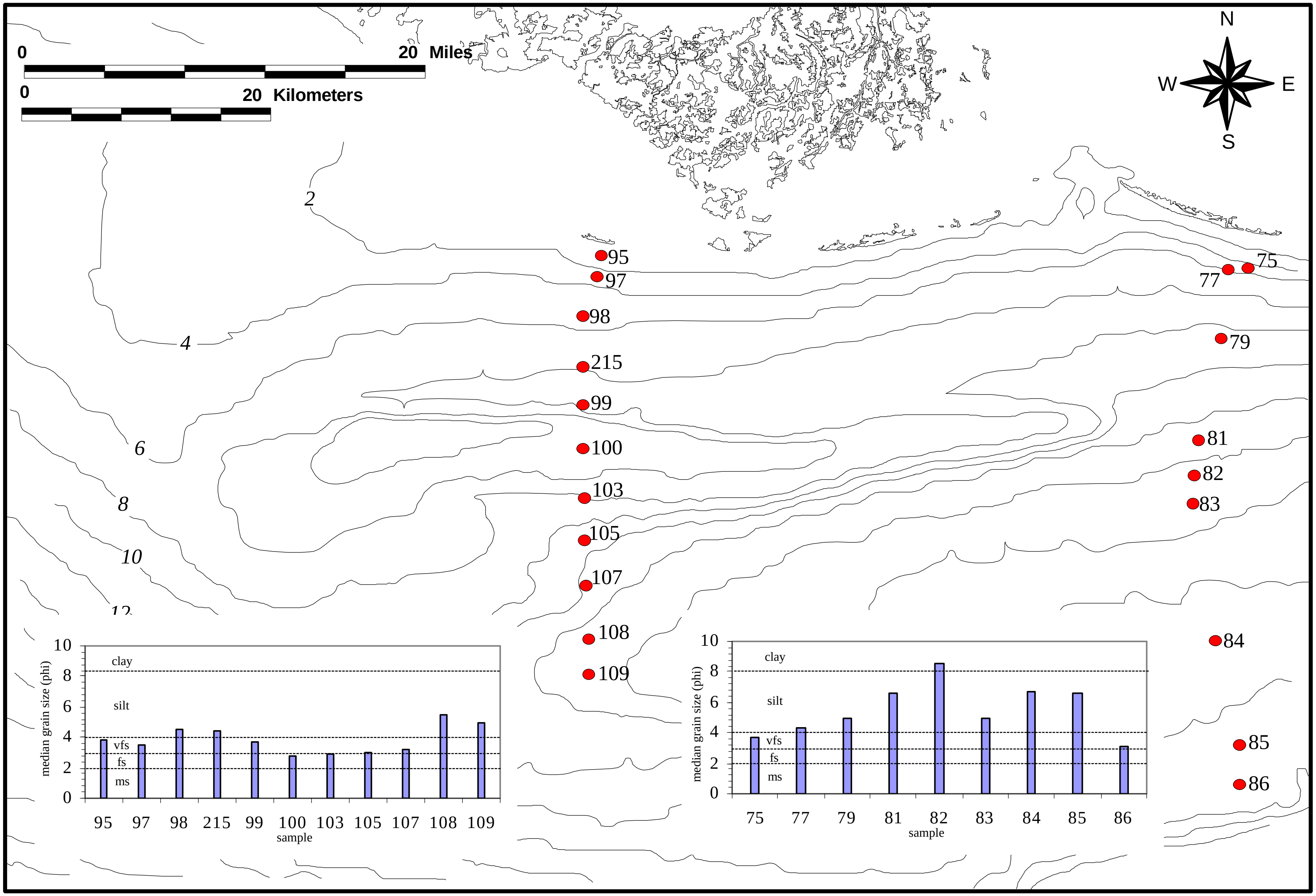


Figure 11. Map of surficial textural data collected by Krawiec (1966); vfs = very fine sand, fs = fine sand, ms = medium sand.

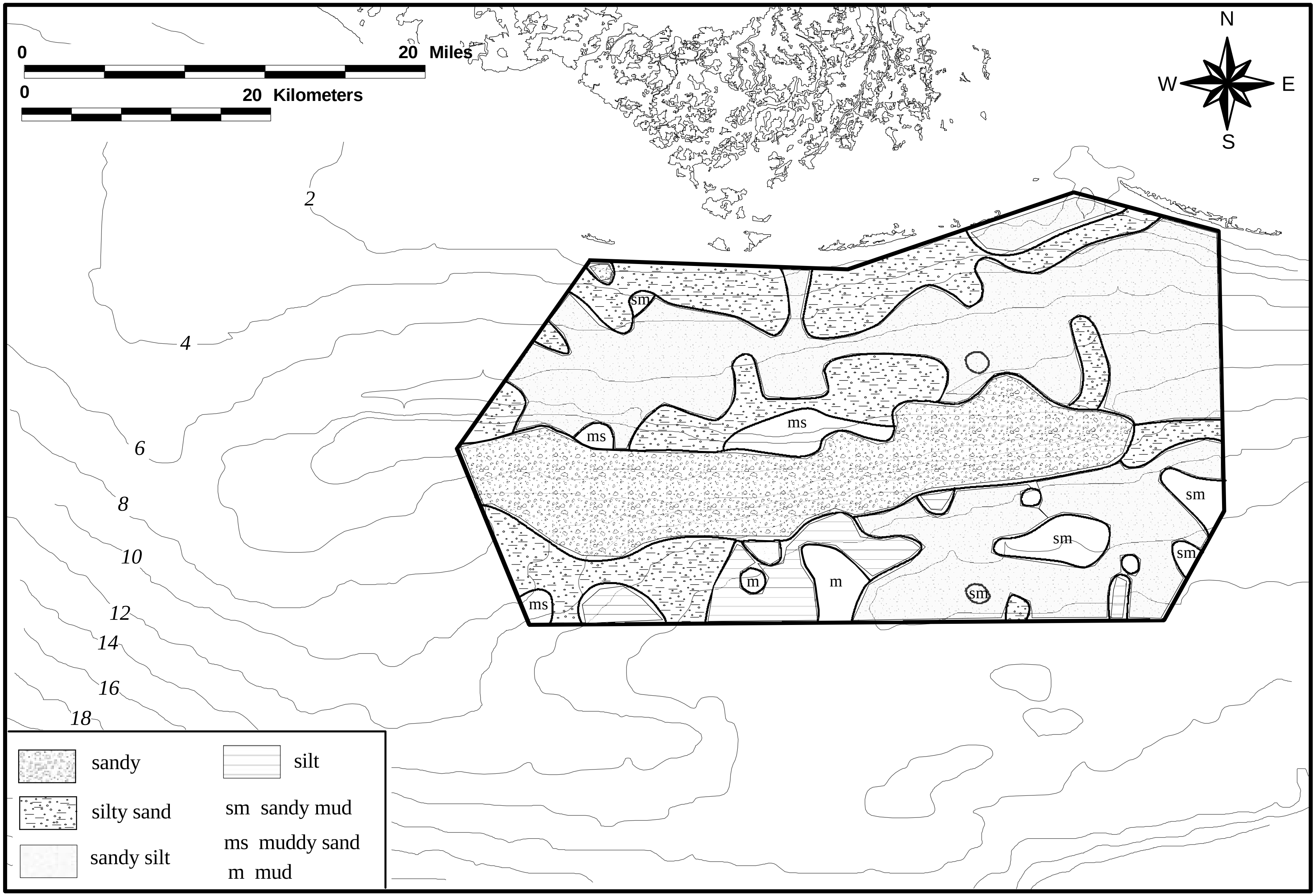


Figure 12. Map of major sedimentary facies in the Ship Shoal area (modified from Williams et al., 1989).

a primary constituent of the surficial sediment with an average, but highly variable, sand content of 54%; however much of Ship Shoal contained 90 to 99% sand.

Stratigraphy and Depositional Environments

The stratigraphy of the Ship Shoal area has been extensively studied. Previous workers divided the stratigraphy of the area into two primary suites of genetically related depositional units: a transgressive suite and regressive suite (Penland et al., 1991). Figure 13 is a stratigraphic log displaying the generalized transgressive-regressive stratigraphy of Ship Shoal. Of primary interest for sand resources is the transgressive component of the Ship Shoal stratigraphy, consisting of a shoal crest, shoal front, and shoal base. A generalized stratigraphic cross section illustrates the facies relationships between the overlying transgressive deposits and the underlying regressive deposits (Fig. 14). The shoal crest, shoal front, shoal base, sand-sheet, and lagoonal stratigraphy are deposited above the regressive units as Ship Shoal migrates landward. The subjacent deltaic interval, consisting of distributary, delta front, and prodelta sediments, represents regressive deposition associated with the earlier progradational phase of Magingouin deposition. Because sand-rich deposits suitable for restoration efforts are primarily located within the transgressive suite of deposits this report focuses on a description of the sedimentary character of the shoal crest, shoal front, and shoal base. Much of the following discussions about the transgressive, sand-rich facies of Ship Shoal are extracted from Penland et al. (1986). Readers are referred to Penland et al. (1986) and Ramsey and Penland (1991) for a thorough discussion on the character and distribution of the regressive stratigraphy of the Ship Shoal area.

Shoal Crest

The shoal crest environment is a shore-parallel accumulation of sand and shell that has been deposited in response to reworking by wave and tidal currents crossing the shoal ramp and adjacent continental shelf. This segment of the shoal is the highest energy environment where

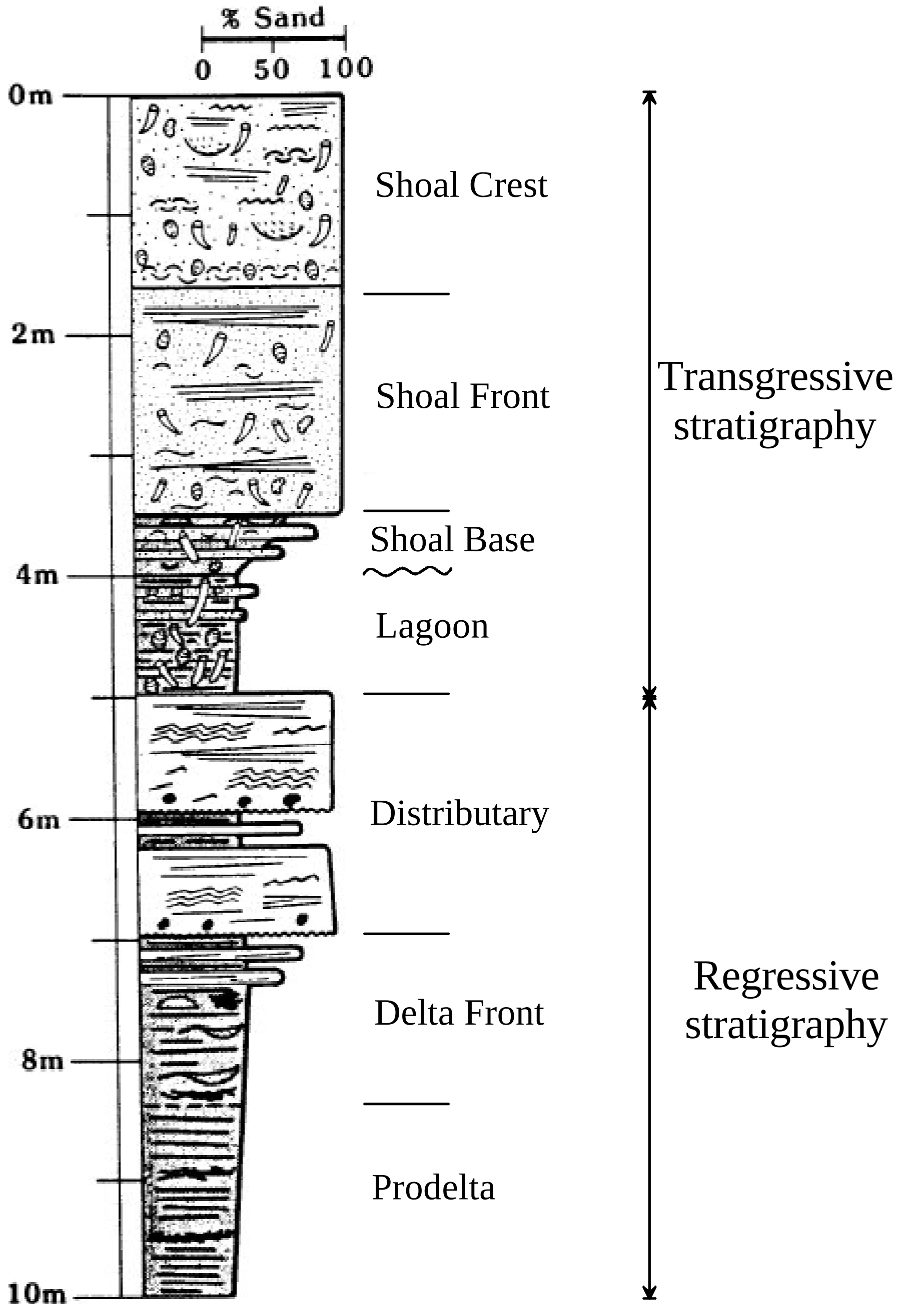


Figure 13. Representative stratigraphic log for the Ship Shoal area. Regressive stratigraphic intervals represent deposition during the progradation of deltaic headlands, whereas transgressive stratigraphic intervals reflect reworking and inundation of abandoned headlands (Penland et al., 1986).

