Final Feasibility Report and Environmental Impact Statement

on

Coastal Storm Damage Reduction

SURF CITY AND NORTH TOPSAIL BEACH, NORTH CAROLINA

Appendix Q

Larval Entrainment

Appendix Q

Assessment Of Potential Larval Entrainment Mortality Due To Hydraulic Dredging Of Beaufort Inlet

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The larval fish distribution, abundance, seasonality, transport and ingress at Beaufort Inlet has been extensively studied, particularly during the fall-winter period coinciding with the permitted dredging window (see references below). The concentration of fish larvae (all species combined) typically ranges from 0.5 to 5 larvae m^{-3}. The concentration (i.e. abundance) of larvae varies both spatially and temporally over a range of scales. It is therefore important to recognize that not all larvae in the inlet would be vulnerable to entrainment. Larvae are not equally distributed in the inlet as the flow has considerable asymmetry. During flood the bulk of the transport is on the eastern side of the inlet and most larvae enter on that side. Ebb flows containing larvae that were not retained in the estuary are strongest on the west side of the inlet. In addition, many larvae exhibit a vertical migration strategy that facilitates tidal stream transport. That is, larvae are up in the water column during flood and descend to near the bottom during ebb. Such behavior helps to prevent larvae from being flushed back out the inlet.

One can estimate the potential larval entrainment mortality due to hydraulic dredging of Beaufort Inlet using a simple mathematical model that incorporates the following:

C = concentration of larvae
= 0.5 to 5.0 larvae m^{-3}

M = proportion of larvae dying by natural causes every six hours
= 0.0125 (i.e. 5 % d^{-1}) to 0.025 (i.e. 10 % d^{-1})

V = volume of water entrained by dredge (24 h operation)
= 173,299 m^3 d^{-1} (USACE)

$\mathbf{P_s}$ = spring tidal prism
= 1.42 E8 m^3 (Jarrett, 1976)

$\mathbf{P_n}$ = neap tidal prism
= 1.32 E8 m^3 (Logan, 1995)

$\mathbf{P_b}$ = proportion of larvae in the bottom of the water column
= 0.1 to 1.0

$\mathbf{P_c}$ = proportion of larvae in the navigation channel
= 0.1 to 1.0

$\mathbf{P_r}$ = proportion of larvae retained inside to estuary during ebb phase
= 0.1 to 1.0

$\mathbf{E_s}$ = proportion of daily spring tidal volume entrained by dredge
$= V / 2 P_s d^{-1}$
= 0.0006

$\mathbf{E_n}$ = proportion of daily neap tidal volume entrained by dredge
$= V / 2 P_n d^{-1}$
= 0.0007

$\mathbf{L_s}$ = initial number of larvae within a spring tidal prism
$= C * P_s$

$\mathbf{L_n}$ = initial number of larvae within a neap tidal prism
$= C * P_n$

$\mathbf{K_{sf}}$ = number of larvae entrained during a single spring tide flood phase
$= (L_s - (L_s * M * 2)) * P_b * P_c * E_s$

$\mathbf{K_{se}}$ = number of larvae entrained during a single spring tide ebb phase
$= (L_s - (L_s * M * 2) - K_{sf}) * P_b * P_c * P_r * E_s$

$\mathbf{K_{nf}}$ = number of larvae entrained during neap tide flood phase
$=(L_n - (L_n * M * 2)) * P_b * P_c * E_n$

$\mathbf{K_{ne}}$ = number of larvae entrained during neap tide ebb phase
$= (L_n - (L_n * M * 2)- K_{nf}) * P_b * P_c * P_r * E_n$

$\mathbf{K_s}$ = absolute larval entrainment mortality d^{-1} during spring tide
$= (K_{sf} + K_{se}) * 2$

$\mathbf{Z_s}$ = percent larval entrainment mortality d^{-1} during spring tide
$= (K_s/L_s*2)*100$

$\mathbf{K_n}$ = absolute larval entrainment mortality d^{-1} during neap tide
$= (K_{nf} + K_{ne}) * 2$

$\mathbf{Z_n}$ = percent larval entrainment mortality d^{-1} during neap tide
= $(K_n/L_n*2)*100$

Mortality due to entrainment was simulated 10,100 times for each level of natural mortality (i.e. 5% d^{-1} and 10% d^{-1}) during both spring and neap tidal conditions by systematically varying **C**, $\mathbf{P_b}$, $\mathbf{P_c}$, and $\mathbf{P_c}$ over the ranges outlined above using SAS Version 8.2 (SAS Institute Inc., Cary, NC). The results depicting the distribution of outcomes are shown below and include the minimum, maximum and mean impact levels as well as the 10%, 25%, 50% (median), 75% and 90% quantiles.

	Natural mortality 10 % d^{-1}				Natural mortality 5 % d^{-1}			
	$\mathbf{K_s}$ No.	$\mathbf{Z_s}$ %	$\mathbf{K_n}$ No.	$\mathbf{Z_n}$ %	$\mathbf{K_s}$ No.	$\mathbf{Z_s}$ %	$\mathbf{K_n}$ No.	$\mathbf{Z_n}$ %
min	914	0.0006	991	0.0008	925	0.0007	1004	0.0008
max	1660902	0.1170	1801169	0.1365	1682195	0.1185	1824261	0.1382
mean	246426	0.0316	267246	0.0316	249585	0.0320	270672	0.0373
10 %	16282	0.0036	17658	0.0042	16490	0.0037	17884	0.0043
25 %	48845	0.0070	52973	0.0082	49471	0.0071	53651	0.0083
50 %	132906	0.0239	144136	0.0278	134610	0.0242	145984	0.0282
75 %	376763	0.0579	408595	0.0676	381594	0.0587	413833	0.0684
90 %	657882	0.0632	713472	0.0737	666316	0.0640	722619	0.0746

What is quite apparent is that both $\mathbf{Z_s}$ and $\mathbf{Z_n}$ (i.e. the percentage of the daily flux of larvae entrained) are very low regardless of larval concentration and the distribution of larvae within the channel. Under the worst-case scenario where the dredge operates 24 h d^{-1}, all larvae are in the navigation channel, on the bottom, and with poor retention in the estuary following flood stage, the maximum percentage entrained barely exceeds 0.1 % d^{-1}. Most of the simulated scenarios (see the 90 % quantiles) indicate the percent entrainment mortality to be less than 0.06 to 0.07 % d^{-1} with over half falling below 0.03 % d^{-1} (see 50 % quantile). The actual number of larvae entrained however, can range from as few as 914 up to over 1.8 million depending on the initial concentration of larvae within the tidal prism.

This simple analysis of the potential entrainment impacts to larvae could be further refined by stochastically varying the spatial and temporal concentration of larvae and their positions within the water column, but, based on the results presented here, such effort is not required to achieve a useful first approximation of the level of impact to the resource. Because the estimated entrainment mortality, even under the worst-case scenario, is minimal (0.1 % d^{-1}), it seems reasonable to conclude that while any larvae

that are entrained will certainly be killed, it is likely that the impact at the population-level would be insignificant.

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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

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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 Alligator Bay to Surf City's Southern Limit

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 Alligator Bay to Surf City's Southern Limit

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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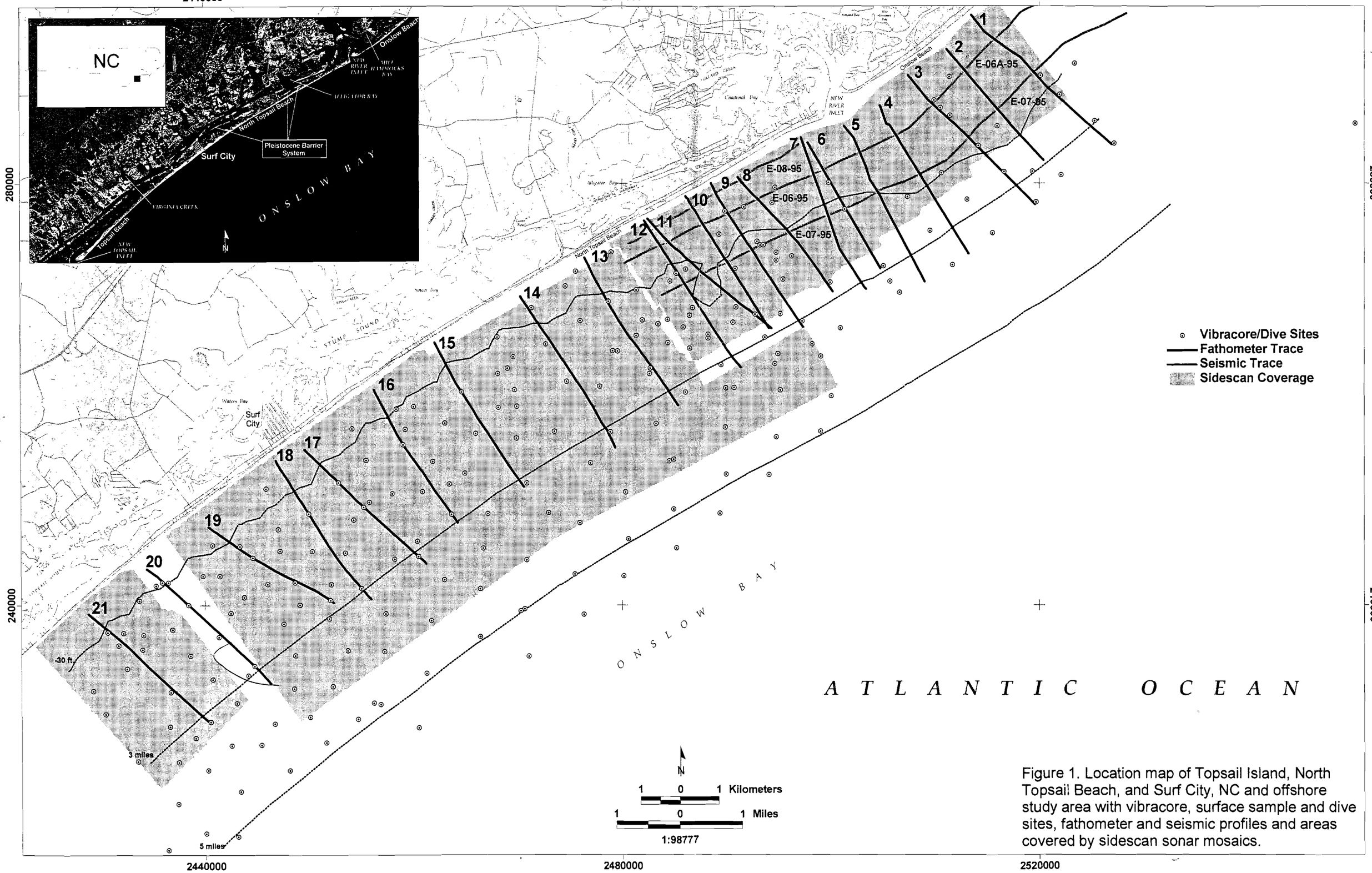


Figure 1. Location map of Topsail Island, North Topsail Beach, and Surf City, NC and offshore study area with vibracore, surface sample and dive sites, fathometer and seismic profiles and areas covered by sidescan sonar mosaics.

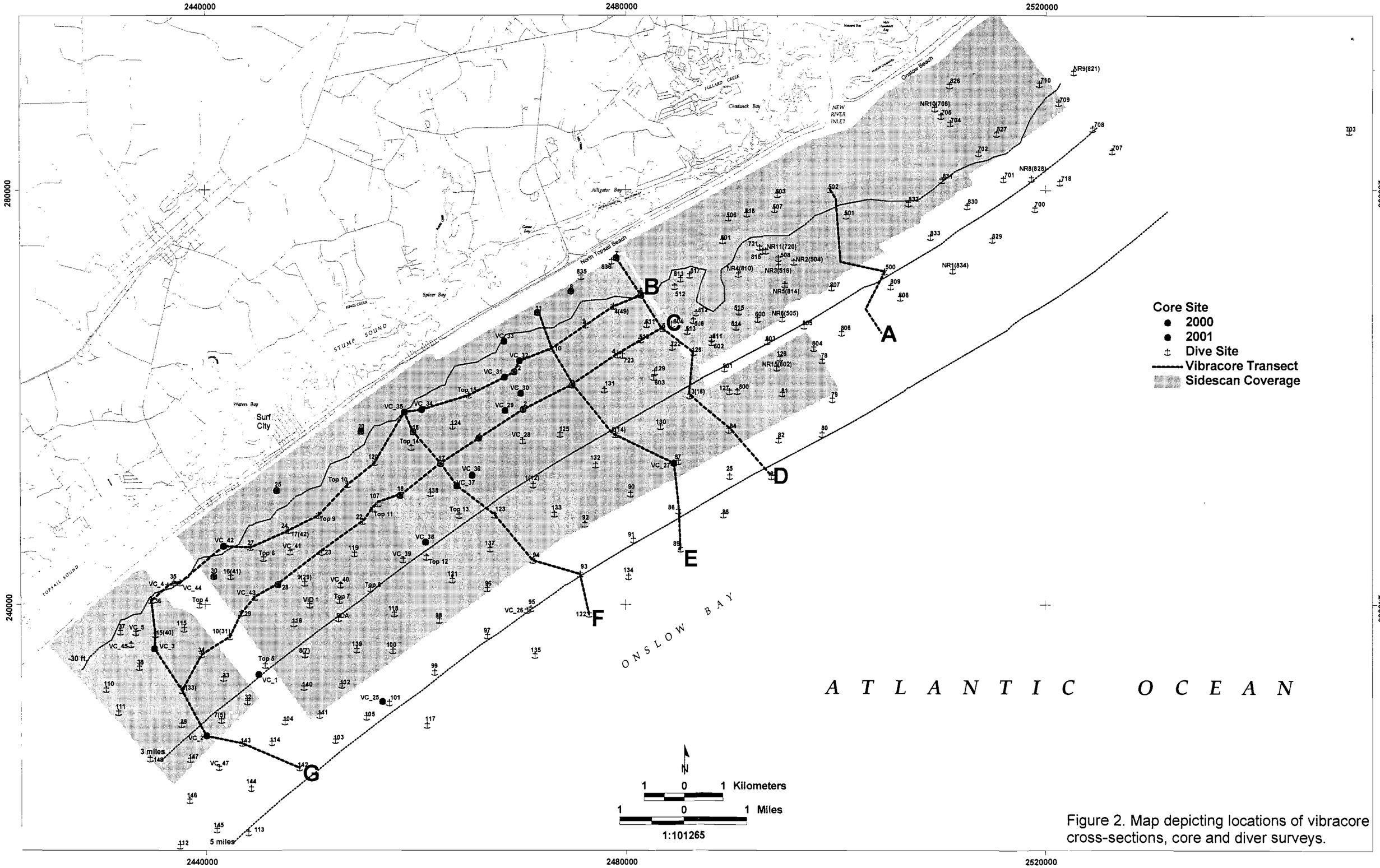


Figure 2. Map depicting locations of vibracore cross-sections, core and diver surveys.

