Feasibility Report
and
Final Environmental Impact Statement

on

Coastal Storm Damage Reduction

SURF CITY AND NORTH TOPSAIL BEACH
NORTH CAROLINA

Appendix R -

Hardbottom Survey Reports

Appendix R -

Hardbottom Survey Reports

The following pages contain the reports of surveys in both the offshore borrow areas and in the nearshore of the project area. These surveys and reports were conducted and prepared by consultants under contract to the U.S. Army Corps of Engineers, Wilmington District. Note that due to size, attachment 4 is only being provided electronically, and as a seperate document.

The scanned reports, prefaced by title pages are listed as follows:

1. Attachment 1 – An Assessment of the Availability of Beach Fill Quality Sand Offshore North Topsail Beach and Surf City, NC, HDR Engineering of the Carolinas, with William J. Cleary, PhD., March 2003, 113 pages

2. Attachment 2 – High-Resolution Remote Sensing of Potential Hard Bottom Habitats: Topsail Island, NC July 2006, Greenhorne & O'Mara Inc., and Geodynamics LLC, 75 pages

3. Attachment 3 – High-Resolution 3D Bathymetric Assessment of Potential Hard Bottom Habitats: Topsail Island, Surf City and North Topsail Island, NC January / February 2007, Greenhorne & O'Mara Inc., and Geodynamics LLC, 60 pages

4. Attachment 4 – Surf City / North Topsail Beach, N.C. Shore Protection Project, Hardbottom Resource Confirmation and Characterization Study, Anamar Environmental Consulting, Inc., June 2008, 233 pages.

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Appendix R
Attachment 1

An Assessment of the Availability of Beach Fill Quality Sand Offshore North Topsail Beach and Surf City, NC

US Army Corps of Engineers®
Wilmington District

An Assessment of the Availability of Beach Fill Quality Sand Offshore North Topsail Beach and Surf City North Carolina

HDR

HDR Engineering, Inc.
of the Carolinas

in association with

William J. Cleary, PhD, P

March 2003

TABLE OF CONTENTS

SECTION **PAGE**

APPENDIX 1

List of Tables

List of Figures

List of Figures (continued)

List of Figures (continued)

List of Figures (continued)

AN ASSESSMENT OF THE AVAILABILITY OF BEACH FILL QUALITY SAND OFFSHORE NORTH TOPSAIL BEACH AND SURF CITY, NC

EXECUTIVE SUMMARY

The United States Army Corps of Engineers (USACE) Wilmington District office is currently preparing a general evaluation report for storm reduction projects along the Town of North Topsail Beach and Surf City, NC. The focal point of the report is the availability of sufficient quantities of beach fill material for the initial project construction and subsequent maintenance during the next 50 years. The USACE Wilmington District has conducted a number of investigations in the Topsail Island area. McQuarrie (1998) and HDR (2002) provided additional information on the unproven sand resource potential of the area offshore of Topsail Beach. The HDR (2002) indicated several potential existing target areas that may contain significant quantities of beach fill material.

It was speculated that a similar sand resource potential would exist off the remainder of Topsail Island; however, the nature of the sedimentary cover was poorly known. In the interest of locating the most economical and environmentally acceptable borrow sites that could support the proposed projects, information of the availability of beach quality material, or its non-availability, was needed. Therefore, site-specific assessments of each area were necessary. The goal of the investigation was the identification and delineation of suitable borrow sites that contained compatible material for the nourishment projects. An equally important objective was the identification of areas of environmentally sensitive hardbottoms.

The shoreface in the northeastern part of the study area is dominated by a platform-like submarine headland comprised of well-indurated limestone. Fathometer sonargraphs demonstrate that the highly irregular surface is characterized by a series of low- (<1.6 feet [0.48 m]) to high-relief (>6.6 feet [2.0 m]) hardbottom scarps and intervening flat hardbottoms. Reconnaissance level investigations have mapped several linear, shore-normal depressions that were interpreted to channel remnants. These shallow features appear as relatively flat areas where thin sequences of sediments have accumulated. The nature of the shoreface, from Alligator Bay to the Town of Surf City's southern limit, is similar to the shoreface segment off the northeastern part of North Topsail Beach. The most significant difference is the lack of high relief hardbottoms >6.5 feet (>2 m).

The USACE reconnaissance level investigation (ICONS) of the Topsail Island region indicated the shoreface was underlain by limestone and calcareous sandstone of Oligocene age. The uppermost stratigraphic unit mapped from seismic data crops out over most of the northern portion of the study area, and is correlative to the upper Oligocene Belgrade Fm. This unit forms the majority of the limestone platform that controls the bathymetry of the area. The Trent Fm crops out over a significant portion of the Surf City shoreface. A second major stratigraphic unit, the Oligocene River Bend Fm, also underlies a major portion of adjacent Topsail Beach. Vibracores recovered along boomer track lines off Topsail Beach indicated the River Bend Fm consisted of an olive green, fine quartz sand and silt. Vibracores and numerous diver surveys from offshore Surf City indicated that the River Bend Fm extends northward and underlies a significant segment of the Surf City shoreface.

An inspection of the sidescan-sonargraph mosaic indicated that several distinct types and zones of sea-floor morphology occur within the study area. The distinctly different accoustic "signatures" are indicative of lateral changes in the lithology and relief of the underlying stratigraphic units and the nature and thickness of the sediment cover. Interpretation of the data indicated that sediment accumulation is extremely limited particularly in the northern portion of the study area.

The sea floor in the southern portion of the study area consists of isolated, irregular areas of 1- to 2-mile (1.6 to 3.2 km) wide fields of shore-normal to shore-oblique sedimentary features interspersed amongst areas of low relief hardbottoms. Most of the fields of these low relief linear features are discontinuous, while several areas extend as much as 1.2 miles (1.9 km) across the study area. The 2-mile (3.2 km) segment of the sea floor to the southwest is markedly different and characterized by a distinct acoustic nature. An abrupt change occurs from the consistently similar sonar signature of the RCD zone to a 2- to 3-mile (3.2- to 4.8-km) wide area of low reflectivity (light colored) that extends obliquely across the shoreface. An area of mixed sonar returns, indicative of sediment patches within low relief hardbottoms, occurs within the innermost portion of this relatively homogenous area of weak sonar returns. Diver surveys indicated that the surface sediment within this zone of low reflectivity was fine sand underlain by calcareous siltstone.

The subcrop and outcrops within the northeastern part of the study area are composed of two basic Oligocene limestone units (Belgrade and Trent Formations) that are similar in composition. Both units are classified as moldic, sandy limestones. The Belgrade limestone is the most widespread unit and forms the extensive platform off New River Inlet. The limestone exposures provide an immediate source of "new" sediment for the surrounding shoreface. The sediment is a by-product of the activities of the many boring and encrusting organisms that are found on the hardbottoms.

The subcrop and outcrop units in the area from Alligator Bay to the southern limit of Surf City are composed of rocks that range in composition from a quartz-rich, calcareous-siltstone (River Bend Fm) to very fine grained sandstone to a moldic, sandy limestone (Trent Fm). The siltstone hardbottoms, which were absent on the northern shoreface segment, are composed of poorly consolidated calcite cemented quartz silt. The siltstone is only exposed in two isolated areas offshore Surf City but underlies a major portion of the shoreface. Bio-erosion and wave quarrying of the siltstone adds a significant volume of fine-grained material to the overlying sediment sequences.

The distribution of the major sediment types and their mixtures was difficult to map due to the extremely complex exposure pattern of the hardbottoms. The distribution of the major sediment types is complex and dictated by the spacing, relief, and composition of the rock exposures. Most of the shoreface in the southern part of the study area is blanketed by shelly, fine quartz sand. Gravel size material is abundant and comprised of limestone lithoclasts and molluscan material. The majority of the gravel and gravelly sand is found near or on hardbottoms.

Data indicated that the sediment sequence is thin and consists of units of very fine quartz sands intercalated with gravel mixtures. Mud-rich back barrier sequences were recovered in a number of vibracores. Thickness of the modern sediment package ranged from less than one-half inch (1.0 cm) in hardbottom areas to more than 6.2 feet (1.9 m) in intervening depressions. The sediment cover on the northern part of the study area was generally too thin (0.65 feet [<20 cm]) to core, except in isolated bathymetric lows and in a narrow channel-like feature off New River Inlet. The broad limestone platform off New River Inlet was generally barren of sediment.

Several cores were recovered from the paleo-channel of New River. The ICONS operations also retrieved cores from this feature. The limited data suggested that this very restricted region off New River Inlet is the only area in the northern part of the study area where sand deposits may be preserved. The shoreface in the southern part of the study area was underlain by relatively thin sequences of very fine quartz sands interbedded with sandy gravels. The thickest modern sediment sequences cored 1.6 to 6.4 feet (0.50 to 1.95 m) were recovered from mud-filled paleo-channels. The majority of the individual units present are less than 1.3 feet (0.40 m) thick. Gravel rich units are widespread and comprise major portions of the thin sequences. Gravel rich sequences were typically found in areas where limestone forms the subcrop unit and near exposures (hardbottoms).

Much of the southern portion of the study area is covered by sediment sequences less than ~one foot (30 cm) thick. The area with the thickest deposits of sediment (>3.0 feet [>1.0 m]) is restricted to a small region located within the central portion of the shoreface offshore the southern portion of North Topsail Beach. The sea floor in this area is characterized by linear shore-normal depressions (RCDs). This highly irregular region is underlain by siltstone. A second area where relatively thick sediments are found is located offshore the southern portion of Surf City. Most of the thicker Holocene sequences are comprised of either organic-rich mud or very fine sand units.

The shoreface off the northern portion of North Topsail Beach contained only one potential target area (Area I). The target area is located southwest of the limestone platform off New River Inlet within the remnants of the paleo-channel of New River. The ICONS data suggest as much as 4.5 feet (1.4 m) of bioclastic quartz rich sand may be present along the trace of the ancestral river channel. The volume of material contained in Area I is estimated to be approximately 1.4 million cubic yards (cy) (1.1 million m^3). The prospect of locating significant accumulations of sand in this area is probably very low; nonetheless, the area warrants a detailed investigation.

Approximately 70 percent of the shoreface southwest of Alligator Bay has no potential for significant volumes of compatible beach fill material. However, there are several areas (Areas II through V) where thin (<3 feet [~1.0 m]) sandy sequences may have accumulated. However, the compatibility and continuity of these materials is very questionable.

The irregularly shaped Area II covers approximately 4.8 mi^2 (12.4 km^2) of the shoreface. The thickness of quality beach fill material in Area II is likely to be extremely variable and, at best, probably averages less than 3.0 feet (0.91 m) in thickness. The volume of material contained in Area II is estimated to be approximately 15.0 million cy (11.7 million m^3). The proximity of hardbottoms may restrict the exploitation of sand resources in the narrower regions of Area II. Areas IIa and IIb are the only viable areas within the confines of Area II where there is a possibility of finding beach fill material. Areas IIa (1.5 $mile^2$ [3.9 km^2]) and IIb (0.7 $mile^2$ [1.8 km^2]) comprise approximately 45 percent of Area II. The potential volume of usable sand in these areas is estimated to range from 2.1 to 3.1 million cy (1.6 to 2.4 million m^3) in Areas IIa and IIb, respectively.

Area III, located southwest of Area II, is an 8.4 $mile^2$ (21.8 km^2) area that may contain as much as 2.3 million cy (1.8 million m^3) of questionable quality material. The presence of hardbottoms may also impact the availability and exploitation of sand resources in the narrower regions of

Area III. Area IV, that encompasses 1.6 $miles^2$ (4.1 km^2) of the shoreface, is located approximately 4.5 miles (7.2 km) offshore Stump Sound. The volume of potentially usable material contained in this region is approximately 0.3 million cy (0.23 million m^3). Area V encompasses approximately 1.1 mi^2 (2.8 km^2) and it is speculated that as much as 1.5 million cy (1.2 million m^3) of material is contained within the target site.

To adequately resolve the stratigraphy of the targeted borrow areas, a detailed geophysical survey utilizing a high quality Chirp system is required. Data from the surveys would be crucial to the detailed mapping of the three-dimensional aspects of the sediment sequences. A detailed coring program should be implemented to ascertain the compatibility of the materials within the target areas. Core data can be used to define the complex three-dimensional aspects of the discontinuous thin sand sequences. The core data can also provide the necessary means of groundtruthing the seismic data in areas where weathered rock units underlie what is interpreted to be a thick sequence of usable material. Additional high-resolution sidescan sonargraph surveys may be necessary to better define the boundaries of selected target sites in hardbottom areas.

1.0 BACKGROUND

The USACE Wilmington District office is currently preparing a general evaluation report for storm reduction projects along North Topsail Beach and Surf City, NC. The purpose of the aforementioned report is to assess the feasibility and interest in constructing beach fill projects that would reduce storm-related damages along this section of the Topsail Island in Pender and Onslow Counties. Alternative scenarios range from protective berms of varying dimensions to project designs that include a berm backed by an artificial dune. The focal point for these projects is the availability of sufficient quantities of beach fill material for the initial project construction and the subsequent maintenance during the next 50 years.

Investigations of the offshore areas of other nearby beaches showed the shoreface to be a very complex region of the inner continental shelf (Thieler, et al., 1995; Marcy and Cleary, 1997; Johnston, 1998; and Cleary and Riggs, 1999). These investigations indicated that each shoreface sector was unique, and could differ significantly in terms of the underlying geologic controls from the immediately adjacent areas. The sand resource potential of the aforementioned areas was also shown to vary from site to site. Data from investigations by Thieler, et al., (1995) and Thieler (1997) suggested the middle and outer portion of the shoreface off Wrightsville Beach provided only a marginal prospect for beach fill sand. An investigation of the shoreface between Bear Island and Onslow Beach indicated that the sand-rich Oligocene Silverdale Fm, that crops out northeast of Onslow Beach had a high resource potential. This extensive potential borrow source lies within the restricted zone offshore the military controlled barriers and could not be exploited. The studies by Meisburger (1979), USACE (1993), Snyder, et al., (1994), and Marcy and Cleary (1997) of the Carolina Beach to Fort Fisher shoreface indicated the offshore areas of this headland shoreline segment contained significant deposits of high quality sand.

The USACE Wilmington District has conducted a number of investigations in the Topsail Island area (USACE 1989 and 1992) primarily within the soundside areas that back New Topsail Inlet. Potential borrow sources identified to-date for the Topsail Beach portion of Topsail Island included portions of the interior bar (flood-tidal delta) and shoals that have formed within the AIWW access channel (Old Topsail Creek). Although significant volumes of high quality beachfill material are available within the interior shoal system, all potential sources within a reasonable distance of Topsail Island will be investigated for evaluation in the study. McQuarrie (1998) and HDR (2002) provided additional information on the unproven sand resource potential of the area offshore of Topsail Beach. A study by HDR (2002) indicated several potential target areas existed on the shoreface that may contain significant quantities of beach fill material. The irregularly shaped potential borrow areas identified contain thin sequences of interbedded sands and gravels. The volume of usable material in the target areas was estimated to range from ~3.1 million cy (2.4 million cubic meters) to ~ 65.8 million cys (50 million cubic meters). Much of the unproven area lies along a region located ~ four miles (6.4 km) offshore Topsail Beach (see Figure 1).

It was speculated that a similar sand resource potential would exist off the central and northern portion of Topsail Island. However, the nature of the sedimentary cover and underlying rock units in this area was poorly known. In the interest of locating the most economical and environmentally acceptable borrow sites that could support the proposed projects, information of the availability of beach quality material, or its non-availability, in the waters seaward of North Topsail Beach and Surf City was needed. Therefore, a site-specific assessment of the areas was necessary. With this purpose in mind, the USACE Wilmington District Office contracted with HDR Engineering, Inc. of the Carolinas (HDR) and William J. Cleary (WJC) on August 15, 2002, to conduct a study of the area offshore of North Topsail Beach and Surf City utilizing published reports and available unpublished data.

The focus of the investigation was the identification of areas of the shoreface where significant deposits of beachfill quality sand resources were located. The study area included the shoreface within a region that extended from 3.3 miles (5.3 km) north of New River Inlet, off Onslow Beach, southwestward a distance of 20.5 miles (32.8 km) to the southern boundary of the Surf City town limit. The area of investigation (see Figure 1) extended from the outer limit of the active beach (-30 feet [9.1 m]) seaward to a distance of ~5.0 miles (8.0 km).

This report describes the results of the investigation aimed at assessing the availability of offshore beachfill-quality sand resources. The goal of the investigation was the identification and delineation of suitable borrow sites that contained a minimum of 0.50 million yd^3 (0.39 million m^3) of compatible material for the initial construction and subsequent renourishment of erosion mitigation and storm reduction projects. A secondary focal point and equally important objective was the identification of areas of environmentally sensitive hardbottoms.

The report summarizes available vibracore data from the offshore portions of the study area, as well as pertinent information gleaned from fathometer, seismic, and sidescan sonar profiles. SCUBA-based diver mapping and seafloor sampling surveys provided an added dimension and a means of groundtruthing selected sites identified on the sidescan sonar seafloor mosaic.

2.0 METHODS

The database for this study consisted of both published and unpublished geological and geophysical information. Unpublished information and data from the various reports were collected during various periods between September 1994 and July 2002. Some low-resolution seismic data were available for the Topsail Beach area that delineated the general geology and stratigraphy of the inner shelf (Meisburger, 1977 and 1979; and Johnston, 1998). The USACE collected a number of reconnaissance level seismic lines in the Topsail Island area in the mid 1970s as part of the Cape Fear Region Inner Continental Shelf Sediment and Structure Program (ICONS). Three shore-normal and one shore-parallel seismic profiles were obtained off Topsail Island and Onslow Beach during ICONS operations. The profiles, together with limited core data, provided information on the general stratigraphy of the area, but no detailed data on the nature of the upper 5 m of sediment sequence comprising the Topsail Island and Onslow Beach shoreface. The USACE collected five vibracores in the Topsail Island area during the ICONS program (Meisburger, 1979) that were used to identify the major reflectors identified on the seismic profiles. Four of the cores were recovered from the area offshore New River Inlet, and the remaining vibracore was retrieved from the shoreface ~ 4 miles (6.4 km) offshore Surf City.

Geological and geophysical information from Johnston (1998) were incorporated into the database utilized for this study to assist in the delineation of the nature of the geologic framework of the area offshore Surf City and North Topsail Beach. The data consisted of 307 miles (492 km) of sidescan sonargraph track lines and approximately 75 miles (120 km) of seismic profile data. Four shore-parallel seismic profiles were obtained by Johnston (1998) using a UNIBOOM™ sound source. The data from the seismic profiles were utilized to refine the generalized geological framework provided by Meisburger (1979) and Snyder, et al., (1994). Johnston (1998) collected 200 m range side scan-sonargraph data in a 19.4 mi^2 (50 km^2) area of the shoreface off New River Inlet and produced a mosaic of the seafloor that was used to delineate the extensive hardbottoms on the shoreface and map the distribution of the overlying sediment cover. Surveys obtained by divers at 135 locations provided data on the nature of the seafloor and a means of groundtruthing the sidescan-sonar sea floor mosaic.

The bulk of the information utilized in the conduct of this study included geological and geophysical data collected by WJC from the shoreface during various time periods between June 1998 and July 2002 (see Figure 1). The database consisted of approximately 63 miles (101 km of fathometer profiles, 35 vibracores [Table 1], 3 rock cores, and 260 surface samples [Table 2]). Data from an additional 61 SCUBA dive based seafloor mapping exercises and diver logs complimented the geological and geophysical data (see Figure 1). A sidescan sonargraph mosaic of the seafloor was produced for a 69 mi^2 (180 km^2) area of the shoreface that extended from

Mile Hammocks Bay (Onslow Beach) to the southern boundary of Surf City. Bottom photographs and videos of the shoreface sediment types and hardbottom features offshore North Topsail Beach and Surf City provided useful information on the complex sediment distribution and its relationship to areas of hardbottom.

The diver-retrieved vibracores provided an excellent database that could be used in conjunction with the geophysical data from which interpretations of shoreface geology and sediment characteristics could be ascertained. Vibracores were logged, described, and sampled at the top, middle, and bottom of major units for sedimentological analyses. Core logs were used to determine the thickness of the sediment cover, depth to rock and the type of rock when encountered, and to construct a series of vibracore cross-sections (see Figure 2).

Limestone samples that were recovered from the hardbottom areas and from the adjacent seafloor were described in hand sample. Sixteen of these samples were selected for petrologic study. All samples were sent to a commercial lab for impregnation with a blue epoxy and thin-sectioned. A 300-point modal analysis was performed for each thin-section to determine quartz sand and nature of the carbonate content (cement and allochems). Modern borings were tabulated during modal analysis, but were not considered in classification, in order to assess the original lithologic character and abundance of grain types. The classification of the rocks that underlie the area is based on Folk (1980).

In addition to existing NOAA bathymetric data, 16 shore normal fathometer sonargraphs (profiles) were collected using a Lowrance X-15 unit (see Figures 1 and 3 through 7) for use in determining the distribution of major hardbottom scarps. Scarps and unique hardbottom features were marked and way-points recorded utilizing a Differential Global Positioning System (see Figures 3 through 7). Hard copies of the fathometer traces were used to determine the distribution of the major hardbottom areas and intervening low areas. The profiles were also utilized in conjunction with the sidescan sonar data to identify sites for diver mapping surveys and vibracoring operations.

Photographic surveys of approximately 20 sites offshore New River Inlet provided an additional data set for groundtruthing the sidescan sonar data and mapping the surface sediment types. Video-graphic files from four hardbottom areas offshore Surf City were also utilized in the conduct of this study. The extensive data were imported into a Geographic Information System (GIS) software package (ARCVIEW™) for further processing, manipulation, and analyses. A series of maps, cross-sections, and photographic plates were produced from the various data used in the conduct of this study.

3.0 STUDY SITES SETTING

The shape of the North Carolina coastal system (see Figure 1) reflects major differences in the underlying geological framework (Riggs, et al., 1995). Cape Lookout separates the 525-km long North Carolina coastline into two distinct provinces. Each province has a unique geologic framework that results in a wide variety of diverse coastal features such as headlands, barriers, and estuaries. The coastal system in the southern province, from Cape Lookout south to the South Carolina border, is underlain by rock units that range in age from Upper Cretaceous through the Pliocene (Snyder, 1982; Snyder, et al., 1994; Cleary, et al., 1996). Only a thin veneer of Quaternary age sediments was preserved on the shoreface in southeastern NC. The underlying lithologic units are composed of rocks that are associated with the Carolina Platform, which underlies the region between Myrtle Beach, South Carolina and Cape Fear, NC (see Figure 1). This structural platform has risen slightly over geologic time, causing them to be truncated by the migrating shoreface. Consequently, an erosional topography exists along the southern coastal system with widespread exposures of rocks across the shoreface (Riggs, et al., 1995).

3.1 Geologic Controls

A limited sand supply characterizes most of the southern portion of the NC coastal system. Narrow barrier islands and spits that comprise the shoreline system are "perched" on older geologic units that constitute the shoreface (Cleary and Hosier 1987; Riggs, et al., 1995). The barriers consist of a relatively thin layer of sand that occurs on top of a shoreface composed of much older, eroding geologic units (Riggs, et al., 1995; Thieler, et al., 1995). Depending upon the composition and geometry, this underlying rock platform can act as a headland strongly influencing the beach dynamics and overlying sediment composition. Dissecting the underlying rock units is a paleo-drainage system consisting of a series of large-scale river valleys and adjacent inter-stream divides (Riggs, et al., 1995). This drainage network has controlled the development of large-scale topography and formation of a series of non-headland and headland influenced coastal reaches. This drainage system, coupled with the geologic framework, has controlled the availability of sand resources.

Several headland dominated coastal segments, present in the southern province, were developed on topographically high inter-stream features composed of geologically old, semi-indurated sediments and rocks (Morefield, 1978; Crowson, 1980; Riggs et al., 1995; Marcy and Cleary, 1998, Johnston, 1998). Materials associated with these features may crop out on the subaerial beach such as the Quaternary sequences along the Kure Beach-Fort Fisher area in southern New Hanover County. More commonly, the rocks occur as submarine features where they crop out on the shoreface forming a submarine headland such as the headland along a portion of North Topsail Beach and neighboring Onslow Beach. In this area, Oligocene age limestones form high-relief hardbottoms (Crowson, 1980; Cleary and Hosier, 1987; Riggs, et al., 1995; Cleary, et al., 1996; Johnston, 1998; Cleary, et al., 2000). These rocks extend beneath North Topsail and Onslow Beaches. The offshore portion of the karstic platform has affected the barriers shape, rates of erosion, and sediment supply.

Non-headland shorelines/shorefaces are the most common type along southeastern NC. These shoreline and upper shoreface segments are generally underlain by one of four different kinds of sedimentary materials that include valley-fill, inlet-fill, transgressing, or regressing shoreface sequences (Cleary and Hosier, 1987; Riggs, et al., 1995). The southern portions of North Topsail and Onslow Beaches that flank the New River Submarine Headland are examples of transgressive barrier segments. In these areas, narrow and low barriers are actively migrating across the upper shoreface that is composed of peat and muddy sand. These young units extend from the estuaries, beneath the barrier, and crop out within the surf zone. Segments of North Topsail Beach are characterized by extensive outcrops of mud and peat (Cleary and Hosier, 1979; Riggs, et al 1995; Cleary and Pilkey, 1996; Young, et al., 1999). The common exposures of these units testify to the thin nature of the modern sand prism. The lack of sand in the system is intimately related to the nature of the offshore geology (Cleary, et al., 1999). The Surf City barrier shoreline in general is a coastal segment that is underlain by several centuries old inlet fill sequences.

3.2 Topsail Island

North Topsail Beach and Surf City extends along the northern portions of Topsail Island, the second longest barrier island located within the Onslow Bay compartment. The Island consists of three communities: North Topsail Beach, which comprises the northern 11.7 mile (18.7 km) segment; Surf City, which covers the central 5.5 miles (8.8 km) of the barrier; and Topsail Beach, which extends along the southern 4.5 miles (7.2 km). The Topsail Island is bordered by New River Inlet to the northeast and New Topsail Inlet to the southwest (see Figure 1). The developed portion of the barrier is approximately 21.7 miles (34.7 km) long and averages approximately 918 feet (280 m) in width. The northeast-southwest barrier orientation exposes the island to frequent winter storms. Prior to 1941, the Island was used as a stock grazing range, with no development or access to the mainland. The Island was used as a U.S. Military Reservation between 1941 and 1947. Development began in the early 1950s, several years after the Island's ownership returned to the private sector.

Topsail Island is situated in a severe, or chronic, overwash zone. Storms that occurred on the Island during the period 1944 to 1962, and during the late 1980s, were particularly devastating. Hurricane Hugo (1989) impacted several sections, particularly North Topsail Beach. Hurricane Hazel (1954) and the Ash Wednesday storm (1962) caused significant damage along the entire barrier. During Hurricanes Fran, Bonnie, and Floyd, much of the Island was overtopped, resulting in the formation of massive and extensive washover topography. The northern and southern segments of the Island have been chronically impacted by winter storms since the mid-late 1980s (Cleary, et al., 2000).

3.3 North Topsail Beach

The Town of North Topsail Beach, the northern study site, comprises the northern 19 km section of Topsail Island. New River Inlet forms the northern boundary of the Town. North Topsail Beach is situated in a chronic overwash zone. Storms during the period of 1944 to 1962, and the winter storms during the late 1980s, were particularly devastating (Cleary and Hosier, 1979; Cleary, et al., 2000). North Topsail Beach, even prior to 1996, was considered to be a high-risk zone. Hurricane Bertha (July 1996) eroded a significant portion of the dune field with the exception of an area immediately downdrift of New River Inlet. Washover features were commonplace. The small amount of recovery due to artificial profile manipulation did little to improve the beach conditions before Hurricane Fran struck the area seven weeks later.

During Hurricane Fran, much of the island was inundated resulting in the damage of a large number of homes, most utilities, and almost all of the fronting dunes. The recession of the HWL following Hurricane Fran ranged from ~11 to 20 m. These low values do not adequately portray the complete devastation of the barrier. The extensive exposures of peat and stump forests on the foreshore clearly indicated that major segments of this barrier were poised for an accelerated increase in rollover rates.

Structural damage during Hurricane Floyd was minimal in comparison to Hurricane Fran and, although few homes were severely damaged, much of the infrastructure was destroyed. The lack of destruction was attributable to the fact that the majority of the poorly constructed homes, and those not built to code, were destroyed by the storms of 1996. A minimum of six temporary inlets formed as the barrier was again breached. Some of the breaches reoccupied former inlets opened during Hurricane Fran. In the aftermath of Hurricane Floyd, the northern portion of North Topsail resembled an extensive flat washover terrace (Cleary and Pilkey, 1996; Young, et al., 1999; and Cleary, et al., 2000).

Several of the breaches that opened during the storm remained opened for several months, testifying to the lack of sand in the system. Numerous winter storms punctuated the intervals between Hurricane Bonnie in 1998 and Hurricanes Dennis and Floyd in 1999. Overwash penetration during Hurricane Floyd was equal to or slightly exceeded that of Hurricane Fran. Since Hurricane Floyd impacted the area in September 1999, a small artificial dune has been reconstructed. Some natural foreshore, as well as backshore recovery, has occurred along the Town's shoreline.

Realignment of the outer bar channel of New River Inlet has promoted significant erosion of the beach and dunes along the extreme northern end of the Island. Since 1997, shoreline retreat has ranged from 45 to 155 feet in the 4,000 feet shoreline reach downdrift of the Inlet. In May 2002, ~300,000 cy (234,000 m^3) of material was placed along the eroding shoreline in an attempt to mitigate the inlet-related erosion.

3.4 Surf City

Surf City occupies the central 8.7 km of Topsail Beach (see Figure 1). The majority of the barrier in this vicinity fronts the relict flood-tidal deltas of Stumpy Inlet that opened and closed several times during the eighteenth and nineteenth centuries. The finger canals were dredged in the mid to late 1960s across the surface of the marsh that caps the coalesced flood tidal deltas.

The average pre-storm (1996) long-term erosion rates for the southern portion of Surf City ranged from 0 to 2 feet/year (ft/yr) (0.61month/year). In contrast, the northern segment of the Town's shoreline was characterized by accretion rates up to >3 ft/y (0.91m) (Benton, et al., 1993). These shoreline change rates do not adequately portray the pre-storm conditions, particularly the nature of the dune line prior to the landfall of Hurricane Bertha. In many places the dunes were low, scattered, and often scarped. Some of the worst structural damage was recorded along segments characterized by long-term accretion. Washover terraces, in the aforementioned segments, extended across much of the low-lying barrier and into some of the finger canals. The southern portion of Surf City was less susceptible to overtopping, and overwash penetration was greatly reduced due to the topographically higher foredune and adjacent dune field. A continuous, relatively low-relief, restored dune currently fronts much of the Town's oceanfront.

4.0 RESULTS AND DISCUSSIONS

4.1 Bathymetry and General Nature of Shoreface

4.1.1 Mile Hammocks Bay (Onslow Beach) to Alligator Bay (North Topsail Beach)

The shoreface in the northern part of the study area (see Figures 1 and 3) is dominated by a platform-like submarine headland comprised of well-indurated limestone. Figure 1 illustrates the extent of this broad shallow platform. Fathometer sonargraphs obtained from this portion of the shoreface show the highly irregular surface is characterized by a series of low- (<1.6 feet [0.48 m]) to high-relief (>6.6 feet [2.0 m]) hardbottom scarps and intervening flat hardbottoms. The scarps trend in a North-Northeast orientation and lie nearly parallel to the present shoreline. Several notable areas of relatively high-relief hardbottoms occur within the area. One such area is located northeast of the inlet offshore Mile-Hammocks Bay on the Onslow Beach portion of the shoreface. This relatively large irregular bathymetric high rises 5 m above the seafloor (see Figures 3 through 5).

A second area of high-relief hardbottoms occurs between Alligator Bay and New River Inlet (see Figure 5). Low-relief limestone scarps are more common south of the Inlet. The scarps generally border relatively flat, low-lying hardbottoms, the most common shoreface feature. Regionally the surface of the karstic platform is marked by small, irregularly shaped depressions, some of which are filled with a variety of sands and gravels (Johnston, 1998, and Cleary and Riggs, 1999).

Reconnaissance level investigations (Johnston, 1998, and Cleary and Riggs, 1999) have also mapped several linear, shore-normal depressions that were interpreted to be either remnants of channels or broad dissolution features. These shallow features trend to the South and Southeast, and are bordered by hardbottoms of variable relief (see Figure 8). On the seafloor, they appear as relatively flat areas of the shoreface where thin sequences of modern and pre-modern sediments have accumulated. Figure 5, line 11 is a sonargraph taken obliquely to the trend of one of the channel-like areas and shows the hummocky nature of the "channel" along the outer 60 percent of the profile. Alligator Bay (see Figure 1) is probably the landward expression of the linear depression mapped offshore North Topsail

Beach that extends beneath the barrier. The significance of these shallow sandy features as potential borrow sites is discussed in a subsequent section of this report.

4.1.2 Alligator Bay to Surf City's Southern Limit

The nature of the shoreface within the southern portion of the study area, from Alligator Bay to Surf City's southern limit, is similar to the shoreface segment off North Topsail Beach. The most significant difference is the lack of high relief hardbottoms >6.5 feet (>2 m) that occur on opposite sides of the area that straddles New River Inlet (see Figure 8). The shoreface off the southern portion of North Topsail Beach and Surf City is characterized by undulating, relatively flat hardbottom platform punctuated by scattered low-relief hardbottom scarps and sediment-filled depressions. Information gleaned from a number of shore-normal fathometer profiles and diver surveys indicated the irregularly spaced, landward facing scarps seldom rise more than 1.0 m (3.3 feet) off the surrounding sea floor (see Figures 6 and 7). The bordering hardbottom surface generally slopes in a seaward direction. Often the depression-like flat areas of the sea floor, between the scarps, are sites where sediment has filled the rock bounded topographic lows.

4.2 Seismic Data

4.2.1 Mile Hammocks Bay (Onslow Beach) to Alligator Bay (North Topsail Beach)

The USACE ICONS of the Topsail Island region of the inner continental shelf indicated the shoreface was underlain by calcareous rich units of Oligocene age. The data of Meisburger (1977 and 1979) provided limited information on sand resources in the area. The stratigraphic geometries of the units underlying the northern portion of the area were investigated by Johnston (1998) in a more detailed study using UNIBOOM™ seismic data. The seismic survey produced images of the upper ~260 feet (80 m) of the shoreface sequence. Figure 9 is a representative shore-parallel profile collected along the inner shoreface offshore North Topsail Beach that depicts the six seismic sequences that were delineated by tracing regional and local unconformities that separated mappable seismic units.

The uppermost stratigraphic unit mapped from seismic data crops out over most of the northern portion of the study area, and was interpreted to be correlative to the upper Oligocene Belgrade Formation (see Figures 9 A-B) exposed inland at the Martin Marietta Belgrade Quarry, ~16 miles (~25 km) inland (Johnston, 1998). This unit forms the majority of the limestone platform that controls the bathymetry of the sea floor in the area (see Figure 8).

Johnston (1998) mapped another unit that crops out on the sea floor in the southernmost portion of the study area that is correlative to the lower Oligocene Trent Formation (O_t). The Trent and Belgrade Formations are compositionally similar (sandy bio-sparrudites) and are separated in the Belgrade Quarry by a highly phosphatized and bored diastem (unconformity ρ) in Figure 9. The location and development of the linear channel-like feature offshore Alligator Bay may be related to the contact between the Trent and Belgrade Fms (see Figure 8).

Johnston (1998) also mapped two types of pre-modern channel structures incised into the Belgrade Formation. The differences between the channels were resolved by diver observation and core data. Type I channels are lined with the Aquitanian age *Crassostrea gigantissima* oysters, as described by Zullo and Harris (1987), and filled with light gray calcite cemented sandstone (designated OM_{pfcf} in Figure 9) . These Tertiary channel structures (OM_{pfcf}) form the core of the bathymetric highs (high relief hardbottoms) as lithified channel features (see Figure 8). A second channel type of Holocene Age (Type II) was identified and mapped off New River Inlet. This feature is traceable over a portion of the shoreface, and core data indicate it is backfilled with unconsolidated sands and estuarine mud (Q_{pfcf} in Figure 9).

4.2.2 <u>Alligator Bay to Surf City's Southern Limit</u>

Although some seismic data are available for the southern portion of the study area, they are low quality and of very limited use in delineating the details of the upper 16.4 feet (5 m) of the shoreface sequences. Data from Johnston (1998) and Snyder (personal communication, 1995) suggest the Trent Fm is the major stratigraphic unit that crops out across much of the Surf City shoreface. Meisburger (1979) reported that the shoreface off Surf City was underlain by Oligocene age units that dipped to the south and southeast. The description of one of the ICONS cores recovered 4.5 miles (7.2 km) offshore Surf City indicated that the Oligocene unit was composed of a calcareous/quartz sand unit that was capped by a thin sediment veneer.

McQuarrie (1998) demonstrated that the principal stratigraphic unit that underlies much of the Topsail Beach shoreface was the Orb-A Oligocene sequence of Snyder, et al., (1994). Vibracores recovered along boomer track lines indicated the Orb-A unit (River Bend formation) consisted of an olive green, silty, often dolomitic, fine quartz sand and silt. This mid Oligocene sequence was identified as the dominant unit that underlies the thin shoreface sediment sequence off the northern portion of the Topsail Beach shoreface (HDR, 2002). Vibracores and numerous diver surveys provided information on the lithology of the shallow subcrop units that are frequently exposed as hardbottoms offshore Surf City. The data that are discussed in a subsequent section, indicated that the Orb-A silty sand unit is present, as are a variety of limestone and sandstone units.

McQuarrie (1998) also mapped a variety of fluvial channel features on the Topsail Beach shoreface. According to McQuarrie (1998) many of these Quaternary channels are continuous and can be traced across the shoreface off the southern portion of Topsail Island. Subsequent groundtruthing with vibracores in some of these features indicated that the channels were infilled with dark gray estuarine mud (HDR, 2002). Modern analogues of these channels are the small coastal plain, marsh filled estuaries such as Bishop, Kings, Turkey and Virginia Creeks (see Figure 1). It is likely that similar mud-filled paleo-channels occur across the southern portion of the shoreface off Surf City and possibly in isolated areas offshore of Alligator Bay.

4.3 Side Scan-Sonargraph Data

4.3.1 Mile Hammocks Bay (Onslow Beach) to Alligator Bay (North Topsail Beach)

An inspection of the sidescan-sonargraph mosaic indicated that there are several very distinct types and zones of sea-floor morphology that occur within the northern portion of the study area (see Figure 10). The distinctly different accoustic "signatures" are indicative of lateral changes in the lithology and relief of the underlying startigraphic units as well as and the nature and thickness of the sediment cover. The various types of seafloor morphology that were identified by their acoustic signatures were ground truthed using data from diver surveys and observations. The data indicated that the shoreface in the vicinity of New River Inlet is dominated by low- to moderate-relief 0.65 to 6.5 feet (0.2 to 2.0 m) scarps and associated flat hardbottoms. Much of the North Topsail Beach shoreface is an area of contiguously exposed limestone hardbottoms of variable relief (see Figure 8).

The dark gray and black colored sonar returns imaged on the sea floor mosaic (see Figure 10) depict areas of high acoustic reflectance, such as hardbottom or rippled coarse shell and lithic gravels. The light colored gray to white sonar signals represent areas of low acoustic reflectivity that are usually indicative of unconsolidated materials, such as fine to medium sized sand. Areas dominated by strong acoustic returns (dark) with weaker (white) reflections produces a "pock-marked" appearance, suggesting a hardbottom area with depressions that are filled with shelly coarse sand and gravel. Areas of mixed acoustic returns produce a "patchwork" or "scaly" appearance that represent rock hardbottoms mantled by a rippled veneer of unconsolidated materials that range in size from sand to gravel (see Figure 10). Much of the continually exposed limestone platfom-like hardbottoms in this area are littered with a thin and patchy veneer of coarse gravels derived from the bio-degradation of the limestone.

Interpretation of the data indicated that sediment accumulation is extremely limited and generally restricted to four irregularly shaped, shore normal "linear" features (see Figures 8 and 10). These "channel-like" features contain only a thin sequence of modern sediment. The sediment ponds located offshore Mile Hammocks Bay (Onslow Beach) and Alligator Bay (North Topsail Beach) represent bathymetric lows that are filled with 3.3 feet (< 1 m) of sediment (see Figure 10). Fields of rippled coarse gravel and sand are commonly found in the linear sediment filled depressions (see Figure 10). Frequently, a cap of rippled, fine to medium grained silty, quartz sand mantles the gravel fields.

4.3.2 Alligator Bay to Surf City's Southern Limit

Figure 11 depicts a side scan sonargraph mosaic of the shoreface off the southern portion of North Topsail Beach and Surf City. The different accoustic "signatures" visible on the sea floor mosaic reflect the complex distribution of the principal stratigraphic units that comprise the underlying geologic framework and the nature of the overlying sediment veneer when present. The data used for groundtruthing the sidescan sonar imagery were obtained from 61 SCUBA diving-based mapping exercises aimed at visually identifying the inferred bottom sediment/rock type and sampling the surficial sediment cover and hardbottoms (see Figure 10). Interpretation of the sea floor mosaic was based on the integration of the accoustic data and the specific sedimentological and lithological characteristics of the various sample sites.

The very dark gray sonar returns depict areas of the shoreface with high acoustic reflectance, such as rock or gravel (see Figure 10). Light gray to white sonar signals represent areas of low acoustic reflectivity indicative of unconsolidated silt to fine sand. Areas dominated by strong acoustic returns (dark) with weaker (white) returns produces a "pock-marked" appearance, suggesting a flat hardbottom area with minor depressions that are filled with shelly coarse sand and gravel. Other portions of the shoreface are characterized by areas of mixed acoustic returns that produces a "patchwork" appearance that represents hardbottoms mantled by a veneer of unconsolidated materials ranging from silt to gravel (see Figure 10).

Interpretation of the side scan sonargraph mosaic indicated that, in general, the sea floor in the southern portion of the study area consists of isolated, irregular areas of 1 to 2 mile (1.6 to 3.2 km) wide fields of shore-normal to shore-oblique sedimentary features interspersed amongst areas of low-relief hardbottoms (see Figure 11). Most of the fields of these low relief linear features are discontinuous, while several areas extend as much as 1.2 miles (2.0 km) across the study area. The channel-like features are similar to the ripple scoured depressions (RSDs) found off Wrightsville Beach and are often floored with rippled coarse shell and lithic gravels, which are imaged on the side scan sonar mosaic as areas of high accoustic reflectivity (Theiler, et al., 1995 and 1998). The immediately adjacent areas that flank the linear (channel-like) depressions (RCDs) are characterized by very fine quartz sand and silt with varying amounts of sand sized shell debris. The presence of these linear depressions on the Topsail Beach shoreface were interpreted to be related to the occurrence of paleo-fluvial channels of varying age (McQuarrie, 1998). The interpretation was based upon analyses of seismic data that indicated the rippled depression features, imaged on side-scan sonargraph profiles, occurred within ancestral fluvial channels.

Scattered areas characterized by high acoustic reflectance and mixed acoustic returns occur in the northeastern portion of the southern segment of the shoreface in a region extending from Alligator Bay southwestward a distance of ~ 2 miles

(3.2 km). Fathometer profiles (see Figures 6 and 7) obtained from this area show the shoreface is characterized by a gently sloping surface, interrupted by a series of 1 to 3 feet (0.30 to 0.91 m) high irregularly spaced scarps. Diver surveys of selected inferred hardbottom sites identified on fathometer profiles indicated that the scarps and scarp backs are composed of moldic limestone of the Trent Fm. A patchy veneer of silty sand and gravel that produces a "pock-marked" or "patchwork" appearance mantles the surface of the flat hardbottom areas.

The morphology and signature of the 2-mile segment of the sea floor to the southwest is markedly different and characterized by a distinct acoustic nature. An abrupt change occurs from the consistently similar sonar signature of the RCD zone to a 2- to 3-mile (3.2- to 4.8-km) wide area of low reflectivity (light colored) that extends obliquely across the shoreface. An area of mixed sonar returns, indicative of sediment patches within low relief hardbottoms, occurs within the innermost portion of this relatively homogeneous area of weak sonar returns. Diver surveys indicated that the surface sediment within the majority of this zone of low reflectivity was a silty, very fine sand underlain by a light tan to olive green, calcareous siltstone.

Sea floor mapping surveys and rocks collected from low lying hardbottoms along the inner shoreface demonstrated the low lying hardbottoms and scarps 1 to 2 feet (0.31 to 0.60) are exposures of the Trent Fm. The southwestern 4 miles of the shoreface, imaged on Figure 10, is an extremely complex area offshore the central portion of Surf City. Diver surveys and fathometer profiles illustrated that numerous saw tooth-like 1 to 2 feet (0.30 to 0.60 m) high limestone scarps occur across much of this shoreface segment. Core data and rock samples collected by divers indicated that Trent Fm limestone underlies much of this area. Some smooth, undulating areas of the sea floor occur within this complex area offshore the northern portion of Surf City. These hummocky and gently sloping areas are mantled by silty sand and underlain by calcareous siltstone (ORB-A).

4.4 Underlying and Exposed Rock Units

4.4.1 Mile Hammocks Bay (Onslow Beach) to Alligator Bay (North Topsail Beach)

A patchy, very thin sediment veneer occurs across much of the shoreface within the northern portion of the study area (see Figures 8 and 11). The surface sediment layer consists of a mixture of modern and palimpsest material that rests disconformably upon the Oligocene Belgrade limestone that crops out over the majority of the North Topsail Onslow Beach shoreface. The complex surface sediment mosaic originates from the reworking of the underlying stratigraphic units (see Figure 9). The surface sediment unit is easily reworked during storms, exposing hardbottom platforms and low relief scarps in areas where the sediment cover is thin.

The subcrop and outcrops within the study area are composed of two basic Oligocene limestone units (Belgrade and Trent Formations) that are similar in composition. The contact between the Belgrade and Trent Formations lies along the southern margin of Alligator Bay, a broad shallow reentrant, located ~ 5 miles (8.0 km) southwest of New River Inlet (see Figure 9). Both rock units are classified as moldic, sandy limestones and are difficult to distinguish in hand specimens. An upper Oligocene/Lower Miocene channel complex, which contains lithified sandstone, is incised into the Belgrade Fm (see Figures 8 and 9). This unit crops out on the shoreface, forming several major bathymetric features. The structural geometry and composition of the geologic units have dictated the morphology of the hardbottom features in the area (Johnston, 1998).

The Belgrade limestone is the most widespread unit and forms the extensive platform off the mouth of New River Inlet. The low-relief (2.5 feet [0.75 m]) scarps in this area of the shoreface are also composed of this well-indurated, bio-moldic limestone (see Figure 11). The scarps that trend to the north-northeast usually border relatively flat surfaces that slope to the east. The surface of the karstic platform is highly irregular and generally lacks any appreciable sediment cover. The barren limestone surface is often mantled by irregular meadows of macroalgae, particularly on the higher and wider protected areas. The surface is also characterized by numerous fractures of variable and many shallow depressions some of which are partially filled with a variety of sediment (see Figure 12).

The large high relief hardbottoms located northeast and southwest of New River Inlet represent exposures of the Upper Oligocene/Lower Miocene Channel unit. These relatively high (6.6 to 16.4 feet [2 to 5 m]) bathymetric features are composed of very erosion-resistant calcareous sandstones. Both features are characterized by a series of step-like ledges. Johnston (1998) mapped the high relief elliptical-shaped exposure located southwest of New River Inlet and demonstrated that the feature was an erosional remnant of the lithified channel complex (see Figure 13). The base of the scarp along this hardbottom has been interpreted to coincide with the floor of the channel (Crowson, 1980; Johnston, 1998). The large oyster valves commonly observed on the shoreface (see Figures 13 and 14) and the adjacent beach is derived from the Tertiary channel complex whose floor is lined with the giant oyster (*Crassostrea Gigantissima*).

The limestone exposures in this area provide an immediate source of "new" sediment for the surrounding shoreface that ranges from silt to boulder size material (see Figures 16 and 17). The sediment is a by-product of the activities of the many boring and encrusting organisms that are found on the hardbottoms (see Figures 18 through 20). The large blocks and lithic gravel and sand found at the base of the limestone scarps is derived from the mechanical erosion and bio-degradation of the limestone that forms the scarps (see Figure 19). Bus-sized blocks of encrusted and corroded limestone are commonly found around the margins of the high relief hardbottom located northeast of the inlet. The blocks are separated from the intact hardbottom by a series of variably wide one-meter deep fractures. These collapsed blocks form an irregular ramp or talus at the base of the feature (Johnston, 1998).

The rock units forming the majority of the platfom and the low to moderate relief scarps offshore North Topsail Beach and Onslow Beach are gray to yellowish-brown, Belgrade and Trent Fm. sandy bio-moldic limestone (Johnston, 1998). The majority of the molds are remnant impressions of pelecypods (Pectens) and gastropods (see Figure 9). The moldic pore space represents aragonitic shell material that was leached during various stages of diagenesis. The higher relief features are composed of calcite-cemented sandstone that is characterized by significantly less moldic pore space. The quartz-rich nature of the sandstones probably accounts for the erosion resistant nature of this unit and the high relief of the aforementioned features.

Johnston (1998) conducted a petrologic analysis of 14 samples collected from the rocks comprising the platform. Thin-section modal analyses of limestones from the platform indicated that the terrigenous fraction, composed dominantly of quartz (0.01 in [~ 0.25mm]), comprised ~ 25 percent of the samples examined while the carbonate allochems and cement comprised the remaining portion of the rocks (see Figures 21 and 22). The great variety of cements observed during the thin-section analyses indicated the Belgrade rocks have a very complicated diagenetic history. The samples analyzed by Johnston (1998) were classified as moldic sandy biosparrudites (Folk, 1962). Figures 22 and 23 illustrate the general characteristics of the Belgrade Formation exposed on the North Topsail Beach – Onslow Beach shoreface (Johnston, 1998).

4.4.2 <u>Alligator Bay to Surf City's Southern Limit</u>

The thickness of the modern sediment cover increases slightly in a southwesterly direction, away from the broad, exposed limestone platform off New River Inlet. The surface sediment sequence in the southern area is similar in composition and texture to the thin sediment sequence found on the northern shoreface segment. Two distinct Oligocene stratigraphic units underlie this region of the study area and occasionally crop out on the shoreface (see Figure 12). The subcrop and outcrop units are composed of stratigraphic units that range in composition from a quartz-rich, calcareous-siltstone to very fine grained sandstone (River Bend Fm) to a moldic, sandy limestone (Trent Fm.) (see Figures 23 and 24).

The Trent limestone forms the numerous low-relief (1 to 3.5 feet [0.30 to 1.06m]) hardbottom scarps offshore the southern portion of North Topsail Beach and Surf City (see Figures 10, 25, and 26). All of the scarps surveyed appear to be landward facing features. The relief of the scarps is highly variable across the shoreface and varies from site to site (see Figures 3, 5 through 7). The barren seaward slope of the limestone hardbottom is hummocky and characterized by numerous irregular fractures and shallow depressions. The surface sediment unit at the base of the larger and more extensive scarps generally contains gravel and cobble size fragments of the units comprising the scarps (see Figures 27 and 28).

The limestone rock unit forming the discontinuous exposures in the southern shoreface segment is similar in color and texture to those found on the northern portion of the shoreface. Generally they are light gray to yellowish-brown, moldic sandy limestones. The majority of the molds are remnant impressions of a variety of pelecypods and gastropods (see Figures 9 and 23). Modal analyses of 20 representative thin-sections of rocks from scarps and flat lying hardbottoms indicate that the terrigenous fraction comprised approximately 25 percent of the samples examined. Subrounded fine grained quartz comprises ~ 99 percent of the terrigenous fraction. The majority of the Trent limestone samples analyzed are classified as moldic, sandy biosparrudites (Folk, 1962). Figures 29 through 32 show the common characteristics of the Trent Formation exposed on the southern segment of the shoreface.

The siltstone hardbottoms, which were absent on the northern shoreface segment, are composed of poorly consolidated calcareous silt (see Figures 31 C through D). The siltstone is only exposed in two isolated areas offshore the central portion of Surf City at the base of limestone scarps that mark the contact between the two units (see Figure 11). However, core data show that the unit is very widespread and underlies major areas of the shoreface off the southern portion of North Topsail Beach and the southern shoreface segment off Surf City (see Figure 11). There is some conjecture as to whether the tan to olive green calcareous siltstone is correlative to the Oligocene River Bend Fm siltstone that crops out over extensive segments of the shoreface from Figure Eight Island to Fort Fisher. McQuarrie (1998) mapped the adjacent Topsail Beach shoreface and assigned the siltstone to the River Bend Fm. However, Harris (2002, personal communication) suggested that the siltstone recovered offshore the central portion of Topsail Island represented a facies of the Trent Fm.

Data from the insoluble residue analysis of 12 siltstone samples from the study area indicated that the quartz silt and sand fraction averaged 72.2 percent by weight of the samples analyzed (Willson, 2002, personal communication). Modal analyses of thin sections of siltstone samples from the Kure Beach shoreface indicated that quartz silt constituted only 17 percent of the dolomite rich samples analyzed (Marcy and Cleary, 1997). In comparison, data from the thin-section analysis of the siltstone offshore Surf City indicated the quartz silt fraction comprised ~ 75 percent of the sample and no dolomite was present. The difference in the percentages of quartz silt between the two sites is a function of the weathering (dissolution) of the carbonate cement (calcite and dolomite) in the siltstone within the study area.

Regardless of the calcareous siltstone's stratigraphic designation, it is an important unit that contributes material to the sediment cover that blankets most of the southern portion of the study area. Bio-erosion and wave quarrying of the siltstone adds a significant volume of fine-grained material to the shoreface sediment sequences. Vibracores that have penetrated the upper 5 feet of the unit show that the siltstone sequence is seldom lithified, commonly bored, and easily disaggregated. The unit's susceptibility to erosion and wave quarrying accounted for the small number of outcrops in the area. The very fine grained and unconsolidated nature of the unit has resulted in uniform erosion and relatively gently sloping subcrop surfaces that are periodically exposed where the sediment cover is thin. The broad depressions that are underlain by the siltstone are the only sites where beach fill quality sand may be preserved.

4.5 Shoreface Surface Sediments

4.5.1 Mile Hammocks Bay to Alligator Bay

The nature of the surface sediment types and their distribution was initially ascertained through an analysis of sidescan sonargraph profiles, diver surveys and eventually megascopic analyses of 125 surface sediment samples. The distribution of the major sediment types (gravel, sand, and mud) and their mixtures is difficult to map due to the extremely complex exposure pattern of the highly variable relief of the scarps and the flat hardbottom areas. Figure 34 depicts a cartoon and bottom photographs of sediments of a generalized area of the shoreface where scarped and flat hardbottoms are common. Figure 34 conveys the fact that the distribution of the major sediment types is complex and is dictated by the spacing, sea floor relief and the composition of the rock exposures. As a general rule, there is a paucity of sediment 0.16 feet (<5 cm) or no sediment cover on scarp backs. Sediment that temporarily accumulates is eventually transported off the exposed topographic highs by incident waves that periodically re-suspend the sediments and erode the barren surfaces. On scarp backs protected by scattered meadows of macro-algae or in topographic lows proximal to the scarps, gravel-sized lithoclasts are common. Ponded accumulations 3.3 feet (~1 m thick) of sand and silty sand were found only at the base of scarps (see Figure 12), in linear depressions, and in irregular, shallow topographic lows (dissolution features) on scarp backs (Johnston, 1998).

Most of the silt to gravel size sediment in the hardbottom areas results from a combination of bio-erosion (see Figures 32 through 35) and wave quarrying. The moderate- to high-relief hardbottom scarps surveyed were undercut due to a combination of abrasion and bio-erosion. Undercutting at the base of the scarp produced thin overhangs of the hardbottom rocks that extended 3.3 to 4.9 feet (1 to 1.5 m) from the main body of the exposure (see Figure 12). The encrusted and extensively bored rock that comprises the protrusion is structurally weakened, and many eventually collapse forming large talus blocks (cobble to boulder size material) at the base of the scarp (Johnston, 1998).

Johnston (1998) found that most (~70 percent) of the shoreface (see Figure 8) off Onslow Beach and North Topsail Beach, between Mile Hammocks Bay and Alligator Bay, was an area of low - to high-relief hardbottoms with a very thin sediment cover (0.33 feet [< 10 cm]). The sediments sampled at the base of the scarps and on scarp backs contained an average of ~72 percent sand and 28 percent gravel sized material (see Figures 35 through 37). The sediments collected were carbonate-rich (26 percent) and reflected the abundance of gravel size limestone lithoclasts, produced by the mechanical and bioerosion of the submarine exposures. Figures 38 and 39 depict the general nature of the carbonate lithic gravel and sand in this area of the shoreface.

Johnston (1998) mapped several poorly defined, very shallow depressions that extend across portions of the shoreface in the vicinity of New River Inlet (see Figure 8). These features trend to the south and southeast and appear as sandy, relatively flat areas of the sea floor. As previously indicated, Johnston (1998) interpreted these irregular, shallow rock-bound topographic lows to be dissolution features or remnants of paleo-channels. Sediments collected from these shore-normal linear "depressions" consisted of 88 percent sand and 12 percent gravel. The average carbonate content of this suite of samples was 14 percent.

4.5.2 Alligator Bay to Surf City's Southern Limit

The distribution and variability of the surface sediment types (see Figure 53) was ascertained through an integration of data from the analyses of sidescan sonargraph profiles and from diver mapping/sampling surveys. Megascopic examination of the sediment samples collected by divers coupled with diver observations, bottom photographs and videotape footage provided added dimensions for mapping the various types of sediments that comprise the mobile sediment veneer in the southern part of the study area (see Figures 44 through 47). Limestone hardbottom areas are common occurrences and comprise a significant portion of the sea floor. The limestone hardbottoms extend intermittingly from Alligator Bay to the southern limit of Surf City and beyond. The relief and spacing of the limestone scarps/hardbottoms control the distribution of the gravel and sand/silt fractions in a manner identical to that depicted for the North Topsail Beach/Onslow Beach portion of the shoreface (see Figure 34x). Fathometer profiles (see Figures 6 and 7) obtained from the southern shoreface segment illustrate that the scarps are generally low to moderate relief 0.5 to 4 feet (0.15 to

1.2 m) features. There is a general lack of sediment (0.16 feet [<5 cm]) or no sediment cover on the hummocky hardbottom surface that back the scarps. Localized accumulations of silty, very fine to fine, shelly quartz sand were observed to pond at the base of scarps or in small dissolution depressions on scarp backs (see Figures 44 and 46).

The River Bend Fm siltstone, the second important stratigraphic unit in the area, forms the subcrop unit in the flat gently sloping non-hardbottom areas of the shoreface (see Figure 11). The regional outcrop pattern of Trent limestone and the River Bend siltstone coupled with the localized bathymetric highs and lows associated with the hardbottoms control the distribution of the major sediment types. Consequently, mapping the distribution of the major sediment types in this area was difficult due to the extremely complex bathymetry.

Compilation of the data suggested that there are several major types of surface sediment. Most of the shoreface is blanketed by shelly, very fine quartz sand to sandy quartz silt (see Figures 33 and 53 to 59). A significant portion of the silt and very fine quartz component of the surface sediment layer is probably derived from the periodic exposure and erosion of the Oligocene siltstone subcrop unit. The proportion of silt within the surface veneer varies from site to site and across areas of hardbottom. Protected areas generally contain a greater percentage of fine material particularly in the lee of outcrops. Clean fine to medium quartz sand is not an abundant sediment type (see Figures 44 to 46 and 48). It is generally restricted to hardbottom areas where the relief is relatively subdued.

Gravel size material is abundant and is generally comprised of limestone lithoclasts and molluscan material (see Figure 47). The shell material is most commonly fragmented and stained orange brown or gray-black in color. The majority of the gravel and gravelly sand is found near or on hardbottoms and within the linear shore-normal features that contain patchy, rippled coarse material (see Figures 49 to 51). Much of the sediment on the shoreface is related to and a by-product of epifauna (encrusters and grazers) and infauna (borers) activity (see Figures 24 to 28 and 46 to 52).

Isolated pockets of fluidized, black to olive gray mud occur in scattered areas of the shoreface. In areas where the fluidized mud was encountered, the bottom visibility was generally very poor, and, therefore, the relationship of the mud to the surrounding sediment and sea floor could not be determined. Divers reported that the mud appeared to form a mobile drape over both soft and hardbottom areas alike. It is likely that the ponds of mud are restricted to a localized topographic low and may be derived in part from the reworking of underlying estuarine units that crop out on the sea floor in the immediate area.

4.6 Shoreface Sediment Sequences

Data derived from the analyses of the various suites of vibracores and observations made during diver surveys indicated that the shoreface Holocene sediment sequence is thin and consisted of units of very fine quartz sands intercalated with sandy gravels and gravelly sands (see Figures 2, 53 to 59). Mud-rich back barrier sequences were recovered in a number of vibracores from backfilled paleo-channel features. Thickness of the modern sediment package across the entire study area, seaward of the active beach, ranged from less than one half inch (1.0 cm) in hardbottom areas to more than 6.2 feet (1.9 m) in intervening regions (see Figure 60). Figures 53 to 59 represent a series of shore-parallel and shore-normal vibracore transects that depict the variability of the major sediment types and the thickness of the units that comprise the Holocene shoreface sediment sequence. Inspection of the cross-sections shows that the thickest sequences recovered were either mud or silt rich in nature. The core data clearly indicated that there is a paucity of usable material in the area.

4.6.1 Mile Hammocks Bay to Alligator Bay

Johnston (1998) reported that the Holocene sediment cover on the shoreface in the northern part of the study area was generally too thin (0.65 feet [<20 cm]) to core, except in isolated bathymetric lows and in a narrow channel-like feature off New River Inlet (see Figure 8). With the exception of the gravel-rich accumulations at the base of hardbottom ledges and on some scarp backs, the broad limestone platform off New River Inlet was generally barren of sediment (see Figures. 8, 34, and 60). Only seven cores of variable length were successfully collected from the hardbottom areas in the northern portion of the study area. In all cores, recovered bioclastic-rich, fine to medium quartz sand was the most dominant sediment; abundant gravel lithoclasts were encountered near the bottom of the cored sequence (Johnston, 1998).

Several of the cores were collected from what has been interpreted to be the incised paleo-channel of New River, including cores NT500, NT502, and NRI1 (Johnston, 1998; Cleary and Riggs, 1999). The ICONS operations (Meisberger,

1979) also retrieved four cores from the paleo-channel (C98 - C101) during the mid 1970s. Figure 53 depicts a shore-normal transect of the cores recovered from this channel-like feature. In general, the cores collected by Johnston (1998) penetrated only a short distance before encountering rock or gravel. The short cores consisted of thin 1.3 feet (<40 cm) bioclastic, fine to medium sands, gravel and mud lenses. Core NRI 1 penetrated only 0.72 feet (0.22 m), before encountering a bluish gray fluidized mud that made core extraction difficult. The 0.30 feet (9.5 cm) of NRI 1 consisted of homogeneous fine quartz sand overlying mud. Core NT 500 located further seaward, between C 100 and C 99, recovered 5.2 feet (1.6 m) of inter-bedded sand and gravel. According to the core logs of Meisburger (1979) Core 100 contained 19.2 feet (5.87 m) of fine to medium quartz sand, calcareous sand and sandstone pebbles and calcareous sandstone, while Cores 98 and 99 recovered 0.75 to 4.5 feet (0.22 to 1.4 m) of the same units before encountering limestone.

Cores 98 to 101 from the ICONS operation were not available for inspection to verify the core descriptions of Meisburger (1979). If the descriptions of aforementioned ICONS cores are correct, and Cores 99 to 100 (see Figure 50) contain sand rather than calcareous sandstone, then this area of the shoreface warrants further investigation on a very detailed scale. These limited data suggested that the shoreface off New River Inlet, seaward of the 30 feet (9.1 m) contour, is the only region where significant sand deposits may occur in the northern part of the study area.

The fact that no other portion of the shoreface in this part of the study area is underlain by Holocene age tidal inlet or backbarrier deposits indicated that the recent transgression has eroded all earlier formed coastal lithosomes with the possible exception of those located 4.2 to 4.4 miles (6 to 7 km) off New River Inlet. The thicker sand accumulations south of New River Inlet may represent preserved tidal inlet sand bodies that were preserved during a rapid rise of sea level that quickly raised the depth of the shoreface ravinement. The rapid rise of sea level coupled with channel incision across the limestone platform may have contributed to the preservation of the suspected inlet-related sand bodies. Theiler, et al., (submitted) have identified a tidal inlet facies of considerable extent offshore Wrightsville Beach in an area where backbarrier deposits are generally lacking on the inner shoreface, except in small mud-filled tidal channels. The authors postulated that a rapid rise of sea level occurred ~7.3 ka that contributed to the preservation of the sand deposits by raising the level of ravinement.

4.6.2 Alligator Bay to Surf City's Southern Limit

Vibracore data and information from diver surveys indicated that the shoreface in the southern part of the study area consisted of relatively thin sequences of silty, fine to very fine quartz sands and interbedded with sandy gravels and gravelly sands (see Figures 54 to 59). The thickest modern sediment sequences cored 1.6 to 6.4 feet (0.50 to 1.95 m) were recovered from mud filled paleo-tidal creek channels incised into the underlying Oligocene siltstone unit or from isolated topographic lows that contain remnant sequences of estuarine material (see Figure 60).

McQuarrie (1998) recognized a variety of incised Quaternary fluvial channel features offshore Topsail Beach. McQuarrie (1998) indicated that many of the channels are continuous and could be traced across the Topsail Beach shoreface. HDR (2002) documented that many of the features on the Topsail Beach shoreface were infilled with dark gray-brown, organic estuarine mud. It is highly unlikely that similar channel features found on the Surf City North Topsail shoreface will provide beach fill quality material. The landward portion of some of the shallow channels extends beneath the barrier island and bar built estuary. The small coastal plain, mud-dominated estuaries incised into the mainland between Alligator Bay and Virginia Creek are the modern analogues of the offshore features (see Figures 57 to 58). Remnants of Holocene backbarrier sequences were recovered during coring operations in isolated areas (see Figures 54 to 59). The estuarine sequences generally contained thin, interbeds of mud and silty, shelly sand and occasionally organic rich lenses (peat).

Figures 54 to 59 represent a series of shore-parallel and shore-normal vibracore transects that depict the variability of the sediment type and thickness of the units that comprise the modern shoreface sediment sequence. These data suggest the sediment cover is patchy and extremely thin. The majority of the individual sand units present, as well as other modern sedimentological units (muddy sands and gravel), are less than 1.3 feet (0.40 m) thick. The burrowing activity of organisms commonly obscures the contacts of many of the layers; and hence, many of the units appear to grade into the underlying units. Commonly, the sediment sequences are extensively mottled and a number of cores recovered contain units that were homogenized due to the extensive bioturbation. The burrowing activity of organisms probably contributes to the fine-grained nature of the longer core sequences recovered in the areas underlain by the siltstone. The burrowing activity of the infauna commonly extends into the underlying weathered calcareous siltstone and weathered limestone (see Figures 55 to 59).

Core logs and vibracore transects (see Figures 54 to 59) illustrate that gravel rich units are widespread and comprise major portions of the thin shoreface sequences. The units contain varying amounts of silt and sand. The shell and lithic gravel units commonly form the basal unit of the modern sediment sequences and are generally capped by 0.32 to 0.82 feet (10 to 25 cm) thick, very fine to fine grain quartz sand units. Megascopic analyses of representative gravel-rich samples indicated that the gravel-rich samples were classified as sandy gravels and gravelly sands. Gravel content comprised as much as 95 percent of some samples (see Figures 51 to 56). Gravel rich sequences were typically found in areas where limestone forms the subcrop unit and near exposures (hardbottoms).

Figure 60, which depicts the thickness of the modern sediment sequence, clearly shows that much of the southern portion of the study area is covered by sediment sequences less than ~1.0 feet (30 cm) thick. The area with the thickest deposits of sediment (> 3.0 feet [>1.0 m]) appears to be restricted to a region located within the central portion of the shoreface offshore the southern portion of North Topsail Beach. The sea floor in this area is characterized by linear shore-normal depressions (RCDs) that contain fields of rippled sand and gravel. This highly irregular region of the shoreface is underlain by the Oligocene siltstone. A second area where relatively thick sediments are found is located offshore the southern portion of Surf City seaward of Topsail Sound (see Figure 60).

Figures 54, 55, and 59, are shore-parallel (B-B' and C-C') and shore-normal (F-F') vibracore transects that depict the variability of the sediment types and thickness of the cored sequences in the aforementioned area offshore North Topsail Beach. Although some relatively thick sediment sequences occur offshore the southern portion of North Topsail Beach, almost all sequences are comprised of either organic mud, very fine sand units or contain gravel beds. Observations from diver surveys have indicated that the upper part of the sediment sequence 1 to 2 feet (0.30 to 0.60 m) in this area contains inter-bedded sand and gravel, and the sequence contains appreciable amounts of very fine sand and silt. Topographic irregularities in the subcrop unit probably dictated where thicker sediment accumulations were preserved. A broad highly irregular area containing thinner sediment sequences 0.98 to 3.3 feet (0.30 to 1.0 m) surrounds the aforementioned region where sediment thickness exceeds 3.3 feet (1.0 m). Most of the sediment sequences cored also contain very fine sands with occasional muddy material and minor gravel lenses (Figures 54 and 55).

Ponding of sediments against the hardbottom scarps and in depressions between ridges may have produced "thick" (0.91 to 1.2 m [-4feet]) very localized deposits. However, due to the density of sampling sites and the complex nature of the hardbottoms and subcrop units, it was difficult to map the thickness of the modern sediment sequence across the shoreface south of Alligator Bay. The distribution and the relief of the hardbottoms clearly show that the nature of the underlying stratigraphic units determines the resultant seafloor morphology. The lithologic character of the underlying stratigraphic units, Pleistocene sea level oscillations and the Holocene transgression also have played a role in determining the thickness of the modern sediments. Localized relief in hardbottom areas and the depth to the subcrop unit is probably related to a combination of variables, including the resistance to erosion of the various rock type and the resultant paleo-drainage network developed during the various low stands of sea level. Differential erosion of the Trent Fm limestone and River Bend Fm siltstone ultimately dictated the accommodation space that is reflected in the sediment thickness depicted by Figure 60.

4.7 Sand Resources

The primary objective of this investigation was to provide an assessment of the availability beach fill quality material for the construction and maintenance of a storm reduction project along the North Topsail Beach Surf City oceanfront in Pender and Onslow Counties. The basis for the sand resource evaluation was a diverse data set consisting of geological and geophysical information collected during the past decade for investigations pertaining to the nature of the geological framework in this sector of southeastern North Carolina. The assessment was based on the integration of data collected for site-specific studies (Johnston, 1998; and McQuarrie, 1998) or from regional investigations (Meisburger, 1977 and 1979; and Cleary, unpublished data). Data from diver surveys and core descriptions, coupled with the geophysical data, provided the framework for the evaluation of sand resource potential. The principal constraints involved in determining the availability of the sand resources were the location of deposits with respect to 30 feet (9.1 m) isobath, the area extent of the sand sequence, its thickness, sediment compatibility (gravel and mud content), and the proximity of the deposits to environmentally sensitive hardbottoms.

4.7.1 Mile Hammocks Bay to Alligator Bay

Aside from the New River Inlet ebb-tidal delta, which contains as much as 7.0 million cy (5.3 million m^3) of material, the shoreface off the extreme northern portion of North Topsail Beach contained only one potential target area (Area I) where beachfill quality sand may be available in significant quantities (see Figure 61). This target area lies offshore North Topsail Beach on the southwest flank of the broad limestone platform seaward of the New River Inlet. The few cores that have recovered potentially usable material were retrieved along what has been interpreted to be the remnants of the paleo-channel of New River (Johnston, 1998 and Cleary and Riggs, 1999). The vague core descriptions of the ICONS vibracores suggest as much as 4.5 feet (1.4 m) of bioclastic quartz rich sand may be present along the trace of the ancestral river channel (Meisburger, 1979). The exact volume of material (compatible or otherwise) within this potential borrow area was difficult to determine due to the lack of detailed core and high-resolution seismic data. Utilizing an assumed average sediment thickness of 3.0 feet (1.1 m), the volume of material contained in Area I is estimated to be approximately 1.4 million cy (1.1 million m^3). Although the prospect of locating significant accumulations of sand in this area is probably very low, nonetheless, the area warrants more detailed investigations.

4.7.2 Alligator Bay to Surf City's Southern Limit

Compilation of data used in the conduct of this study indicated that the numerous areas of hardbottom (limestone exposures) and the shallow subcrop depths precluded the existence of significant accumulations of usable beach fill material. Given the fact that 40 million cy (31.2 million m^3) of compatible material are needed for the 50-year project, it is very unlikely that the shoreface can provide that volume of material. Approximately 70 percent of the shoreface southwest of Alligator Bay has no potential for significant volumes of compatible beach fill material (see Figure 61). However, there are several areas (Areas II through V) offshore the southern portion of North Topsail Beach and Surf City where thin (<3 feet [~1.0 m]) sandy sequences may have accumulated (see Figure 61). However, the compatibility and continuity of these materials in these areas is very questionable. The core and diver survey data suggested that the potential for finding significant quantities of beach compatible material in these areas is marginal at best (see Figure 62).

The irregularly shaped Area II (see Figure 61) covers approximately 4.8 mi^2 (12.4 km^2) of the shoreface. Area II is bordered by hardbottoms of variable relief and the target area is located in a region of the shoreface where the calcareous siltstone forms the subcrop unit. This irregular shaped depression may represent the remnants of a former drainage system that formed during low stands of sea level (see Figure 25). The thick sediment sequences recovered in cores from this area contained Holocene estuarine units. Most of the sediment sequences comprising the backbarrier facies were muddy in nature. The sequences consisted of a thin sand veneer (0.80 feet [0.25 m]) overlying interbedded dark gray muds and thin sand lenses. Vibracores VC 12, 31, 32, and 37 recovered 5.2 to 6.4 feet (1.4 to 1.6 m) thick sequences of bioturbated, interbedded very fine quartz sand, silt and organic-rich, dark gray mud (see Figures 62). The sediment sequences recovered are underlain by Oligocene siltstone. Core VC 36 was the only core recovered that contained a relatively thick sequence of sand rich material (see Figure 62). The modern sediment (sand) sequence (0.60 feet [0.20 m]) was underlain by ~1.1 m thick sequence of mottled quartz sand and thin muddy sand units. The thicker sand rich units in the cores from this area probably represent small shallow tidal channels or sand rich portions of tidal flats.

The thickness of quality beach fill material in Area II is likely to be extremely variable and, at best, probably averages less than 3 feet in thickness in very restricted areas. Utilizing an assumed average sediment thickness of 3.0 feet (0.91 m), the volume of material contained in Area II is estimated to be approximately 15.0 million cy (11.7 million m^3). A significant portion of this volume of material may contain appreciable amounts of fine material and/or gravel. The proximity of hardbottoms may restrict the exploitation of sand resources in the narrower regions of Area II that are within 1,640 feet (500 m) of "designated" high-relief rock exposures. Areas designated IIa and IIb are the only viable areas within the confines of Area II where there is a good possibility of finding beach fill material. Areas IIa (1.5 $mile^2$ [3.9 km^2]) and IIb (0.7 mi^2 [1.8 km^2]) comprise approximately 45 percent of Area II (see Figure 61). Using liberal estimates of sand thickness (2.0 feet for IIa and 3.0 feet for IIb), the potential volume of usable sand in these areas is estimated to range from 2.1 to 3.1 million cy (1.6 to 2.4 million m^3) for Areas IIa and IIb, respectively. If only 70 percent of the sediment is compatible fill material, the available combined volumes of Areas IIa and IIb (5.1 million cy [4.0 million m^3]) would provide 3.6 million cy (2.8 million m^3), an amount that may be sufficient for the initial construction of a small portion of the proposed beachfill project. A detailed seismic survey, coupled with a suite of forty well-placed vibracores, should provide the necessary data to evaluate the quality and continuity of the usable material within this area.

Area III, located southwest of Area II, is an 8.4 mi^2 (21.8 km^2) area that may contain as much as 2.3 million cy (1.8 million m^3) of questionable quality material. This area is also underlain by the calcareous siltstone. The volume of potentially usable sand material contained in this area has been based on an assumed average sediment thickness of 2.5 feet (0.76 m). This value was derived from approximately 16 diver surveys and from core logs of vibracores 25 and 01. Vibracore 25 contained ~3.0 feet (0.91 m) of gravelly sand while core 01 recovered only 1.3 feet (0.41 m) of fine quartz sand. The sediment sequence that underlies this area may contain large percentages of silt and very fine sand and gravel. The presence of hardbottoms may also impact the availability and exploitation of sand resources in the narrower regions of Area III (see Figures 61 and 62).