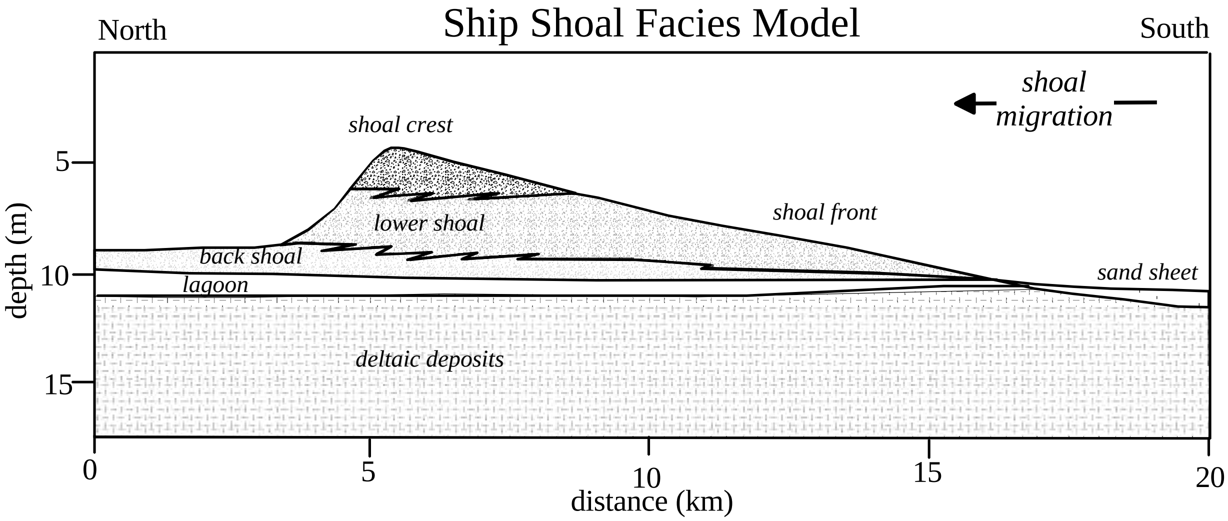


Figure 14. Generalized stratigraphic cross section of Ship Shoal showing the relationships between the sedimentary facies of Ship Shoal (Penland et al., 1986).

currents and waves winnow, sort, and abrade the available sediment into a uniform grain size. The shoal crest is typically within the upper 4 meters of stratigraphic section. Sediment consists of very well-sorted, well-rounded, quartz sand with parallel, horizontal to subhorizontal laminations. Whole and reworked shells (*Mulinia, Olivella, Rangia, Crassostrea*) are heavily concentrated within this interval, which generally displays a coarsening upward grain size. This section of the shoal locally consists of as much as 99% sand. Mean grain size in this sedimentary facies ranges between 1.5 and 2.7ϕ, with a sorting value of 0.5 to 1.6ϕ units.

Shoal front

The shoal-front facies borders the shoal crest facies along the seaward edge, consisting of moderately sorted, fine- to very fine-grained sand. Mean grain size in this facies ranges between 2.7 and 3.1ϕ, with a sorting value of 0.5 to 0.9ϕ. The shoal front through most of the area has been suggested to be approximately 75 to 95% sand. Sedimentation along the shoal front is primarily the result of storm events that pass over the shoal crest and transport sediment into deeper, off-shoal waters.

Shoal base

Sediments of the shoal base typically consist of interbedded silty clay and lenticular-to-wavy bedded, poorly sorted, very fine-grained sands. Mean grain size of these sediments ranges between 3.1 and 3.6ϕ with a sorting value of 1.2 to 1.5 ϕ units. The shoal base contains 50 to 75% sand. The low-energy, shoal-base environment marks the advancing edge of the landward migrating Ship Shoal depositional surface. The shoal base lies between the 8- to 9-m isobath in the west and the 11- to 12-m isobath in the east. Because of greater water depths in the shoal base area than in the shoal-front and shoal-crest environments, sedimentation is even more episodic and primarily the product of storm events.

Sand Sheet

A discontinuous sand sheet covers much of the seaward slope of Ship Shoal marking the path of the shoal’s landward migration. Grain size of the sediment within the sand sheet ranges between 2.7 and 3.2ϕ with sorting values of 1.7 to 2.3ϕ units. Thickness of the sand sheet is variable but may be as much as one meter. The sand sheet likely represents the amalgamated deposits of storm events that have mobilized sediment and transported them seaward from more landward located locations.

Stratigraphic Cross Sections

Three stratigraphic cross sections illustrate the strike- and dip-parallel architecture of Ship Shoal (Fig. 15). South-trending cross-sections A-A’ and B-B’ provide an excellent overview of the overall facies relationships and geometry of the shoal (Figs. 16 and 17). On both cross sections the Ship Shoal sand body consists of shoal crest, shoal front, and shoal base deposits sitting unconformably upon a regressive deltaic sedimentary package. Cross-section A-A’ indicates a thickness of sand-rich shoal sediment in excess of 4 meters locally, whereas cross-section B-B’ indicates a thickness of approximately 3 meters. The subjacent regressive sequence is approximately 8- to 12-m thick and consists primarily of fine-grained lagoonal and delta-front deposits. Lagoonal muds directly below the transgressive shoal deposits are persistent throughout the Ship Shoal area but are not synchronous with the overlying transgressive deposits. Lagoonal deposits on the landward side of the shoal are however, temporally equivalent to parts of the shoal body and reflect low-energy deposition taking in the back shoal area.

Cross section C-C’ trends parallel along the shoal axis and similarly reveals the relationship of the transgressive shoal deposits to underlying regressive deltaic deposits (Fig. 18). Basal shoal sands sit disconformably atop the underlying lagoonal deposits. A large distributary

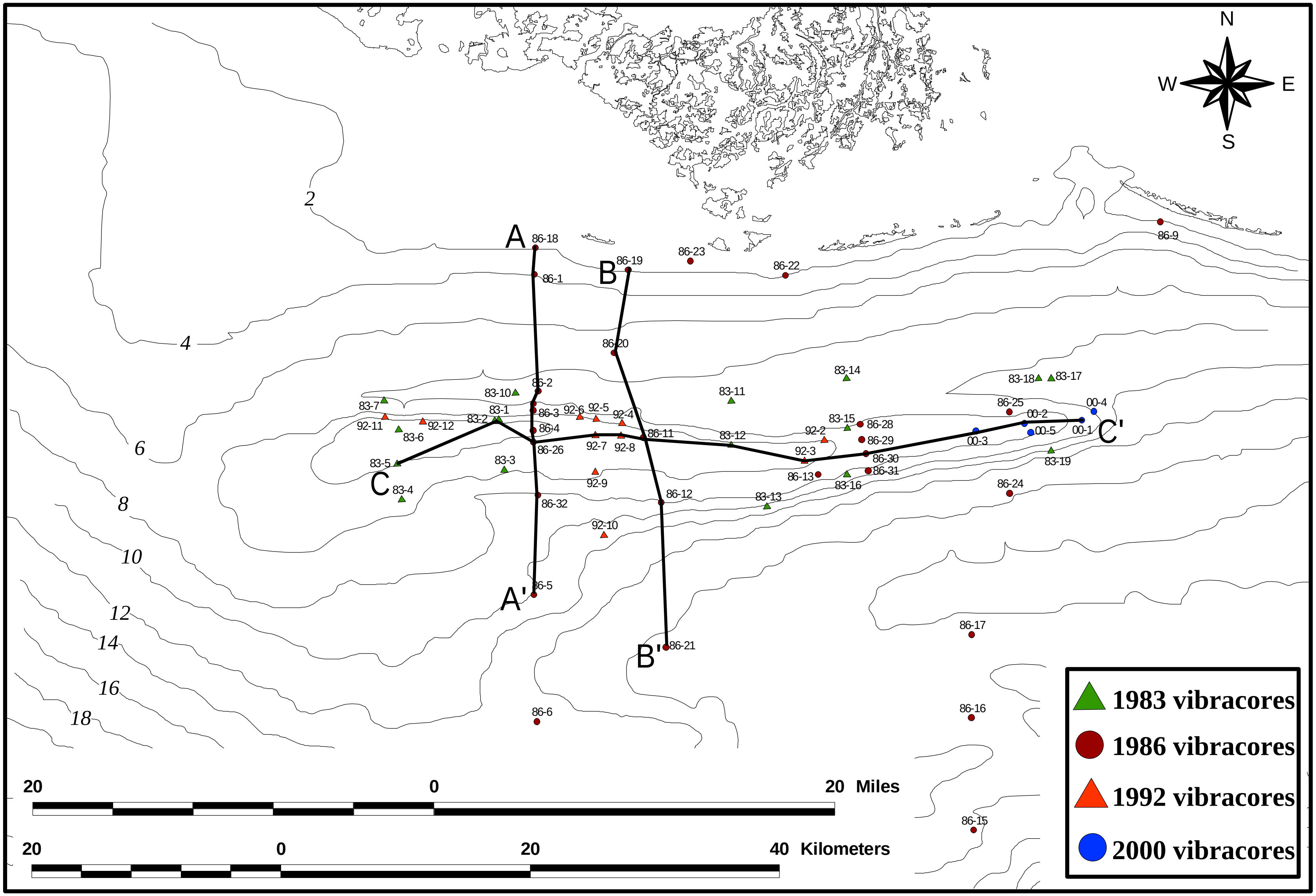


Figure 15. Location of cross sections discussed in the text.

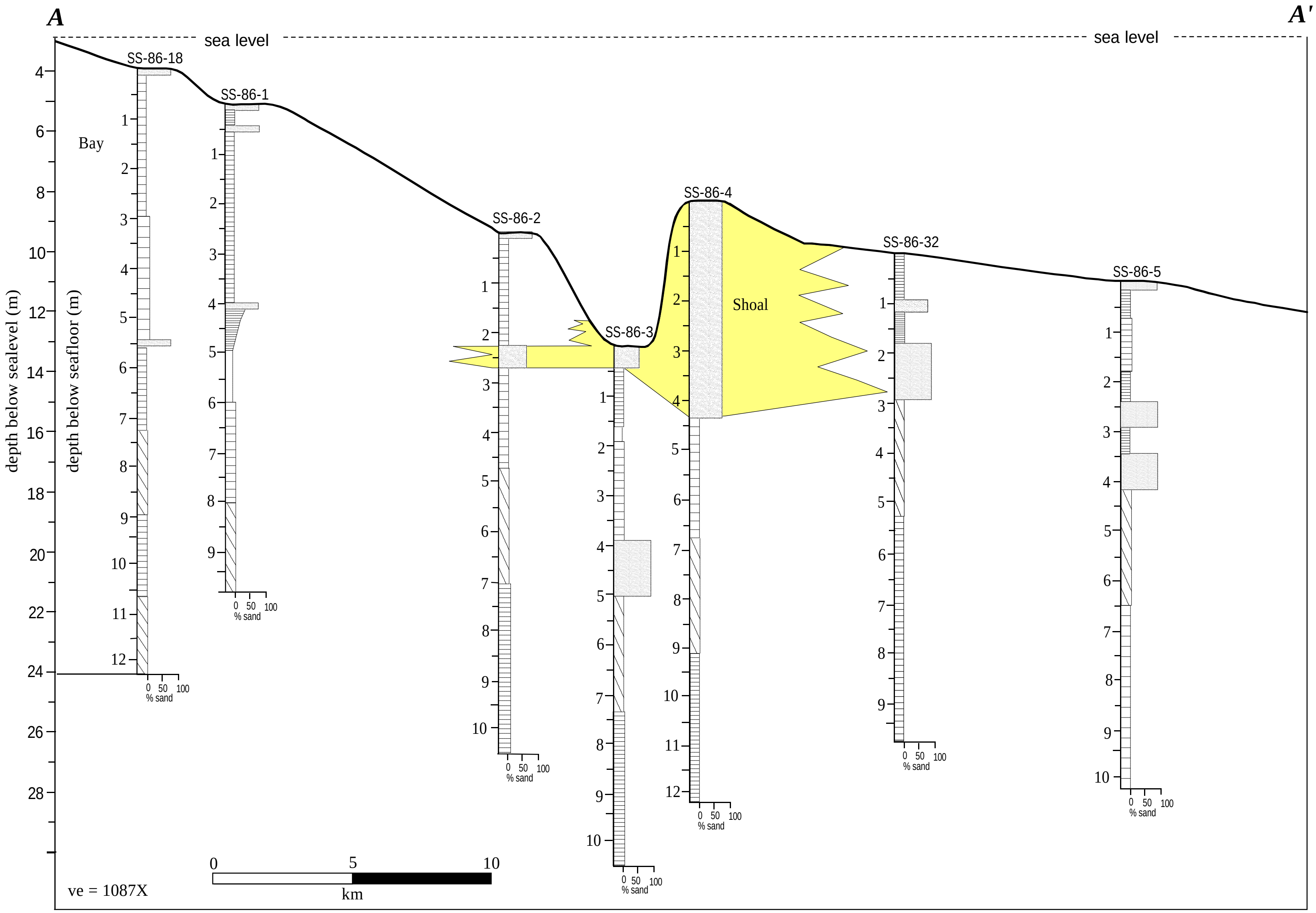


Figure 16. Cross section A-A'.

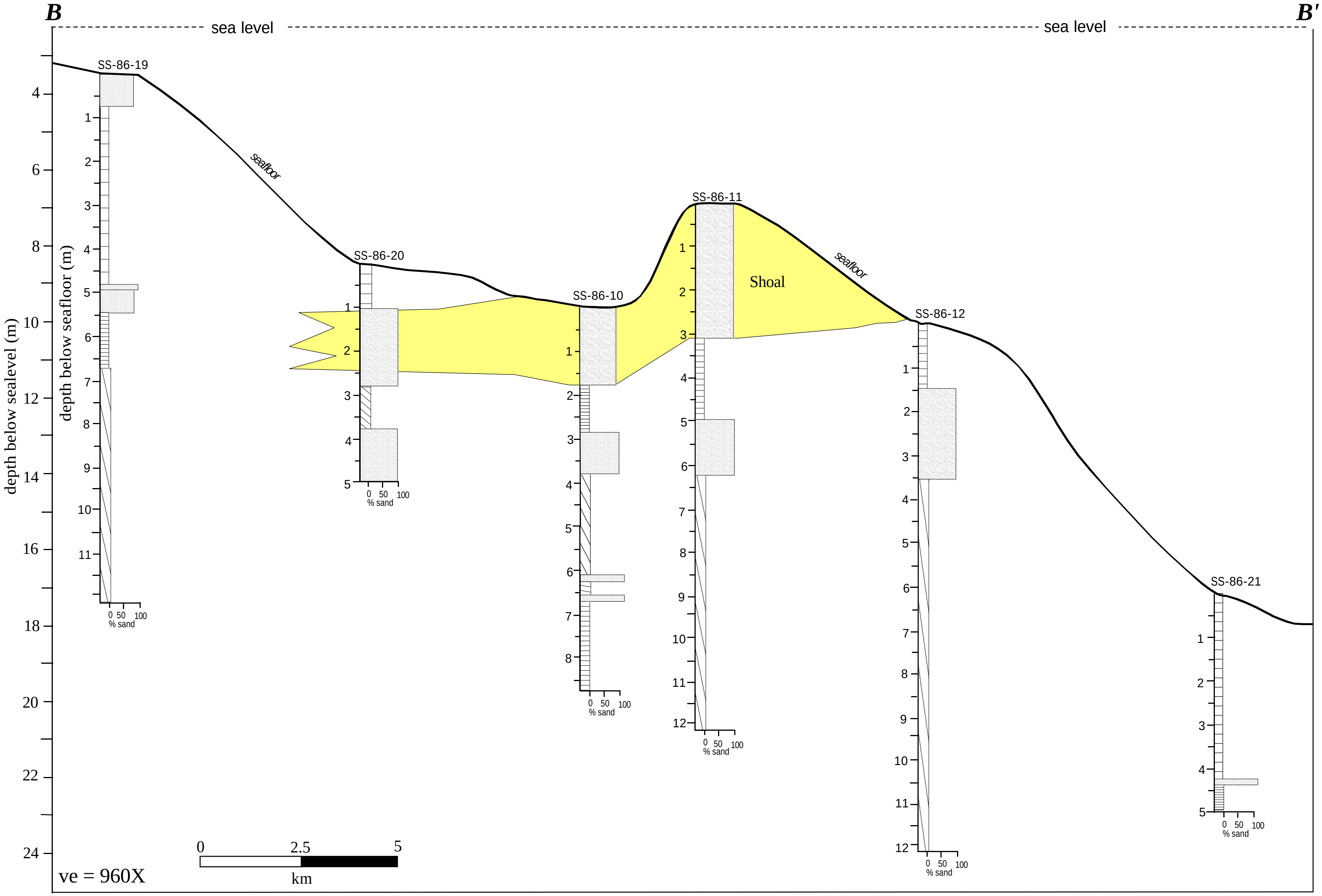


Figure 17. Cross section B-B'.