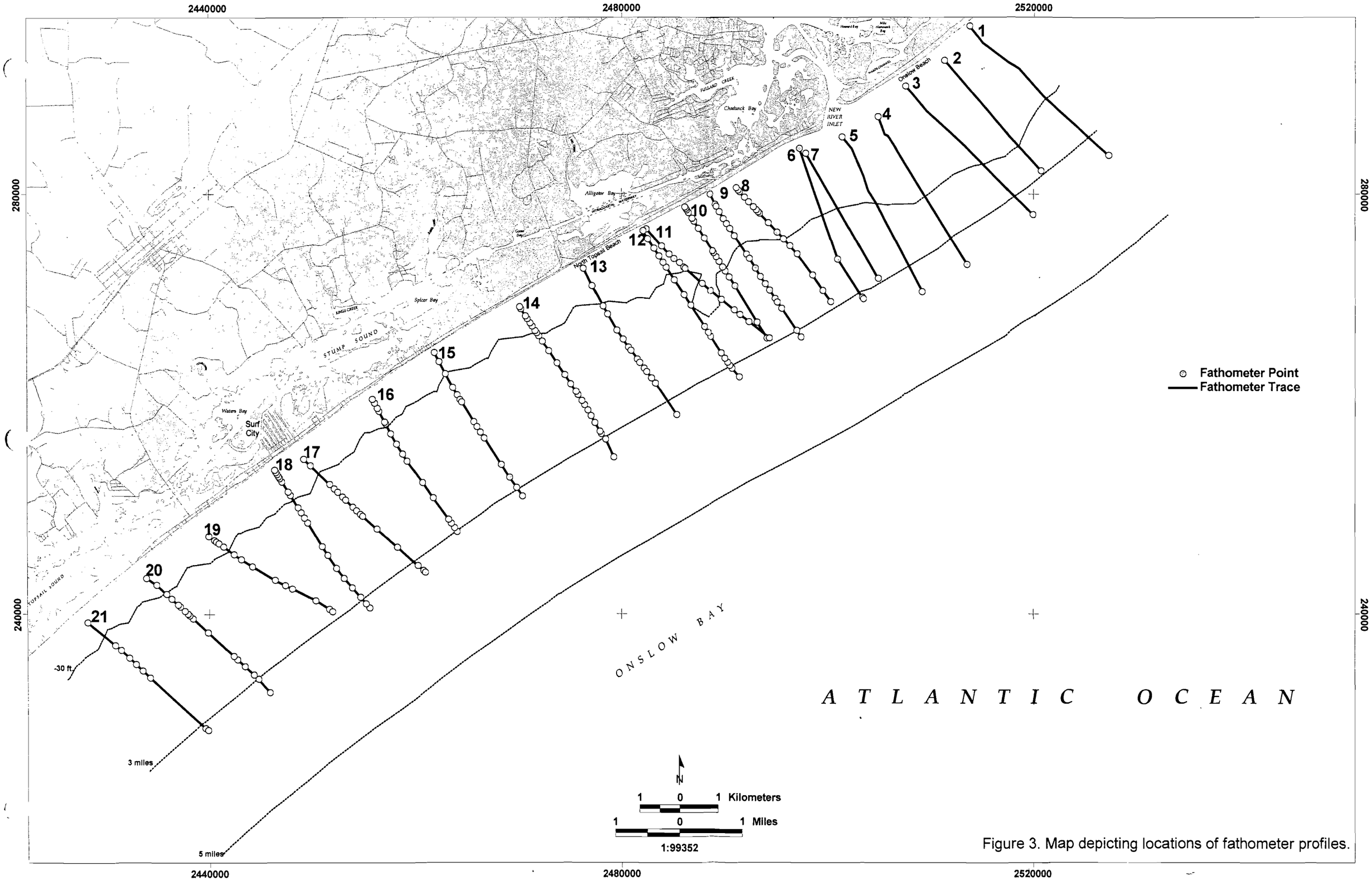


Figure 3. Map depicting locations of fathometer profiles.

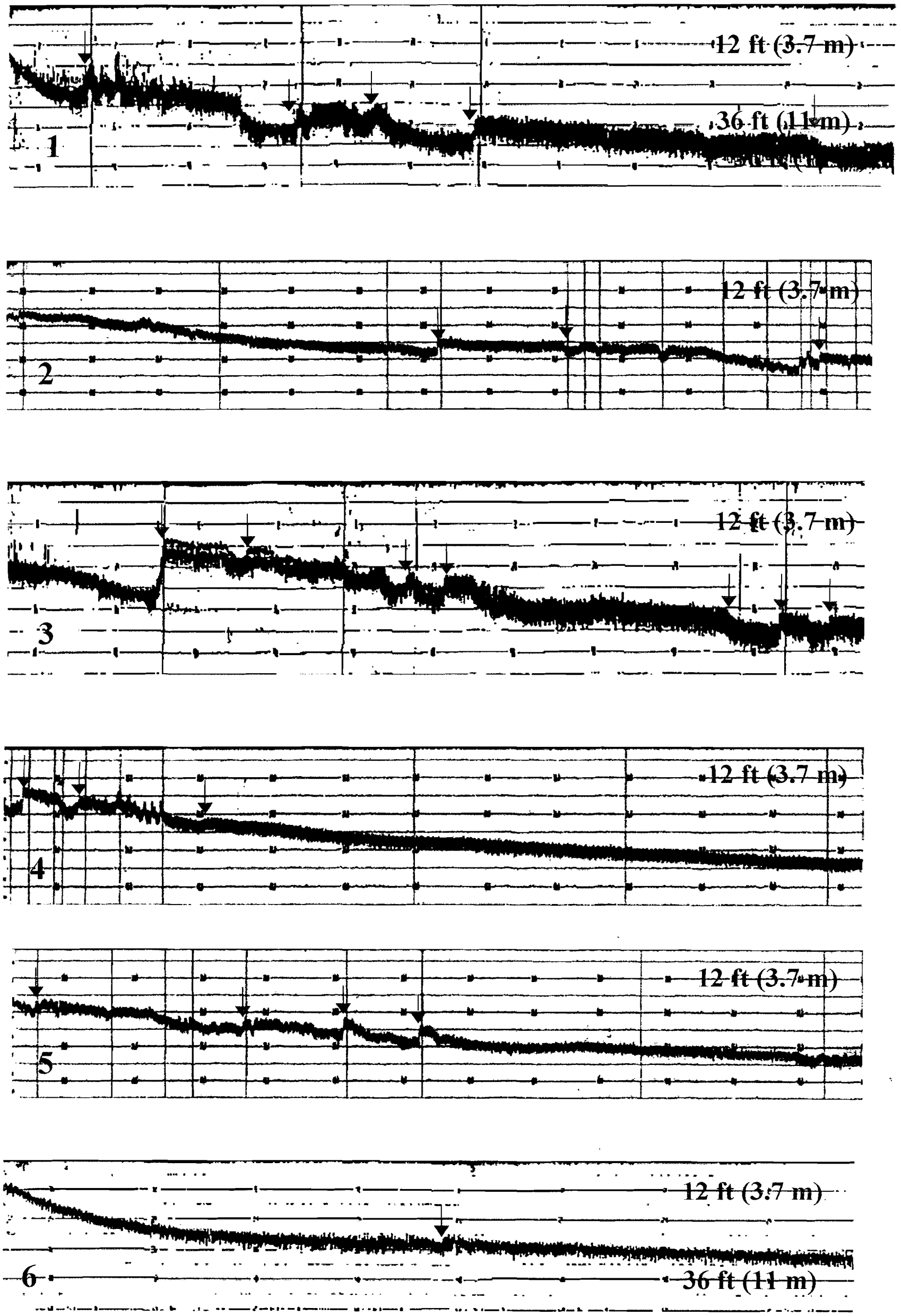


Figure 4. Shore normal fathometer profiles offshore Onslow Beach and New River Inlet. See Figure 3 for locations. Red Arrows represent limestone hardbottoms (Scarps). Note irregular nature of profiles. Horizontal scale is approximately 3 miles (4.8 kilometers).

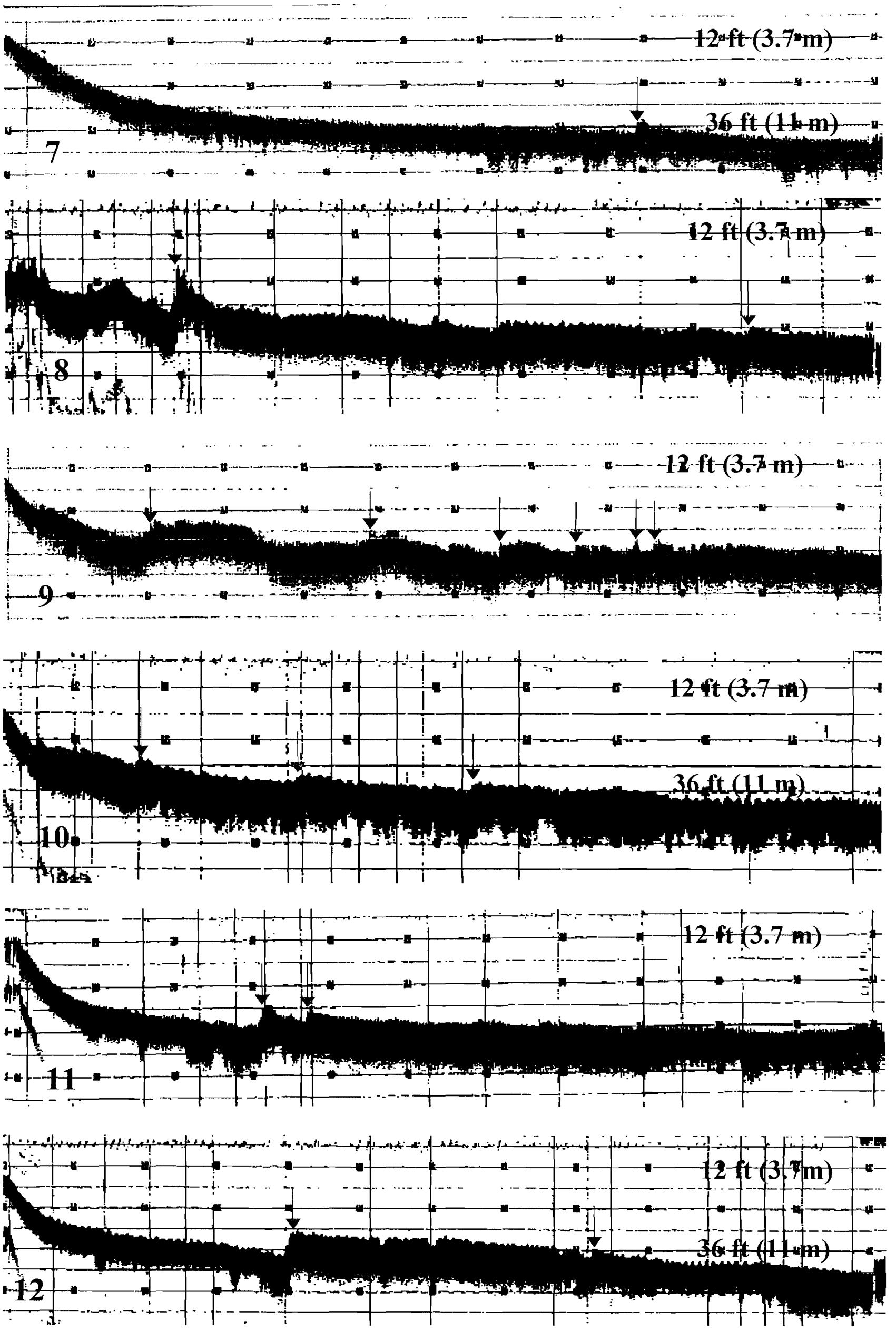
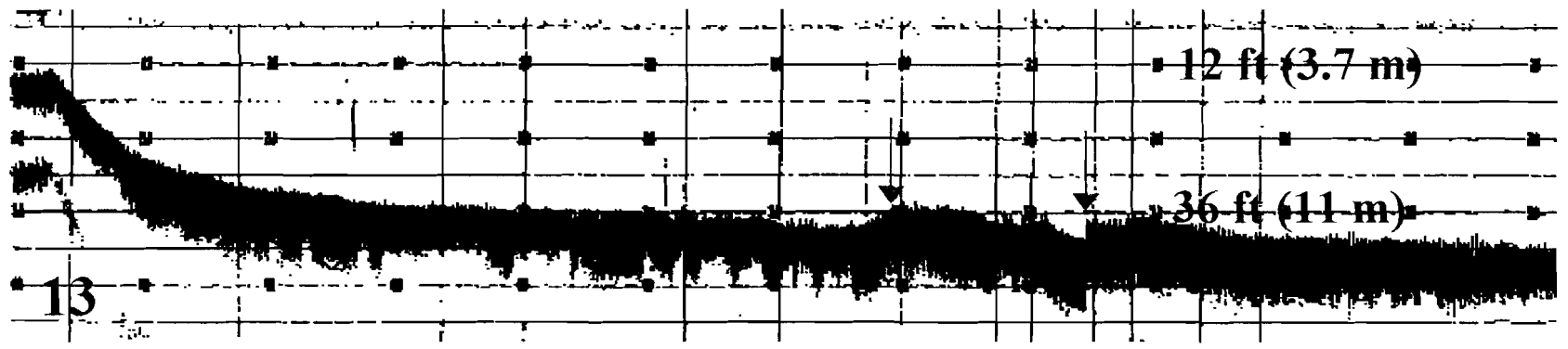
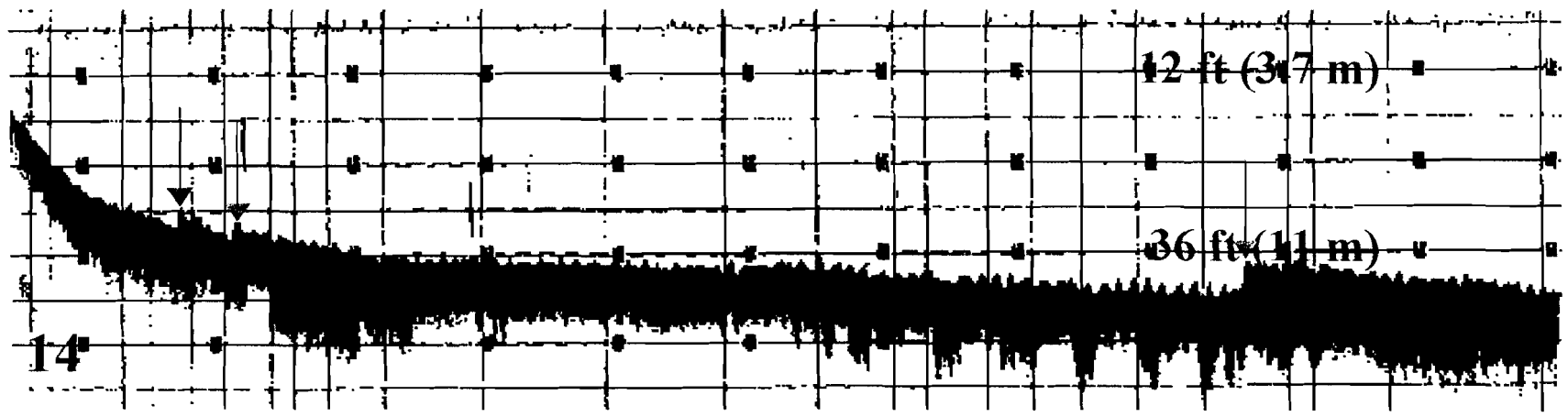
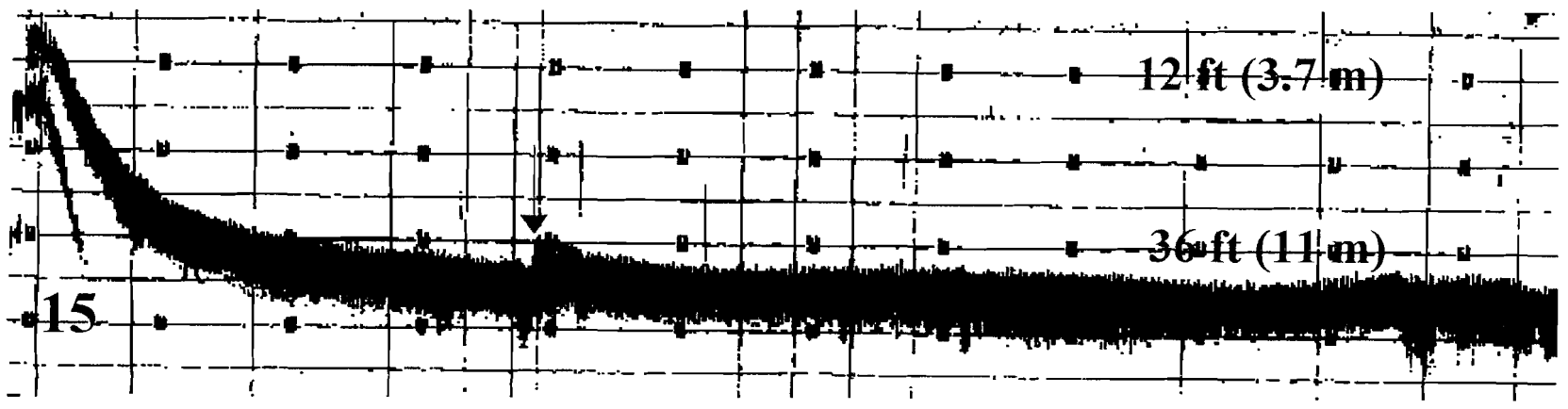
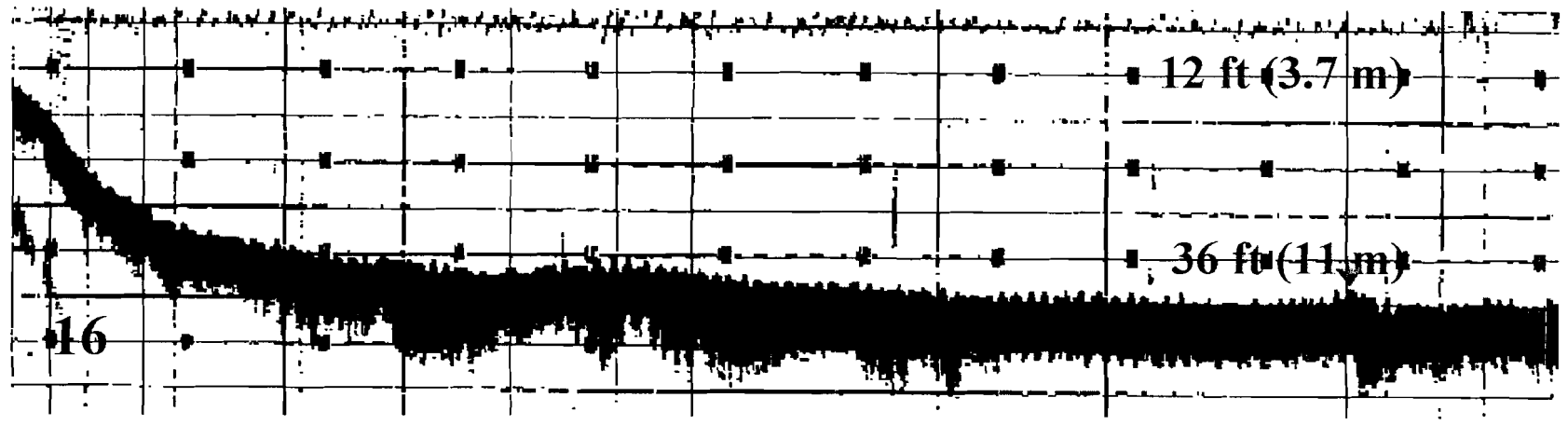