Area IV, located approximately 4.5 miles (7.2 km) offshore Stump Sound, is another area of the shoreface with a marginal sand resource potential. This 1.6 mi^2 (4.1 km^2) area borders the seaward fringes of Area II. The materials within this target area accumulated within what is interpreted to be a shallow depression surrounded by limestone hardbottoms (see Figure 25). Diver surveys in other parts of the area indicated that as much as 3.0 feet (0.91 m) of fine to very fine quartz sand and a basal gravel unit mantled the underlying siltstone. If one assumes that the average sediment thickness in this area is 2.0 feet (0.61 m), the volume of potentially usable material contained in this region is approximately 0.3 million cy (0.23 million m^3).

Area V encompasses approximately 1.1 mi^2 (2.8 km^2) where data are basically non-existent. Only two vibracores have been recovered from sites along the western boundary of the area. Both cores recovered relatively thick estuarine sequences. The surface sand veneer was less than 1.1 feet (0.35 m). Core contained ~4.8 feet (~1.45 m) of interbedded thin units of fine quartz sand and organic rich mud (see Figure 62). The backbarrier units recovered in the core probably represent a potion of tidal flat complex that has been preserved in a shallow depression. The early Holocene sediment package presumably rests on the calcareous siltstone. Assuming the average sediment thickness in this area is approximately 2.0 feet (0.61 m), it is speculated that as much as 1.5 million cy

(1.2 million m^3) of material is contained in the area (see Figures 60 to 62). Only very detailed follow-up geophysical and geological surveys will provide the needed data to trace the sand rich facies of this early Holocene estuarine lithosome.

5.0 RECOMMENDATIONS FOR FUTURE WORK

The next logical step in the evaluation of the sand resource potential in the target areas involves the use of a high quality Chirp system, such as the Edgetech 512i unit. Table 3 lists the corner points for the recommended seismic surveys of Borrow Areas I through IV. The data from the geophysical surveys would be crucial to the detailed mapping of the three-dimensional aspects of the sediment sequence (see Figure 61). Standard Chirp units will not provide the type or quality of data needed to adequately resolve the stratigraphy of the borrow areas for exploitation purposes.

In order to adequately ascertain the compatibility of the materials within the target areas, the USACE should begin the formulation and implementation of a detailed exploratory coring program. This effort can be viewed as a stand-alone operation in all target areas. Data derived from suites of closely spaced cores would provide the information needed to define the complex three-dimensional aspects of the discontinuous thin sandy units and the inter-bedded muddy sand and gravel-rich units. Core data would also provide the necessary means of groundtruthing the Chirp data in areas where degraded (weathered) sandy limestone, calcareous sandstone or siltstone underlie what is interpreted to be a thick sequence of usable material.

The ubiquitous nature of the environmentally sensitive hardbottoms may require additional high-resolution sidescan sonargraph surveys after specific target sites have been identified for dredging operations.

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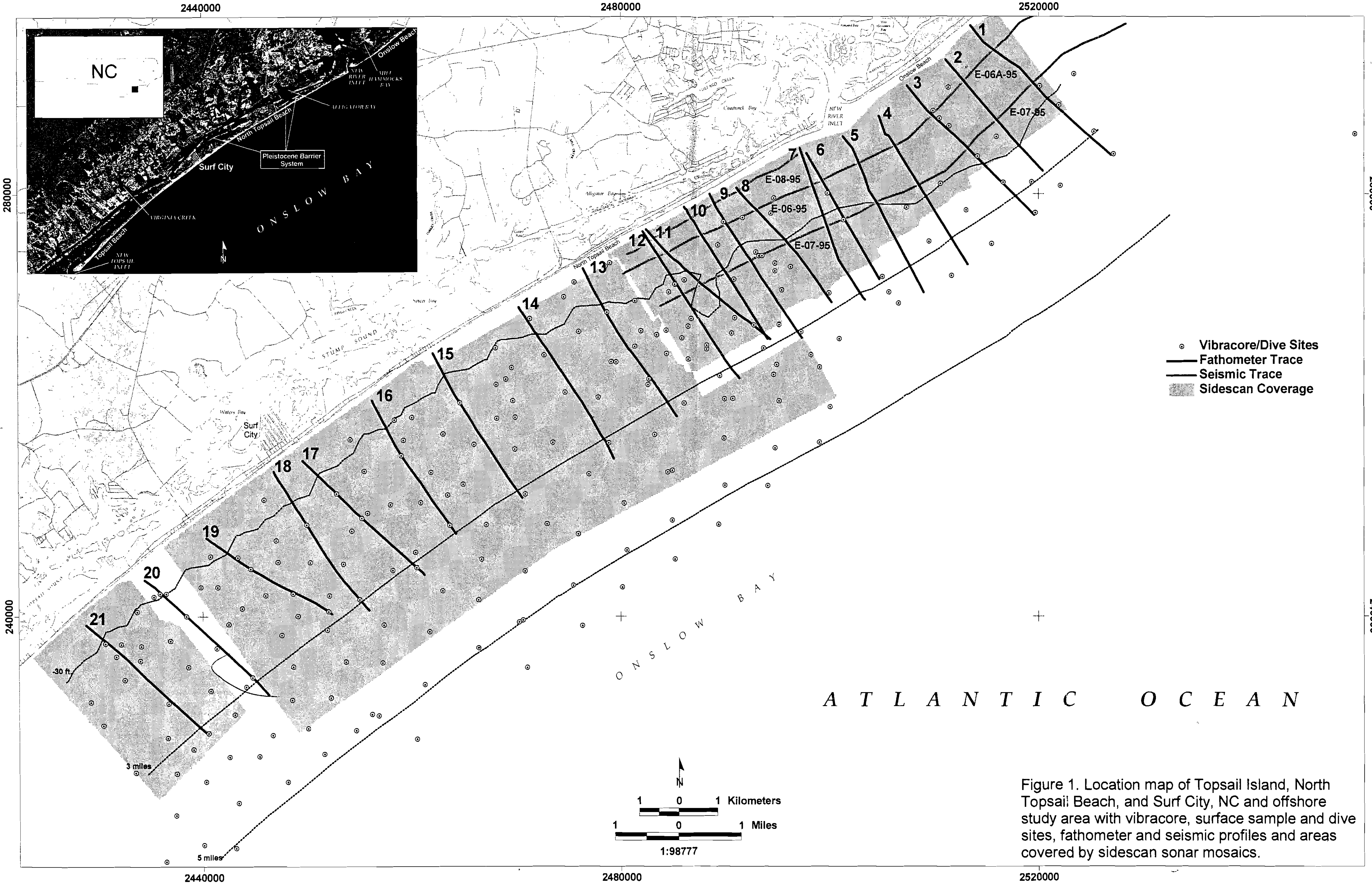


Figure 1. Location map of Topsail Island, North Topsail Beach, and Surf City, NC and offshore study area with vibracore, surface sample and dive sites, fathometer and seismic profiles and areas covered by sidescan sonar mosaics.

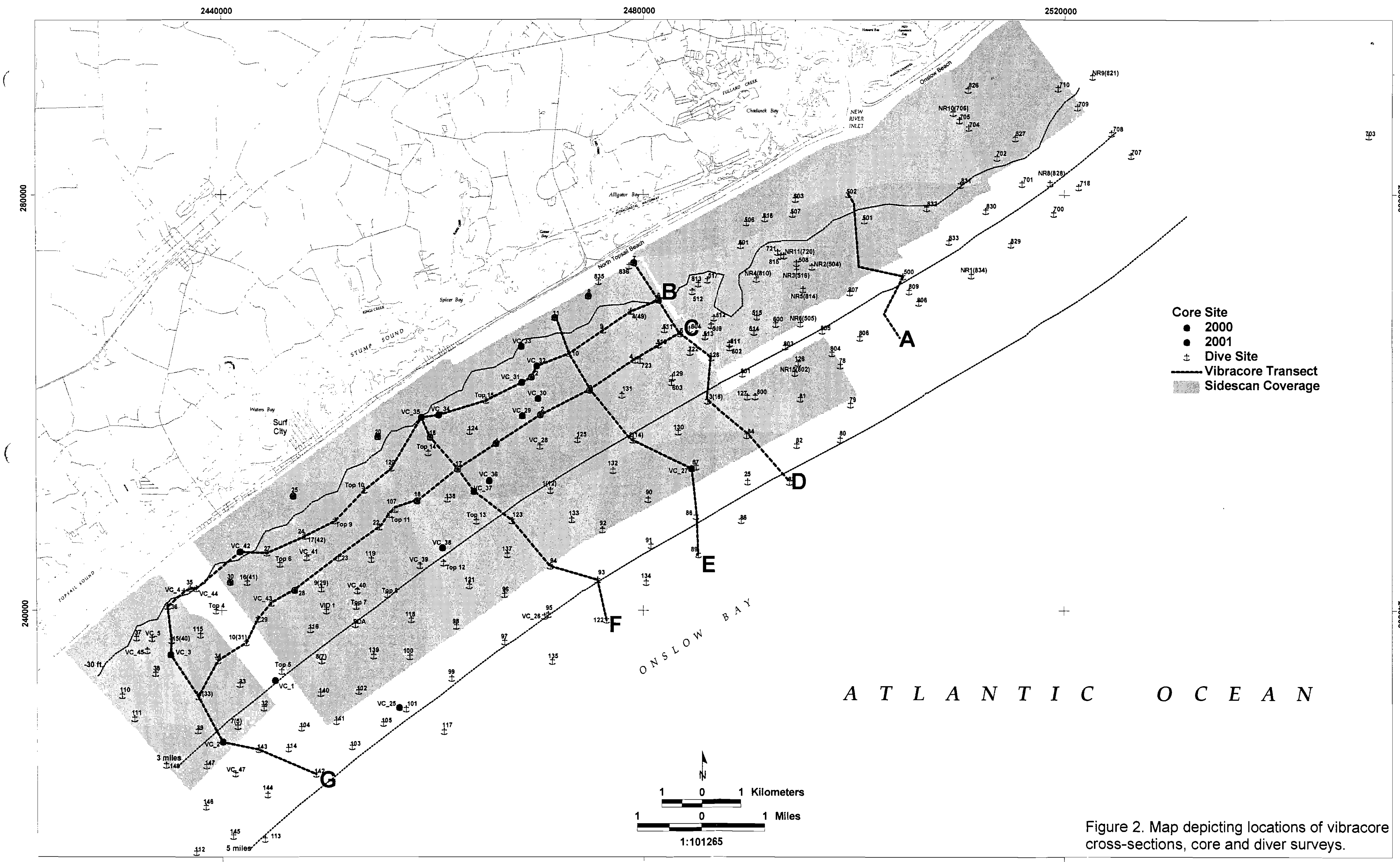


Figure 2. Map depicting locations of vibracore cross-sections, core and diver surveys.

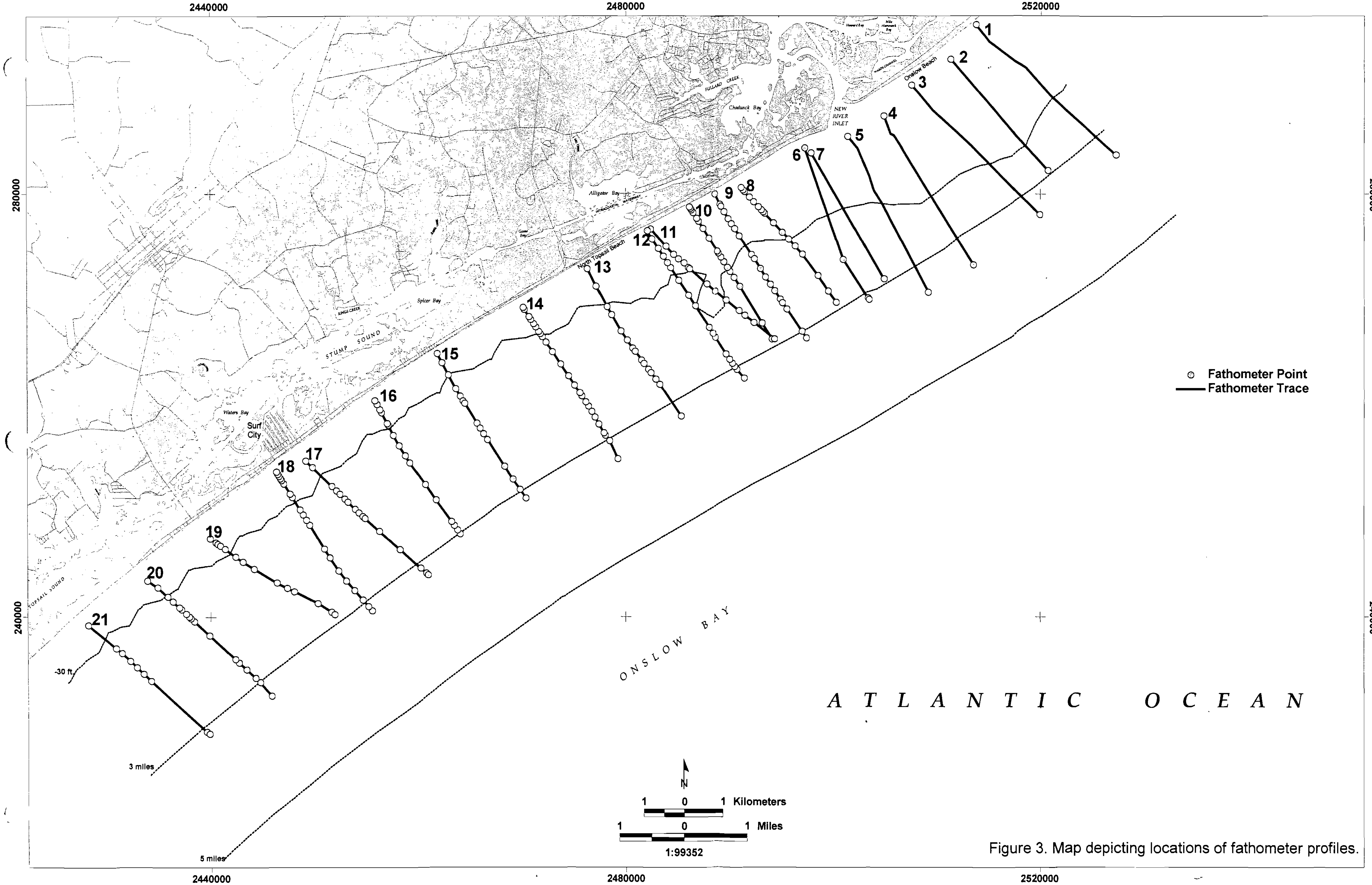


Figure 3. Map depicting locations of fathometer profiles.

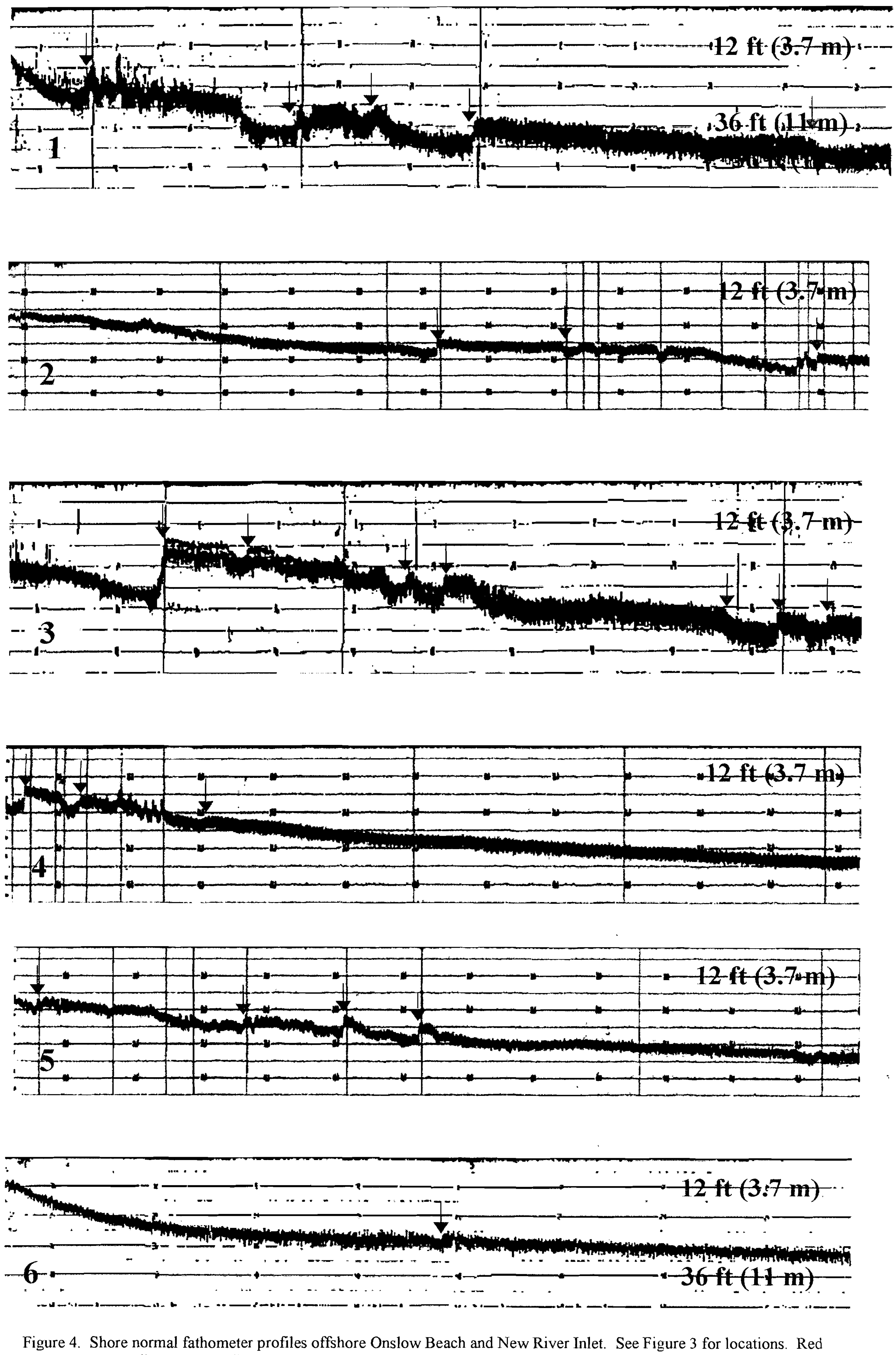


Figure 4. Shore normal fathometer profiles offshore Onslow Beach and New River Inlet. See Figure 3 for locations. Red Arrows represent limestone hardbottoms (Scarps). Note irregular nature of profiles. Horizontal scale is approximately 3 miles (4.8 kilometers).

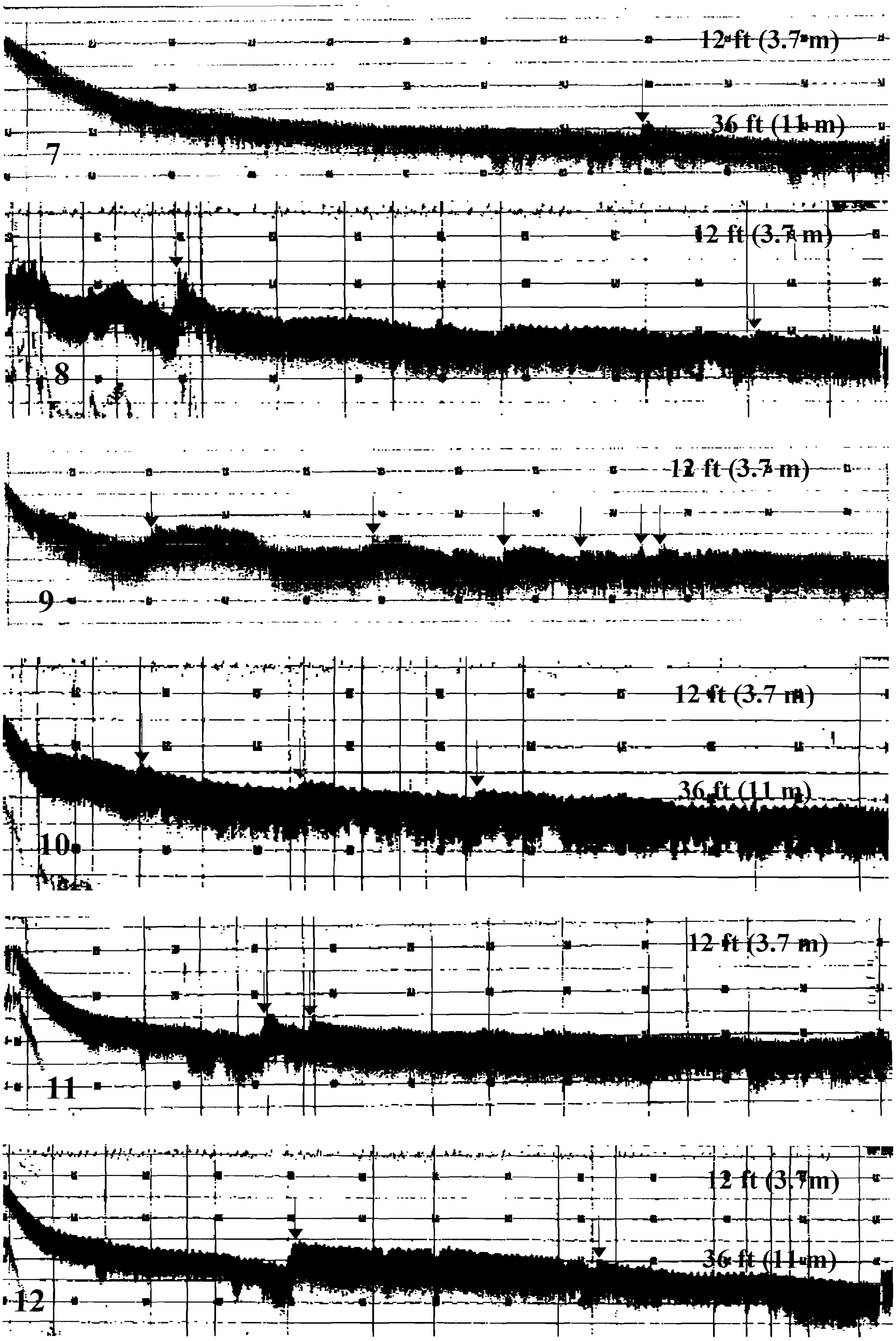


Figure 5. Shore normal fathometer profiles offshore North Topsail Beach. See Figure 3 for locations. Red Arrows represent limestone hardbottoms (Scarps). Note irregular nature of profiles. Horizontal scale is approximately 3 miles (4.8 kilometers).

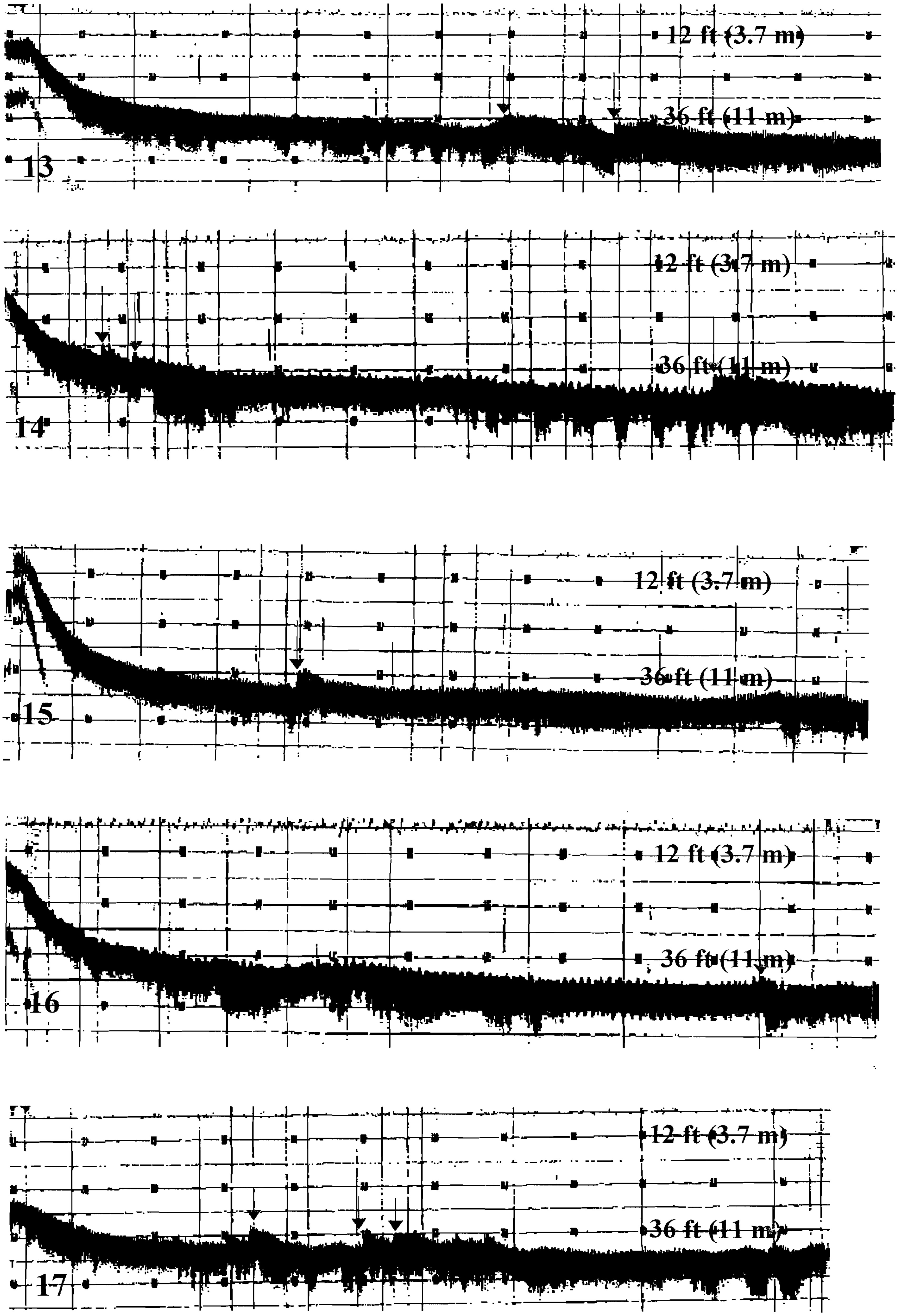


Figure 6. Shore normal fathometer profiles offshore North Topsail Beach - Surf City. See Figure 3 for locations. Red arrows represent limestone hardbottoms (Scarps). Note irregular nature of profiles. Horizontal scale is approximately 3 miles (4.8 kilometers).

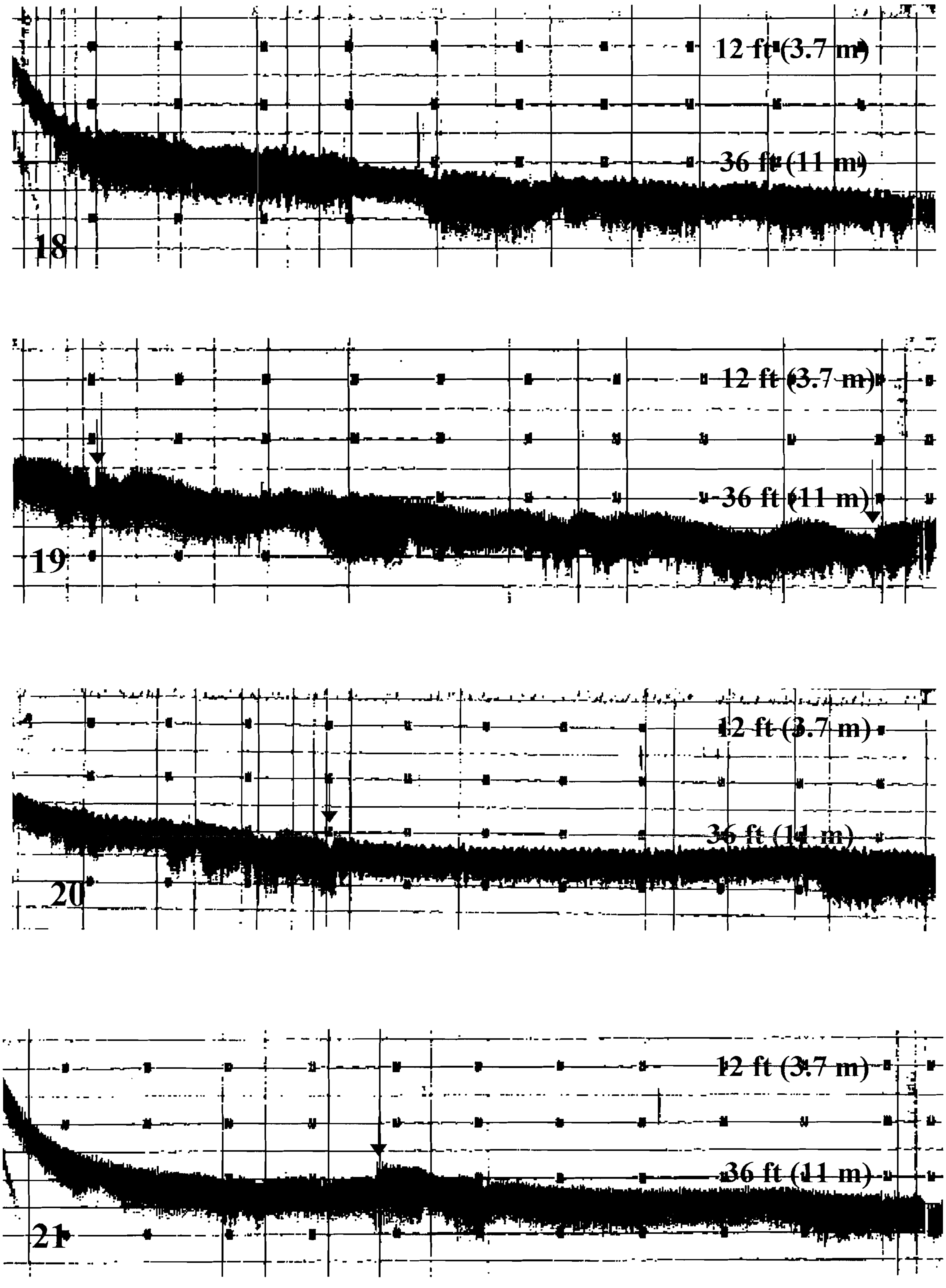


Figure 7. Shore normal fathometer profiles offshore Surf City. See Figure 3 for locations. Red arrows represent limestone hardbottoms (Scarps). Note irregular nature of profiles. Horizontal scale is approximately 3 miles (4.8 kilometers).

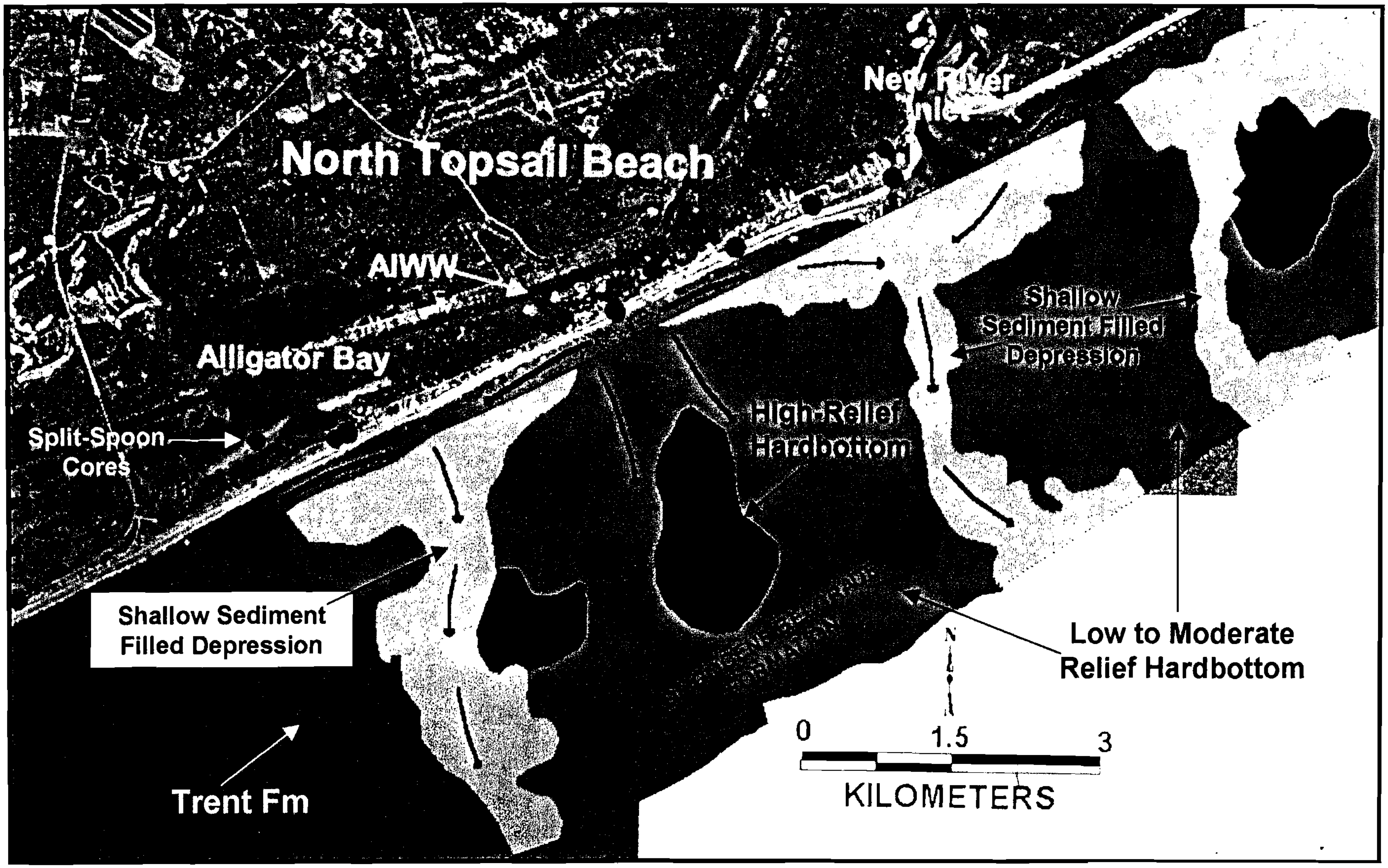


Figure 8. Map depicting nature of shoreface hardbottoms. Photograph (1993) depicts location of split-spoon cores recovered along barrier. Data indicate a saddle in the underlying limestone occurs beneath the barrier in the vicinity of Alligator Bay and the shallow linear depression that extends seaward from the bay (After Johnston, 1998; Cleary, 1999; and Cleary et al 2001).

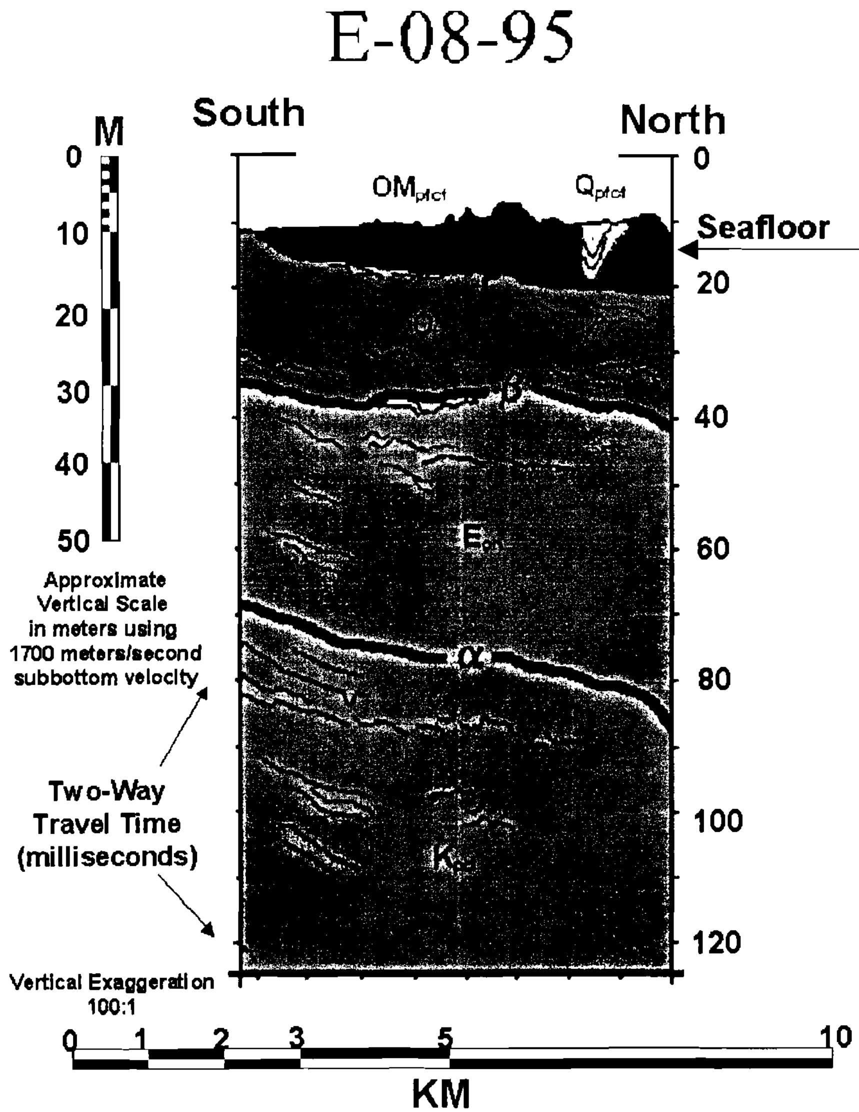
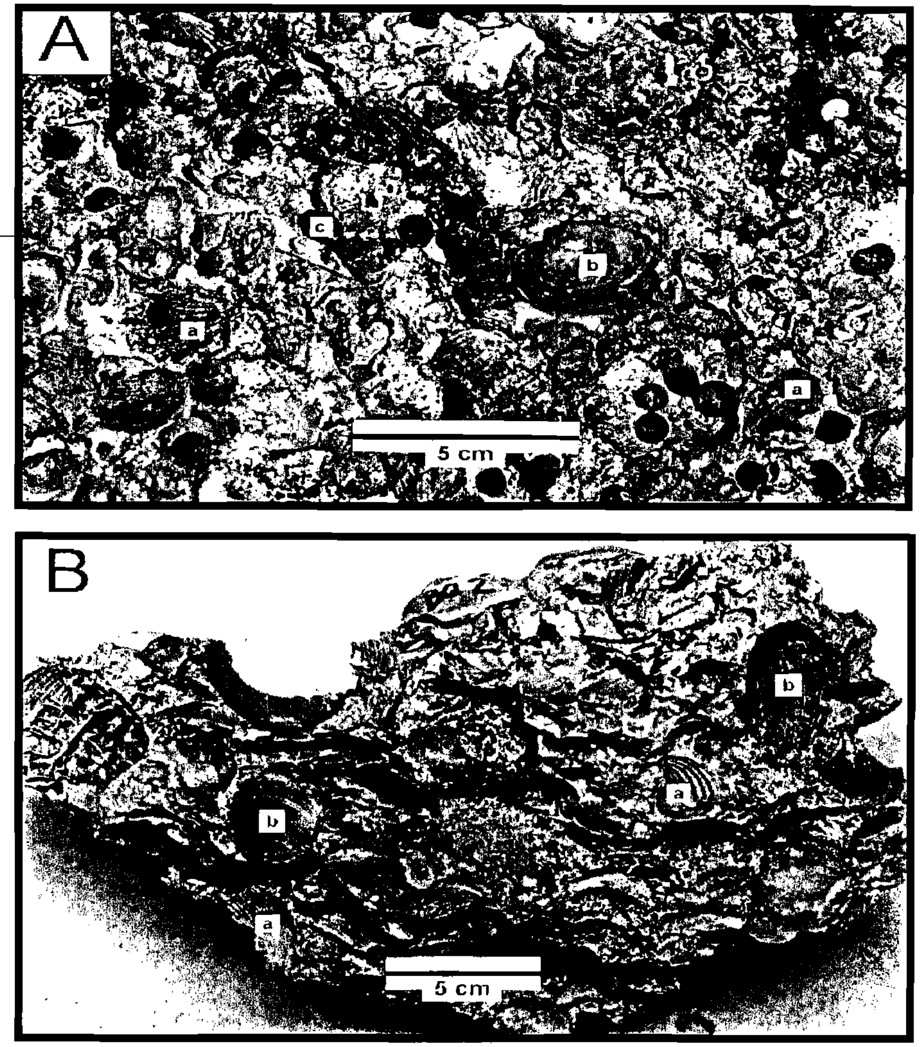


Figure 9. High resolution seismic line offshore North Topsail Beach and photographs of limestone. See Figure 1 for location of seismic line (After Johnston, 1998 and Cleary and Riggs, 1999).



Photographs of clasts of limestone from the Belgrade Formation. **A**. Bored sandy bio-moldic limestone exposure on Onslow Beach shoreface off New River Inlet. **B**. Same rock unit exposed in Belgrade quarry near Jacksonville, NC. The Belgrade Fm underlies much of the northern segment of the study area from Mile Hammocks Bay to Alligator Bay (Modified after Johnston, 1998).

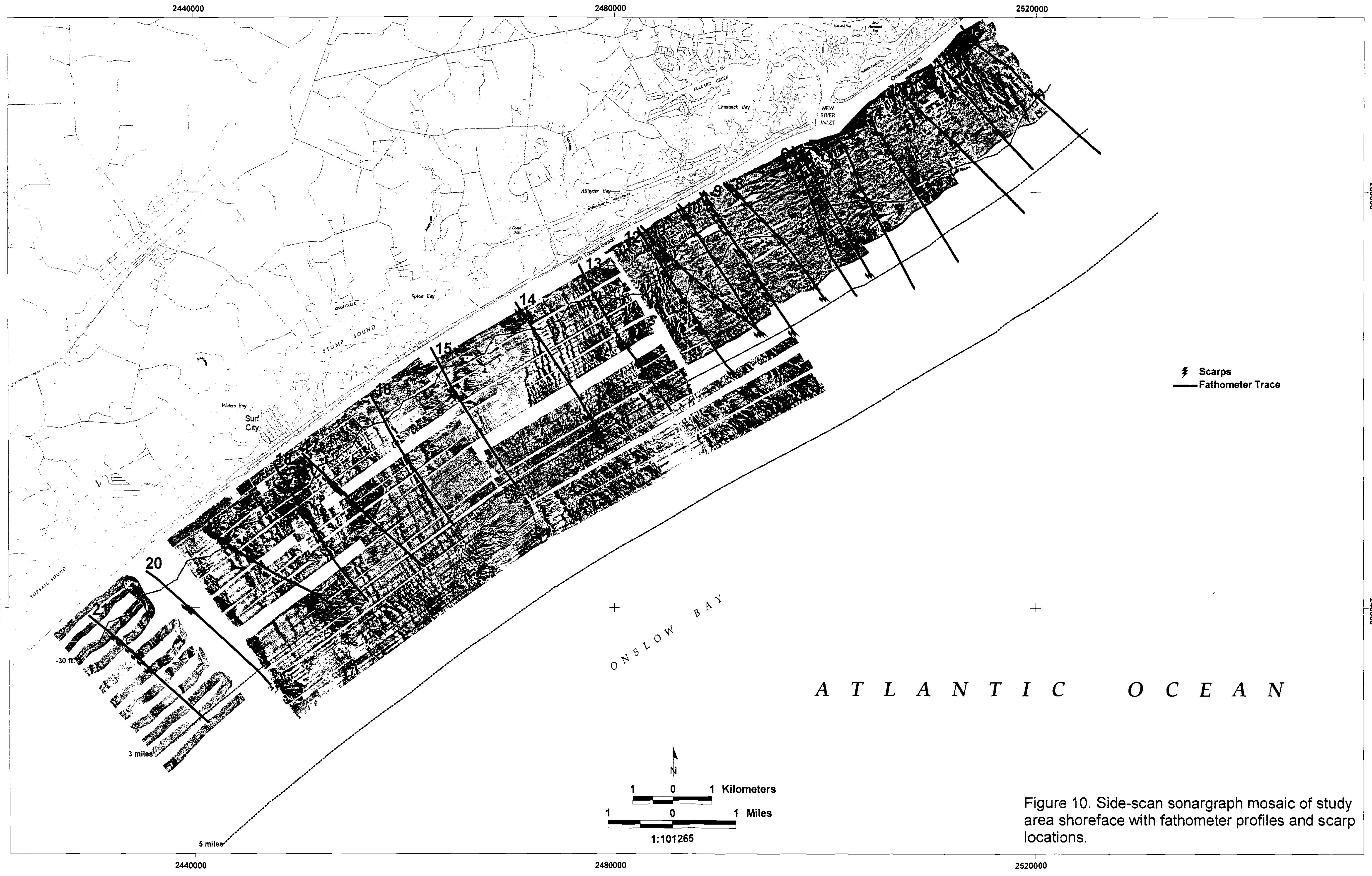


Figure 10. Side-scan sonargraph mosaic of study area shoreface with fathometer profiles and scarp locations.

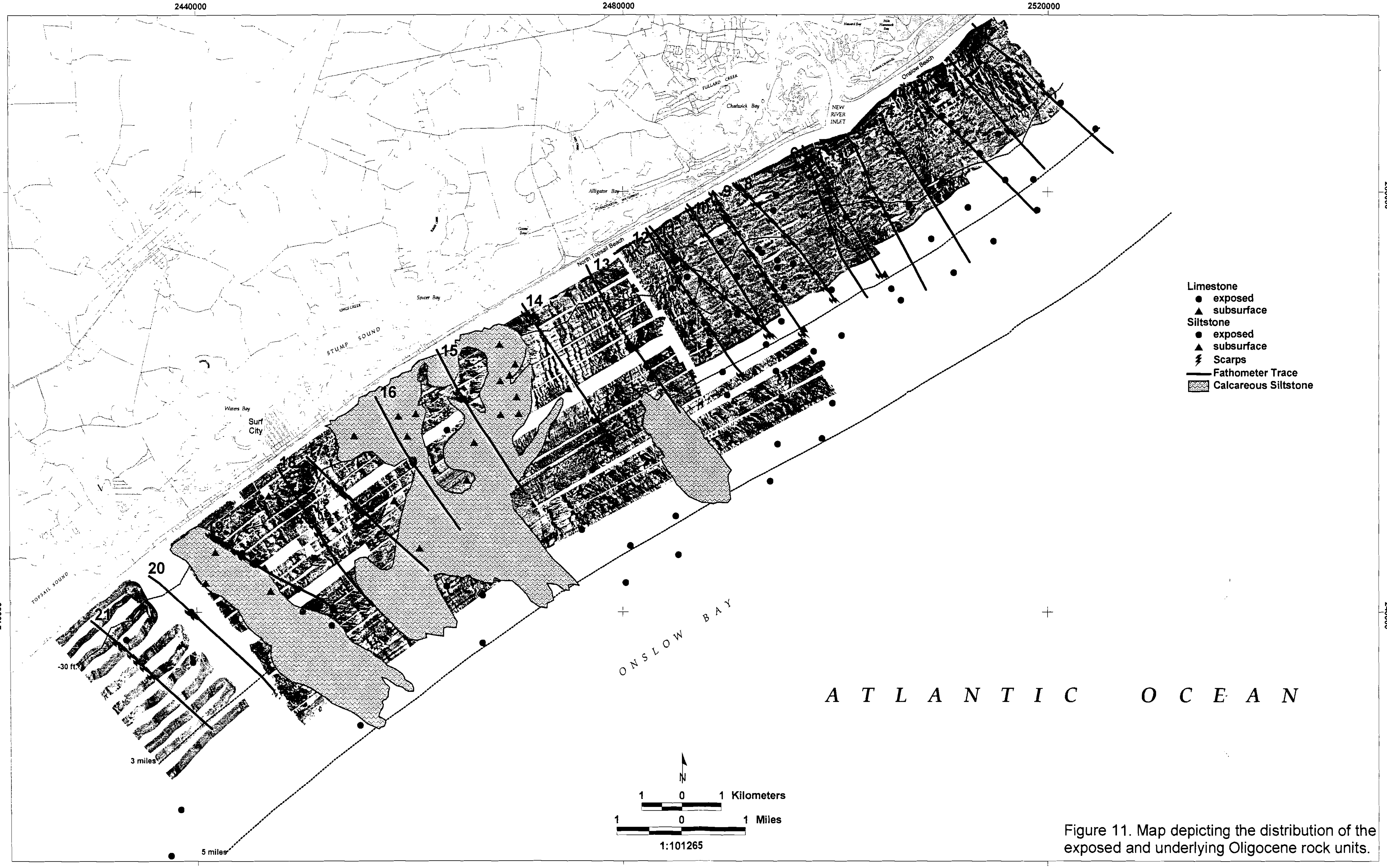


Figure 11. Map depicting the distribution of the exposed and underlying Oligocene rock units.

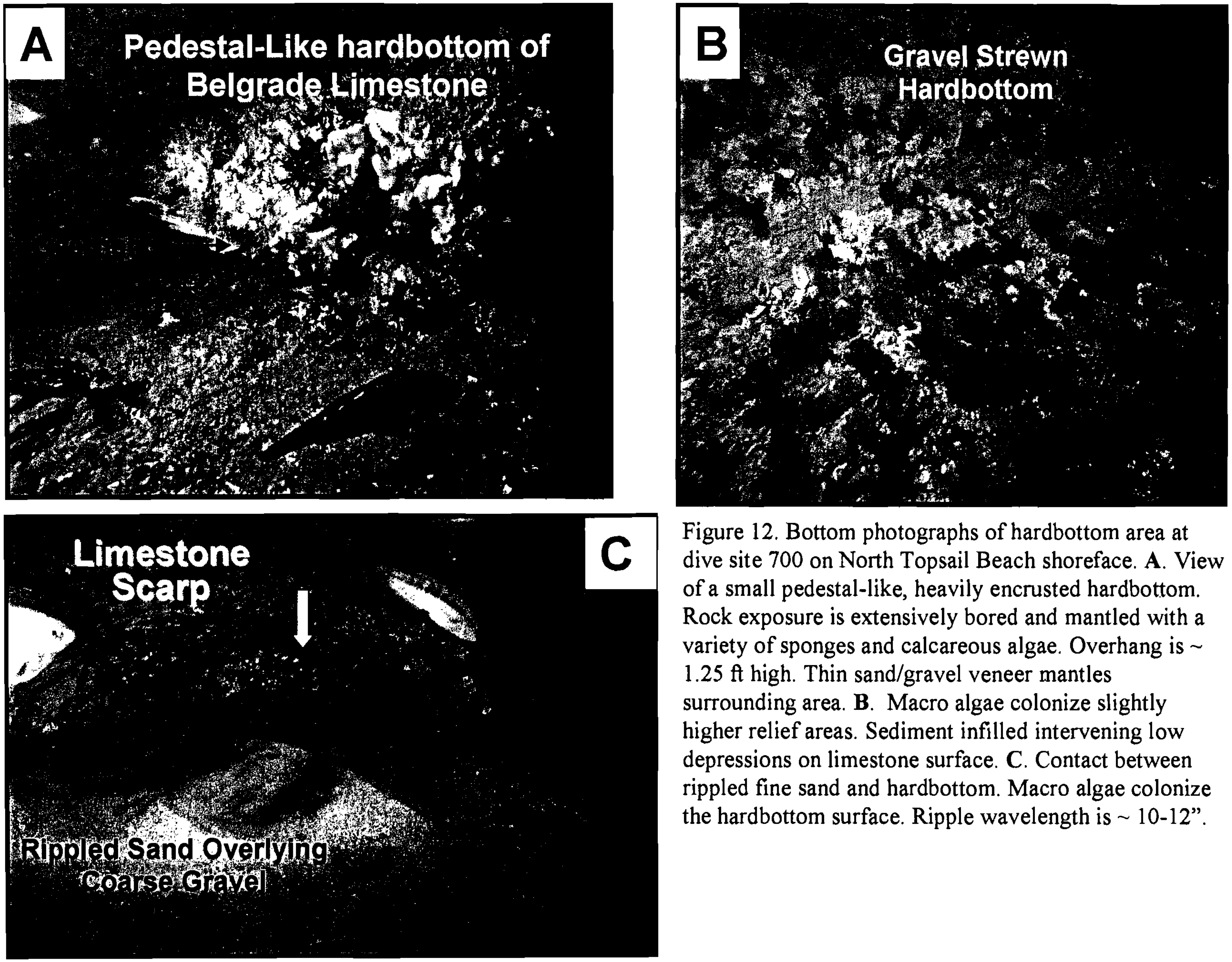


Figure 12. Bottom photographs of hardbottom area at dive site 700 on North Topsail Beach shoreface. **A**. View of a small pedestal-like, heavily encrusted hardbottom. Rock exposure is extensively bored and mantled with a variety of sponges and calcareous algae. Overhang is ~ 1.25 ft high. Thin sand/gravel veneer mantles surrounding area. **B**. Macro algae colonize slightly higher relief areas. Sediment infilled intervening low depressions on limestone surface. **C**. Contact between rippled fine sand and hardbottom. Macro algae colonize the hardbottom surface. Ripple wavelength is ~ 10-12".

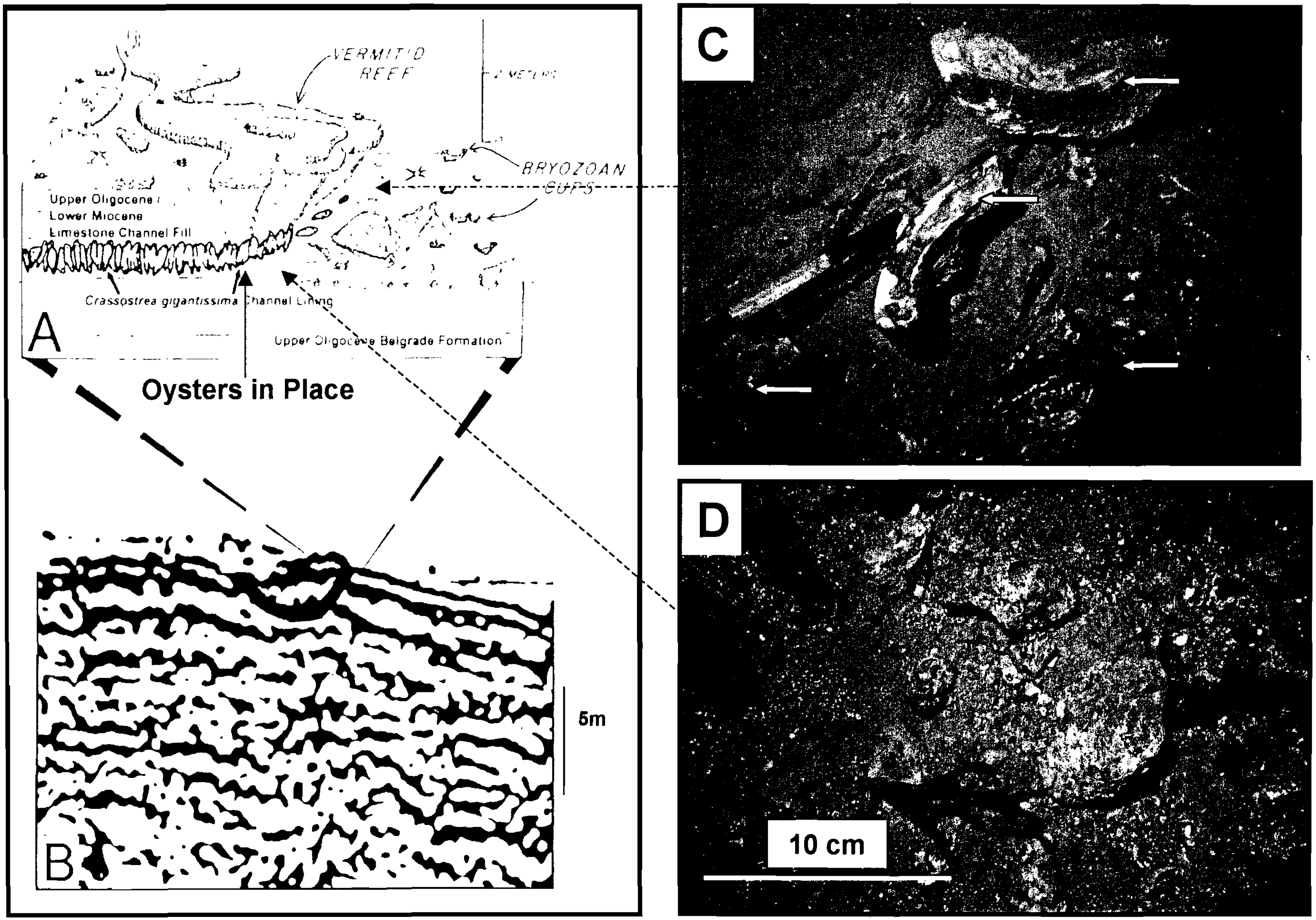
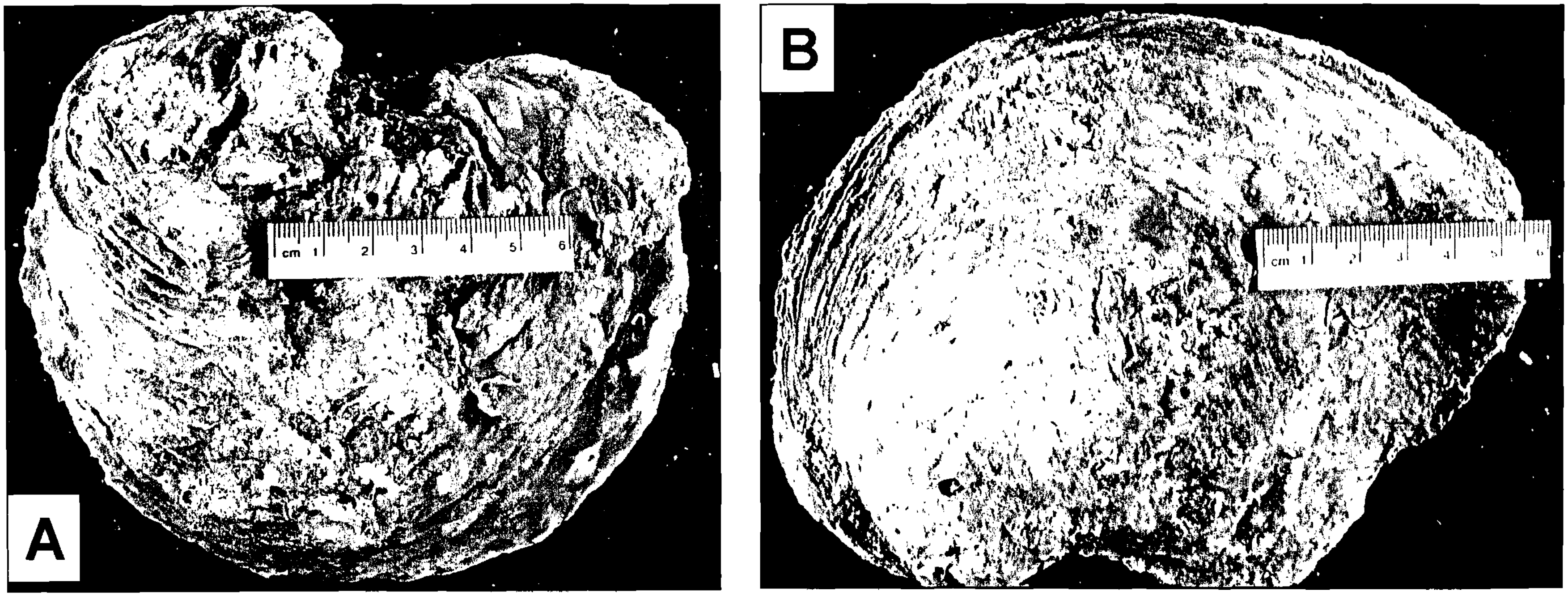
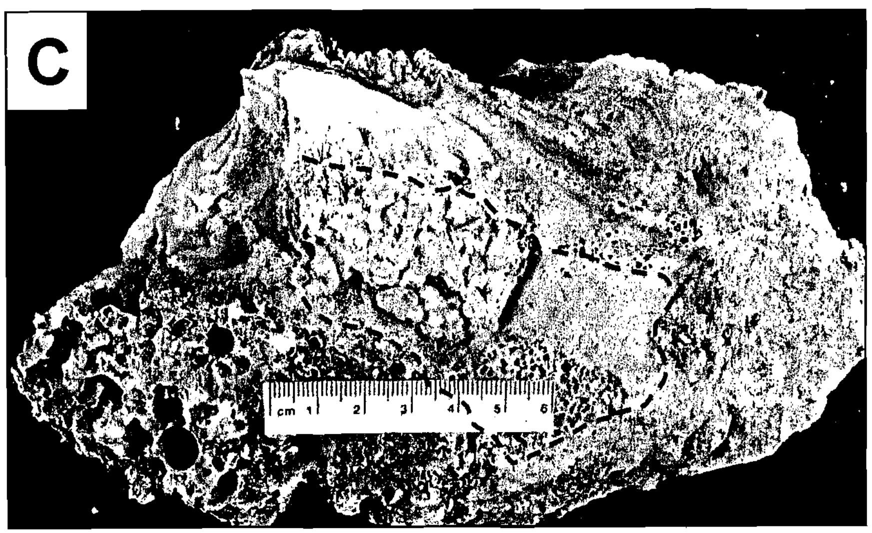


Figure 13. Cross-sectional view of Crassostrea gigantissima channel structure forming moderate relief hardbottom. **A**. exposed channel fill (calcareous cemented sandstone) and giant oysters lining channel bottom (after Crowson,1980). **B**. Enlarged seismic profile section (E-06-95) showing channel structure incised into Belgrade Fm. (A & B modified after Johnston 1998). **C**. Scattered oyster valves at Site 504. **D**. Algal encrusted rubble at base of scarp at site 516.





Fiugure 14. Giant oyster (Crassostrea Gigantissima) valves. **A**. Articulated oyster from Site 720. **B**. Articulate oyster with few encrusting organisms from Site 720. **C**. Fragment of valve estimated to be >50cm in length. Interior is filled with sandy lime mud (micrite).

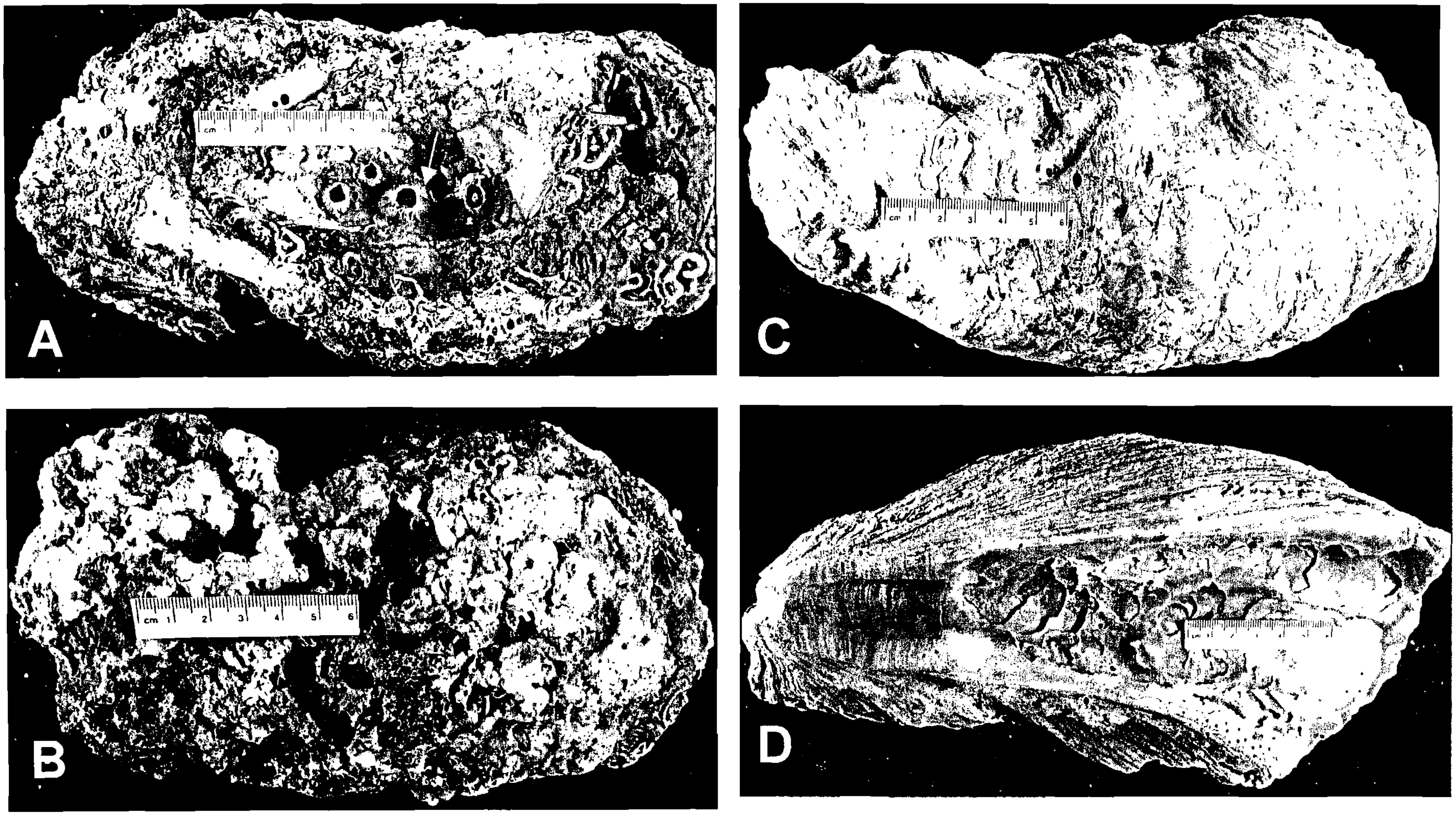


Figure15. Giant oyster (Crassostrea Gigantissima) valves. **A**. Encrusted disarticulated oyster valve from Site 721 offshore North Topsail Beach (interior view). **B**. Bored and encrusted disarticulated oyster valve from Site 721 (top view) **C**. Large fragment of disarticulated valve of oyster estimated to be ~75cm in length from Site NTP 5014. D. Interior view of valve pictured in "C". Most encrusting organisms have been worn off due during landward transport of clast.

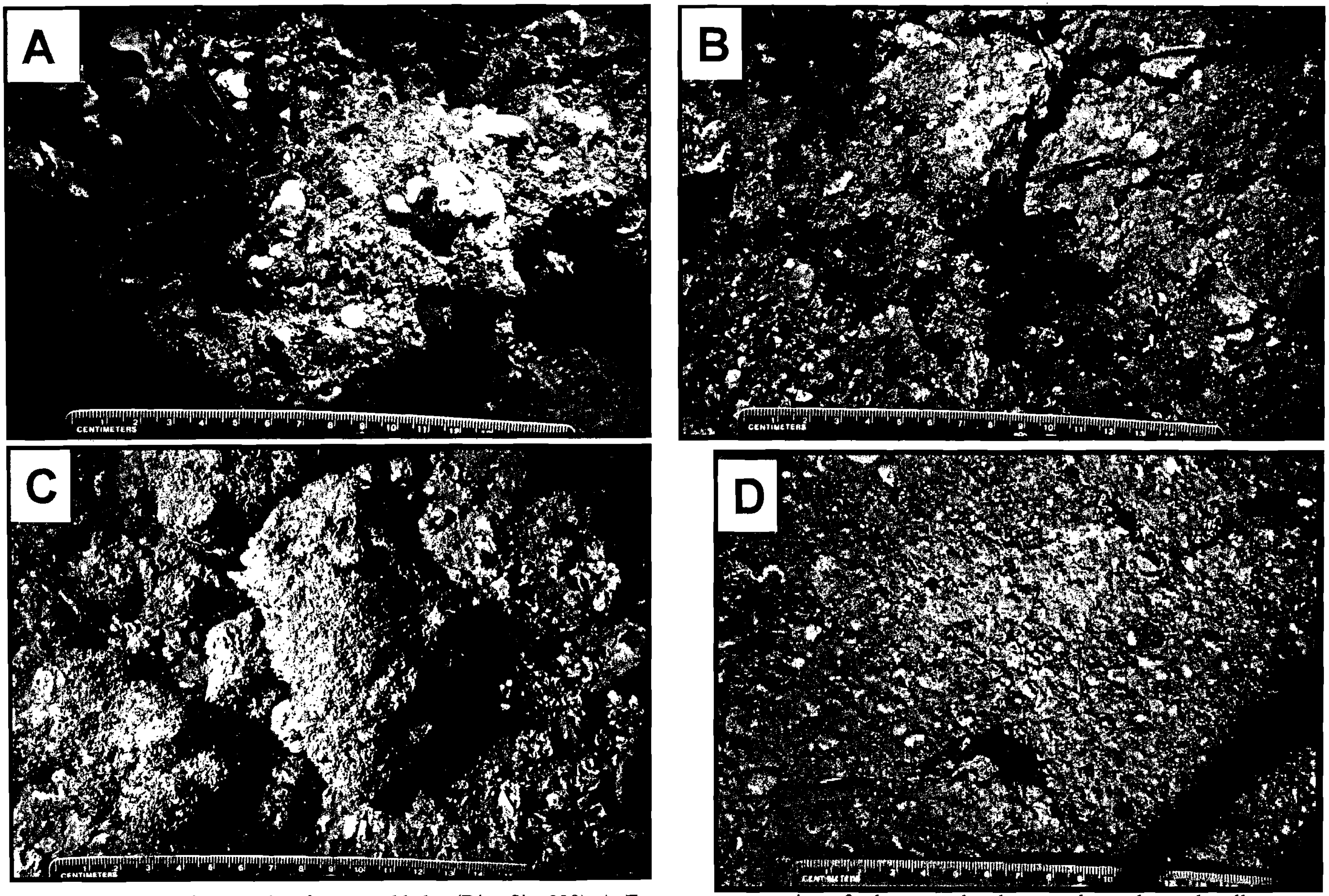


Figure 16. Bottom photographs of encrusted ledge (Dive Site 828). **A**. Encrusters are a variety of calcareous alga, bryozoa, barnacles, and molluscs. Sponges and macro alga also colonize the higher portions of the hardbottom ledges and scarps. Small overhang is visible in lower right where sand abuts the rock. **B**. Thin veneer of silty very fine sand and gravel overlies the lower portions of the hardbottom and rubble ramp. **C**. Thin silt veneer on eencrusted rubble that typically forms ramp at scarp base. **D**. A poorly-sorted, silty to sandy gravel forms a variably thick sequence of sediment between ledges. Scale is 15 cm in length.

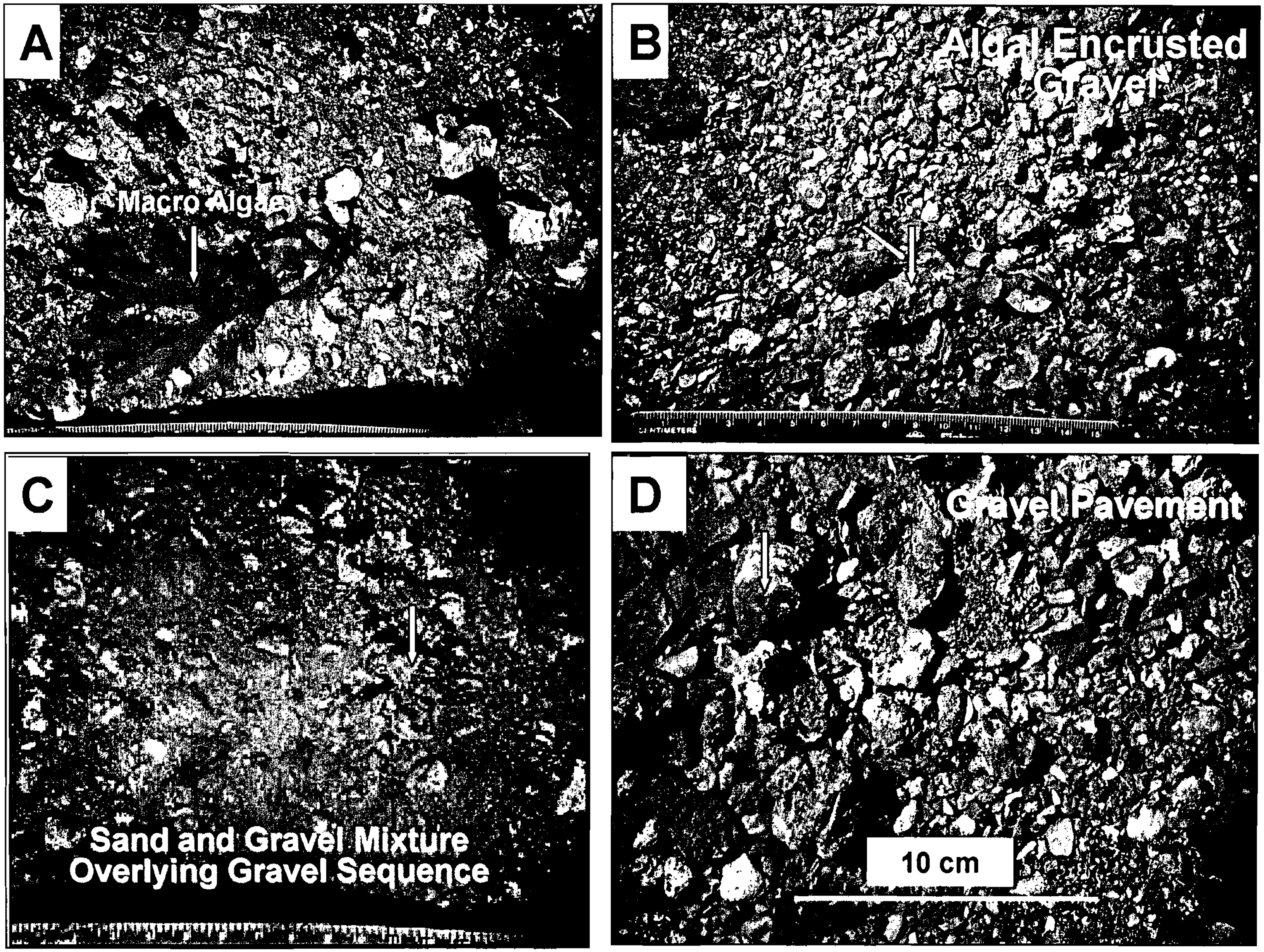


Figure 17. Bottom photographs of Dive Site 810 on North Topsail Beach shoreface in an area of moderate to high relief hardbottoms (>6 ft). **A**. Sand and gravel mixture overlying rock surface. **B**. Gravel lag produced by bioerosion, **C**. Sandy gravel mixture at protected scarp base. **D**. Gravel-sized material on a scarp back. Sandier sediment is usually located closer to scarp. A significant portion of the coarse gravel is coated with a thin crust of calcareous algae (arrows in **B**, **C** and **D**). Scale is 15 cm in length. Bar scale in **D** equals 5cm.