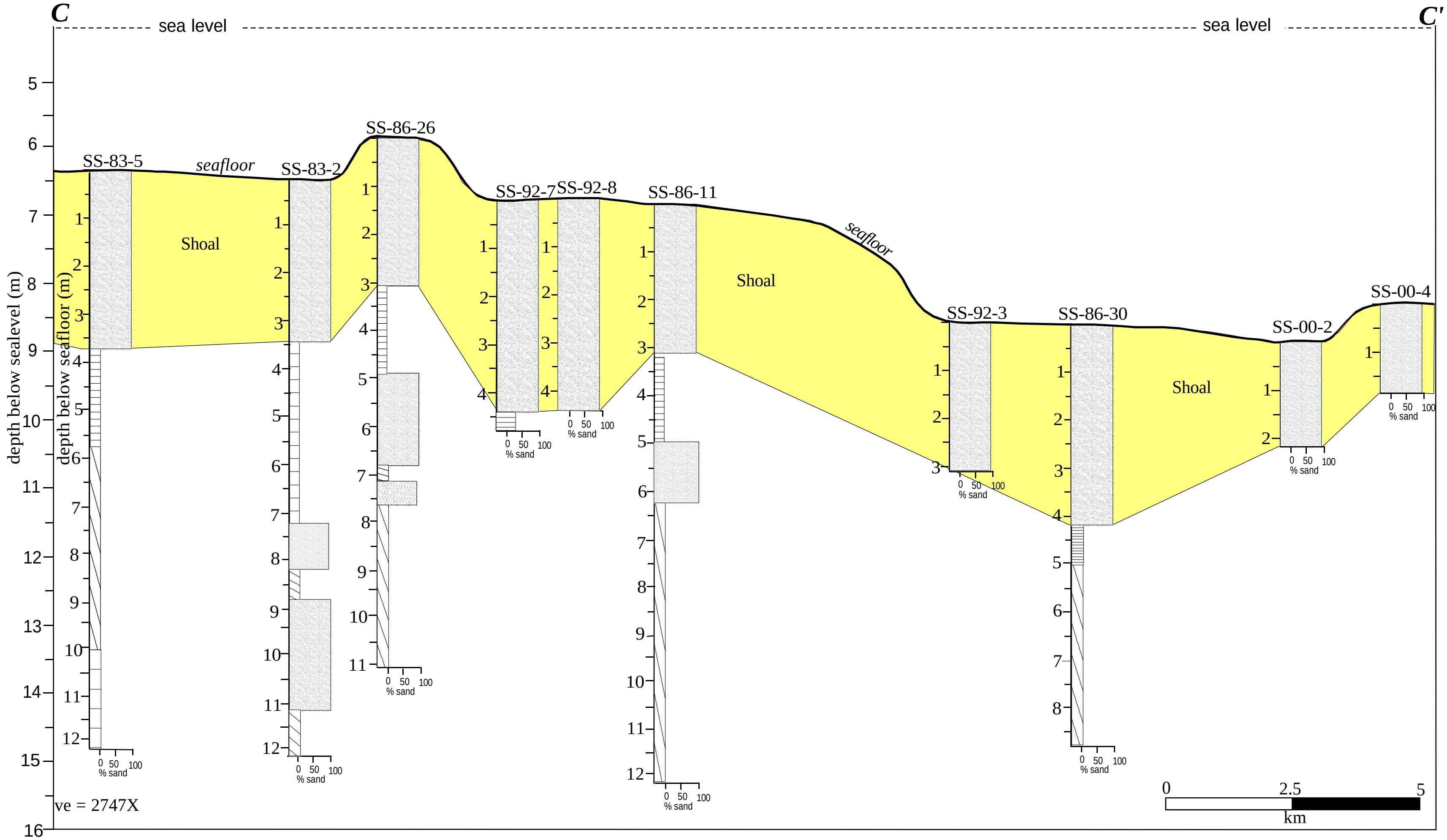


Figure 18. Cross section C-C'.

body is suggested to be present along much of the cross section, extending from vibracore 86-26 to 86-11, to the east this sedimentary body appears to pinch out into the overlying lagoonal and underlying delta-front deposits. Although typically separated from the overlying shoal sediments by clay-rich lagoonal sediments, distributary sediments as much as 2-m thick are present below portions of the western shoal. These distributary networks potentially hold a considerable quantity of sand-rich sediment but further study is required to isolate their distribution and thickness. Penland et al (1991) suggested that the volumetric measure of Ship Shoal sand contained within shoal front, shoal base, and shoal crest facies is approximately 1.2 billion m^3.

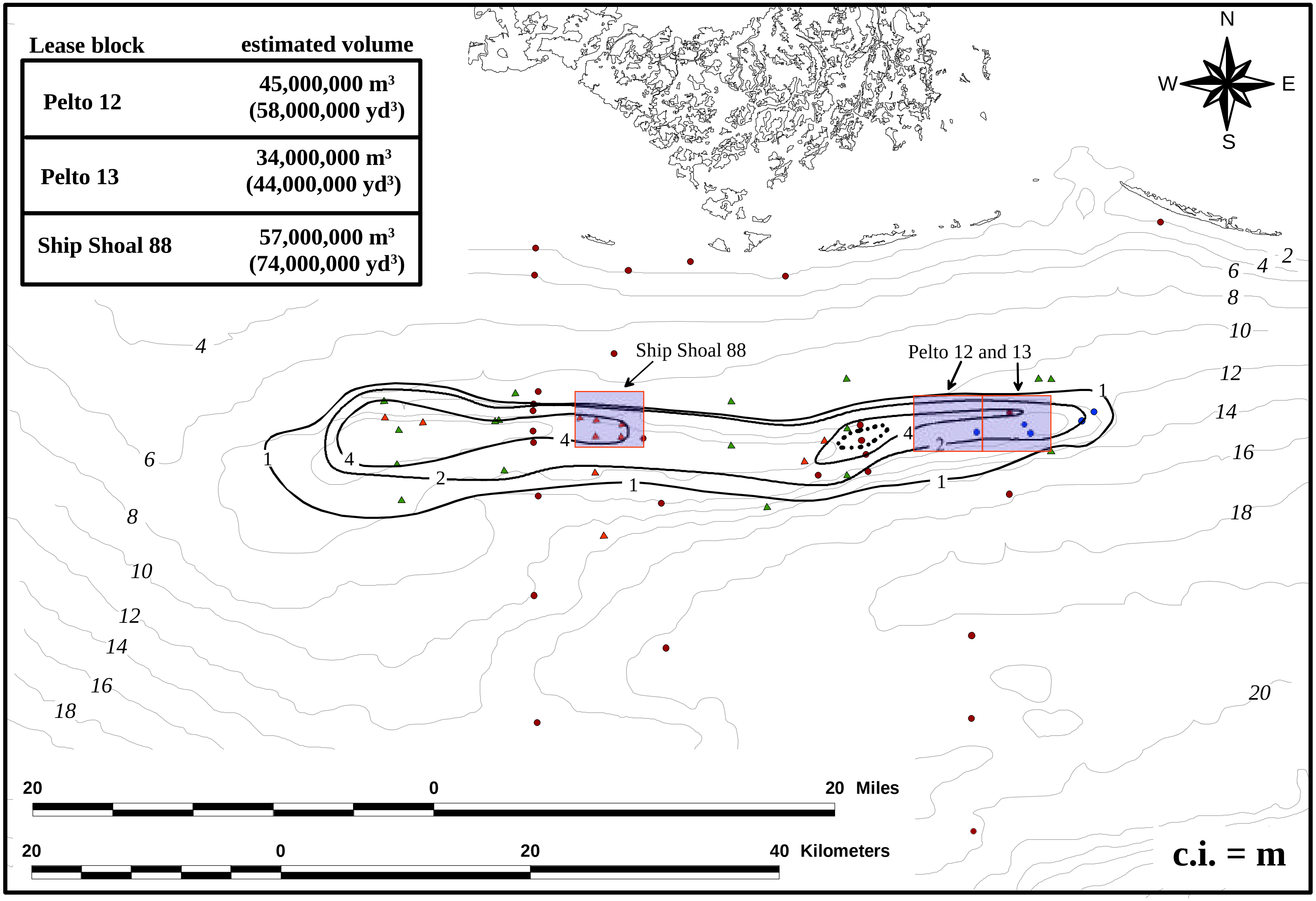
Isopachous Map of Ship Shoal

Figure 19 is an isopachous map of the Ship Shoal area, constructed from the available vibracore data and high-resolution seismic profiles. Maximum thickness of the shoal, including the shoal crest, shoal front, and shoal base is on the western and eastern ends along the shoal axis, locally the thickness exceeds 4 meters. Figure 19 also identifies the U.S. Minerals Management Service (MMS) lease blocks, Ship Shoal 88 (SS 88), Pelto 12 (PL 12), and Pelto 13 (PL 13), that are being considered as areas from where sediment can be dredged and used as borrow material. Estimated borrow quantities for these lease blocks, also shown on figure 19, range between 34,000,000 m^3 (PL 12) and 57,000,000 m^3 (SS 88). Grain-size statistics indicate that the upper 4 meters of sediment within these lease blocks consists of predominantly well-sorted, fine-grained sand (Figs. 20 and 21).

RISKS AND FACTORS TO CONSIDER

Overfill Calculations

The textural character of stable shorelines is a reflection of the hydrodynamic conditions along the shoreline. Ideally, borrow material used for a beach/shoreline restoration and re-nourishment project is texturally equivalent to the native shoreline sediment it is replacing.



Lease block	estimated volume
Pelto 12	45,000,000 m^3 (58,000,000 yd^3)
Pelto 13	34,000,000 m^3 (44,000,000 yd^3)
Ship Shoal 88	57,000,000 m^3 (74,000,000 yd^3)

Figure 19. Isopachous map of the Ship Shoal sand body. Proposed areas of sediment removal lease blocks Ship Shoal 88, Pelto 12, and Pelto 13 -- are indicated. Volumetric measures of available sediment within the proposed areas are estimated using the currently available stratigraphic data and rounded down to the nearest millionth.

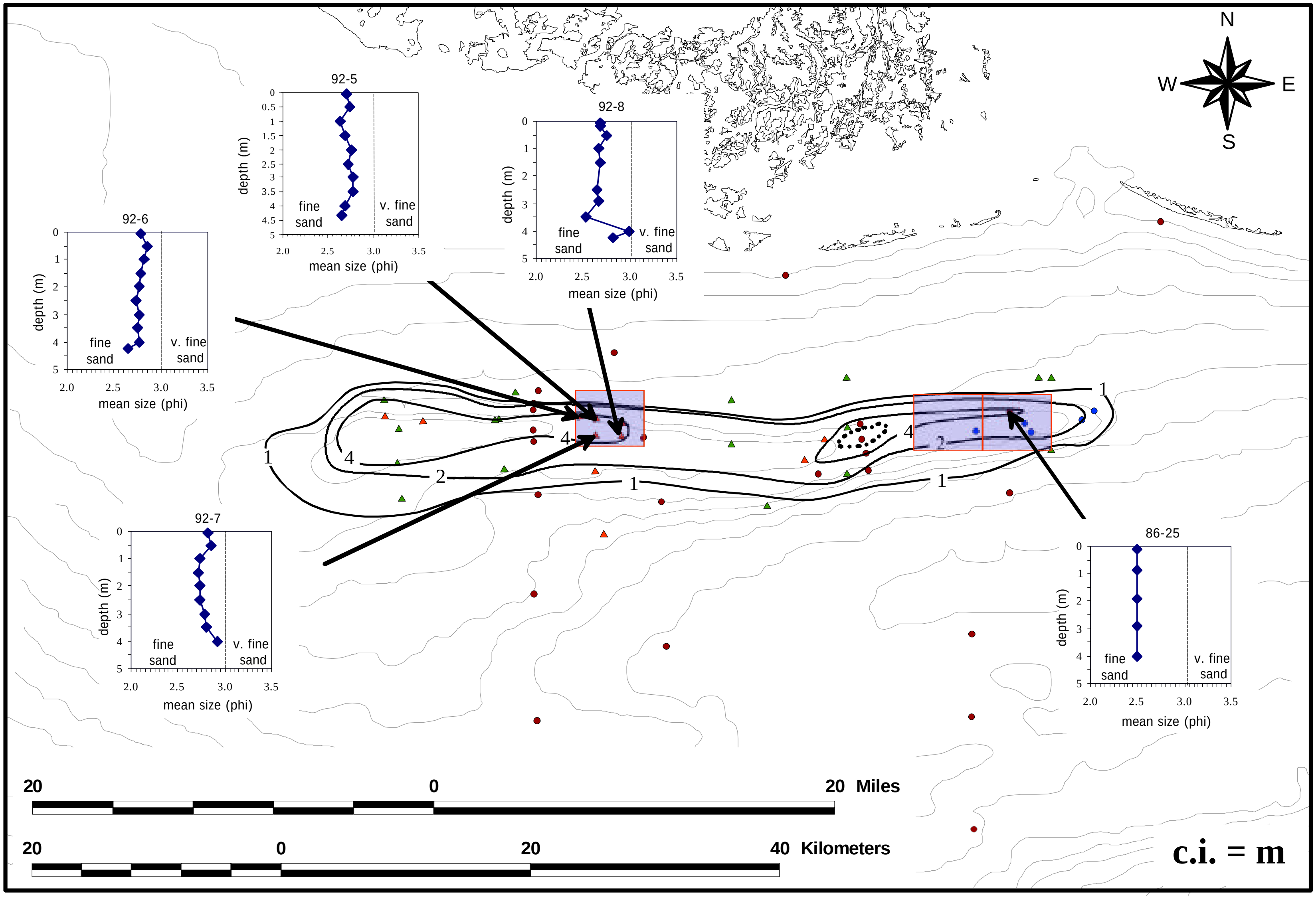


Figure 20. Map showing mean grain size versus depth charts for cores within the proposed areas of sediment removal; Ship Shoal 88, Pelto 12, and Pelto 13. Data suggests that sediments of the upper approximately four meters within the targeted areas consist predominantly of fine sand.