Figure 5. Shore normal fathometer profiles offshore North Topsail Beach. See Figure 3 for locations. Red Arrows represent limestone hardbottoms (Scarps). Note irregular nature of profiles. Horizontal scale is approximately 3 miles (4.8 kilometers).









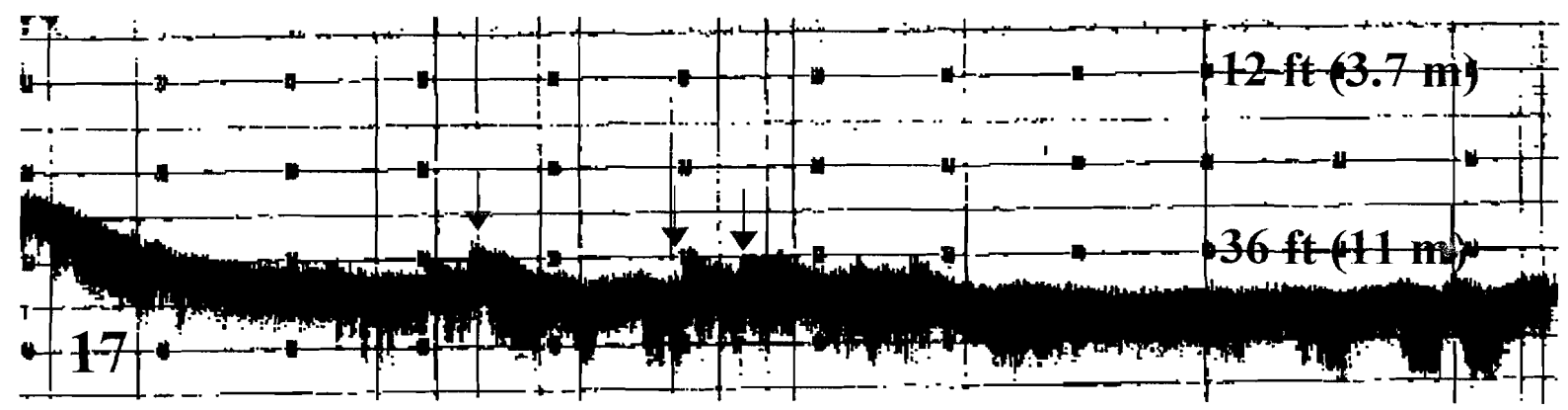


Figure 6. Shore normal fathometer profiles offshore North Topsail Beach - Surf City. See Figure 3 for locations. Red arrows represent limestone hardbottoms (Scarps). Note irregular nature of profiles. Horizontal scale is approximately 3 miles (4.8 kilometers).

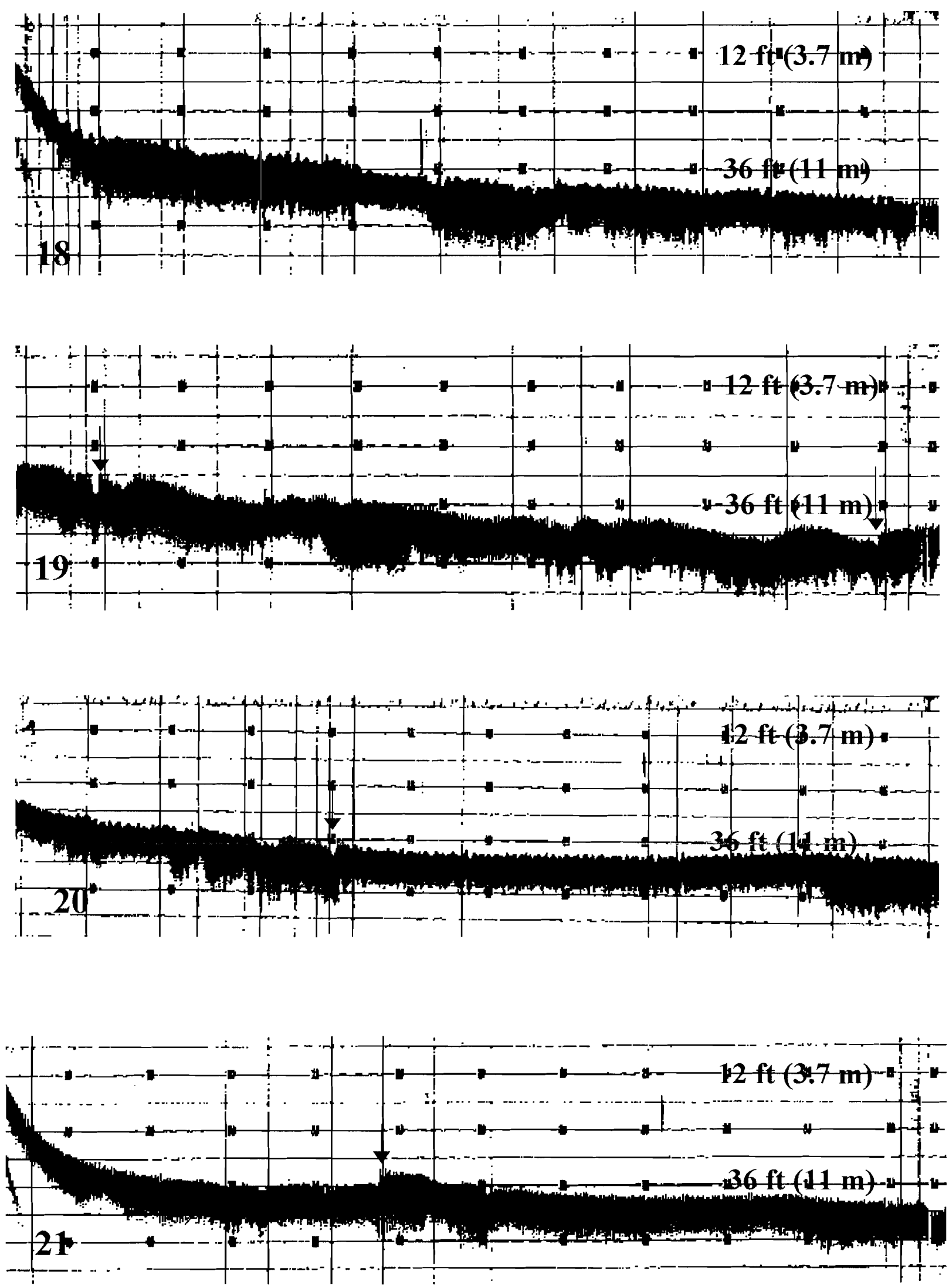


Figure 7. Shore normal fathometer profiles offshore Surf City. See Figure 3 for locations. Red arrows represent limestone hardbottoms (Scarps). Note irregular nature of profiles. Horizontal scale is approximately 3 miles (4.8 kilometers).

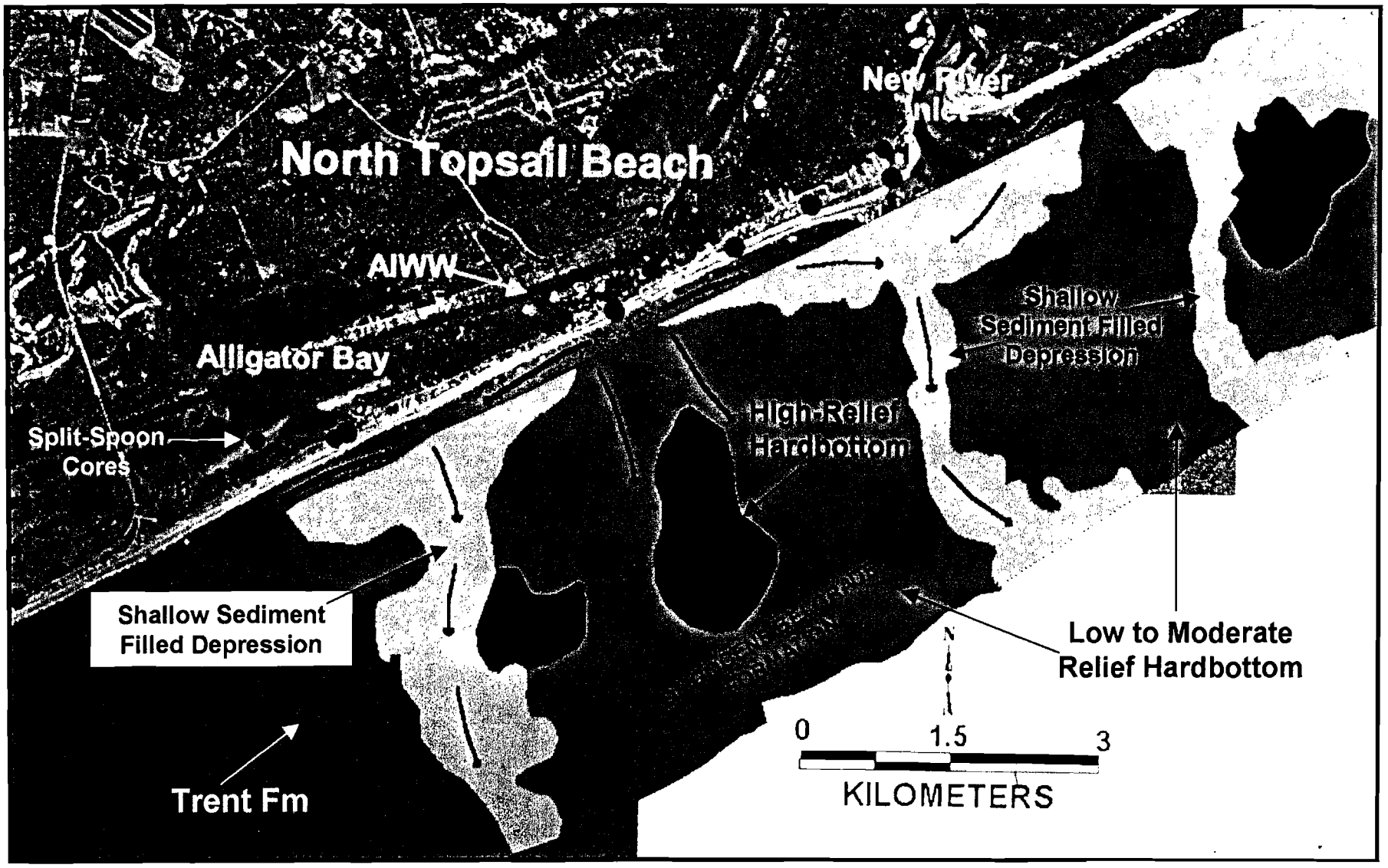


Figure 8. Map depicting nature of shoreface hardbottoms. Photograph (1993) depicts location of split-spoon cores recovered along barrier. Data indicate a saddle in the underlying limestone occurs beneath the barrier in the vicinity of Alligator Bay and the shallow linear depression that extends seaward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