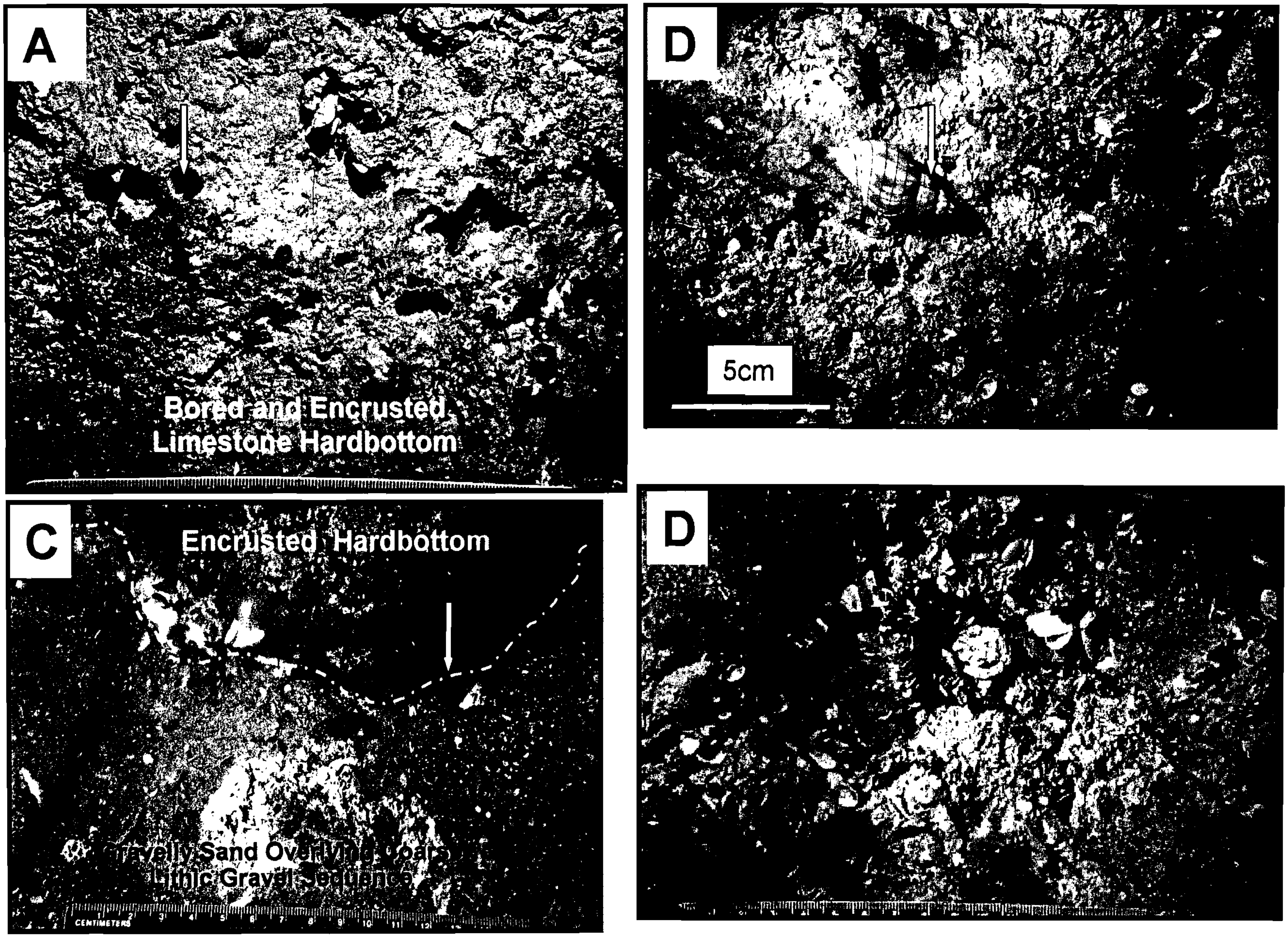
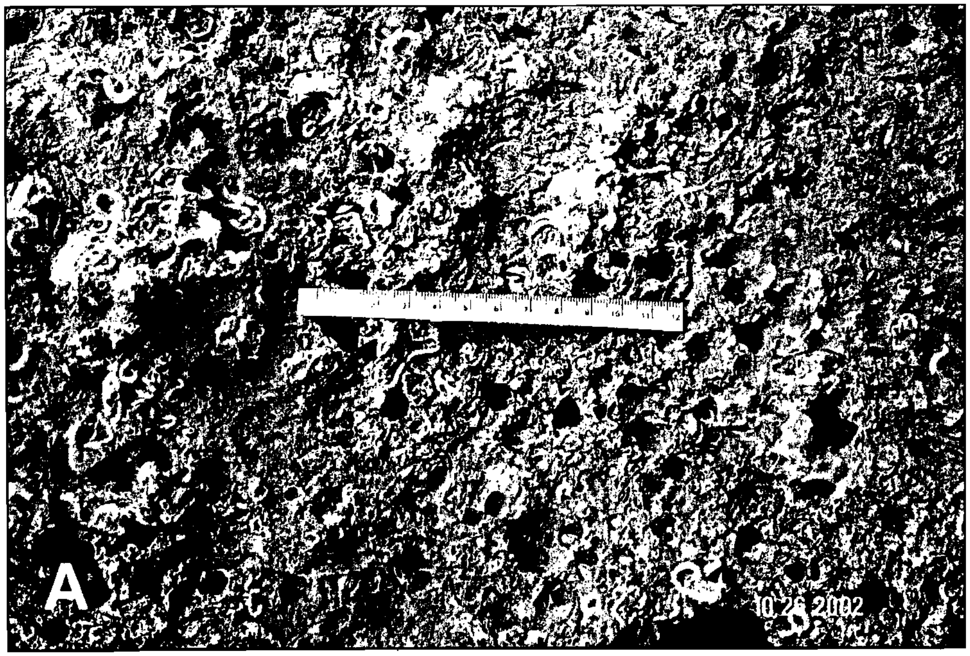
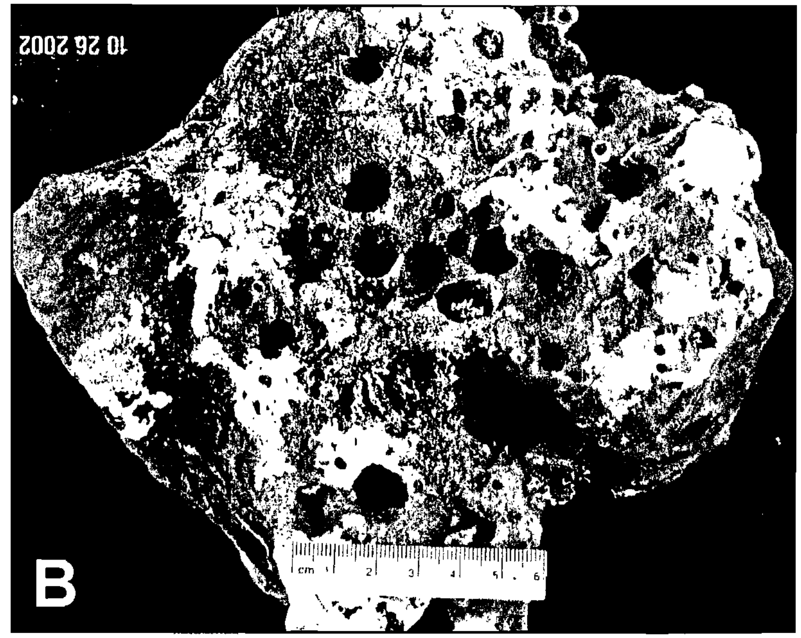


Figure 18. Bottom photographs at dive Site 814 on flat irregular hardbottom. Scale is 15 cm in length. **A**. Bored algal encrusted limestone platform. **B**. Low relief bored and encrusted ledge and contact between rock and sand veneer (lower right). Note grazing gastropod. **C**. Low relief limestone ledge and contact between gravelly, silty sand. Note macro algae. Sandy sediment fills low relief solution depression. **D**. Macro algae and black shell gravel lag deposit on low relief ledge.





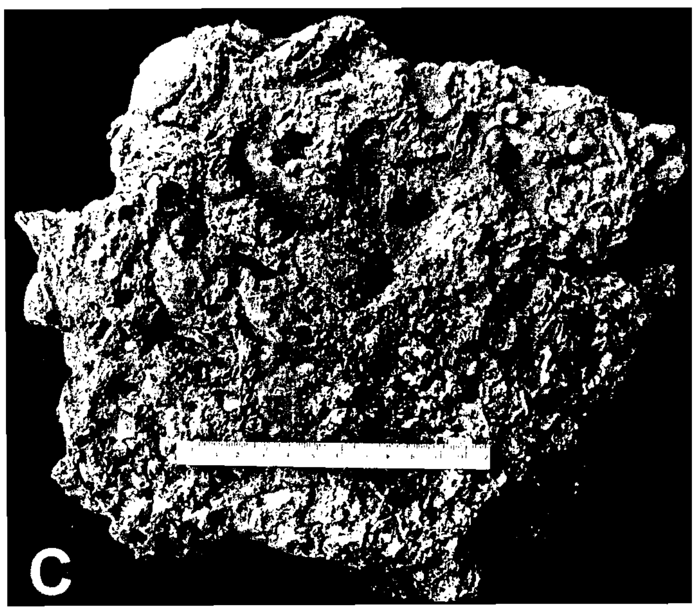
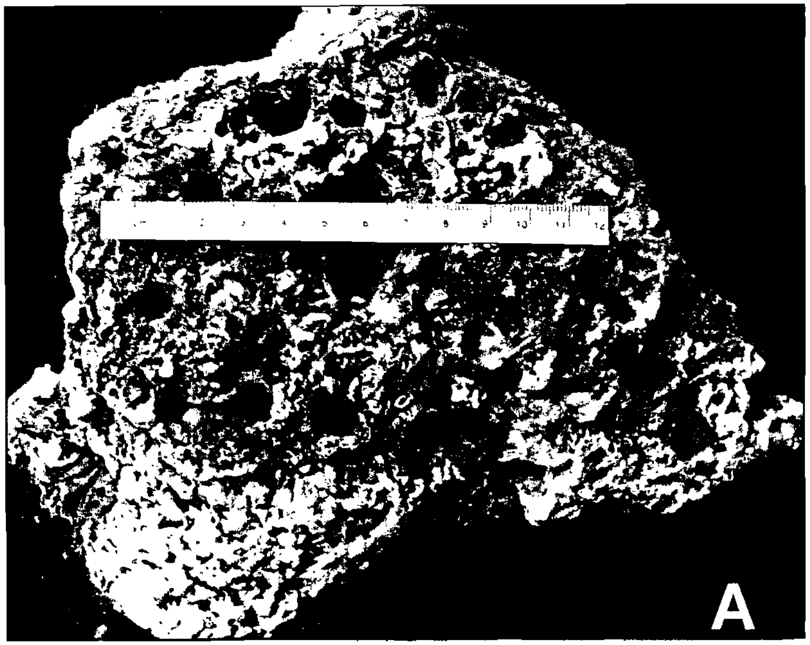
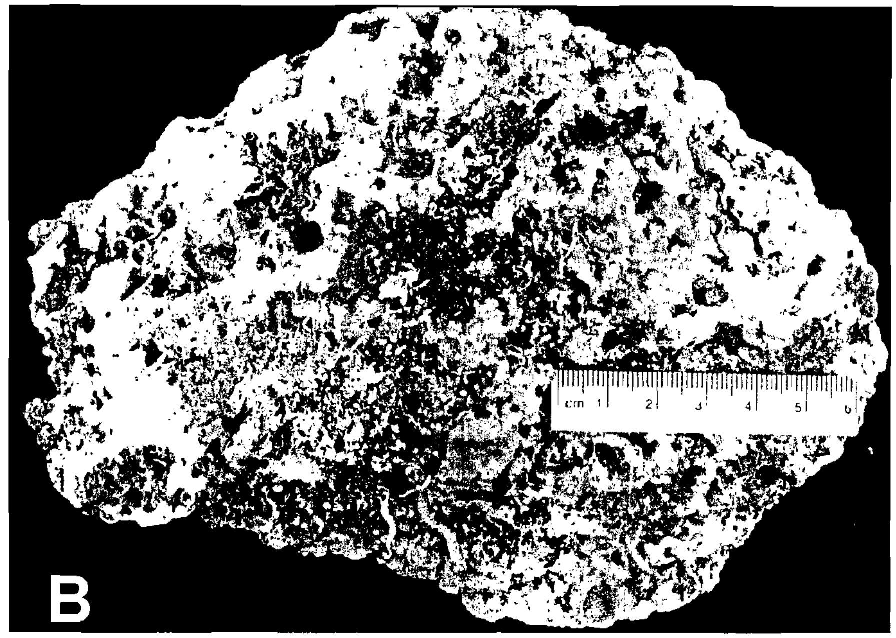


Figure 19. **A**. Top of large sandy biomoldic limestone slab with bores and encrusting organisms (coral, worm tubes, algae,and bryozoans). The 10 x 50 x 70 cm slab was found at base of a scarp near Site 508 offshore North Topsail Beach. **B**. Rounded, iron-stained, bored and encrusted calcite cemented sandstone. The rock unit from which this clast was derived is erosion resistant and forms a portion of the Upper Oligocene/Lower Miocene Channel Complex (Site 505). **C**. Bored, biomoldic sandy limestone from a high relief hardbottom (Site 704) offshore Mile Hamocks Bay (Onslow Beach).





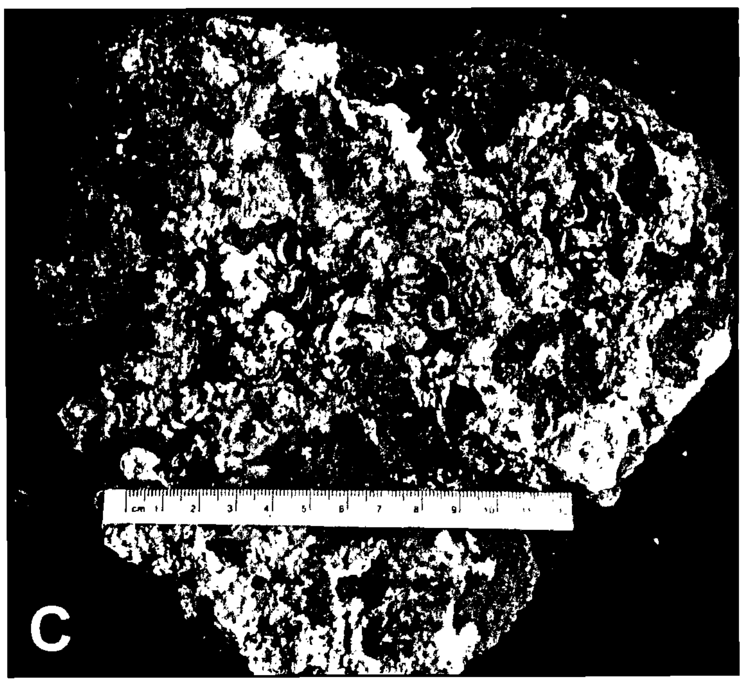


Figure20. Bored and encrusted limestone fragments. **A**. Bored and algal encrusted limestone fragment from debris at base of small overhang in vicinity of Site 516 offshore North Topsail Beach. **B**. Algal and worm tube encrusted surface of sandy limestone at Site 712 near base of High relief scarp offshore North Topsail Beach. **C**. Top of bored and encrusted sandy limestone at base of small overhang at Site NS 006 offshore Alligator Bay.

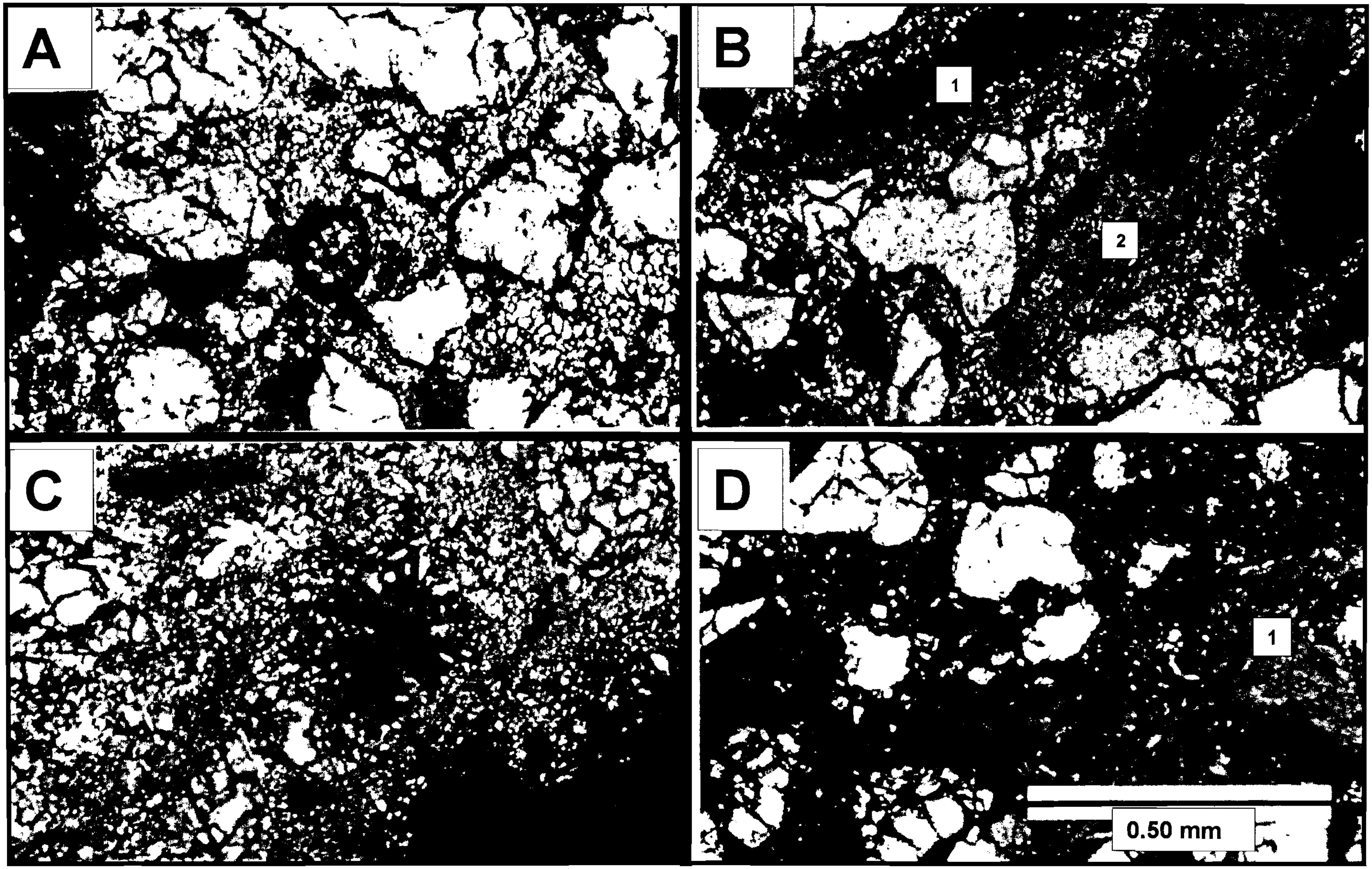


Figure 21. Photomicrographs of Belgrade Limestone from the North Topsail Beach shoreface (modified after Johnston, 1998). Red color is a stain used to enhance the identification of constituents. Plain light. **A**. Equant calcite cemented quartz . **B**. Pelcypod mold formed by dissolution of shell material (1) calcite cement lines mold. Large allochem is bryozoan fragment (2). **C**. Moldic pore space lined with bladed calcite. Equant calcite cement is dominant variety. **D**. Phosphatized sandy limestone. (After Johnston 1998).

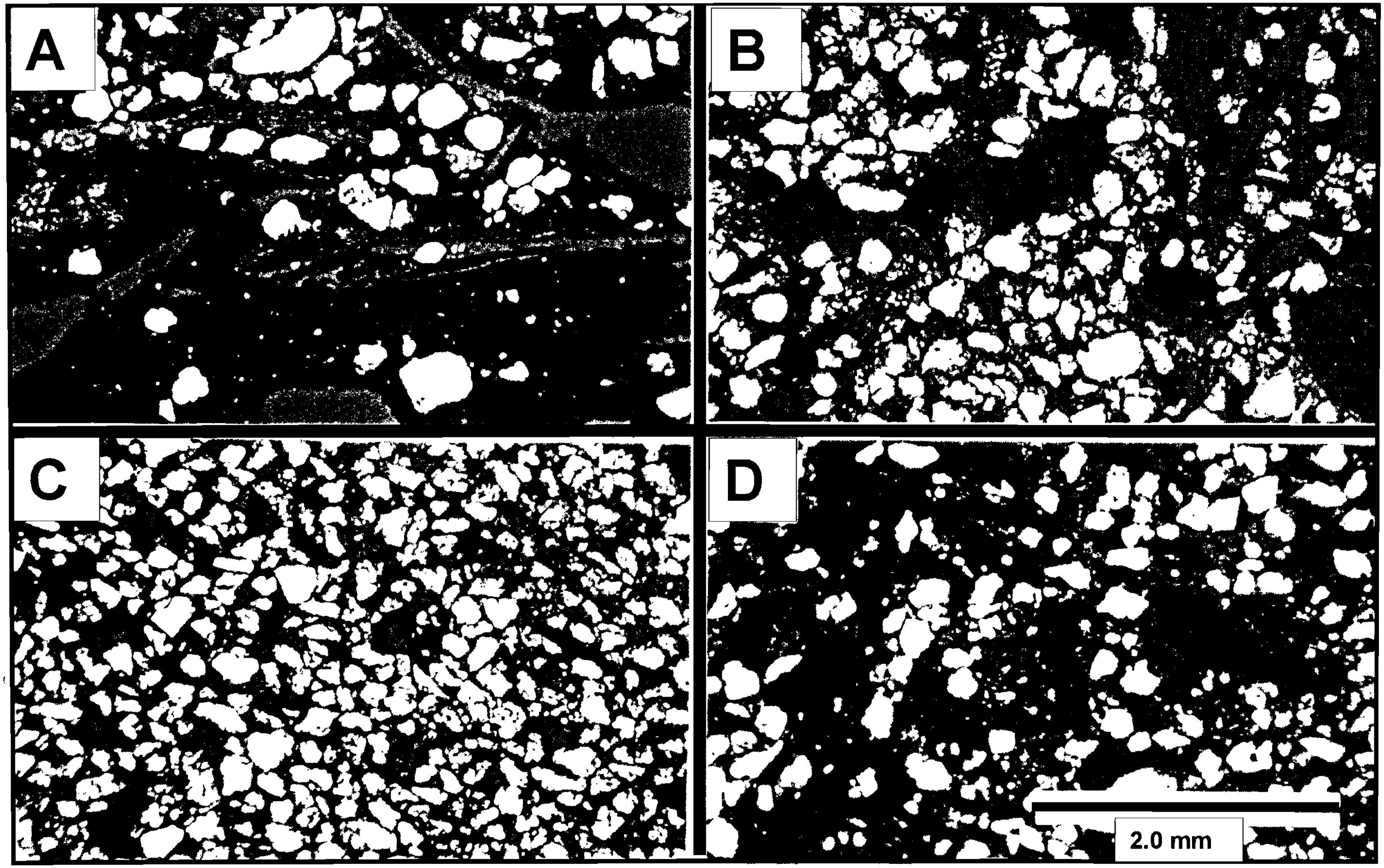


Figure 22. Photomicrographs of loose lithoclasts from shoreface platform (after Johnston, 1998). **A**. Sandy moldic biomicrudite with abundant molds. Blue background is from dye in impregnating medium. **B**. Sandy moldic biosparrudite. Note segregation of bio moldic pores (dissolved shells). **C**. Quartz rich calcite cemented sandstone. Clast was likely derived from high relief hardbottom composed of Upper Oligocene/Lower Miocene channel structure. **D**. Phosphatized sandy limestone. Scale bars refers to A-D. (Modified after Johnston, 1998).

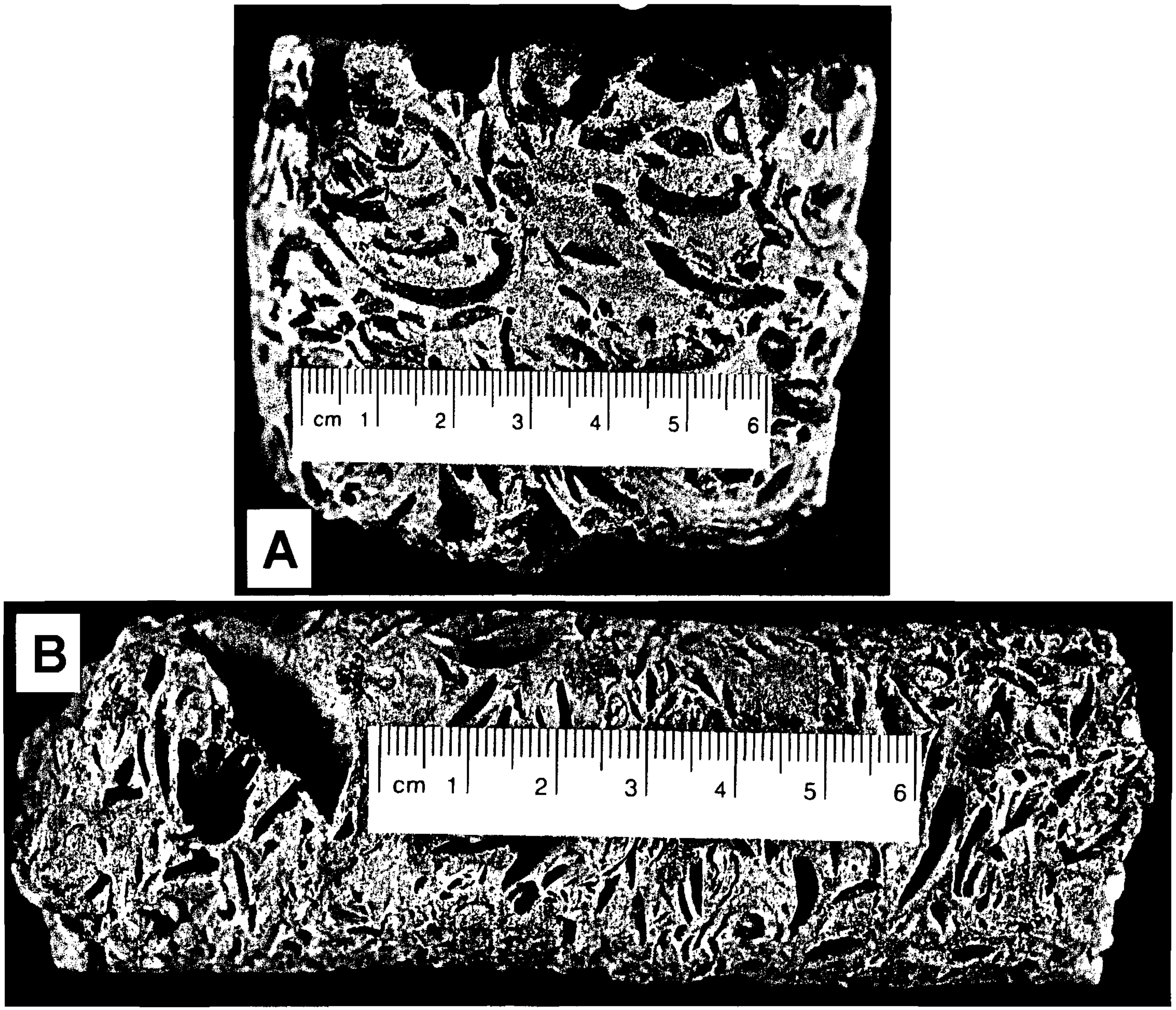


Figure 23. Slabbed cores of Trent Fm (?) arenaceous moldic limestone. Most aragonite bearing shell material has been dissolved leaving voids. **A**. TP-116. **B**. TP-14. Sandy pelecypod-moldic limestone is the dominant rock unit that underlies most of the the shoreface in the southern portion of the study area.

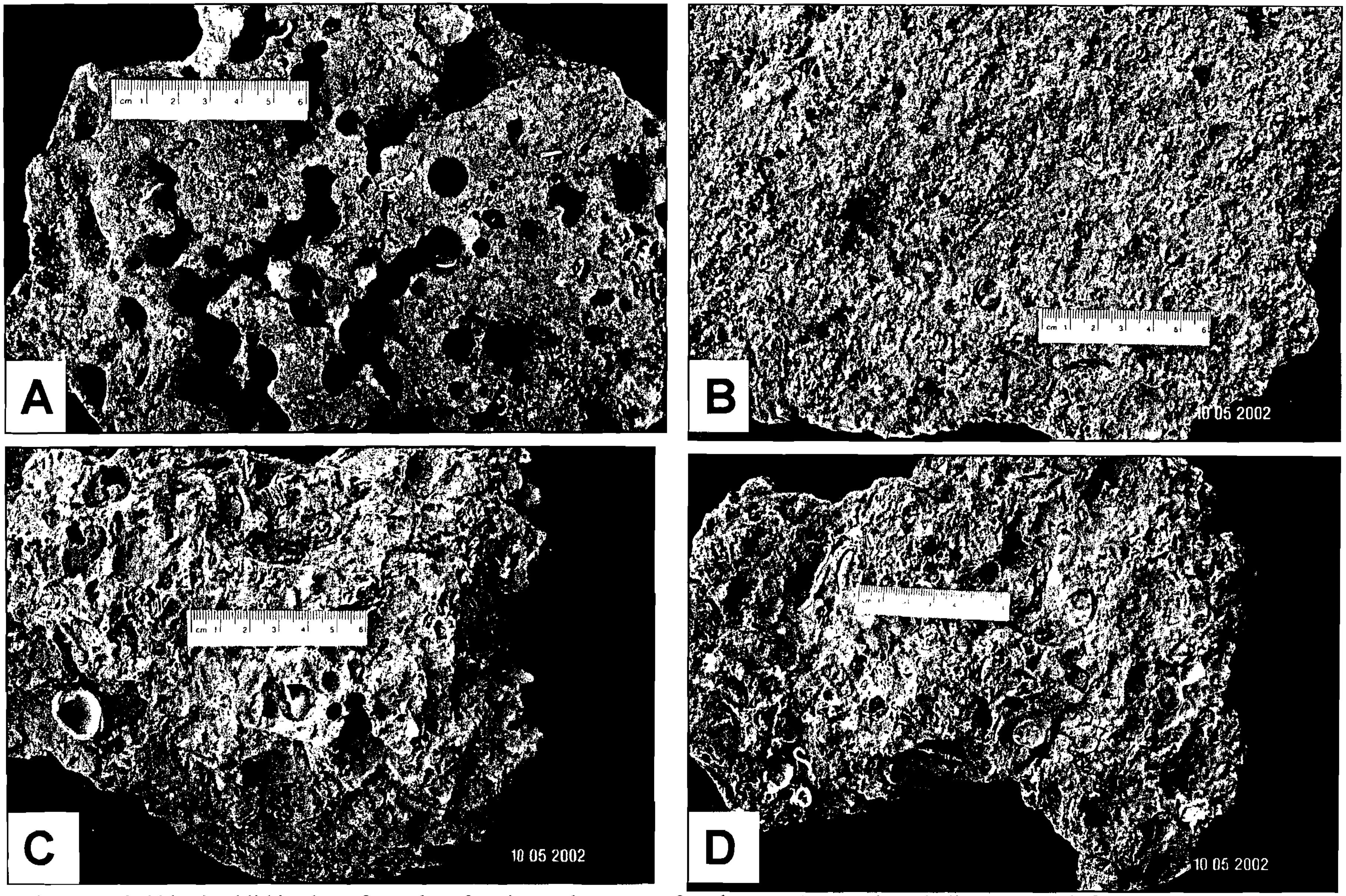


Figure24. Cobble sized lithic clasts from shoreface in southern part of study area. **A**. Bored sandy limestone unit from Trent Formation (SC 100). **B**. Large cobble sized slab of bored limestone near hardbottom scarp (Site 22) . **C**. Top of slightly encrusted, bored moldic limestone slab (SC 9). **D**. Bottom of same slab pictured in "C" (SC 9).

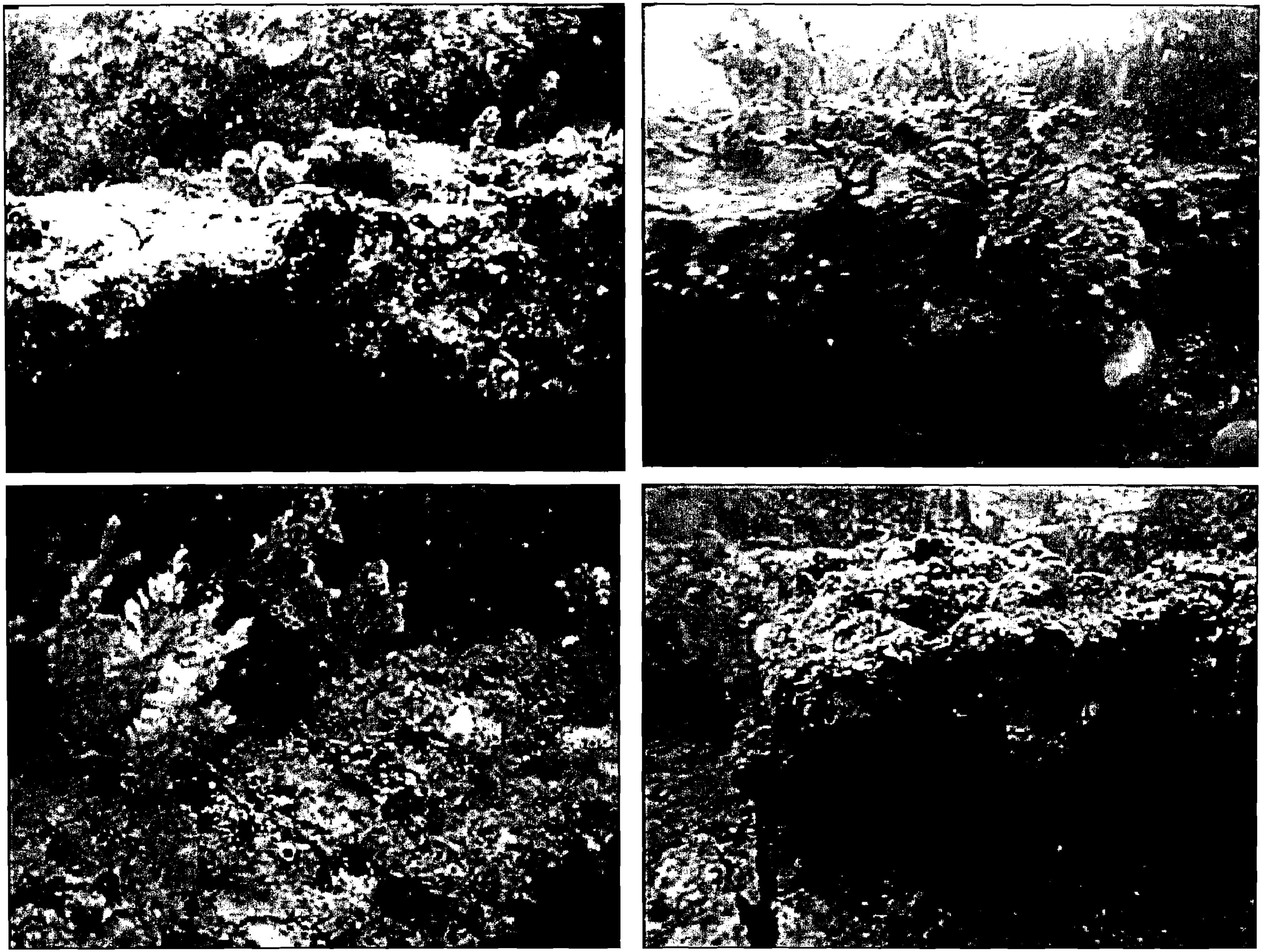


Figure 25. Hardbottom ledge offshore Surf City at Site VID 1. **A.** - **D**. Algal and epifauna encrusted limestone ledge with gravel mixture at base of scarp. Step-like ledges are encrusted with a variety of organisms. Small overhangs occur at rear of each step.

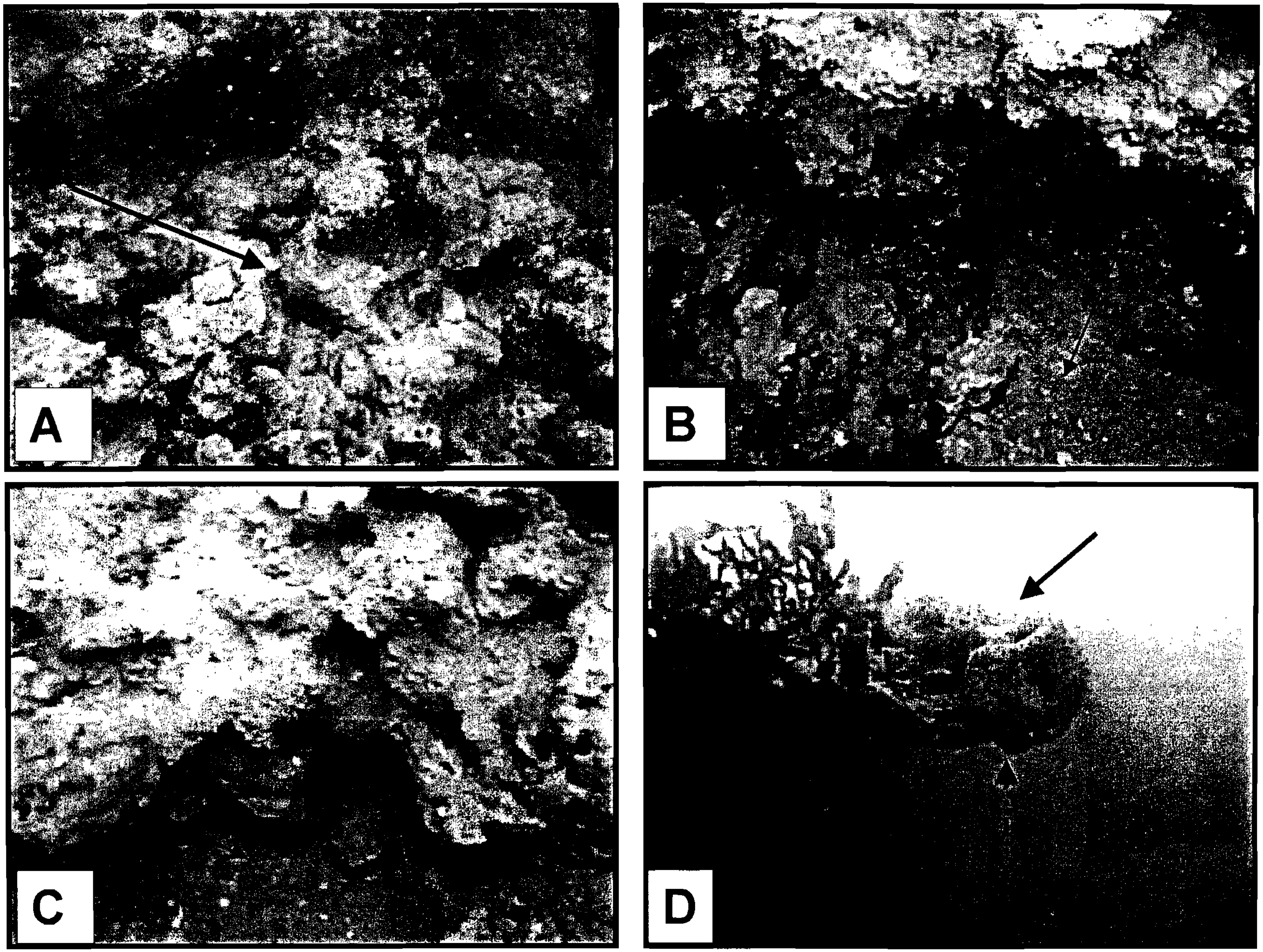


Figure 26. Hardbottom scarp and overhang at Site VID 1 offshore Surf City. A. Poorly sorted angular blocks at base of scarp. B. Sand/gravel mixture at base of corroded limestone scarp. C. Highly bored and corroded limestone scarp face with gravel/sand mixture at base. D. Encrusted overhang with macro algae and sponges. Future collapse of overhang will produce rubble ramp seen in "A".

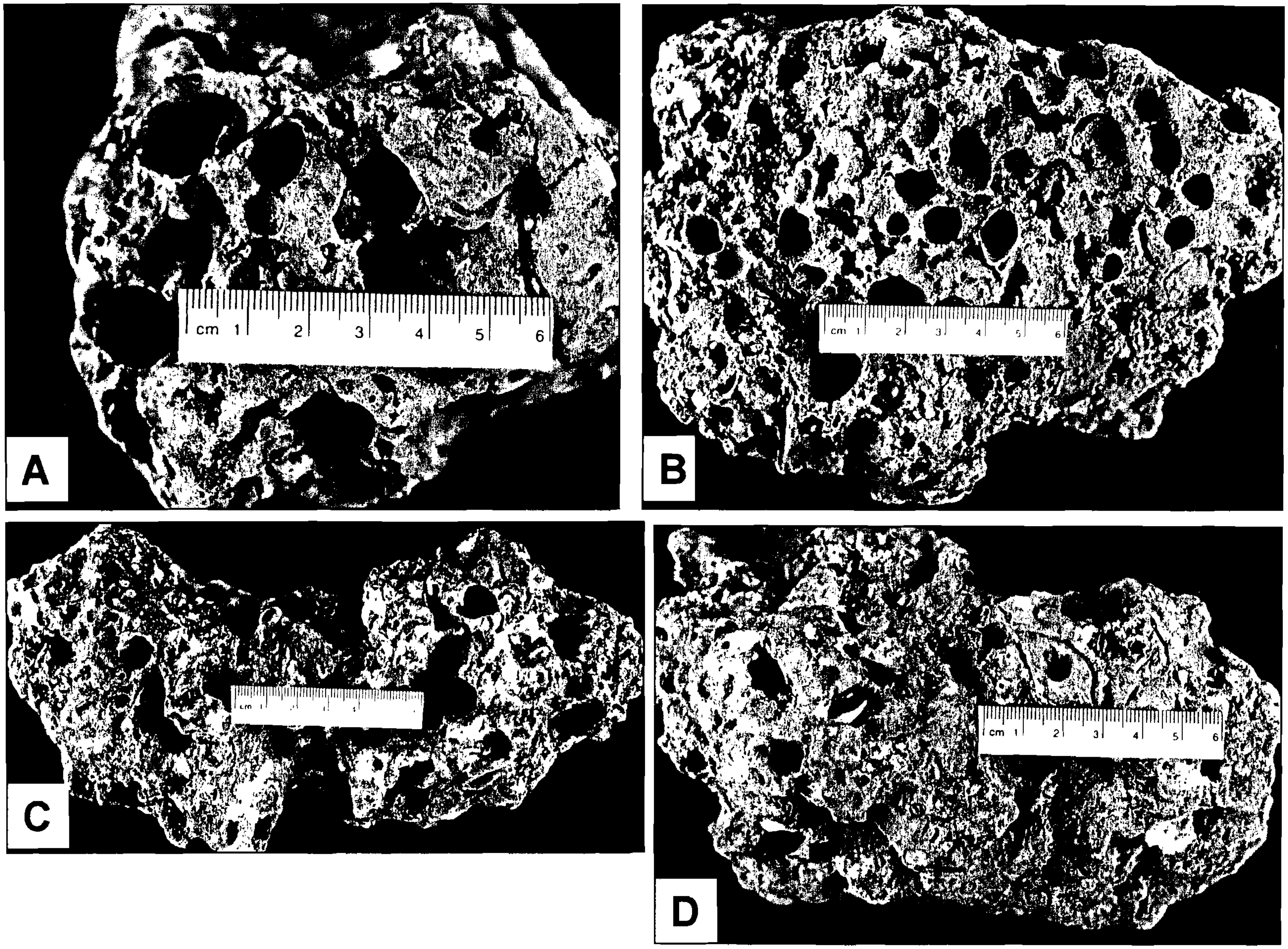


Figure 27. Cobble sized clasts of bored limestone from gravel-rich areas of the shoreface in the southern part of the study area. Cobbles are derived from various units of the Trent Formation (?) **A**. Rounded cobble of bored, quartz sand-rich limestone (SC 16 [4]). **B**. Highly bored limestone. Note some bores are filled with mud and silt from overlying thin veneer of surface sediment (SC 97). **C.** Elongated, encrusted cobble of bored limestone (SC VC 44). **D**. Cobble size clast derived from adjacent overhang (SDA 9).

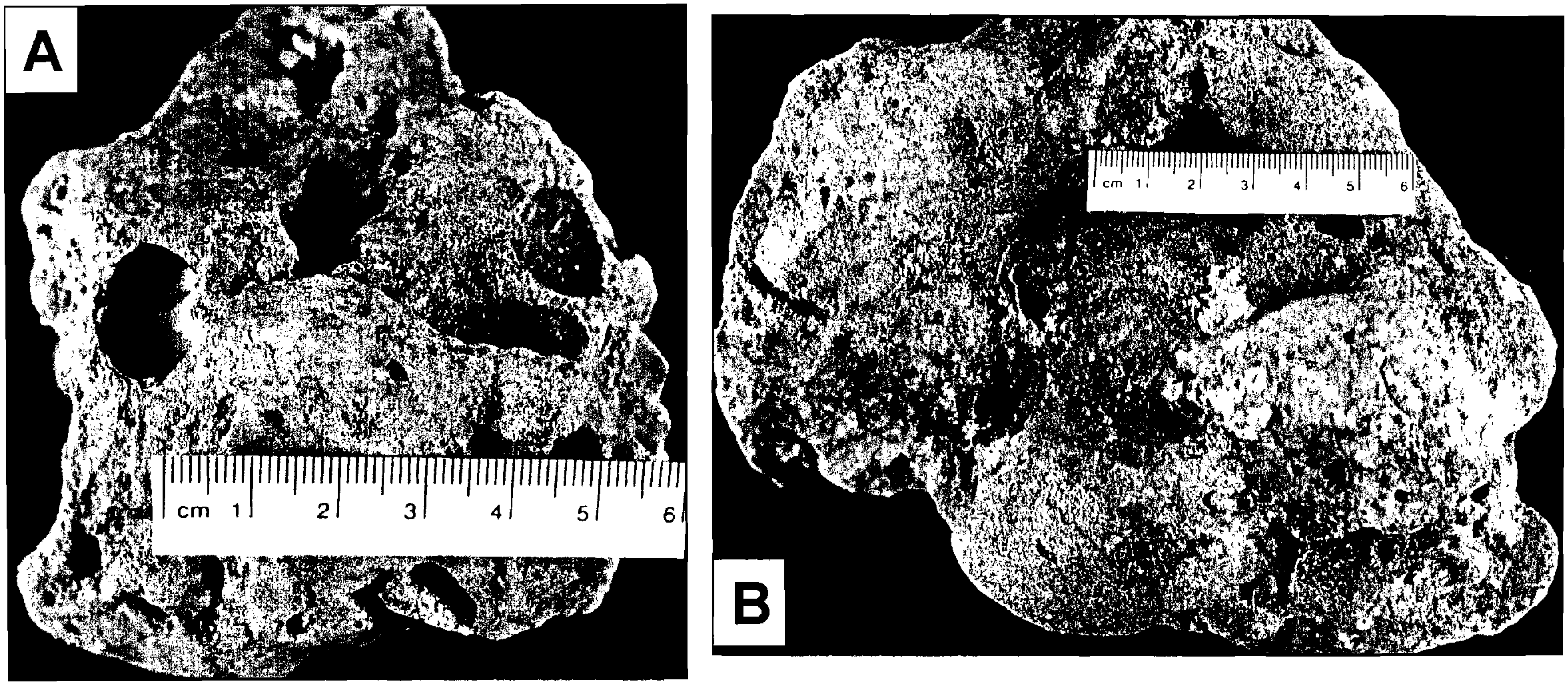


Figure 28. Rounded cobble size clasts from the dominant stratigraphic units that underlie the shoreface in the southern part of the study area. **A**. Bored clast of the Oligocene River Bend Fm. The olive green dolosilt clast is very friable and easily disaggregated with transport (SD 7 19). Most of the silt found in the surface sediment veneer is derived from the erosion of the siltstone. **B**. Rounded cobble of quartz bearing limestone from the Trent Formation (?). The Trent Fm forms the majority of the hardbottoms off Surf City and the southern part of North Topsail Beach (SC 10).

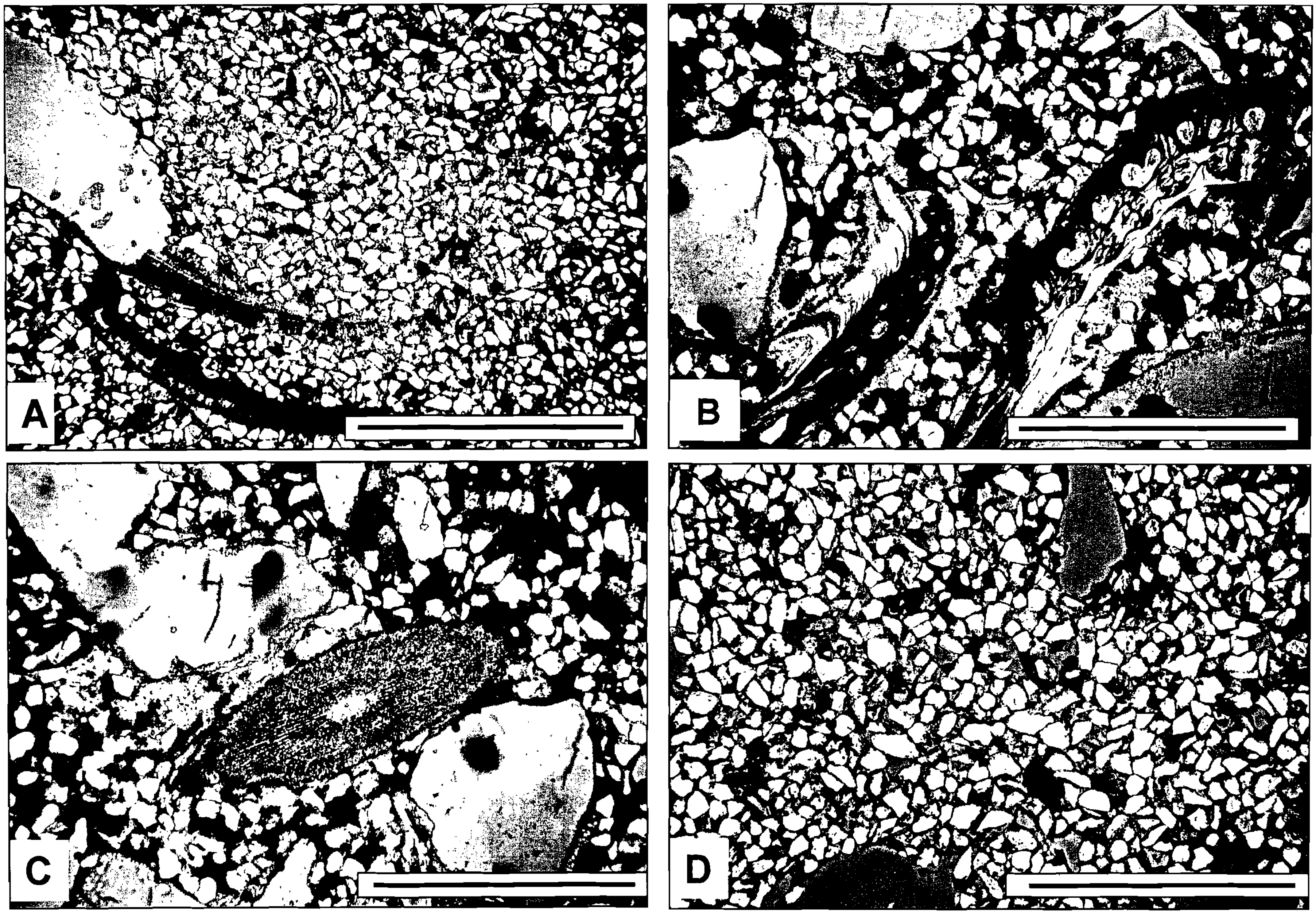


Figure 29. Thin-section photomicrographs of rocks from the southern segment of the shoreface. Scale bar =2.25mm. **A**. Sandy moldic Ls showing molds of dissolved shell material (Site SDA) in recrystallized micrite. **B**. Hollow wall barnacle in microcrystalline calcite cement (Top 15). **C**. Biomoldic sandy limestone with recrystallized echinoid fragment. Dark brown areas represent micritized allochems and partially altered micrite cement (Top 15). **D**. Sandy biomoldic limestone. Molds represent dissolved shell material. Dark brown opaque grains are micritized allochems set in a variety of cement (Top 6).

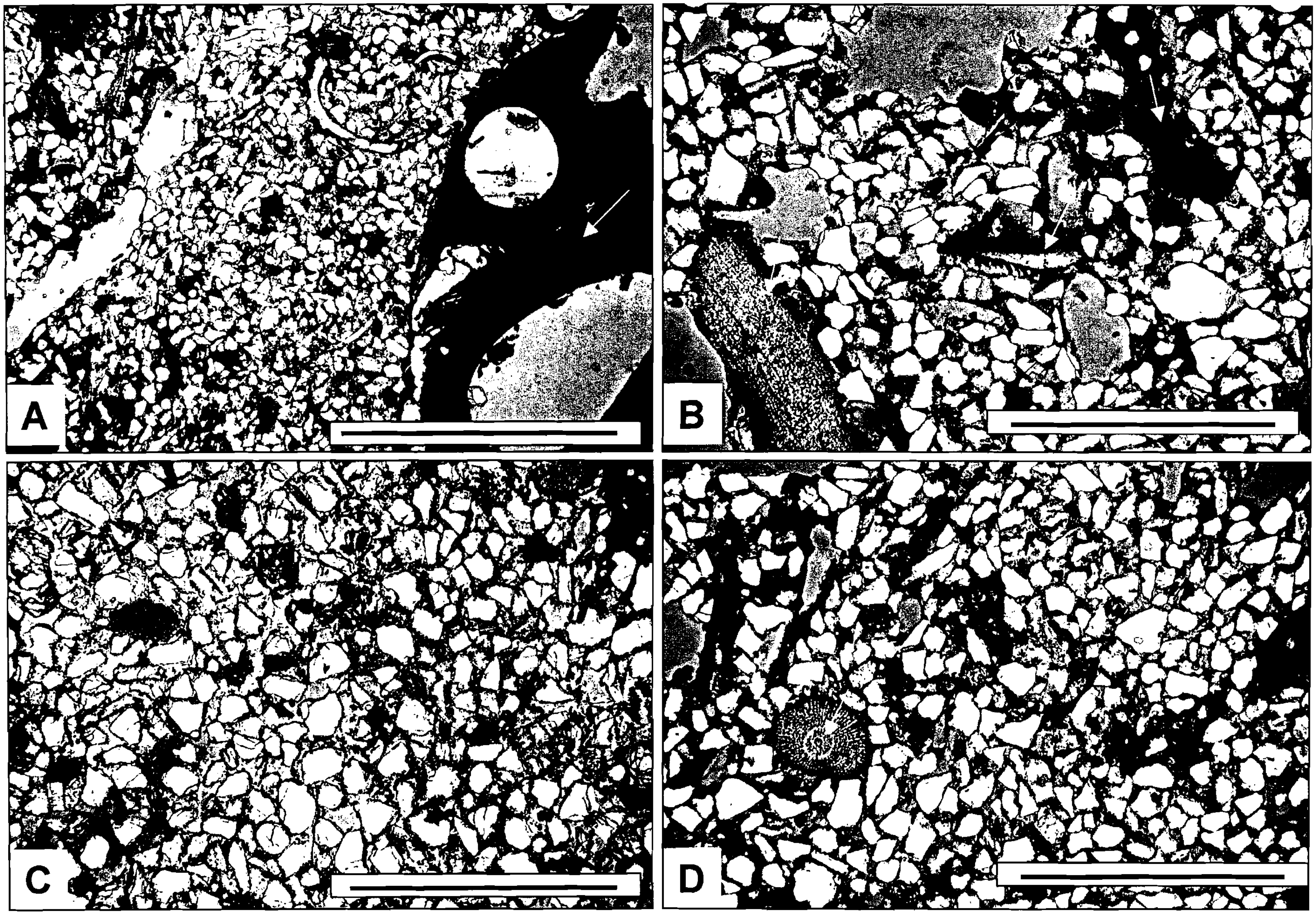


Figure30. Thin-section photomicrographs of rocks from the southern segment of the shoreface. Scale bar = 2.25mm. **A**. Sand- silt rich biomoldic Ls. Quartz and allochems set in recrystallized micrite cement, a variety of calcite cement has filled molds and pores. Opaque grains are mixture of micritized allochems (peloids) and phosphatized shells. Large opaque areas (arrow) are worm tubes (Top 4). **B**. Sandy biomoldic Ls. Angular -subrounded fine quartz sand, phosphatized and micritized allochems set in partially recrystallized micrite cement (SC 111). **C**. Poorly cemented calcareous sandstone with small molds of shell. A variety of calcite cement types are present. Some phosphate (opaque grains) are present (SC 95). **D**. Sandy biomoldic Ls. Micritized and phosphatized pelecypod grains, recrystallized echinoid plate and fine quartz sand are set in an aggraded micrite and phosphate matrix (SC 105).

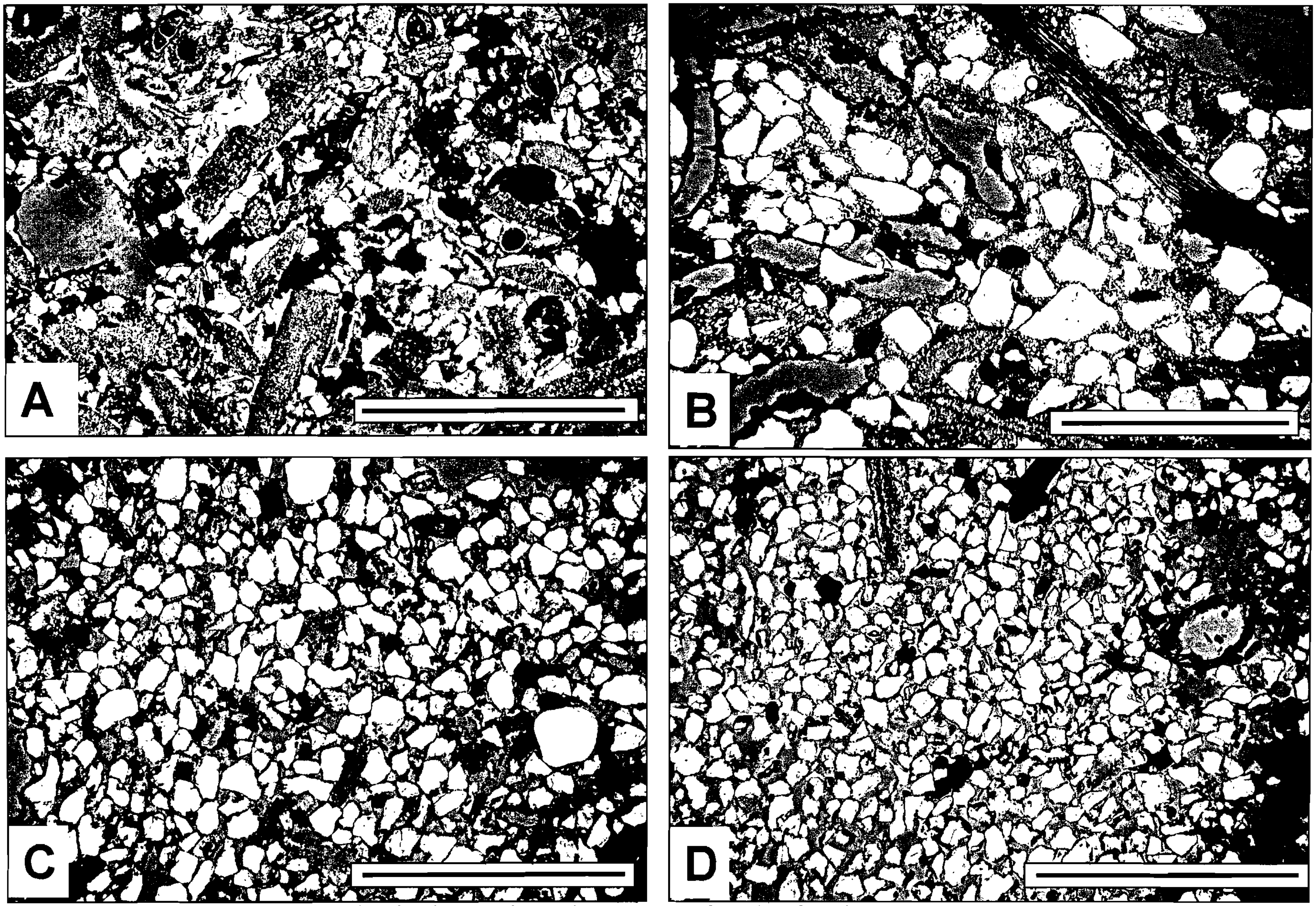


Figure 31. Thin-section photomicrographs of rocks from the southern segment of the shoreface. Scale bar = 2.25mm. **A**. Sandy biomoldic Ls. Quartz and allochems (echinoid plates and molluscan fragments) set in sparry calcite cement, clusters of calcite overgrowths on original grains are abundant (SC 122). **B**. Sandy biomoldic Ls. Angular - subrounded fine quartz sand and shells are set in recrystallized cement. Molds and pores are infilled with a variety of calcite cement types. (SC 89). **C**. – **D**. Severely weathered calcareous siltstone (Lower River Bend unit ?). Angular very fine quartz sand and silt with minor amounts of micritized shells and recrystallized echinoid plates with traces of calcite cement (SC VC 30).

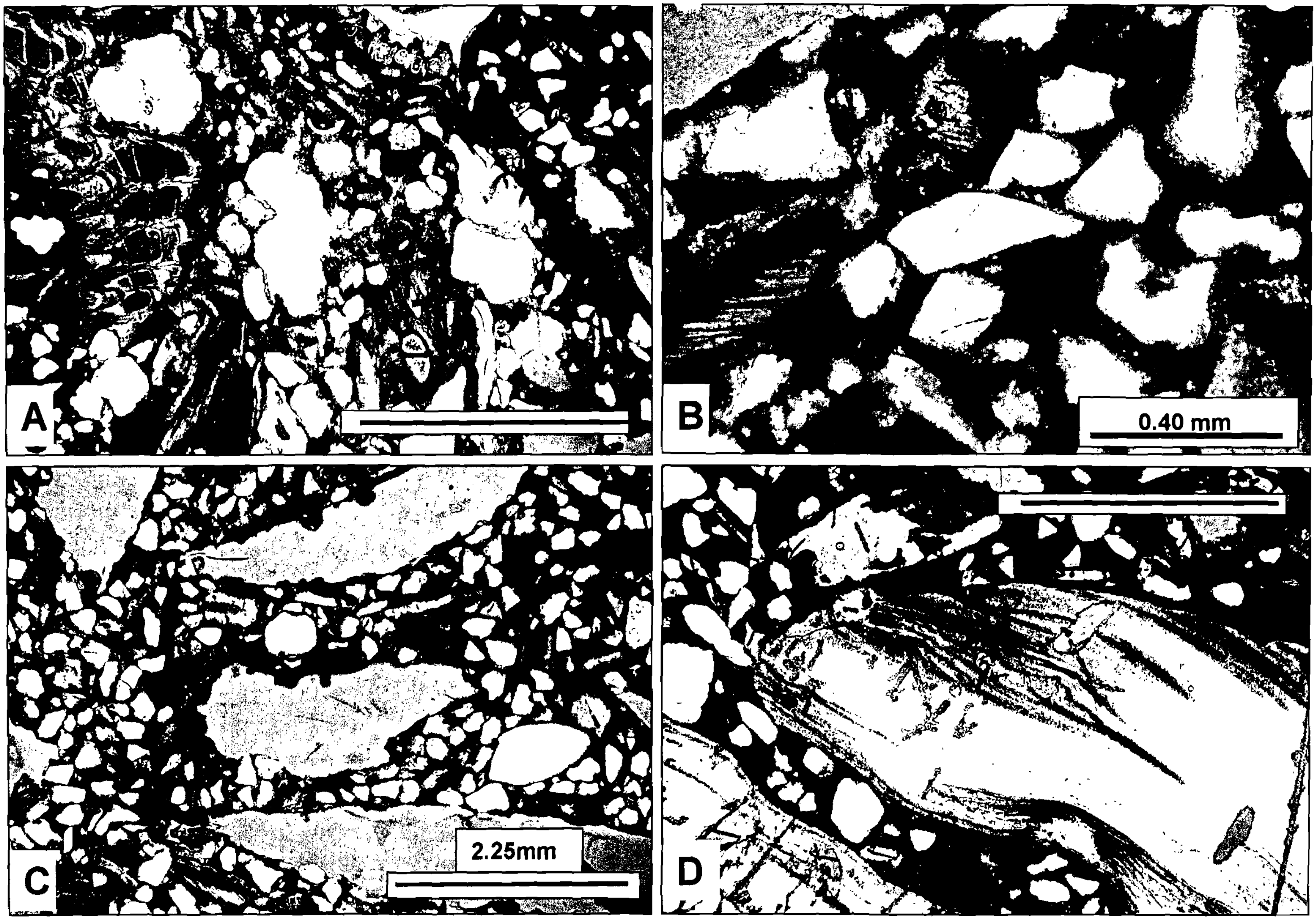


Figure 32. Thin-section photomicrographs. A, C & D scale bar = 2.25mm. **A**. Sandy bio moldic Ls. Quartz and allochems (barnacle) set in micrite cement (SC 79). **B**. Sandy biomoldic Ls. Angular fine quartz sand and recrystallized allochems are set in partially recrystallized micrite cement (SC 81). **C**. Sandy moldic Ls. with molds of dissolved shell material and fine quartz sand set in micrite matrix. Some phosphate (opaque grains) are present (SC 81). **D**. Sandy biomoldic Ls. Large bored and partially altered allochem (pelecypod) and fine quartz sand set in micrite and phosphate matrix (SC 85).

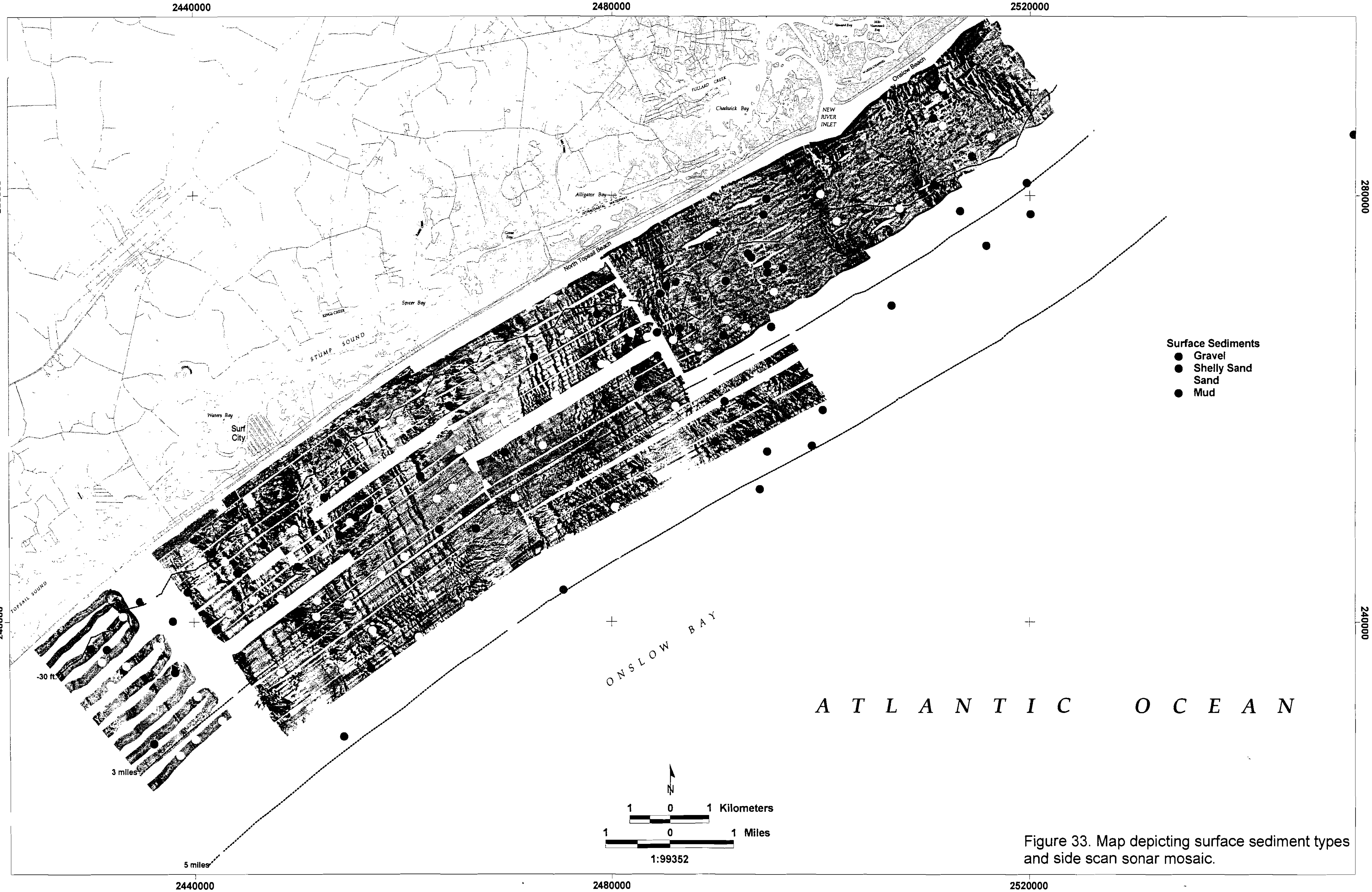


Figure 33. Map depicting surface sediment types and side scan sonar mosaic.

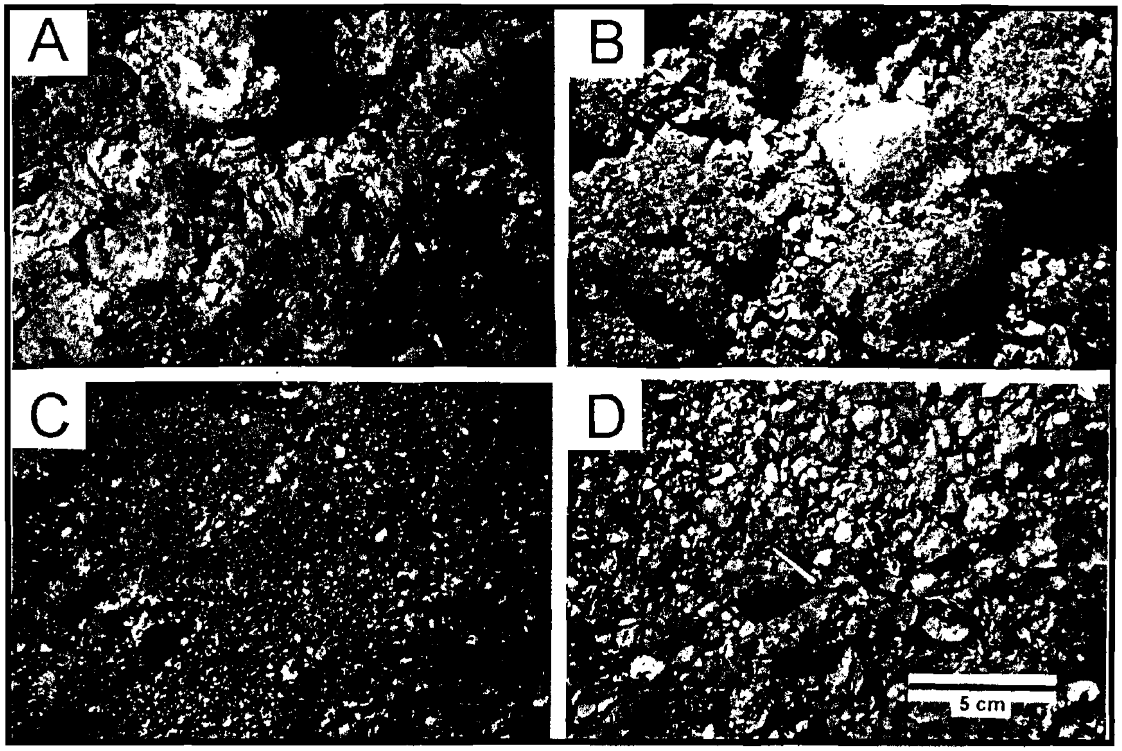
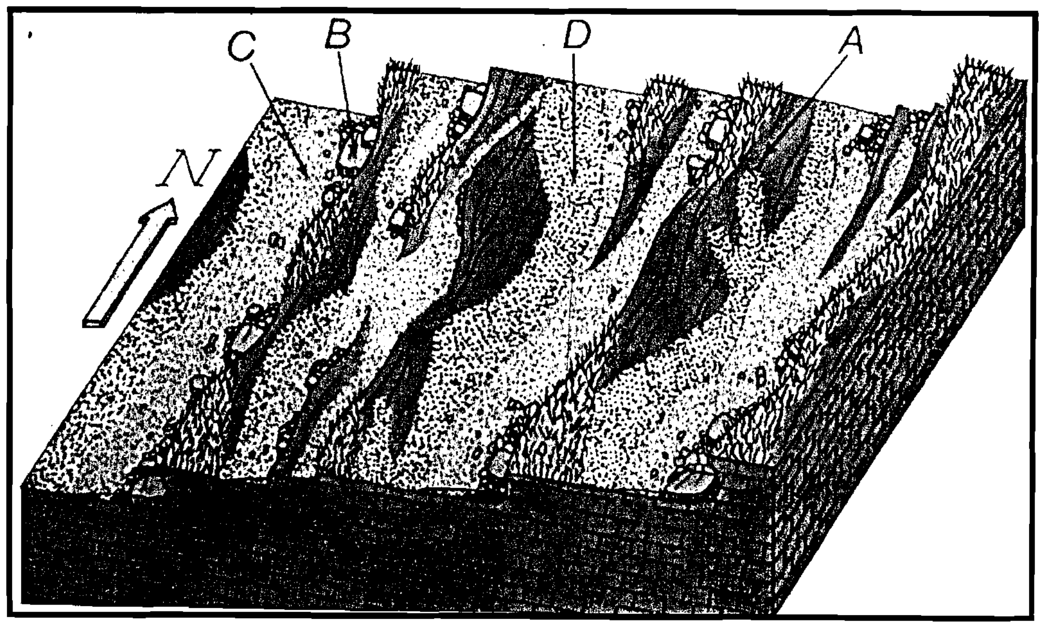


Figure 34. Bottom photographs of sediments and cartoon illustrating the general nature of step-like hardbottom features of shoreface off North Topsail Beach - Onslow Beach. **A**. East sloping scarp backs are generally barren of sediment near scarp edge. **B**. Poorly sorted rubble at base of scarp (talus ramp) is by-product of bio-erosion and mechanical erosion (undercutting) of overhangs. **C**. Poorly sorted sand mixture accumulates at base of scarp and grades into lithic gravels. **D**. Patches of lithic gravel accumulates on scarp backs. Distribution and thickness of sediment types is a function of scarp spacing, relief and composition of hardbottoms. Meadows of macroalgae are scattered across barren surfaces (modified after Johnston, 1998).



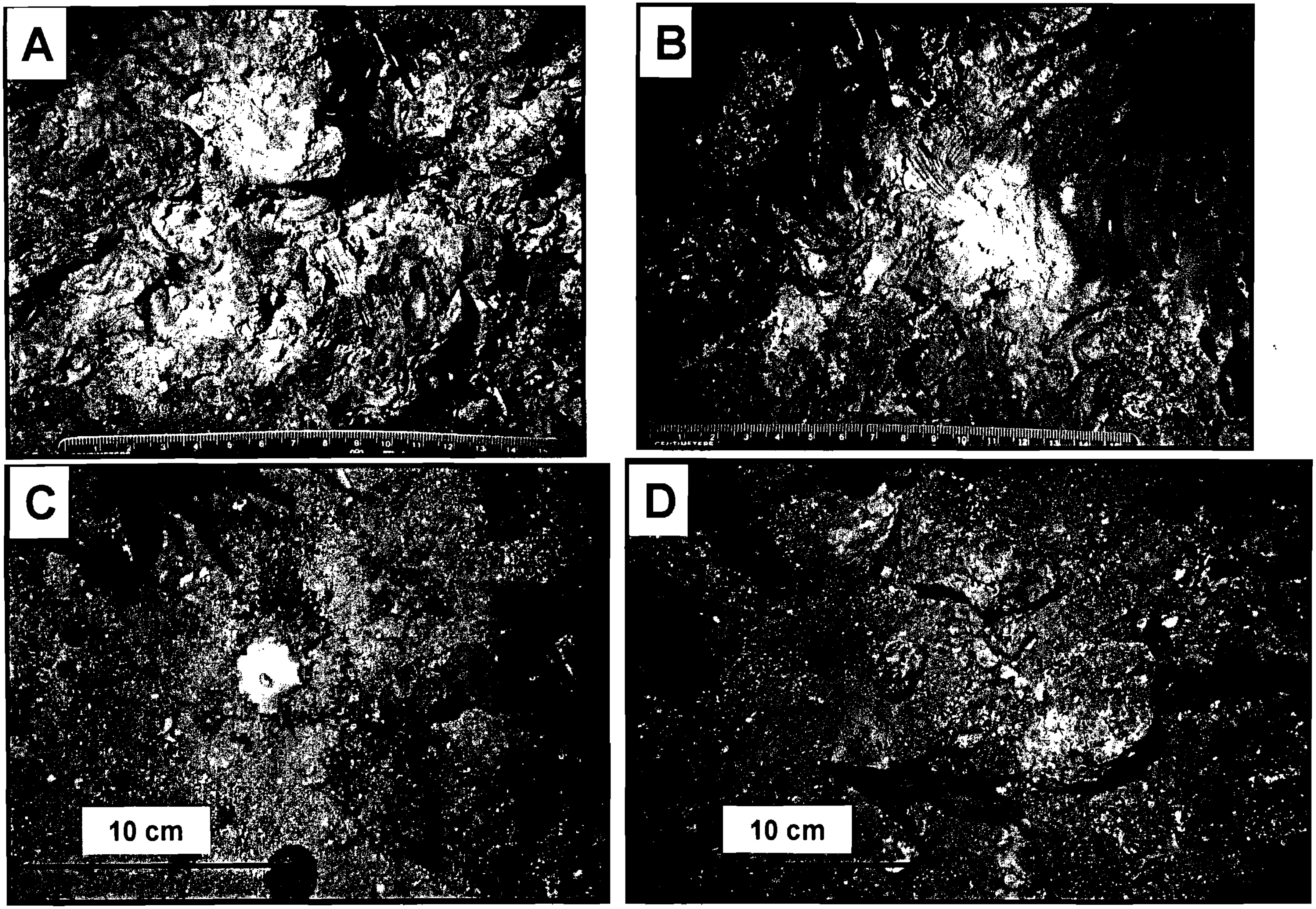


Figure 35. Bottom photographs of Dive Site 516 on high relief (>6 ft) hardbottom scarp on North Topsail Beach shoreface. **A**. Algal encrusted surface of bio moldic limestone in a sheltered area. **B**. Macro algae on lower portion of encrusted scarp face. **C**. Sand covered basal portion of scarp. A large variety of sponges and macro algae cover the karstic platform surface. **D**. Algal encrusted gravel and sand mixture at base of scarp. Scale in **A** and **B** are 15 cm in length. Scale bars in **C** and **D** are 5cm.