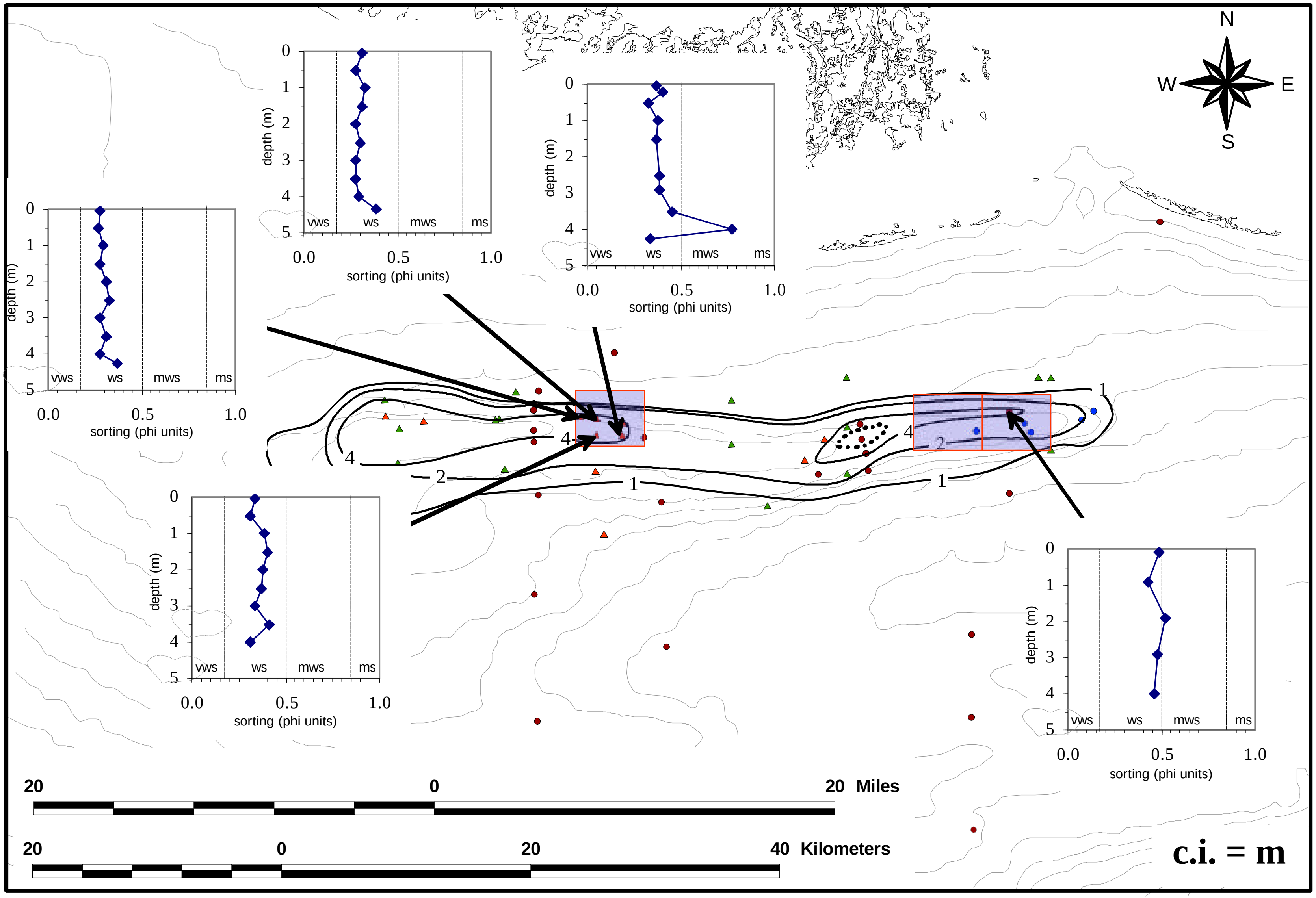


Figure 21. Map showing sorting verses depth charts for cores within the proposed areas of sediment removal; Ship Shoal 88, Pelto 12, and Pelto 13. Vws = very well sorted, ws = well sorted, mws = moderately well sorted, ms = moderately sorted. Sand resources of the upper approximately four meters within the targeted areas are primarily well sorted.

Otherwise, fine-grained borrow material added to a relatively coarser-grained deposit will tend to be winnowed from the shoreline by marine processes; and volumes of sediment fill added to a shoreline will eventually be reduced if the fill material does not closely match the native beach sediment. Overfill factors provide an estimate of the cubic meters of borrow material required to produce one cubic meter of sediment with the specific native grain-size characteristics, assuming that the comparatively fine-grained component of the fill will be lost. James (1975) demonstrated a methodology for calculating overfill ratios using mean grain size and sorting values of proposed borrow material in comparison to the same grain-size statistics for the native material it is replacing.

Grain-size samples from the Isle Dernieres barrier islands indicate that the sediment along this section of the Louisiana coastline consists of 99%, moderately to very well-sorted, fine-grained, quartzose sand with an average grain size of 2.7ϕ and sorting value of 0.49ϕ units (Fig. 22). Overfill values were calculated for the Isle Dernieres assuming borrow material would be taken from the previously mentioned MMS lease blocks. A mean grain size of 2.5 and sorting value of 0.47 for PL 13 and a mean grain size of 2.7 and a sorting value of 0.34 for SS 88 were used in the methodology presented by James (1975). These preliminary calculations indicate an overfill ratio of 2.0 for the upper 4 m of sediment in SS 88 and that sediment from PL 13 would be stable along the Isle Dernieres, approximating an overfill value of 1.0 (Fig. 23).

Infrastructure of Proposed Dredge Areas

Dredging in the shallow Gulf waters of coastal Louisiana presents a unique challenge because of the preponderance of offshore hydrocarbon infrastructure. The presence of offshore platforms and pipelines could inhibit the ability to efficiently dredge potentially favorable sections of Ship Shoal. Figure 24 shows the known hydrocarbon infrastructure of lease blocks PL 12 and PL 13. Large sections of these lease blocks are relatively free of hydrocarbon with

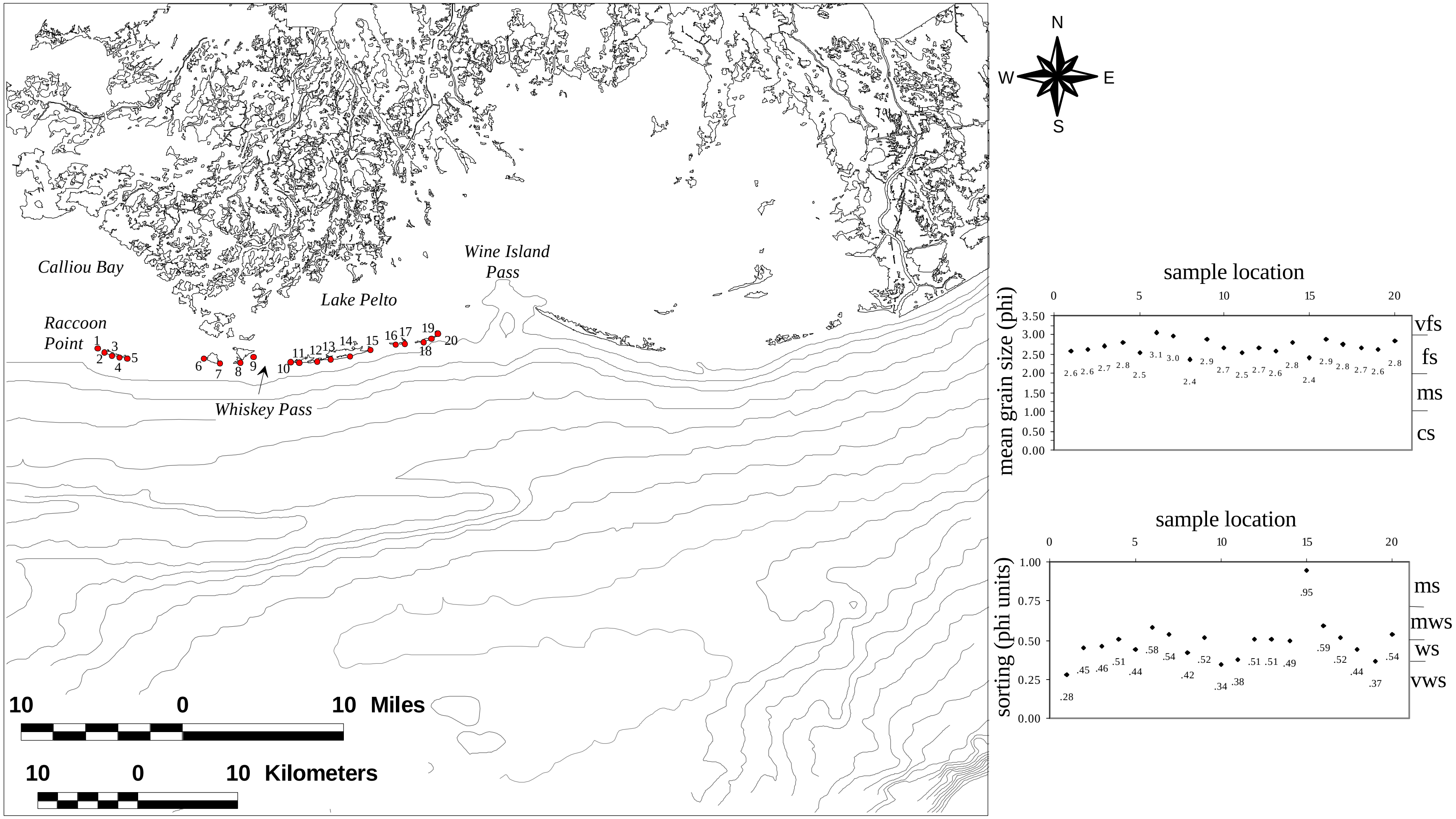


Figure 22. Grain-size data for beach samples from the Isles Dernieres barrier islands. From Williams et al. (1989).

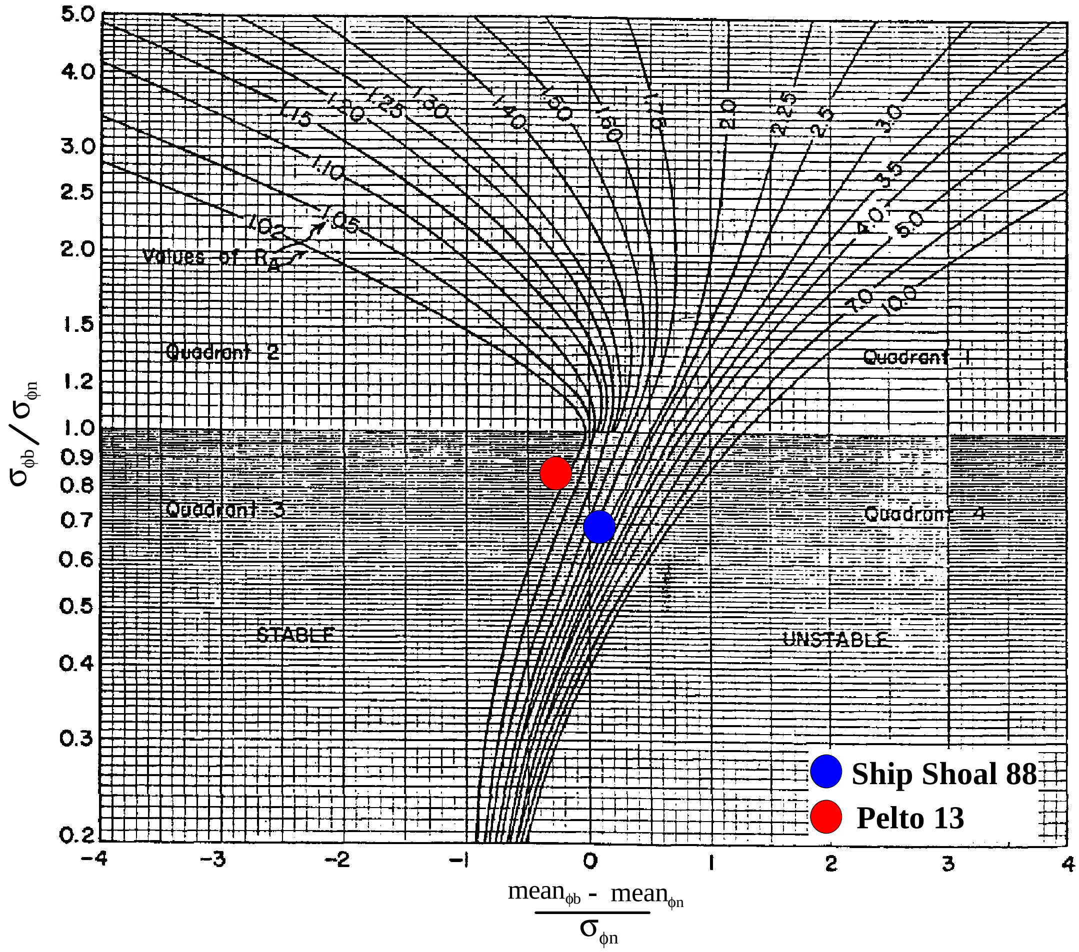


Figure 23. Plot of fill ratios for Isles Dernieres beach samples using sediment from Ship Shoal 88 and Pelto 13. Cut to fill ratio for Isles Dernieres beaches using Ship Shoal 88 sediment is approximately 1.75, whereas Pelto 13 sediment is approximately 1.0. Method and graph from (USACE, 1977).