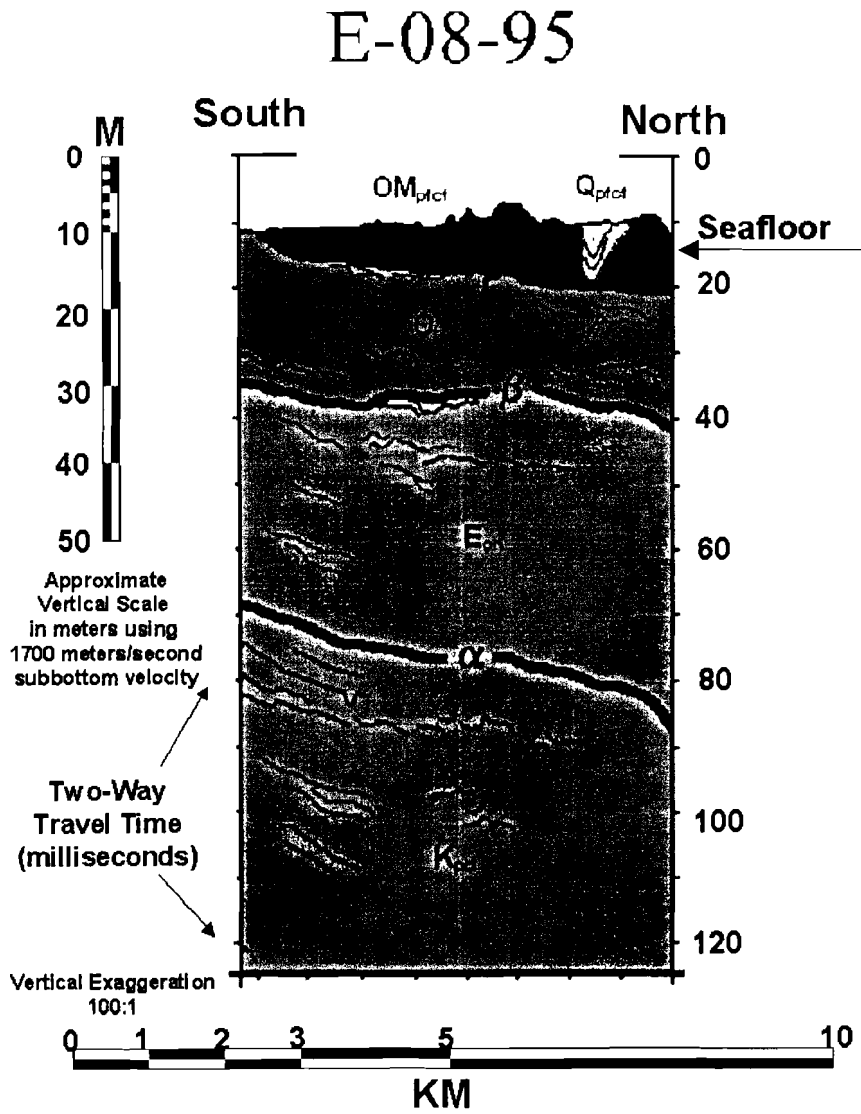
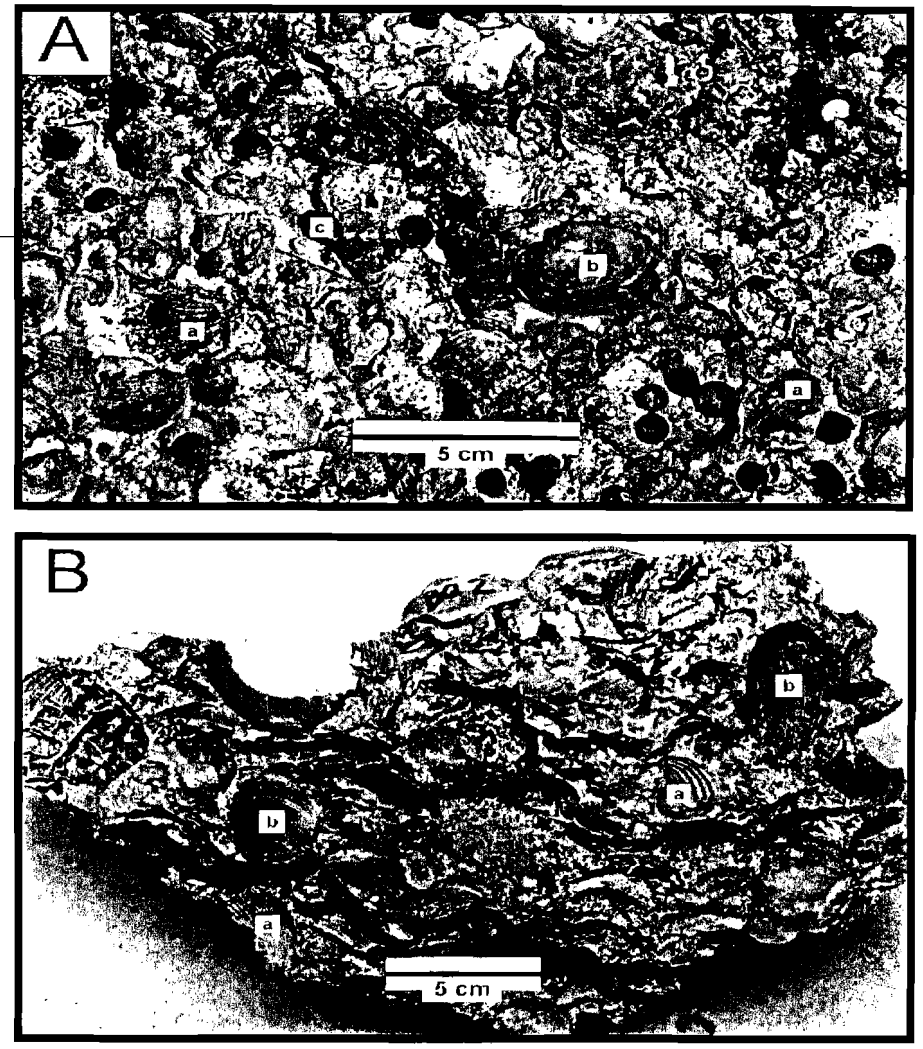


Figure 9. High resolution seismic line offshore North Topsail Beach and photographs of limestone. See Figure 1 for location of seismic line (After Johnston, 1998 and Cleary and Riggs, 1999).



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).

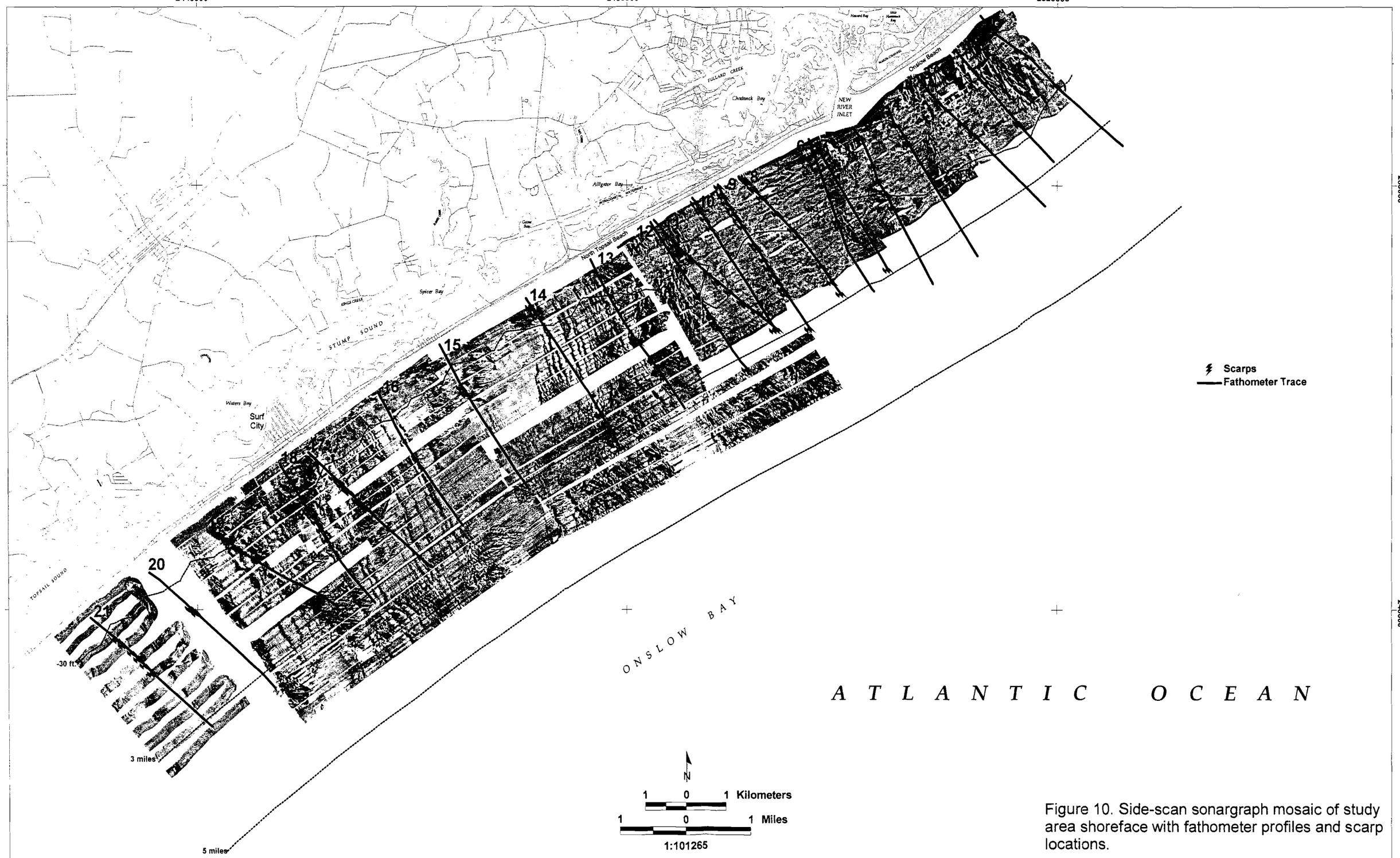


Figure 10. Side-scan sonargraph mosaic of study area shoreface with fathometer profiles and scarp locations.

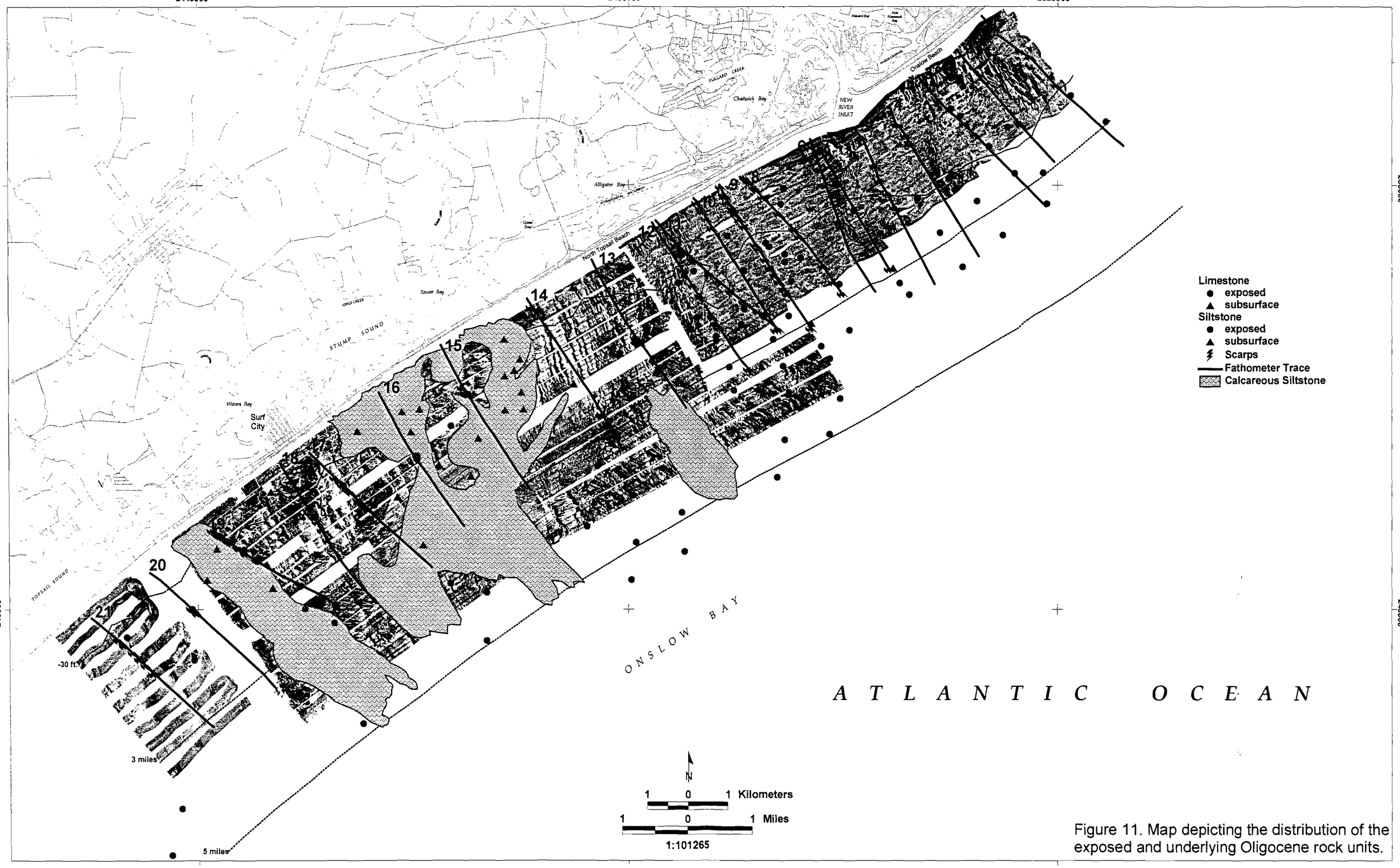
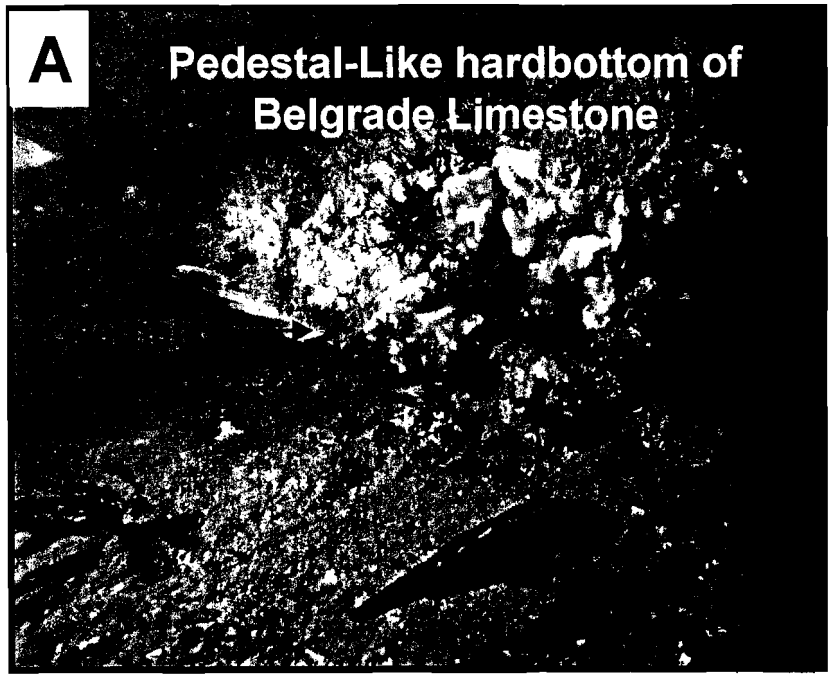


Figure 11. Map depicting the distribution of the exposed and underlying Oligocene rock units.