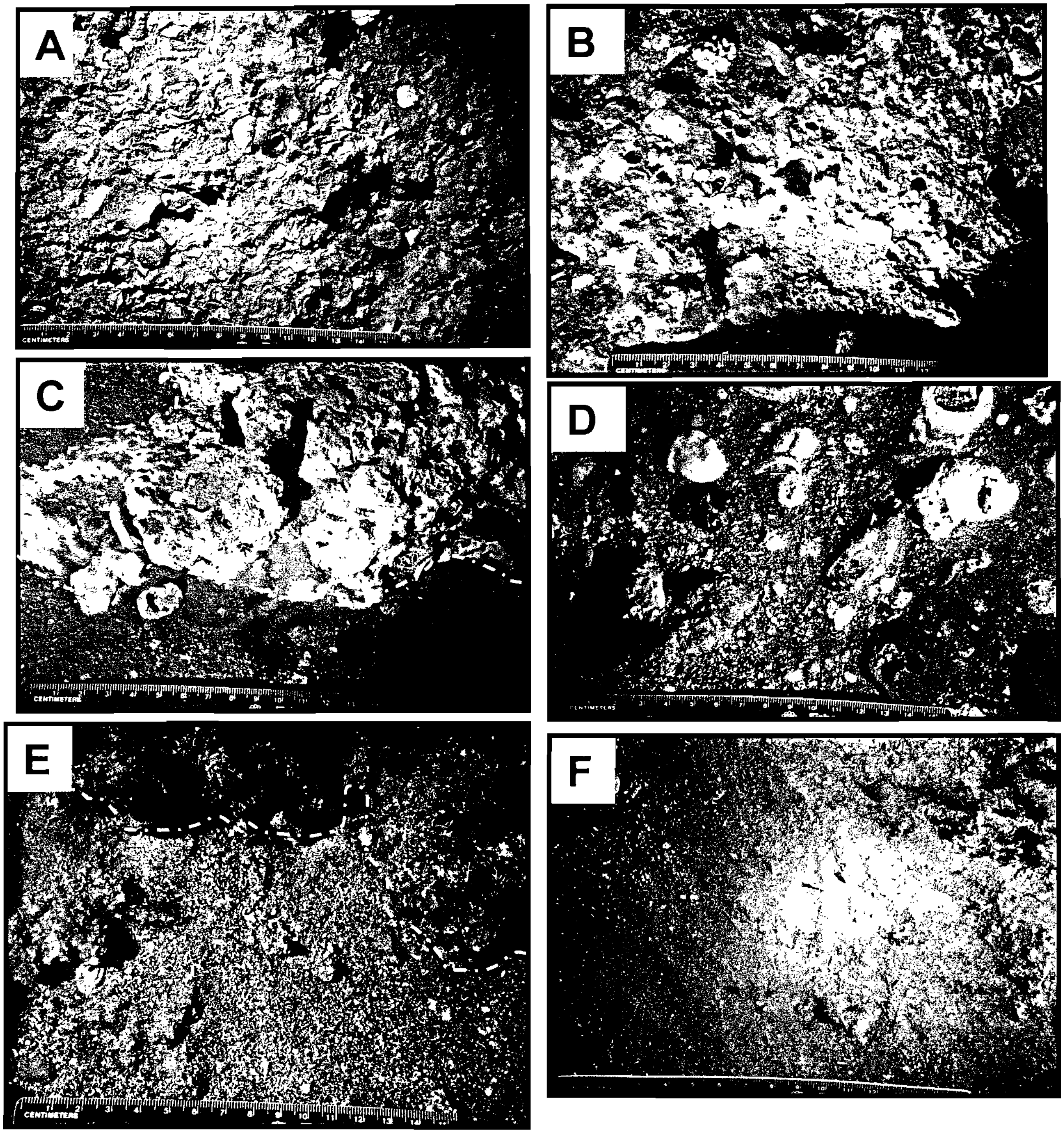


Figure 36. Bottom photographs of Dive Site 505 on North Topsail Beach shoreface in area of moderate relief hardbottom ledges. **A**. Irregular barren surface of moldic limestone ledge. **B**. Bored and encrusted limestone surface. **C**. Contact of mobile fine sand and irregular hardbottom **D**. Poorly sorted sand and gravel mixture away from base of scarp. **E**. Contact between gravelly sand and algal encrusted hardbottom scarp. **F**. Subdued, rippled fine sand field at base of scarp. A thin layer of very fine silt drapes the fine sand ripples. Scales are 15 cm in length.

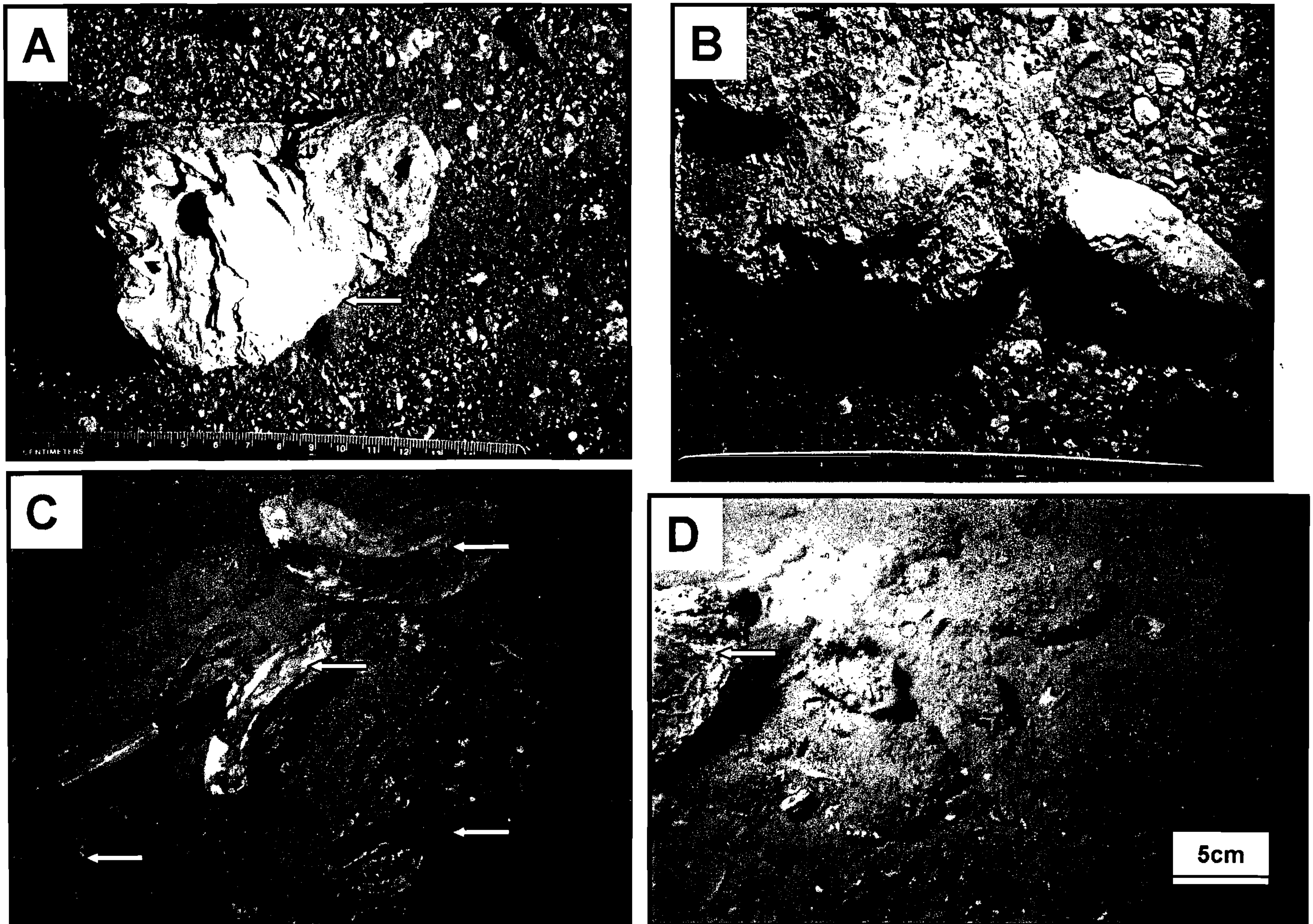
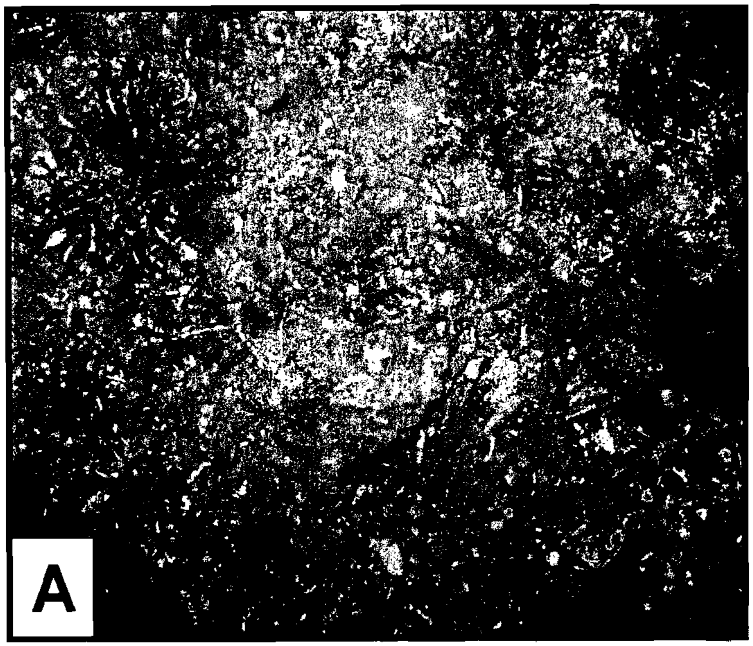


Figure 37. Bottom photographs at dive Site 504 on North Topsail Beach shoreface. Scale in A and B is 15 cm in length. **A.** Abraded lower valve of *Crassostrea gigantissima* (Oyster) and sand/ gravel mixture on limestone platform. **B.** Contact between limestone exposure (hardbottom) and silty fine sand veneer. Large white elongated cobble is fragment of oyster. **C.** In-place *Crassostrea gigantissima* Oyster Reef. Cobbles of *Crassostrea gigantissima* (arrows) are abundant in the vicinity of the lower Miocene channel structures. Divisions on crowbar are 10 cm in length. **D.** Mud draped oyster shell fragments litter the platform area. The sediment veneer in the area is generally less than 10-15 cm. Dissolution related depressions in the area are filled by modern sediment. Scale bar is ~ 5cm in length.



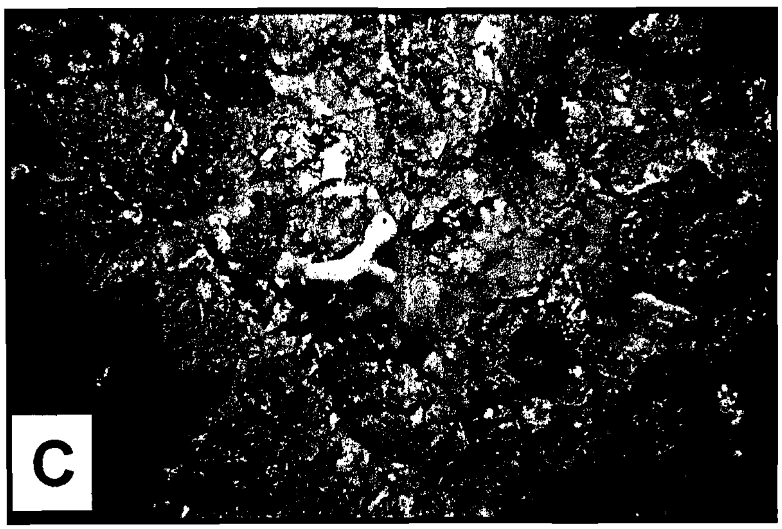


Figure 38. Bottom photographs of various dive sites on the Onslow Beach shoreface. Sites cluster around high relief hardbottom and karstic platform updrift of New River Inlet. Strong currents characterize this irregular platform. **A**. Thin veneer of sand and gravel mantles the irregular limestone surface at Site 703. Extensive colonies of macro algae are located at this site. **B**. Shells and lithic gravel comprise the sediment veneer within shallow rock bound depressions at Dive Site 704. **C**. Highly irregular, encrusted surface of moldic Belgrade limestone at Dive Site 702.

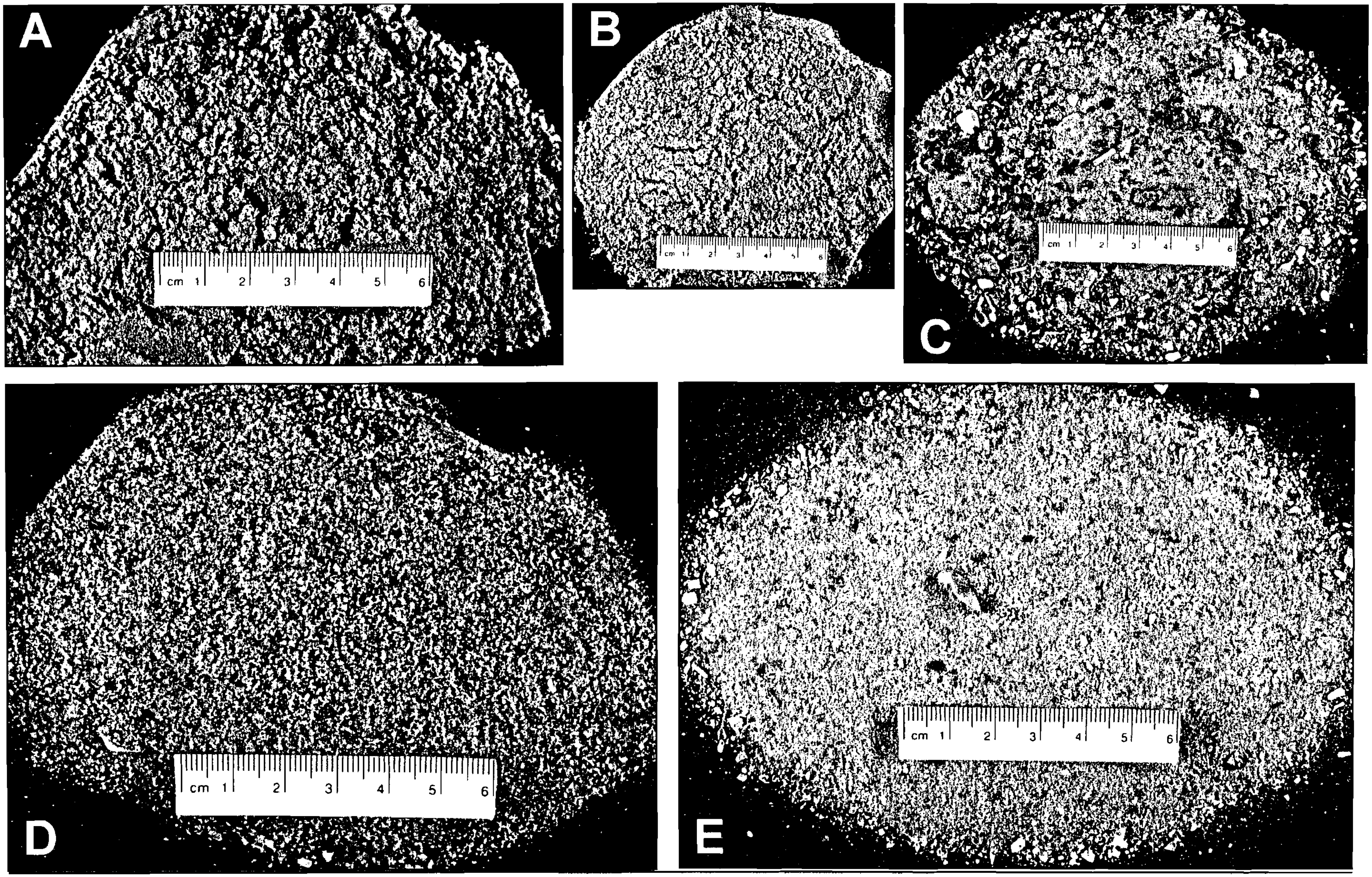


Figure 39. Silt and very fine shelly quartz sand surface sediments. **A**. Calcareous quartz silt offshore Alligator Bay inner shoreface (Site 835). **B**. Very fine quartz sand and silt withjin linear depression off shore Alligator Bay (Site 812). **C**. Black shell rich fine quartz sand offshore Alligator Bay (linear depression). Shells reworked from paleo channel. **D**. Orange brown fine quartz sand with minor shell material near hardbottom offshore Onslow Beach (Site 827). **E**. Clean fine quartz sand with minor shell material. Near ancestral channel of New River (Site NS 017).

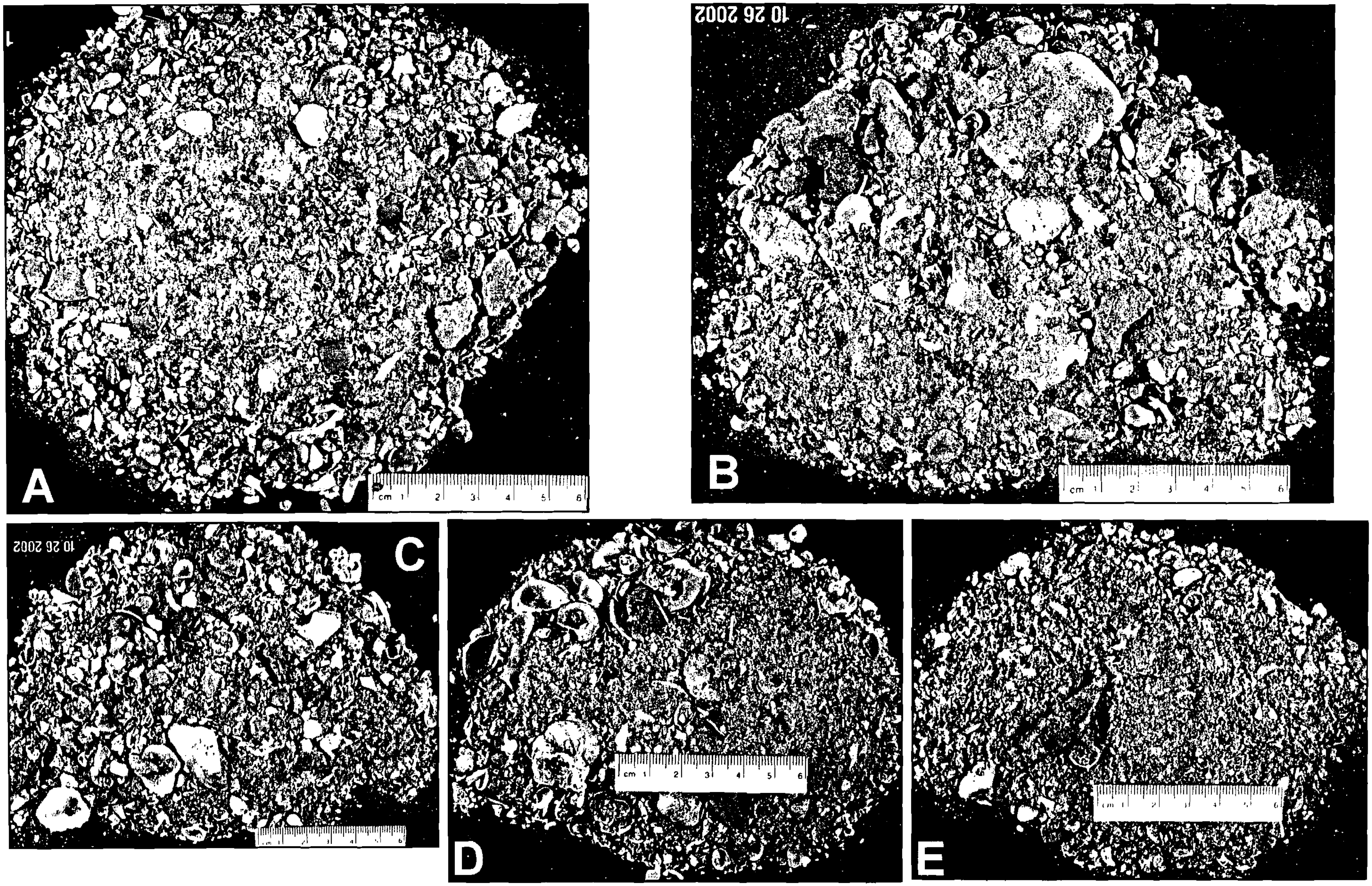


Figure 40. Sandy gravel and gravelly sand surface sediments. **A**. Sandy, lithic and shell gravel near high relief hardbottom (Site 509). **B**. Poorly sorted sandy lithic gravel offshore Alligator Bay (Site 602). **C**. Sandy algal, shell-rich lithic gravel on limestone platform off New River Inlet (Site 829). **D**. Gravel rich quartz sand offshore North Topsail Beach (Site 806). **E**. Gravelly, lithic sand near high relief scarp off Alligator Bay (Site 813).

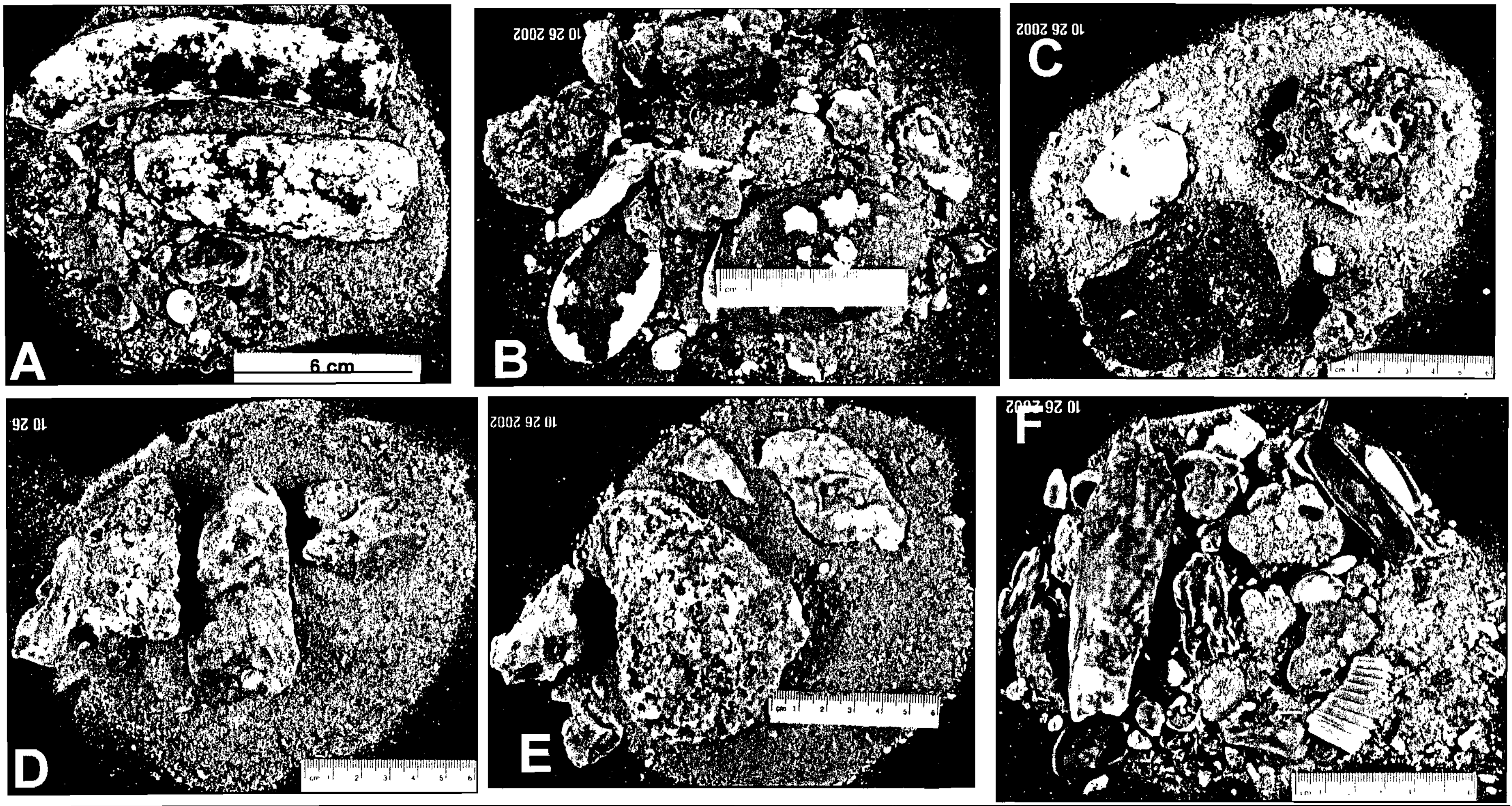


Figure 41. Gravelly sand and sand gravel mixtures. A. Orange brown quartz sand with lithic and shell gravel material. Large brown black fragments are encrusted bones from Site 701 offshore Onslow Beach (Site701). B. Poorly sorted sand/gravel mixture from Site 718 near outer platform offshore Onslow Beach. Quartz cobbles are derived from units farther offshore. C. Gravelly quartz and lithic sand mixture from Site 728 offshore Onslow Beach. Large black gravel is fragmented phosphatized sandy limestone clast. D. Fine quartz sand with subrouded moldic limestone fragments from Site 603 offshore Alligator Bay. E. Quartz sand and limestone gravel from Site 601on inner shoreface offshore North Topsail Beach.E. Sandy gravel mixture from outer platform offshore New River Inlet (Site 834). Black and gray oyster shells are derived from reworking of Holocene age backbarrier deposits.

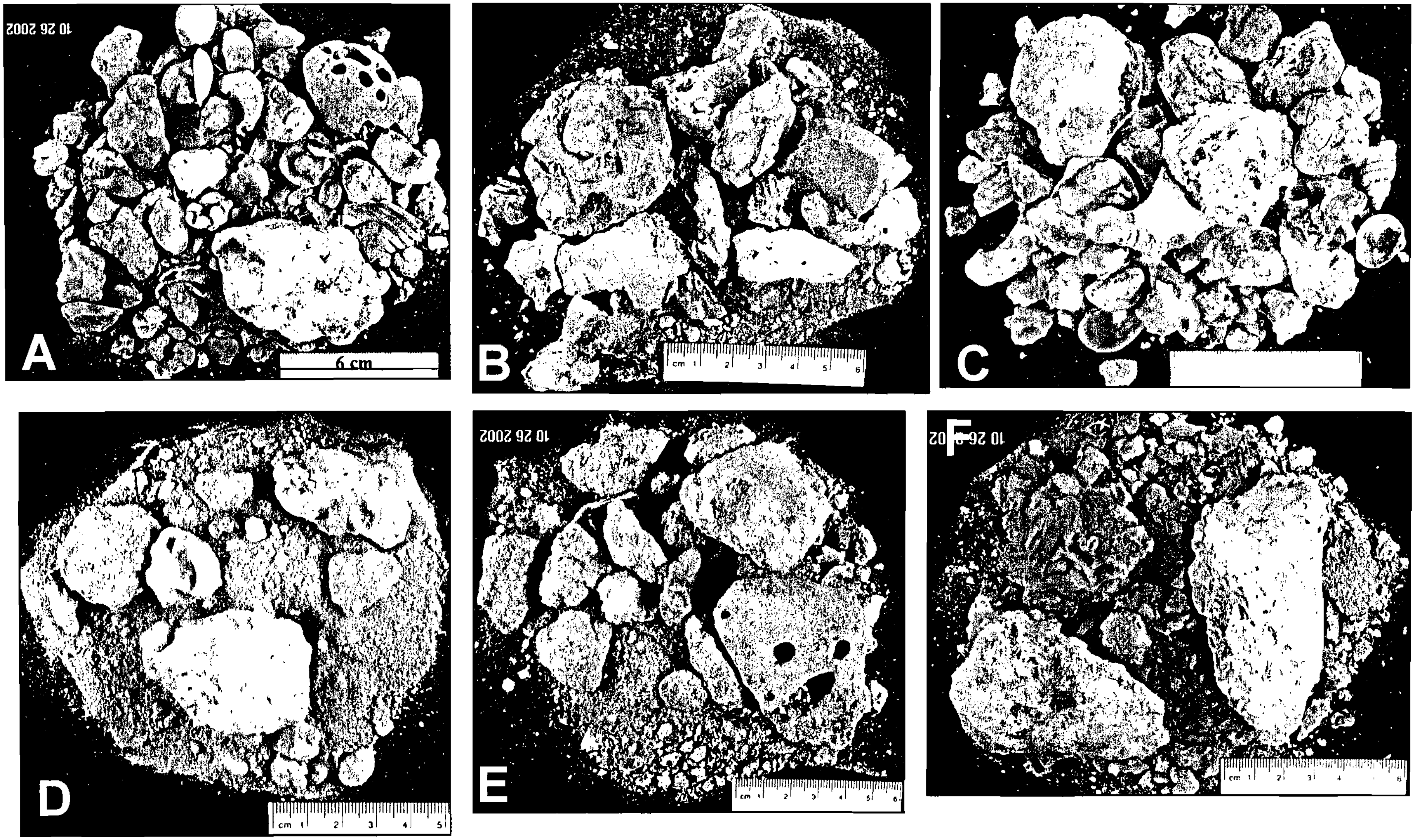


Figure 42. Lithic gravels, silt and sand rich gravel. **A**. Sandy subrounded to rounded limestone gravel (Site 511). **B**. Poorly sorted silt/sand rich angular lithic gravel near scarp (Site 515) offshore North Topsail Beach. **C**. Lithic and shell gravel on inner shoreface offshore North Topsail Beach (Site 507). **D**. Weathering residuum at base of small scarp. Fine material is calcareous mud (Site 513) offshore Alligator Bay. **E**. Weathering residuum near scarp. Fine material is lithic, quartz sand (Site 510) offshore Alligator Bay. **F**. Poorly sorted angular gravel mixture from gravel ramp at Site 516 near high relief hardbottom offshore North Topsail Beach.

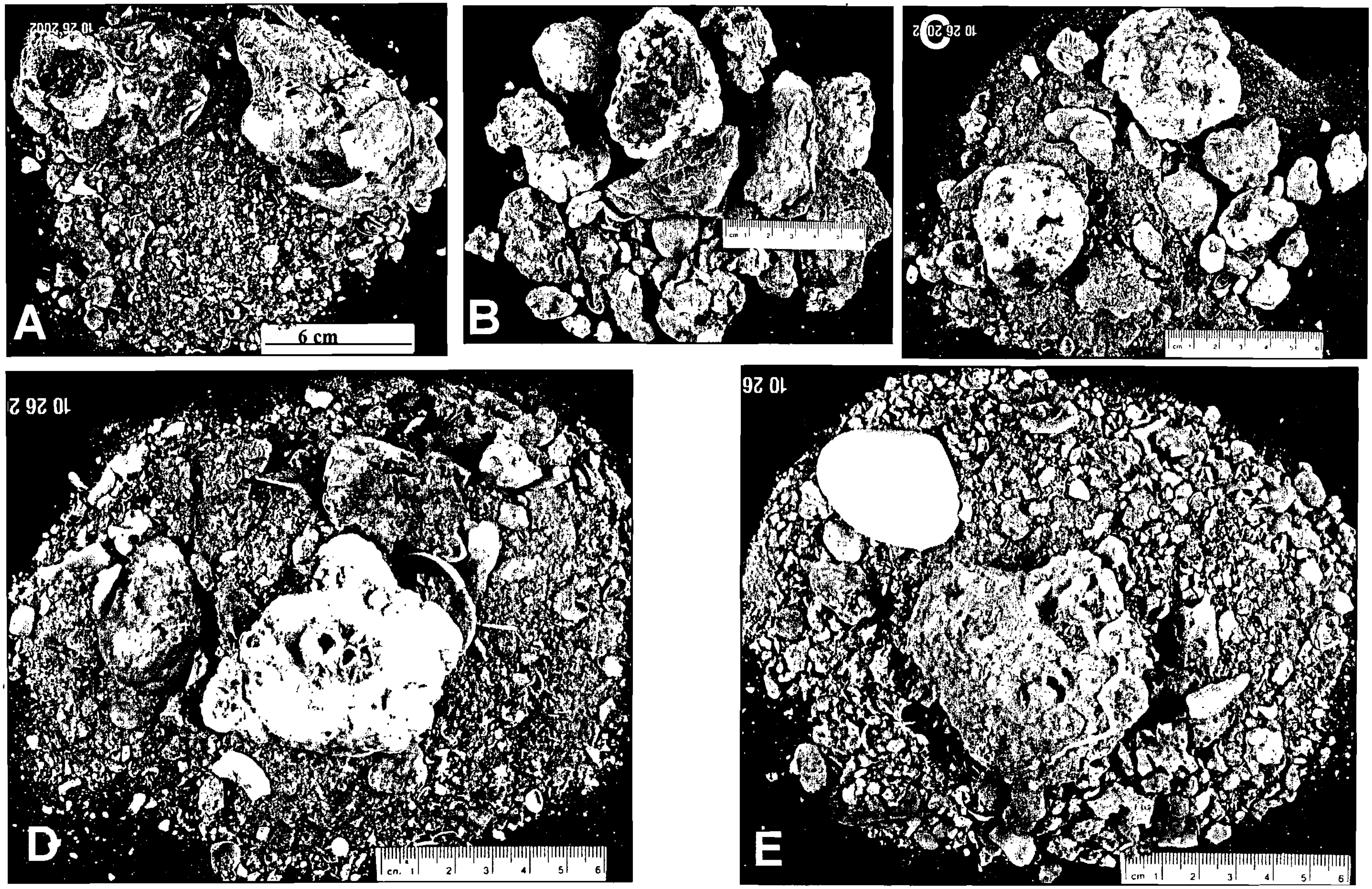


Figure 43. Lithic gravel and sandy gravel. A. Poorly sorted limestone gravel from platform near high relief scarp offshore Onslow Beach (Site 703). B. Subrounded lithic gravel on scarp back offshore North Topsail Beach (Site 720). C. Poorly sorted gravel/sand mixture. Some clasts are encrusted with calcareous algae (Site 810). D. Sandy lithic gravel from Site 721 near scarp. Gravels are bored and encrusted. E. Sandy poorly sorted gravel mixture from Site 830 offshore New River Inlet.

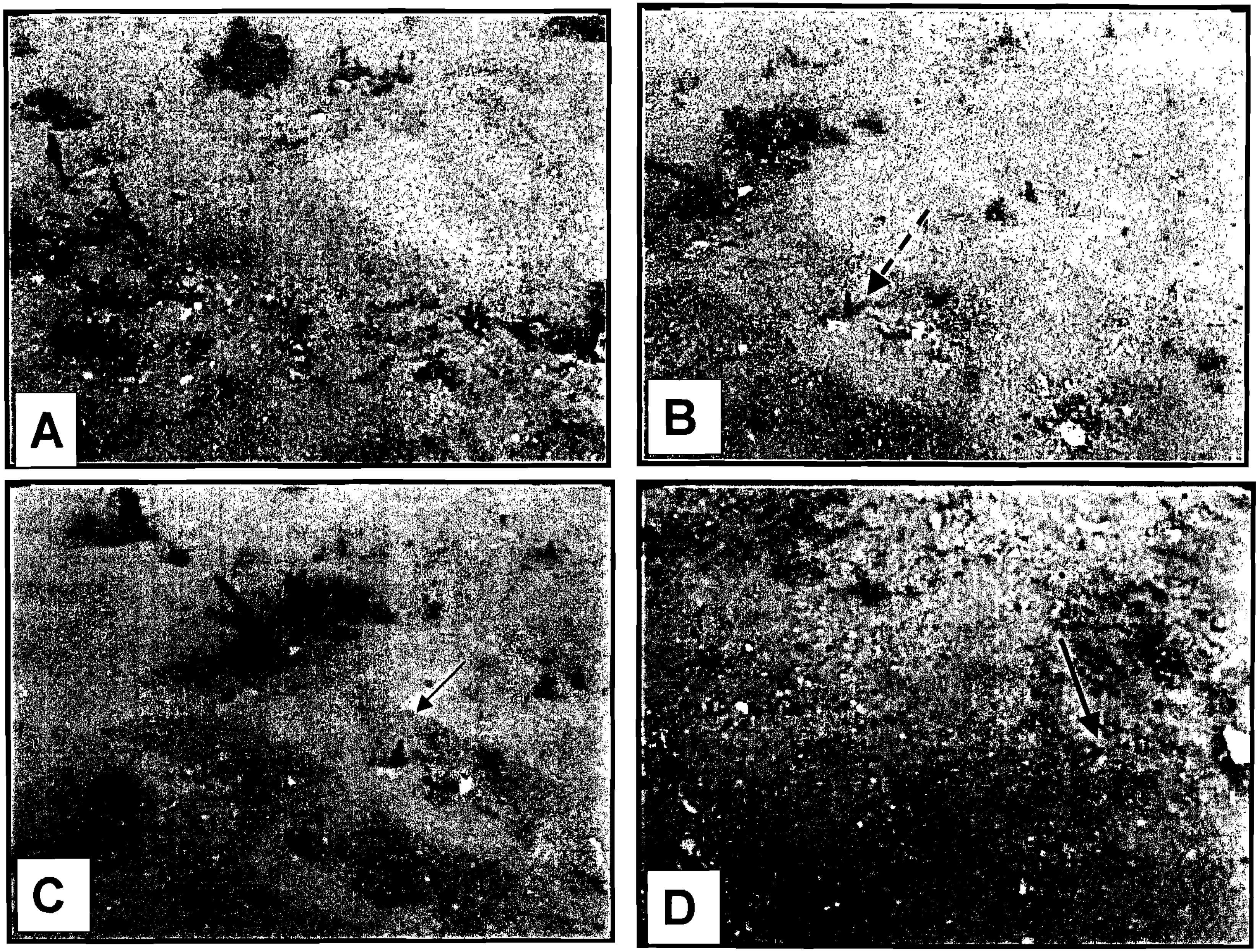


Figure 44. Bottom photos of hardbottom area with thin sand veneer off Surf City (Site SC 78). **A. - C**. Thin rippled sand veneer overlying limestone exposure. Gorgonians and epifauna are partially buried by mobile sand cover. **D**. Thin sand veneer with bored limestone protruding above sediment cover.

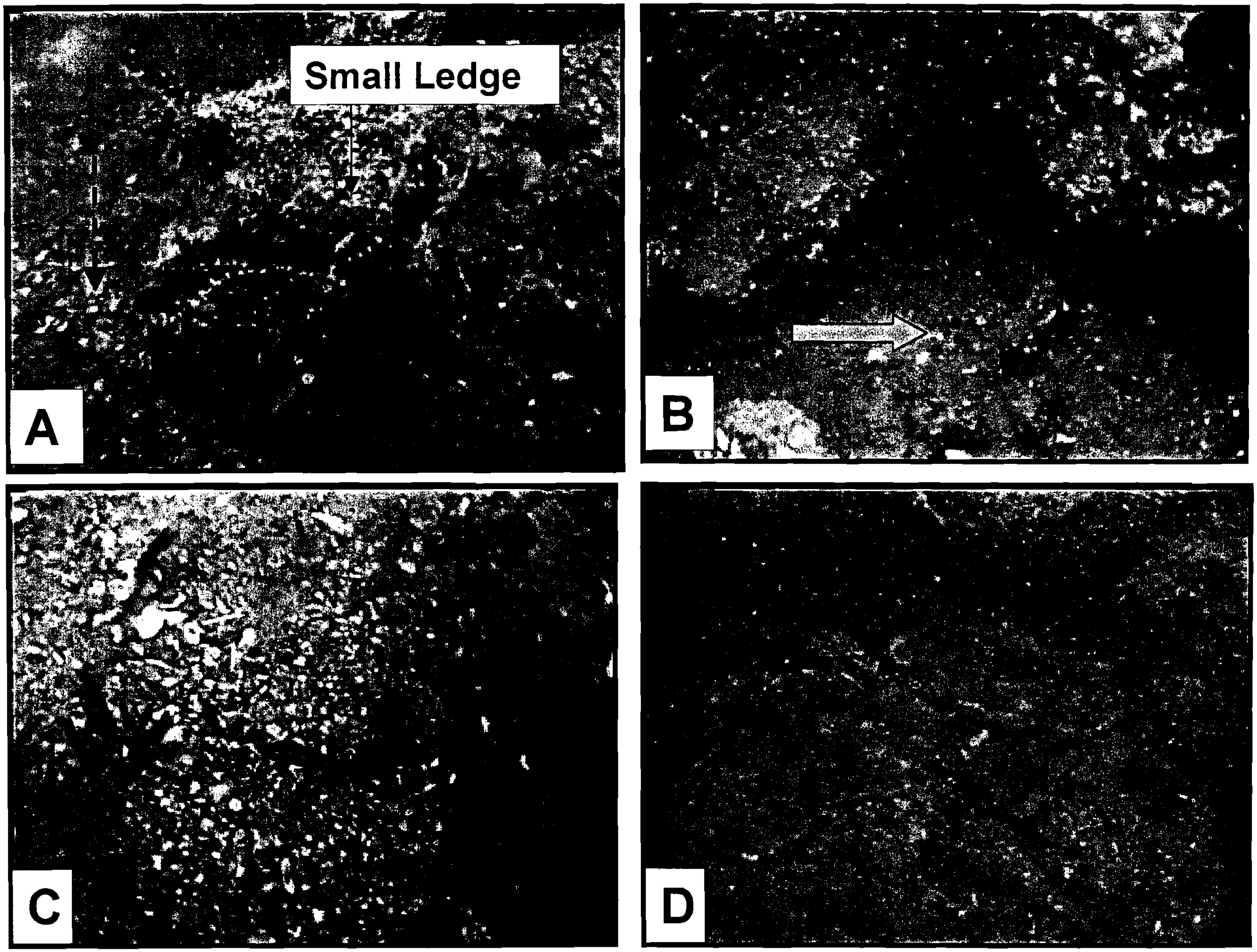


Figure 45. Small encrusted limestone scarp offshore Surf City (Site SDA). **A**. Macro algae and silt layer mantle ledge with poorly sorted gravel/sand mixture at base. **B**. Gravel/sand mixture at base of step like scarp. **C**. Buried macro algae at base of scarp. **D**. Rubble ramp at base of scarp. Silt to garvel size material infilled void spaces in ramp feature.

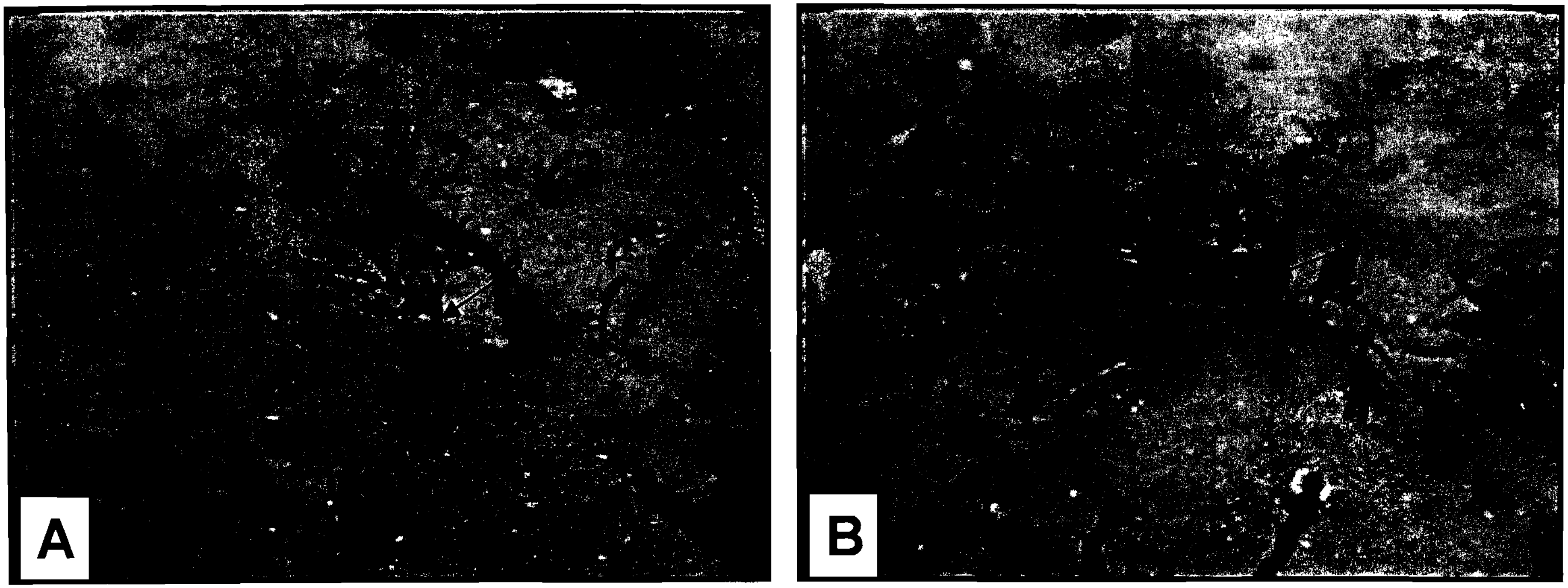


Figure 46. Thin sediment cover overlying limestone hardbottom at Site SC 83 offshore Surf City. **A**. Epifauna and macro algae meadows on limestone scarp back mantled with thin rippled sand veneer. **B**. Macro algae partially buried by a mobile silty fine-medium sand veneer.

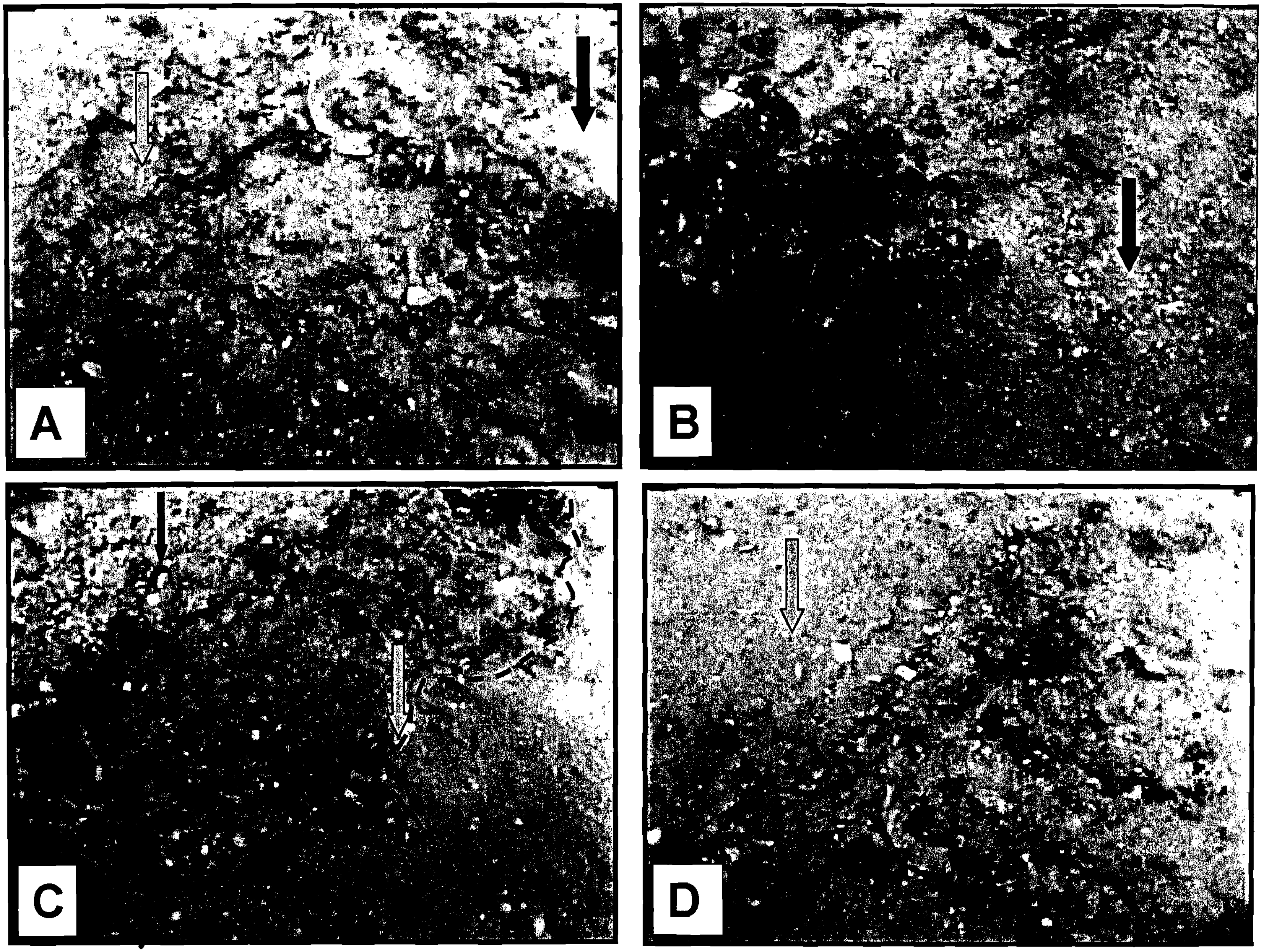


Figure 47. Hardbottom area offshore Surf City (Site 78). **A**. Thin layer of very fine sand (black arrow) overlying corroded limestone surface (white arrow). **B**. Gravel rich sand mixture overlying limestone. **C**. Bored (arrow) low relief limestone exposure and contact of surficial sand unit. **D**. Step-like limestone exposure covered with thin veneer of very fine sand.

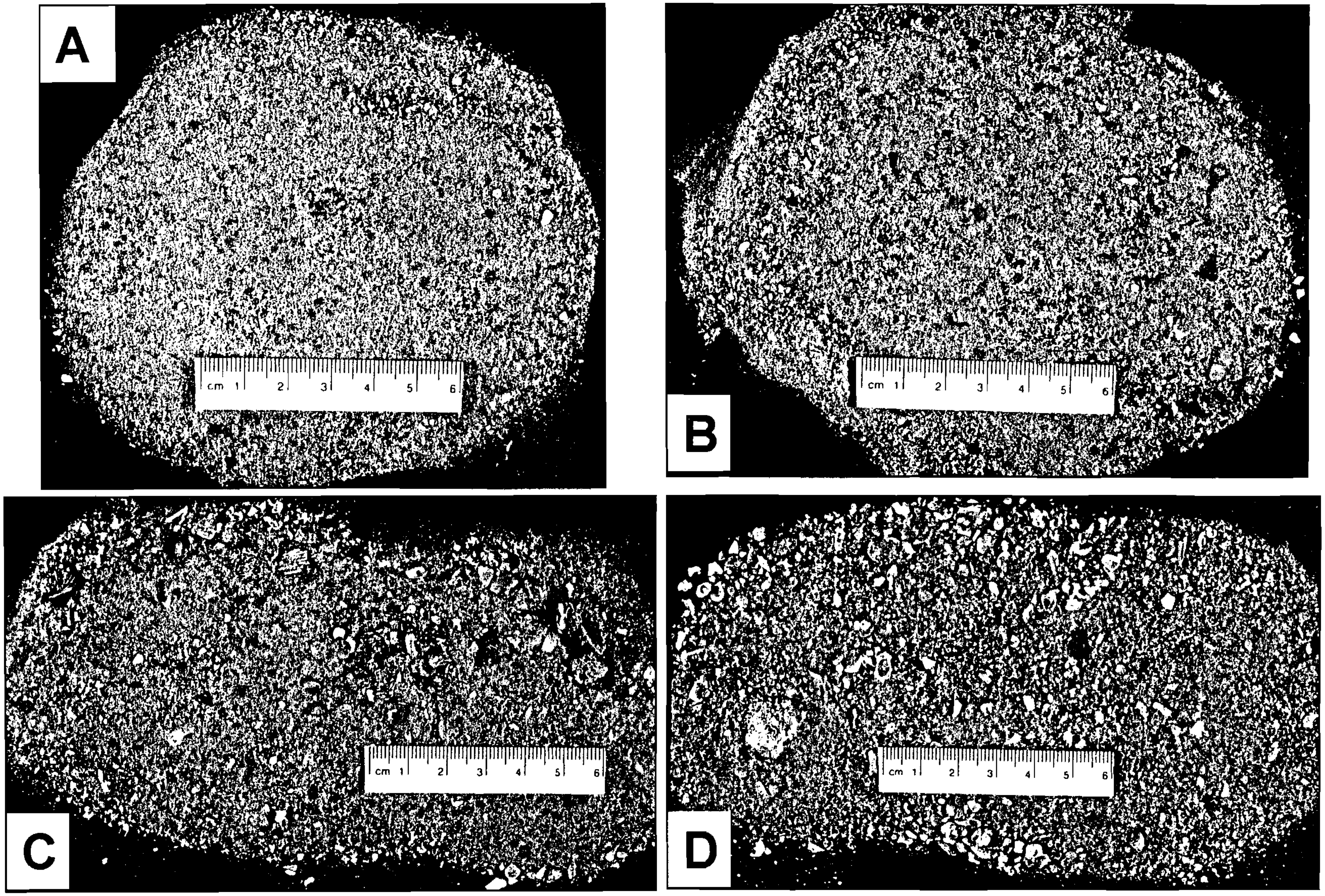


Figure 48. Shelly, fine to medium quartz sands from the shoreface in the southern part of the study area. The carbonate content is usually less than 15 % but can be higher near hardbottoms **A**. (SC3). **B**. (SC 104). **C**. (SC 40). **D**. (SC 80).

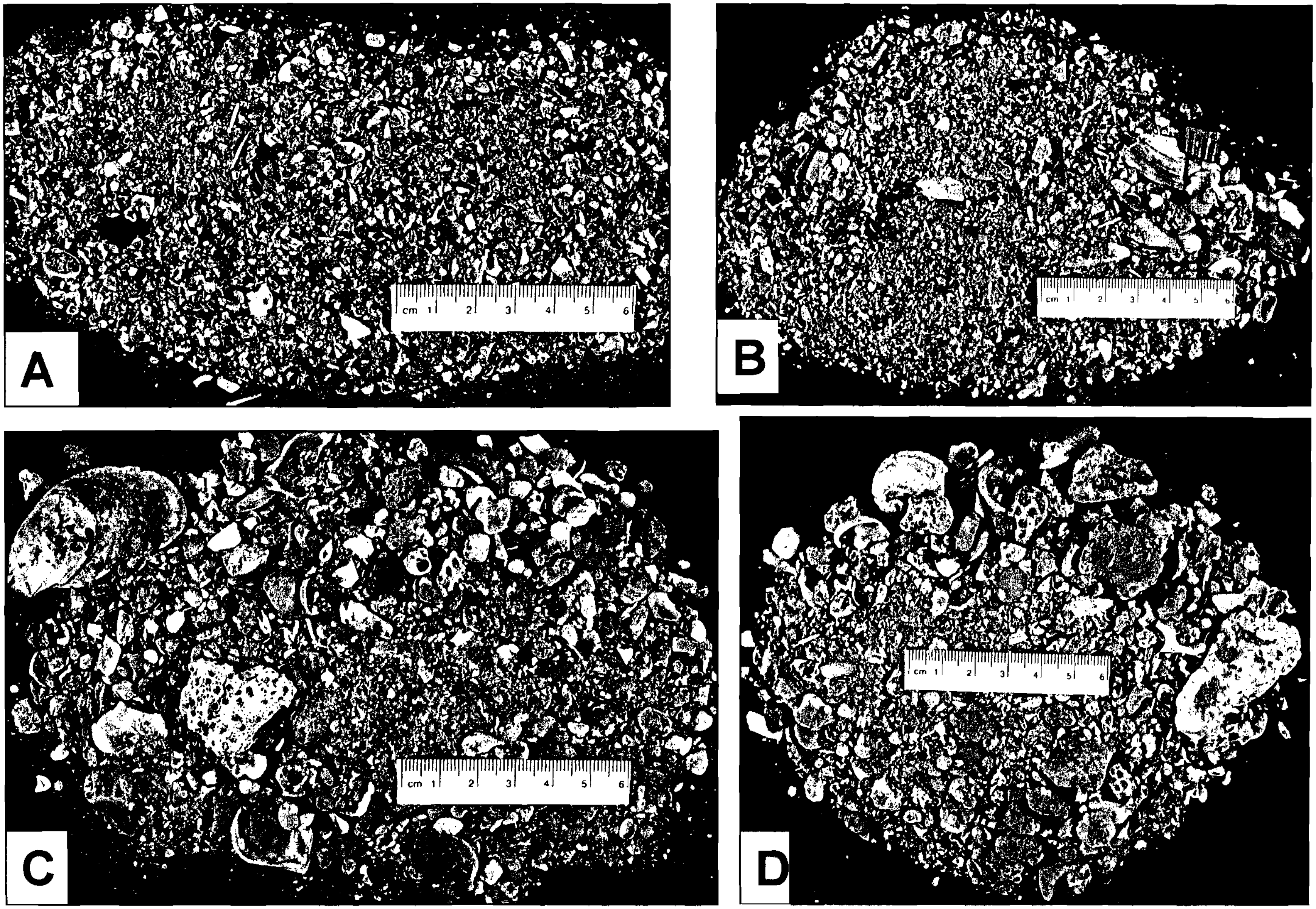


Figure 49. Sandy gravel and gravelly sand from the southern segment of the shoreface. **A**. (SC 82) and **B**. (SC113) are typical of the patches of rippled coarse sand and gravelly sand found near hardbottoms **C**. (TP 4) and **D**. (SC 22) are typical coarse sand and fine gravel. **C.** and **D.** contain 10-15 % coarse silt.

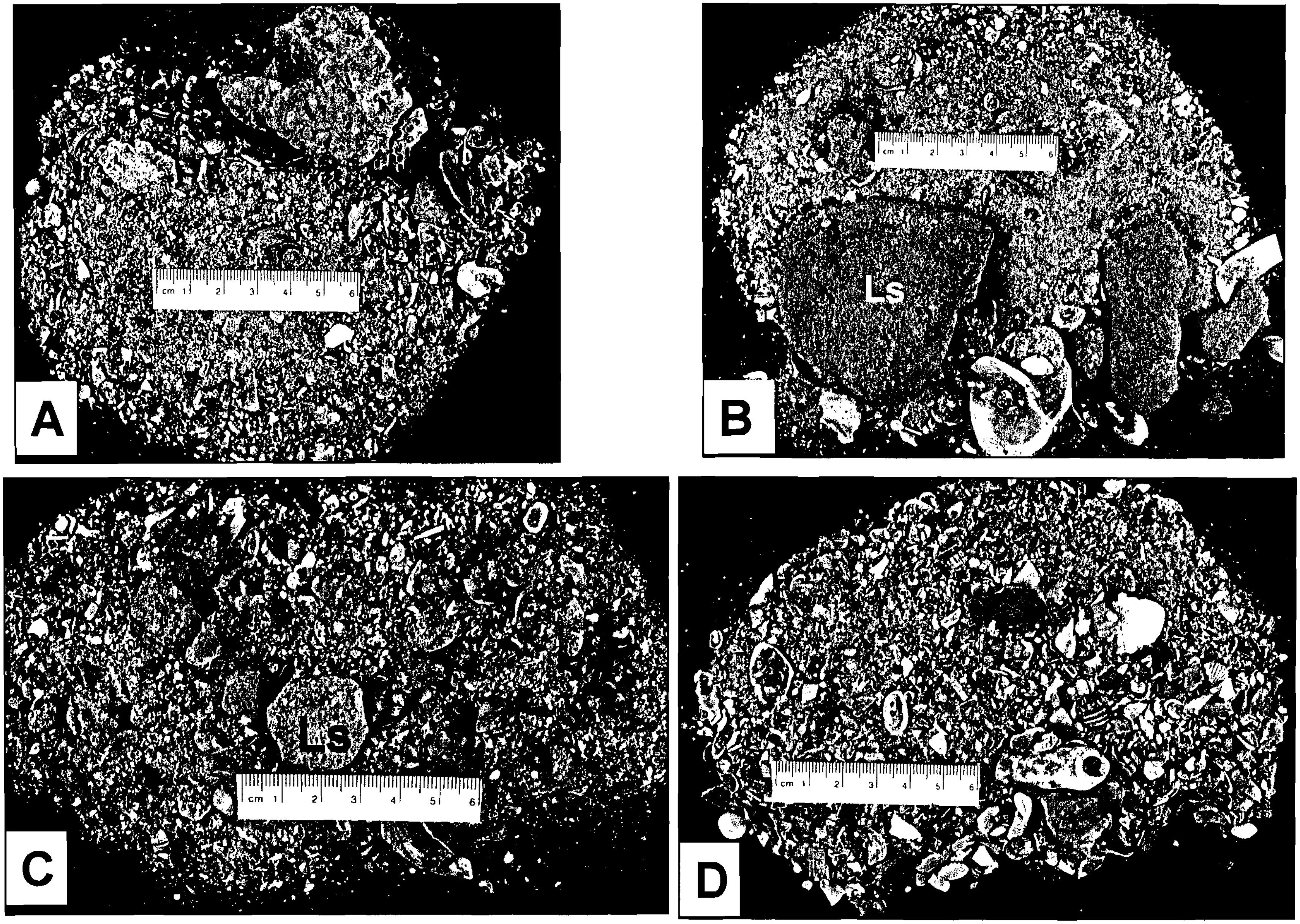


Figure 50. Gravel rich sand from the southern segment of the shoreface. **A. – D.** The composition of the gravel fraction varies from site to site depending upon the nature of the underlying substrate. Arenaceous and moldic limestone lithic fragments constitute a range of sizes. The black and gray shell material reflects reworked backbarrier channel deposits. **A**. SD 4 (49). **B**. SC 84. **C**. SC-VC 28. **D**. TP 10.

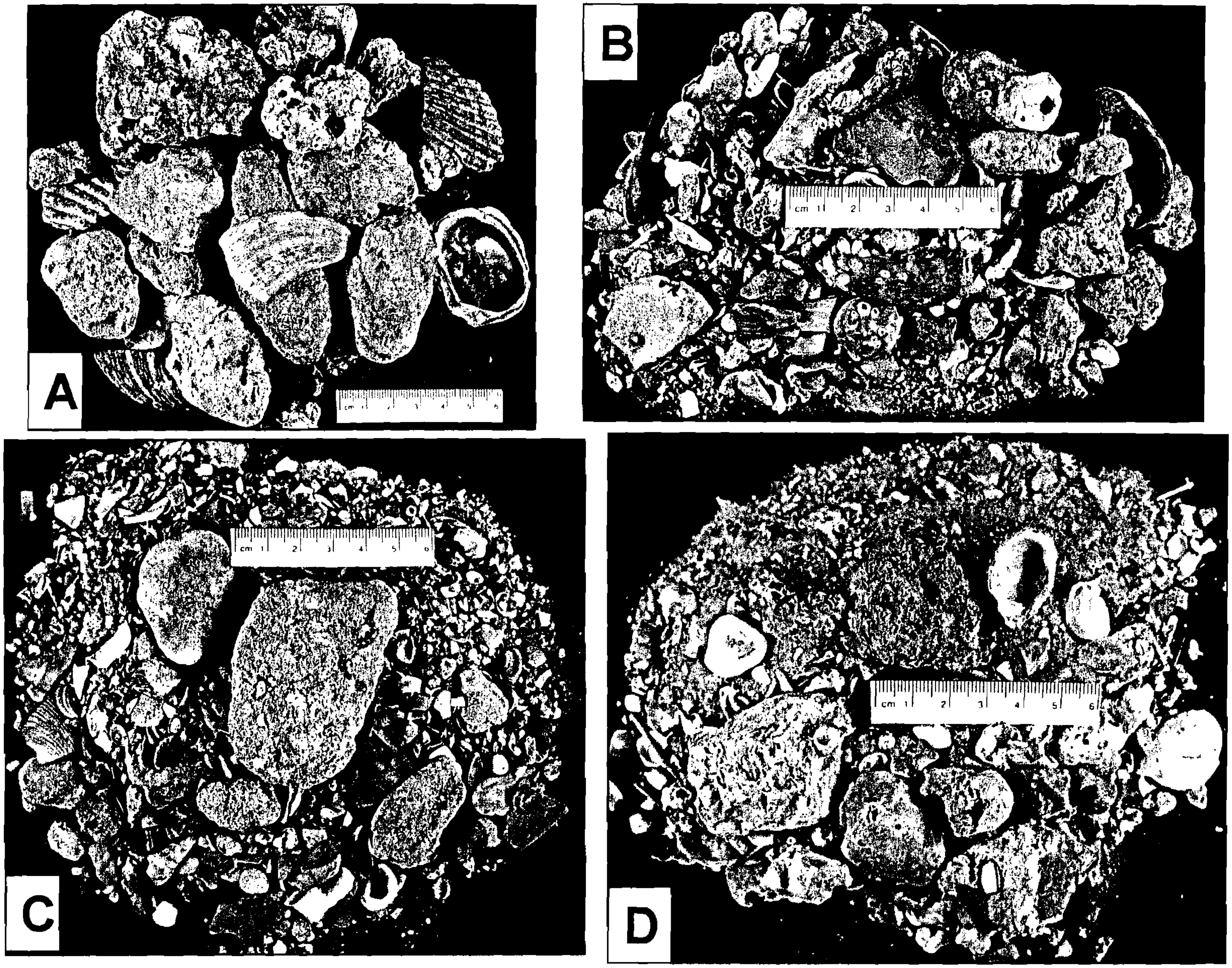


Figure 51. Gravel and sand/gravel mixtures from the shoreface surface sediment veneer in the southern part of the study area. **A**. Cobble size rounded fragments of Tertiary limestone and blackened shells. Shell material is derived from reworked backbarrier units (SC 40). **B**. Mixture of sandy shell and lithic gravel (SC 24). **C**. Poorly sorted sandy gravel. Note abundant black and gray shell fragments. Most large fragments are rounded (SC 105). **D**. Sand-rich lithic gravel (SC 100).

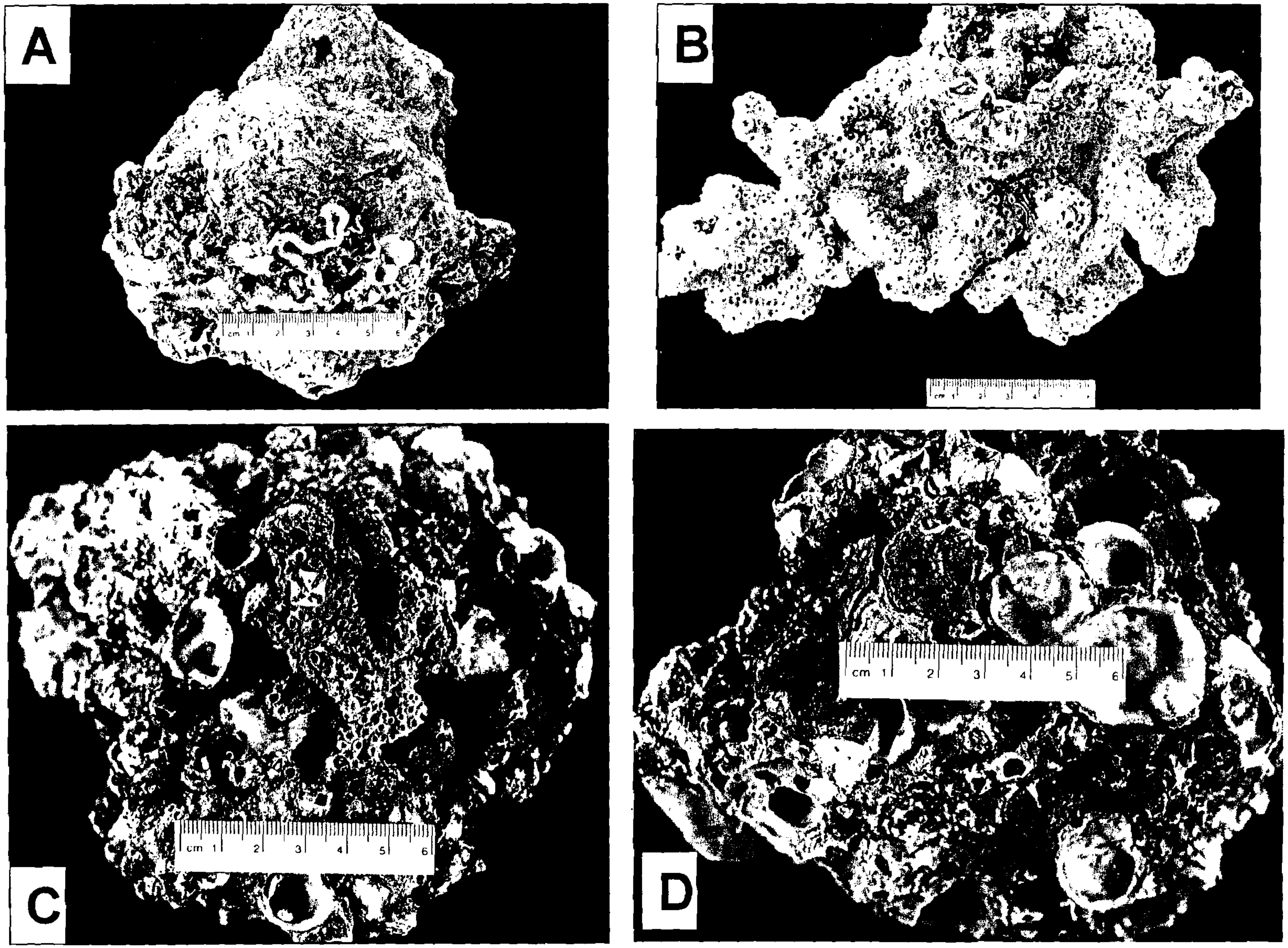


Figure 52. Hardbottom fauna and flora. **A**. (SC105) A variety of mollusks and worm tubes are commonly found encrusting large cobbles and surfaces. **B**. (SC 9 [29]) A variety of species of corals are typically found on the higher relief hardbottoms and on some cobbles in areas were sedimentation rates are low. **C**. (SDA 12) Cobble encrusted with molluscs, worm tubes, algae, and coral. **D**. (SDA 12) Bottom surface of cobble pictured in **C**. Note articulated mollusks and barnacles. Limestone fragment is extensively bored.

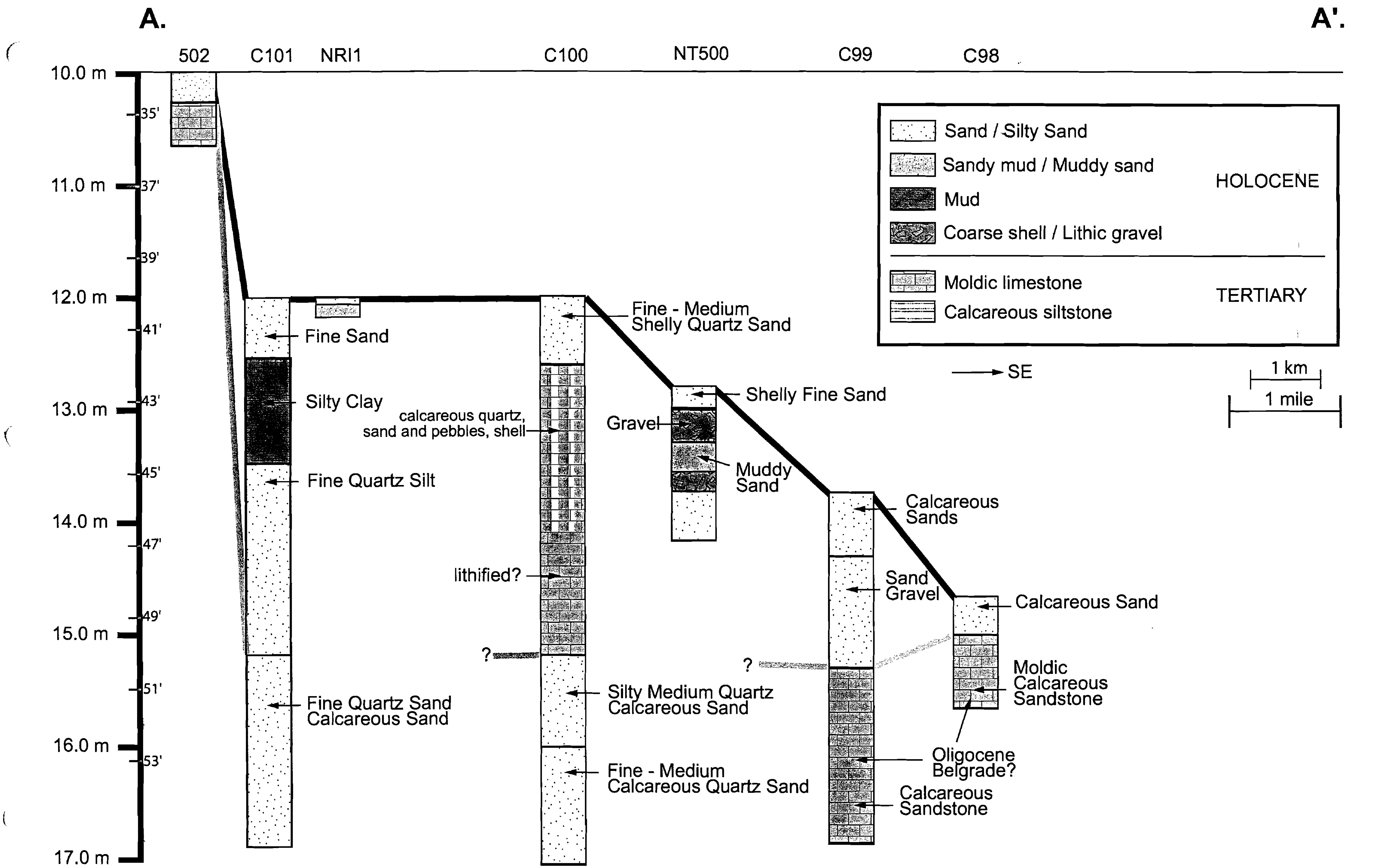


Figure 53. Shore-normal vibracore cross-section A-A'.