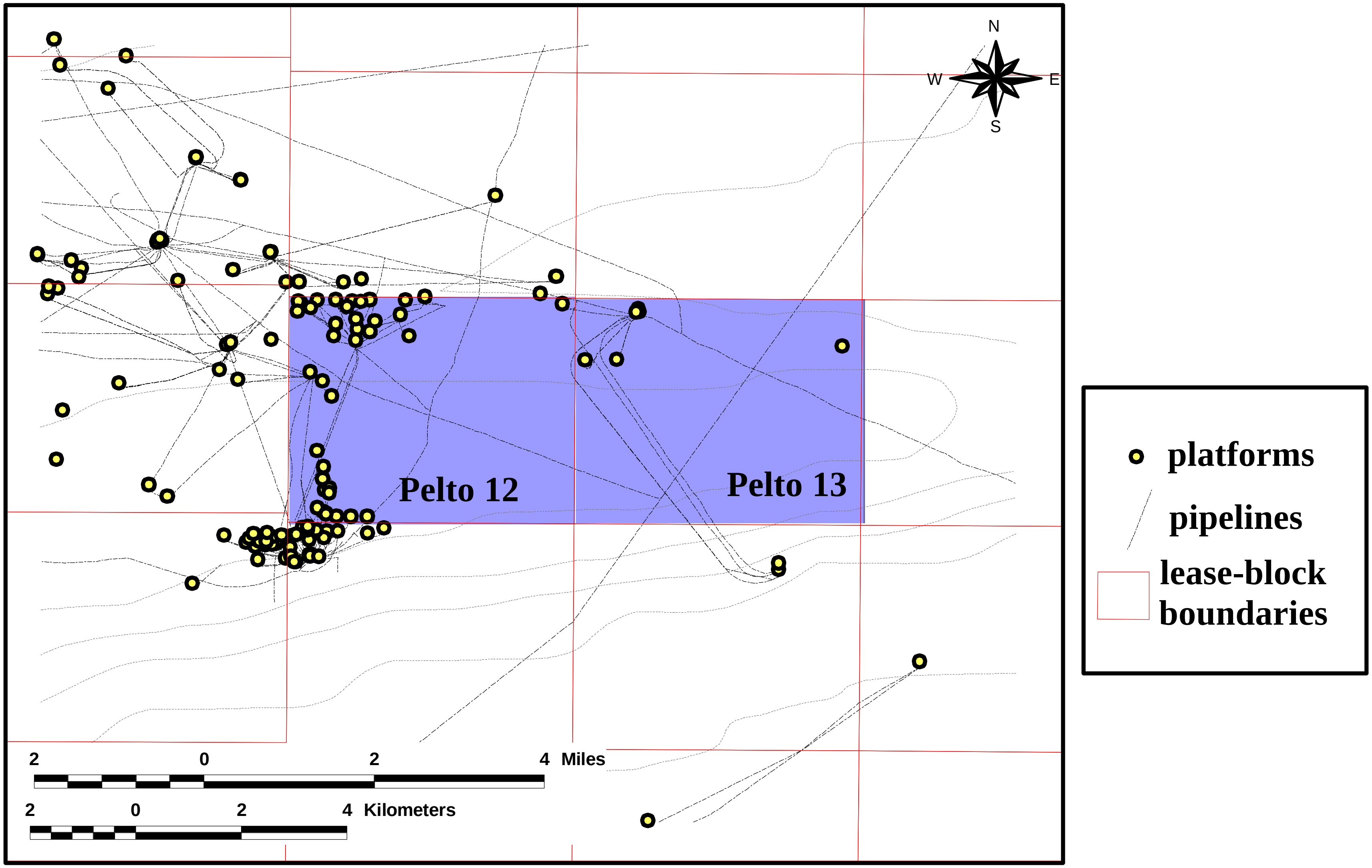


Figure 24. Hydrocarbon infrastructure of the Pelto 12 and Pelto 13 lease blocks on the eastern end of Ship Shoal (Fig. 20). Infrastructure data taken from the U.S. Department of the Interior Mineral Management Service (2001).

most of the current platforms located on the periphery of the lease blocks. However, multiple pipelines do cross the lease blocks. Figure 25 shows the known infrastructure for SS 88, which according to currently available data consists of one pipeline in the extreme southwest corner of the block. Although data used to map the location of infrastructure within the lease blocks was the most current available from the MMS more detailed mapping and magnetometer surveying of the lease blocks will be necessary prior to dredging.

Archeological Resource Considerations

The federally mandated National Historic Preservation Act of 1966 (NHPA) ensures the recognition and preservation of historical and archeological properties of the United States. The MMS is therefore responsible for ensuring that significant archeological sites are not damaged or altered in areas of the outer continental shelf where it has permitted activity. The following section provides an overview of the requirements established by the MMS for archeological surveys of outer-continental shelf lease blocks. Information presented below was taken from the MMS website for archeological studies (Gulf of Mexico Archeological Information, 2001).

An archeological resource refers to material remnants of human life and activities, which are at least 50 years old and possess archeological interest. Scientific and scholarly investigations of archeological resources provide a scientific and/or humanistic understanding of past human behavior, cultural adaption, and similar topics. Probable archeological resources of the Louisiana continental shelf include: 1) prehistoric Native American cultural sites dating from the time when sea level was lower than modern sea level and thus the continental shelf was subaerially exposed and 2) historic shipwrecks. Guidelines for conducting archeological surveys and generating resultant reports are implemented by the MMS and available in publication “Notice to Lessees 98-06.” Specific archeological-survey requirements vary

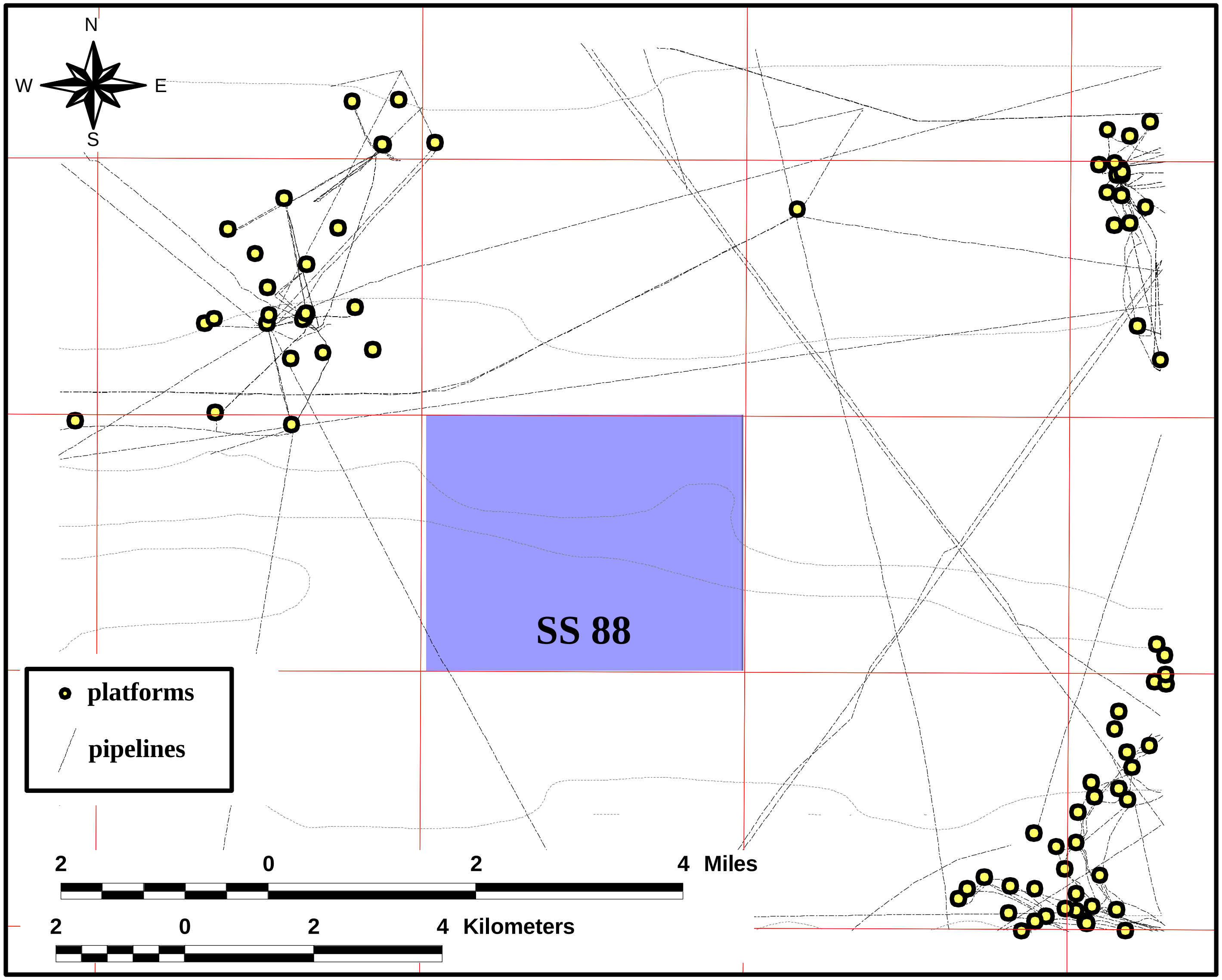


Figure 25. Map showing the hydrocarbon infrastructure of the Ship Shoal 88 lease block on the central part of Ship Shoal (Fig. 19). Infrastructure data taken from the U.S. Department of the Interior Mineral Management Service (2001).

depending upon whether the block has been determined to have a probability for historic shipwrecks or for submerged prehistoric cultural sites.

Archeological investigations of the continental shelf are conducted utilizing an array of remote sensing instruments such as a magnetometer, dual-channel side-scan sonar, sub-bottom profiler, and depth sounder. Additional investigative techniques that may be required include the use of underwater television, still and video cameras, archeological divers, and remote or manned submersibles. Geophysical instrumentation utilized in these investigations is required to be state-of-the-art technology and used in a fashion as to minimize intra-system interference. Moreover, data recorders must be interfaced with a continuous positioning navigation system capable of a 5 m or less accuracy. Final reports, providing details of the collected data and resulting interpretations, must be presented and signed by an archeologist and geophysicist with appropriate credentials and experience.

Survey-line spacing depends upon the suspected type of archeological resource; lease blocks with a high probability for historic shipwrecks are surveyed with a line spacing of 50 m, whereas lease blocks with a high probability for containing prehistoric sites must be surveyed at a line spacing of 300 m. Information currently provided by MMS indicates that lease block Ship Shoal 88 would have to be surveyed with 50-m line spacing and lease blocks Pelto 12 and 13 with a survey spacing of 300 meters.

Environmental Impacts

Dredging redistributes sediments, modifies bottom topography, disrupts habitats, and potentially alters water-circulation patterns. Although the environmental effects of estuarine dredging elsewhere have been studied (e.g., Jeane et al., 1975; Kenkel et al., 1976; Johnston, 1981) large-scale dredging of the Louisiana inner-continental shelf is a new endeavor and the possible environmental side affects of open-water dredging have not been well documented. Deleterious effects are possible both in the area being dredged as well as the area of sediment placement.

In estuarine environments, circulation changes resulting from dredging have been shown to affect natural chemical regimes and thus the availability of nutrients and dissolved gases to aquatic fauna (Johnston, 1981). Moreover, increased turbidity in marine waters at both the removal and dispersal sites may affect aquatic biota by disrupting normal photosynthetic processes, smothering benthic fauna, or inhibiting substrate re-colonization upon completion of dredge operations (Johnston, 1981). The result, either immediately or over a longer period of time, is a change in species composition, a loss of biodiversity, and potentially a reduction in commercial and recreational fisheries. Although primarily lacking in the Ship Shoal area, cohesive clays may be nuclei for adsorption of many pollutants, radioisotopes, petroleum products, pesticides, and metals (Wells, et al., 1981). As such, disposal of dredged material constitutes an environmental perturbation and depending upon the environmental quality of the material may result in ecosystem-level damage.

The uncertain environmental impacts of removing large volumes of Ship Shoal sediment and disposing it onto shoreline environments will likely necessitate a thorough and detailed environmental management plan. Additional permitting in accordance with state and federal laws may be required with the extent of documentation determined by the quantity and biological and chemical quality of sediment proposed for dredging. Probable methods of analysis include subsurface investigations, surface grab samples, sediment testing, probing, and additional methods of habitat analysis.

Hydrodynamic Impacts

In a numerical modeling effort, removal of the entire shoal was simulated and the impact on wave propagation and energy levels discussed (Stone et al., 2001; Appendix A). It is important to note that an additional numerical modeling effort will be required, using state-of-the-art models (e.g., SWAN) when the volume and dimensions of the borrow site are designed. Removal of Ship Shoal will alter the wave propagation, dissipation and the wave energy distribution. The magnitude and spatial distribution of the alteration depend on the initial wave conditions. During severe storms (Case 1) and strong storms (Case 2), propagating waves reach breaking conditions seaward of the western flank of Ship Shoal. Therefore, removal of Ship Shoal causes a maximum increase of the significant wave height by 90% - 100% (i.e., almost double the present value) in Case 1, and 40% - 50% in Case 2, over the shoal and immediately adjacent to the lee of the complex. Wave breaking does not occur on the east flank of the shoal because of much deep water, and the magnitude of the wave height increase due to shoal removal is significantly less on comparison with that on the west flank.

During weak storms (Case 3) and fair weather conditions (Case 4), waves do not reach breaking conditions over any part of Ship Shoal. The magnitudes of the significant wave height increase due to the removal of the shoal is considerably smaller, only 10% - 20% on the west part of the shoal. The values of wave height change on the east part of the shoal are minimal.

The nearshore wave fields are largely dependent on the offshore wave conditions. Under high energy conditions in Case 1 and Case 2, removal of Ship Shoal results in higher nearshore breaking wave heights, however, the breaker zone is displaced between 0.5 – 1.0 Km offshore. Ultimately, wave in the surfzone eventually collapse to the same energy level on comparing with and without shoal scenarios, suggesting that shoal removal will not have a significant impact on wave energy conditions along the Isles Dernieres. The nearshore impact is even less noticeable under the weaker energy conditions in Case 3 and Case 4, particularly along the east of the study area.

Wave approach direction exerts significant control on the wave climate leeward of Ship Shoal for stronger storm conditions (Case 1 and 2) but not weak storms or fairweather waves. Inclusion of the wind function increases wave height in all simulations. The magnitude of the increase is dependant on the deep water wave height and the slope of the shoreface profile. In Case 1, the surfzone is widened by almost 1.0 Km whereas in Case 4, the change is minimal. Removal of Ship Shoal results in a 50% increase of the significant wave height. This is much larger than the magnitude (between 25% to 30%) when wind forcing is neglected. The magnitude of wave height increase due to the wind forcing over the east part of the shoal is as much as 0.8m. While inclusion of the wind forcing function allows for an increase in the wave height, the effects attributable to the removal of Ship Shoal are limited to the periphery of the leeward flank of the system, particularly along its western boundary.

Changes in wave approach direction redistributes the increase in wave height in the lee of the shoal complex. This does not, however, impact breaker wave heights in the nearshore along the Isles Dernieres. Simulation of long wave propagation landward during Hurricane Andrew indicates near total wave energy dissipation, as opposed to breaking, over Ship Shoal. A much smaller percentage of low amplitude waves crossed the shoal complex. Peak wave energy dissipation rates occurred, however, seaward of Ship Shoal in approximately 25 – 30 m water depths.