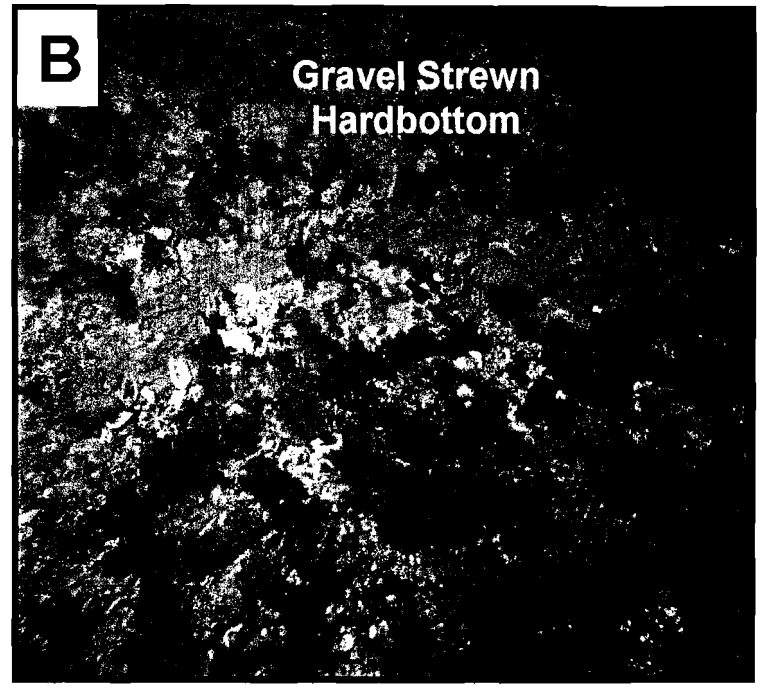


Figure 12. Bottom photographs of hardbottom area at dive site 700 on North Topsail Beach shoreface. **A**. View of a small pedestal-like, heavily encrusted hardbottom. Rock exposure is extensively bored and mantled with a variety of sponges and calcareous algae. Overhang is ~ 1.25 ft high. Thin sand/gravel 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".

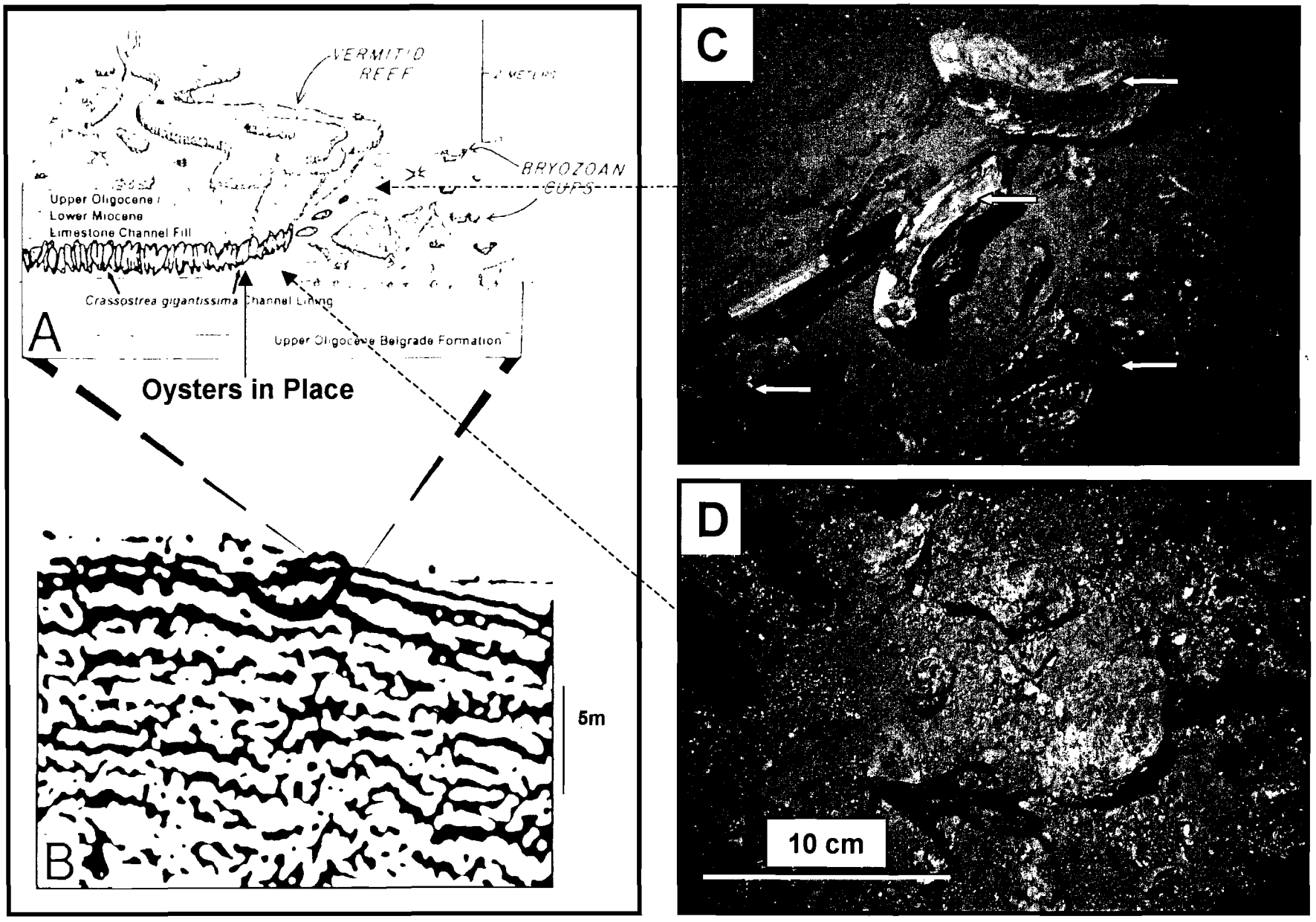
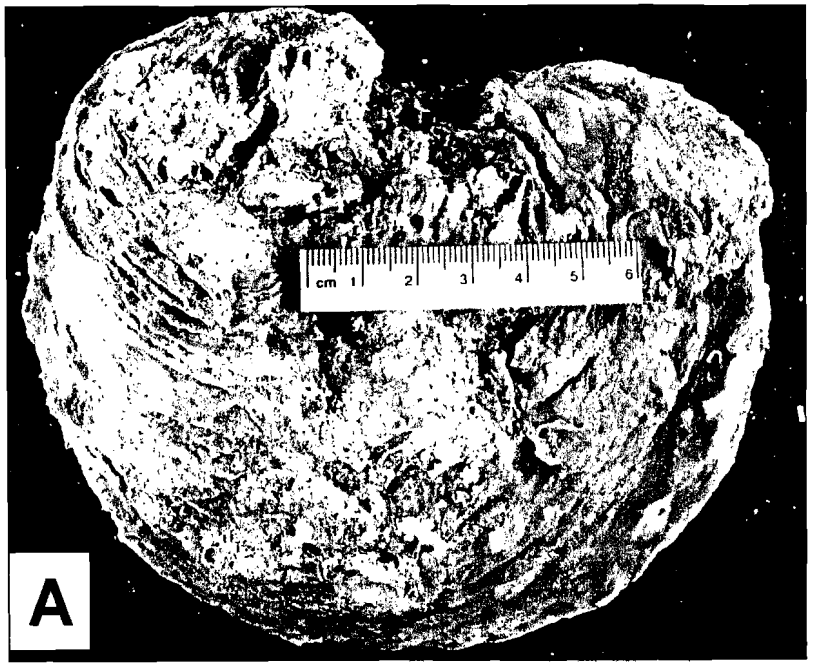
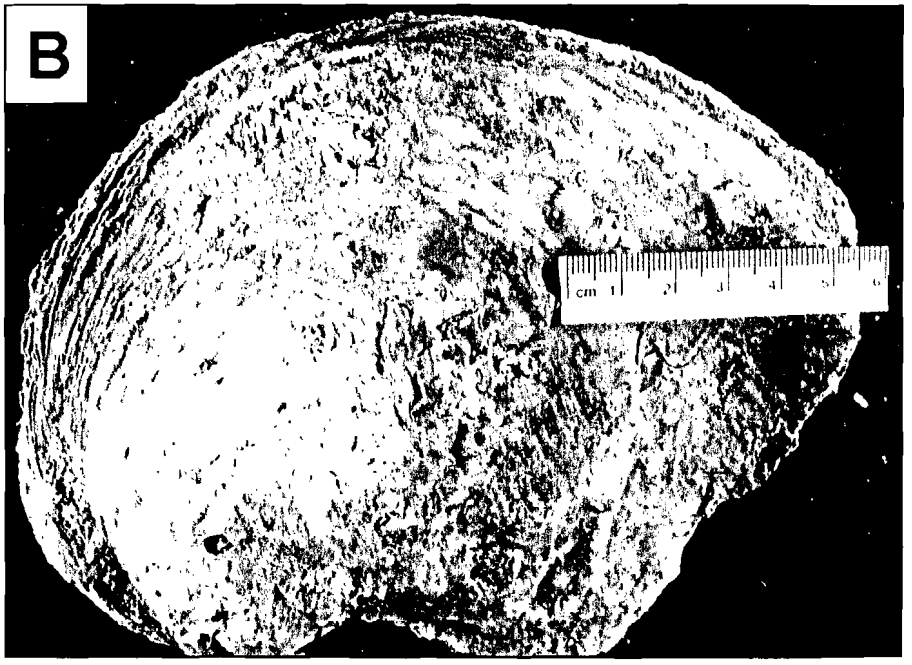
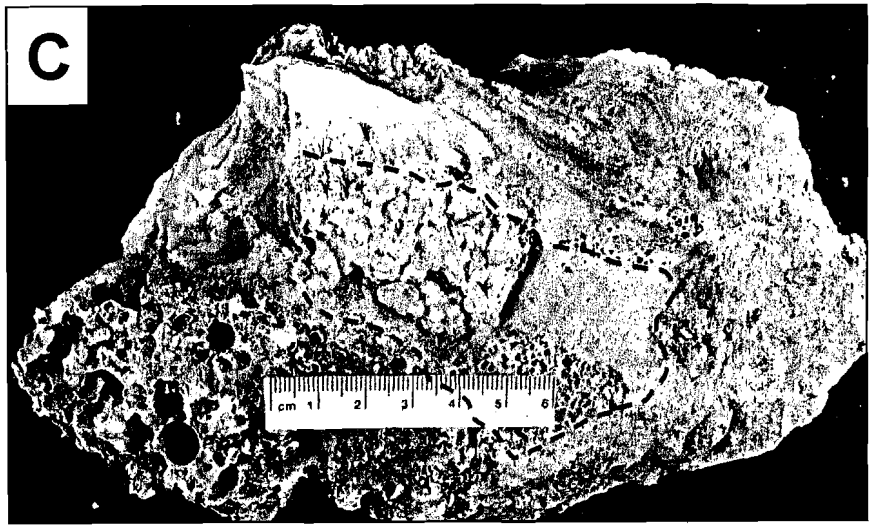


Figure 13. Cross-sectional view of Crassostrea gigantissima channel structure forming moderate relief hardbottom. **A**. exposed channel fill (calcareous cemented sandstone) and giant oysters lining channel bottom (after Crowson,1980). **B**. Enlarged seismic profile section (E-06-95) showing channel 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).

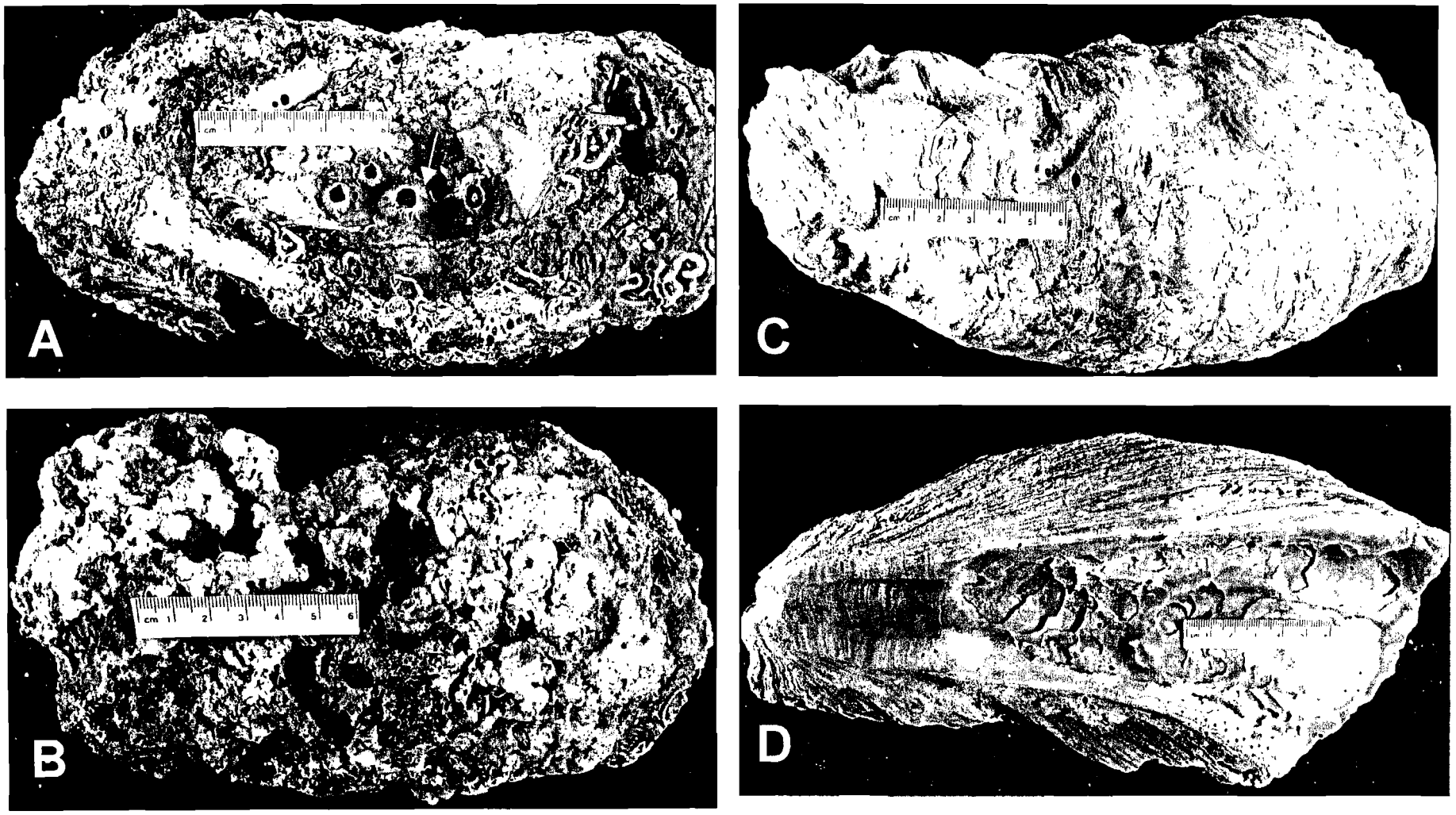


Figure15. Giant oyster (Crassostrea Gigantissima) valves. **A**. Encrusted disarticulated oyster valve from Site 721 offshore North Topsail Beach (interior view). **B**. Bored and encrusted disarticulated oyster valve from Site 721 (top view) **C**. Large fragment of disarticulated valve of oyster estimated 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.