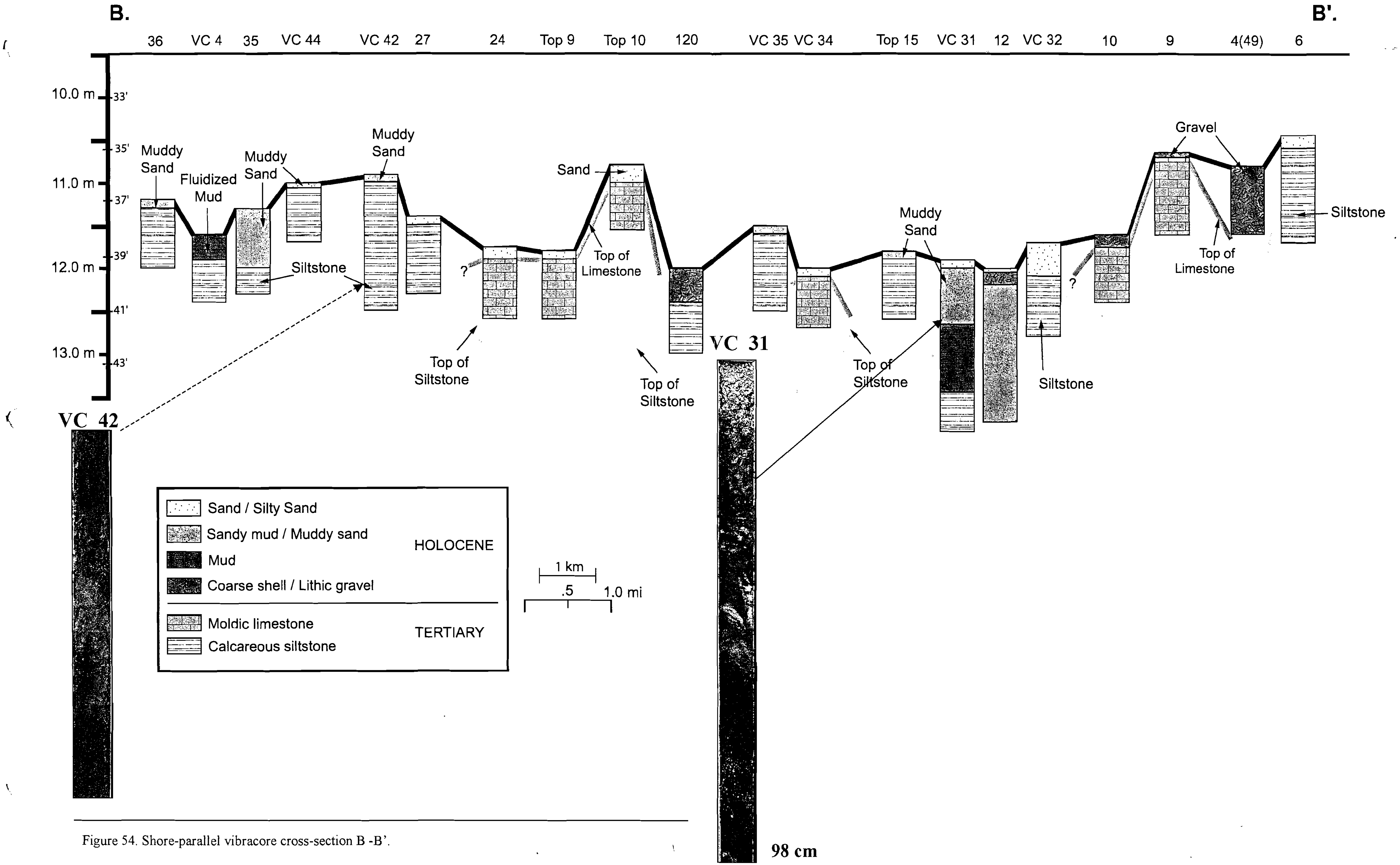


Figure 54. Shore-parallel vibracore cross-section B -B'.

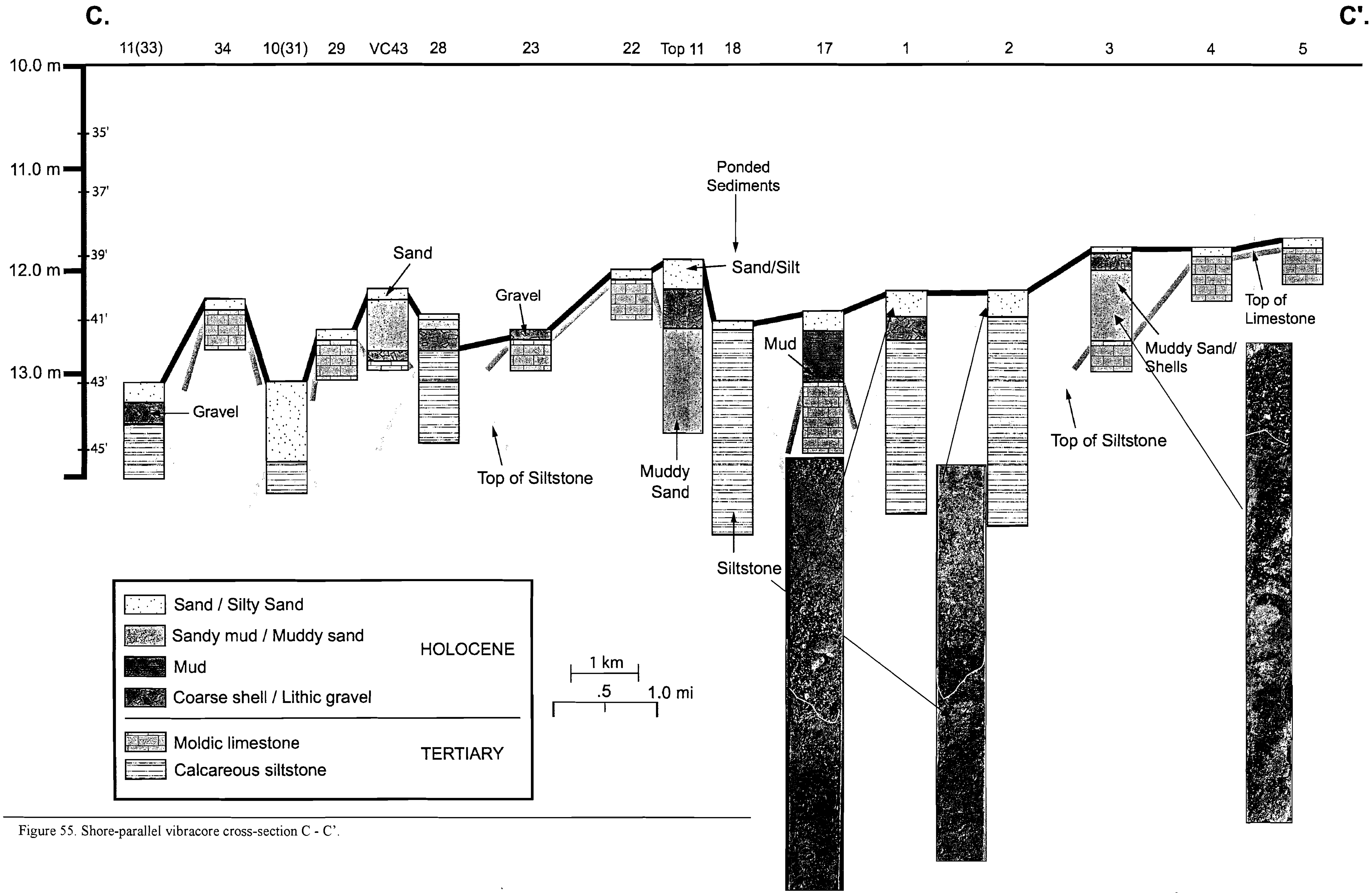


Figure 55. Shore-parallel vibracore cross-section C - C'.

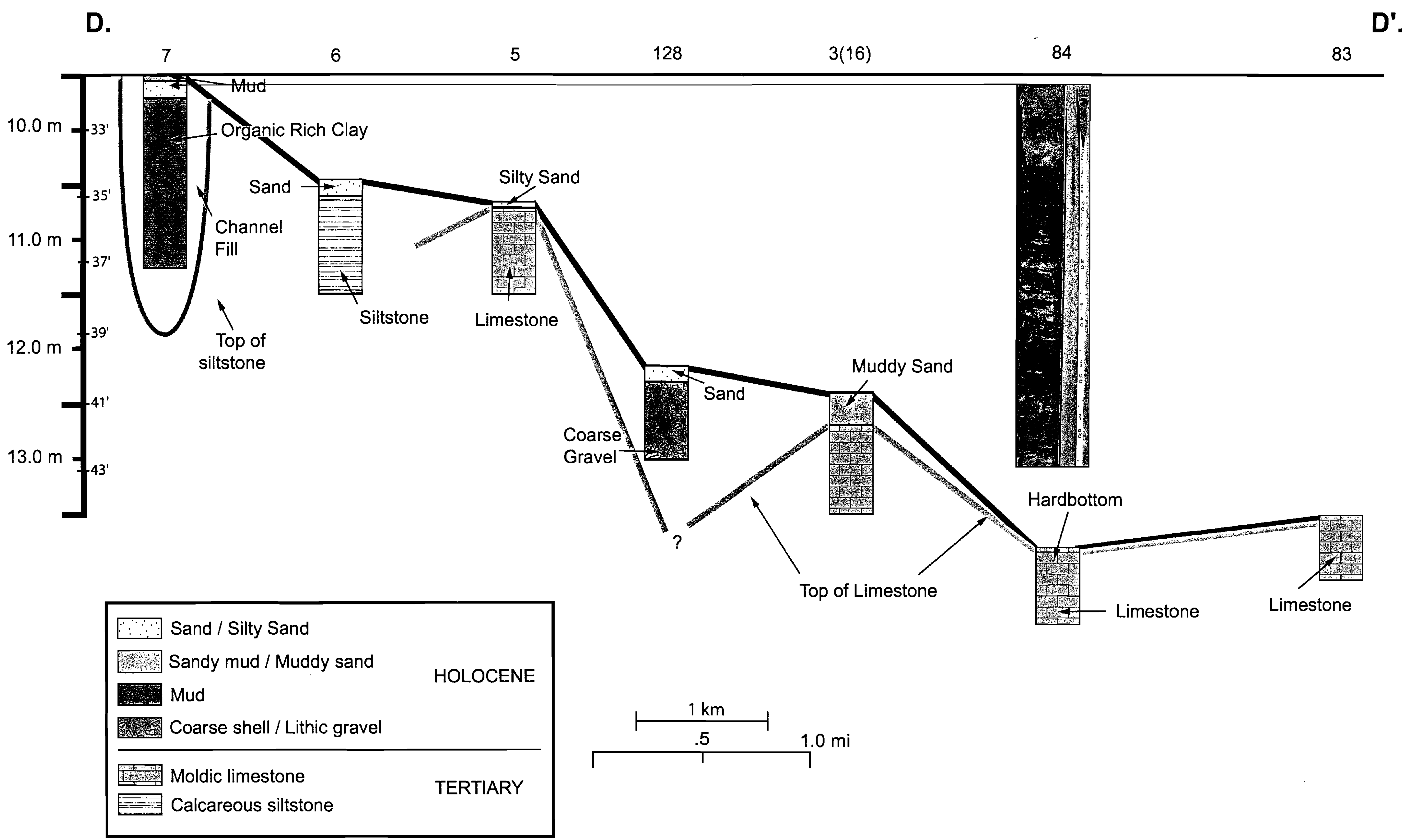


Figure 56. Shore-normal vibracore cross-section D - D'.

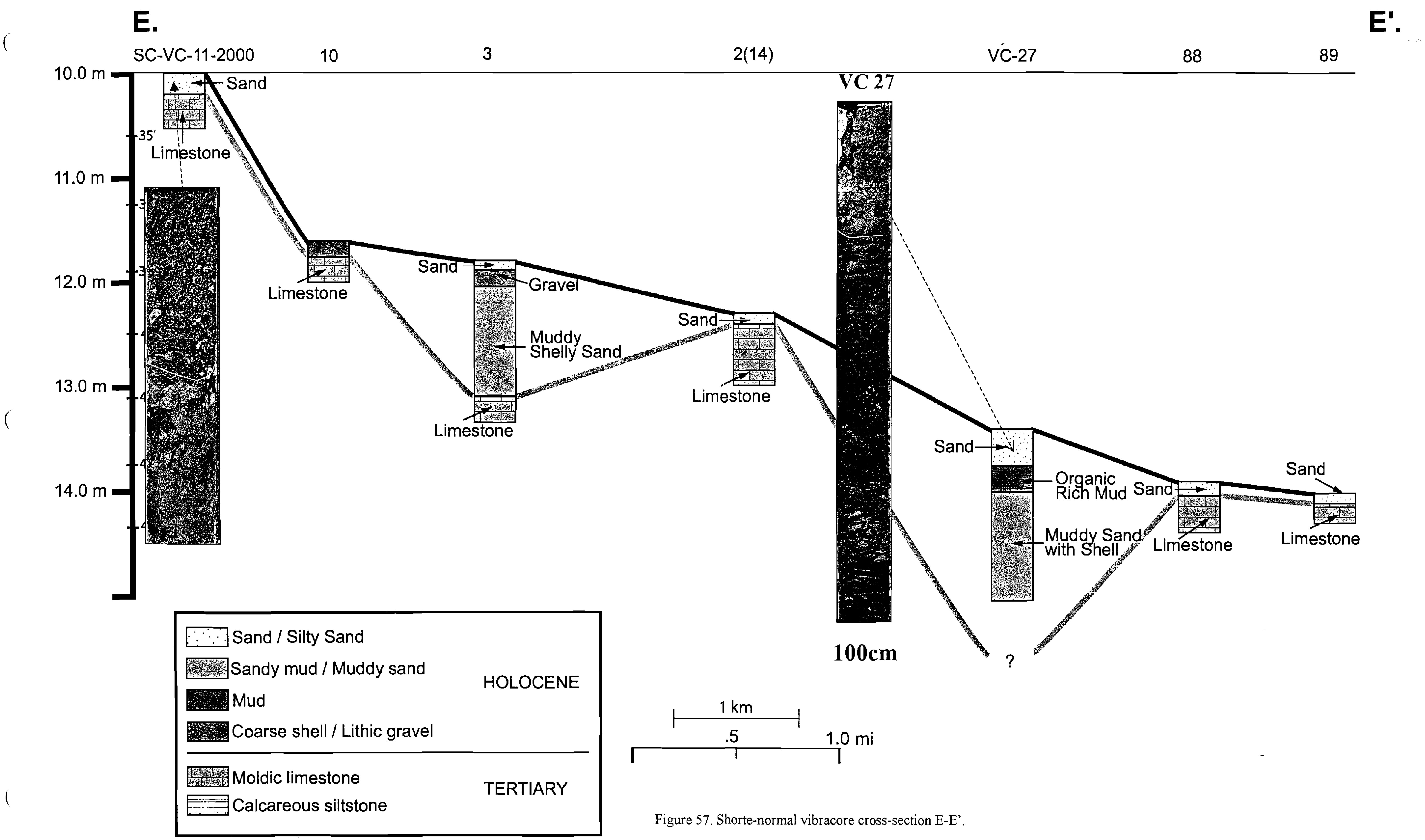


Figure 57. Shorte-normal vibracore cross-section E-E'.

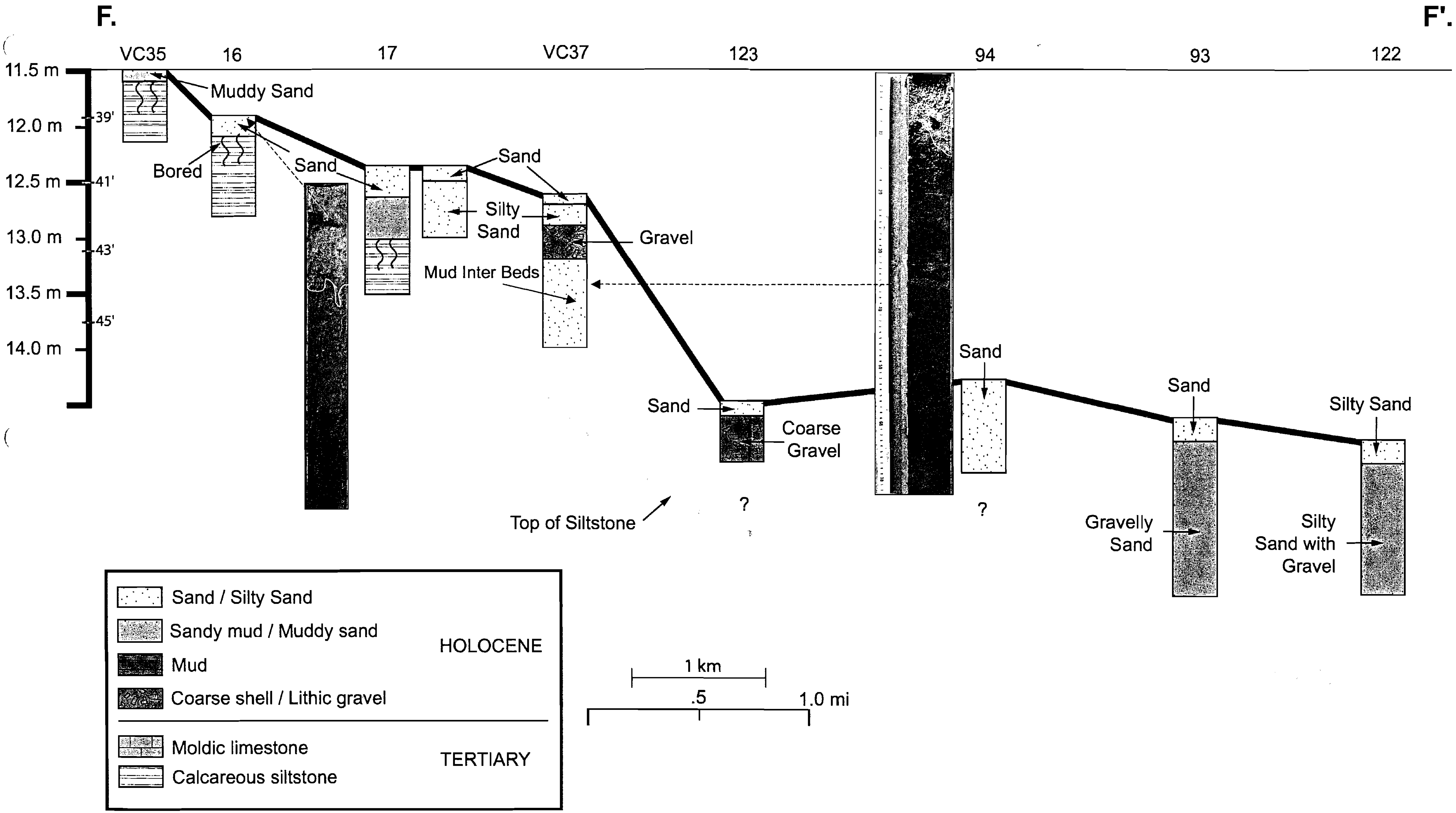


Figure 58. Shore-normal vibracore cross-section F-F'.

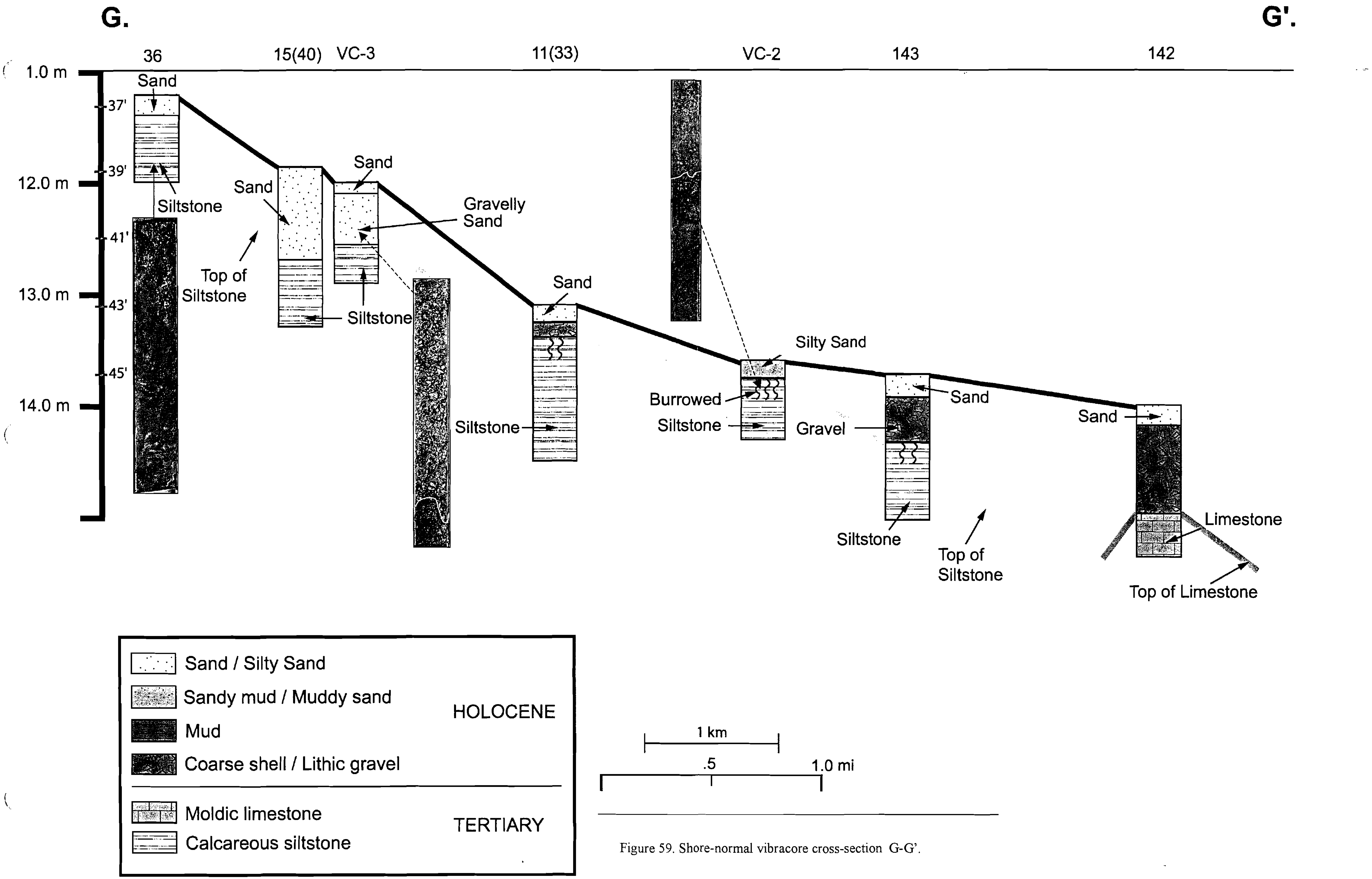


Figure 59. Shore-normal vibracore cross-section G-G'.

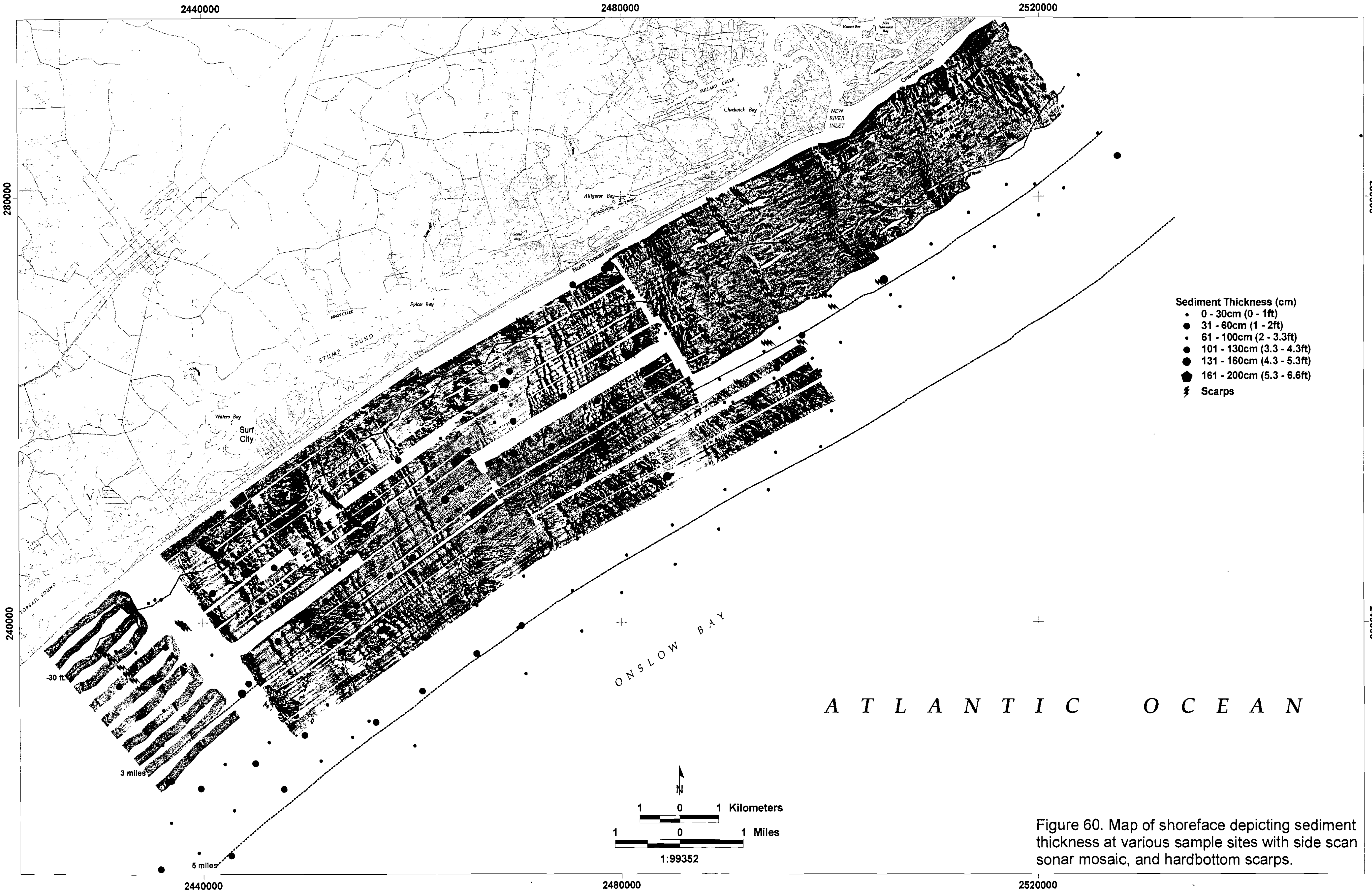


Figure 60. Map of shoreface depicting sediment thickness at various sample sites with side scan sonar mosaic, and hardbottom scarps.

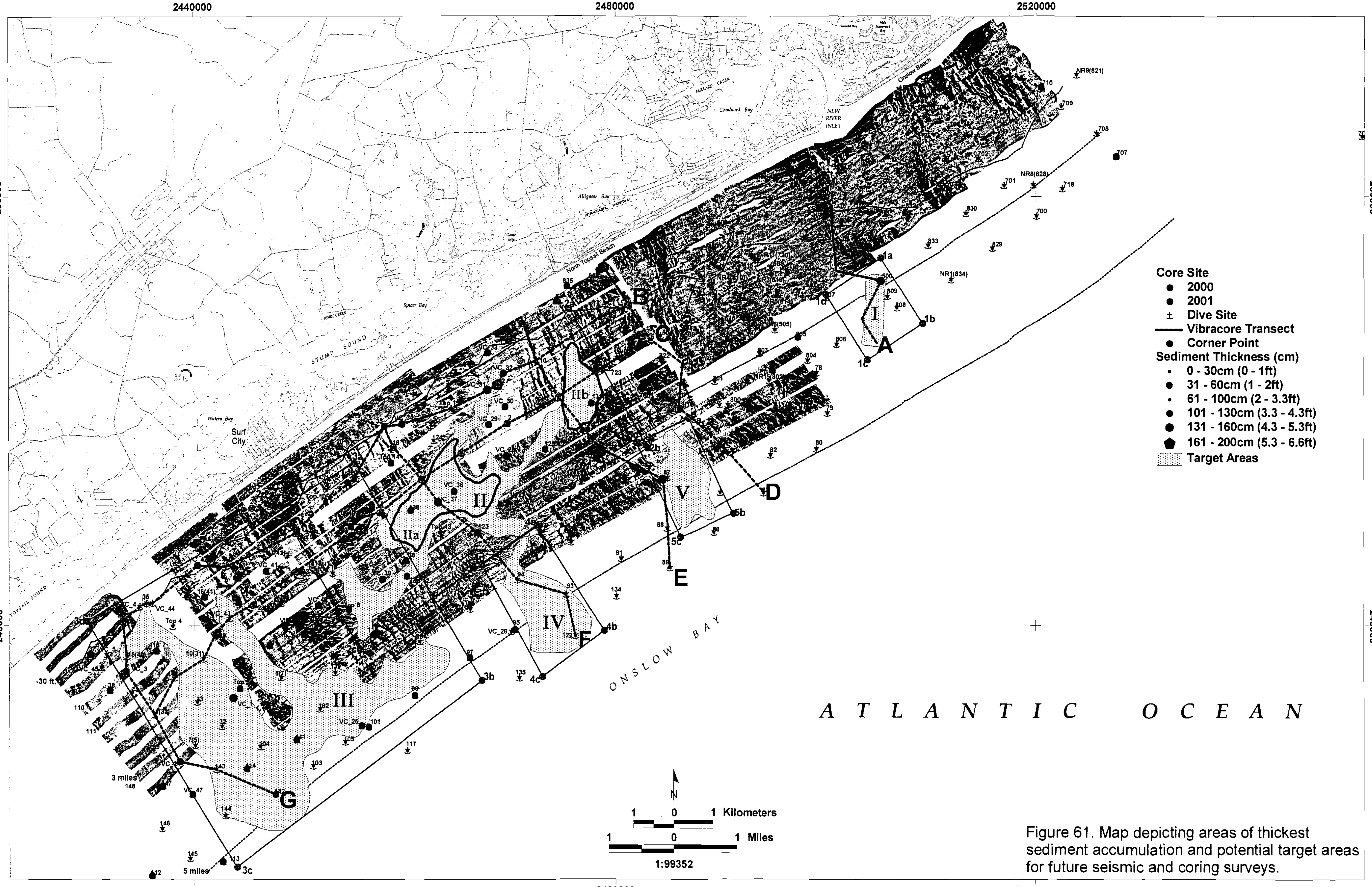


Figure 61. Map depicting areas of thickest sediment accumulation and potential target areas for future seismic and coring surveys.

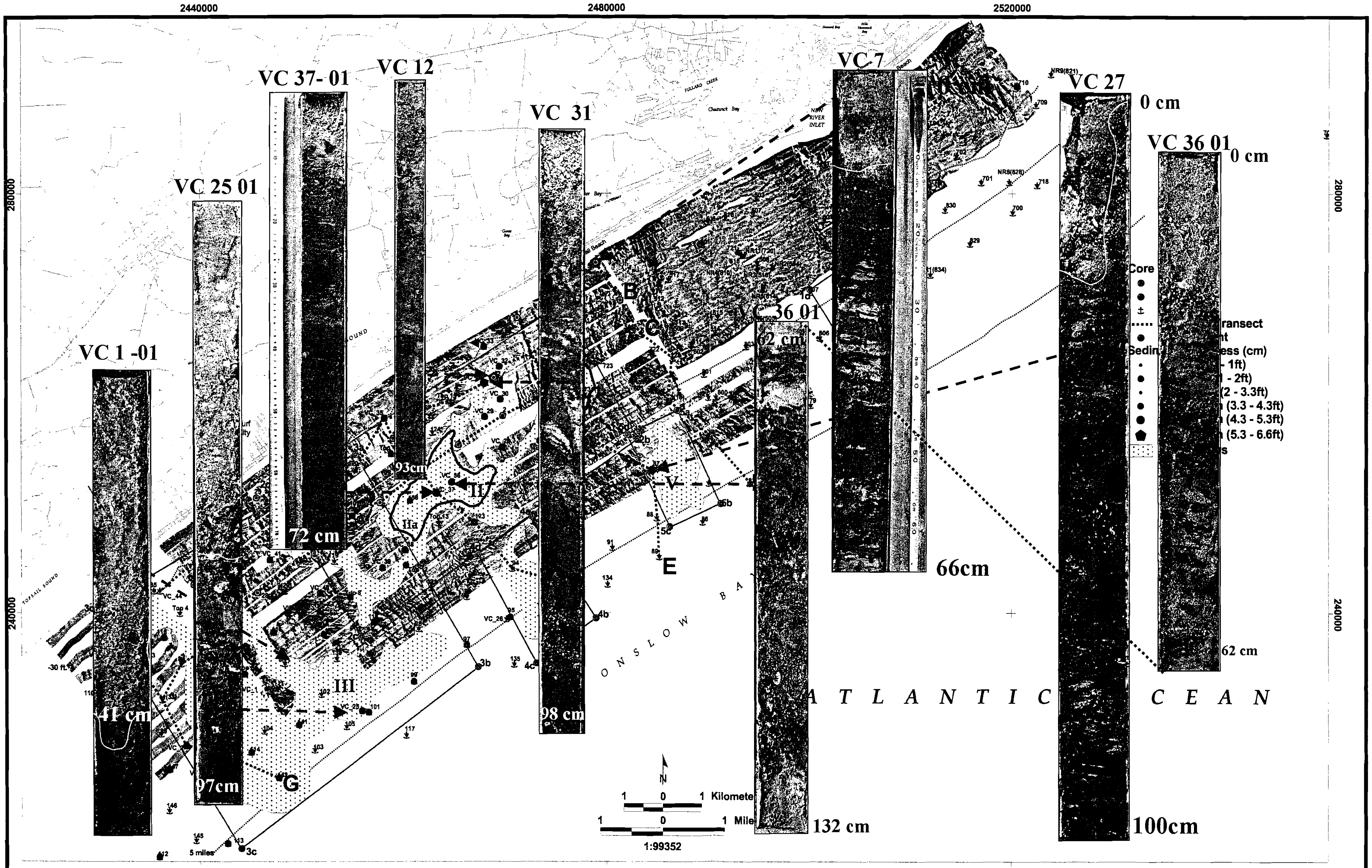


Figure 62. Map depicting areas of thickest sediment accumulation, potential target areas and photographs of representative vibracores.

Core	Date Retrieved	Latitude	Longitude	Length (meters)
1	8/23/2000	34.444	-77.456	1.9
2	8/23/2000	34.451	-77.441	1.7
3	8/23/2000	34.457	-77.425	1.6
6	8/23/2000	34.481	-77.403	0.93
7	8/23/2000	34.491	-77.411	1.67
8	8/23/2000	34.482	-77.425	1.64
11	8/23/2000	34.477	-77.436	0.35
12	8/23/2000	34.461	-77.444	1.66
16	10/11/2000	34.446	-77.477	1.2
17	10/11/2000	34.437	-77.468	1.17
18	10/11/2000	34.429	-77.481	1.63
20	10/11/2000	34.446	-77.494	0.5
25	10/11/2000	34.431	-77.521	0.24
28	10/11/2000	34.406	-77.521	0.76
30	10/11/2000	34.408	-77.542	0.27
VC-1	5/23/2001	34.382	-77.528	1.43
VC-2	5/23/2001	34.366	-77.545	0.49
VC-25	6/20/2001	34.374	-77.488	0.98
VC-27	6/20/2001	34.436	-77.393	1.47
VC-29	6/20/2001	34.451	-77.447	1.3
VC-3	5/23/2001	34.389	-77.561	0.62
VC-30	6/20/2001	34.455	-77.442	1.63
VC-31	6/20/2001	34.460	-77.447	1.59
VC-32	6/20/2001	34.464	-77.442	2.03
VC-33	6/20/2001	34.469	-77.447	1.52
VC34	6/20/2001	34.451	-77.474	2.02
VC-35	6/20/2001	34.451	-77.480	0.92
VC-36	6/20/2001	34.434	-77.458	1.32
VC-37	6/20/2001	34.431	-77.463	1.38
VC-38	6/21/2001	34.416	-77.474	1.34
VC-42	6/21/2001	34.416	-77.539	1.32
500	9/9/1994	34.486	-77.324	1.6
502	9/9/1994	34.508	-77.341	0.85
512	9/12/1994	34.483	-77.392	0.75

Table 1. Vibracores used in conduct of study.

Sample	Latitude	Longitude	Date Retrieved	Sample	Latitude	Longitude	Date Retrieved
4	34.465	-77.411	8/23/2000	125	34.444	-77.429	8/6/2002
5	34.472	-77.396	8/23/2000	126	34.464	-77.358	9/18/2002
9	34.473	-77.421	8/23/2000	127	34.455	-77.375	9/18/2002
10	34.467	-77.432	8/23/2000	128	34.465	-77.386	9/18/2002
22	34.422	-77.494	10/11/2000	129	34.460	-77.399	9/18/2002
23	34.414	-77.507	10/11/2000	130	34.446	-77.397	9/18/2002
24	34.420	-77.518	10/11/2000	131	34.456	-77.415	9/18/2002
29	34.398	-77.533	10/11/2000	132	34.436	-77.418	9/18/2002
33	34.381	-77.539	5/14/2001	133	34.423	-77.432	9/18/2002
35	34.407	-77.555	5/14/2001	134	34.406	-77.408	9/18/2002
36	34.402	-77.562	5/14/2001	135	34.386	-77.439	9/18/2002
37	34.394	-77.573	5/14/2001	137	34.414	-77.453	9/18/2002
38	34.384	-77.567	5/14/2001	138	34.429	-77.472	10/2/2002
39	34.369	-77.553	5/14/2001	139	34.388	-77.496	9/18/2002
78	34.463	-77.344	6/12/2001	140	34.378	-77.514	9/18/2002
79	34.452	-77.341	6/12/2001	141	34.371	-77.509	10/3/2002
80	34.443	-77.345	6/12/2001	142	34.357	-77.515	10/3/2002
81	34.454	-77.357	6/12/2001	143	34.364	-77.534	10/3/2002
82	34.442	-77.359	6/12/2001	144	34.352	-77.531	10/3/2002
83	34.432	-77.361	6/12/2001	145	34.341	-77.542	10/3/2002
84	34.445	-77.375	6/12/2001	146	34.349	-77.551	10/3/2002
85	34.433	-77.375	6/12/2001	147	34.360	-77.551	10/3/2002
86	34.422	-77.377	6/12/2001	148	34.360	-77.564	10/3/2002
87	34.437	-77.392	6/12/2001	1(12)	34.431	-77.439	7/19/2000
88	34.424	-77.392	6/12/2001	10(31)	34.392	-77.537	7/19/2000
89	34.413	-77.391	8/22/2001	11(33)	34.378	-77.553	7/19/2000
90	34.428	-77.407	8/22/2001	15(40)	34.393	-77.561	7/19/2000
91	34.416	-77.406	8/22/2001	16(41)	34.408	-77.537	7/19/2000
92	34.420	-77.422	8/22/2001	17(42)	34.420	-77.518	7/19/2000
93	34.407	-77.424	6/12/2001	2(14)	34.444	-77.412	7/19/2000
94	34.411	-77.439	8/22/2001	3(16)	34.454	-77.388	7/19/2000
95	34.398	-77.440	6/12/2001	4(49)	34.478	-77.412	7/19/2000
96	34.404	-77.454	8/22/2001	7(5)	34.370	-77.540	7/19/2000
97	34.391	-77.454	6/12/2001	8(7)	34.387	-77.513	7/19/2000
98	34.396	-77.470	8/22/2001	9(29)	34.406	-77.513	7/19/2000
99	34.382	-77.471	6/12/2001	SDA	34.396	-77.502	7/19/2000
100	34.388	-77.485	8/22/2001	Top 10	34.432	-77.498	7/27/1998
101	34.374	-77.486	6/12/2001	Top 11	34.425	-77.491	7/27/1998
102	34.379	-77.501	8/22/2001	Top 12	34.412	-77.473	7/27/1998
103	34.364	-77.504	6/12/2001	Top 13	34.423	-77.463	7/27/1998
104	34.369	-77.520	8/22/2001	Top 14	34.442	-77.478	7/27/1998
105	34.370	-77.494	8/22/2001	Top 15	34.455	-77.459	7/27/1998
107	34.427	-77.489	8/22/2001	Top 4	34.401	-77.547	7/27/1998
110	34.379	-77.577	8/6/2002	Top 5	34.384	-77.526	7/27/1998
111	34.372	-77.574	8/6/2002	Top 6	34.413	-77.526	7/27/1998
112	34.337	-77.554	8/6/2002	Top 7	34.401	-77.502	7/27/1998
113	34.340	-77.532	8/6/2002	Top 8	34.404	-77.492	7/27/1998
114	34.364	-77.524	8/6/2002	Top 9	34.424	-77.508	7/27/1998
115	34.394	-77.552	8/6/2002	VC_26	34.398	-77.441	5/20/2001
116	34.395	-77.516	8/6/2002	VC_28	34.443	-77.442	5/20/2001
117	34.368	-77.474	8/6/2002	VC_39	34.412	-77.481	6/21/2001
118	34.398	-77.484	8/6/2002	VC_4	34.406	-77.557	5/23/2001
119	34.414	-77.497	8/6/2002	VC_40	34.405	-77.501	6/21/2001
120	34.438	-77.490	8/6/2002	VC_41	34.414	-77.517	6/21/2001
121	34.406	-77.465	8/6/2002	VC_43	34.402	-77.529	6/21/2001
122	34.397	-77.421	8/6/2002	VC_44	34.407	-77.553	6/21/2001
123	34.423	-77.451	8/6/2002	VC_45	34.390	-77.569	6/21/2001
124	34.447	-77.464	8/6/2002	VC_47	34.357	-77.541	6/21/2001

Table 2. Surface samples used in conduct of study.

Sample	Latitude	Longitude	Date Retrieved	Sample	Latitude	Longitude	Date Retrieved
VC_5	34.394	-77.567	5/23/2001	805	34.472	-77.350	6/4/1996
501	34.501	-77.336	9/9/1994	806	34.470	-77.338	6/4/1996
503	34.507	-77.358	9/9/1994	807	34.482	-77.341	6/5/1996
506	34.501	-77.374	9/9/1994	808	34.479	-77.319	6/5/1996
507	34.503	-77.359	9/9/1994	809	34.482	-77.322	6/5/1996
508	34.490	-77.358	9/9/1994	811	34.469	-77.380	6/5/1996
509	34.474	-77.386	9/9/1994	812	34.476	-77.385	6/5/1996
510	34.469	-77.403	9/12/1994	813	34.485	-77.390	6/5/1996
511	34.473	-77.401	9/12/1994	815	34.492	-77.363	6/5/1996
513	34.471	-77.388	9/12/1994	816	34.502	-77.368	6/5/1996
514	34.472	-77.372	9/12/1994	826	34.535	-77.302	6/6/1996
515	34.476	-77.371	9/12/1994	827	34.522	-77.287	6/6/1996
517	34.486	-77.387	9/12/1994	829	34.494	-77.289	6/7/1996
600	34.474	-77.365	NA	830	34.503	-77.297	6/7/1996
601	34.495	-77.376	NA	831	34.510	-77.305	6/7/1996
602	34.468	-77.380	NA	832	34.504	-77.316	6/7/1996
603	34.459	-77.399	NA	833	34.495	-77.309	6/7/1996
604	34.473	-77.393	NA	835	34.486	-77.422	6/7/1996
700	34.502	-77.275	8/31/1995	836	34.490	-77.412	6/7/1996
701	34.510	-77.285	8/31/1995	NR1(834)	34.486	-77.302	6/24/1996
702	34.517	-77.293	8/31/1995	NR2(504)	34.489	-77.353	6/24/1996
703	34.521	-77.173	8/31/1995	NR3(516)	34.488	-77.358	6/24/1996
704	34.525	-77.302	8/31/1995	NR4(810)	34.486	-77.371	6/24/1996
705	34.527	-77.305	8/31/1995	NR5(814)	34.483	-77.356	6/24/1996
707	34.517	-77.250	8/31/1995	NR6(505)	34.474	-77.357	6/24/1996
708	34.523	-77.256	8/31/1995	NR7	NA	NA	6/24/1996
709	34.530	-77.267	8/31/1995	NR8(828)	34.510	-77.276	6/25/1996
710	34.535	-77.273	8/31/1995	NR9(821)	34.538	-77.262	6/25/1996
718	34.509	-77.267	9/1/1995	NR10(706)	34.529	-77.307	6/25/1996
719	34.486	-77.324	9/1/1995	NR11(720)	34.492	-77.362	6/25/1996
721	34.493	-77.364	9/1/1995	NR12(810)	34.486	-77.371	6/25/1996
722	34.467	-77.393	9/1/1995	NR13	NA	NA	6/25/1996
723	34.465	-77.409	9/1/1995	NR14(834)	34.486	-77.302	8/6/1996
800	34.455	-77.372	6/4/1996	NR15(802)	34.461	-77.359	8/6/1996
801	34.461	-77.376	6/4/1996	NR16	NA	NA	8/6/1996
803	34.468	-77.362	6/4/1996	VID 1	34.400	-77.511	9/18/2002
804	34.466	-77.347	6/4/1996				

Table 2 (continued). Surface sampes used in conduct of study.

Corner Point	X	Y
1a	2505011.58000	274287.78312
1b	2509003.90742	268163.18993
1c	2503809.34504	264760.63815
1d	2499907.75234	270862.54767
2a	2475680.29831	269531.46941
2b	2483061.71851	256544.60980
2c	2456033.51069	237785.81259
2d	2448097.09648	251882.66020
3a	2455508.96953	255130.28245
3b	2467501.26325	234862.60475
3c	2444428.37065	217540.40270
3d	2430332.16574	240473.03456
4a	2472721.79341	249289.29331
4b	2478996.28451	239540.94232
4c	2473206.51804	235232.27890
4d	2467497.53901	245653.85855
5a	2486913.45354	259333.86490
5b	2491249.04611	250474.17575
5c	2486186.36659	248265.98574
5d	2482039.27805	257044.88746

Table 3. Coordinates for recommended seismic surveys of Borrow Areas I - IV.

Feasibility Report
and
Final Environmental Impact Statement

on

Coastal Storm Damage Reduction

SURF CITY AND NORTH TOPSAIL BEACH
NORTH CAROLINA

Appendix R
Attachment 2

High-Resolution Remote Sensing of Potential Hard Bottom Habitats: Topsail Island, NC

High-Resolution Remote Sensing of Potential Hard Bottom Habitats: Topsail Island, NC July 2006

Survey Report

Project No. DACW54-02-D-0006, Delivery Order 0035, Nearshore Hardbottom Sidescan Survey, Topsail Island, NC
G&O Project Number 146046.T35.6480.GEO

Submitted by:

GREENHORNE & O'MARA
CONSULTING ENGINEERS

With Subconsultant:

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

TABLE OF CONTENTS

Executive Summary

Geodynamics LLC was contracted on June 30th by the USACE Wilmington District through Greenhorne & O'Mara Inc. to perform a detailed side-scan sonar survey between New Topsail Inlet, NC and the Surf City, NC boarder. This high-resolution survey is phase one of a two phase effort to located and quantify potential hard bottom habitats by the US Army Corps of Engineers Wilmington District for future renourishment efforts in the region. To better assess hard bottom locations, provide increased positioning accuracy for the side-scan mosaic and to increase productivity for phase two, Geodynamics provided multibeam bathymetry acquisition and processing at no cost to the project.

The July 17-18 side-scan and multibeam surveys of the Topsail Island shoreface employed a Klein 3000 digital side-scan sonar and a Simrad EM3002 shallow water multibeam sonar system to collect spatially dense seafloor imagery and bathymetric data for the assessment of nearshore hard bottom habitats as described in the official Scope of Work (Appendix A). The dual frequency side-scan system runs at both 100 and 500 kHz nominal. In order to maximize the resolution of the system we brought the swath widths to 100m-150m (range of 50m-75m) and a pixel resolution of 4096. The multibeam system runs at 300 kHz and is compensated for motion and heading with an Applanix POS MV 320 v4 inertial navigation system. The EM3002 produces a swath of sonar approximately 4 times the water depth and collects approximately 400 soundings per square meter. Sound velocity was calculated using an Odom Digibar Pro sound velocity meter.

Tidal corrections and positioning information were acquired using a site calibrated Trimble 5700 Real-Time Kinematic GPS (RTK-GPS) system integrated with the POS MV 320 through a Pacific Crest PDL radio modem. The RTK-GPS system uses a land-based station coupled with a 25-watt radio and a Maxrad 5 dB high-gain antenna to broadcast the computed real-time horizontal and vertical corrections at 10 Hz to the survey rovers (hydro/topo survey platforms). To compute centimeter-scale position and elevation information, determine the relationship between WGS-84 and local grid coordinates, and to evaluate the local geoid-spheroid separation, we first performed a detailed network adjustment and site calibration. Information on the site calibration can be found in the corresponding section of this final report and published accuracies on each of the systems can be found in Appendix D.

Survey Preparation

Survey Area

Topsail Island, located approximately 20 miles northeast of Wilmington and separates Lee Island to the south and Onslow Beach to the north. The Topsail Island nearshore survey was comprised of 6 planned survey lines spaced 320' (100m) in depths ranging from ~5' MLLW to ~30' MLLW. The distance between survey lines was calculated in separate zones of relatively equal depths using 4 times the water depth for multibeam and 394’ swaths (120m) for side-scan as indicated on the NOAA digital nautical chart 11541_4.kap. The total area of the survey encompassed 3.2 square miles

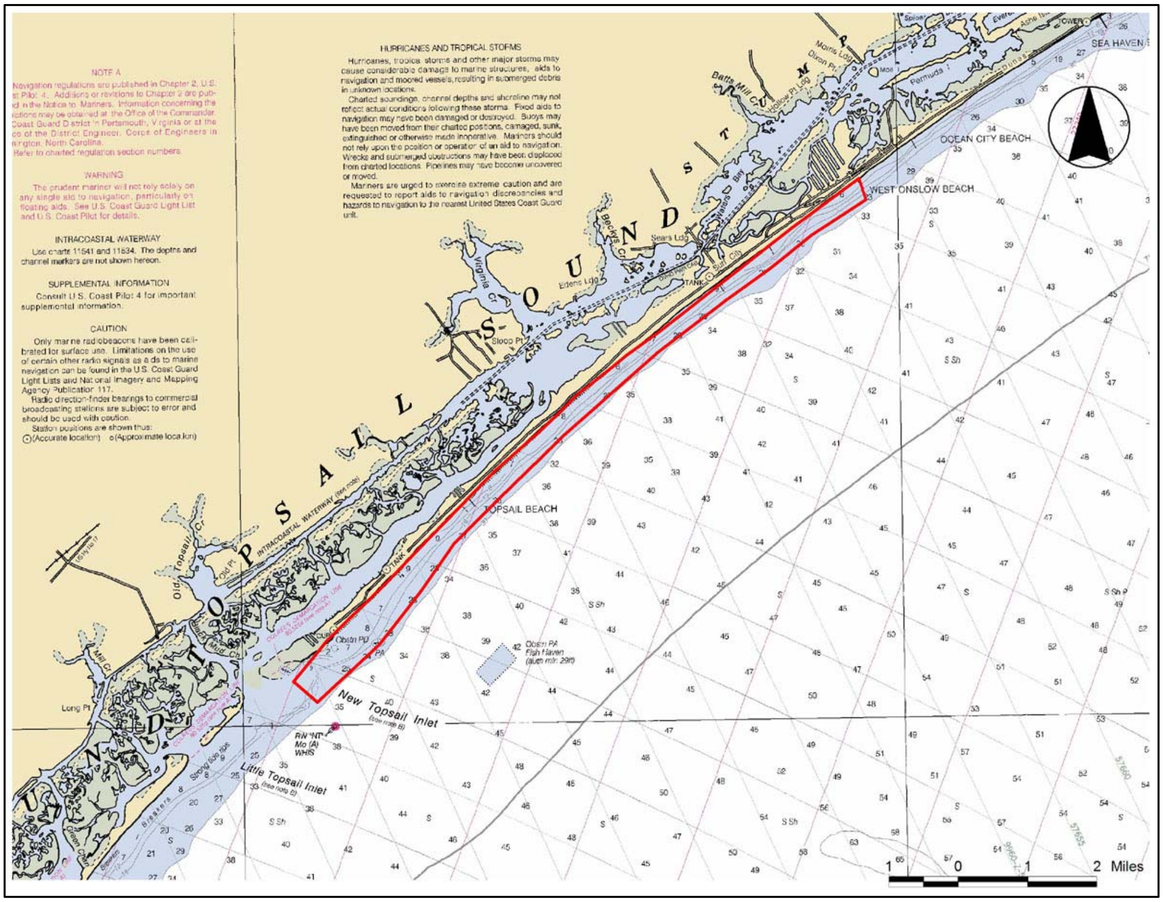


Figure 1. Topsail Island side-scan survey planning map illustrating the proposed survey extents.

RTK-GPS Survey Control & Multibeam Calibration

Introduction & Purpose

The most common problem in accurately measuring the seafloor with any sonar-based system, especially in and around a tidal inlet, is the calculation of the tidal elevation offset. Commonly a tide staff or gauge is deployed in one location near the survey site and is used to calculate the tides for the entire survey area. However, it is widely understood that non-linear tidal phenomena, phase lags and tidal gradients can drastically influence the tidal elevation spatially across a tidal inlet and therefore the use of a single point measurement is often unreliable.

To avoid these potential tidal elevation errors which can translate into significant departures from the true bottom depth, we use geodetic Global Positioning Systems (GPS) with real-time kinematic (RTK) baseline processing that is integrated with the multibeam and inertial navigation instruments. The motion and Geoid 03 compensated positions and orthometric elevations of the RTK-GPS data stream are tagged with each sonar ping. In effect, the RTK-GPS mounted on the hydrographic survey vessel acts as a roving tide gauge collecting the most accurate tidal measurements throughout the survey area.

Multibeam swath sonar systems combine a complex array of instruments, consisting of the transducer, motion sensor, gyrocompass, and geodetic GPS system. Standards developed by the International Hydrographic Organization (IHO), USACE Standards for Hydrographic Surveys, and the NOS Hydrographic Surveys Specifications and Deliverables for shallow water (<30 m) hydrography (IHO 1987; USACE 2003; NOS 2003) are used as the protocol for calibration. Proper alignment of these instruments with one another and with the vessel's reference frame is critical to achieve the high-accuracy required in the SOW. Calculation of the horizontal and vertical offsets between each of the instruments is followed by a series of sea-based measurements known as the patch test.

The patch test is performed to calculate several residual biases influenced by the dynamics of the survey vessel and the alignment of the instruments. Results of the patch test, documented in the following sections, are used to calculate a pitch, roll and heading offset and positioning time delay or navigation latency. Additional calibration measures are performed in the field including comparison of nadir depths with a lead line and frequent sound velocity profiles. The results of these daily field checks can be found in the html metadata file accompanying the final soundings.

To keep bathymetric accuracy the highest for phase one of this project we have kept the soundings in NAVD 88 until we can assess the best way to make this translation. Prior to phase 2 of multibeam acquisition we will need to model the difference in orthometric height between the North American Vertical Datum of 1988 (NAVD 88) and the National Geodetic Vertical Datum of 1929 (NGVD 29) for each benchmark used in the site calibration. This can be completed with VERTCON 2.0 a datum transformation model considered accurate at the 2 cm (one sigma) level. According to studies by Milbert (1999), higher accuracy is particularly noticeable in the eastern United States but there will be some level of inaccuracy that we will attempt to quantify.

RTK-GPS Network Adjustment & Site Calibration

There are many environmental and operator-based influences that can affect the accuracy of RTK-GPS and the resultant baseline solutions (Bilker 2001; Trimble Navigation Limited 1998; Magellan Corporation 2001). Although RTK-GPS is an emerging tool among hydrographers, little attention has been given to an accuracy standard for this methodology—especially in the field of coastal mapping and monitoring (Morton et al., 1993). In an effort to limit operator error and to quantify daily environmental error, we have developed an internal standards protocol for RTK error estimation based on thresholds developed by the California Department of Transportation and the US Army Corps of Engineers (USACE) Topographic Accuracy Standards (CALTRANS 2002; USACE 1994).

The first step in our protocol is to determine an appropriate land-based GPS station that will provide the most accurate corrections and range to the outer limits of the survey area. We chose to use a location that that provided both exceptional range and benchmark quality that was situated on a circa 1940's rocket observation platform called "Tower 3".

The second step in our RTK-GPS protocol is to perform a detailed GPS site calibration prior to the collection of any hydrographic survey data. The site calibration is used to determine the basestation quality relative to the local network of NGS and NOS survey control and to analyze any potential spatial separations between the local geoid heights (GEOID 03) and ellipsoidal values (WGS-84) that may influence the resulting orthometric elevations. The calibration entails selecting the control to be used for the RTK-GPS basestation receiver and radio broadcast system and then checking at least three known geodetic benchmarks of exceptional horizontal and vertical quality within and even outside the survey boundaries. The benchmarks are occupied in "site calibration mode" over 300 epochs or approximately 3 to 5 minutes.

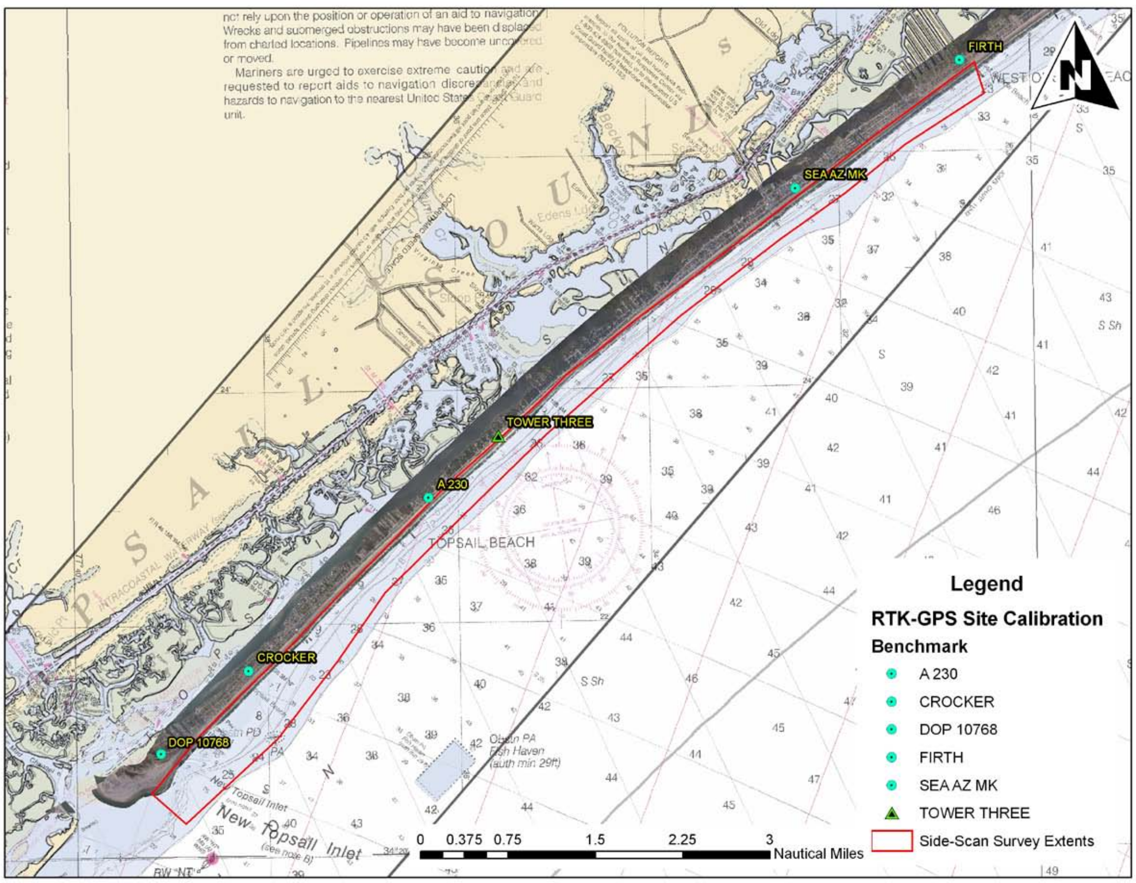


Figure 2. Topsail Island RTK-GPS site calibration map.

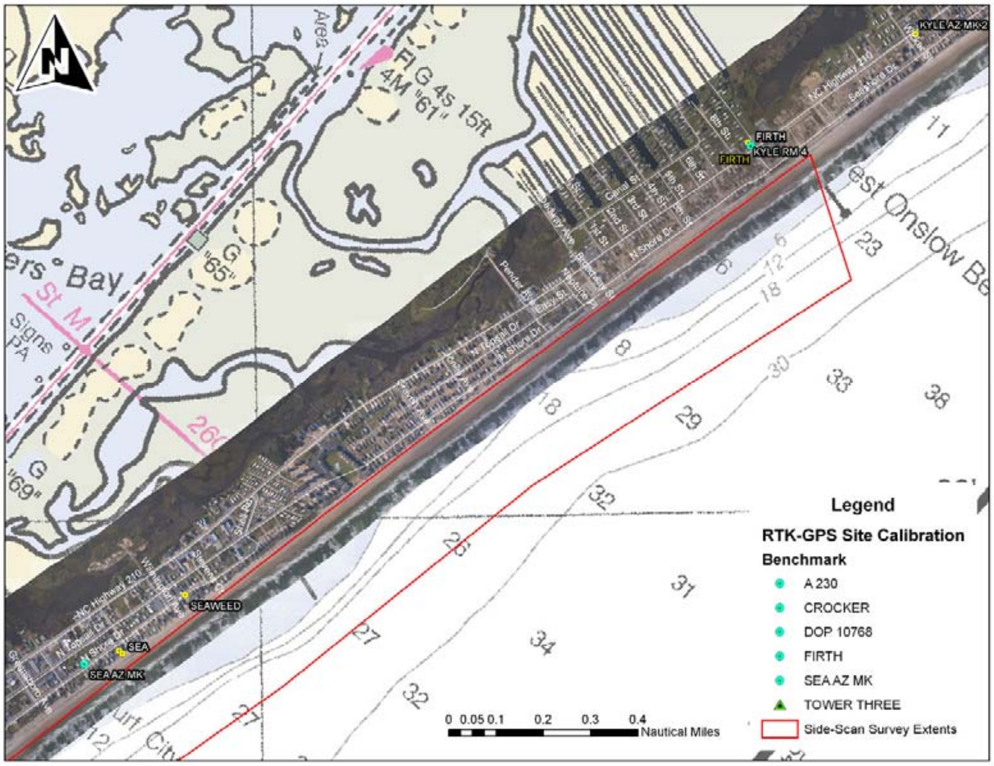


Figure 3. Topsail Island site calibration planning and control search map of the Surf City area.

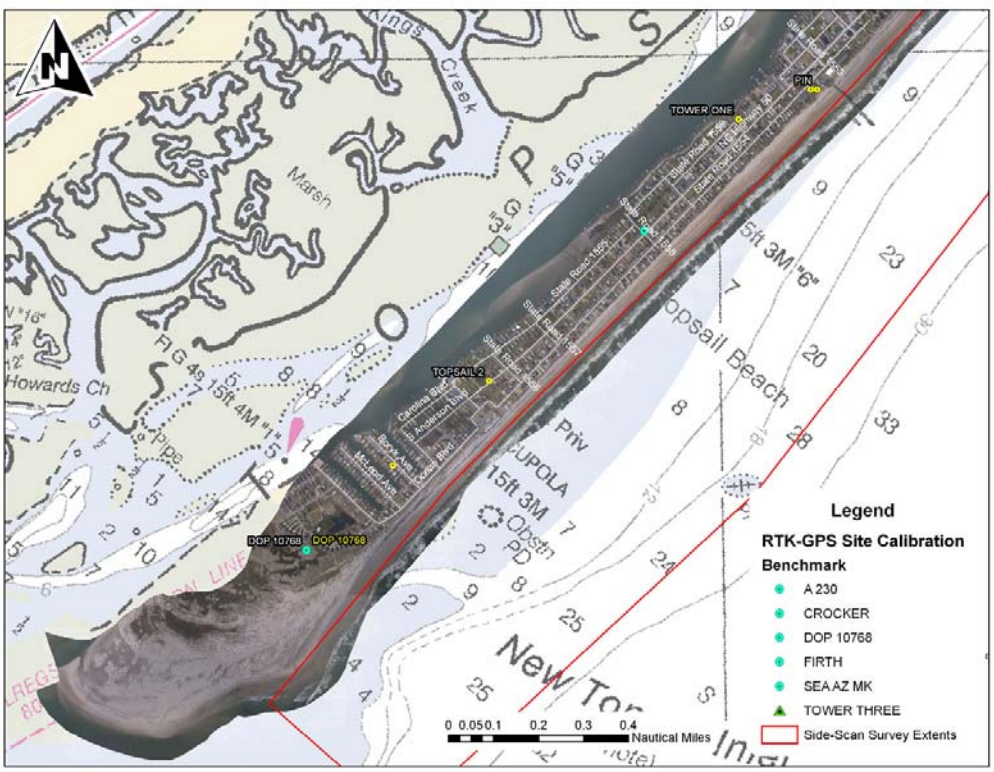


Figure 4. Topsail Island site calibration planning and control search map of the New Topsail Inlet area.

RTK-GPS Pre-Survey Site Calibration

General

Date	6/10/2005 & 6/11/2006
Project	USACE Topsail Island Side Scan - phase 1
Surveyor(s)	Freeman / Bernstein
Equipment	Trimble 5700 Basestation, Trimmark III 25 watt RTK Radio, Maxrad 5dB gain Antenna, Zepher Geodetic base antenna, Trimble 5700 RTK rover, Zepher antenna
Weather	Sunny, Few Clouds, 84 F, ESE Wind 10-15 kts, humid
Units	Meters
Notes	Day 1 of site cal-initail Benchmark scouting and base feasibilty of using a tower. Basestation set on top of Tower 3. Permission granted by owner John Gresham (910-328-4471). Tower stairs are in tack and benchmark is accessible. No power on site. Day 2 of site cal-basestation setup, accuracy checks and range checks.
Coordinate System	NC State Plane, NAD83 (horiz), NAVD88 (vert)

Basestation Information

Designation	Tower Three 1947
PID	EA0695
Agency	CGS
Horiz Order	2
Vert Order	2
N	72282.902
E	738983.122
Z	15.434

Tower Three

Tower Three - looking NE

Benchmark Checks

Designation	DOP 10768
PID	AI0899
Agency	NCGS
Horiz Order	1
Vert Order	3

DOP 10786 Benchmark

	Recorded	Published	Difference
N	67222.286	67222.119	-0.167
E	733619.27	733619.291	0.021
Z	2.341	2.31	-0.031

DOP 10768 BM Check

Notes: Benchmark is it the south end of Topsail Island behind cottage # 2125 A

Benchmark Checks (cont.)

Designation	CROCKER		
PID	AI0831		
Agency	NCGS		
Horiz Order	1		
Vert Order	3		
	Recorded	Published	Difference
N	68542.204	68542.046	-0.158
E	735010.538	735010.571	0.033
Z	1.351	1.33	-0.021
Notes	Benchmark is at intersection of Crocker and S. Anderson		

Crocker Benchmark

Crocker BM Check

Designation	A 230		
PID	EA0696		
Agency	CGS		
Horiz Order	1		
Vert Order	2		
	Recorded	Published	Difference
N	71298.722	71298.606	-0.116
E	737877.39	737877.413	0.023
Z	3.460	3.480	0.02
Notes	Benchmark is located in shrubs at 715 Shore Drive about 0.54 miles south of Catherine Drive.		

A 230 Benchmark

A 230 BM Check

Designation	FIRTH		
PID	AI0904		
Agency	NGS		
Horiz Order	1		
Vert Order	3		
	Recorded	Published	Difference
N	78267.573	78267.452	-0.121
E	746327.18	746327.233	0.053
Z	1.234	1.20	-0.03
Notes	Benchmark is on NW side of W 9th St. North of Surf City.		

Firth Benchmark

Firth BM Check

Benchmark Checks (cont.)			
Designation	SEA AZ MK		
PID	AI0866		
Agency	NCGS		
Horiz Order	1		
Vert Order	3		
	Recorded	Published	Difference
N	76227.279	76227.107	-0.172
E	743713.279	743713.317	0.038
Z	2.605	2.57	-0.035
Notes	Benchmark is located on the N side of house at 313 N. Shore Dr		

Sea AZ MK Benchmark

Sea AZ MK MB Check

Multibeam Echosounder Calibration Report

Calibration Date:	June 24, 2006
Ship	
Vessel	RV 4-Points
Echosounder System	EM3002
Positioning System	POS MV (tightly coupled)-RTK GPS
Attitude System	POS MV
Sound Velocity Probe	Odem Digibar Pro (profiler) / Valeport Mini SVS (at head)

Annual		
Installation	x	
System change	x	
Periodic/QC		
Other		

Calibration type: Multibeam Sonar

The following calibration report documents procedures used to measure and adjust sensor biases and offsets for multibeam echosounder systems. This report has been adopted and modified from NOAA. Calibration must be conducted A) prior to CY survey data acquisition B) after installation of echosounder, position and vessel attitude equipment C) after changes to equipment installation or acquisition systems D) whenever the Hydrographer suspects incorrect calibration results. The Hydrographer shall periodically demonstrate that calibration correctors are valid for appropriate vessels and that data quality meets survey requirements. In the event the Hydrographer determines these correctors are no longer valid, or any part of the echosounder system configuration is changed or damaged, the Hydrographer must conduct new system calibrations.

Multibeam echosounder calibrations must be designed carefully and individually in consideration of systems, vessel, location, environmental conditions and survey requirements. The calibration procedure should determine or verify system offsets and calibration correctors (residual system biases) for draft (static and dynamic), horizontal position control (DGPS), navigation timing error, heading, roll, and pitch. Standard calibration patch test procedures are described in *Field Procedures for the Calibration of Multibeam Echo-sounding Systems*, by André Godin (Documented in Chapter 17 of the Caris HIPS/SIPS 6.0 User Manual, 2006). Additional information is provided in *POS/MV Model 320 Ver 4 System Manual* (10/2003), Appendix F, Patch Test, and the NOAA Field Procedures Manual (FPM, 2003). The patch test method only corrects very basic alignment biases. These procedures are used to measure static navigation timing error, transducer pitch offset, transducer roll offset, and transducer azimuth offset (yaw). Dynamic and reference frame biases can be investigated using a reference surface.

Pre-calibration Survey Information

Reference Frame Survey

RV 4-Points was surveyed by the National Geodetic Survey on February 15, 2006 for precise centerline and instrument locations. Steve Breidenbach performed the survey with a Trimble 5603 total Station.

(IMU, Ref Pt., and XY of CG are all co-aligned and attitude and position is valid at the sensor. The values below are entered in POSview software.)

Reference to IMU Lever Arm

X(m)	Y (m)	Z (m)
0	0	0

Reference to Pri. GPS

X(m)	Y (m)	Z (m)
1.849	-1.061	-1.724

IMU frame w.r.t. Reference frame

X(deg)	Y (deg)	Z (deg)
0	0	0

Reference to Sensor Lever Arm

X(m)	Y (m)	Z (m)
-0.097	-2.130	0.849

Reference to CG

X(m)	Y (m)	Z (m)
0	0	0.313

Figure 5. Photo of the centerline and instrument survey by NGS.

Reference to Vessel (Pt of validation for attitude and nav)

X(m)	Y (m)	Z (m)
-0.097	-2.130	0.849

__X__Measurements verified for this calibration.
___ __Drawing and table attached.
_____Drawing and table included with project report

POS MV Configuration File: 4_points_022806. *________________

Notes: _NGS vessel survey results were put in POSview and GAMS calibration was done on February 28, 2006___.

Calibration Area

Site Description

This patch survey was conducted in the Port of Morehead City's turning basin near Beaufort Inlet, North Carolina (N34 41 39.16 W076 40 07.53). This site was selected for its particular bottom features, such small scale ripple fields, sand waves (wavelength: ±5m, amplitude: ±0.15m), deep flat areas, and high slopes.

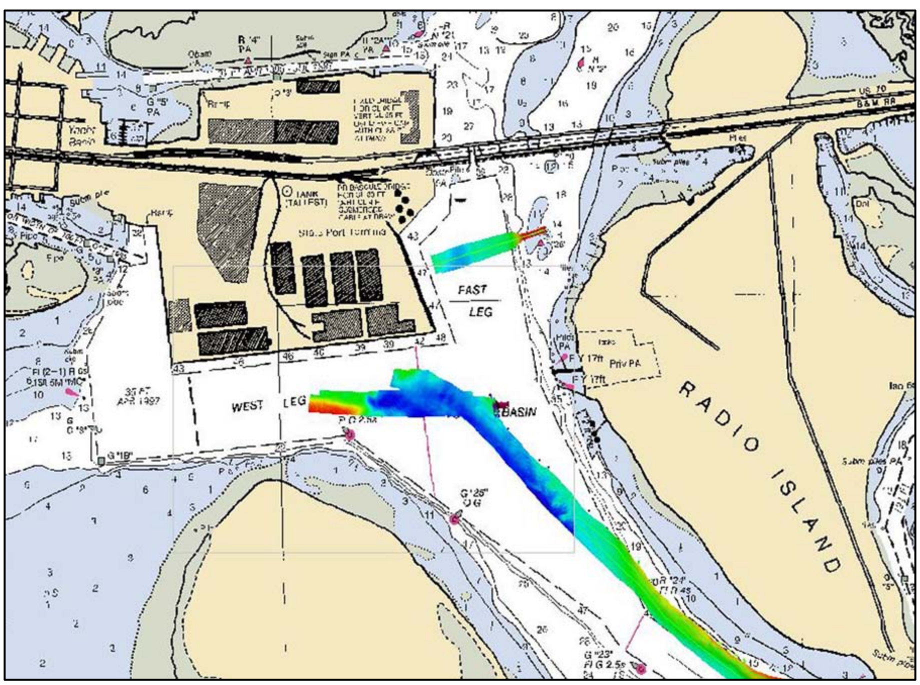


Figure 6. Map of the patch survey area within the Morehead City Turning Basin.

Survey Procedure

Vessel biases were determined through a patch test survey procedure. Data was acquired and analyzed in Kongsberg SIS package. The latency test was performed first by surveying the same survey line in the same direction at 2 different vessel speeds. The latency test was done twice to verify initial results. The pitch test was done second by surveying the same survey line in opposite directions at the same speed and evaluating the sloped portion of the survey line. The roll test was performed next by surveying the same survey line in opposite directions at the same speed and evaluating the deep flat portion of the survey line. The roll test was done twice to verify initial results. The yaw test was performed next by surveying 2 adjacent survey lines in the same direction, with similar speeds, with enough overlapping coverage such that the outer beams from each swath overlap (±40%).

Calibration Lines

Hypack Line	Line File	Az.	Spd	Correction			
				Pitch	Roll	Yaw	Latency
1	0000_20060301_163731_4points.all	57°	3.3kts				X
1	0001_20060301_164249_4points.all	57°	7.1kts				X
1	0002_20060301_165502_4points.all	237°	3.2kts				X
1	0003_20060301_165938_4points.all	237°	7.0kts				X
1	0002_20060301_155849_4points.all	237°	7.0kts	X			
1	0003_20060301_160222_4points.all	57°	7.0kts	X			
1	0000_20060301_172142_4points.all	57°	7.0kts		X		
1	0001_20060301_172427_4points.all	237°	7.0kts		X		
1	0000_20060301_183521_4points.all	237°	7.0kts		X		
1	0001_20060301_183741_4points.all	57°	7.0kts		X		
8	0001_20060301_191059_4points.all	280°	7.0kts			X	
7	0002_20060301_191957_4points.all	100°	7.0kts			X	

Sound Velocity Correction

Measure water sound velocity (SV) prior to survey operations in the immediate vicinity of the calibration site. Conduct SV observations as often as necessary to monitor changing conditions and acquire a SV observation at the conclusion of calibration proceedings. If SV measurements are measured at the transducer face, monitor surface SV for changes and record surface SV with profile measurements.

Sound Velocity Measurements

Time	Max Depth	Surface SV	Change Observed	Position	
				Latitude	Longitude
14:52:00	15.5m	1490.2		34 42.9705	76 41.6239
Continuous SV at head			<4 m/s throughout entire calibration		

Data Acquisition and Processing Guidelines

Initially, calibration measurement offsets should be set to zero in vessel configuration files. Static and dynamic draft offsets, inertial measurement unit (IMU) lever arm offsets, and vessel reference frame offsets must be entered in appropriate software applications prior to bias analysis. Perform minimal cleaning to eliminate gross flyers from sounding data.

Navigation Timing Error (NTE)

Measure NTE correction through examination of a profile of the center beams from lines run in the same direction at maximum and minimum vessel speeds. NTE is best observed in shallow water.

Transducer Pitch Offset (TPO)

Apply NTE correction. Measure TPO correction through examination of a profile of the center beams from lines run up and down a bounded slope or across a conspicuous feature. Acquire data on lines oriented in opposite directions, at the same vessel speed. TPO is best observed in deep water.

Transducer Roll Offset (TRO)

Apply NTE and TPO corrections. Measure the TRO correction through examination of roll on the outer beams across parallel overlapping lines. TRO is best observed over flat terrain in deep water. An additional check for TRO adjustment can be performed by running two lines parallel to a sloped surface.

Transducer Azimuth Offset (TAO or yaw)

Apply NTE, TPO and TRO corrections. Measure TAO correction through examination of a conspicuous topographic feature observed on the outer beams of lines run in opposite directions.

Patch Test Results and Correctors

Evaluator	NTE (sec)	TPO (deg)	TAO (deg)	TRO (deg)
Bernstein/Hohing	0.00	0.00	0.00	-0.65
Final Values	0.00	0.00	0.00	-0.65

Corrections Calculated in:	
Caris	
ISIS (BathyPro)	
Other	SIS

NOTE: TRO bias of -0.65 was put in SIS software.