The data presented suggest that the entire removal of Ship Shoal will not significantly influence the wave climate beyond the leeward periphery of the complex, such as the nearshore zone along the Isles Dernieres. The data suggest that this conclusion is valid for winter storm conditions and hurricanes similar to that of Hurricane Andrew. This conclusion implies that given the unlikely situation that the entire volume mass of sediment be removed from Ship Shoal during a single dredging event, wave climate changes peripheral to the shoal will be substantially reduced given the removal of significantly lower volumes of sediment than that simulated here.

Field research on hydrodynamics and sediment transport in the vicinity of Ship Shoal, has for the most part been conducted exclusively by researchers from the Coastal Studies Institute at Louisiana State University, and is discussed in Pepper et al. (1998), Pepper et. al. (1999), Pepper (2000), and Pepper and Stone (submitted, 2001). The region is generally characterized by low-energy processes, including low waves (mean significant wave height less than 0.7 m), weak near-bottom currents (generally less than 10 cm s^{-1}) and fairly low rates of sand transport (on the order of 0.1 g cm^{-1} s^{-1}). However, winter cold front passages, and presumably, tropical storms and hurricanes, are forcing mechanisms which provide an input of energy to the inner-shelf system which may cause increases of more than an order of magnitude in hydrodynamic parameters and sediment transport rate. Winter storm (cold front) passages were found to consist of two distinctive end-member types in terms of their associated inner-shelf response, although other types of frontal passages may undoubtedly occur. Type 1 storms were characterized by weak southerly pre-frontal and strong northeasterly post-frontal winds. They generally resulted in strong post-frontal responses that included high, short-period, southerly waves, strong, southwesterly currents, and moderately high sediment transport that was southwesterly overall. Type 2 storms included periods of both strong southerly pre-frontal winds and strong northerly post-frontal winds. They generated high, long-period northerly swell waves prior to the frontal passage that persisted throughout most of the post-frontal phase, during which time energetic southerly storm waves developed, creating a complex, bimodal wave spectrum. Currents prior to the frontal passage were fairly strong and northerly, while subsequent to the frontal passage, they became rotational, likely as a result of inertial effects, but were southeasterly in direction overall.

Shear velocity was elevated during both the pre- and post-frontal phases, while sediment transport occurred predominantly during the post-frontal phase, when mean sediment transport was directed southeasterly, and low-frequency and wind-wave flows produced northerly transport.

It is apparent that Ship Shoal influences these processes measurably. During a two-month winter period, mean wave height and period on the landward side were 36% and 9% lower, respectively, than on the seaward side, due to attenuation, while across-shelf currents were offshore on the seaward side and onshore on the landward side, where flow speed was10% higher. During a subsequent one-month period, mean significant wave height decreased from its seaward value by 15% and 25% as measured on the middle and the landward portions of the shoal, respectively. Sediment transport direction was also predicted to differ considerably between the seaward and landward sides of the shoal, with fair-weather transport directed towards the west on the seaward side and towards the northeast on the landward side, while during cold front passages, transport was toward the southeast on the seaward side, and variable, but generally southward on the landward side. Sediment flux across Ship Shoal appears to have been divergent during fair weather conditions, potentially causing shoal erosion, and convergent during cold front passages, potentially causing accretion. It appears, therefore, that removal of sand from Ship Shoal would likely result in a modification of hydrodynamic and sediment transport processes on what is currently the landward side of the shoal, including an increase in wave height and wave period, an increase in offshore current flow, and potentially, a decrease in landward transport of sediment during fair weather. The magnitude of these effects is difficult to predict however, since the bathymetry of the shallow inner shelf would undoubtedly influence these processes, even discounting the influence of Ship Shoal itself, and the possible change in bottom substrate (from fine sand to other materials) would change bottom boundary layer characteristics and resuspension processes.

DREDGING

There have been many dredging and beach fill projects in the United States. However, very few of these have utilized borrow sites with distances of more than a few miles from the restoration location. In Louisiana, the U.S. Army Corps of Engineers routinely dredges navigation channels using the dredge spoil to crate new habitats. Barrier island restoration has historically occurred using sands from nearshore borrow areas and channels or inland ridges. Most of the offshore aggregate mining occurs in Europe due to the advance dredging technology and equipment. In the United States, the two largest offshore aggregate mining operations are in New Jersey and California. McCormack Aggregates in Amboy, New Jersey and Tidewater Sand and Gravel in Oakland, California produce concrete sand, a medium grain-sand that is mined by hopper barges propelled by integrated tugs. Tidewater mines approximately 400,000 yd^3 per year, while McCormick mines approximately 800,000 yd^3 per year (Kraut, 1986).

The availability of detailed information regarding dredge operations and costs in the United States has been limited due to industry competition. However, research indicates that pipelines are most appropriate for short distances (less than 3 mi) between borrow sites and fill locations. Hopper dredges are better suited for borrow areas 3 to 5 miles away and tugs and scows are the best alternative for longer distances (Chisholm, 1989).

There are three basic types of dredging operations: 1) hydraulic, 2) mechanical, and 3) a combination of hydraulic and mechanical (Table 2).

Hydraulic dredging techniques include the hopper, sidecaster, and dustpan dredges along with hydraulic-pipeline and plain-suction dredges. This method is favored by the U.S. Corps of Engineers (USACE) for channel dredging in navigation channels and restoration through dredge spoil. Mechanical dredging moves material by removal and relocation. Clamshell, dipper, and

Table 2. Characteristics of Dredge Types

Dredge Type	Operation	Carrying capacity (yd^3)	Vessel draft (ft)	Approx. production rates yd^3/hr	Dredging depths (ft)		Limiting wave ht (ft)	Limiting current* (knts)	Advantages	Disadvantages
					min.	max.				
Hopper	3- to 30-m depth limit	300 to 16,000 yd^3	12 to31	500 to 2,000	10 to 28	80	< 7	7	• effective in rough, open seas	• too deep a draft for shallow waters • can't dredge continuously • less precision than other dredges
Sidecasting Dredge	used to dredge bar channels and small coastal inlets	pipes into barge	5 to 9	325 to 650	6	25	< 7	7	• rapid mobilization between projects • continuous operation • works in relatively exposed waters • shallow draft	• small • low production rates
Bucket Dredge	limited to 30-m depths	limited to 30 m depths	5 to 6 (barge mounted)	30 to 500	0	100	< 3	7	• effective around piers and structures • inexpensive • can dredge most material except consolidated or solid rock. • usually most efficient long-distance transport method	• soft, fine-grained material tends to leak out. • not normally used in exposed waters • sea conditions decrease production • working depth is limited to about 30 m.
Cutterhead Dredge	draft to over 30 m	limited to barge capacity	3 to 14	25 to 10,000	3 to 14	12 to 65	< 3	7	• efficient on upland disposal sites • almost continuous dredging cycles • more powerful machines can dredge rock-like consolidated sediment.	• limited capability for working in open areas • designed to operate in calm water and not offshore • requires towboats
Suction dredge	same as cutter	N/A	N/A	N/A	N/A	N/A	< 3	7	• pipeline transports operated continuously; no cutter, not easily damaged by wave action	• can't dredge hard or consolidated material • may have bars on end to exclude large debris
Dustpan	similar to suction dredge	N/A	N/A	N/A	N/A	N/A	< 3	7	• designed for Miss. River shoal dredging	• not commonly used in exposed water.

Table 2. Characteristics and features of dredges discussed in the text.

ladder dredges are examples of mechanical dredging. Combination dredges loosen material mechanically and then transport it hydraulically. Cutterhead dredges are an example of a combination dredge. This type of technique limits dredging to the capacity of the barge and is efficient on upland disposal sites. However, cutter dredges are designed to operate in calm water and not offshore.

The selection of which dredging equipment is best suited for restoration depends on the physical characteristics, quantity, and dredging depth of the material, as well as the distance to disposal area. More detailed information on the different types of dredging equipment is listed below.

Hydraulic Dredges

Hopper Dredges

Hopper dredges are probably the most effective dredges in rough open water. They can operate in water depths of 3 to 30 m and have a carrying capacity of approximately 300 to 16,000 yd^3. Production rates range from 500 - 22,000 cubic yards per hour. Hopper dredges are self-propelled, with molded hulls. They are equipped with propulsion machinery, dredging equipment, and sediment containers called hoppers that are required to remove and transport material from a channel bottom or sea floor. Hydraulic dredges draw the borrow material and water slurry through drag arms into the hoppers. The hoppers are then transported to the restoration site where the dredge material is unloaded. However, the vessel draft ranges from 12 to 31 ft depending on sediment load. Many newer hopper dredges have split hulls instead of doors allowing the vessel to open along a center line with faster unloading rates in shallow water. Many hoppers pump out their loads through a discharge pipe to allow disposal to upland restoration sites. The hopper is unloaded and then returns the borrow site to resume dredging. A major advantage of using this type of dredge is that is can move quickly and economically to the dredging project under its own power. They travel at approximately 9 to 16 knots and do not generally interfere with other channel traffic. However, the disadvantage of this dredging method is a deep draft that inhibits shallow water operations. Moreover, this type of dredge excavates with less precision than other dredges and is inefficient in hard-packed sands and side banks.

The Hopper dredge appears to be the most suitable equipment for dredging Ship Shoal. Cost estimates to move sand from Ship Shoal onto Isles Deniers ranges between $5.00 and $12.00 per yd^3. As a result of draft restrictions, the hopper dredge would require moving lighter loads and thus more frequent trips between the borrow site and the placement location.

Sidecasting Dredge

The sidecasting dredge is another variation of hydraulic dredging. It differs from the hopper dredge in that it operates continuously and has a shallow draft. In this dredging technique, the sediment is picked up from the bottom through two drag arms and pumped through a boom-supported discharge pipe. The vessel can independently travel the entire length of a shoaled area, excavating between 6 and 25 ft below the seafloor. Sidecasting dredges have been used to deposit material into hopper barges traveling parallel to the dredge. The advantage of using a sidecasting dredge is that it can work in relatively exposed water and is self sustaining, so it can perform work in remote locations. It can also be rapidly mobilized between projects. However, most sidecasting dredges in the United States are small with relatively low-production rates of approximately 325 to 650 yd^3. The only sidecast dredges in the United States are owned and operated by the USACE. Due to its low production rates, it would be costly to operate this type of dredging system on Ship Shoal.

Plain Suction and Dustpan Dredges

The plain suction dredge is the same as the cutterhead described later in the combination section only the cutter is removed. It transports through a pipe line so it operates continuously and is not easily damaged by wave action. However, the plain suction dredge is uncommon in the United States. The dustpan dredge is similar to the suction dredge but is mainly designed for dredging shoals on the Mississippi River. It is not commonly used in exposed waters.

Mechanical Dredges

Clamshell Dredge

A clamshell dredge is a mechanical cable excavator dredge that uses a single bucket. The bucket is attached to the dredge crane with cables. This type dredge operates by lifting the bucket, or the clamshell, dropping it into the bottom sediments, lifting the bucket and dredged material to the surface, and emptying the dredged material into a nearby disposal facility, scows, or barges for transportation to a disposal facility. The use of clamshell bucket dredging and transfer by bottom-release scow maintains much of the integrity of the sediments. This method usually produces positive relief features in the placement area. The deposited sediment occupies a volume only about 1.1 times greater than it did in the channel, and the slope of the deposit is considerably greater than for hydraulically dredged and deposited sediments. Clamshell dredges are suited more for channel dredging and not for offshore mining.

Combination Dredges

Cutterhead Dredge

The most efficient and versatile dredge type is the hydraulic-pipeline with a motorized cutter known as a cutterhead-suction dredge. This type of dredge has a centrifugal pump mounted on a barge. A pipe supported by a framework, called the ladder, is mounted on the front of the barge and extends down to the bottom. Cables lift the ladder to control the depth cutter at the end of the ladder and hence the depth of cut. Dredging depths of the cutterhead dredge range between 3 and 65 ft. Production rates range from 25 to 10,000 cubic yd^3. The cutterhead has a limited open-area carrying capacity and is designed to operate in calm water rather than offshore. A cutter section dredge was successfully used in 1984 for placing renourishment material from Cat Island Pass onto Isles Dernieres (Jones and Edmonson, 1987).

SHIP SHOAL COST ANALYSIS

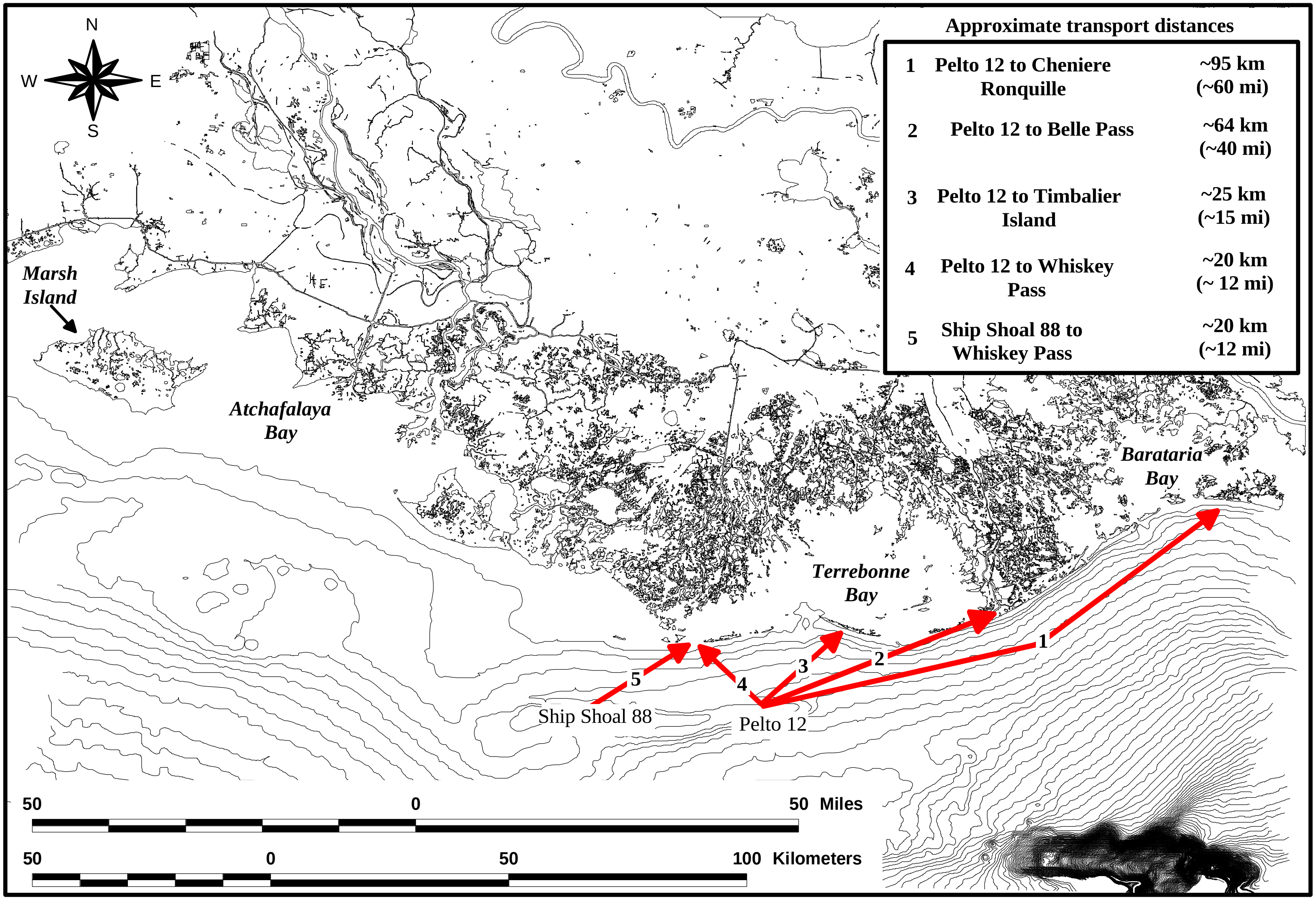
The following cost-analysis sections are excerpted from a report completed by Picciola and Associates, Inc. (1996). This report was originally constructed as a cost analysis for utilizing Ship Shoal borrow material along the Fourchon headland adjacent to and east of Belle Pass.