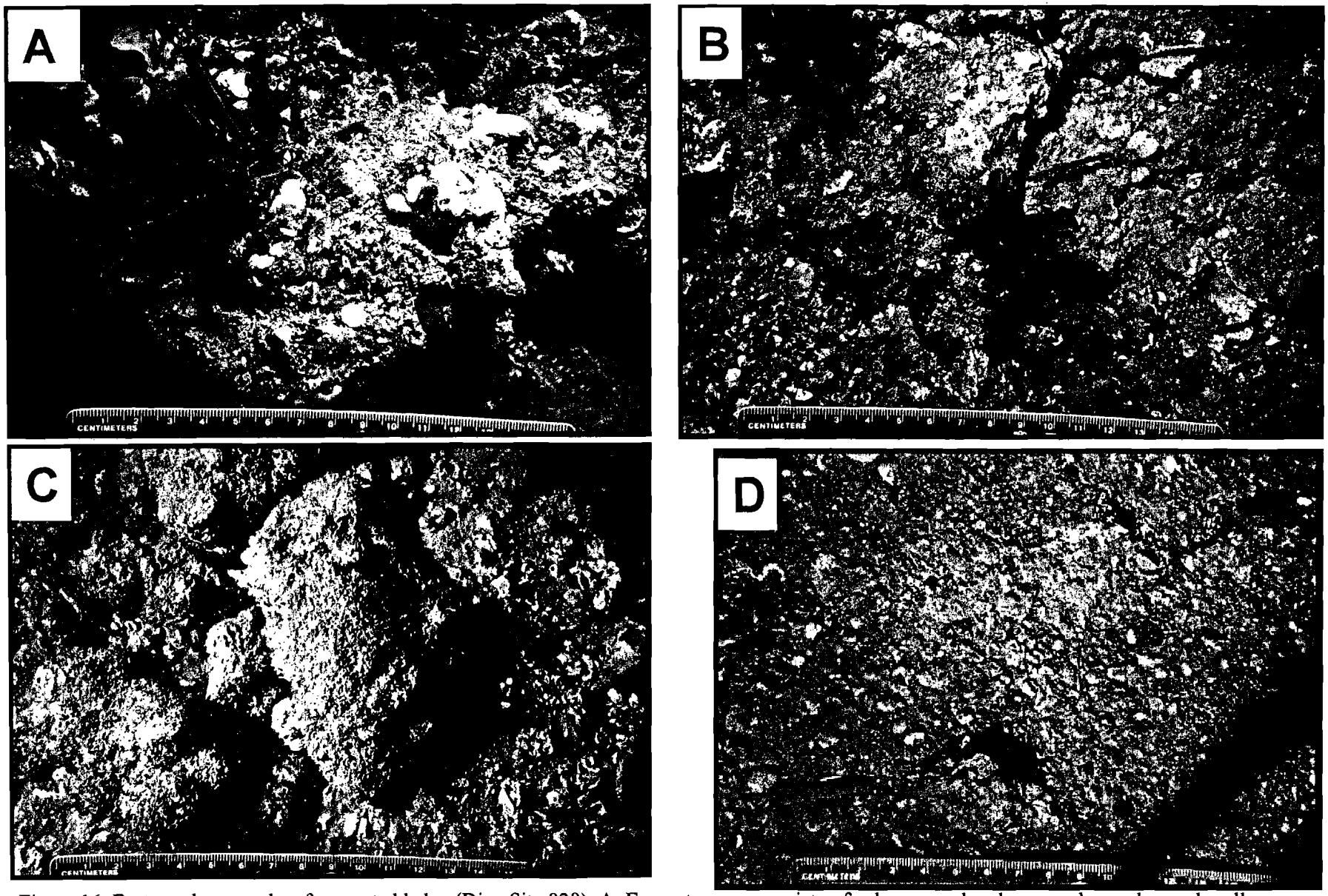


Figure 16. Bottom photographs of encrusted ledge (Dive Site 828). **A**. Encrusters are a variety of calcareous alga, bryozoa, barnacles, and molluscs. Sponges and macro alga also colonize the higher portions of the hardbottom ledges and scarps. Small overhang is visible in lower right where sand abuts 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.

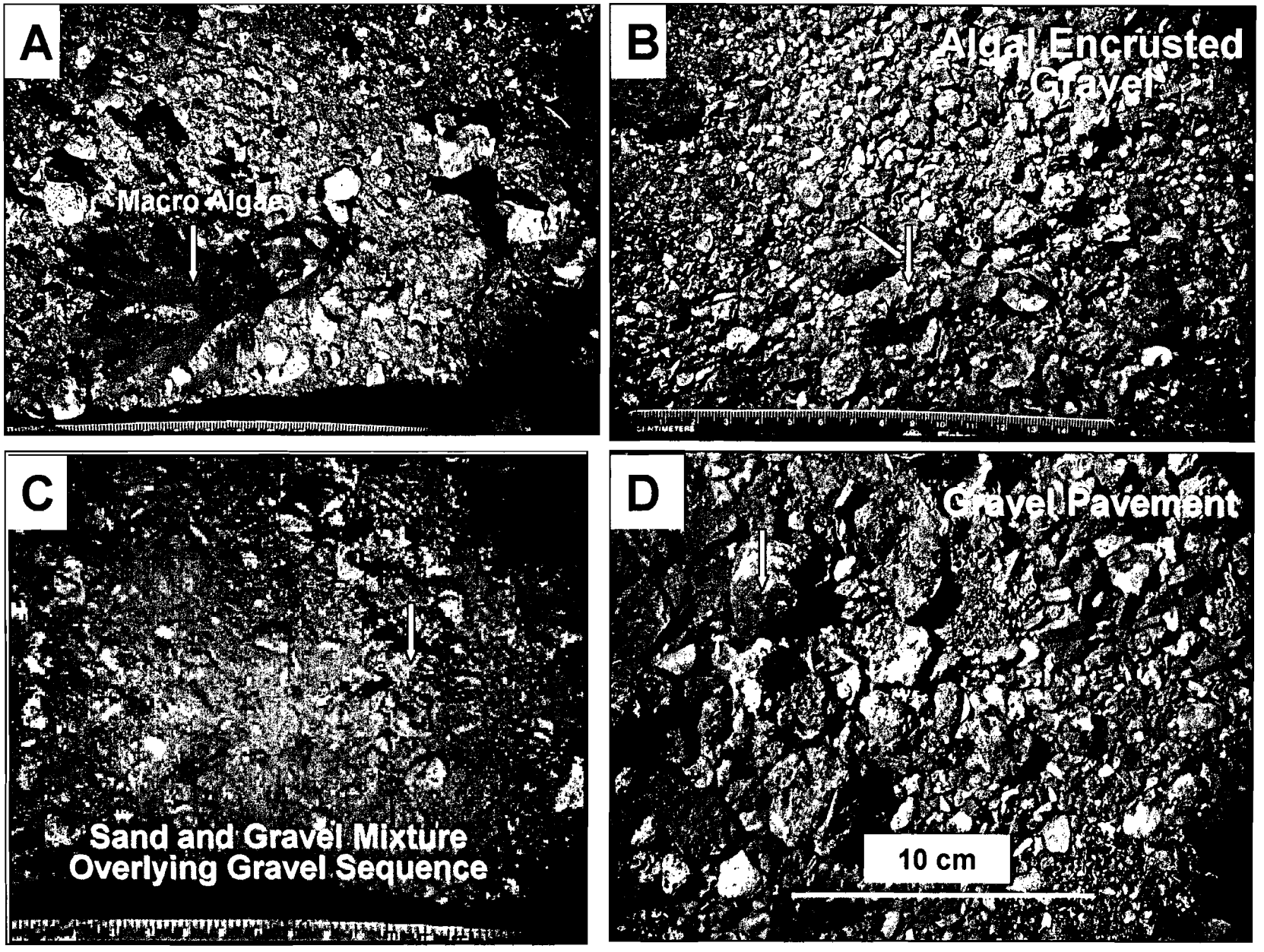


Figure 17. Bottom photographs of Dive Site 810 on North Topsail Beach shoreface in an area of moderate to high relief hardbottoms (>6 ft). **A**. Sand and gravel mixture overlying rock surface. **B**. Gravel lag produced by bioerosion, **C**. Sandy gravel mixture at protected scarp base. **D**. Gravel-sized 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.

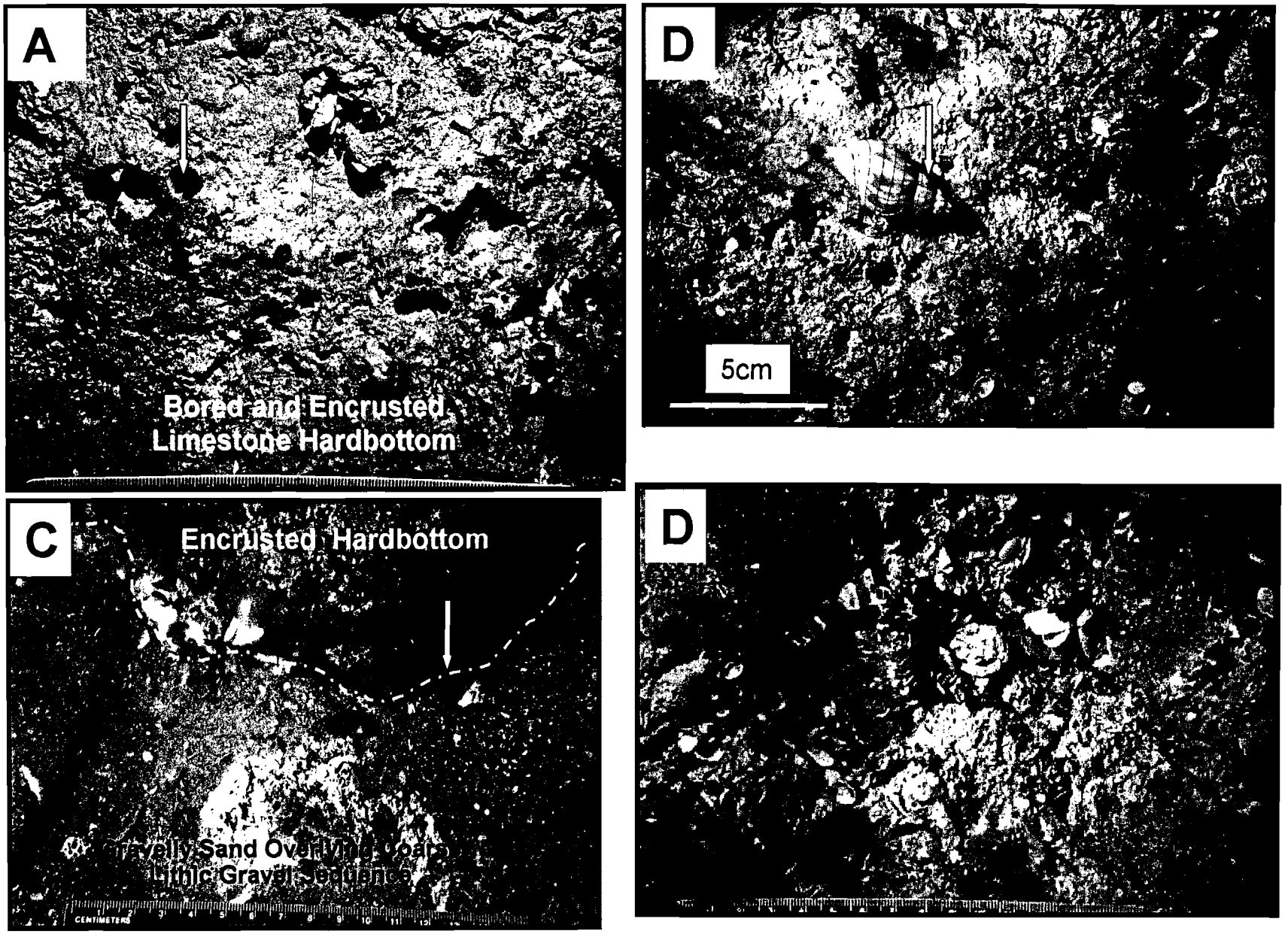
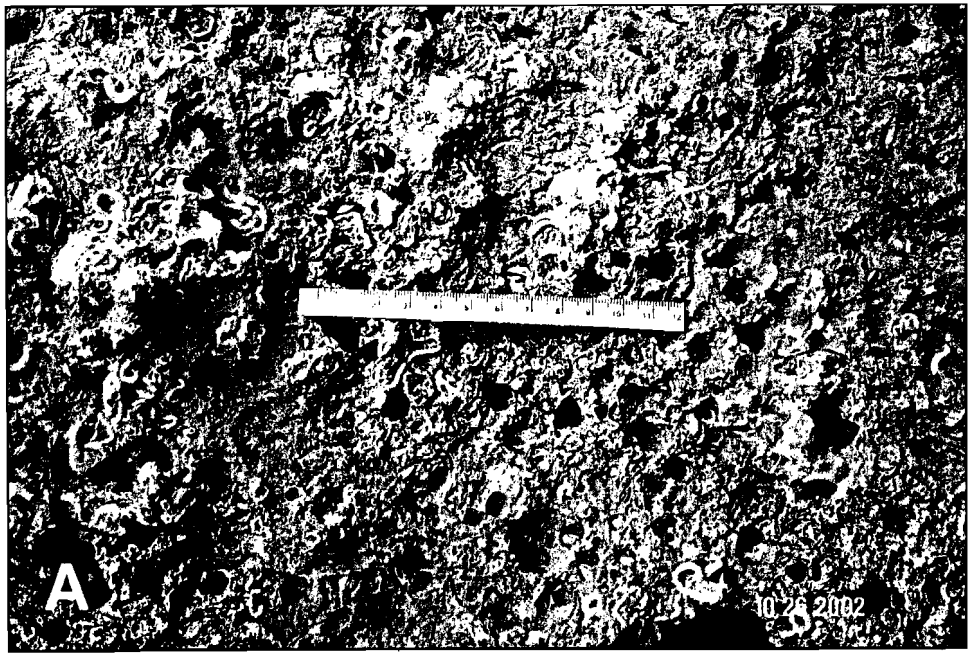
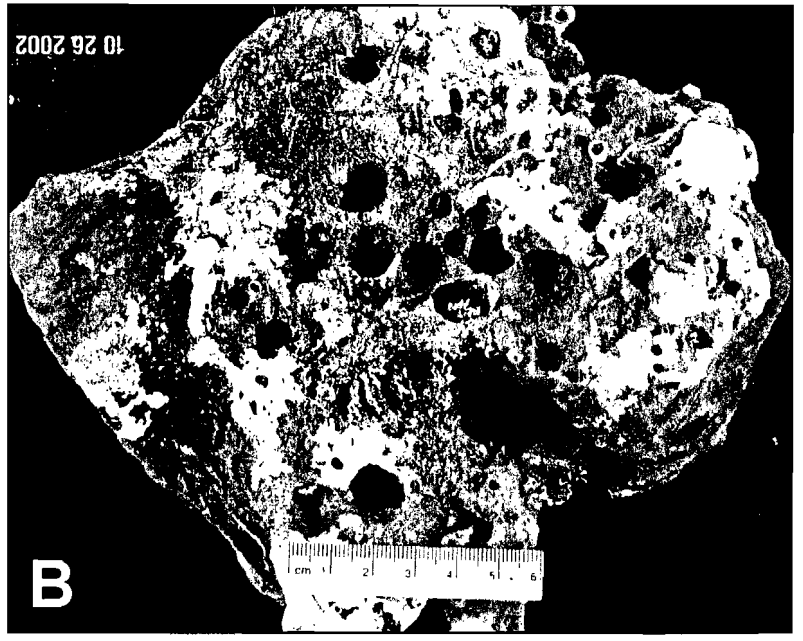


Figure 18. Bottom photographs at dive Site 814 on flat irregular hardbottom. Scale is 15 cm in length. **A**. Bored algal encrusted limestone platform. **B**. Low relief bored and encrusted ledge and contact between rock and sand veneer (lower right). Note grazing gastropod. **C**. Low relief limestone 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.