Evaluator: ______Dave Bernstein______
Reviewed by: ___Dave Bernstein ______
Accepted by: ___Dave Bernstein ____
Date accepted: _June 25, 2006______

Graphical Examples of Calibration Acceptance

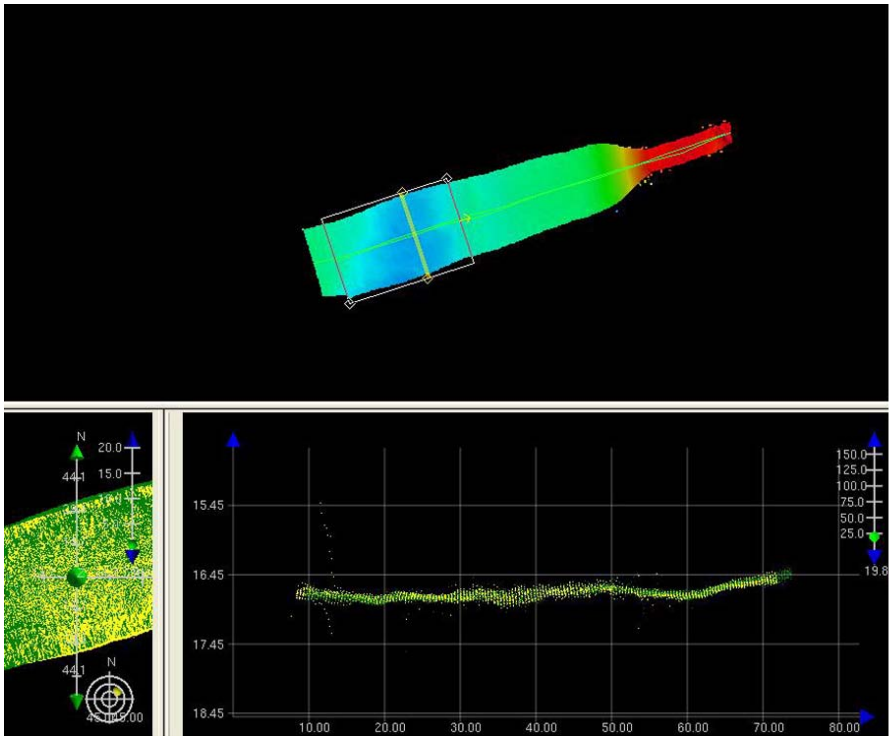


Figure 7. Caris screen grab illustrating acceptance of roll calibration.

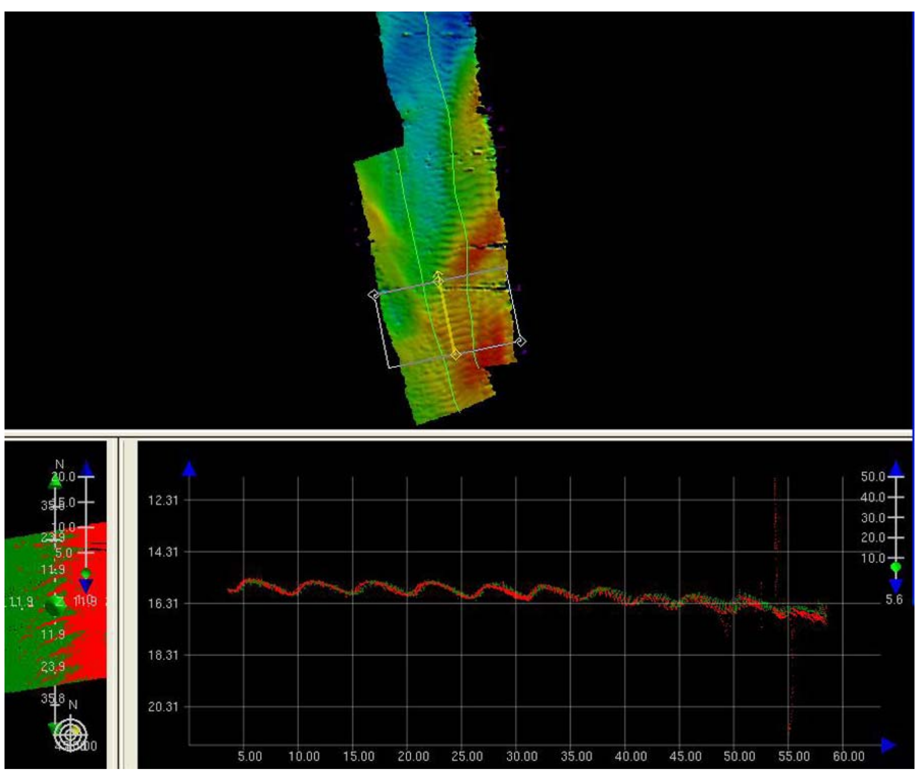


Figure 8. Caris screen grab illustrating acceptance of yaw calibration.

Data Processing Routines & QA/QC Information

Introduction

Processing high-density multibeam bathymetry and backscatter data requires a multitude of processing routines and data quality analyses. The following section will detail all aspects of data post-processing for the Beaufort Inlet multibeam surveys. Also presented in this section is detailed QA/QC information and analysis generated throughout the various processing procedures.

Bathymetry Processing

The multibeam collects swath widths approximately 4 times the water depth. The portions of swath, mainly in the outer beams, that exhibit areas of inconsistent data are clipped and not included in the final digital file. Sounding track lines are generally parallel to each other and parallel to the seafloor contour. Sinuous lines and data acquired during turns are not included in the final processed data. To meet the accuracy and resolution standards for measured depths specified in the USACE Hydrographic Surveying Manual and the NOS Hydrographic Surveys, Specifications and Deliverables Manual, measured echosounder depths were corrected for all departures from true depths attributable to the method of sounding or to faults in the measuring apparatus. These corrections are subdivided into four categories, and are listed below in the sequence in which they were applied to the data.

1. Instrument error corrections: included to account for the sources of error related to the sounding equipment itself.

2. Vessel offsets: added to the observed soundings to account for the depth of the echosounder below the water surface, positioning of the motion reference unit, and GPS antenna.

3. Velocity of sound correctors: applied to the soundings to compensate for the fact that echosounders may only display depths based on an assumed sound velocity profile while the true velocity may vary in time and space.

4. Heave, pitch, roll, heading and navigation latency corrections: applied to the multibeam soundings to correct for the effect of vessel motion caused by waves and swells, the error in the vessel's heading, and the time delay from the moment the position is measured until the data is received by the GPS receiver.

Multibeam Data Processing Steps in CARIS HIPS software:

The EM3002 sonar system has a unique arrangement of data flow. Most settings that influence the data are put in before and during a survey and therefore are not a factor in data processing (these include vessel offsets, lever arms, vessel biases, timing biases, and survey sound velocity). Vessel attitude is also processed real-time during a survey.

Post-processing of multibeam data consist of attitude and navigation editing, merging, swath editing, area-based editing, and exporting of final data.

1. Attitude & Navigation Editing: Errors or gaps in attitude and navigation information causing errors in soundings are edited.

2. Merging: Computing and integrating the GPS tide in the sounding data. Additional sound velocity corrections are made if needed in this phase. Draft changes for datum conversions are made here as well.

3. Total Propagated Error (TPE) is calculated

4. Swath- and beam-based filters and TPE (IHO standards) filters are applied.

5. Swath Editing: Swaths are edited for erroneous data if needed

6. Base or CUBE Surface is created for area- and CUBE-based editing.

7. Area-based editing using the subset editor to edit/check erroneous data only within the desired subset.

8. CUBE filtering (if needed)

9. Recompute TPE

10. Recompute CUBE and/or base surface

11. Final export of base surface to XYZ decimated soundings (1m).

NOTE: Bathy is delivered in NAVD 88 until we determine if phase 2 will require the NGVD 29 vertical datum. Also, bathy data maybe adjusted in phase 2 once we get some overlapping coverage to determine slight offsets that may need to be applied for roll due to the towing of the side-scan sonar.

Side-Scan Processing

1. Side scan is replayed (ISIS) and slant range corrected. Areas that have lost bottom track data are manually digitized to replace lost altitude data.

2. Appropriate image corrections are determine in ISIS and defined for the mosaic procedure.

- A threshold of 4 was used for all files incorporated in the mosaic. This means the 8 bit or 16 bit data is shifted by 4 bits to correct the histogram when the data is played for mosaic.

- A “STANDARD: TVG correction with a Pixel to Pixel Balance correction was applied to all files in the mosaic. This correction implemented a 4% darkness and a 10% decay rate.

3. The data is then mosaiced using ISIS to play back the data and Delphmap Mosaic to create the mosaic file.

All of the mosaic setting and corrections are applied in Delph Mosaic.
- layback = 4.5m
- X shift = 4.3m
- set data resolution 50 cm for channels 1-2 15cm for channels 3-4
- cover up for overlapping lines
- fill gaps between pings
- use course made good for heading (heading not as useful due to unknown declinations to the klein mag compass)

During this stage, the depth, delay, and duration settings are altered for each file played back in order to provide adjacent lines with specific coverage (overlap) in ISIS.

4. The mosaic in Triton DDS_VIF format is then exported to Geo-Tiff file format with associated .world file.

Typical Side-Scan Artifacts

Feature Accuracy Information: Side-scan sonar artifact information has been synthesized from the Handbook of Seafloor Sonar Imagery, Blondel & Murton, Geoff Shipton at Triton Imaging, and from out past experience with these data.

The Klein 3000 is a digital side-scan sonar system capable of producing digital image maps of the seafloor from reflected sound waves or acoustic backscatter from the seafloor. These images are created by transmitting a series of sound pulses and recording their echoes from the seafloor as the survey vessel moves across a set course. The sound source and receivers are built into a "tow fish" that moves through the water at varying depths and distances from the survey vessel dependent on the water depth. The returned signal is then recorded by shipboard computers with an amplitude range of 0-255 with strong returns recorded as higher values and weak returns recorded as lower values. The darkness or brightness of a side-scan mosaic is a function of the gradient or slope of the seafloor, surface roughness, and the sediment characteristics such as texture which can all be interpreted by a marine geologist.

The main advantage of side-scan sonar over the backscatter product generated from multibeam sonar is the greater coverage that can be achieved (ex. in 10m of water = 40m for multibeam and up to 300m (although this dataset uses a swath width of 120m for higher detail) with side-scan) and a more detailed image of the seafloor. However, side-scan data tends to be much noisier and contains far more artifacts than multibeam. Below are some of the major artifacts to be expected in any side-scan mosaic.

Heave & Motion Artifacts: In a perfect scenario side-scan would be collected in flat calm conditions with zero boat motion that would translate into the towed vehicle. In addition, towing a side-scan into shallow water creates additional heave artifacts due to the short tow. Flat calm conditions rarely happen in an oceanic environment and really never happen when approaching the nearshore environments where waves begin to propagate. Heave artifacts are caused by changes in pitch due to tugging on the vehicle line. At the point where the fish moves through the horizontal (Pitch = 0) the sonar beam strikes the bottom at a right angle and the return path is directly along the axis, which gives a good return. Either side of the zero pitch point the returns become weaker. The effect on the record is banding in the across track direction. Aside from slight pitch corrections made in the processing software (ISIS in this case) there is nothing that can be done to correct for the fact that the point where the return comes from moves fore and aft as the pitch changes. Roll, Pitch, Yaw can all be taken into account in post processing to some reasonable level; however, the towfish based altimeter and flux gate compass are not to the standard of those used for compensating bathymetric data.

Running Parallel to a Slope Artifacts: Depending on how steep the slope is you will see a stronger return on the uphill slope and a weaker return on the downhill slope. How much this affects the image will depend on two things; how steep the slope and how reflective the seafloor. The slope could, in some cases, decrease the grazing angle sufficiently that the sound simply bounces off completely and hardly anything gets back. This angle varies with different bottom types. The artifact that can be generated in this scenario, provided there is a highly reflective bottom (which we see in several areas at Topsail) is a two toned effect on the area of interest. There are a few independent gain settings for each sonar channel that can help; however, applying different gain settings for each opposing line becomes a bit black magic and hence we don't typically tweak these settings beyond a certain point.

Sea Surface Reflection Artifacts: In shallow water applications such as the Topsail Island project side-scan sonar imagery can be corrupted by multiple reflections from the sea surface. The first reflection is formed when the sonar beam reflects once from the seafloor and once from the sea surface. This artifact can manifest itself as bright lines parallel to the sonar track, at a distance from the sonar track roughly equivalent to the water depth. If the swath is wide enough subsequent multiples will also be present as equidistant bright lines parallel to the first reflections. They primarily occur in areas with flat and smooth sedimentary features or from white capping of waves on the surface. A few of these artifacts can be seen in the inshore side-scan line at Topsail.

Water Column Artifacts: Artifacts related to the propagation of the acoustic pulse in the water column from the sensor to the seafloor and back can be attributed to two sources. The first are variations in the structure of water column due to density variations, salinity variations and temperature variations. Depending on the depth, a certain amount of thermocline layers will modulate the depth and angle at which the acoustic rays propagate. These artifacts are generally at the far range of the swath and look similar to linear bedforms. The second artifact that can be produced from speed of sound variations are derived from the presence of bubbles in the water. This may come from the wake of the survey vessel or from cavitation caused by the ships propellers. High-frequency systems such as the Klein 3000 are sensitive to bubbles and cause the sonar beams to become partially dispersed and partially reflected before they reach the seafloor. The artifact that can be created in this case is random data gaps at all ranges. In the Topsail data there is no indication that thermoclines are playing a role in artifact generation (sound velocity measurements for multibeam do not indicate any presence of thermoclines); however, prop wash may be the cause for some random gaps in across track data.

Radiometric Artifacts: The most frequent cause of systematic radiometric artifacts reside in the acquisition system itself. Connections between the cable and topside computers, broken points in cable, faulty grounds, etc. Another cause is interference between other acoustical systems. Although we turn off our shipboard singlebeam sonar since this is a known point of origin for artifact we are running the Simrad EM3002 multibeam sonar simultaneously which might create a small level of cross-talk. We have never seen this in the data per say but there are some slight noise artifacts on the edges of some swaths that might be attributed to cross-talk between the two systems. Another possible radiometric artifact is the rapid attenuation of the backscattered signal when the sonar platform goes up or down too rapidly or an abrupt change in seafloor depth. This change is usually too localized and rapid to be corrected with the normal time-varying gain (TVG).

Geometric Artifacts: Side-scan data can become distorted by the variations in the horizontal and vertical movement of the towfish such as those created by motion; however, variations in the survey vessel speed, if not taken into account properly, can cause distortion in the along-track direction. If the platform speed assumed during processing is higher than the actual value the swath lines will be positioned too far away from each other, and the image will be stretched along-track. Conversely, if the platform speed is lower, the swath lines will be positioned too close to each other, and the image will be compressed along-track. Discrepancies between matching seafloor morphology will be the result. Since we collected multibeam sonar simultaneously we were able to use the cm-scale positioning from the RTK-GPS to align each successive swath.

Examples of Known Artifacts in Topsail Side-Scan Data

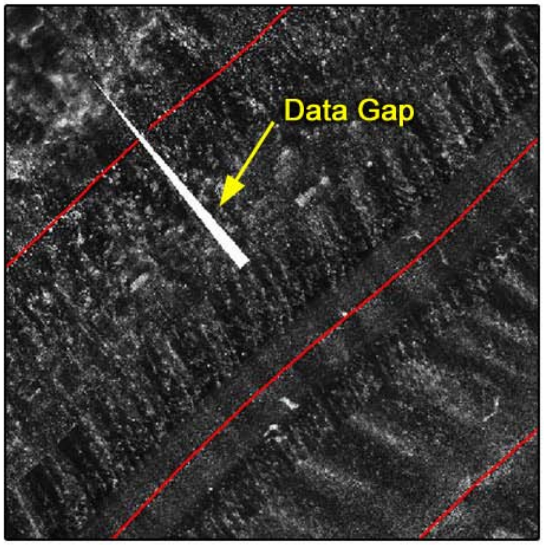


Figure 9a. Data Gap in side-scan record.

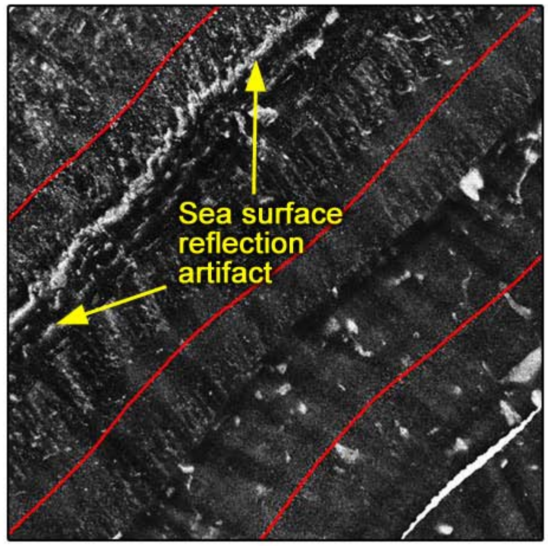


Figure 9b. Sea surface reflection artifact.

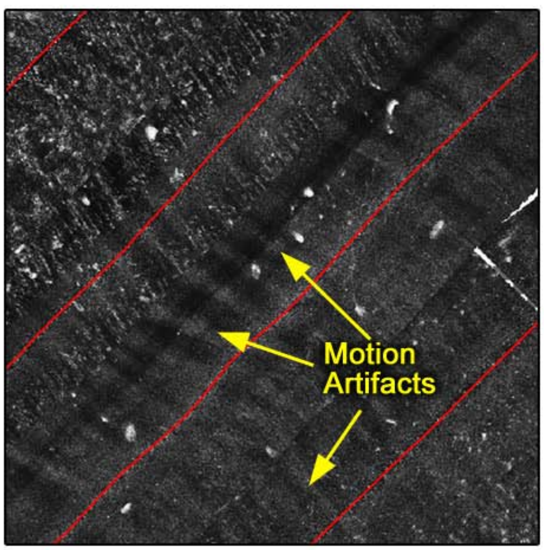


Figure 9c. Artifacts produced by vessel-towfish motion.

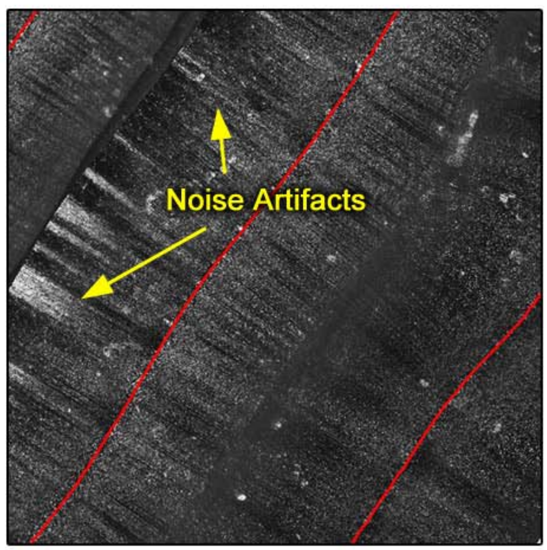


Figure 9d. Noise artifacts.

Potential Hardbottom Identification

To facilitate maximum efficiency in identifying hardbottom regions for phase 2 of the project we completed a QTC analysis of the backscatter which fell outside of the official SOW. Data from this analysis is provided on the accompanying DVD and the Quester Tangent report is provided in Appendix E. Preliminary results of the QTC unsupervised classification show several classes that exist on areas of known artifact. However, visual inspection of the data shows that QTC Class 4 correlates to our interpretation of potential hardbottom regions.

In order to synthesize these data into a structure to identify potential hardbottom regions and to eliminate much of the noise present in these data we manually digitized the areas that we feel have the most potential of being hardbottom. To provide a more quantitative digitization we used both the QTC Class 4 data and some preliminary analysis completed in Triton SeaClass software.

Between the three preliminary analyses it appears that most all of the potential hardbottom regions exist starting approximately 800 ft offshore (2004 wet/dry line) to the end of the survey which is approximately 1800 ft offshore (2004 wet/dry line). There are a few areas on the inshore seam, from approximately 300 ft to 800 ft from the 2004 wet/dry line, that exhibit a differing signature from the surrounding seafloor. It is thought that these areas are likely artifact since we have compared the overlapping multibeam backscatter and there are no correlations that can be made between the two. However, closer inspection may be required during phase two in an effort to eliminate these zones as possible hardbottom.

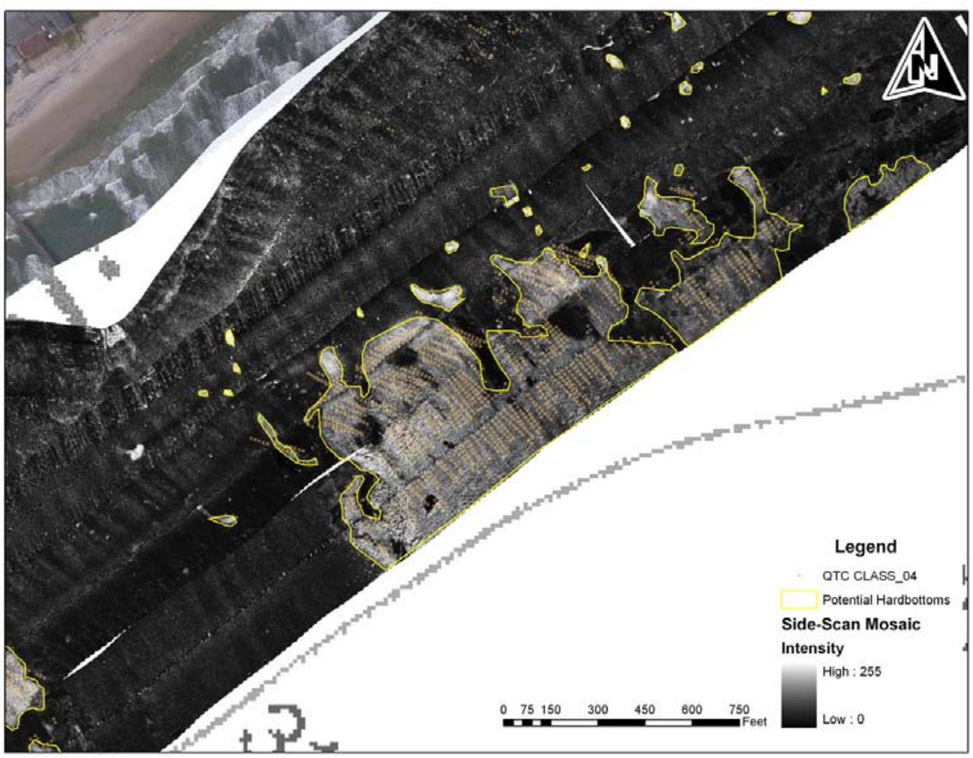


Figure 10. Map illustrating potential hardbottom areas.

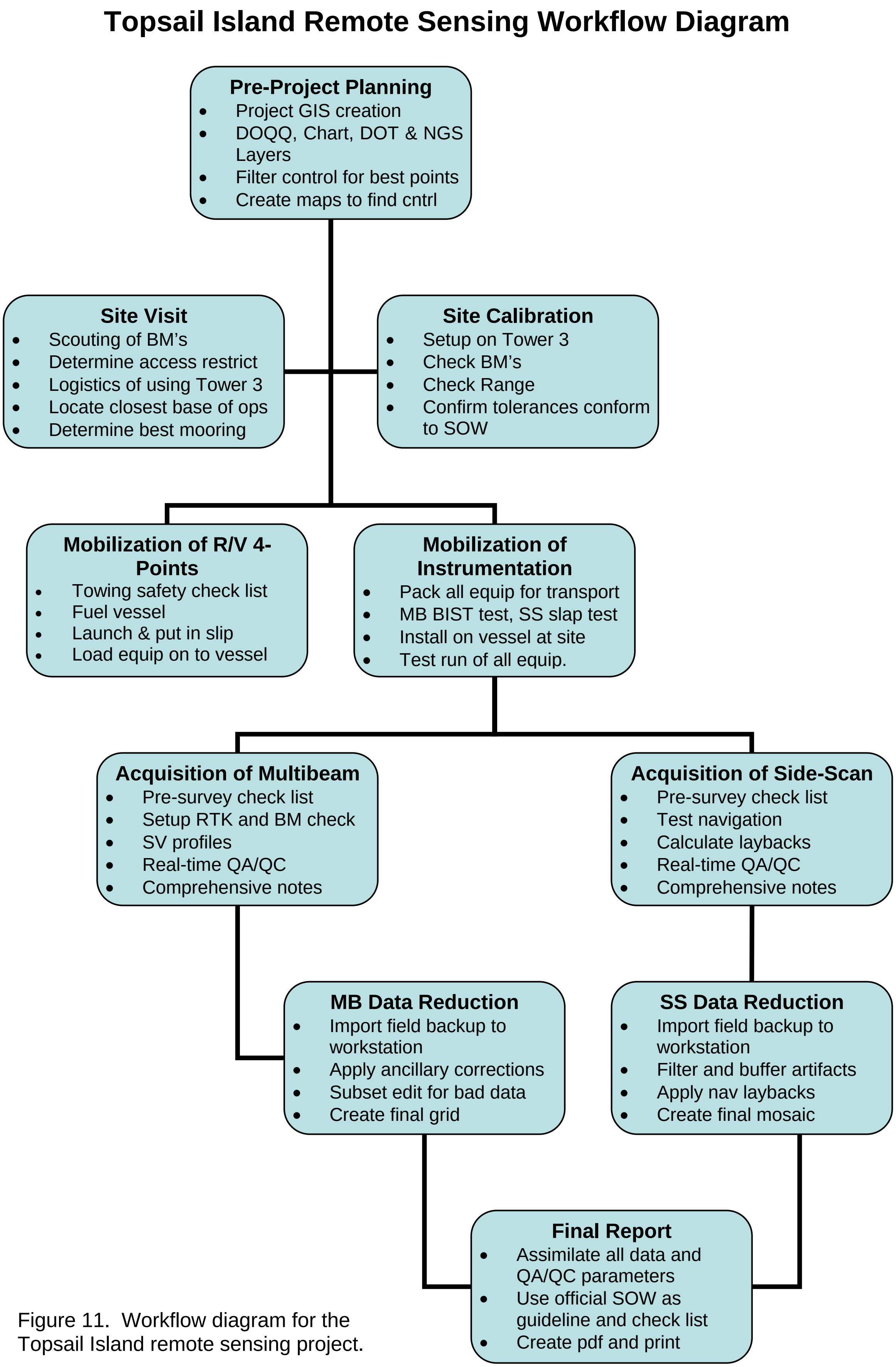


Figure 11. Workflow diagram for the Topsail Island remote sensing project.

Topsail Island Remote Sensing QA/QC Workflow Diagram

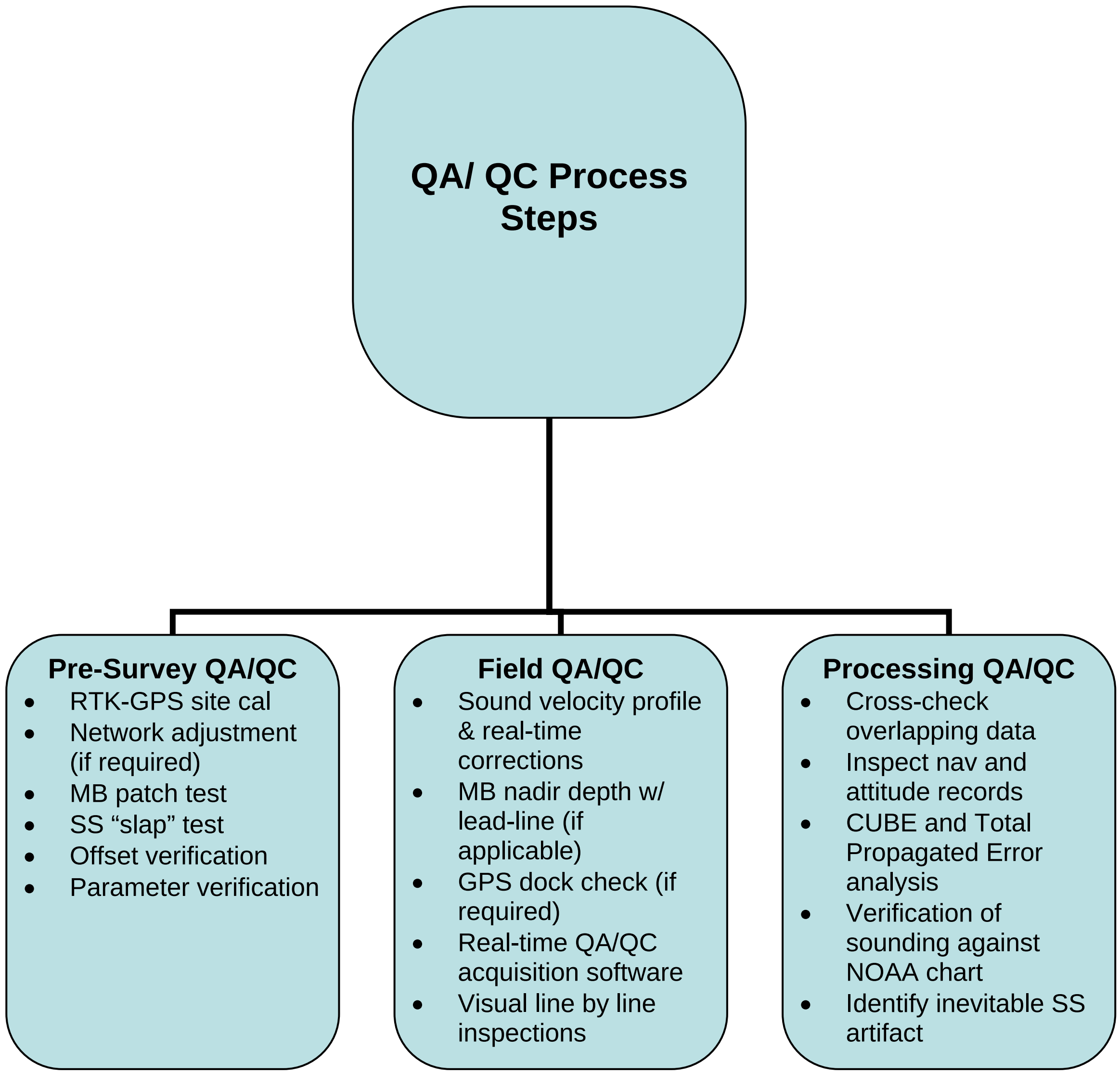


Figure 12. QA/QA Workflow diagram for the Topsail Island remote sensing project.

Graphical Summary of Deliverables

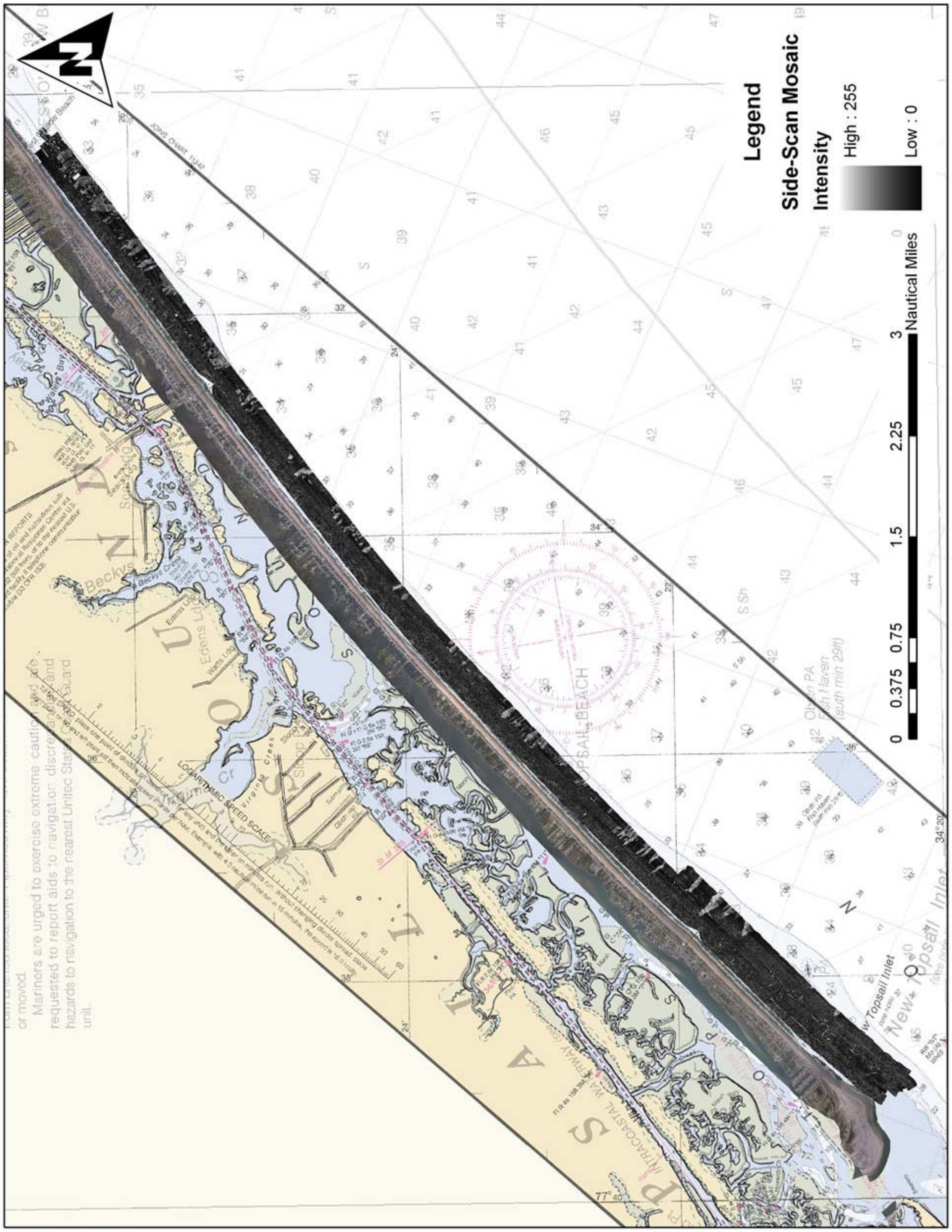


Figure 13. Side-scan sonar mosaic.

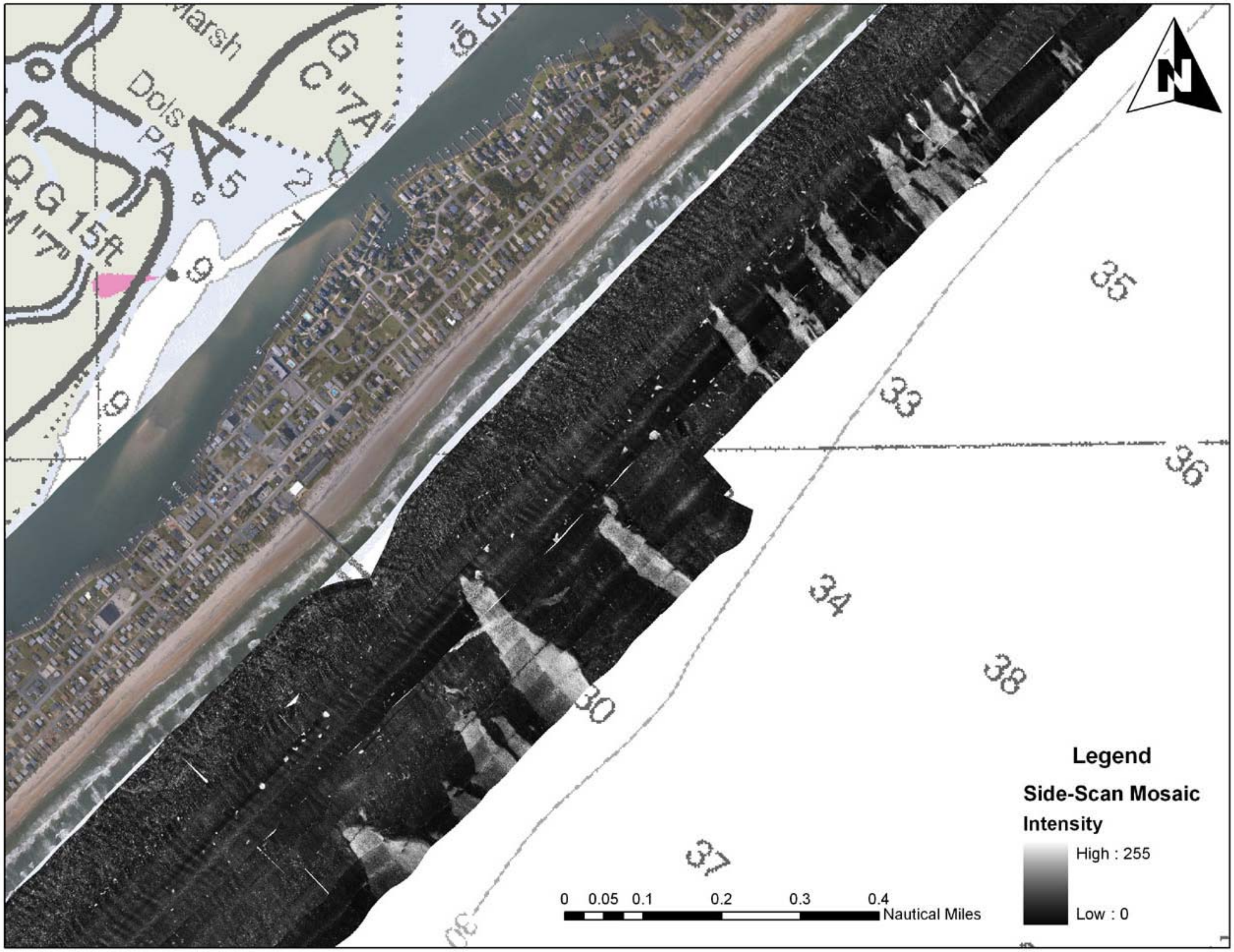


Figure 14. Close-up view of the side-scan sonar mosaic in the sourth portion of the survey area.

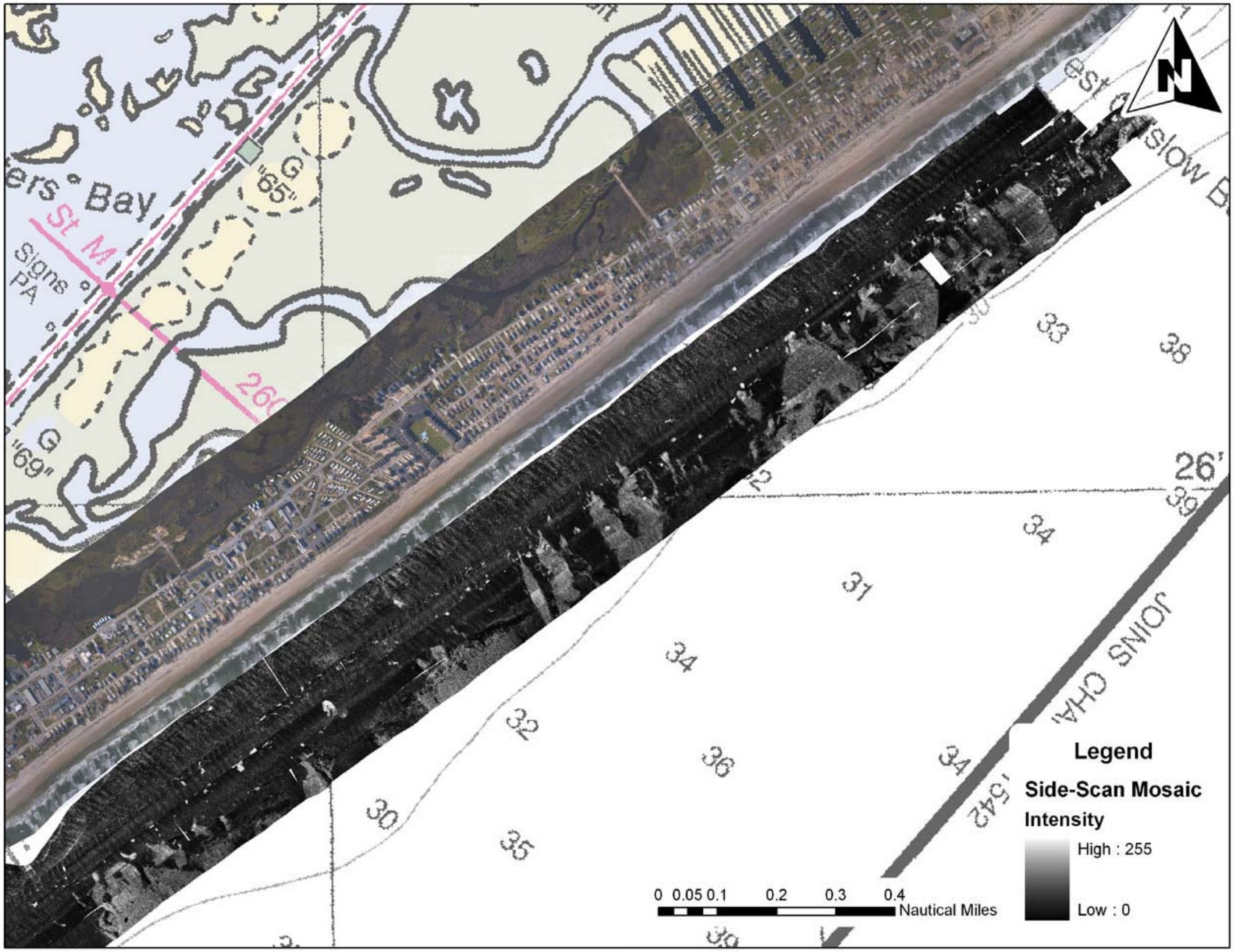


Figure 15. Close-up view of the side-scan sonar mosaic in the north portion of the survey area.

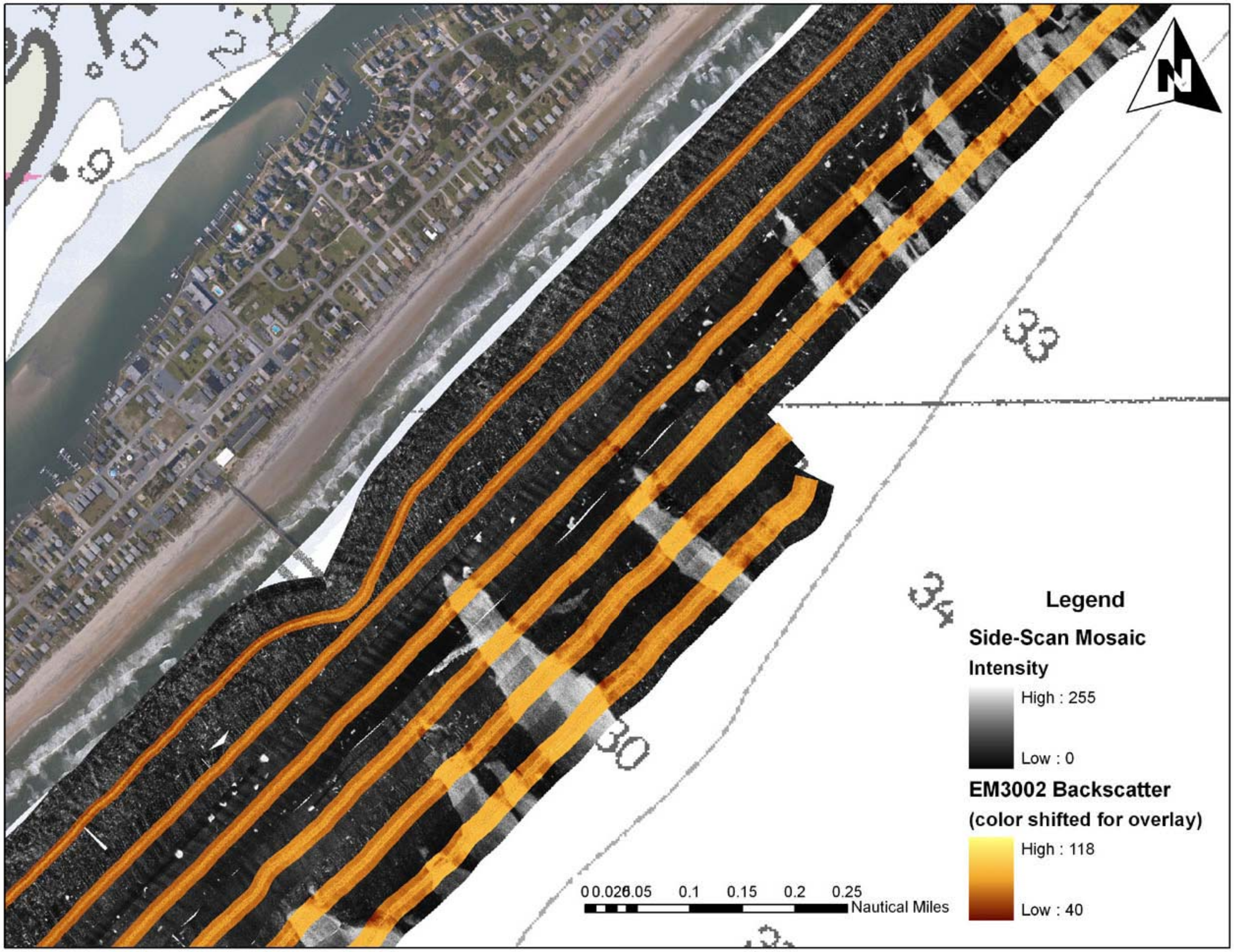


Figure 16. Side-scan sonar mosaic overlaid with EM3002 backscatter data. Alignment of features between datasets illustrates excellent positioning calculation for the side-scan mosaic.

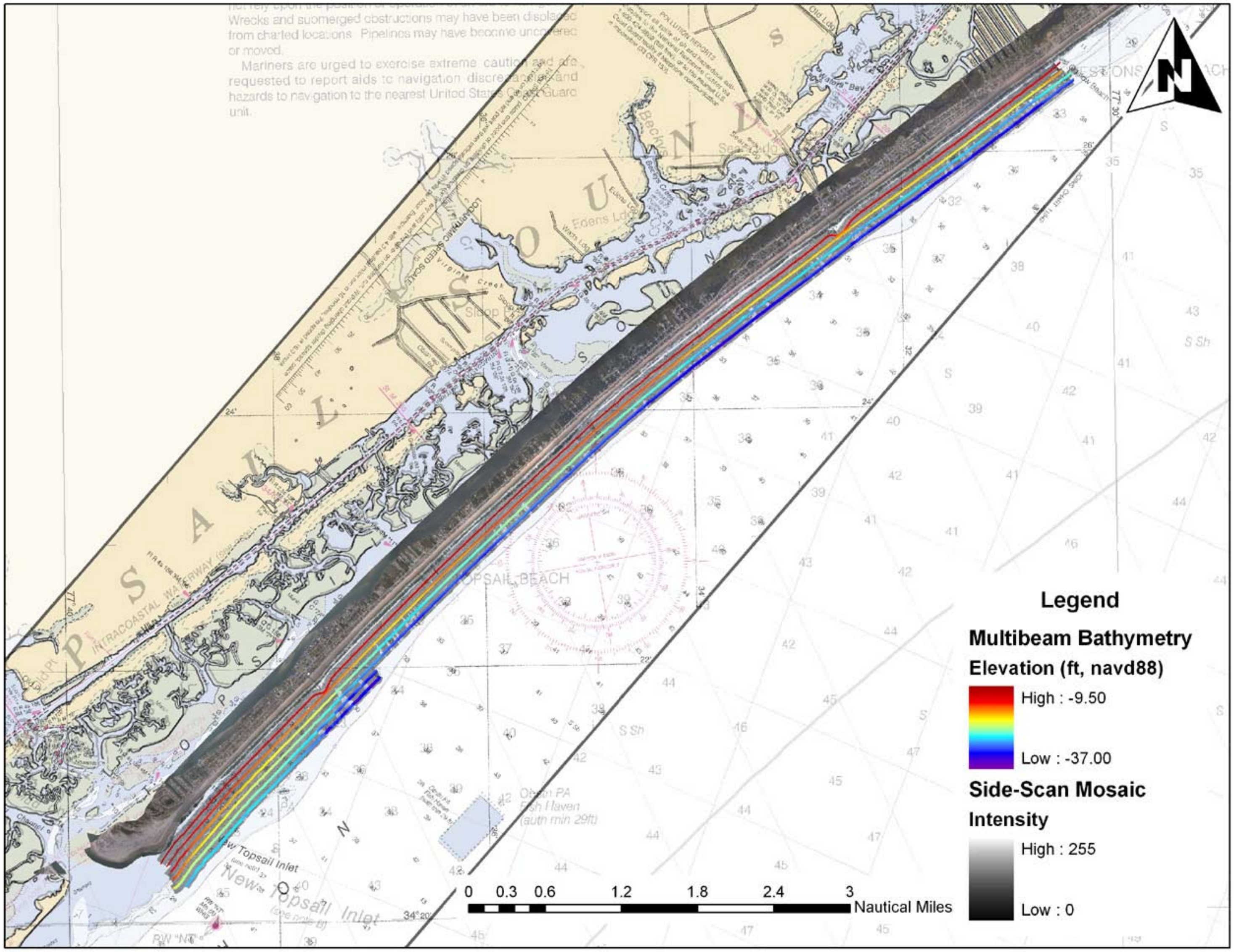


Figure 17. EM3002 Multibeam bathymetry.

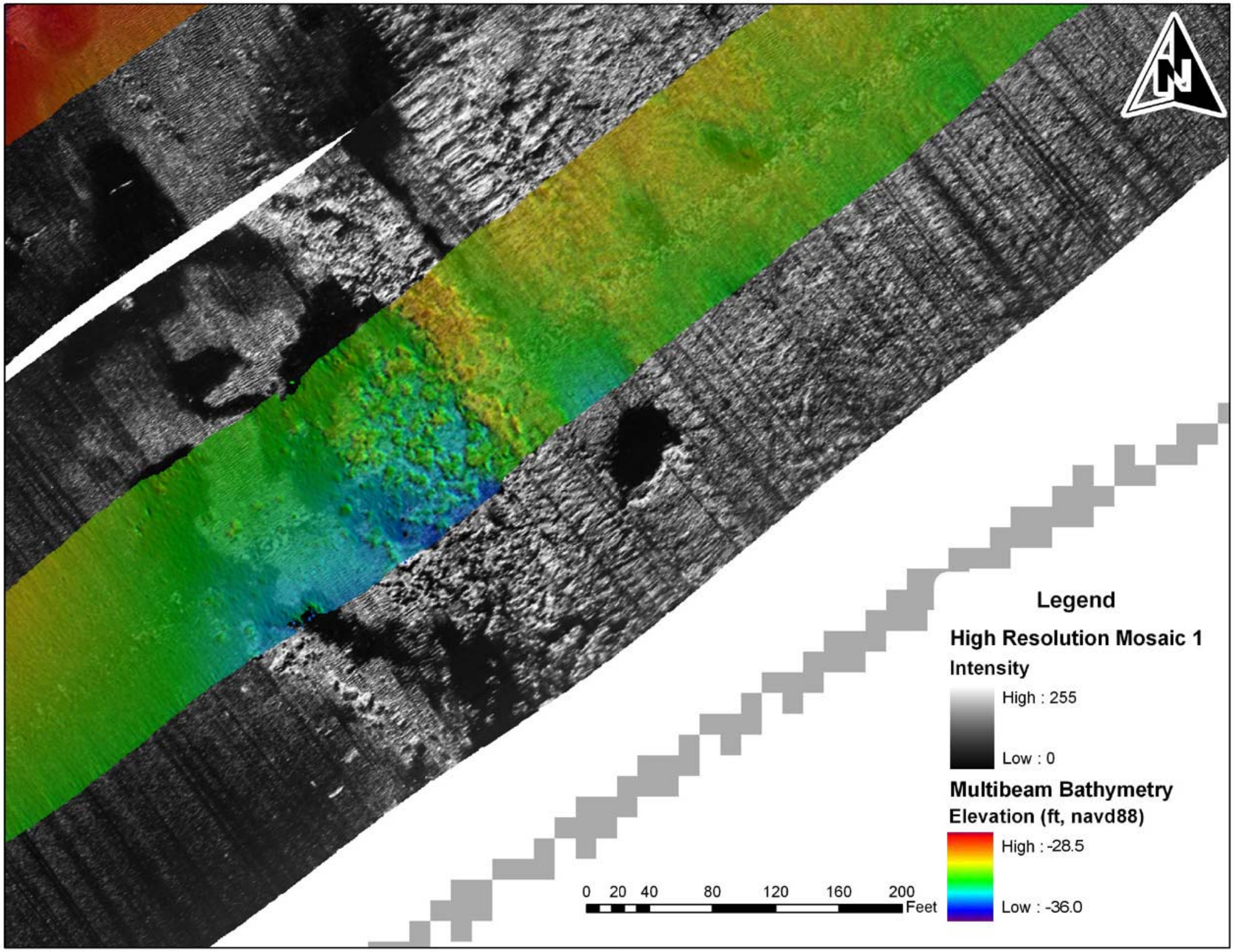


Figure 18. Rendered bathymetry overlaid on high-resolution side-scan sonar imagery. Map illustrates a low-relief hardbottom and sediment interface.

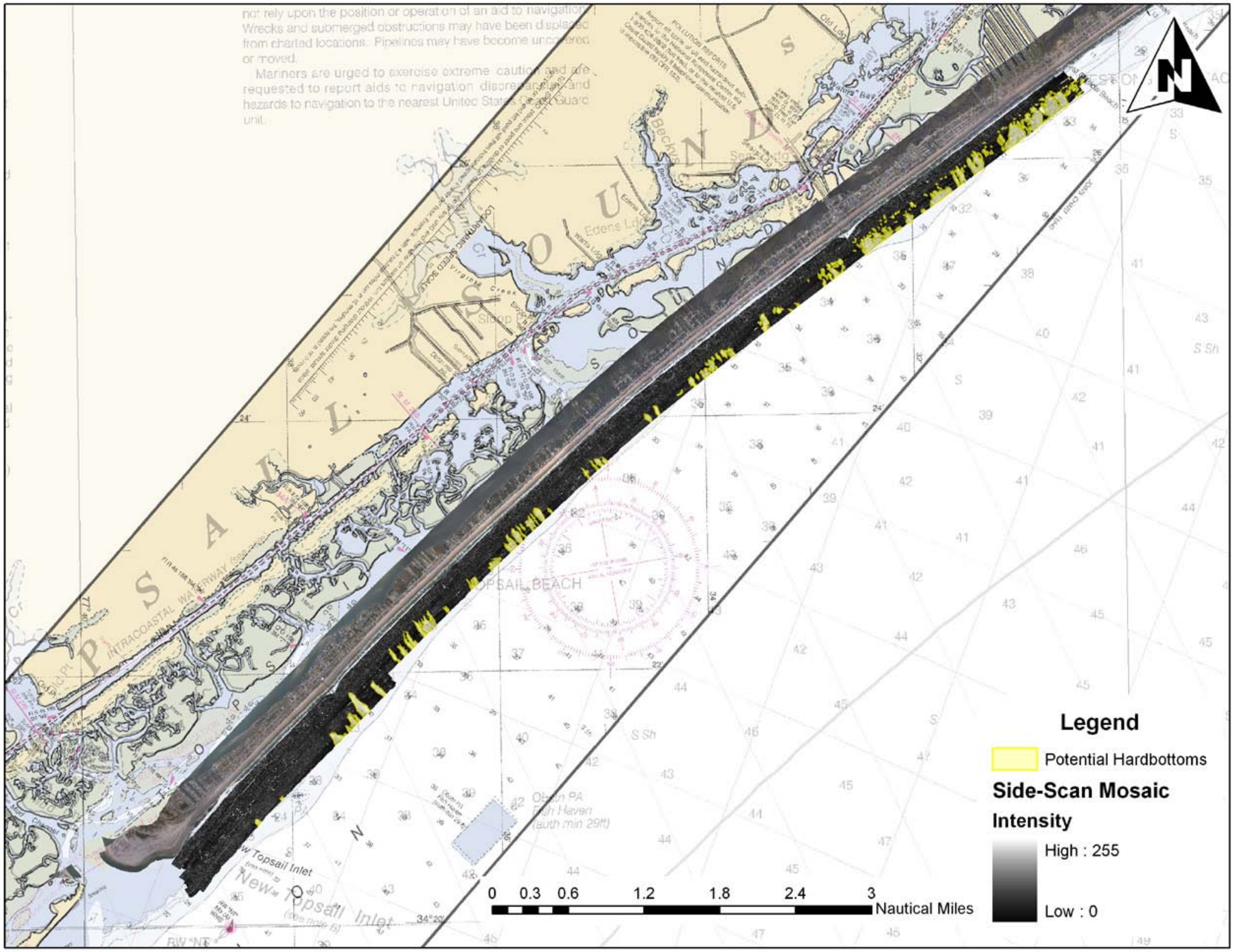


Figure 19. Side-scan sonar mosaic overlaid with polygon shapefile of potential hardbottom areas.

Appendix A – Official USACE Scope of Work

SCOPE OF WORK
NEARSHORE HARD BOTTOM SIDESCAN SURVEY
TOPSAIL ISLAND, NORTH CAROLINA

1. General. The Contractor shall acquire Sidescan Sonar Data along Topsail Island, North Carolina for the purposes of identifying and mapping potential Hard Bottom Areas. The longshore limits of the data collection extend form New Topsail Inlet to the Surf City/North Topsail town line as identified on the Government furnished map. The offshore limits shall extend from the mean low water contour to the -25 feet NGVD 1929 contour as identified on the Government furnished map.

2. Survey Control. All horizontal and vertical control used for this survey shall be from the North Carolina or a Federal Agency Network and be of third order accuracy or better. All control loops must be tied to at least two or more control points. The Contractor shall furnish a list of all points used to the Government. All work shall be relative to NAD 1983 North Carolina State Plane Feet in the horizontal plane and NGVD 1929 in the vertical plane. The Government will provide control information for previously established Control Points along the length of the project area.

3. Clearances. The Contractor shall acquire all Clearances necessary to obtain the required data. All discussions for access to private or public property or restricted waters or airspace must be included in the required weekly status report with name of person, address, and telephone number.

4. Required Deliverables. The Contractor is required to deliver Side Scan Mosaic Raster Data Sets, Shapefiles, Metadata Records, a Weekly Status Reports, and a Final Written Report.

4.1 Side Scan Mosaic Raster Data Sets. The Contractor shall deliver Georeferenced Mosaics of the Raster Data sets from the Side Scan Survey. The Raster Data sets shall depict the backscatter information used to map the potential hard bottom areas in the project area. The Raster Data Sets shall be in a format compatible with ESRI ArcView/ArcInfo Version 9.0.

4.2 Shapefiles. The Contractor shall deliver Polygon Shapefiles defining the potential hard bottom areas within the project area. The Shapefiles shall be in a format compatible with ESRI ArcView/ArcInfo Version 9.0.

4.3 Metadata Record. An FGDC compliant metadata record for each spatial data deliverable shall be created using ESRI ArcView/ArcInfo ArcCatalog version 9.0. Appropriate information shall be entered in all required fields. The Contractor shall attach the appropriate metadata record to each spatial data file using ArcCatalog so that no importing or formatting of the metadata record is required by the Government.

5. Weekly Status Report. **The Contractor is required to submit a Weekly Status Report each week, beginning on the Task Order Award Date, until all deliverables are received and accepted by the Government**. The Weekly Status Report shall be delivered via e-mail no later than 8:00 AM each Monday and shall document the Contractor's progress from the previous Monday through the previous Sunday. The status report shall itemize each scope item with percent of work complete and an estimated date of completion. The report shall also include the number and type of field crews working, a description of any problems and/or delays encountered, and any photographs of the site and/or significant site features (such as outlet structures, retaining walls, escarpments, etc.) and/or specialized data collection activities.

6. Final Written Report. A written report summarizing all data collection activities shall be submitted as a Portable Document File (PDF) and in bound hardcopy. The following items shall be included in the survey report:

- Written description of workflow to complete task order (start to finish) including flowchart diagram and detailed description of QA/QC process
- Dates and times of each data collection activity
- Atmospheric Conditions for each day of data collection activity
- All Horizontal and Vertical Control used including monument name, establishing agency, date established, description, and published horizontal and vertical values
- TBM descriptions with vertical values
- Copy of all field notes
- Complete and detailed list of all survey equipment used including copy of last factory calibration report
- Metadata Record as described in 4.3 above
- Photographs of the site and any significant features or data collection techniques used

7. Quality Control. If work is found to be in error, incomplete, illegible or unsatisfactory after assignment is completed, the Contractor shall be liable for all cost in connection with correcting such errors. Corrective work may be performed by Government personnel or Contractor personnel at the discretion of the Contracting Officer. In any event, the Contractor shall be responsible for all costs incurred for correction of such errors, including salaries, automotive expenses, equipment rental, supervision, and any other costs in connection therewith. All data and deliverables shall be reviewed for the following:

- Required coverage of the project limits
- Capture of all required features
- Required accuracies
- Required horizontal and vertical datum
- Adherence to the delivery order requirements

8. Technical POC. All technical questions concerning work under this task order shall be directed to Jim Jacaruso at (910) 251-4064.

9. Completion Date. All work required under this task order shall be **completed and delivered no later than 14 calendar days from the Task Order Award Date.**

This schedule is subject to adjustment by the Contracting Officer in writing.

10. Deliver To. All work shall be delivered to:

U. S. Army Corps of Engineers
Wilmington District
Attn: Jim Jacaruso, TS-EE
69 Darlington Avenue
PO Box 1890
Wilmington, NC 28402-1890

Appendix B - Benchmark Descriptions

NGS Mark Designated Tower Three (1947)

DESIGNATION: TOWER THREE (used for survey control basestation)
PID: AEA0695
STATE/COUNTY: NC/PENDER
USGS QUAD: HOLLY RIDGE (1997)

Current Survey Control:
NAD 83(1986): 34 23 35.96043(N) 077 35 34.60089(W) ADJUSTED
NAVD 88: 15.434 (meters) 50.64 (feet)

LAPLACE CORR: -2.78 (seconds) DEFLEC99
GEOID HEIGHT: -37.37 (meters) GEOID03
DYNAMIC HT: 15.419 (meters) 50.59 (feet) COMP
MODELED GRAV: 979,654.0 (mgal) NAVD 88
HORZ ORDER: SECOND
VERT ORDER: SECOND CLASS 0

DMA Mark Designated DOP 10768 (1981)

DESIGNATION: DOP 10768
PID: AI0899
STATE/COUNTY: NC/PENDER
USGS QUAD: HAMSTEAD (1970)

Current Survey Control:
NAD 83(1986): 34 20 54.15165(N) 077 39 07.26281(W) ADJUSTED
NAVD 88: 2.31 (meters) 7.6 (feet) ADJUSTED

LAPLACE CORR: -3.37 (seconds) DEFLEC99
GEOID HEIGHT: -37.32 (meters) GEOID03
DYNAMIC HT: n/a (meters) n/a (feet) COMP
MODELED GRAV: n/a (mgal) NAVD 88
HORZ ORDER: FIRST
VERT ORDER: THIRD

NCGS Mark Designated Crocker (1988)

DESIGNATION: CROCKER
PID: AI0831
STATE/COUNTY: NC/PENDER
USGS QUAD: HAMSTEAD (1970)

Current Survey Control:
NAD 83(1986): 34 21 36.36724(N) 077 38 12.12062(W) ADJUSTED
NAVD 88: 1.33 (meters) 4.4 (feet) ADJUSTED

LAPLACE CORR: -3.41 (seconds) DEFLEC99
GEOID HEIGHT: -37.34 (meters) GEOID03
DYNAMIC HT: n/a (meters) n/a (feet) COMP
MODELED GRAV: n/a (mgal) NAVD 88
HORZ ORDER: FIRST
VERT ORDER: THIRD

CGS Mark Designated A 230 (1947)

DESIGNATION: A 230
PID: EA0696
STATE/COUNTY: NC/PENDER
USGS QUAD: HOLLY RIDGE (1997)

Current Survey Control:
NAD 83(1986): 34 23 04.52612(N)   077 36 18.42596(W) ADJUSTED
NAVD 88: 3.480 (meters)   11.42   (feet) ADJUSTED

LAPLACE CORR: -2.97 (seconds)   DEFLEC99
GEOID HEIGHT: -37.36 (meters)   GEOID03
DYNAMIC HT: 3.476 (meters)   11.40 (feet) COMP
MODELED GRAV: 979,654.2   (mgal)   NAVD 88
HORZ ORDER: FIRST
VERT ORDER: SECOND   CLASS 0


NGS Mark Designated Firth (1988)

DESIGNATION: FIRTH
PID: AI0904
STATE/COUNTY: NC/PENDER
USGS QUAD: HOLLY RIDGE (1997)

Current Survey Control:
NAD 83(1986): 34 26 46.68504(N) 077 30 43.60383(W) ADJUSTED
NAVD 88: 1.20 (meters) 3.9 (feet) ADJUSTED

LAPLACE CORR: -1.31 (seconds) DEFLEC99
GEOID HEIGHT: -37.40 (meters) GEOID03
DYNAMIC HT: n/a (meters) n/a (feet) COMP
MODELED GRAV: n/a (mgal) NAVD 88
HORZ ORDER: FIRST
VERT ORDER: THIRD

NCGS Mark Designated Sea AZ MK (1988)

DESIGNATION: SEA AZ MK
PID: AI0866
STATE/COUNTY: NC/PENDER
USGS QUAD: HOLLY RIDGE (1997)

Current Survey Control:
NAD 83(1986): 34 25 41.73477(N)   077 32 27.16683(W)   ADJUSTED
NAVD 88: 2.57 (meters)   8.4   (feet) ADJUSTED

LAPLACE CORR: -1.79 (seconds)   DEFLEC99
GEOID HEIGHT: -37.40 (meters)   GEOID03
DYNAMIC HT: n/a (meters)   n/a (feet)   COMP
MODELED GRAV: n/a   (mgal)   NAVD 88
HORZ ORDER: FIRST
VERT ORDER: THIRD

Appendix C– Field Notes, Daily GPS Quality & Copy of Field Book

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

Multibeam Daily Operation Proceedures & Checklist

Pre-Survey Operations	Complete	Notes		
		Latitude (Northing)	Longitude (Easting)	Elev.
Perform Survey GPS Check	X	n/a	n/a	Δ0.017m
Power up POS MV	X			
Power up UPS	X			
Power up EM3002 PU	X			
Power up Acquisition PC	X			
Power up Navigation PC	X			
Power up Trimble GPS	X			
Perform BIST (head in water)	X			

Survey Operations		Latitude (Northing)	Longitude (Easting)	Value
Input Initial SV cast in SIS Runtime	X	34 20 42.48	077 38 46.45	1542.0
SV Cast #1	X	34 20 42.48	077 38 46.45	1542.0
SV Cast #2	X	34 23 49.52	077 34 57.73	1542.6
SV Cast #3	X	34 26 27.46	077 30 47.34	1543.7
SV Cast #4				
SV Cast #5				
SV Cast #6				
SV Cast #7				
SV Cast #8				
Vessel Draft Check (waterline to ducer)				0.53m

General Survey Notes

Project	USACE Topsail SS1
Survey Area	Southern 11miles of Topsail nearshore
Sea State	2' SSE swell, glassy (am), surface wind chop by 2 pm
Wind	N 5 kts to variable (am), SE 10kts by 2pm)
Air Temperature	75 F(am), 91 F (pm)
Sea Temperature	
Tides	L: 8:55 am H: 2:54pm EST
Survey Features & Navigational Aids	N/A
Comments	- NAV from POS into ISIS for Side Scan at 19200 intermitten. Used Hypack NMEA out at 9600 for SS NAV. Can't split to auto helm. Get powered splitter operational. - Tide too low for acqusition in the nearshore first thing in am. Starting on mid lines - Trawling activity in Northern reach of survey bounds. Look for trawl scars in data - Water clarity excellent for this region. No New river water in place? - Check for new version of ISIS for Neuse River project. Improved bottom track?

Line Name	MS/CL	Direction	Notes
0	MS	NE	HP 7 7:04 am EST Start line
1	MS	NE	cont - SS swath at 90m
2	MS	NE	cont
3	MS	NE	cont
4	MS	NE	cont
5	MS	SW	HP 9 (spacing 100m)- start 9:10am EST
6	MS	SW	cont - SS swath at 135m
7	MS	SW	cont
8	MS	SW	cont
9	MS	NE	HP 11 (spacing 100m) - start 11:10am
10	MS	NE	HP 11 cont - SS swath at 135m
11	MS	NE	HP 11 cont
12	MS	NE	HP 11 cont
13	MS	SW	HP 5 - inshore line (same swath 135m)
14	MS	SW	HP 5
15	MS	SW	HP 5
16	MS	SW	HP 5
17	MS	NE	HP 13
18	MS	SW	HP 15
	End Survey Day 6:50pm		
	Side Scan Operation Notes		
23.5 ft length on tow line from block			
Position is 4.3m to STBD of Ships NAV PT			

Comments:
- We got a 3:40am start
- Setup basestation by 4:15am
- After another "slap test" of side-scan we left the dock at ~ 4:35am
- Made it to the New Topsail Inlet crossing at AIWW by 5:15am and out the inlet by 5:30am
- On the first line by 5:45am but having nav problems since ISIS won't take the string at 19200
- Finally were able to split nav from Hypack at 9600 but can't use auto helm. :(
- First line by 6:50am

Acquisition comments:
- Inshore lines have slight artifacts due to shallow water and possible aeration of water in surfzone
- Mid water lines looking a little cleaner
- Imaging old pilings from piers. very cool.
- Very distinct returns on possible hard bottoms in NorthEastern section of survey area. Low relief in bathy.
- Getting quite hot in cabin by 11am. Call Danny M. @ new AC unit.
- Using a 100m range on the inshore lines and ~ 120m on the outside. Overlap looking great.
- Slight seabreeze kicking up around 3pm. Data still looking good though......
- Finished acquisition by ~ 6pm. Headed back to dock.
- Layback calculations and geometry in field book.

USACE TOPSAIL SS 1 6-11-06

SITE CAL

BASE = TOWER THREE 1947

DOP 10768 (1,3)

67222.119 N	67222.286
733619.291 E	733619.270
2.31 m	2.341
pub	

CROCKER (1,3)

68542.046	68542.204
735010.571	735010.538
1.33	1.351
pib.	

A230

	722
71298.606	71298.768 TOPO
737877.413	737877.388
3.480	3.452 390
	3.460 CNTRL

1.21 ↑

1.95 →

~~PCL~~ 15

3263

FIRTH (1,3) steel rod

78267.452 — 78267.573

746327.233 — 746327.180

1.20m — 1.234

PUB — rec

SEA AZ MK

76227.107 — 76227.279

743713.317 — 743713.279

2.57 — 2.605

pub — rec

AI 0866

1,3

NCGS

USACE Topsail Side Scan

July 17, 2006

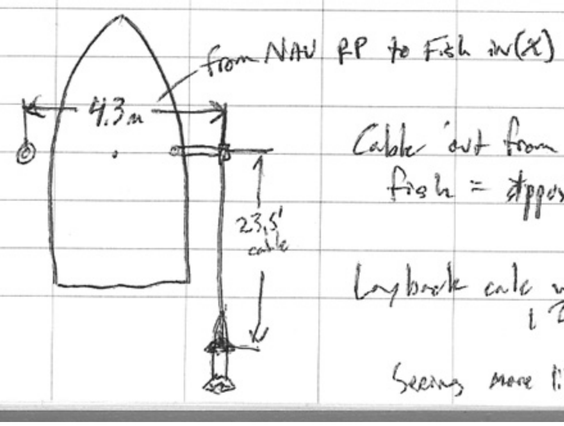
mobilization

- left PKS ~ 12:15pm after USACE estimate
- Got boat in water + slip ~ 2:00pm
- Set up base on Tower 3
  - checked mark ~ 1.3cm!
- Set side scan + tested MB at Dock
- Turned off base and charge batteries for Survey

July 18, 2006

- left dock at 4:00am
- for survey notes see digital survey log!

Side Scan Measurements



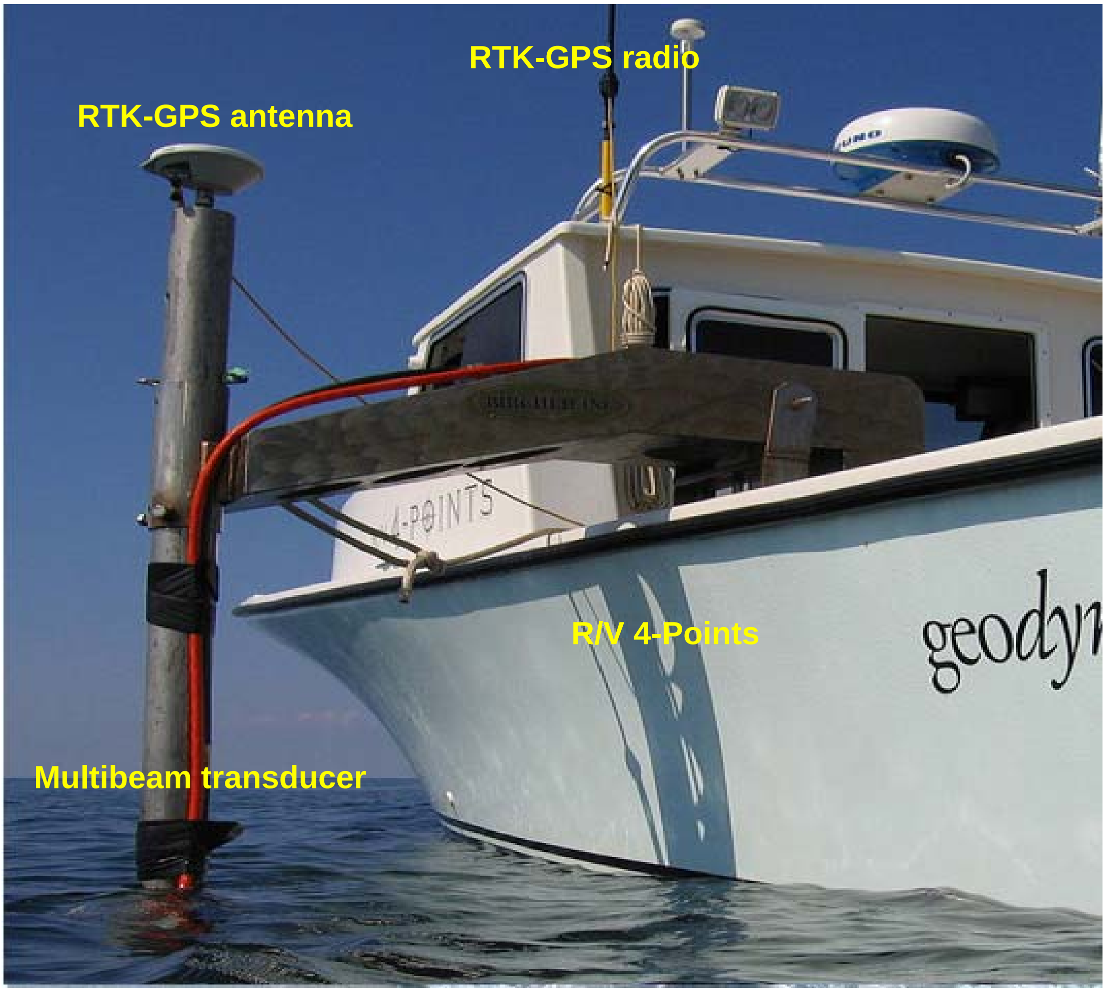
Cable out from block to fish = approx. 23.5'

Layback calc would come to: 12.5 m roughly

Seeing more like 6 in data

Appendix D - *R/V 4-Points* Setup & Instrument Accuracies

Multibeam Deployment



Side-Scan Deployment

Survey Instruments & Published Accuracies

Survey Vessel

The research vessel *4-Points* is a custom fiberglass survey boat designed specifically for shallow water sonar and acoustical operations. The vessel is 25' long with a 10' beam; the bottom tapers from a deep "Carolina" style Vee to a relatively flat-bottomed stern that provides a shallow draft of approximately 1.2'. Twin 140 four-stroke engines, hung on a stainless steel bracket, power the vessel. All electronics and generators are grounded to the sea via a bottom mounted bonding plate to eliminate all electrical noise. The transducer mount was engineered and designed at the University of North Carolina at Chapel Hill's Institute of Marine Science specifically for multibeam and ADCP surveys (Hench, et. al, 2000 "A portable retractable ADCP boom-mount for small boats". *Estuaries*, 23 (3): 392-399.). The mount was designed to keep the transducer below any potential bow wave and to also house the motion sensor directly over the transducer. Side-scan instrumentation is deployed, towed and retrieved from custom davit on starboard side.