There are many ways to obtain sand from offshore. However, the extreme distance, between the borrow and deposit sites, pose many logistical problems and represented the challenge in making this project feasible (Fig. 26). Additionally, the fact that Ship Shoal is located in exposed waters represents a serous factor in determining acceptability of equipment to be considered for this project.

Another difficulty for dredging at Ship Shoal is draft restrictions imposed on dredges by the shoal waters of south Louisiana. Deeper draft dredges will not be able to dredge on top of Ship Shoal or get very close to shore. They would likely dredge on the landward side of Ship Shoal and to take advantage of calmer water conditions.

The estimate developed herein provides the cost per yd^3 of sand on the beach, ranging between \$8.70 per yd^3 and \$10.00 per yd^3. It is recommended that the higher end of the range be used for estimated purposes. Initial project costs will likely tend to be higher than estimated, but will probably decrease as contractors become familiar with the area.

Maintaining a hopper at Port Fourchon may be a feasible solution to providing borrow material to the beach. This would certainly be an economic advantage, provided that the initial



Approximate transport distances

1	Pelto 12 to Cheniere Ronquille	~95 km (~60 mi)
2	Pelto 12 to Belle Pass	~64 km (~40 mi)
3	Pelto 12 to Timbalier Island	~25 km (~15 mi)
4	Pelto 12 to Whiskey Pass	~20 km (~ 12 mi)
5	Ship Shoal 88 to Whiskey Pass	~20 km (~12 mi)

Figure 26. Map showing approximate transport distances from areas of suggested borrow removal to restoration project areas.

costs and annual operational/maintenance costs can be overcome. Most significant is the cost estimate for purchasing and maintaining a permanent first year dredging operation at the Port. The initial cost (first year) are projected to be approximately \$17.38 /yd^3 of material on the beach. However, yearly costs thereafter reduce to \$4.27 /yd^3. If mining of Ship Shoal for Fourchon Beach or any of the other barrier islands in the area (i.e. Isle Dernieres or Timbalier Islands) prove feasible, specific dredging equipment can be developed which would be better suited to operating efficiently for this particular project. Tailoring equipment to the specific site would certainly decrease the cost per unit of material moved over that estimated herein. A way to make this project more credible would be to pair multiple restorations with that project. If a dredge or dredges were to be permanently maintained at Port Fourchon or another nearby port, it could be utilized to supply material from Ship Shoal to Isle Dernieres, Timbalier Islands, Wine Islands, or any other nearby barrier islands.

Dredging Configuration

The proposed configuration of dredging operations for the project is to dredge on Ship Shoal with hopper dredges, either tug/barge combination or self propelled vessels. The dredging vessel will then travel to Port Fourchon, up Belle Pass to a rehandling facility just offshore of the beach at Fourchon.

The first scenario will have a rehandling facility where the material in the hopper will be pumped out via pipeline onto the beach (Fig. 27). If the vessel does not have self pumped-up capability, a barge unloader will be used to pump the material to the replenishment area by pipeline where it will be shaped into the final profile.

Part of the mobilization will be the installation of a rehandling station in Belle Pass. This could consist of a barge moored along the shores of Bayou Lafourche against pilings. The barge

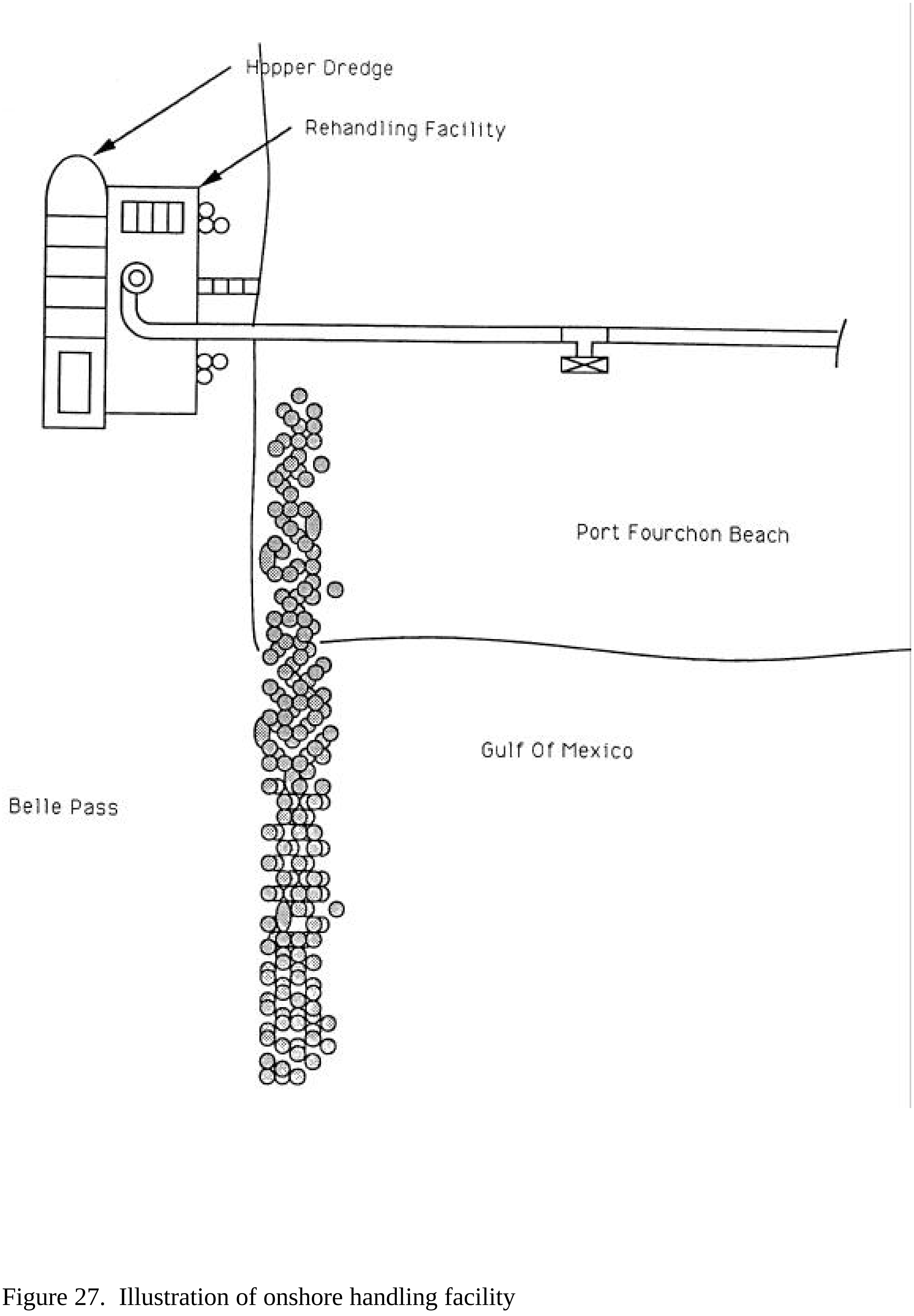


Figure 27. Illustration of onshore handling facility

will house rehandling pumps and generators for power to run the pumps. The discharge pipe will depart from this location and run onto the beach.

The advantages of this proposed method, are that the rehandling facility is within protected waters, moored onshore, and can be reached by vehicles. However, one disadvantage is that the hopper dredge will be limited in draft by the depth of the navigation channel at Fourchon.

To alleviate this problem, permits can be obtained to dredge Belle Pass to a depth suitable to the loaded draft of the hopper dredge. This can be completed first and material dredged from the channel dumped onto the beach or offshore.

The second scenario involves mooring a work barge just offshore of the beach replenishment area (Fig. 28). The work barge would hold the seaward end of the discharge pipeline. The discharge pipeline would come off the barge and run shoreward along the bottom up to the beach.

The advantage of this method is that the work barge could be moored far enough offshore such that the hopper dredge could operate at maximum draft when full. Disadvantages are that the rehandling facility would be isolated from shore and only accessible by boat. Additionally, the station would be exposed in adverse weather and possibly have to be demobilized during extreme weather conditions. It is not recommended to pursue this option unless permits cannot be obtained to dredge Belle Pass.

On the beach where the dredged material is being placed the pipeline will be identical for both rehandling facility configurations. The pipeline will have Y-branch discharge lines, controlled by gate valves, to the main pipeline in order to stage the placement of each fill. The importance of this procedure can be appreciated when one understands that along the

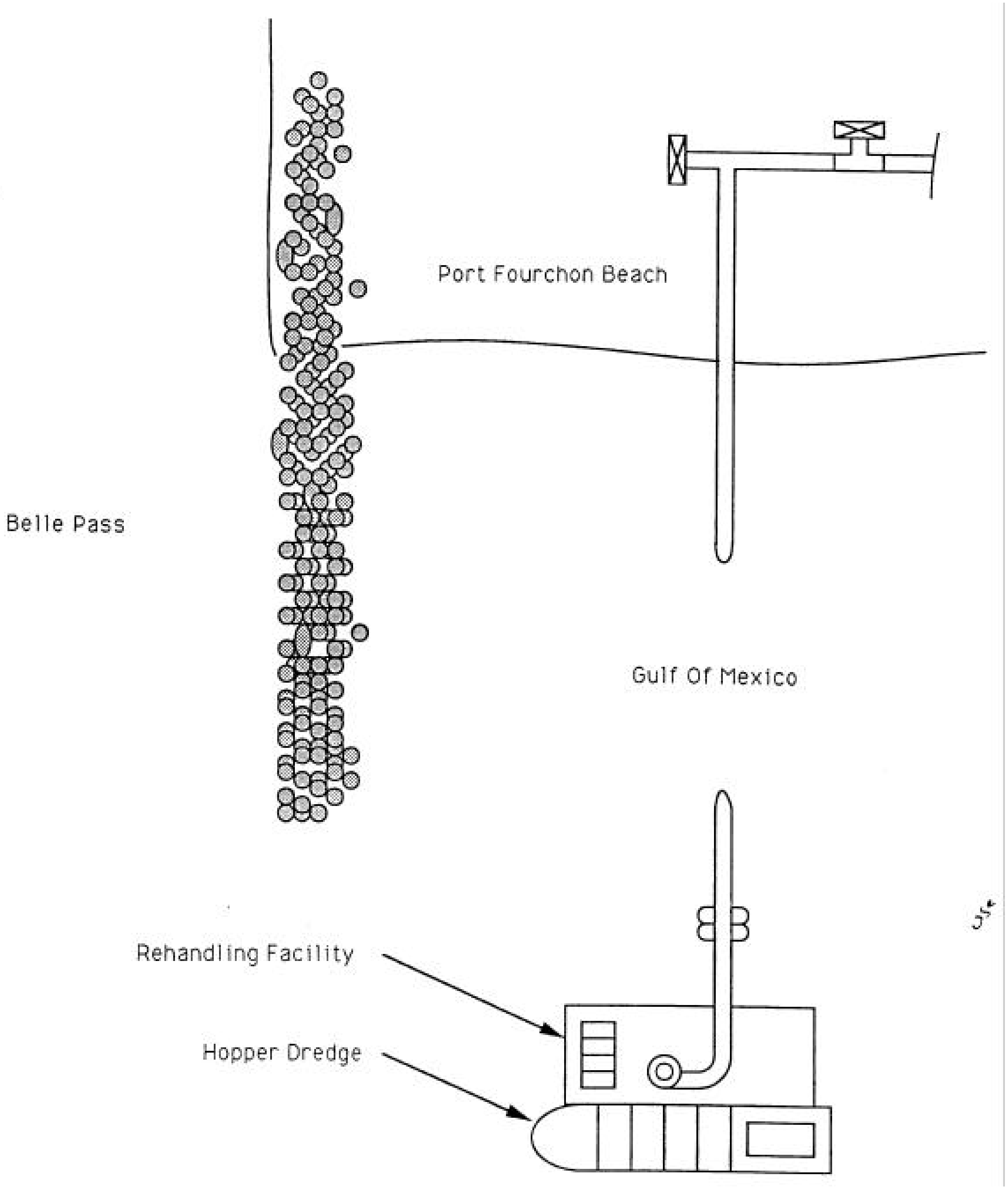


Figure 28. Illustration of offshore handling facility

approximate seven miles of the replenishment area the contractor can direct material onto the beach for distribution by dozers. Along the beach the pipeline will be run above ground to each of the distribution points.

Projected Cost Estimate

The cost estimate for this study is based on actual information provided by the U.S. Corp of Engineers from previous projects in which hopper dredges were used to dredge navigational channels (mostly the Mississippi River) and deposit the sediment offshore. For these projects, the deposit material was dumped offshore using split hull hopper dredges or from doors beneath the hopper bins. Therefore, an estimate was made for the approximate time required to offload the dredge using a pumping system.

Project Costs are split into several items including Mobilization and Demobilization, Pipeline Construction, Sand Fill, and Engineering (Table 3). Mobilization and Demobilization was based on examining the average cost from contractor's bids for five projects consisting of dredging the Mississippi and Calcasieu rivers. These bids averaged approximately $230,000 and included moving the dredge and equipment to and from the site. In addition to this, the Ship Shoal/Fourchon Project would require the construction of a rehandiling facility on or near shore. It is assumed that the assembly of the Rehandling Facility, including all associated equipment, would cost approximately $320,000.