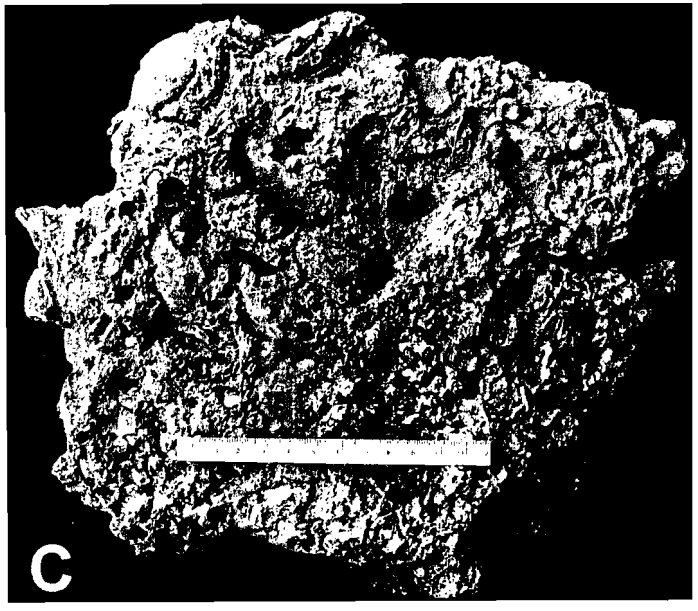
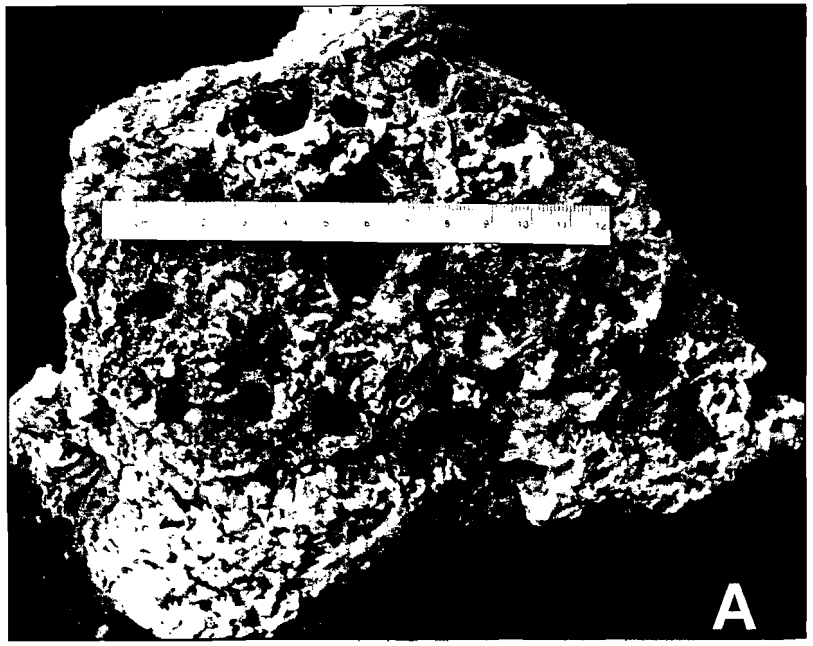
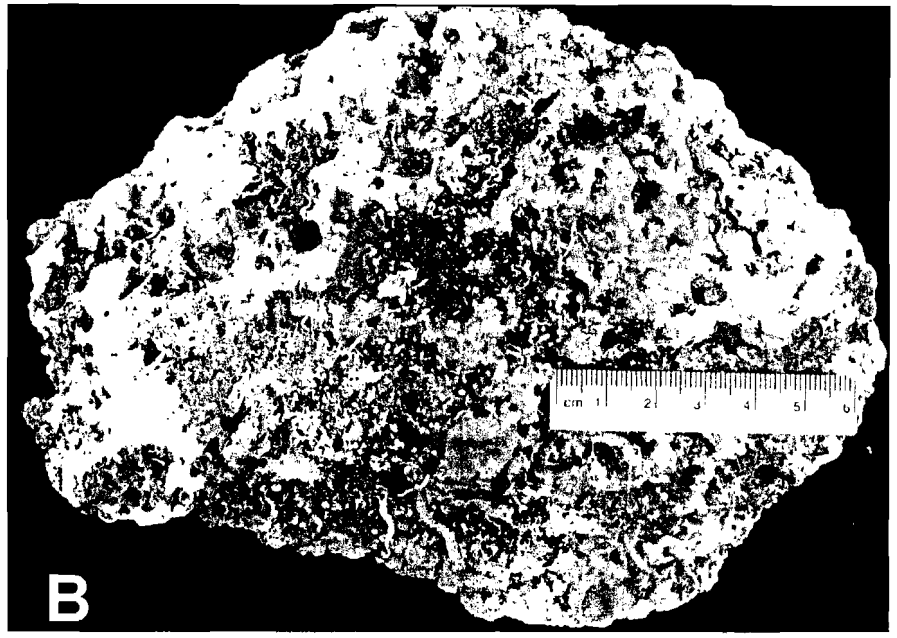


Figure 19. **A**. Top of large sandy biomoldic limestone slab with bores and encrusting organisms (coral, worm tubes, algae,and bryozoans). The 10 x 50 x 70 cm slab was found at base of a scarp near Site 508 offshore North Topsail Beach. **B**. Rounded, iron-stained, bored and encrusted calcite cemented 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).





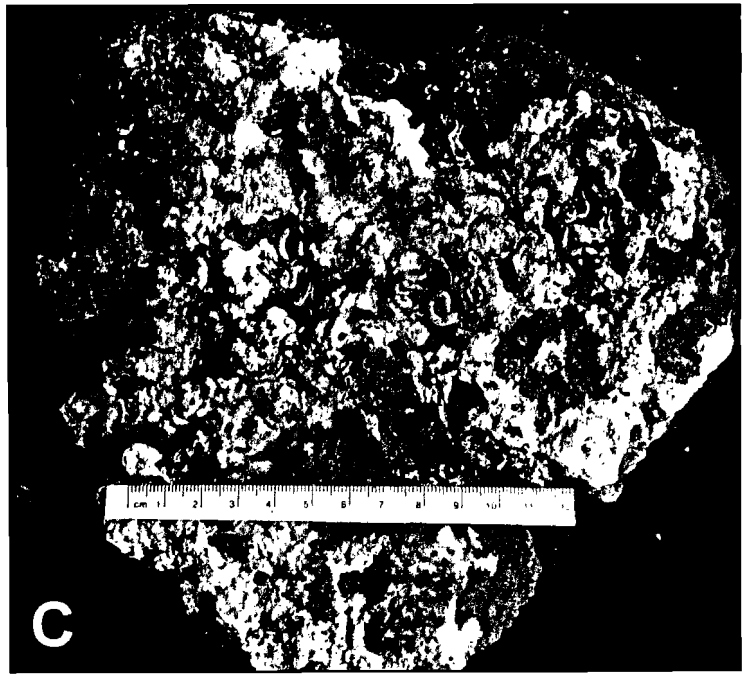


Figure20. Bored and encrusted limestone fragments. **A**. Bored and algal encrusted limestone fragment from debris at base of small overhang in vicinity of Site 516 offshore North Topsail Beach. **B**. Algal and worm tube encrusted surface of sandy limestone at Site 712 near base of High relief scarp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

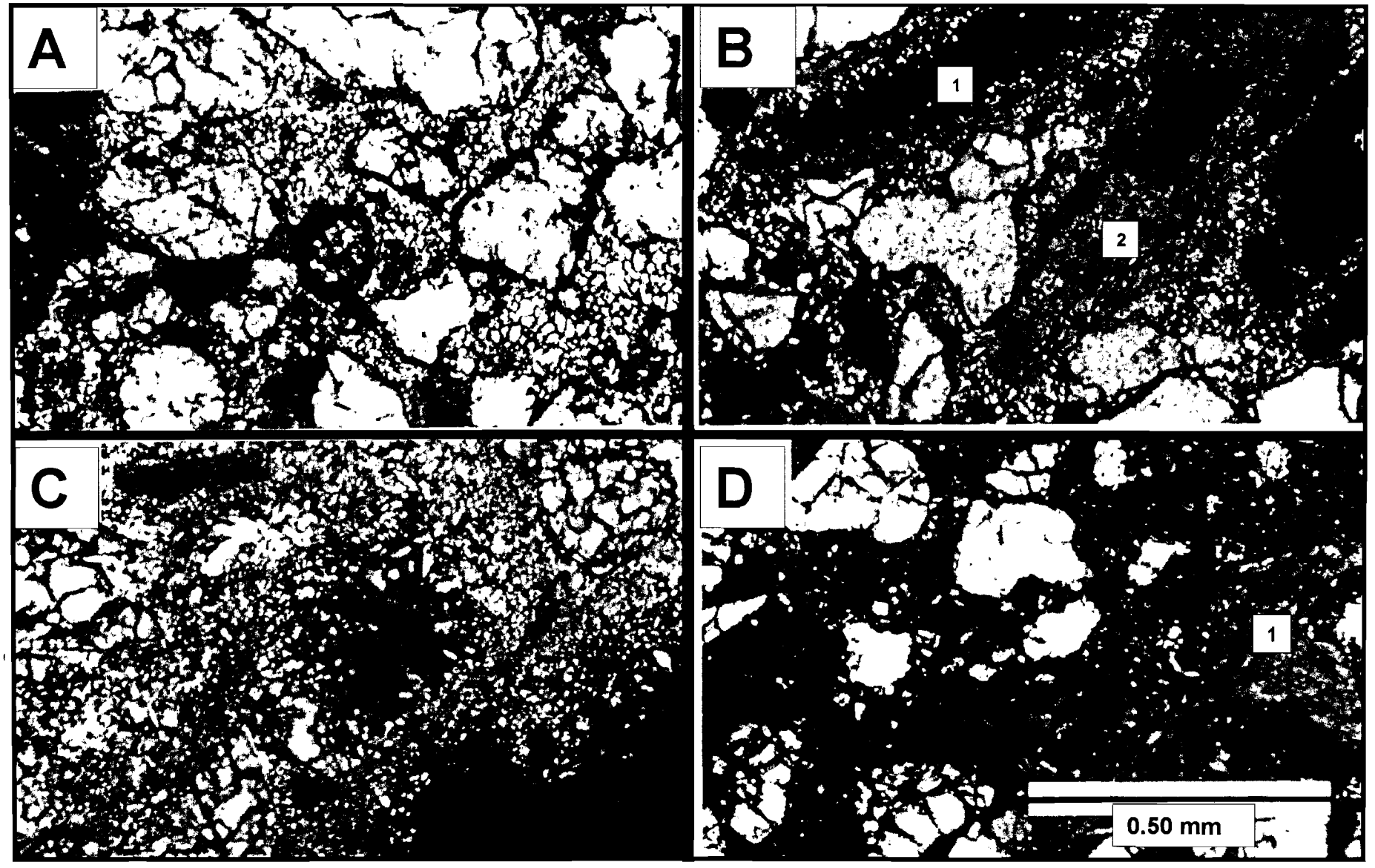


Figure 21. Photomicrographs of Belgrade Limestone from the North Topsail Beach shoreface (modified after Johnston, 1998). Red color is a stain used to enhance the identification of constituents. Plain light. **A**. Equant calcite cemented quartz . **B**. Pelcypod mold formed by dissolution of shell material (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).

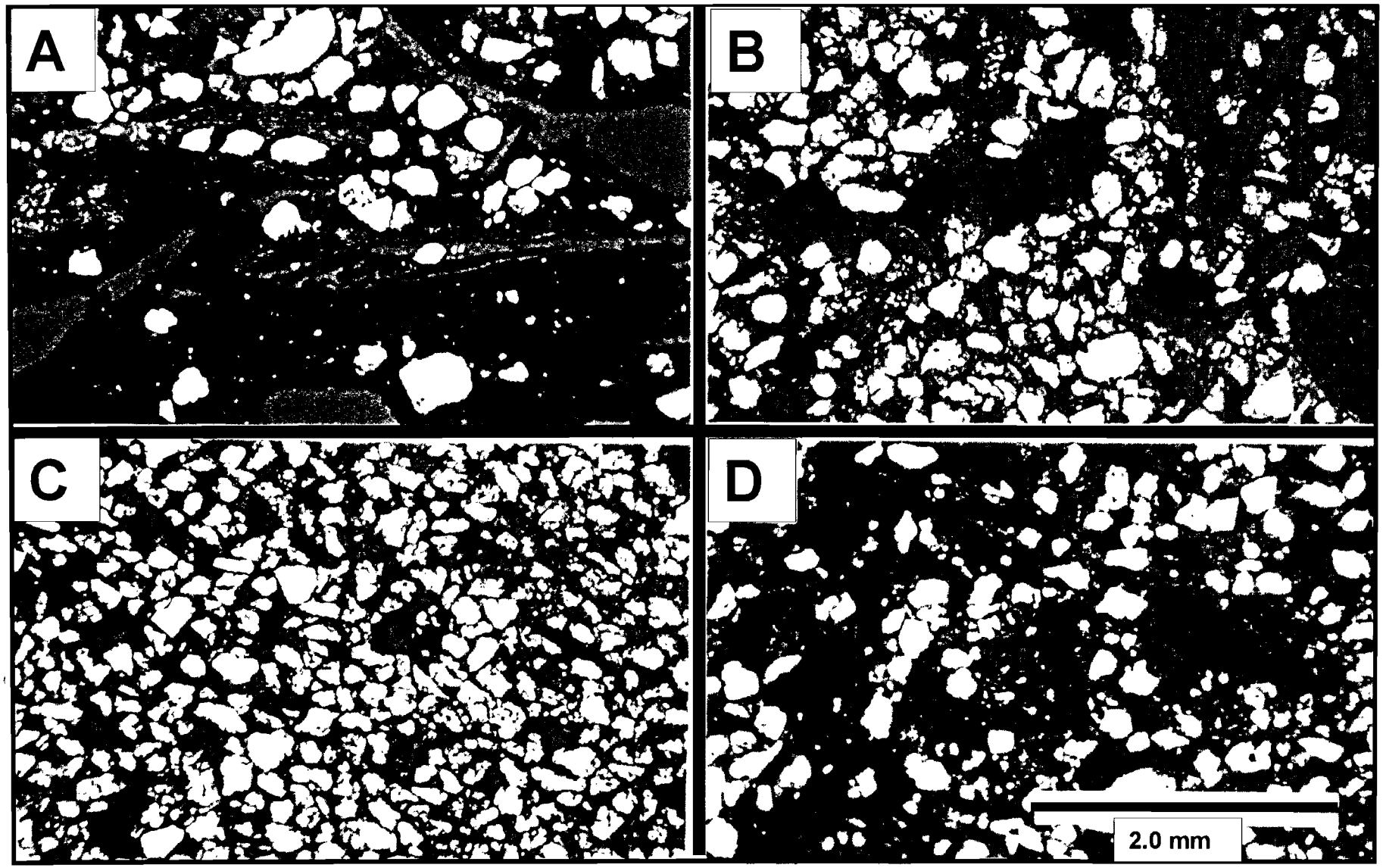


Figure 22. Photomicrographs of loose lithoclasts from shoreface platform (after Johnston, 1998). **A**. Sandy moldic biomicrudite with abundant molds. Blue background is from dye in impregnating medium. **B**. Sandy moldic biosparrudite. Note segregation of bio moldic pores (dissolved shells). **C**. 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).