Side-Scan Sonar Equipment

- **Klein 3000 side-scan sonar towfish**
    - Frequency: 132 kHz and 445 kHz
    - Transmission pulse: tone burst selectable from 25-400 usec. Independent pulse for each frequency
    - Beams: horz-100 kHz 7 degrees, horz-500 kHz 21 degrees, vertical-40 degrees
    - Range: 100 kHz to 450m, 500 kHz to 150m
    - Multiplexer: T1, 1.5 MB/sec
    - Note: There are no calibration reports associated with side-scan

Multibeam Equipment

- **Simrad EM 3002 multibeam sonar transducer**
    - Multi-Frequency: in 300 kHz band
    - Max ping rate: 40 Hz
    - No. of beams/ping: 254 Roll and Pitch stabilized
    - Beam width: 1.5^{o} x 1.5^{o}
    - Beam spacing: 0.9^{o}
    - Depth range from sonar head: 1 to 150 m
    - Depth resolution: 1 cm
    - Depth accuracy: 5 cm RMS
    - Range sampling rate: 15 kHz
    - Bottom detection by phase or amplitude. Seabed imaging & classification with backscatter (sidescan-like) output.
    - Full swath width accuracy to the latest IHO standard

- **POS MV 320 v4 Main Specifications (with RTK Corrections)**

- Roll, Pitch accuracy: 0.02° (1 sigma with GPS or DGPS) 0.01° (1 sigma with RTK)
- Heave Accuracy: 5 cm or 5% (whichever is greater) for periods of 20 seconds or less
- Heading Accuracy: 0.02° (1 sigma) with 2 m antenna baseline, 0.01 (1sigma) with 4 m baseline
- Position Accuracy: 0.5 - 2 m (1 sigma) depending on quality of differential corrections 0.02 - 0.10 m (RTK) with input
- Velocity Accuracy: 0.03 m/s horizontal

- **Trimble 5700 dual frequency GPS system & RTK-Basestation**
  - Instrument used for positioning and tidal corrections
  - High precision L1 and L2 measurements
  - 24 channels L1 C/A code, L1/L2 full cycle carrier
  - Extremely low latency (20 milliseconds)
  - RTK-GPS accuracy depends on conditions such as multipath, obstructions, satellite geometry, atmospheric parameters and basestation control quality.
    - Published horizontal accuracy: 10 mm + 1ppm RMS
    - Published vertical accuracy: 20 mm + 1ppm RMS

- **Odom Hydrographics Digibar Pro sound velocity probe**
  - Sampling rate: 10 Hz
  - Depth accuracy: > 31 cm
  - Velocity accuracy: +/- 0.3 m/sec

Computers & Software

- Rack mounted multibeam acquisition PC
  - 3.0 GHz Intel Pentium 4 processors with 800 MHz system bus
  - 1 GB of RAM
  - Triton Elics International (TEI) Isis version 6.2 acquisition software
  - CARIS HIPS/SIPS processing software

- Rack mounted Simrad multibeam power unit
  - EM3002 controller and power modulator

- (3) Fujitsu pentop navigation PC
  - Hypack Max.

- (4) Dell high-end GIS processing workstations
  - Arcview 3.3, ArcGIS 9.1, Surfer 8.0, Trimble Geomatics Office, Matlab 12, TEI Bathypro and DelphMap, CARIS

Backup field & processing computers and instrumentation

- (2) Dell laptops

- (3) Fujitsu pentop
- (5) Maxtor 250 – 300 gigabyte external backup drive

Appendix E – QTC Report

Quester Tangent

SIDESCAN SEABED CLASSIFICATION

Processing of Klein 3000 data

Prepared for Geodynamics LLC

SC75-840C

Issue Date: July 28, 2006

Making Data Intelligent™

DATE	REVISION	DESCRIPTION
06.07.28	R00	Original Issue

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Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

Quester Tangent received approximately 5 GB of Klein 3000 XTF data acquired on July 18, 2006 by Geodynamics LLC from the Topsail, NC area. The data are from the first survey of a 2-phase project. The data were processed in QTC SIDEVIEW, automated seabed classification for sidescan sonar imagery. Although the overall results were less than satisfactory due to the challenges of acquiring sidescan data in a shallow water, very dynamic environment, some specific classes such as reef areas were well demarcated. Specific issues relating to original data quality and recommendations for improvement are outlined in the report.

INTRODUCTION

The following report describes the classification of a set of sidescan data using QTC SIDEVIEW. The original data were acquired using a Klein 3000 sidescan and provided to Quester Tangent on 2 DVDs in XTF format.

It is well known that the statistical characteristics of a sonar backscatter image depend on the bottom type. Even to a novice user, the texture differences between images of rocks, sand, and mud are readily apparent. Differences between silt and clay are less obvious. Statistical processing can capture many of the pertinent details of the interaction between the sound and the bottom and of its vertical relief. Multivariate statistics can then isolate those details that are rich in information about the bottom, producing features that contain the information necessary for accurate and reliable bottom classifications.

Image-based seabed classification is the segmentation of seabeds into discrete classes based on the characteristics of acoustic backscatter throughout a region. Segmentation is a valid and useful survey tool, even though it does not independently identify geophysical types. Dividing the seabed into classes is useful because seabed characteristics are relatively constant throughout a class and distinct from the characteristics of other classes. Therefore, the amount of ground truth that needs to be collected, visually or mechanically, is dramatically reduced. The strategy of identifying classes with a few samples and confidently extrapolating those characteristics throughout the acoustic classes is both scientifically valid and very cost effective.

The Quester Tangent approach to automated classification involves the data first being transformed into a format readable by QTC SIDEVIEW software. Both automatic and manual data quality assessment is performed throughout the process including the reformatting stage. Image patches or rectangles are placed on only the most suitable data. Features capturing the subtleties of image intensity and texture are generated. A statistical analysis helps to further refine the information to the point where classification can occur. Classification of the bottom that gave rise to these features is done by an automated clustering method that adapts to the characteristics of the multibeam or sidescan data set. Each cluster represents a bottom type, which can be identified based on ground truth; for example, photographs, grain-size analysis, or other local data. If the bottom type is known before classification, data from the areas of known sediment type can be used to build a catalogue, which would then be used to classify subsequent or archived data. This is called supervised classification. The alternative, unsupervised classification, forms the data into logical clusters that can then be identified based on ground truth. The effectiveness of unsupervised classification in uncovering practical and valuable information from the acoustic data has been demonstrated in many projects. This clustering technology, with its ability to easily perform supervised and unsupervised classification, forms part of QTC SIDEVIEW.

PROCESSING THE DATA

Loading Data

Backscatter images from a wide variety of sidescan systems can be loaded with position and ancillary data. Validation and quality control are important considerations. Backscatter data points can be flawed for various reasons, including tow fish and vessel motion, and interference from another sonar source. The data are cleaned to ensure the highest quality data available are presented to the classification. Data designated as not usable are captured in a mask. The mask is used to exclude regions of poor quality from further processing. QTC SIDEVIEW gives the user several cleaning options (Table 1).

Name	Function
Preserve Bottom Edits	The altitude line in the sidescan images may be edited. This function saves those edits.
Water Column Offset (m)	The water column must always be masked. This tool allows a specified distance from the altitude pick into the image to be masked.
Angle	The image can be masked using the sonar depression angle. The angle values are as follows: zero degrees is in the horizontal plane with the sonar and ninety degrees is directly below the sonar
Range (m)	Parts of the image can be excluded using absolute or percent range. All data greater than the specified range value will be masked.
Surface Echo (m)	The sidescan image may display some along track banding which does not represent the seafloor. This may be a result of surface echo. This tool allows for masking of this banding.
Preserve Border Edits	A tool is provided to edit the border in the sidescan images. This function saves those edits.
Despeckle	The program facilitates removal of speckle during feature generation. Despeckle level allows the user to choose the size of the median filter kernel (low, medium or high) used in the despeckle algorithm during feature generation.

Table 1: Cleaning tools.

Placing Rectangles

The seabed in the image is divided into rectangular patches. Patch placement depends on data quality through use of the mask. The mask and the user-selected patch sizing determine the number of patches per side (to port and to starboard). A class assignment will be generated for each patch.

Generate Features

A large number of features are extracted from the backscatter amplitudes in each rectangular patch of each image. QTC SIDEVIEW is able to use many features because Principal Components Analysis (PCA), in the next processing step, will select those combinations of features best suited to each data set.

For bottom classification, features are extracted from both backscatter image data and depth data using the following algorithms:

Basic Statistics: Mean, standard deviation, and higher-order moments are indicative of acoustic impedance changes and interface roughness

Quantile and Histogram: These measure the distribution of backscattered information intensities at low resolution.

Power Spectra: Fast Fourier Transforms (FFTs) are used to find power spectra, which describe statistical characteristics on many resolution scales.

Ratios based on Power Spectra (Pace): Ratios of log-normalised power in various frequency bands provide good discrimination for classifying images.

Grey-Level Co-occurrence Matrices: Grey-Level Co-occurrence Matrices (GLCMs) describe the amplitude changes over selected distances and directions in the image patch, and are widely used to assess texture.

Fractal Dimension: Fractal dimension is a sensitive measure of the distribution and structure of both backscatter and depth variations.

These features have been selected to capture as many useful aspects of the data as possible. As QTC SIDEVIEW was developed, the selection of features was frequently examined to determine which features were providing useful discrimination and to determine if any algorithm consistently produced redundant features. One interesting result from these studies was that mean intensity was rarely the sole determining feature in the overall classification process. It is combinations of intensity and texture that seem to drive classifications.

Multivariate Statistical Analysis

A major strength of QTC SIDEVIEW processing is the incorporation of multivariate statistical techniques as they permit the use of many features. Experience has shown that some features are important in what might be called the standard classifications: mud, sand, gravel, and so on. Others are important for more specialised classifications such as discriminating among sand/mud mixtures. For any particular data set, PCA selects the features that are most useful for the discrimination task at hand. Features that are close to constant are largely disregarded. Redundancies, that is, correlated features, are also acceptable, but only one remains significant. What is left is a reduced feature set that compactly describes the diversity of the data set. While some features may have little diversity or be tightly correlated when used to describe one set of seabed sediments such as open continental shelf sand and gravel, they may be found to give useful discrimination in other cases, such as on deltaic sediments. Thus, the connection between features and classification adapts to the character of the data set.

For each patch of each image, the features are calculated and then arranged as a row vector containing 132 elements. The name we give to these rows of features is Full Feature Vectors (FFVs). This information must be optimised or reduced without losing any details of the sediment. The dimension of the FFVs is reduced by multivariate statistical processing to isolate the combinations of features that are responsible for most of the diversity in the data set. In general, the top three combinations capture a very high percentage of the variance, so the rest of the combinations can be disregarded. These top three combinations are called Q-values.

The result of this reduction process is contained in the reduction matrix. Any FFV can be reduced to three Q-values by matrix multiplication. The reduction matrix is part of the catalogue used for supervised classification. New FFVs, derived from any subsequent acoustic survey, can be reduced to Q-values in this way as part of the supervised classification process. Alternatively, the multivariate statistical processing can be run on any partial or complete data set to find new information.

Cluster Analysis

The acoustic response - represented by Q1, Q2, and Q3 - from like seabeds will be similar. When plotted on a three-axis plot, called Q-space, points with similar values, for example from a single seabed type, form a cluster. Thus, data from three different seabeds form three clusters and new data points are classified based on their locations relative to the clusters in Q-space.

Each catalogue is specific to the sonar system used for data collection and may also be specific to particular operating conditions of that sonar.

Catalogues can be based on a set of sample sonar images or by sampling the whole data set. Over time, a library of classes could be produced from which various catalogues can be created, depending on the application. With the catalogue selected, the complete data file can be classified.

Classification of Seabed

Classify Seabed is the process of applying a catalogue to a data set. If the entire data set is used in an unsupervised classification process, the result is both a catalogue and a classified data set. Confidence and probability values are also calculated during Classify Seabed. If less than the entire data set was clustered, this step is used to classify all the data. Both these processes are unsupervised classification.

Catalogues can also be useful for supervised classification. In this process, each new patch is assigned to one of the clusters, or sediment types, based on a pre-existing catalogue.

Presentation

The final product is an ASCII comma-delimited file that can be imported into mapping software for the production of plots and 3D models. GIS systems are often used to demonstrate correlations between acoustic classes and other GIS layers. Another popular presentation is of the classifications draped over a bathymetric model of the surveyed area.

SIDESCAN DATA QUALITY

Data Challenges

The Klein 3000 data provided by Geodynamics presented significant quality challenges. The survey vessel was a small boat, operating in open seas with a substantial swell from the southeast. The maximum water depth was about 10 m. The sidescan was towed from a sheave supported overboard on the starboard side, on enough cable that it was about 6 m aft of the sheave (which was 4.3 m to starboard of the ship reference point). Other acoustic equipment that affected the sidescan images were an EM3002 on a pole on the vessel's port side and a sounder on the towfish.

Preparing the images for classification in QTC SIDEVIEW required an atypical amount of effort. Also, towfish instability introduced some artefacts into the images that could not be removed by pre-processing. These issues included:

Towfish yaw

Figure 1 shows towfish heading and yaw rate on a line from this survey. A heading is plotted for each ping time, and pings were 0.1 s apart. Because the horizontal beam width on the Klein 3000 is very small, yaw rates exceeding a few degrees per second can give non-recoverable gaps in images. The explanation goes like this: In plan view, sound is transmitted into a narrow fan. It takes a few milliseconds for sound to reach the seabed at typical ranges and for the echo to return to the towfish. The transmit and receive beams are identical, so as the towfish yaws they both sweep around. If they have swept more than some angle, the echo arrives at the towfish outside the receive beamwidth and is not recorded. The Klein 3000 has transmit and receive beamwidths of 0.3° (taken together, they give the advertised system beamwidth of 0.21°). It takes 67 ms for the round-trip to 50 m range. Thus echoes from 50 m are lost if the yaw rate exceeds 0.3°/0.067 s = 4.5 °/s. Much of the time, the yaw rates in Figure 1 are much larger than this. 31% of the time, they are less than 4.5 °/s. This is the primary explanation for bright and dark streaks in the outer parts of the images.

Towfish pitch

Erratic towfish motion is caused by vessel heave being transmitted down the towcable. This causes heave, which drives pitch unless the connection is precisely at the hydrodynamic centre of effort (which moves about, so this is impossible). Pitch and heave lead to yaw, roll, sway, and surge. Yaw has the most serious effect on the sonar image, with pitch second. In this survey, towfish pitch (Figure 2) had some effects, but it would be difficult to isolate these from those caused by yaw.

Towfish roll

Towfish roll does not lead to parts of the image going missing but can affect the image in other ways. The vertical beam pattern is very broad (about 40° for the Klein 3000), far exceeding any occurring towfish roll. However details of the beam pattern move across the image with roll. There is less backscatter amplitude near nadir to port, suggesting that this towfish tows slightly port up.

Low altitude

The towfish altitude, that is, its height above the seabed, ranged from 0 to 6.5 m during this survey, and was often only 2 m or so. At the ranges used, 50 or 75 m, the angle between the sound ray and the bottom, the grazing angle, is very small, less than 1° through most of the range. Very small grazing angles give very large shadows for even small bottom irregularities, and indeed big parts of these images are shadow. This is not ideal for acoustic seabed classification since the amplitude and texture of seabed backscatter from these areas have been lost.

Bottom Picking

There is a sounder on the towfish to record towfish altitude. This is often done on sidescan towfish because the sidescan transducers send very little power vertically down, meaning that the start of the sidescan seabed echo is often not a reliable measure of altitude. Altitude is needed for slant-range correction and for image compensation. (QTC SIDEVIEW does slant-range correction of classified positions, not of the image). During this survey, though, only an erratic small fraction of these altitudes was logged. This meant several hours of work manually tracing a bottom pick for each line.

Interference from a multibeam echosounder

Crosstalk between different acoustic systems operated simultaneously is often found, even if their primary frequencies are quite different. If one is an imaging sonar, interference is often called walkover, because the extraneous echoes appear atop the image. If the systems are unsynchronised, as they often are, the interference appears in regular patterns, loosely suggesting footprints. In this survey, the EM3002 on the port side walked over the port sidescan image. Typically, it can be seen only at ranges greater than about 40 m, because the sidescan gain increases with range. In some lines the walkover is a major interference; in others it can barely be seen. One reason may be that the towfish was astern of the multibeam, and thus receives the multibeam echoes only when yawed appropriately. Walkover can have a major effect on classification because it adds a major artificial texture. Either it has to be filtered away, or these regions must be excluded from the classification process. In QTC SIDEVIEW, the despeckle filter is effective at averaging away the walkover, but also smoothes the entire image. While this may have been effective in this survey, the approach that was taken was to mark a border on the images, the inner boundary at which the walkover appears. In 14 lines, borders were drawn on the port side at ranges near 40 m. On half of these, multipath reverberation caused some walkover to starboard at long ranges (where the gain is high), so border s were drawn near 60 m, typically, to exclude ranges beyond that from classification.

Wake

With the towfish 6 m aft of the sheave, the vessel wake was above it and to port. It could be seen clearly on six lines, at a range of 4 m. Eddies from the wake sometimes extended to almost 6 m. QTC SIDEVIEW contains a filter for this situation, called the surface-return filter. It was used to mask the image from 3.7 to 5.5 m on these lines. This filter operates on both sides, so the same mask had to be applied to the starboard image, even though it was not needed there.

Artificial samples at end of each ping

A common artefact in Klein imagery is that the last 40 or so samples of each ping are artificially large, often at or close to the maximum possible digital value. QTC SIDEVIEW has a filter for this. It was used to remove the last 3% of each ping from the region to be classified.

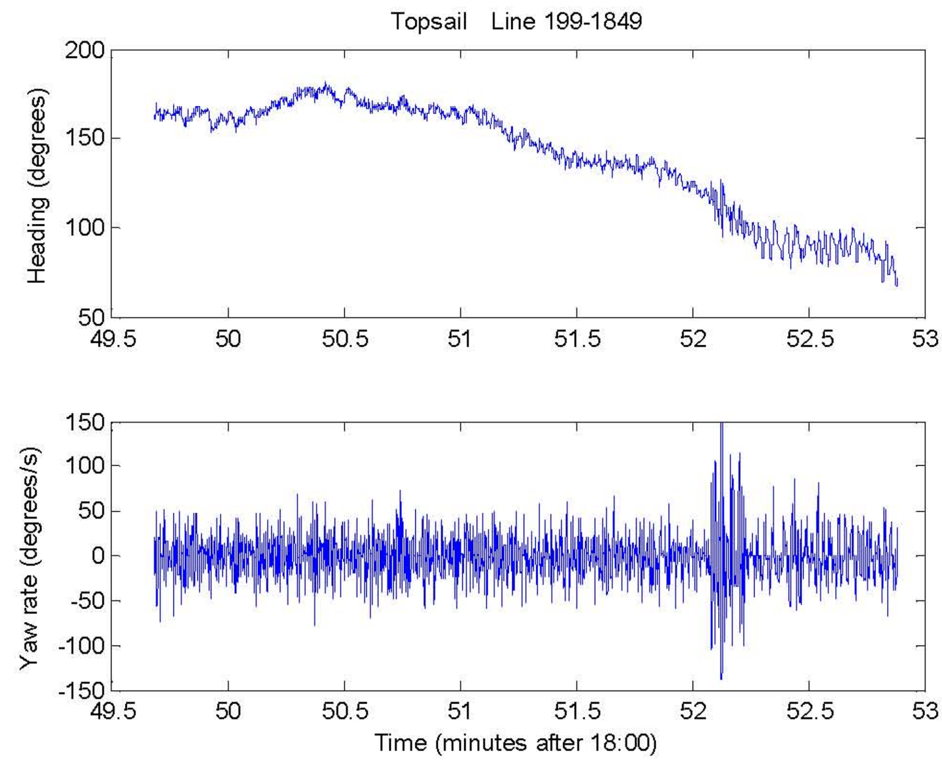

Figure 1: Towfish heading and yaw rate in a line of Topsail data set

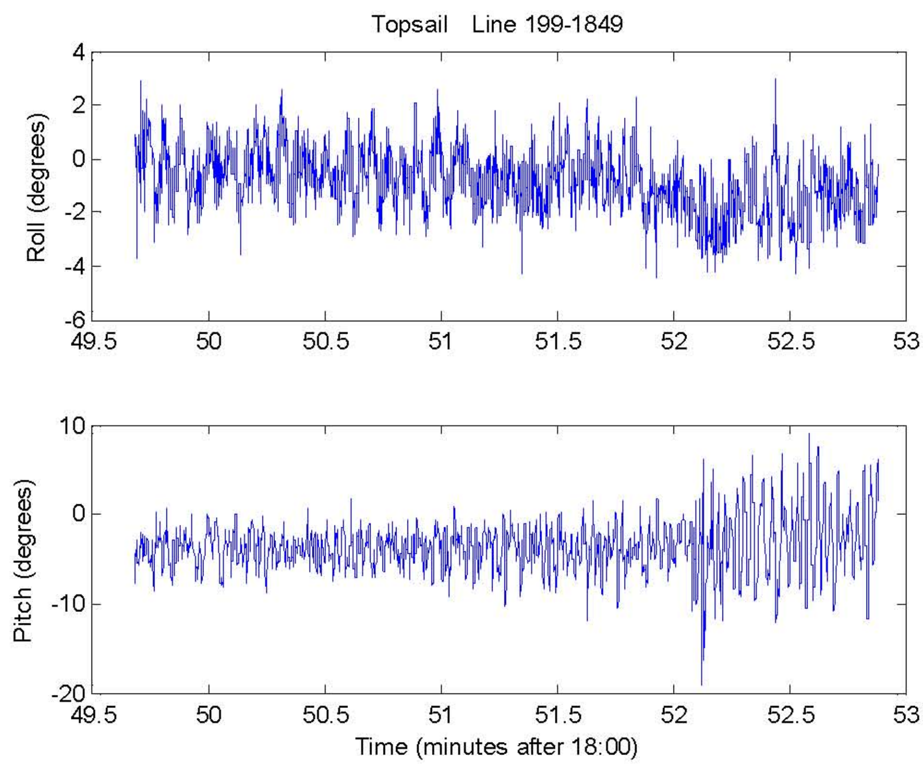

Figure 2: Towfish pitch and roll in a line of the Topsail data set

Individual Line Cleaning

Table 2 shows an assessment of each line and the cleaning process used for it. In addition, bottom picking was done for each line.

Line number	Sonar range (m)	Typical altitude (m)	EM3002 walkover on port image	Border cleaning applied	Wake cleaning applied
199-1104	50	0 – 4	> 40 m, important	Yes	Yes
199-1122	50	1.4 – 4	Not evident		
199-1139	50	0.8 – 2	Not evident		
199-1157	50	3 – 4	Not evident		
199-1214	50	2.5 – 4	Not evident		
199-1232	50	3	Not evident		
199-1312	75	4	> 50 m, important	Yes	
199-1317	75	3.5 – 5	Negligible		
199-1335	75	4	Negligible		
199-1353	75	4	Negligible		
199-1410	75	4	Negligible		
199-1428	75	4	Negligible		
199-1446	75	0 – 4	> 55 m, important	Yes	
199-1507	75	1.5	> 35 m, important	Yes	
199-1508	75		Issues with altitude	Ignore line	Ignore line
199-1509	75	2 – 4	> 45 m, important	Yes	
199-1527	75	4 – 5	> 60 m, important		
199-1545	75	5	> 60 m, important		
199-1603	75	5	Negligible		
199-1620	75	5.5 – 6.3	> 650 m, important		
199-1638	75	5.5 – 6.5	Negligible		
199-1656	75	6	Negligible		
199-1658	75	1 – 5	Negligible		
199-1701	75		Often on bottom	Ignore line	Ignore line
199-1703	75	1 – 2.5	> 40 m, important	Yes	
199-1720	75	1.4 – 4	> 40 m, important	Yes	
199-1738	75	1	> 40 m, important	Yes	Yes
199-1756	75	1 – 2	> 40 m, important	Yes	Yes
199-1814	75	1.5 – 3.4	> 40 m, important	Yes	Yes
199-1831	75	0.5 – 2.2	> 40 m, important	Yes	Yes
199-1849	75	1.3 – 4	> 40 m, important	Yes	Yes
199-1853	75	5	> 40 m, important	Yes	
199-1911	75	5	> 50 m, important	Yes	
199-1919	75	5	Negligible		
199-1920	75	4 – 5.5	Negligible		
199-1938	75	4	Negligible		

Table 2. Survey lines in Topsail data set

Processing Parameters

In addition to the line by line cleaning detailed in Table 2, Table 3 outlines additional cleaning parameters used. Rectangle size was 17 pixels along track by 129 pixels across track, which generated 388017 records. This represents an approximate seafloor footprint of 4.0 metres by 4.0 metres.

Name	Value
Preserve Bottom Edits	Yes
Magnetic Variation	24^0
Angle	As specified in Table 2
Range (m)	As specified in Table 2
Surface Echo (m)	Yes, where applicable
Preserve Border Edits	Yes
Despeckle	No

Table 3: Cleaning parameters.

Additional Filtering

Additional filtering of the FFV data was done as follows:

Time

From 18:49:40 to 18:54:10, to remove the 180° turn in the southwest corner. Filtered 3082 records.
From 19:19:13 to 19:22:22, to remove the 180° turn part ways up the east edge. Filtered 686 records.

Slant range

Slant range > 50 m. Filtered 70873 records. This aids somewhat in reducing range dependence, in that it hides the longest-range rectangles.

CLASSIFICATION RESULTS

Prior to the presentation of the classification results it helps to understand the nature of the backscatter from the entire survey area. This is important when analyzing the relationship between the geology, its backscatter response and the results of the automated classification. This is accomplished by the generation of a backscatter mosaic as shown in Figure 3.

Unsupervised classification was applied on a line by line basis and 8 classes were identified. The results are presented in Figure 4 as a series of data points, where individual points are assigned a class. Additionally, the data can be interpolated to provide a gridded plot suitable for overlay on bathymetry. QTC CLAMS was used to generate such a plot (figure 5). The class colours used in Figure 5 are termed "similarity colours". Acoustically similar seabeds are displayed using similar colours. It is important to understand that the plot is a map of acoustic diversity. It is incumbent on the interpreter to assign labels such as "reef" to the classes based on an interpretation of the original backscatter data or ground truth data.

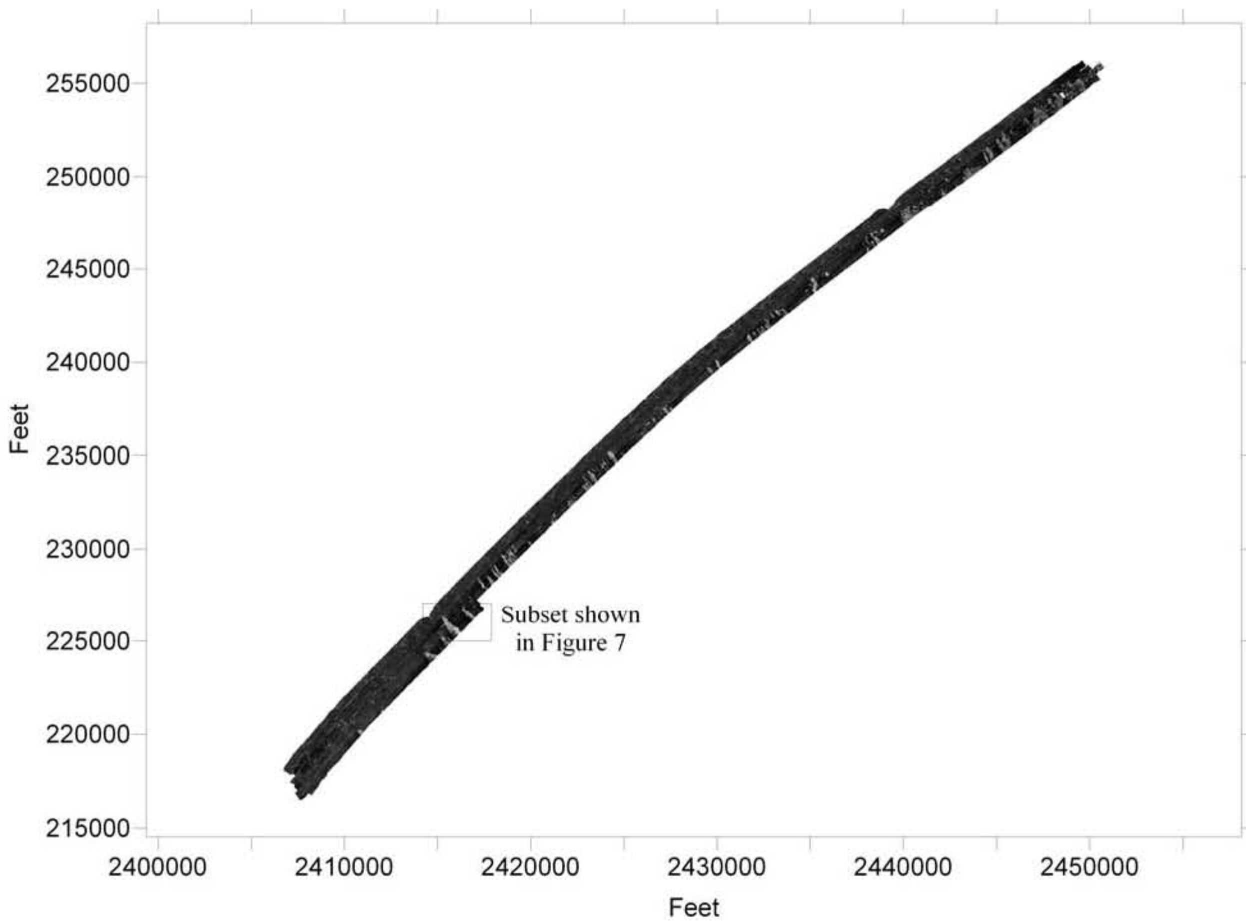

Figure 3. : Backscatter Mosaic of "Topsail" survey area. (source: Geodynamics Group)

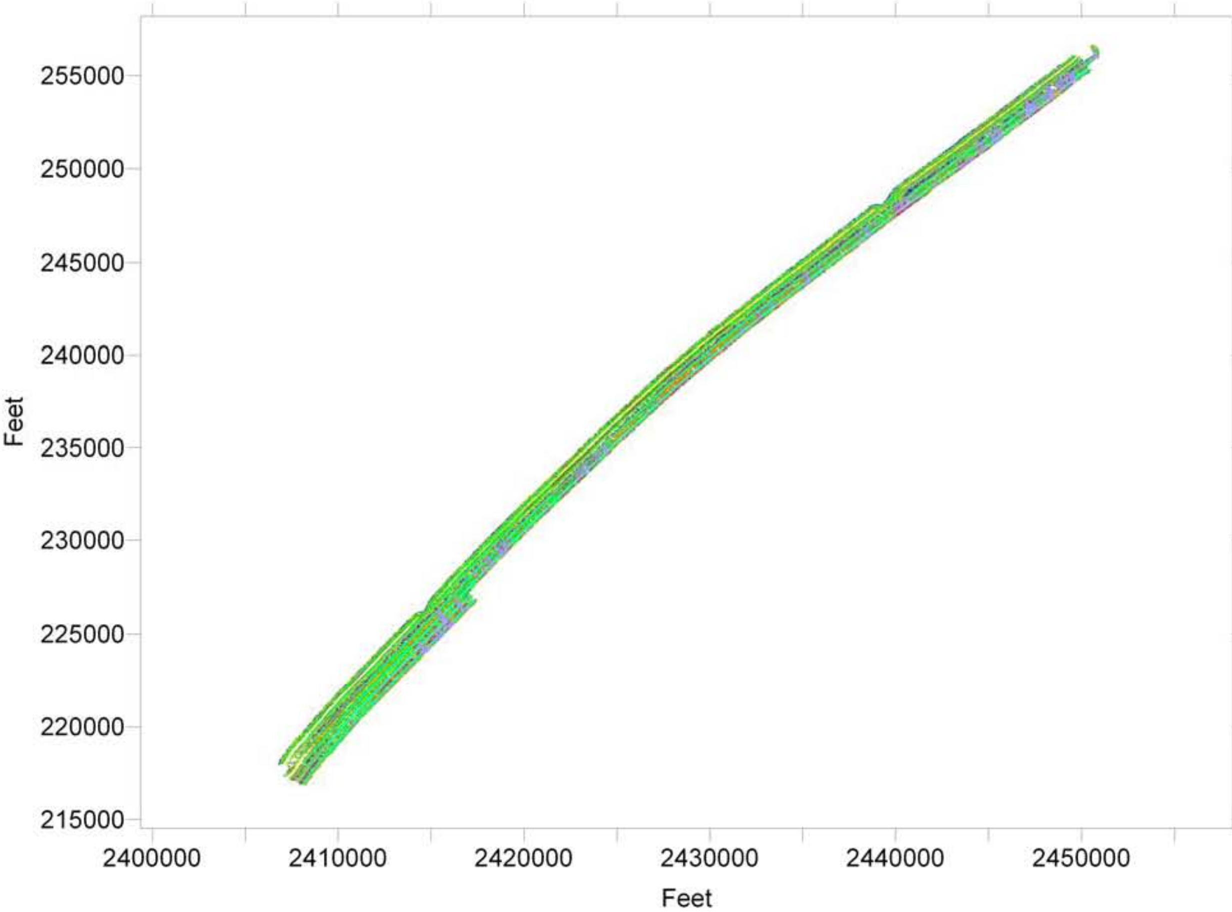

Figure 4: Acoustic Classes Overlaid on Bathymetry

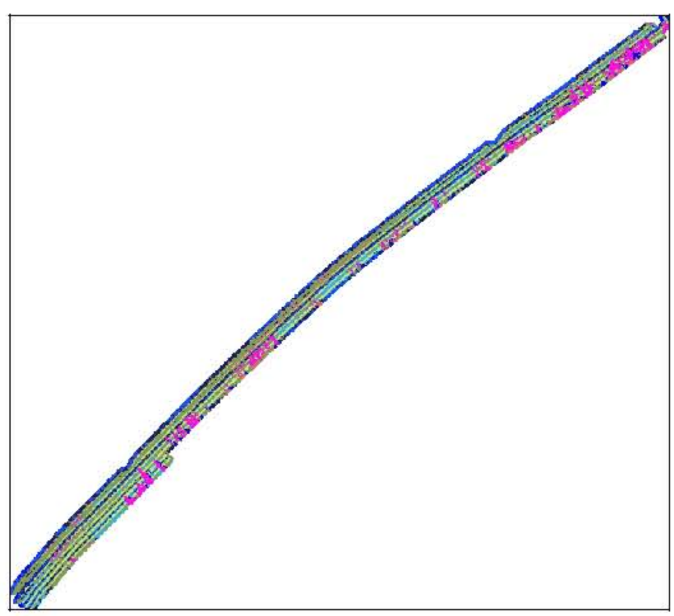

Figure 5 Interpolated classified point data set.

The results were not of the high quality normally achieved when processing data in QTC SIDEVIEW. Several examples of Klein 3000 data in XTF format have been processed previously with excellent results. The striping in the classification particularly evident on Figure 5 is a result of the original data quality. The classification has nevertheless identified the reef areas as a unique class, as shown in Figure 6.

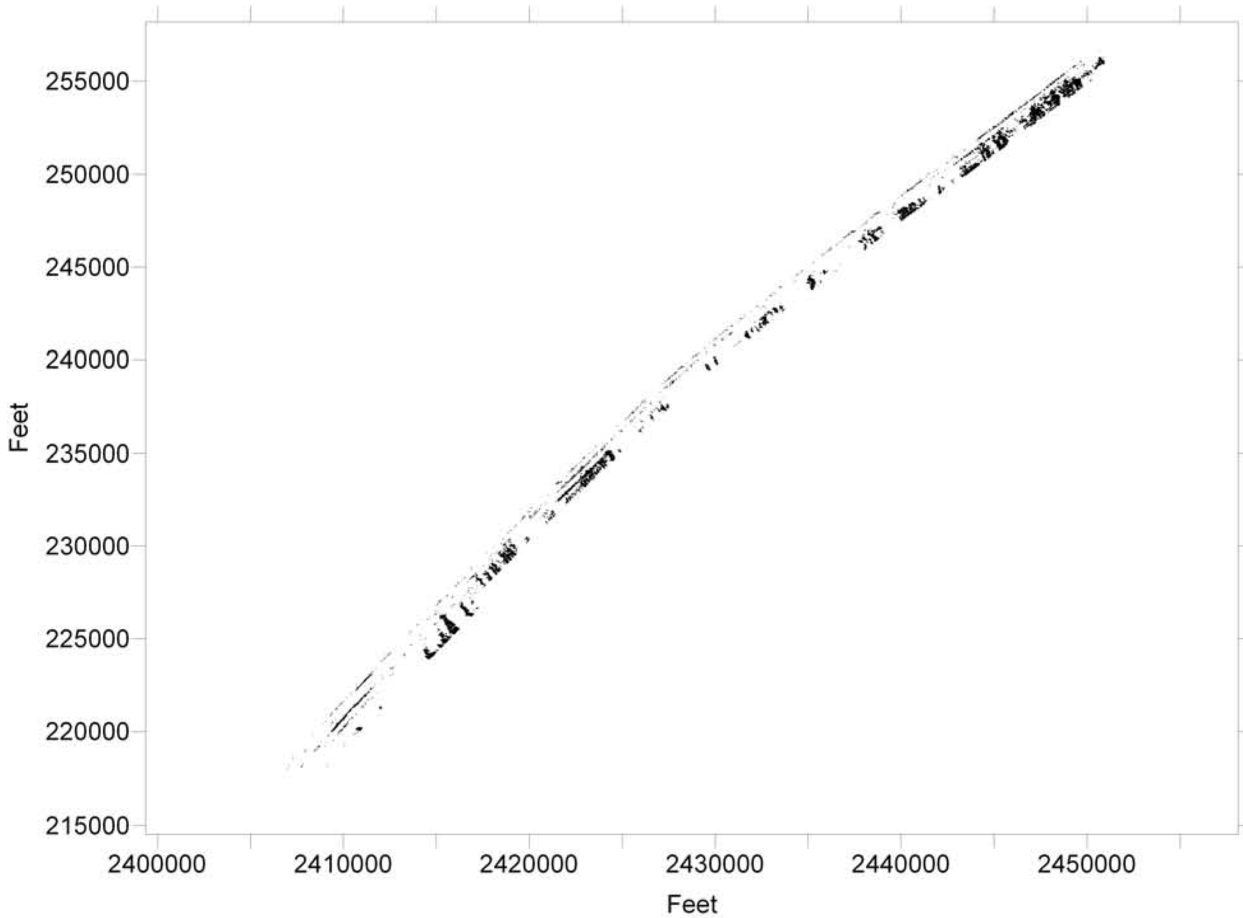

Figure 6: The results of automatic classification showing only Class 5 which is interpreted as reef.

A subset of the imagery is shown in Figure 7. The individual records associated with each original rectangular patch on the image are plotted on the backscatter mosaic. There is a clear correlation between the high intensity backscatter interpreted as reef and the purple class. The other note is the apparent offset in the heading causing the records associated with each ping to be somewhat oblique to vessel track.

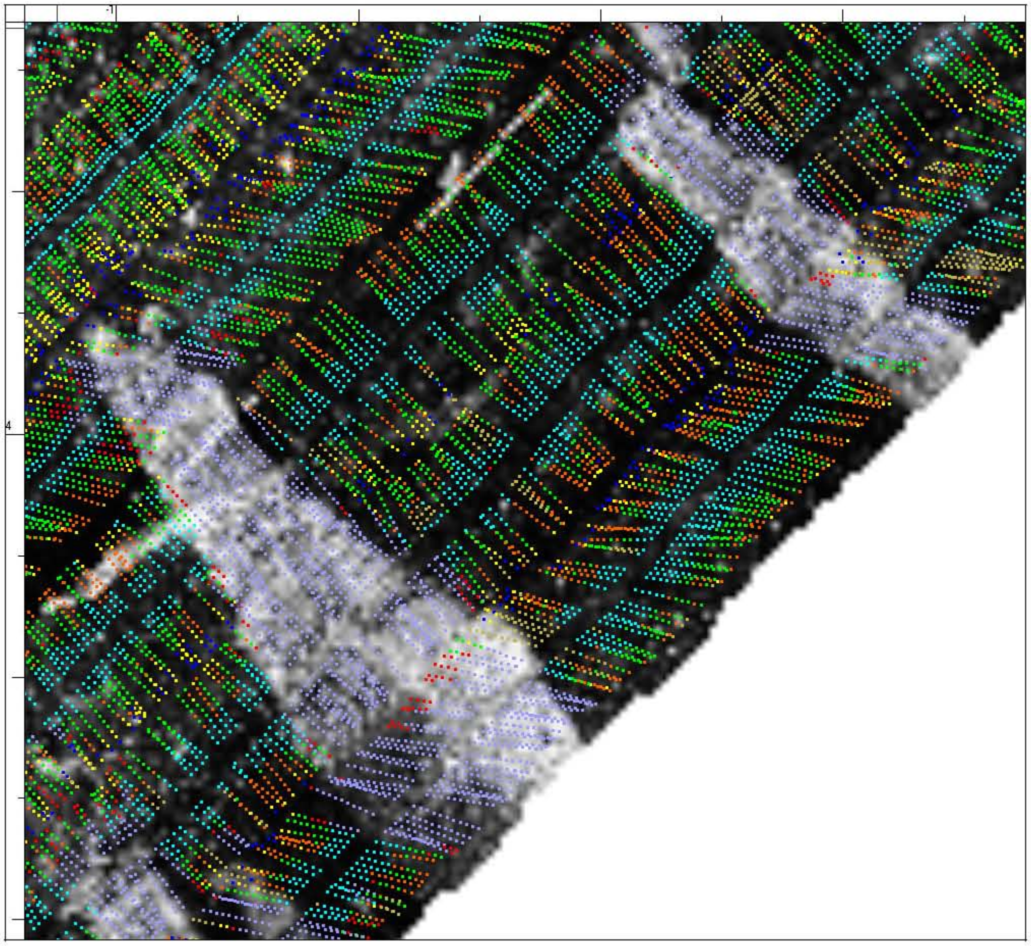

Figure 7: Class 5 interpreted as reef only. The purple class (Class 5) correlates with the reef class seen on the sidescan sonar mosaic. Please see Figure 3 for location of this area.

DISCUSSION AND RECOMMENDATIONS

While there are numerous challenges relating to the acquisition of sidescan sonar, data perhaps the two that stand out are the stability of the towfish and the towfish altitude. Given the environment in which the data were collected this is not surprising. Indeed, the results as shown in the sidescan sonar mosaic are quite acceptable for manual interpretation of the geology. The combination of these acquisition challenges however, diminish the ability automatic classification of all except for the most broad features (e.g. reefs) and perhaps even the subtleties of the geology as interpreted by a marine geologist or geophysicist.

Based in information passed on by the client there exist a veneer of sand over top of some of the reefs. This is evident from the existence of sandwaves. Typically sandwaves exhibit a regular pattern in texture that can be identified in QTC SIDEVIEW. Only the "reef class" could, for example, be submitted to the statistical analysis and clustering to identify "subclasses" of reef with a veneer of sand. Given the data quality previously mentioned this advanced processing was not considered.

Recommendations

1. Given the environment it might be advisable to experiment with a fixed hull or pole-mounted towfish to maximize altitude (rule-of-thumb is altitude 10% to 15% of max. range). This should have the added advantage of reducing fish yaw.

2. If possible, refrain from having an echosounder at similar frequency running at the same time as the sidescan sonar data are being collected.

3. Having access to good quality bottom picks would have decreased the amount of time taken for automatic classification. We recommend an analysis of the reasons for the poor quality bottom picks in the data.

SELECTED READING

J. T. Anderson, R.S. Gregory, and W.T. Collins, Acoustic classifications of marine habitats in coastal Newfoundland, *ICES J of Marine Science* vol. 59, pp. 156-167, 2002.

J.M. Preston and A.C. Christney, Compensation of sonar image data primarily for seabed classification, US Patent Application serial number 427624, 2004.

N.G. Pace and H. Gao, Swathe Seabed Classification, *IEEE J. Oc. Eng.*, 13, pp. 83-90, 1988.

J.M. Preston, A.C. Christney, L.S. Beran and W.T Collins, Statistical seabed segmentation – from images and echoes to objective clustering. In *Proc. of the 7th. European Conference on Underwater Acoustics*, 813-818, Delft, Netherlands, 2004.

J.M. Preston, A.C. Christney, L.S. Beran and W.T Collins, R.A. McConnaughey, and S.E. Syrjala, Considerations in large-scale acoustic seabed characterization for mapping seabed habitats. *ICES Annual Science Conference*, CM 2004/T:13, Vigo, Spain, 2004.

R.M. Haralick, K. Shanmugam, and I. Dinstein, Textural features for image classification, *IEEE Trans. Syst. Man Cybern.* SMC-3, pp. 610-621, 1973.

APPENDIX A FORMAT OF SEABED FILE

The default position format is geographical decimal degrees. For this survey the data were converted to survey feet.

An example of a *.seabed file is given below:

20030406,170547453,-122.85029029,48.60624788,-25.22,18.86254692,-4.39753675,-99.68022919,99,
72,01,CLASS_01,MIDDLEBANK,20030406,114_1705,9,0

The above sample classification record is interpreted as follows:

Field Index	Field Value	Representation
A	20030406	the date-stamp (yyyymmdd) for that record
B	170547453	the time stamp (hhmmssms) for that record
C	-122.85029029	the longitude in decimal degrees
D	48.60624788	the latitude in decimal degrees
E	-25.22	the depth expressed in metres, displayed as a negative value
F	18.86254692	Q-Space value Q1
G	-4.39753675	Q-Space value Q2
H	-99.68022919	Q-Space value Q3
I	99	the class confidence in percent
J	72	the class probability in percent
K	01	the class ID
L	CLASS_01	the class name
M	MIDDLEBANK	the source vessel or survey name
N	20030406	the source date-stamp
O	114_1705	the source data set name
P	9	the source FFV file ID
Q	0	the source FFV file record index

Feasibility Report
and
Final Environmental Impact Statement

on

Coastal Storm Damage Reduction

SURF CITY AND NORTH TOPSAIL BEACH
NORTH CAROLINA

Appendix R
Attachment 3

High-Resolution 3D Bathymetric Assessment of Potential Hard Bottom Habitats: Topsail Island, Surf City and North Topsail Island, NC

High-Resolution 3D Bathymetric Assessment of Potential Hard Bottom Habitats: Topsail Island, Surf City and North Topsail Island, NC January / February 2007

Survey Report

Project No. DACW54-02-D-0006, Delivery Order 0035 Modification 01 Nearshore Hardbottom Sidescan Survey for Multibeam Data Collections Topsail Island, NC
G&O Project Number 146046.T35.6481.GEO

Submitted by:

GREENHORNE & O'MARA
CONSULTING ENGINEERS

With Subconsultant:

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

TABLE OF CONTENTS

Executive Summary

Geodynamics LLC was contracted by the USACE Wilmington District through Greenhorne & O'Mara Inc. on January 16th 2007 to perform a detailed bathymetric survey (phase 2) of zones identified as potential hard bottoms from the July 2006 side-scan sonar study performed by Geodynamics in July 2006 (phase 1). The January 26 – February 6th multibeam surveys employed a Simrad EM3002 shallow water multibeam sonar system to collect spatially dense bathymetric data across 0.85 square miles of seafloor for the development of an accurate surface model as described in the official Scope of Work (Appendix A). The system runs at 300 kHz and is compensated for motion and heading with an Applanix POS MV 320 v4 inertial navigation system. Sensor offsets have been surveyed to close within 1 millimeter by the National Geodetic Survey. The EM3002 produces a swath of sonar approximately 4 times the water depth and collects approximately 400 soundings per square meter. Sound velocity was calculated in real-time at the transducer head with an Applied Microsystems miniSV and profile data was collected with an Odom Digibar Pro.

Tidal corrections and positioning information were acquired using a site calibrated Trimble 5700 Real-Time Kinematic GPS (RTK-GPS) system integrated with the POS MV 320 through a Pacific Crest PDL radio modem. The RTK-GPS system uses a land-based station coupled with a 25-watt radio and a Maxrad 5 dB high-gain antenna to broadcast the computed real-time horizontal and vertical corrections at 10 Hz to the hydro survey platform. To compute centimeter-scale position and elevation information, determine the relationship between WGS-84 and local grid coordinates, and to evaluate the local geoid-spheroid separation, we first performed a detailed network adjustment and site calibration. Information on the site calibration can be found in the corresponding section of this final report and published accuracies on each of the systems can be found in Appendix C.

Survey Preparation

Survey Area

Topsail Island is located approximately 20 miles northeast of Wilmington and separates Lee Island to the south and Onslow Beach to the north. The Topsail Island nearshore survey was comprised of 18 planned survey lines (6 line per survey area) spaced 70' to 90' apart to obtain 100% seafloor coverage (Figure 1). The total area of the survey encompassed 0.85 square miles with a total of 57 line miles.

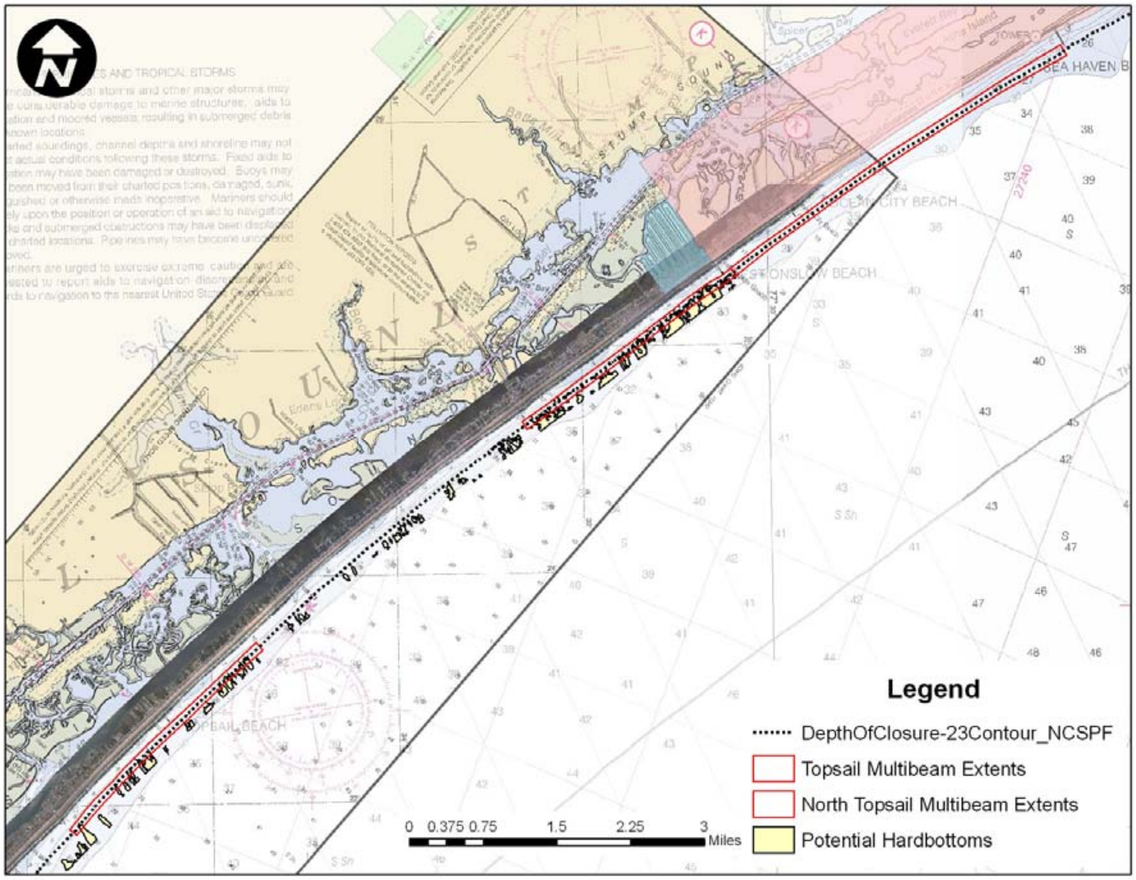

Figure 1. Map of Topsail, Surf City and North Topsail Island survey extents.

RTK-GPS Survey Control & Multibeam Calibration

Introduction & Purpose

The most common problem in accurately measuring the seafloor with any sonar-based system, especially in and around a tidal inlet, is the calculation of the tidal elevation offset. Commonly a tide staff or gauge is deployed in one location near the survey site and is used to calculate the tides for the entire survey area. However, it is widely understood that non-linear tidal phenomena, phase lags and tidal gradients can drastically influence the tidal elevation spatially across a tidal inlet and therefore the use of a single point measurement is often unreliable.

To avoid these potential tidal elevation errors which can translate into significant departures from the true bottom depth, we use geodetic Global Positioning Systems (GPS) with real-time kinematic (RTK) baseline processing that is integrated with the multibeam and inertial navigation instruments. The motion and Geoid 03 compensated positions and orthometric elevations of the RTK-GPS data stream are tagged with each sonar ping. In effect, the RTK-GPS mounted on the hydrographic survey vessel acts as a roving tide gauge collecting the most accurate tidal measurements throughout the survey area.

Multibeam swath sonar systems combine a complex array of instruments, consisting of the transducer, motion sensor, inertial navigation, and geodetic GPS systems. Standards developed by the International Hydrographic Organization (IHO), USACE Standards for Hydrographic Surveys, and the NOS Hydrographic Surveys Specifications and Deliverables for shallow water (<30 m) hydrography (IHO 1987; USACE 2003; NOS 2006) are used as the protocol for calibration. Proper alignment of these instruments with one another and with the vessel's reference frame is critical to achieve the high-accuracy required in the SOW. Calculation of the horizontal and vertical offsets between each of the instruments completed by the National Geodetic Survey is followed by a series of sea-based measurements known as the patch test.

The patch test is performed to calculate several residual biases influenced by the dynamics of the survey vessel and the alignment of the instruments. Results of the patch test, documented in the following sections, are used to calculate a pitch, roll and heading offset and positioning time delay or navigation latency. Additional calibration measures are performed in the field including comparison of nadir depths with a lead line and frequent sound velocity profiles. The results of these daily field checks can be found in the html metadata file accompanying the final soundings.

RTK-GPS Network Adjustment & Site Calibration

There are many environmental and operator-based influences that can affect the accuracy of RTK-GPS and the resultant baseline solutions (Bilker 2001; Trimble

Navigation Limited 1998; Magellan Corporation 2001). Although RTK-GPS is an emerging tool among hydrographers, little attention has been given to an accuracy standard for this methodology—especially in the field of coastal mapping and monitoring (Morton et al., 1993). In an effort to limit operator error and to quantify daily environmental error, we have developed an internal standards protocol for RTK error estimation based on thresholds developed by the California Department of Transportation and the US Army Corps of Engineers (USACE) Topographic Accuracy Standards (CALTRANS 2002; USACE 1994).

The first step in our protocol is to determine an appropriate land-based GPS station that will provide the most accurate corrections and range to the outer limits of the survey area. Phase one of the project we used a benchmark atop a circa 1940's rocket observation platform called "Tower 3". Our initial plan was to use this mark for phase 2 of the project; however, after approximately 3 weeks of trying to contact the owner for access to the site we were unable to reach the current owners of the property. We then chose to use "A230", which is approximately 0.5 miles south of "Tower 3".

The second step in our RTK-GPS protocol was to perform a detailed GPS site calibration on the new basestation prior to the collection of any hydrographic survey data. The site calibration is used to determine the basestation quality relative to the local network of NGS and NOS survey control and to analyze any potential spatial separations between the local geoid heights (GEOID 03) and ellipsoidal values (WGS-84) that may influence the resulting orthometric elevations. The calibration entails selecting the control to be used for the RTK-GPS basestation receiver and radio broadcast system and then checking at least three known geodetic benchmarks of exceptional horizontal and vertical quality within and even outside the survey boundaries. The benchmarks are occupied in "site calibration mode" over 300 epochs or approximately 3 to 5 minutes.

A detailed RTK-GPS site calibration for phase 2 of this project was performed on January 26, 2007 prior to the start of the multibeam data acquisition phase. Three benchmarks from various government and state agencies were used in the calibration and results can be found in Table 1. Results showed an average deviation of 4.8cm (0.157') in the Northing, 1.5cm (0.049') in the Easting and 3.0cm (0.098') in the Elevation.

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RTK-GPS Pre-Survey Site Calibration

General

Date	1/26/2007
Project	USACE Topsail Island Multibeam - phase 2
Surveyor(s)	Freeman / Bernstein
Equipment	Trimble 5700 Basestation, Trimmark III 25 watt RTK Radio, Maxrad 5dB gain Antenna, Zepher Geodetic base antenna, Trimble 5700 RTK rover, Zepher antenna
Weather	Sunny, Few Clouds, 45 F, NW Wind 15-25 kts, gust to 30 kts
Units	Meters
Notes	Access to Tower 3 basestaion used in phase 1 could not be obtained. A230 was then selected as the best possible RTK-GPS basestaion. Base was set on A230 and marks were checked to verify RTK quality throughout the survey extent.
Coordinate System	NC State Plane, NAD83 (horiz), NAVD88 (vert)

Basestation Information

Designation	A230
PID	EA0696
Agency	CGS
Horiz Order	1
Vert Order	2
N	71298.606
E	737877.413
Z	3.480

A230

A230 Benchmark

Benchmark Checks

Designation	CROCKER
PID	AI0831
Agency	NCGS
Horiz Order	1
Vert Order	3

	Recorded	Published	Difference
N	68542.047	68542.046	-0.001
E	735010.569	735010.571	0.002
Z	1.323	1.33	0.007

Notes: Benchmark is at intersection of Crocker and S. Anderson

Crocker Benchmark

Crocker BM Check

Benchmark Checks (cont.)

Designation	FIRTH		
PID	AI0904		
Agency	NGS		
Horiz Order	1		
Vert Order	3		
	Recorded	Published	Difference
N	78267.399	78267.452	0.053
E	746327.217	746327.233	0.016
Z	1.246	1.20	-0.05
Notes	Benchmark is on NW side of W 9th St. North of Surf City.		

Firth Benchmark

Firth BM Check

Benchmark Checks (cont.)

Designation	DUNE AZ MK		
PID	AI0855		
Agency	NCGS		
Horiz Order	1		
Vert Order	3		
	Recorded	Published	Difference
N	82569.585	82569.674	0.089
E	752975.095	752975.121	0.026
Z	1.698	1.66	-0.038
Notes	see NGS datasheet for location description		

Dune AZ MK Benchmark

Dune AZ MK Benchmark Check

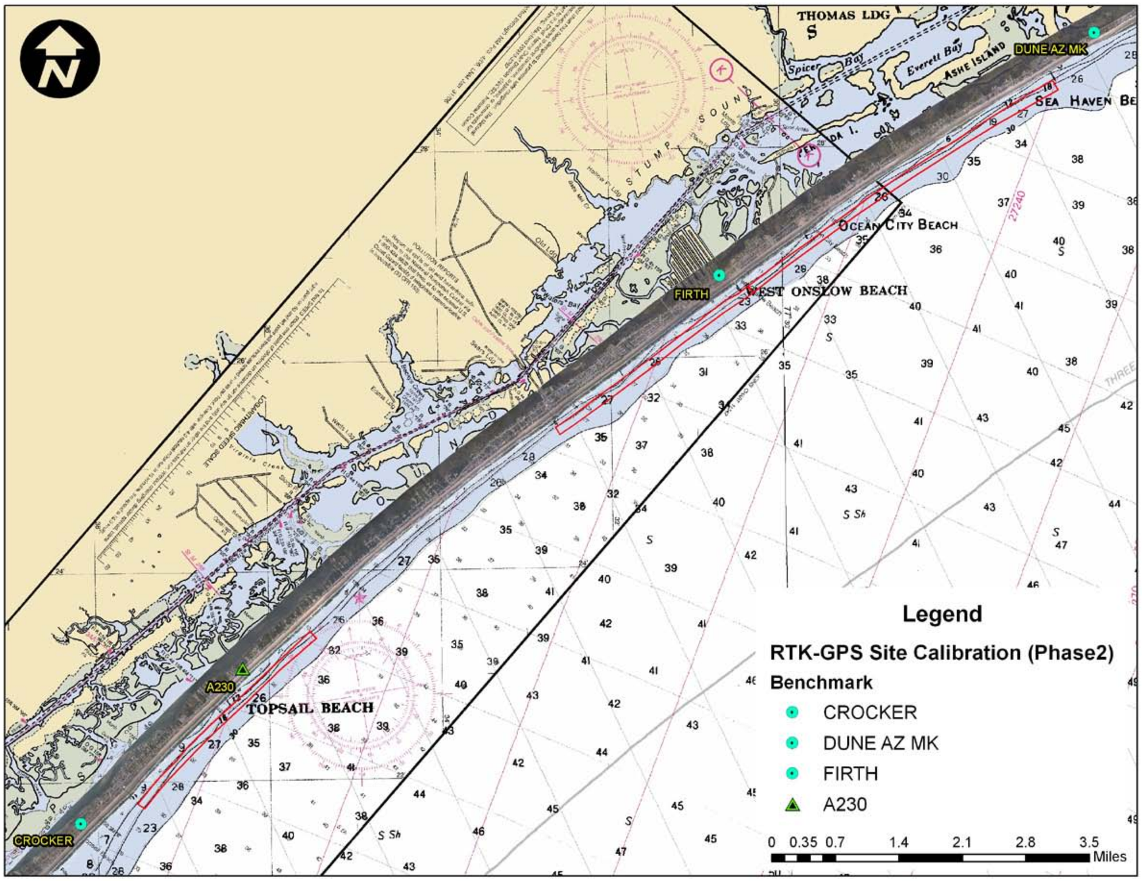


Figure 2. Map of new site calibration on A230 and the BM's checked.

Multibeam Echosounder Calibration Report

Calibration Date:	April 19, 2006
Ship	
Vessel	RV 4-Points
Echosounder System	EM3002
Positioning System	POS MV (tightly coupled)-RTK GPS
Attitude System	POS MV
Sound Velocity Probe	Odem Digibar Pro (profiler) / Valeport Mini SVS (at head)

Annual		
Installation	x	
System change	x	
Periodic/QC		
Other		

Calibration type: Multibeam Sonar

The following calibration report documents procedures used to measure and adjust sensor biases and offsets for multibeam echosounder systems. This report has been adopted and modified from NOAA. Calibration must be conducted A) prior to CY survey data acquisition B) after installation of echosounder, position and vessel attitude equipment C) after changes to equipment installation or acquisition systems D) whenever the Hydrographer suspects incorrect calibration results. The Hydrographer shall periodically demonstrate that calibration correctors are valid for appropriate vessels and that data quality meets survey requirements. In the event the Hydrographer determines these correctors are no longer valid, or any part of the echosounder system configuration is changed or damaged, the Hydrographer must conduct new system calibrations.

Multibeam echosounder calibrations must be designed carefully and individually in consideration of systems, vessel, location, environmental conditions and survey requirements. The calibration procedure should determine or verify system offsets and calibration correctors (residual system biases) for draft (static and dynamic), horizontal position control (DGPS), navigation timing error, heading, roll, and pitch. Standard calibration patch test procedures are described in *Field Procedures for the Calibration of Multibeam Echo-sounding Systems*, by André Godin (Documented in Chapter 17 of the Caris HIPS/SIPS 6.0 User Manual, 2006). Additional information is provided in *POS/MV Model 320 Ver 4 System Manual* (10/2003), Appendix F, Patch Test, and the NOAA Field Procedures Manual (FPM, 2003). The patch test method only corrects very basic alignment biases. These procedures are used to measure static navigation timing error, transducer pitch offset, transducer roll offset, and transducer azimuth offset (yaw). Dynamic and reference frame biases can be investigated using a reference surface.

Pre-calibration Survey Information

Reference Frame Survey

RV 4-Points was surveyed by the National Geodetic Survey on February 15, 2006 for precise centerline and instrument locations. Steve Breidenbach performed the survey with a Trimble 5603 total Station.

(IMU, Ref Pt., and XY of CG are all co-aligned and attitude and position is valid at the sensor. The values below are entered in POSview software.)

Reference to IMU Lever Arm

X(m)	Y (m)	Z (m)
0	0	0

Reference to Pri. GPS

X(m)	Y (m)	Z (m)
1.849	-1.061	-1.724

IMU frame w.r.t. Reference frame

X(deg)	Y (deg)	Z (deg)
0	0	0

Reference to Sensor Lever Arm

X(m)	Y (m)	Z (m)
-0.097	-2.130	0.849

Reference to CG

X(m)	Y (m)	Z (m)
0	0	0.313

Figure 3. Photo of the centerline and instrument survey by NGS.

Reference to Vessel (Pt of validation for attitude and nav)

X(m)	Y (m)	Z (m)
-0.097	-2.130	0.849

__X__Measurements verified for this calibration.
___ __Drawing and table attached.
_____Drawing and table included with project report

POS MV Configuration File: 4_points_022806._*________________

Notes: _NGS vessel survey results were put in POSview and GAMS calibration was done on February 28, 2006___.

Calibration Area

Site Description

This patch survey was conducted in the Port of Morehead City's turning basin near Beaufort Inlet, North Carolina (N34 41 39.16 W076 40 07.53). This site was selected for its particular bottom features, such small scale ripple fields, sand waves (wavelength: ±5m, amplitude: ±0.15m), deep flat areas, and high slopes.

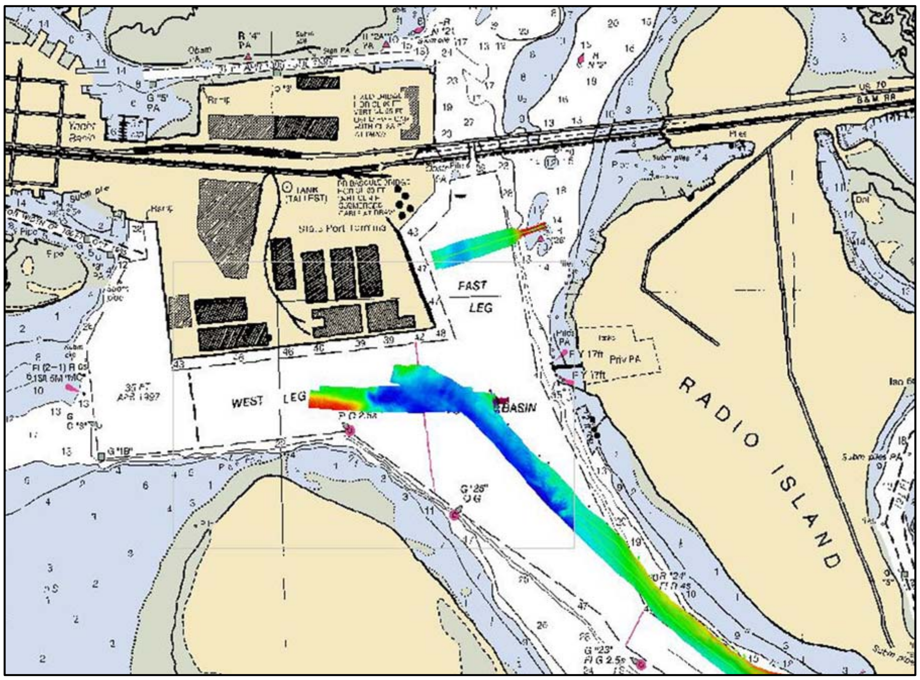


Figure 4. Map of the patch survey area within the Morehead City Turning Basin.

Survey Procedure

Vessel biases were determined through a patch test survey procedure. Data was acquired and analyzed in Kongsberg SIS package. The latency test was performed first by surveying the same survey line in the same direction at 2 different vessel speeds. The latency test was done twice to verify initial results. The pitch test was done second by surveying the same survey line in opposite directions at the same speed and evaluating the sloped portion of the survey line. The roll test was performed next by surveying the same survey line in opposite directions at the same speed and evaluating the deep flat portion of the survey line. The roll test was done twice to verify initial results. The yaw test was performed next by surveying 2 adjacent survey lines in the same direction, with similar speeds, with enough overlapping coverage such that the outer beams from each swath overlap (±40%).

Calibration Lines

Hypack Line	Line File	Az.	Spd	Correction			
				Pitch	Roll	Yaw	Latency
1	0000_20060301_163731_4points.all	57°	3.3kts				X
1	0001_20060301_164249_4points.all	57°	7.1kts				X
1	0002_20060301_165502_4points.all	237°	3.2kts				X
1	0003_20060301_165938_4points.all	237°	7.0kts				X
1	0002_20060301_155849_4points.all	237°	7.0kts	X			
1	0003_20060301_160222_4points.all	57°	7.0kts	X			
1	0000_20060301_172142_4points.all	57°	7.0kts		X		
1	0001_20060301_172427_4points.all	237°	7.0kts		X		
1	0000_20060301_183521_4points.all	237°	7.0kts		X		
1	0001_20060301_183741_4points.all	57°	7.0kts		X		
8	0001_20060301_191059_4points.all	280°	7.0kts			X	
7	0002_20060301_191957_4points.all	100°	7.0kts			X	

Sound Velocity Correction

Measure water sound velocity (SV) prior to survey operations in the immediate vicinity of the calibration site. Conduct SV observations as often as necessary to monitor changing conditions and acquire a SV observation at the conclusion of calibration proceedings. If SV measurements are measured at the transducer face, monitor surface SV for changes and record surface SV with profile measurements.

Sound Velocity Measurements

Time	Max Depth	Surface SV	Change Observed	Position	
				Latitude	Longitude
14:52:00	15.5m	1490.2		34 42.9705	76 41.6239
Continuous SV at head			<4 m/s throughout entire calibration		

Data Acquisition and Processing Guidelines

Initially, calibration measurement offsets should be set to zero in vessel configuration files. Static and dynamic draft offsets, inertial measurement unit (IMU) lever arm offsets, and vessel reference frame offsets must be entered in appropriate software applications prior to bias analysis. Perform minimal cleaning to eliminate gross flyers from sounding data.

Navigation Timing Error (NTE)
Measure NTE correction through examination of a profile of the center beams from lines run in the same direction at maximum and minimum vessel speeds. NTE is best observed in shallow water.

Transducer Pitch Offset (TPO)
Apply NTE correction. Measure TPO correction through examination of a profile of the center beams from lines run up and down a bounded slope or across a conspicuous feature. Acquire data on lines oriented in opposite directions, at the same vessel speed. TPO is best observed in deep water.

Transducer Roll Offset (TRO)
Apply NTE and TPO corrections. Measure the TRO correction through examination of roll on the outer beams across parallel overlapping lines. TRO is best observed over flat terrain in deep water. An additional check for TRO adjustment can be performed by running two lines parallel to a sloped surface.

Transducer Azimuth Offset (TAO or yaw)
Apply NTE, TPO and TRO corrections. Measure TAO correction through examination of a conspicuous topographic feature observed on the outer beams of lines run in opposite directions.

Patch Test Results and Correctors

Evaluator	NTE (sec)	TPO (deg)	TAO (deg)	TRO (deg)
Bernstein/Hohing	0.00	0.00	0.00	-0.65
Final Values	0.00	0.00	0.00	-0.65

Corrections Calculated in:	
Caris	
ISIS (BathyPro)	
Other	SIS

NOTE: TRO bias of -0.65 was put in SIS software.

Evaluator: _____Dave Bernstein_____
Reviewed by: __Chris Freeman _____
Accepted by: ___Dave Bernstein ____
Date accepted: _April 21, 2006______

Graphical Examples of Calibration Acceptance

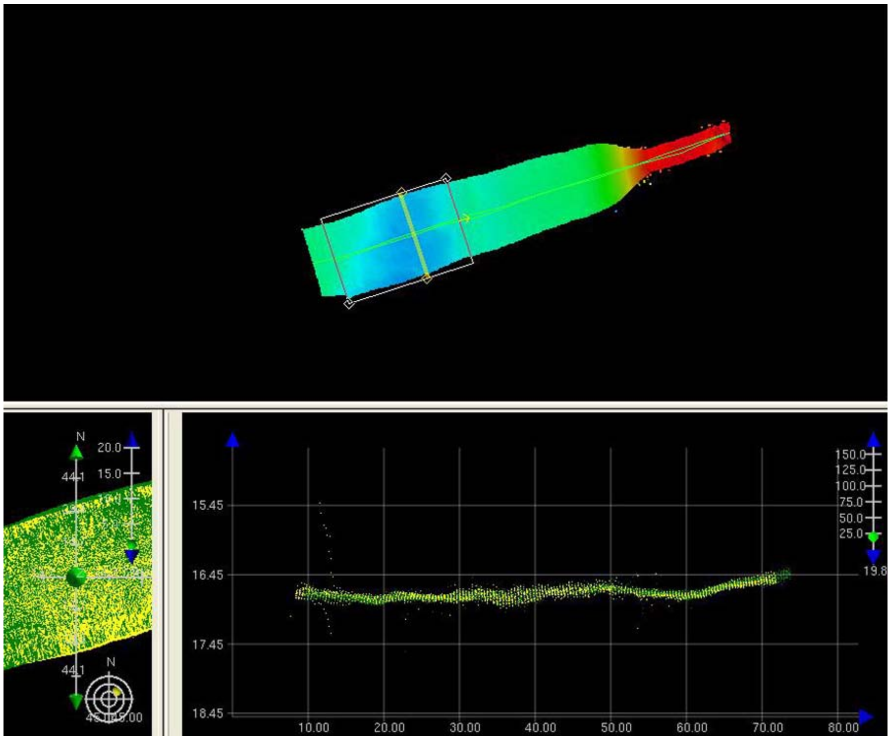


Figure 5. Caris screen grab illustrating acceptance of roll calibration.

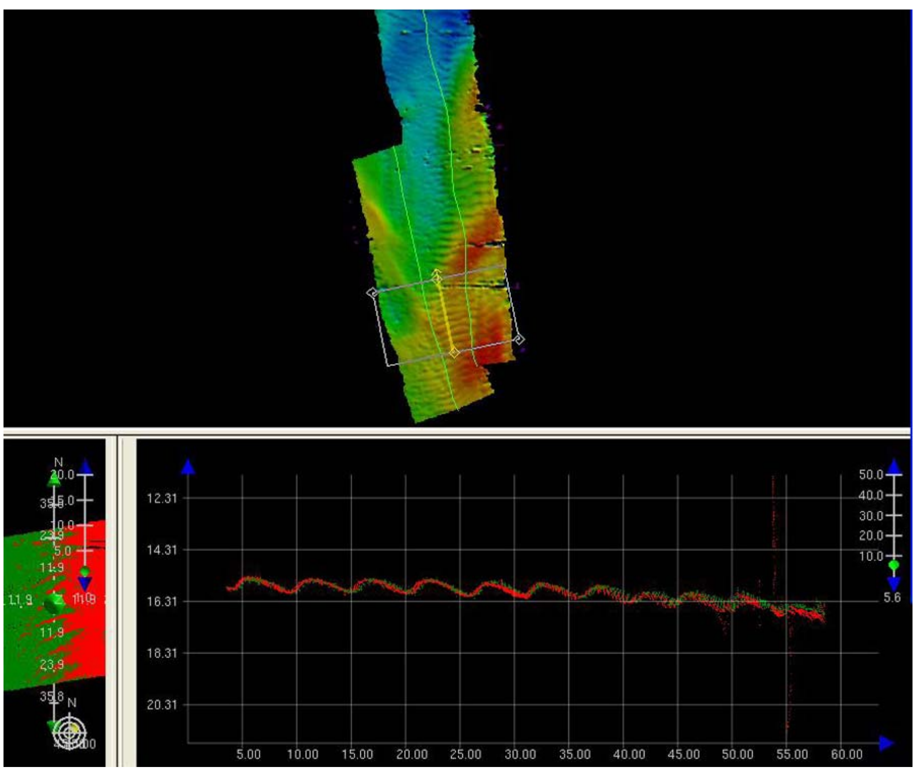


Figure 6. Caris screen grab illustrating acceptance of yaw calibration.

Data Processing Routines & QA/QC Information

Introduction

Processing high-density multibeam bathymetry and backscatter data requires a multitude of processing routines and data quality analyses. The following section will detail all aspects of data post-processing for the Topsail Island multibeam surveys. Also presented in this section is detailed QA/QC information and analysis generated throughout the various processing procedures.

Bathymetry Processing

The multibeam collects swath widths approximately 4 times the water depth. The portions of swath, mainly in the outer beams, that exhibit areas of inconsistent data are clipped and not included in the final digital file. Sounding track lines are generally parallel to each other and parallel to the seafloor contour. Sinuous lines and data acquired during turns are not included in the final processed data. To meet the accuracy and resolution standards for measured depths specified in the USACE Hydrographic Surveying Manual and the NOS Hydrographic Surveys, Specifications and Deliverables Manual, measured echosounder depths were corrected for all departures from true depths attributable to the method of sounding or to faults in the measuring apparatus. These corrections are subdivided into four categories, and are listed below in the sequence in which they were applied to the data.