Pipeline construction was estimated by reviewing bid abstracts from the USCAE for previous jobs where a pipeline was constructed on the beach for restoration projects. Estimates are based on $30 per foot and a project length of seven miles (36,960 ft). Bid abstracts from the Grand Isle Beach Restoration Project were used in deriving this estimate.

Table 3. Cost estimates for task 1.

Item	Dredge(27/3600)	Dredge(28/4000)	Dredge(33.5/6300)
Mobilization and Demobilization	\$550,000.00	\$550,000.00	\$550,000.00
Pipeline Construction	\$1,108,800.00	\$1,108,800.00	\$1,108,800.00
Sand Fill	\$41,745,450.00	\$46,779,150.00	\$40,502,250.00
Engineering, Surveying,&Sub Soil Investigation	\$1,300,000.00	\$1,300,000.00	\$1,300,000.00
Total Project Cost	\$44,704,205.00	\$49,737,950.00	\$43,461,050.00
Cost per yd^3 Material on Beach	\$8.94	\$9.95	\$8.69

Sand fill for this project was computed using results of previous projects administrated by US Army Corps of Engineers. Production rates were tabulated and averages calculated for percentage of hopper capacity (Table 4). Additionally, the parameters such as excavation time, down time, and travel time were examined to reasonably estimate project time based on the capacity of each dredge.

Hourly rates for different hopper dredge sizes were estimated from bid abstracts on several projects administrated by the USACE. Three different sizes of hopper dredges were considered for determining costs for this project. Sizes of 27" diameter pipe and 3600 yd^3 hopper capacity, 28"diameter pipe and 4000 yd^3 hopper capacity, and a 33.5" diameter pipe 6300 yd^3 hopper capacity were estimated form information provided by the USACE. Total cost varies depending upon the size of the dredge used, but in general the results from the three estimates ranged less then \$1 per yd^3 of material on the beach. It would make sense that the larger dredges should be more cost effective because of they require fewer trips to deliver similar quantities of material. Details of the cost analysis are presented in Appendix B.

Table 4. Cost Estimates for Task 2.

TASK 2 COST ESTIMATE

Item	Year 1 Cost	Year 2 Cost	Year 3 Cost
Rehandling Facility Construction	$400,000.00		
Pipeline Construction	$400,000.00	$300,000.00	$300,000.00
Dredge Construction/ Purchase	$16,000,000.00		
Engineering, Surveying,&Sub Soil Investigation	$1,000,000.00	$300,000.00	$300,000.00
Yearly Operation/ Maintenance	$5,000,000.00	$5,000,000.00	$5,000,000.00
Total Project Cost	$22,800,000.00	$5,600,000.00	$5,600,000.00
Total Material on Beach (yd^3)	1,312,000.00	1,312,000.00	1,312,000.00
Cost per yd^3 material on Beach	$17.38	$4.27	$4.27

The engineering estimate is listed as a lump-sum effort which includes developing beach profiles, surveying, rehandling facility design, obtaining permits, soil borings, and construction supervision. The cost estimate for maintaining a full-time dredge at Port Fourchon to continually move sand from Ship Shoal to Fourchon was developed utilizing the same information established in Task 1. It was assumed that pipeline construction would be deferred as a yearly cost based on the movement of the work along the beach. Also, construction or purchase of a dredge would be absorbed in the initial year cost of equipment in the size range required for the project. Yearly operation and maintenance considers the cost of fuel, crew salaries, groceries and supplies, as well as equipment maintenance.

CONCLUSIONS

Ship Shoal is a shore-parallel sand body located approximately 15-km offshore of the Isle Dernieres Islands of south-central Louisiana. Ship Shoal is the remnant of a former deltaic headland and barrier shoreline that has been progressively inundated by marine waters due to relative sea-level rise and transgressive submergence (Penland et al., 1988). Previously, the recoverable sand of Ship Shoal has been estimated to be 1,200,000 billion m^3. However, large areas of Ship Shoal are also the sites of extensive hydrocarbon infrastructure, presenting a technical difficulty for the efficient removal of sediment. Currently suggested areas of sediment removal are offshore lease blocks SS 88, PL 12, and PL 13. Volumes, not considering the presences of infrastructure within these blocks, are estimated at 57,000,000 m^3, 45,000,000 m^3, and 34,000,000 m^3 respectively. Factors that need to be considered prior to dredging include the: 1) environmental and hydrodynamic impacts of dredging Ship Shoal, 2) possibility of archeological sites within proposed dredge areas, 3) most suitable dredging method, 4) the associated economics of dredging, and 5) the performance of Ship Shoal sediments in contract to poorer quality nearshore sediment as it relates to project construction and maintenance costs. The development of new innovative dredging technologies will be required to deliver offshore sediment resource over long distances to shallow water project construction sites.

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Appendix A

Supplemental Hydrodynamic Impact Contributions

This is the executive summary of a two-part report capturing the efforts of a comprehensive program funded by the Minerals Management Service and conducted by Dr. Greg Stone and other scientists in the Coastal Studies Institute, Louisiana State University, to evaluate the physical processes and sediment transport at Ship Shoal. The first part documents a detailed numerical wave modeling effort designed to assess the potential impacts of removing Ship Shoal through dredging, and subsequent impacts on the wave field. The second deals with a physical measurement program focusing on measuring the bottom boundary layer physics and sediment transport at the shoal. In both reports a considerable literature is reviewed that pertain to previous efforts pertinent to Ship Shoal and sediment transport processes. Given the length of the report, only the executive summary is provided here. The report is available on the web at http://erin.csi.lsu.edu/projects.

In a numerical modeling effort, removal of the entire shoal was simulated and the impact on wave propagation and energy levels discussed (Stone et al., 2001). It is important to note that an additional numerical modeling effort will be required, using state-of-the-art models (e.g., SWAN) when the volume and dimensions of the borrow site are designed. Removal of Ship Shoal will alter the wave propagation, dissipation and the wave energy distribution. The magnitude and spatial distribution of the alteration depend on the initial wave conditions. During severe storms (Case 1) and strong storms (Case 2), propagating waves reach breaking conditions seaward of the western flank of Ship Shoal. Therefore, removal of Ship Shoal causes a maximum increase of the significant wave height by 90% - 100% (i.e., almost double the present value) in Case 1, and 40% - 50% in Case 2, over the shoal and immediately adjacent to the lee of the complex. Wave breaking does not occur on the east flank of the shoal because of much deep water, and the magnitude of the wave height increase due to shoal removal is significantly less on comparison with that on the west flank.

During weak storms (Case 3) and fair weather conditions (Case 4), waves do not reach breaking conditions over any part of Ship Shoal. The magnitudes of the significant wave height increase due to the removal of the shoal is considerably smaller, only 10% - 20% on the west part of the shoal. The values of wave height change on the east part of the shoal are minimal.

The nearshore wave fields are largely dependent on the offshore wave conditions. Under high energy conditions in Case 1 and Case 2, removal of Ship Shoal results in higher nearshore breaking wave heights, however, the breaker zone is displaced between 0.5 – 1.0 Km offshore. Ultimately, wave in the surfzone eventually collapse to the same energy level on comparing with and without shoal scenarios, suggesting that shoal removal will not have a significant impact on wave energy conditions along the Isles Dernieres. The nearshore impact is even less noticeable under the weaker energy conditions in Case 3 and Case 4, particularly along the east of the study area.

Wave approach direction exerts significant control on the wave climate leeward of Ship Shoal for stronger storm conditions (Case 1 and 2) but not weak storms or fairweather waves. Inclusion of the wind function increases wave height in all simulations. The magnitude of the increase is dependant on the deep water wave height and the slope of the shoreface profile. In Case 1, the surfzone is widened by almost 1.0 Km whereas in Case 4, the change is minimal. Removal of Ship Shoal results in a 50% increase of the significant wave height. This is much larger than the magnitude (between 25% to 30%) when wind forcing is neglected. The magnitude of wave height increase due to the wind forcing over the east part of the shoal is as much as 0.8m. While inclusion of the wind forcing function allows for an increase in the wave height, the effects attributable to the removal of Ship Shoal are limited to the periphery of the leeward flank of the system, particularly along its western boundary.

Changes in wave approach direction redistributes the increase in wave height in the lee of the shoal complex. This does not, however, impact breaker wave heights in the nearshore along the Isles Dernieres. Simulation of long wave propagation landward during Hurricane Andrew indicates near total wave energy dissipation, as opposed to breaking, over Ship Shoal. A much smaller percentage of low amplitude waves crossed the shoal complex. Peak wave energy dissipation rates occurred, however, seaward of Ship Shoal in approximately 25 – 30 m water depths.

The data presented suggest that the entire removal of Ship Shoal will not significantly influence the wave climate beyond the leeward periphery of the complex, such as the nearshore zone along the Isles Dernieres. The data suggest that this conclusion is valid for winter storm conditions and hurricanes similar to that of Hurricane Andrew. This conclusion implies that given the unlikely situation that the entire volume mass of sediment be removed from Ship Shoal during a single dredging event, wave climate changes peripheral to the shoal will be substantially reduced given the removal of significantly lower volumes of sediment than that simulated here.

Field research on hydrodynamics and sediment transport in the vicinity of Ship Shoal, has for the most part been conducted exclusively by researchers from the Coastal Studies Institute at Louisiana State University, and is discussed in Pepper et al. (1998), Pepper et. al. (1999), Pepper (2000), and Pepper and Stone (submitted, 2001). The region is generally characterized by low-energy processes, including low waves (mean significant wave height less than 0.7 m), weak near-bottom currents (generally less than 10 cm s^{-1}) and fairly low rates of sand transport (on the order of 0.1 g cm^{-1} s^{-1}). However, winter cold front passages, and presumably, tropical storms and hurricanes, are forcing mechanisms which provide an input of energy to the inner-shelf system which may cause increases of more than an order of magnitude in hydrodynamic parameters and sediment transport rate. Winter storm (cold front) passages were found to consist of two distinctive end-member types in terms of their associated inner-shelf response, although other types of frontal passages may undoubtedly occur. Type 1 storms were characterized by weak southerly pre-frontal and strong northeasterly post-frontal winds. They generally resulted in strong post-frontal responses that included high, short-period, southerly waves, strong, southwesterly currents, and moderately high sediment transport that was southwesterly overall. Type 2 storms included periods of both strong southerly pre-frontal winds and strong northerly post-frontal winds. They generated high, long-period northerly swell waves prior to the frontal passage that persisted throughout most of the post-frontal phase, during which time energetic southerly storm waves developed, creating a complex, bimodal wave spectrum. Currents prior to the frontal passage were fairly strong and northerly, while subsequent to the frontal passage, they became rotational, likely as a result of inertial effects, but were southeasterly in direction overall. Shear velocity was elevated during both the pre- and post-frontal phases, while sediment transport occurred predominantly during the post-frontal phase, when mean sediment transport was directed southeasterly, and low-frequency and wind-wave flows produced northerly transport.

It is apparent that Ship Shoal influences these processes measurably. During a two-month winter period, mean wave height and period on the landward side were 36% and 9% lower, respectively, than on the seaward side, due to attenuation, while across-shelf currents were offshore on the seaward side and onshore on the landward side, where flow speed was10% higher. During a subsequent one-month period, mean significant wave height decreased from its seaward value by 15% and 25% as measured on the middle and the landward portions of the shoal, respectively. Sediment transport direction was also predicted to differ considerably between the seaward and landward sides of the shoal, with fair-weather transport directed towards the west on the seaward side and towards the northeast on the landward side, while during cold front passages, transport was toward the southeast on the seaward side, and variable, but generally southward on the landward side. Sediment flux across Ship Shoal appears to have been divergent during fair weather conditions, potentially causing shoal erosion, and convergent during cold front passages, potentially causing accretion. It appears, therefore, that removal of sand from Ship Shoal would likely result in a modification of hydrodynamic and sediment transport processes on what is currently the landward side of the shoal, including an increase in wave height and wave period, an increase in offshore current flow, and potentially, a decrease in landward transport of sediment during fair weather. The magnitude of these effects is difficult to predict however, since the bathymetry of the shallow inner shelf would undoubtedly influence these processes, even discounting the influence of Ship Shoal itself, and the possible change in bottom substrate (from fine sand to other materials) would change bottom boundary layer characteristics and resuspension processes.

Part 1: Wave Climate Modeling and Evaluation Relative to Sand Mining on Ship Shoal

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Part 2: Wave Climate and Bottom Boundary Layer Dynamics with Implications for Offshore Sand Mining and Barrier Island Replenishment, South-Central Louisiana

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Appendix B

BELLE PASS COST ESTIMATES (from Picciola and Associates, 1996)

STANDARD BEACH PROFILE~ 125 cu. yd/ft
RF CRIT =1.03
= 128.75 cu. yd/ft
Borrow Material = 5,000,000 yd^3
Linear Ft. of Beach 7 mi. (36,960 ft)

PIPELINE

30 $/ft. * 36,960
$1,108,800.00

MOB&DEMOB

$450,000.00

INSHORE DREDGE APPLICATION

(27" / 3,600 yd^3)
Hopper Yield = 65%
One (1) Trip = 3,600*0.65
= 2,340 cu. yd.
Number. of Trips =5,000,000 / 2,340
=2,137
Down Time =7.5%
* Total Hours = (2,137 / 1.75) * 1.075* 24
=31,506 hrs
*Assume 1.75 trips per day i.e.
2.5 hours extraction
7.5 hours travel
3.5 hours off load
Cost per Hour = 1,325 $/hr
Total Cost = 1,325* 31,506
=$41,745,450.00

OFFSHORE DREDGE APPLICATION

(28" / 4,000 yd^3)
Hopper Yield = 65%
One (1) Trip = 4,000*0.65
= 2,600 cu. yd.
Nb. of Trips =5,000,000 / 2,600
=1,923
Down Time =7.5%
* Total Hours = (1,923 / 1.75) * 1.075* 24
=28,351 hrs
*Assume 1.75 trips per day i.e.
2.5 hours extraction
7.5 hours travel
3.5 hours off load
Cost per Hour = 1,650 $/hr
Total Cost = 1,650* 28,351
=$46,779,150.00

DREDGE

(33.5" / 6,300 yd^3)
Hopper Yield = 65%
One (1) Trip = 6,300*0.65
= 4,095 cu. yd.
Number of Trips =5,000,000 / 4,095
=1,221
Down Time =7.5%
* Total Hours = (1,221/ 1.75) * 1.075* 24
=18,001 hrs
*Assume 1.75 trips per day i.e.
  2.5 hours extraction
  7.5 hours travel
  3.5 hours off load
Cost per Hour = 2,250 $/hr
Total Cost = 2,250* 18,001
=$40,502,250.00