1. Instrument error corrections: included to account for the sources of error related to the sounding equipment itself.

2. Vessel offsets: added to the observed soundings to account for the depth of the echosounder below the water surface, positioning of the motion reference unit, and GPS antenna.

3. Velocity of sound correctors: applied to the soundings to compensate for the fact that echosounders may only display depths based on an assumed sound velocity profile while the true velocity may vary in time and space.

4. Heave, pitch, roll, heading and navigation latency corrections: applied to the multibeam soundings to correct for the effect of vessel motion caused by waves and swells, the error in the vessel's heading, and the time delay from the moment the position is measured until the data is received by the GPS receiver.

Multibeam Data Processing Steps in CARIS HIPS software:

The EM3002 sonar system has a unique arrangement of data flow. Most settings that influence the data are put in before and during a survey and therefore are not a factor in data processing (these include vessel offsets, lever arms, vessel biases, timing biases, and survey sound velocity). Vessel attitude is also processed real-time during a survey.

Post-processing of multibeam data consist of attitude and navigation editing, merging, swath editing, area-based editing, and exporting of final data.

1. Attitude & Navigation Editing: Errors or gaps in attitude and navigation information causing errors in soundings are edited.

2. Merging: Computing and integrating the GPS tide in the sounding data. Additional sound velocity corrections are made if needed in this phase.

3. Total Propagated Error (TPE) is calculated

4. Swath- and beam-based filters and TPE (IHO standards) filters are applied.

5. Swath Editing: Swaths are edited for erroneous data if needed

6. Base or CUBE Surface is created for area- and CUBE-based editing.

7. Area-based editing using the subset editor to edit/check erroneous data only within the desired subset.

8. CUBE filtering and editing

9. Recompute TPE

10. Recompute CUBE and/or base surfaces

11. Final export of base surface to XYZ decimated soundings.

TPE (Total Propagated Error)

Although tidal corrections are perhaps the largest source of error, the combination of multiple sensors, vessel geometry and sound velocity variations also contribute to uncertainty in shallow water hydrographic surveying (Allen, 2005). Precise calculations of these uncertainty values are fundamental to the field of hydrographic surveying. To accurately estimate uncertainty we analyze each individual error source and calculate a total propagated error (TPE) for the Topsail Island survey using CARIS HIPS Pro v 6.1. The TPE function with the Combined Uncertainty and Bathymetry Estimator (CUBE) filters data for soundings with uncertainty values that fall outside the limits set by the International Hydrographic Organization (IHO, 1998) and USACE standards (USACE, 2003). The average vertical TPE value for the Topsail Island survey is 0.43 ft (13 cm) and the average horizontal TPE value is 0.39 ft (12cm), allowing us to achieve a vertical and horizontal accuracy that exceeds IHO special order and the highest USACE for Navigation and Dredging Support Surveys for individual soundings (not swath coverage).

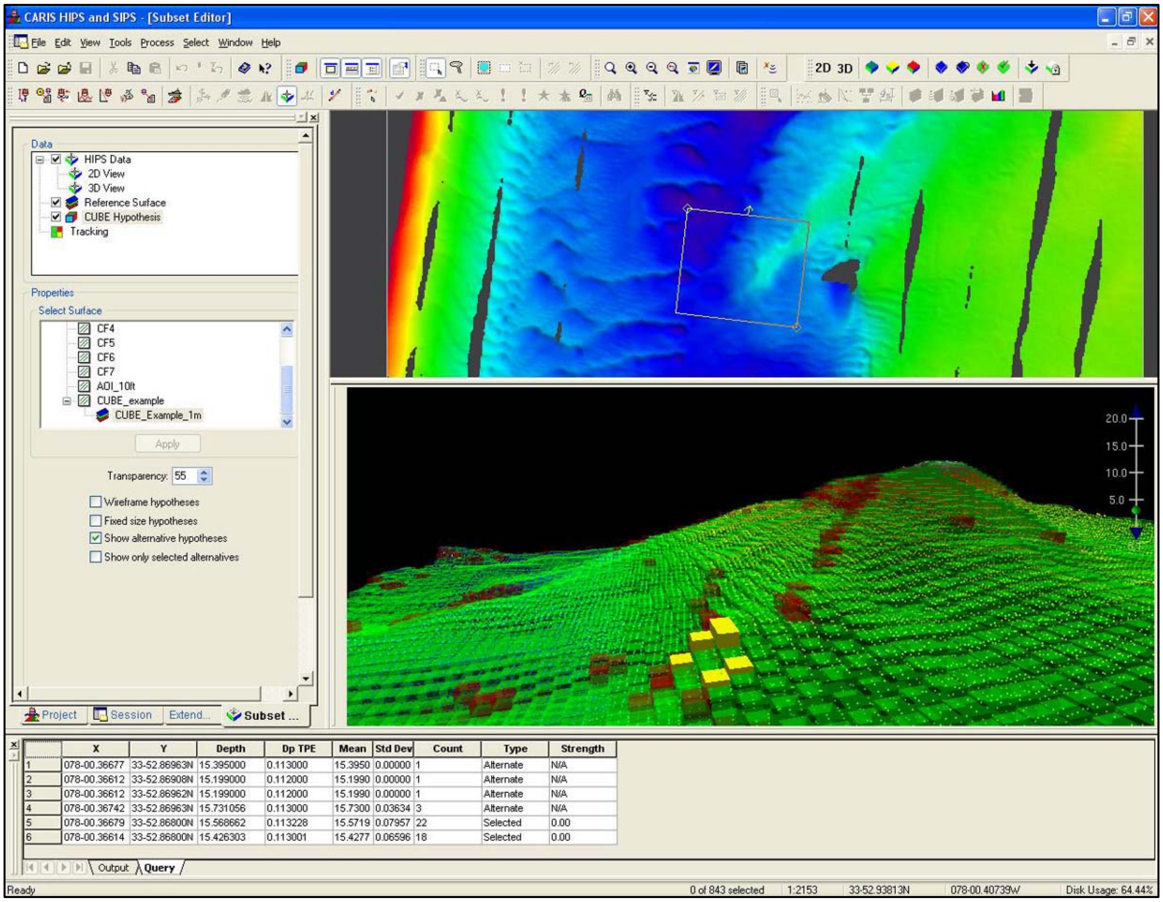
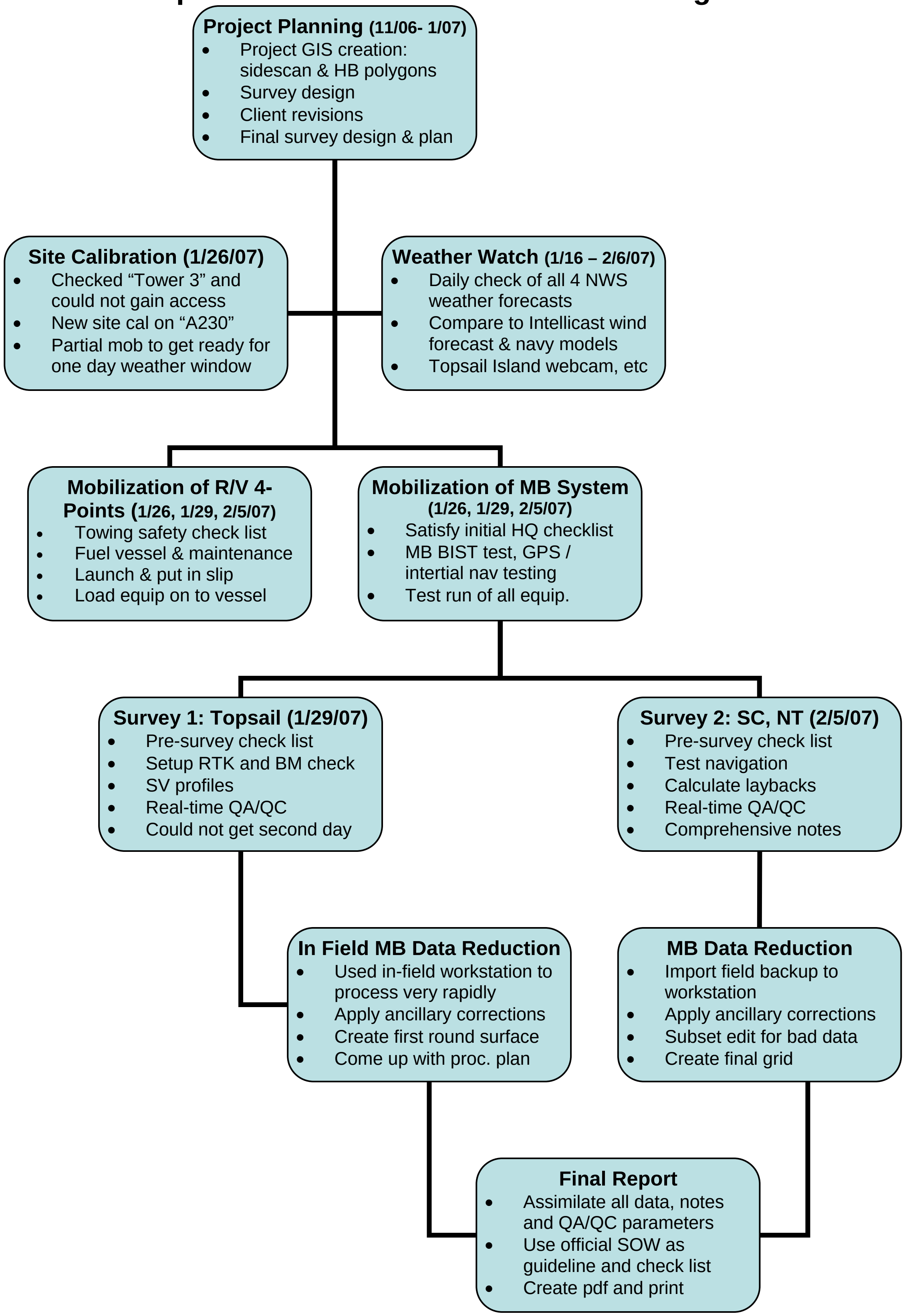
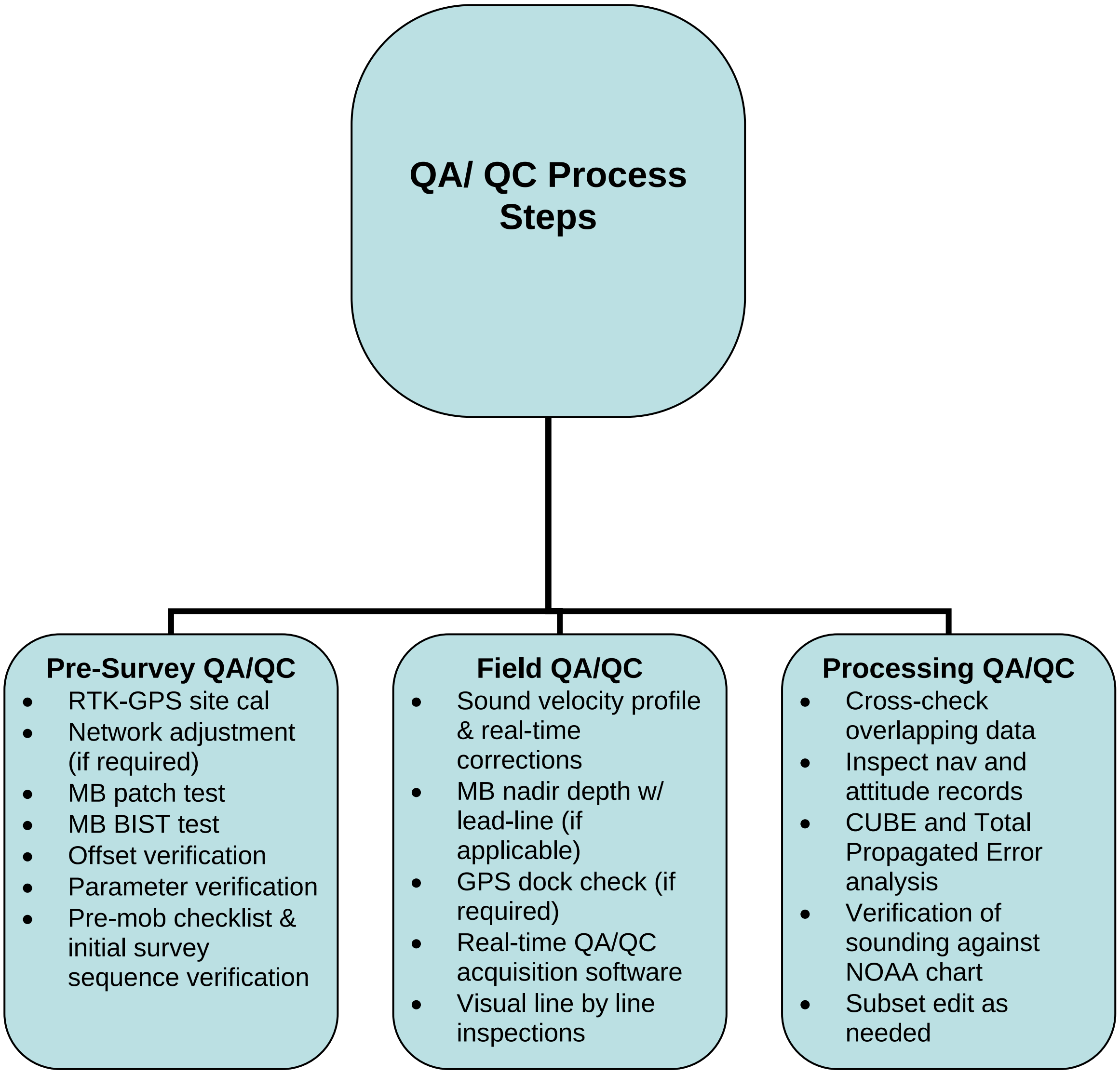


Figure 7. Screen capture showing an example of the CUBE editing process.

Topsail Island Multibeam Workflow Diagram



Topsail Island Multibeam QA/QC Workflow Diagram



Graphical Summary of Deliverables

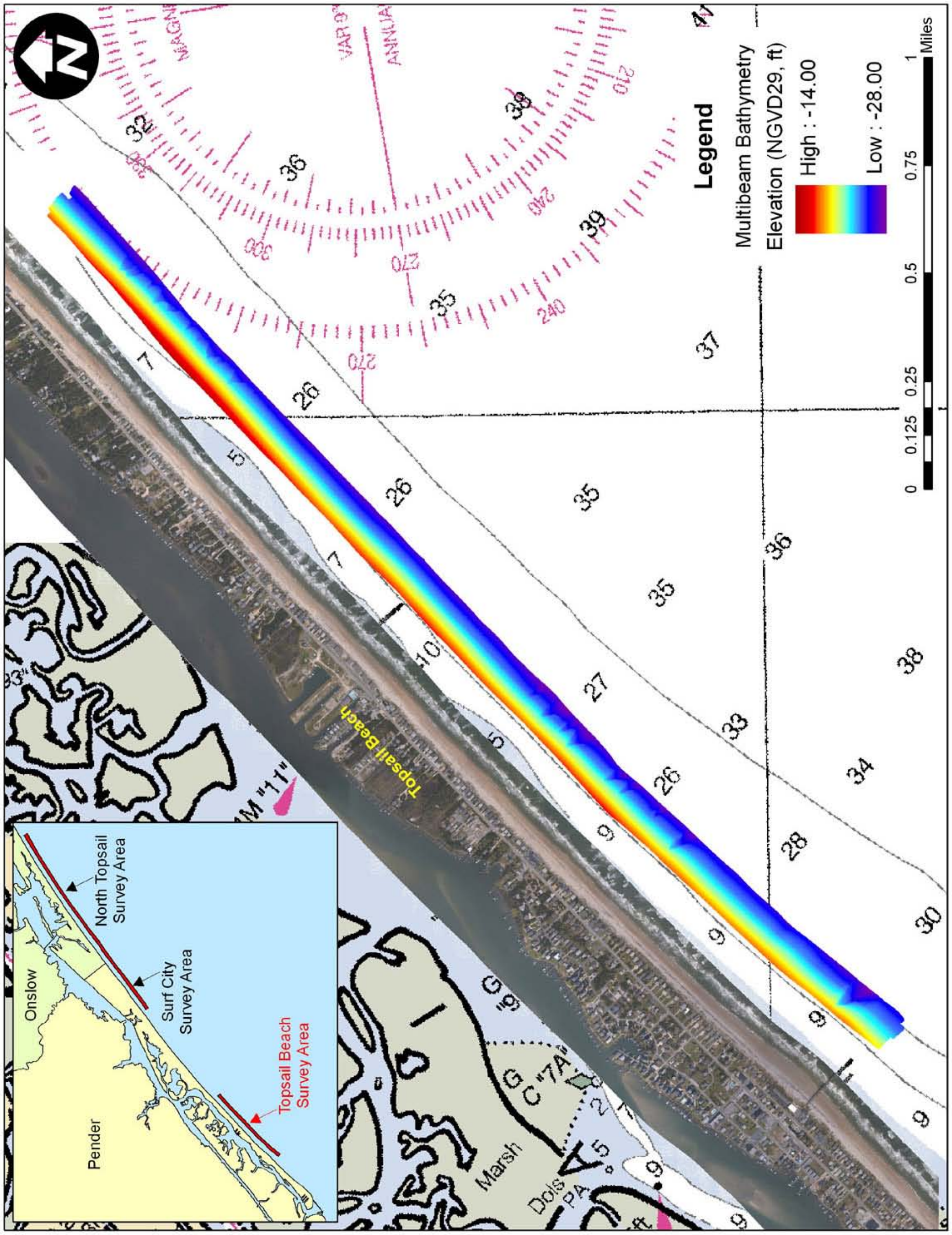


Figure 8. Plan view bathymetric map showing the “southern” survey reach.

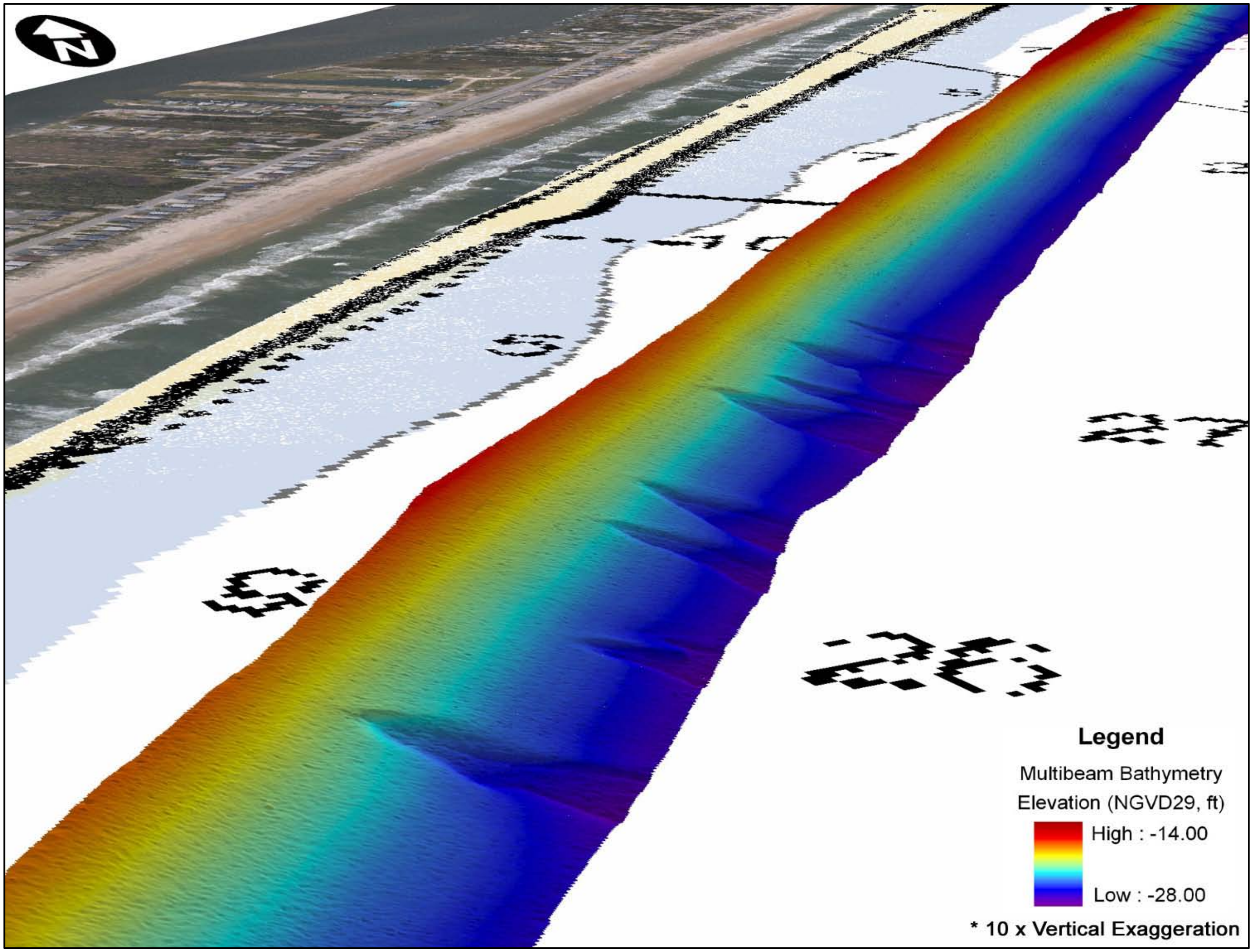


Figure 9. 3D perspective view of Topsail Island inner shoreface. Inshore signature or scour depressions that likely extend offshore.

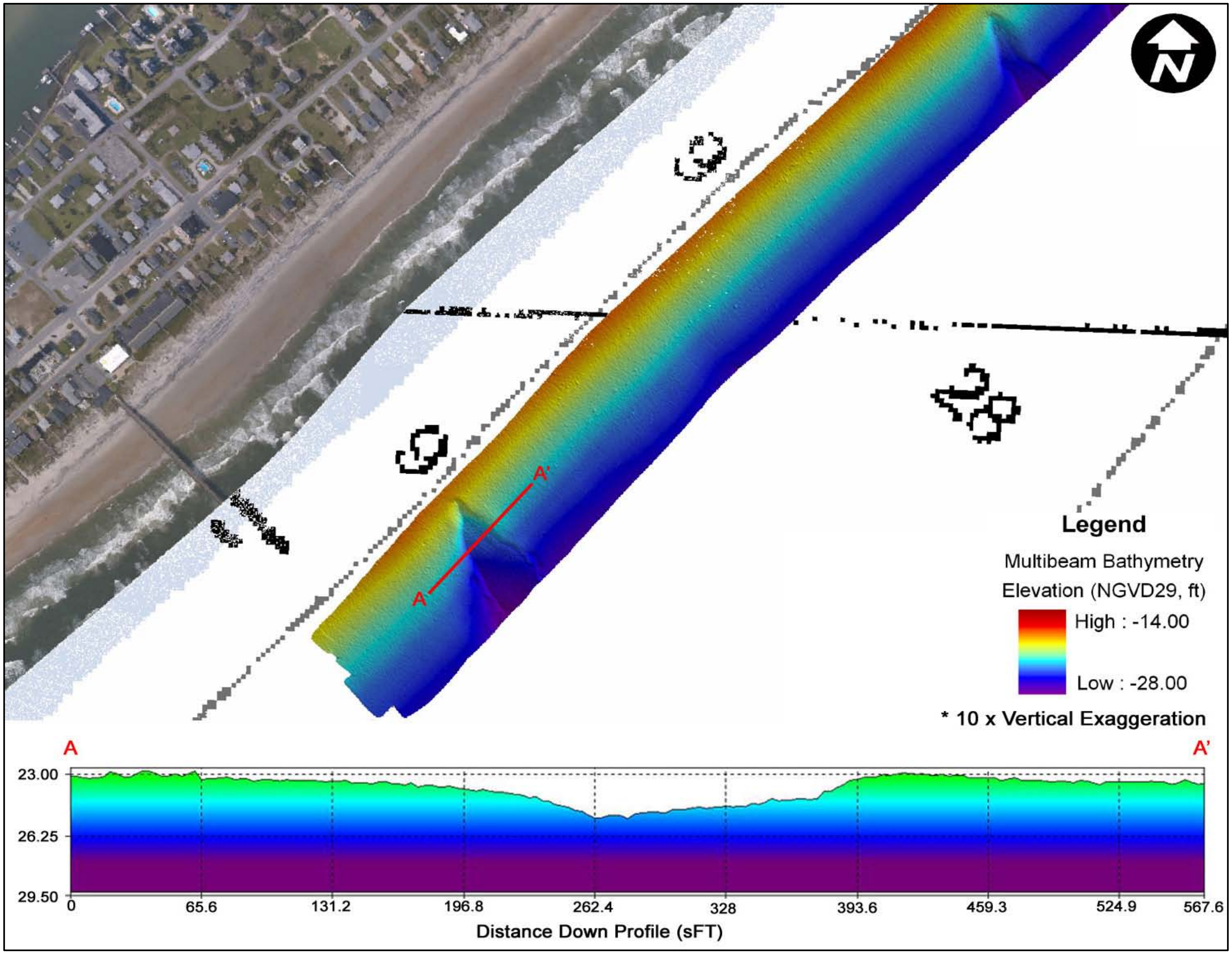


Figure 10. Zoom in on scour depression area for Topsail Island with profile cross section.

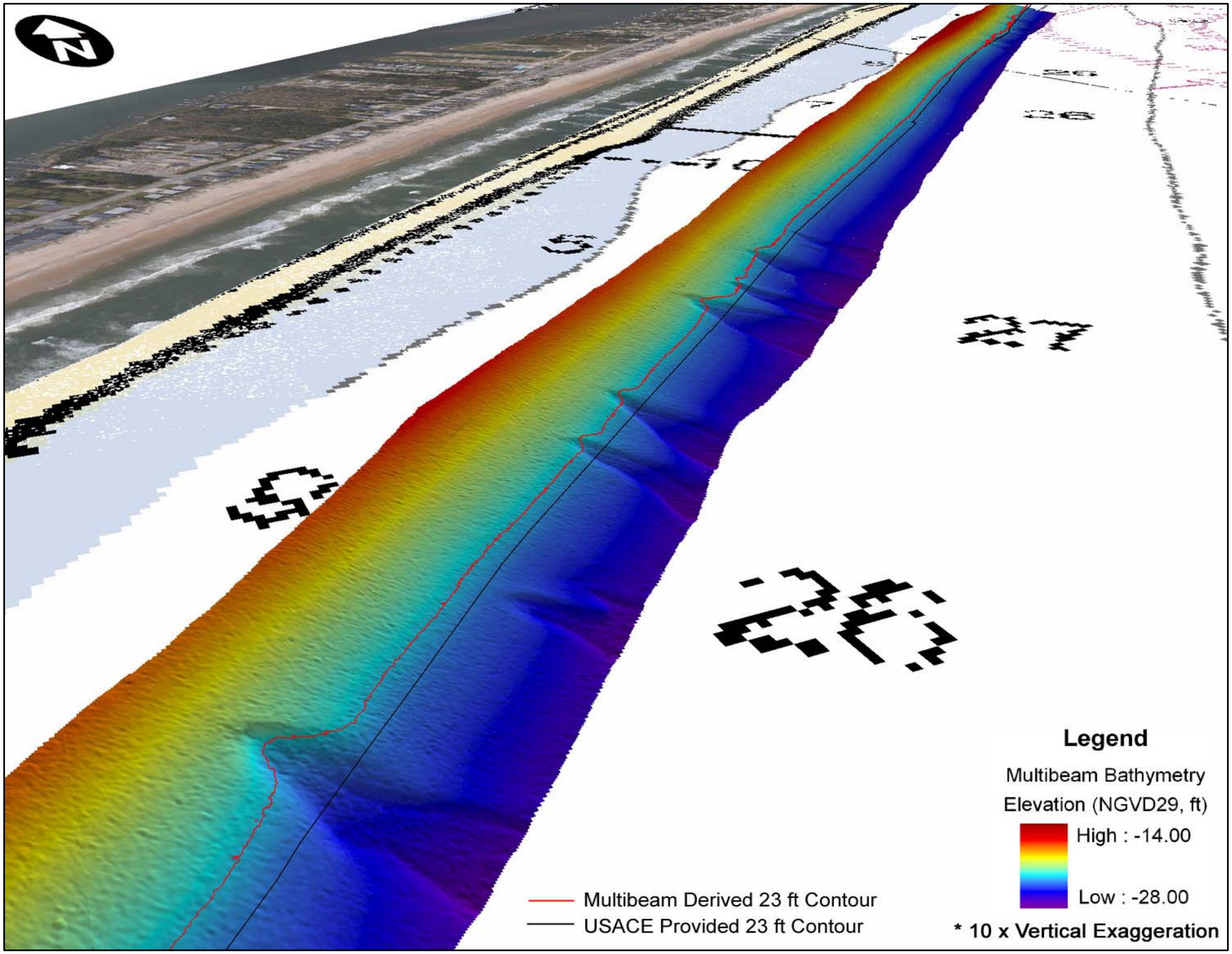


Figure 11. 23' multibeam and 23' USACE contours draped on 3D perspective view of the Topsail Beach inner shoreface.

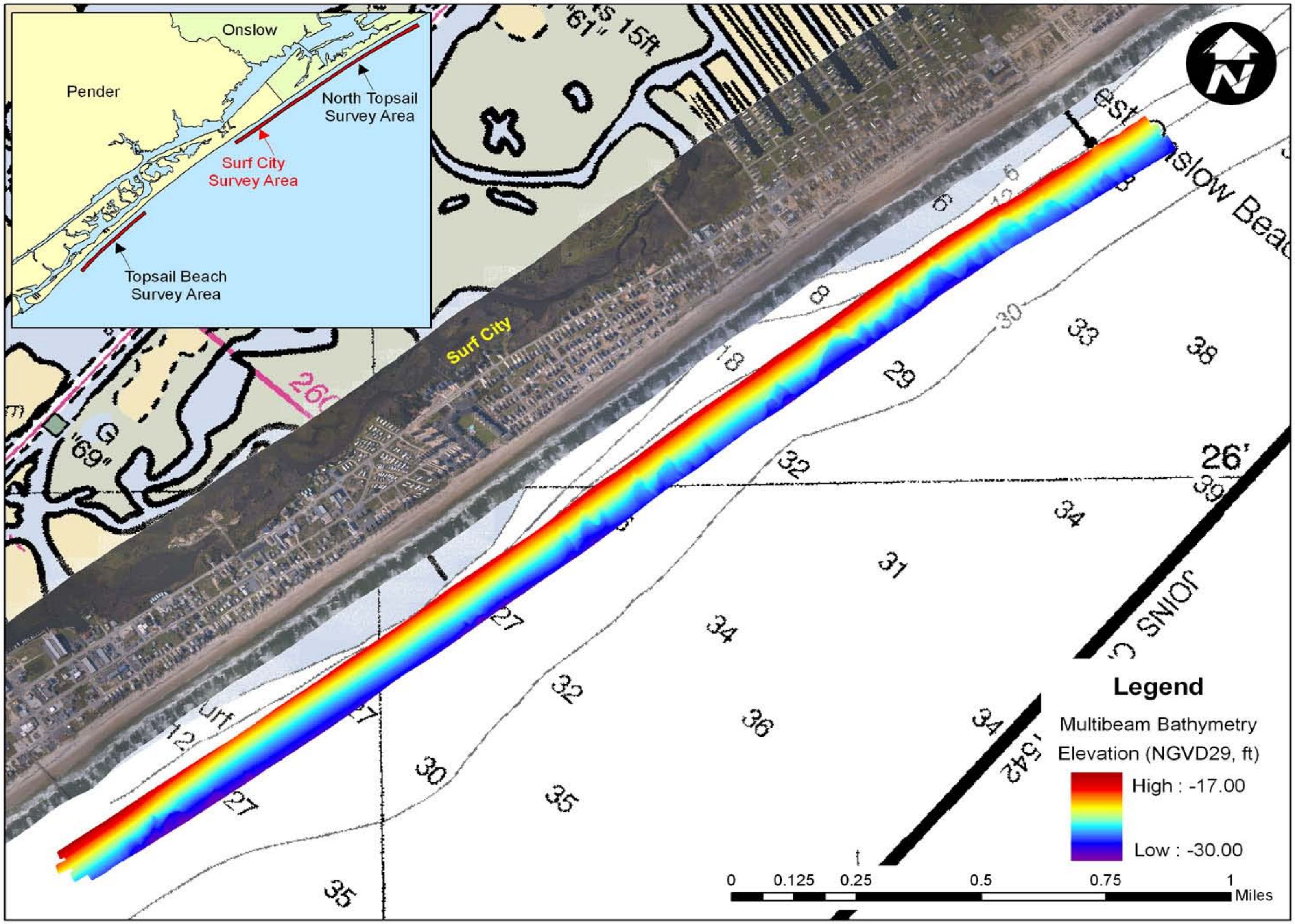


Figure 12. Plan view bathymetric map of the Surf City or “middle” survey area.

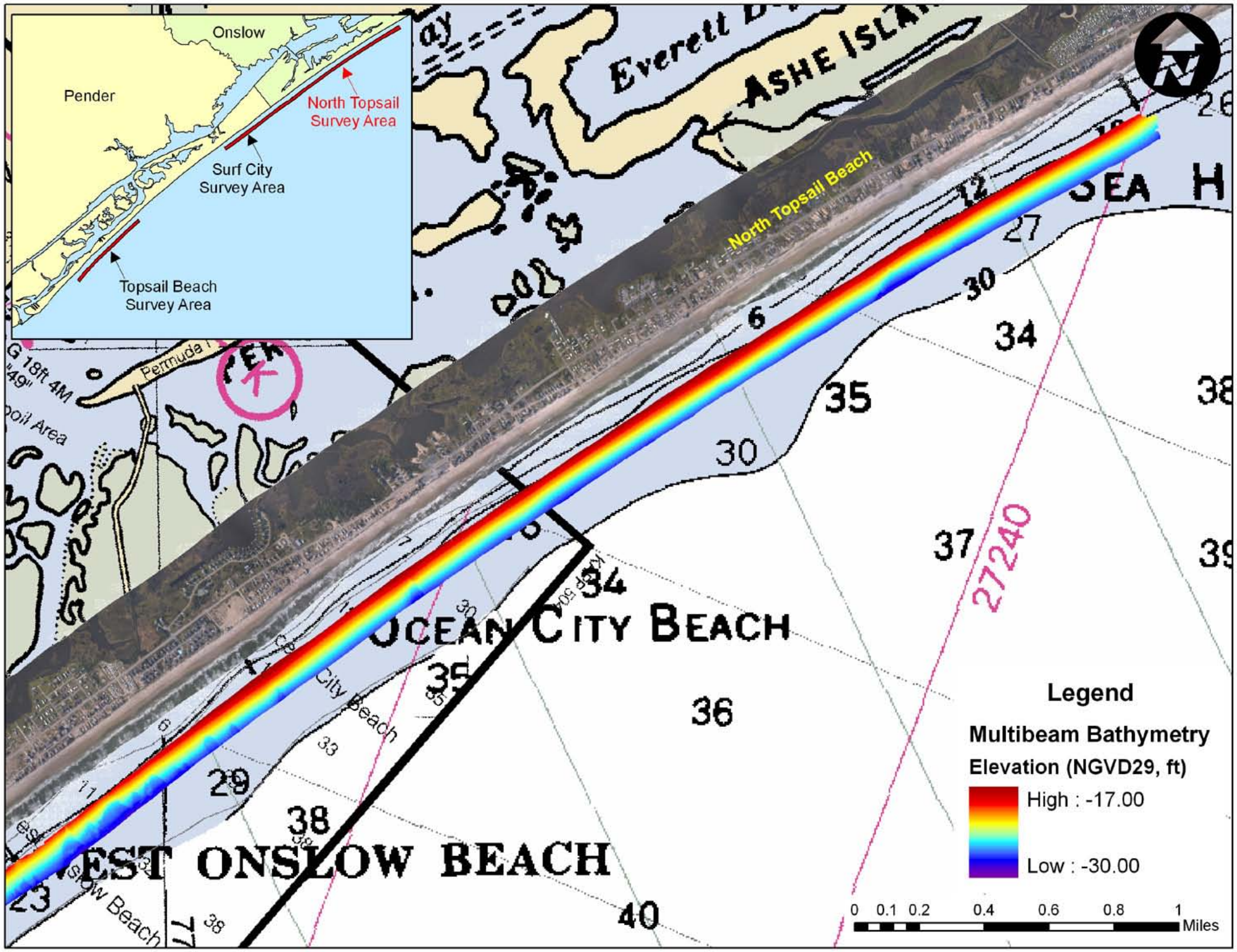


Figure 13. Plan view bathymetric map of the North Topsail or “northern” survey area.

Appendix A – Official USACE Scope of Work (Scanned G&O Copy)

CONTRACT DACW54-02-D-0006, TASK ORDER 00-5, MOD. 01

MODIFICATION
TO
SCOPE OF WORK
NEARSHORE HARD BOTTOM SIDESCAN SURVEY
FOR MULTIBEAM DATA COLLECTION
TOPSAIL ISLAND, NORTH CAROLINA

1. Location of Work. The tasks to be performed under this scope of work pertain to the geographic area of Topsail Island, North Carolina as indicated on figure 1.

2. General Requirements. The Contractor shall supply all necessary labor, materials, equipment, rentals, and travel expense to conduct and document the work as described herein.

3. Detailed Requirements. The Contractor shall acquire full coverage multibeam sonar data within zones identified to contain potential hardbottom regions as identified in Phase 1 of the project as well as those areas previously identified as potential hard bottom in North Topsail by CPE Inc.

The Contractor shall provide all necessary services, equipment, labor, and materials to perform a multibeam survey within the survey limits as indicated on figure 1, and the post processing of the collected field data into the required formats and deliverables as indicated. The following survey datums are required:

Horizontal – North Carolina State Plan, NAD83, US Survey, Feet
Vertical – NGVD 1929, Feet

A. Hydrographic Data. Hydrographic survey coverage for the area depicted on the attached map shall be provided. The Contractor shall conduct the multibeam surveys as to ensure 100% coverage to the extent practical of the survey area shown on the attached map. Survey lines should be taken at sufficient intervals to ensure this coverage. Coordinates shown on the attached map are in feet and reference the North Carolina State Plane Coordinate System, NAD83. All data shall meet the recommended minimum performance standards established in EM 1110-2-1003 (Table 3-1) for the "Other General Surveys and Studies" project classification.

B. System Calibration and Check. The Contractor shall calibrate and check the multibeam system in accordance with the procedures outlined in EM 1110-2-1003. A log (either written or digital) containing the results of all calibrations and checks shall be kept by the Contractor.

C. Data Editing. All hydrographic survey data shall be fully edited and corrected. The data shall undergo a gridded depth reduction using 5-foot cells or less, where the depth saved shall be the depth closest to the center of the cell.

Note: USACE documents can be downloaded from the following web site:
http://www.usace.army.mil/inet/usace-docs/eng-manuals/em.htm

4. Survey Control. Phase 2 multibeam surveys will use US Coast and Geodetic Survey benchmark Tower Three 1947 for RTK-GPS corrections. A complete site calibration has been performed on this mark during Phase 1; however, prior to the start of surveying in Phase 2 Contractor shall check at least one mark within the control network to verify correct basestation setup.

5. Clearances. The Contractor shall acquire all Clearances necessary to obtain the required data. All discussions for access to private or public property or restricted waters or airspace must be included in the required weekly status report with name of person, address, and telephone number.

6. Required Deliverables. The Contractor is required to deliver Shapefiles, Raster Data Sets, Metadata Records, a Weekly Status Reports, and a Final Written Report.

6.1 GIS-Compatible Data The Contractor shall deliver data in a format compatible with ESRI ArcView/ArcInfo Version 9.x.

6.1.1 Multibeam Data. The Contractor shall deliver an ArcGrid of each Multibeam Survey area specified in the attached project design map. The ArcGrid shall represent the final data with all appropriate corrections (motion, tides, CUBE, TPE, etc) applied.

6.1.2 Point Shapefiles. The Contractor shall deliver any ancillary data that could possibly be imported into a geodatabase in shape file format.

6.2 Metadata Record. An FGDC compliant metadata record for each spatial data deliverable shall be created using ESRI ArcView/ArcInfo ArcCatalog version 9.0. Appropriate information shall be entered in all required fields. The Contractor shall attach the appropriate metadata record to each spatial data file using ArcCatalog so that no importing or formatting of the metadata record is required by the Government.

7. Weekly Status Report. **The Contractor is required to submit a Weekly Status Report each week, beginning on the Task Order Award Date, until all deliverables are received and accepted by the Government.** The Weekly Status Report shall be delivered via e-mail no later than 8:00 AM each Monday and shall document the Contractor's progress from the previous Monday through the previous Sunday. The status report shall itemize each scope item with percent of work complete and an estimated date of completion. The report shall also include the number and type of field crews working, a description of any problems and/or delays encountered, and any

photographs of the site and/or significant site features (such as outlet structures, retaining walls, escarpments, etc.) and/or specialized data collection activities.

8. Final Written Report. A written report summarizing all data collection activities shall be submitted as a Portable Document File (PDF) and in bound hardcopy. The following items shall be included in the survey report:

- Written description of workflow to complete task order (start to finish) including flowchart diagram and detailed description of QA/QC process
- Dates and times of each data collection activity
- Atmospheric Conditions for each day of data collection activity
- All Horizontal and Vertical Control used including monument name, establishing agency, date established, description, and published horizontal and vertical values
- TBM descriptions with vertical values (N/A)
- Copy of all field notes
- Complete and detailed list of all survey equipment used including copy of last factory calibration report
- Metadata Records as described in 4.4 above
- Photographs of the site and any significant features or data collection techniques used

9. Quality Control. If work is found to be in error, incomplete, illegible or unsatisfactory after assignment is completed, the Contractor shall be liable for all cost in connection with correcting such errors. Corrective work may be performed by Government personnel or Contractor personnel at the discretion of the Contracting Officer. In any event, the Contractor shall be responsible for all costs incurred for correction of such errors, including salaries, automotive expenses, equipment rental, supervision, and any other costs in connection therewith. All data and deliverables shall be reviewed for the following:

- Required coverage of the project limits
- Capture of all required features
- Required accuracies
- Required horizontal and vertical datum
- Adherence to the delivery order requirements

10. Technical POC. All technical questions concerning work under this task order shall be directed to Jim Jacaruso at (910) 251-4064.

11. Schedule & Completion Date. A completed product for the Topsail Beach portion of this modification shall be delivered in its entirety no later than 31 January 2007. Upon award of this modification, fieldwork for the Phase 2 multibeam survey project should proceed such that the final deliverables are completed and delivered no later than 21 days from the modification date, weather conditions permitting. Safety of field

personnel is the priority, followed by timeliness of schedule. The Contractor is to use judgment on the exact days of data collection for both safety and data quality concerns. Scheduling of surveys should be coordinated with the POC in advance and weekly updates of progress to obtain field data will be provided. Data analysis, documentation, and computer files should be delivered by early February pending the ultimate schedule for data acquisition. This schedule is subject to adjustment by the Contracting Officer.

12. Deliver To. All work shall be delivered to:

U. S. Army Corps of Engineers
Wilmington District
Attn: Jim Jacaruso, TS-EE
69 Darlington Avenue
PO Box 1890
Wilmington, NC 28402-1890

Appendix B – Field Notes

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data

Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)

15 January 2006	Eastern Standard Time
Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.

Total Daylight: 10-11hrs

DATE: 1/26/07

TIME	TASK	NOTES
6:30am	mobilization of 4-Points and trailer check, fuel vessel, travel to Topsail, put vessel in the water and moor	There was a change in the survey plan by the Corps to get on site and mobilize to try and get one of these one day windows we are having. So we can get the data before the 31st deadline
11:30am	New site calibration	Could not gain access to Tower 3. Could not reach owners of property for ~3 weeks now. Even found a possible number for them in Jacksonville but no answering machines on either line. After putting vessel in we started hunting for A230
12:00pm	Bench mark and range check.	Found A230 and were able to put radio antenna out on the beach with the 100' GPS cable. First step was to get all the way to the northern survey extents and check marks. Thing checked out w/in 3cm. Then we worked our way south checking various marks.
5:30pm	Wrap up site cal and break down GPS equipment. Get boat safe in slip.	Weather forecast changed once again. In fact wind was already SW at about 15 ~4pm and the marine forecast is still calling it NW? Looks like tomorrow is a wash. Will leave boat in slip for the next couple days
6:00pm - 7:30	Drive back to PKS	After getting boat secure we headed back to HQ. Get GPS equipment on charge and semi unpacked

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data

Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)

15 January 2006	Eastern Standard Time
Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.

Total Daylight: 10-11hrs

DATE: 1/27/07

TIME	TASK	NOTES
		SW wind. No survey

SURF CITY TO CAPE FEAR NC OUT 20 NM-

559 AM EST SAT JAN 27 2007

SMALL CRAFT ADVISORY REMAINS IN EFFECT FROM 1 PM EST THIS AFTERNOON THROUGH LATE TONIGHT

TODAY

W TO SW WINDS 15 TO 20 KT...BECOMING SW 20 TO 25 KT. SEAS BUILDING TO 5 TO 6 FT. SEAS 2 TO 3 FT NEAR SHORE.

TONIGHT

SW WINDS 20 TO 25 KT...BECOMING W 15 TO 20 KT AFTER MIDNIGHT. SEAS 5 TO 7 FT...EXCEPT AROUND 3 FT NEAR SHORE. A SLIGHT CHANCE OF SHOWERS AFTER MIDNIGHT.

SUN

W WINDS 10 TO 15 KT WITH GUSTS UP TO 25 KT. SEAS 2 TO 4 FT. A CHANCE OF SHOWERS IN THE MORNING.

SUN NIGHT

W WINDS 15 TO 20 KT...BECOMING NW 25 TO 30 KT AFTER MIDNIGHT. SEAS 5 TO 7 FT.

MON

NW WINDS 20 TO 25 KT...DIMINISHING TO 15 TO 20 KT IN THE AFTERNOON. SEAS 4 TO 6 FT.

AFTERNOON. SEAS 4 TO 6 FT.

MON NIGHT

NW WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT. SEAS AROUND 3 FT.

TUE

W WINDS 10 TO 15 KT. SEAS 2 TO 3 FT.

WED

N WINDS 10 TO 15 KT. SEAS 2 TO 3 FT.

SURF CITY TO CAPE FEAR NC OUT 20 NM-

320 PM EST SAT JAN 27 2007

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data

Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)	
15 January 2006	Eastern Standard Time
Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.
Total Daylight: 10-11hrs	

DATE: 1/28/07

TIME	TASK	NOTES
		Gustsy winds. No survey

859 AM EST SUN JAN 28 2007

GALE WARNING REMAINS IN EFFECT FROM 4 PM EST THIS AFTERNOON THROUGH MONDAY MORNING

TODAY

NW WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT...INCREASING TO 15 TO 20 KT WITH GUSTS UP TO 35 KT LATE THIS MORNING AND AFTERNOON. SEAS 4 TO 5 FT. SEAS AROUND 2 FT NEAR SHORE. RAIN EARLY THIS MORNING...THEN A SLIGHT CHANCE OF RAIN LATE THIS MORNING.

TONIGHT

W WINDS 20 TO 25 KT WITH GUSTS UP TO 30 KT...BECOMING NW 30 TO 35 KT WITH GUSTS UP TO 40 KT. SEAS 6 TO 8 FT...EXCEPT UP TO 3 FT NEAR SHORE. A SLIGHT CHANCE OF RAIN IN THE EVENING.

MON

NW WINDS AROUND 25 KT WITH GUSTS UP TO 35 KT... DIMINISHING TO 15 TO 20 KT IN THE AFTERNOON. SEAS 6 TO 7 FT... SUBSIDING TO 3 TO 5 FT IN THE AFTERNOON.

MON NIGHT

W WINDS 10 TO 15 KT...INCREASING TO 15 TO 20 KT AFTER MIDNIGHT. SEAS BUILDING TO 3 TO 5 FT.

TUE

TUE

W WINDS 15 TO 20 KT WITH GUSTS UP TO 25 KT. SEAS 4 TO 5 FT.

TUE NIGHT

NW WINDS 15 TO 20 KT...BECOMING N AFTER MIDNIGHT. SEAS
3 TO 5 FT.

WED

N WINDS 10 TO 15 KT...BECOMING NE. SEAS 2 TO 4 FT.

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data

Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)

15 January 2006	Eastern Standard Time
Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.

Total Daylight: 10-11hrs

DATE: 1/29/07

TIME	TASK	NOTES
6:30am	Check weather and verified a go. Packed GPS equipment	Drove down ~ 7am
9:00am	Setup base and check mark	Set the base up and checked BM Crocker
9:45am	Prepare boat	Had to wait for the winds to die down a bit. Was blowing up to 30knts in the am and then died to ~20knts mid day. Unclear if surface conditions will allow good data at this stage
11:45am	Begin transit to site	on the transit to site we marked some of the nav aids for safe return home.
12:30pm	On site and start survey	Started survey in southern section. Was able to get both the southern and middle sections. This is the data that is needed by the 31st. Looks like we'll make the deadline but still have to process. Got the base surface generated on the way home! Thank goodness for new mobile workstation
5:30pm	Dock	Got to the dock just before dark. Moored and prepared for tomorrow. Forecast still looking decent for tomorrow am but they have the winds increasing out of the west. Will check updated intellicast at hotel
6:30pm - 9:30pm	In-field data processing	Was able to get some level of processing completed this evening. Data is looking very clean. Hopefully we can make some headway offshore tomorrow

geodynamics — COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data

Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)

15 January 2006 Eastern Standard Time

Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.

Total Daylight: 10-11hrs

DATE: 1/30/07

TIME	TASK	NOTES
5:30am to 1:30pm	Tried to survey but got blow out, pulled boat out of water, packed gps gear, head back and get gps gear on charge	1/2 acqusition day. The south forcast had winds W at 15-20 for today but it was blowing light SW at prior to first light. By 9am it was blowing 15 plus out of the SW. They finally changed the forecast to reflect this at at the 10am forecast

SURF CITY TO CAPE FEAR NC OUT 20 NM-

307 PM EST TUE JAN 30 2007

SMALL CRAFT ADVISORY REMAINS IN EFFECT FROM 8 PM EST THIS EVENING THROUGH WEDNESDAY MORNING

THROUGH 6 PM

SW WINDS 15 TO 20 KT. SEAS AROUND 3 FT. SEAS AROUND 2 FT NEAR SHORE.

TONIGHT

W WINDS 15 TO 20 KT...INCREASING TO 20 TO 25 KT LATE THIS EVENING AND EARLY MORNING...THEN BECOMING NW LATE. SEAS 4 TO 5 FT. SEAS AROUND 3 FT NEAR SHORE.

WED

NW WINDS 20 TO 25 KT...BECOMING N 10 TO 15 KT IN THE AFTERNOON. SEAS 3 TO 5 FT...SUBSIDING TO 2 TO 3 FT IN THE AFTERNOON.

WED NIGHT

N WINDS AROUND 10 KT...BECOMING E AFTER MIDNIGHT. SEAS 2 TO 3 FT.

THU

SE WINDS AROUND 10 KT...BECOMING SW WITH GUSTS UP TO 20 KT IN THE AFTERNOON. SEAS 2 TO 4 FT...BUILDING TO 4 TO 6 FT IN THE

THE AFTERNOON. SEAS 2 TO 4 FT...BUILDING TO 4 TO 6 FT IN THE AFTERNOON. A SLIGHT CHANCE OF RAIN IN THE MORNING...THEN SHOWERS LIKELY IN THE AFTERNOON.

THU NIGHT

SW WINDS 15 TO 20 KT...INCREASING TO 20 TO 25 KT WITH GUSTS UP TO 30 KT AFTER MIDNIGHT. SEAS 6 TO 9 FT. SHOWERS IN THE EVENING...THEN RAIN AFTER MIDNIGHT.

FRI

W WINDS 20 TO 25 KT...DIMINISHING TO 15 TO 20 KT IN THE AFTERNOON. SEAS 6 TO 9 FT. NEAR SHORE...SEAS 4 TO 6 FT... SUBSIDING TO 2 TO 4 FT IN THE AFTERNOON. A CHANCE OF RAIN IN THE MORNING.

FRI NIGHT

W WINDS 20 TO 25 KT...BECOMING NW 15 TO 20 KT AFTER MIDNIGHT. SEAS 4 TO 6 FT...EXCEPT UP TO 3 FT NEAR SHORE.

SAT

N WINDS 10 TO 15 KT. SEAS 2 TO 4 FT.

SUN

N WINDS 10 TO 15 KT. SEAS 3 TO 5 FT.

S OF CAPE LOOKOUT TO N OF SURF CITY NC OUT 20 NM

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data	
Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)	
15 January 2006	Eastern Standard Time
Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.
Total Daylight: 10-11hrs	

DATE: 1/31/07

TIME	TASK	NOTES
		N winds in forecast. No survey

S OF CAPE LOOKOUT TO N OF SURF CITY NC OUT 20 NM-

409 PM EST TUE JAN 30 2007

SMALL CRAFT ADVISORY REMAINS IN EFFECT THROUGH WEDNESDAY AFTERNOON

TONIGHT

W WINDS 20 TO 25 KT. SEAS 3 TO 5 FT...BUILDING TO 5 TO 7 FT AFTER MIDNIGHT.

WED

NW WINDS 20 TO 25 KT...BECOMING N 15 TO 20 KT IN THE AFTERNOON. SEAS 4 TO 6 FT.

WED NIGHT

N WINDS AROUND 5 KT...BECOMING E AFTER MIDNIGHT. SEAS AROUND 2 FT.

THU

S WINDS 5 TO 10 KT...INCREASING TO 20 TO 25 KT IN THE AFTERNOON. SEAS 3 TO 5 FT BUILDING TO 4 TO 6 FT. SHOWERS LIKELY.

THU NIGHT

S WINDS 20 TO 25 KT. SEAS 6 TO 8 FT. A CHANCE OF SHOWERS.

FRI

FRI

SW WINDS 20 TO 25 KT...BECOMING W 15 TO 20 KT IN THE
AFTERNOON. SEAS 6 TO 8 FT...SUBSIDING TO 5 TO 7 FT IN THE AFTERNOON.

FRI NIGHT

W WINDS 15 TO 20 KT. SEAS 4 TO 6 FT.

SAT

NW WINDS 10 TO 15 KT...BECOMING N 15 TO 20 KT. SEAS 3 TO
5 FT.

SUN

N WINDS 15 TO 20 KT. SEAS 3 TO 5 FT.

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes		
Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07		
US Navy Astronomical Data		
Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)		
15 January 2006 Eastern Standard Time		
Begin civil twilight 6:49 a.m.		
Sunrise 7:16 a.m.		
Sun transit 12:20 p.m.		
Sunset 5:23 p.m.		
End civil twilight 5:50 p.m.		
Total Daylight: 10-11hrs		
DATE: 2/1/07		
TIME	TASK	NOTES
		Stong NE winds in forecast. No survey

SURF CITY TO CAPE FEAR NC OUT 20 NM-

317 PM EST THU FEB 1 2007

SMALL CRAFT ADVISORY REMAINS IN EFFECT THROUGH FRIDAY EVENING

THROUGH 6 PM

NE WINDS 15 TO 20 KT. SEAS 4 TO 6 FT. SEAS AROUND 2 FT NEAR SHORE. LIGHT RAIN WITH AREAS OF DRIZZLE.

TONIGHT

NE WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT...BECOMING N WITH GUSTS UP TO 20 KT LATE. SEAS AROUND 7 FT. SEAS AROUND 3 FT NEAR SHORE. RAIN LIKELY WITH AREAS OF DRIZZLE THIS EVENING...THEN RAIN LIKELY AFTER MIDNIGHT.

FRI

NW WINDS 10 TO 15 KT...BECOMING W IN THE AFTERNOON. GUSTS UP TO 25 KT. SEAS 6 TO 9 FT...EXCEPT UP TO 6 FT NEAR SHORE. A CHANCE OF RAIN IN THE MORNING.

FRI NIGHT

W WINDS 20 TO 25 KT. SEAS 4 TO 7 FT... SUBSIDING TO 3 TO 5 FT AFTER MIDNIGHT. NEAR SHORE...SEAS 2 TO 4 FT.

SAT

NW WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT. SEAS 3 TO 5 FT.

NW WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT. SEAS 3 TO 5 FT.

SAT NIGHT

W WINDS 10 TO 15 KT...INCREASING TO 20 TO 25 KT AFTER MIDNIGHT. SEAS 2 TO 4 FT.

SUN

NW WINDS 15 TO 20 KT WITH GUSTS UP TO 25 KT. SEAS 2 TO 4 FT.

SUN NIGHT

NW WINDS 10 TO 15 KT. SEAS 2 TO 3 FT.

MON

NW WINDS 10 TO 15 KT...INCREASING TO 15 TO 20 KT. SEAS 2 TO 4 FT.

TUE

N WINDS 20 TO 25 KT...DIMINISHING TO 15 TO 20 KT. SEAS 3 TO 5 FT.

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR		
Project Timeline & General Field Notes		
Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07		
US Navy Astronomical Data		
Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)		
15 January 2006	Eastern Standard Time	
Begin civil twilight	6:49 a.m.	
Sunrise	7:16 a.m.	
Sun transit	12:20 p.m.	
Sunset	5:23 p.m.	
End civil twilight	5:50 p.m.	
Total Daylight: 10-11hrs		
DATE: 2/2/07		
TIME	**TASK**	**NOTES**
		Gusty winds. No survey

SURF CITY TO CAPE FEAR NC OUT 20 NM-

616 PM EST SAT FEB 3 2007

SMALL CRAFT ADVISORY REMAINS IN EFFECT FROM SUNDAY EVENING THROUGH MONDAY MORNING

TONIGHT

W WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT. SEAS AROUND 3 FT. SEAS 2 FT OR LESS NEAR SHORE.

SUN

W WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT...INCREASING TO 15 TO 20 KT WITH GUSTS UP TO 25 KT IN THE AFTERNOON. SEAS 3 TO 5 FT...EXCEPT 2 TO 3 FT NEAR SHORE.

SUN NIGHT

W WINDS 20 TO 25 KT...BECOMING NW. SEAS 4 TO 6 FT.

MON AND MON NIGHT

NW WINDS 20 TO 25 KT WITH GUSTS UP TO 30 KT. SEAS 4 TO 6 FT.

TUE AND TUE NIGHT

NW TO W WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT. SEAS 2 TO 4 FT.

WED
N WINDS 10 TO 15 KT...INCREASING TO 15 TO 20 KT. SEAS BUILDING TO 3 TO 5 FT.

THU
N WINDS 15 TO 20 KT...BECOMING NW 10 TO 15 KT. SEAS 3 TO 5 FT.

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data	
Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)	
15 January 2006	Eastern Standard Time
Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.
Total Daylight: 10-11hrs	

DATE: 2/3/07

TIME	TASK	NOTES
		Gusy winds in forecast. No survey.

SURF CITY TO CAPE FEAR NC OUT 20 NM-

616 PM EST SAT FEB 3 2007

SMALL CRAFT ADVISORY REMAINS IN EFFECT FROM SUNDAY EVENING THROUGH MONDAY MORNING

TONIGHT

W WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT. SEAS AROUND 3 FT. SEAS 2 FT OR LESS NEAR SHORE.

SUN

W WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT...INCREASING TO 15 TO 20 KT WITH GUSTS UP TO 25 KT IN THE AFTERNOON. SEAS 3 TO 5 FT...EXCEPT 2 TO 3 FT NEAR SHORE.

SUN NIGHT

W WINDS 20 TO 25 KT...BECOMING NW. SEAS 4 TO 6 FT.

MON AND MON NIGHT

NW WINDS 20 TO 25 KT WITH GUSTS UP TO 30 KT. SEAS 4 TO 6 FT.

TUE AND TUE NIGHT

NW TO W WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT. SEAS 2 TO 4 FT.

WED

N WINDS 10 TO 15 KT...INCREASING TO 15 TO 20 KT. SEAS BUILDING TO 3 TO 5 FT.

THU

N WINDS 15 TO 20 KT...BECOMING NW 10 TO 15 KT. SEAS 3 TO 5 FT.

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data	
Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)	
15 January 2006	Eastern Standard Time
Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.
Total Daylight: **10-11hrs**	

DATE: 2/4/07

TIME	TASK	NOTES
		SW winds in forecast. No survey. They have offshore winds for tomorrow but pretty strong. Might have a chance if they change it tonight to be a lttle lighter. Anything can happen with how the forecasts have been lately.

640 AM EST SUN FEB 4 2007

SMALL CRAFT ADVISORY REMAINS IN EFFECT FROM 6 PM EST THIS EVENING THROUGH MONDAY MORNING

TODAY

W WINDS 10 TO 15 KT WITH GUSTS UP TO 20 KT... INCREASING TO 15 TO 20 KT WITH GUSTS UP TO 25 KT LATE THIS MORNING AND EARLY AFTERNOON...THEN BECOMING SW 20 TO 25 KT WITH GUSTS UP TO 30 KT LATE. SEAS BUILDING TO 4 TO 5 FT. SEAS 2 TO 3 FT NEAR SHORE.

TONIGHT

W WINDS 20 TO 25 KT...BECOMING NW AFTER MIDNIGHT. GUSTS UP TO 35 KT. SEAS 4 TO 7 FT...EXCEPT UP TO 4 FT NEAR SHORE.

MON

NW WINDS 20 TO 25 KT WITH GUSTS UP TO 35 KT. SEAS 4 TO 7 FT.

MON NIGHT

NW WINDS 15 TO 20 KT WITH GUSTS UP TO 30 KT. SEAS 4 TO 6 FT.

TUE

NW WINDS 15 TO 20 KT...BECOMING W 10 TO 15 KT IN THE AFTERNOON. SEAS 2 TO 4 FT.

TUE NIGHT
W WINDS 15 TO 20 KT...BECOMING SW 20 TO 25 KT AFTER MIDNIGHT. SEAS 3 TO 5 FT.

WED
W WINDS 15 TO 20 KT...BECOMING N. SEAS 3 TO 5 FT.

THU
N WINDS 15 TO 20 KT...BECOMING NW 10 TO 15 KT. SEAS 3 TO 5 FT...SUBSIDING TO 2 TO 3 FT.

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

Project Timeline & General Field Notes

Project: Topsail Island Phase 2 Multibeam 1/26-2/5/07

US Navy Astronomical Data

Sunday: Surf City, Pender County, North Carolina (longitude W77.5, latitude N34.4)

15 January 2006	Eastern Standard Time
Begin civil twilight	6:49 a.m.
Sunrise	7:16 a.m.
Sun transit	12:20 p.m.
Sunset	5:23 p.m.
End civil twilight	5:50 p.m.

Total Daylight: 10-11hrs

DATE: 2/5/07

TIME	TASK	NOTES
6:00am	Check forecast and verified a go for today. Packed GPS gear and drove down	Got all the gear ready and headed out the door by 7:45am. At this point not sure it will be favoritable but at least it is offshore. Might die like it did last week.
9:30am	Setup base and prepared boat for survey	Got the base going and checked a mark. Winds are still strong but the surface conditions are flat. Going to give it a go
10:45am	Transit to northern survey site	still having hydraulic steering problems but we were able to transit at 27knts
11:25am	Start survey	Had a brief sonar glitch that kept us in suspense. Was able to get it to lock in. Thinking it was just cold.
5:15pm	Dock and final demob	Got back to the dock and started the demob process. Got boat out of water and broke the base down.
6:45pm - 8pm	Head back to HQ	Check trailer for brake wear

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

Multibeam Daily Operation Proceedures & Checklist

Pre-Survey Operations	**Complete**	**Notes**		
		Latitude (Northing)	**Longitude (Easting)**	**Elev.**
Perform Dock-side GPS Check	X	See Metadata for BM Check		
Power up POS MV	X			
Power up UPS	X			
Power up EM3002 PU	X			
Power up Acquisition PC	X			
Power up Navigation PC	X			
Power up Trimble GPS	X			
Perform BIST (head in water)	X			
Survey Operations		**Latitude (Northing)**	**Longitude (Easting)**	**Value**
Input Initial SV cast in SIS Runtime		34 21.7451	077 37.3611	1492.2
SV Cast #1		34 21.7451	077 37.3611	1492.2
SV Cast #2		34 25.2728	077 32.5627	1492.7
SV Cast #3				
SV Cast #4				
SV Cast #5				
SV Cast #6				
SV Cast #7				
SV Cast #8				
Vessel Draft Check (waterline to ducer)				0.53m

General Survey Notes

Project	USACE Topsail MB 2
Survey Area	Multibeam Southern Area & Middle area
Sea State	2' SSE swell, wind chop on top
Wind	NW 15 gust to 25-30kts
Air Temperature	34 F at start
Sea Temperature	51.7 F at start
Tides	L:11:40 am H: 4:50 pm EST
Survey Features & Navigational Aids	N/A
Comments	Had to wait 1/2 day for winds to calm a bit.

Line Name	MS/CL	Direction	Notes
0	MS	NE	HP 2 Start 12:24 pm EST
1	MS	NE	HP 2 cont due to PPS off E 12:51
2	MS	SW	HP 3
3	MS	NE	HP 4
4	MS	SW	HP 5
5	MS	NE	HP 6
6	MS	SW	HP 1 - end S section E 2:41
7	MS	NE	HP 2 - S 2:59 E 3:20
8	MS	SW	HP 3
9	MS	NE	HP 4
10	MS	SW	HP 5
11	MS	NE	HP 6
End Survey Day			

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COMPLEX COASTAL CHANGE MADE CLEAR

Multibeam Daily Operation Proceedures & Checklist

Pre-Survey Operations	Complete	Notes		
		Latitude (Northing)	Longitude (Easting)	Elev.
Perform Dock-side GPS Check	X	See Metadata for BM Check		
Power up POS MV	X			
Power up UPS	X			
Power up EM3002 PU	X			
Power up Acquisition PC	X			
Power up Navigation PC	X			
Power up Trimble GPS	X			
Perform BIST (head in water)	X			

Survey Operations		Latitude (Northing)	Longitude (Easting)	Value
Input Initial SV cast in SIS Runtime				
SV Cast #1				
SV Cast #2				
SV Cast #3				
SV Cast #4				
SV Cast #5				
SV Cast #6				
SV Cast #7				
SV Cast #8				
Vessel Draft Check (waterline to ducer)				0.53m

General Survey Notes	
Project	USACE Topsail MB 2
Survey Area	Multibeam Northern Area
Sea State	2' SSE swell, decent S wind chop on top
Wind	SSW 10-15kts at 7:00am
Air Temperature	31 F at start
Sea Temperature	51.7 F at start
Tides	L:12:35 pm H: 5:48 pm EST
Survey Features & Navigational Aids	N/A
Comments	SSW winds picking up seas building to 2-4 quickly. Survey terminated

Topsail Phase II Multibeam
Jan 29-Feb 5, 2007 01-30-07 Page 1

Line Name	MS/CL	Direction	Notes
0	MS	NE	
1	MS		
2	MS		
3	MS		
4	MS		
5	MS		
6	MS		
7	MS		
8	MS		
9	MS		
10	MS		
11	MS		

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COMPLEX COASTAL CHANGE MADE CLEAR

Multibeam Daily Operation Proceedures & Checklist

Pre-Survey Operations	Complete	Notes		
		Latitude (Northing)	Longitude (Easting)	Elev.
Perform Dock-side GPS Check	X	See Metadata for BM Check		
Power up POS MV	X			
Power up UPS	X			
Power up EM3002 PU	X			
Power up Acquisition PC	X			
Power up Navigation PC	X			
Power up Trimble GPS	X			
Perform BIST (head in water)	X			

Survey Operations		Latitude (Northing)	Longitude (Easting)	Value
Input Initial SV cast in SIS Runtime		34 26.5378	077 30.3729	1488.9
SV Cast #1		34 26.5378	077 30.3729	1488.9
SV Cast #2		34 28.0899	077 27.8448	1487.2
SV Cast #3				
SV Cast #4				
SV Cast #5				
SV Cast #6				
SV Cast #7				
SV Cast #8				
Vessel Draft Check (waterline to ducer)				0.53m

General Survey Notes

Project	USACE Topsail MB 2
Survey Area	Multibeam Northern Area
Sea State	1-2' SSW swell, decent S wind chop on top
Wind	SSW 10-15kts at 7:00am
Air Temperature	31 F at start
Sea Temperature	49.8 F at start
Tides	H: 9:30 L: 4:26 pm EST
Survey Features & Navigational Aids	N/A
Comments	Initial BIST on Head =7 TX error, cleared on re-test out of water

Line Name	MS/CL	Direction	Notes
0	MS	NE	HP 1 S 11:10am EST
1	MS	NE	HP 1
2	MS	NE	HP 1 S 11:26am EST E 11:58am Est
3	MS	SW	HP 2 S 12:01pm EST
4	MS	SW	HP 2 S 12:01pm EST
5	MS	NE	HP 3
6	MS	NE	HP 3
7	MS	SW	HP 4
8	MS	SW	HP 4
9	MS	NE	HP 5
10	MS	NE	HP 5
11	MS	SW	HP 2
12	MS	SW	HP 2
13	MS	NE	HP 1 Redo
14	MS	NE	HP 1 Redo
End Survey			

Appendix C – Equipment & Instrument Accuracies

R/V 4-POINTS

Hydrographic Survey






The research vessel *4-Points* is a custom fiberglass survey boat designed specifically for shallow water sonar and acoustical operations. The vessel is 25' long with a 10' beam; the bottom tapers from a deep "Carolina" style Vee to a relatively flat-bottomed stern that provides a shallow draft of approximately 1.2'. Twin 140 four-stroke engines, hung on a stainless steel bracket, power the vessel. All electronics and generators are grounded to the sea via a bottom mounted bonding plate to eliminate all electrical noise. Side-scan instrumentation is deployed, towed and retrieved from custom davit on starboard side.

Instrumentation:

- **Simrad EM 3002 multibeam sonar**
  - Multi-Frequency: in 300 kHz band
  - Max ping rate: 40 Hz
  - No. of beams/ping: 254 Roll and Pitch stabilized
  - Beam width: 1.5^{o} x 1.5^{o}
  - Beam spacing: 0.9^{o}
  - Depth range from sonar head:1 to 150 m
  - Depth resolution: 1 cm
  - Depth accuracy: 5 cm RMS
  - Range sampling rate: 15 kHz
  - Bottom detection by phase or amplitude. Seabed imaging & classification with backscatter (sidescan-like) output.
  - Full swath width accuracy to the latest IHO standard

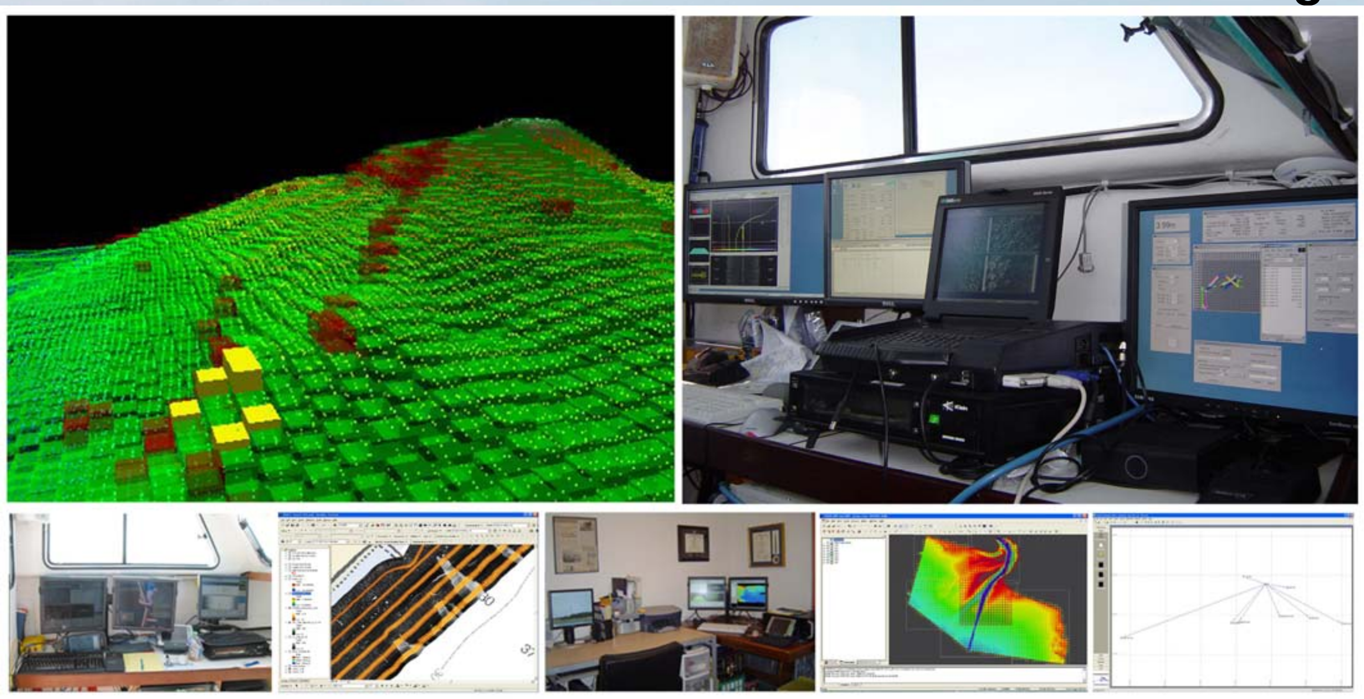
- **POS MV 320 v4 (with RTK Corrections)**
  - Roll, Pitch accuracy: 0.02° (1 sigma with GPS or DGPS)
  - 0.01° (1 sigma with RTK)
  - Heave Accuracy: 5 cm or 5% (whichever is greater)
  - Heading Accuracy: 0.02° (1 sigma) with 2 m antenna baseline
  - Position Accuracy: 0.02 - 0.10 m (RTK) with input

- **Trimble 5700 dual frequency GPS system & RTK-Basestation**
  - Instrument used for topo/bathy positioning and tidal corrections
  - High precision L1 and L2 measurements
  - 24 channels L1 C/A code, L1/L2 full cycle carrier
  - Extremely low latency (20 milliseconds)
  - Published horizontal accuracy: 10 mm + 1ppm RMS
  - Published vertical accuracy: 20 mm + 1ppm RMS

- **Odom Hydrographics Digibar Pro sound velocity probe**
  - Sampling rate: 10 Hz
  - Depth accuracy: > 31 cm
  - Velocity accuracy: +/- 0.3 m/sec

- **Applied Microsystems MicroSV sound velocity sensor**
  - SV: time of flight
  - Sampling rate: 10 Hz or continuous programmable
  - Velocity accuracy: 0.05 m/sec
  - Sampling rate: 10 Hz
  - AC or DC power

Processing



Geodynamics maintains a cluster of high-end computer workstations and file/backup servers for the most demanding geospatial data acquisition, processing and analysis. At geodynamics we specialize in high-end spatial data processing and analysis through geographic information science and 3D visualization.
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Instrumentation:

Hardware

- **Field**
  - Custom rack mounted multibeam acquisition PC
  - 3.6 GHz Intel Pentium 4 processors with 800 MHz system bus
  - 2 GB of RAM
  - 512 Dual DVI graphics card
  - (2) 500 GB SATA hard drives
  - Simrad SIS & Applanix POS View acquisition software
  - CARIS HIPS/SIPS
  - (3) Fujitsu pentop navigation PC
  - (3) Maxtor external backup hard drives ~ 850 GB of storage

- **Office**
  - (4) high-end Dell GIS processing workstations
  - (2) Dell workstation laptops
  - (2) 1 TB RAID network attached storage devices
  - (4) Maxtor / Seagate external backup drives ~ 1.2 TB of storage

Software

- **Multibeam / Side Scan**
  - Caris HIPS / SIPS 6 sp2
  - Triton Imaging ISIS
  - Triton Imaging BathyPro & DelphMap

- **Singlebeam**
  - **Hypack Max v. 6.2 sp1**
  - Caris HIPS / SIPS 6 sp2

- **Topographic**
  - Trimble Geomatics Office
  - Caris HIPS / SIPS 6 sp2 (Lidar)

- **GIS**
  - ArcView 3.3a (Spatial, 3D & Image Analyst)
  - ArcGIS 9.1 (Spatial, ArcScene, 3D, Survey & Geostatistical Analyst)
  - Surfer 8.0
  - ArcIMS

Final General Reevaluation Report
and
Final Environmental Impact Statement

on

Hurricane Protection and Beach Erosion Control

SURF CITY AND NORTH TOPSAIL BEACH
NORTH CAROLINA

Appendix R
Attachment 4

Surf City / North Topsail Beach, N.C. Shore Protection Project, Hardbottom Resource Confirmation and Characterization Study