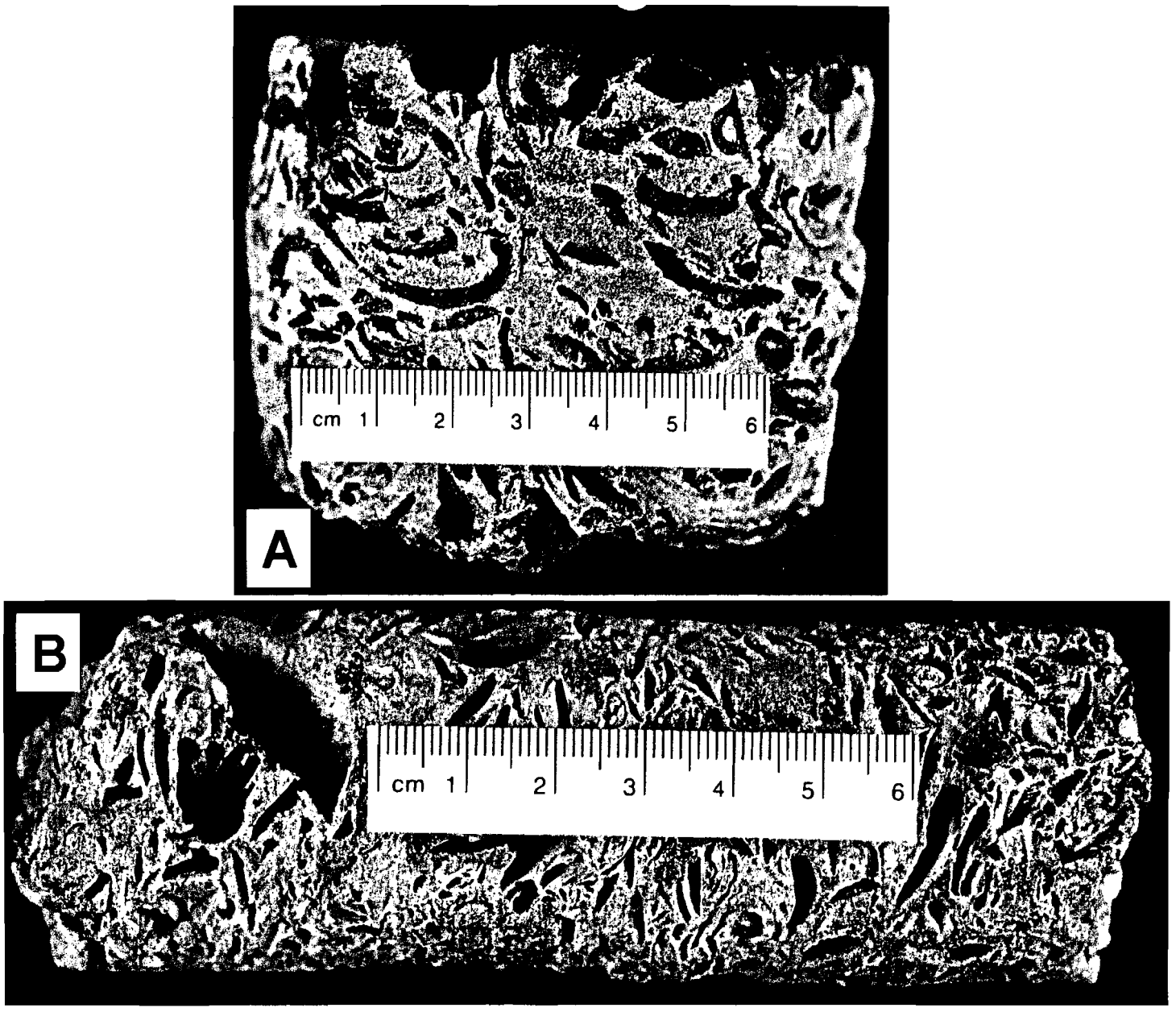


Figure 23. Slabbed cores of Trent Fm (?) arenaceous moldic limestone. Most aragonite bearing shell material has been dissolved leaving voids. **A**. TP-116. **B**. TP-14. Sandy pelecypod-moldic limestone is the dominant rock unit that underlies most of the the shoreface in the southern portion of the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

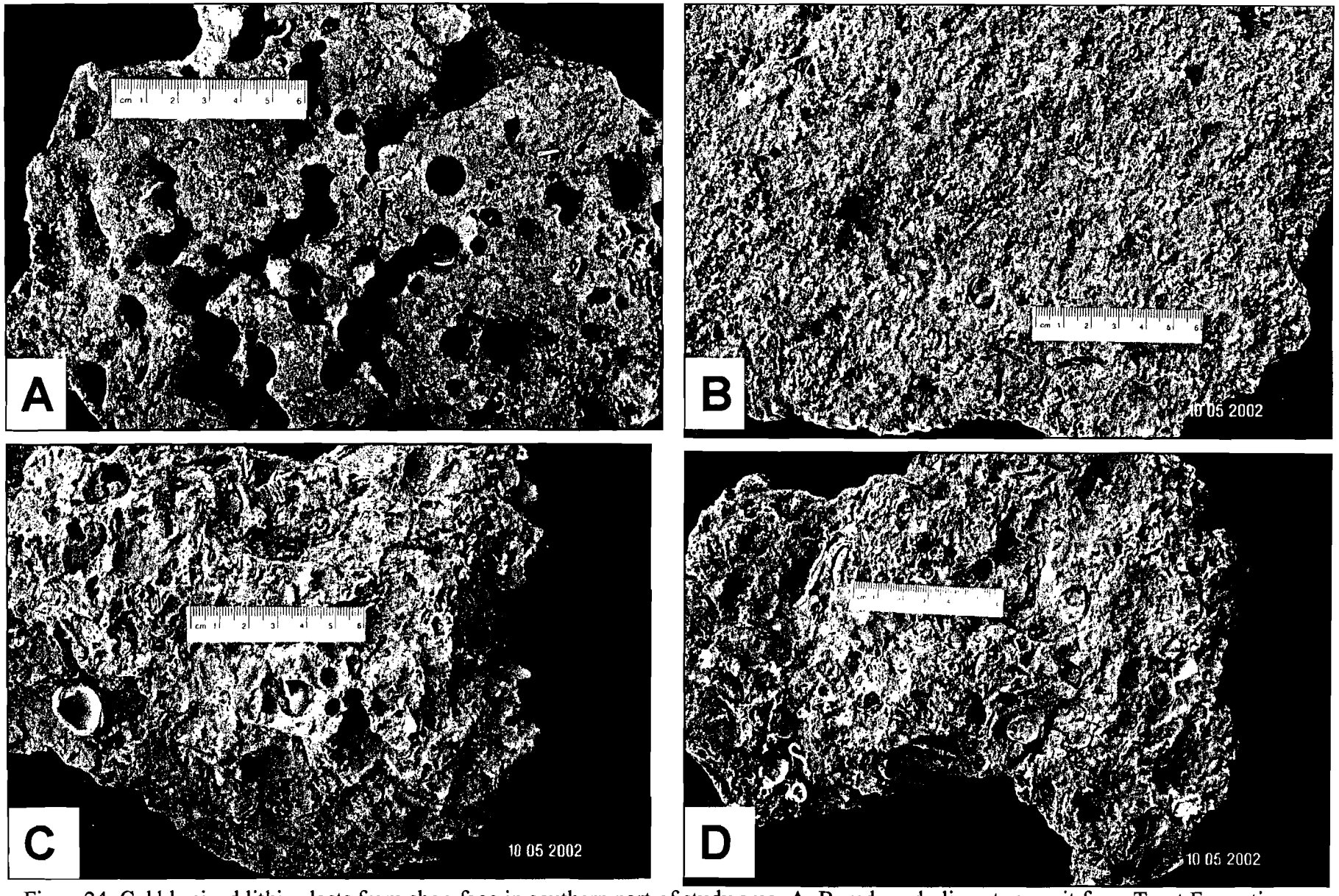


Figure24. Cobble sized lithic clasts from shoreface in southern part of study area. **A**. Bored sandy limestone unit from Trent Formation (SC 100). **B**. Large cobble sized slab of bored limestone near hardbottom scarp (Site 22) . **C**. Top of slightly encrusted, bored moldic limestone slab (SC 9).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

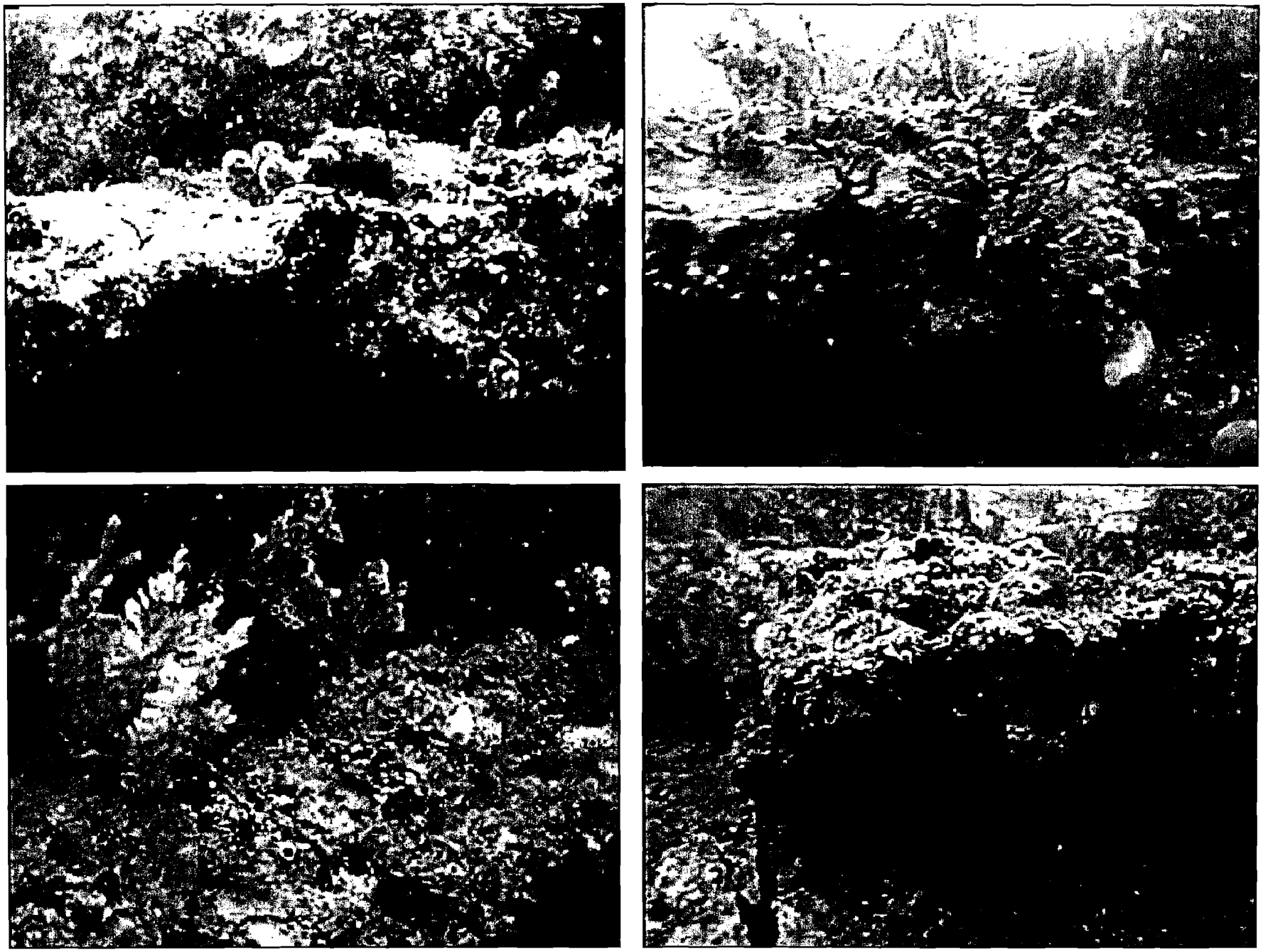


Figure 25. Hardbottom ledge offshore Surf City at Site VID 1. **A. - D**. Algal and epifauna encrusted limestone ledge with gravel mixture at base of scarp. Step-like ledges are encrusted with a variety of organisms. Small overhangs occur at rear of each step.

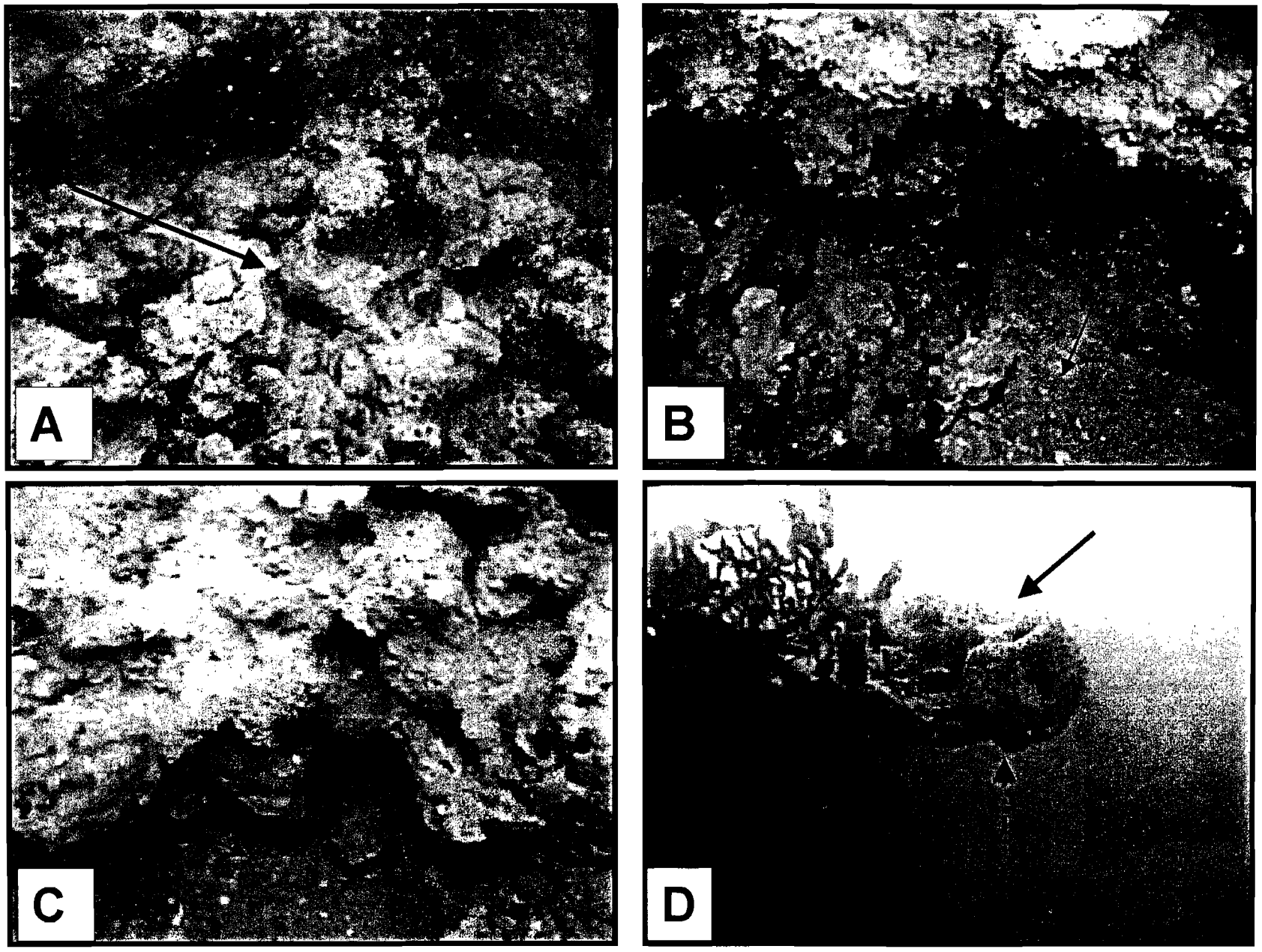


Figure 26. Hardbottom scarp and overhang at Site VID 1 offshore Surf City. A. Poorly sorted angular blocks at base of scarp. B. Sand/gravel mixture at base of corroded limestone scarp. C. Highly bored and corroded limestone scarp face with gravel/sand mixture at base. D. Encrusted overhang with macro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

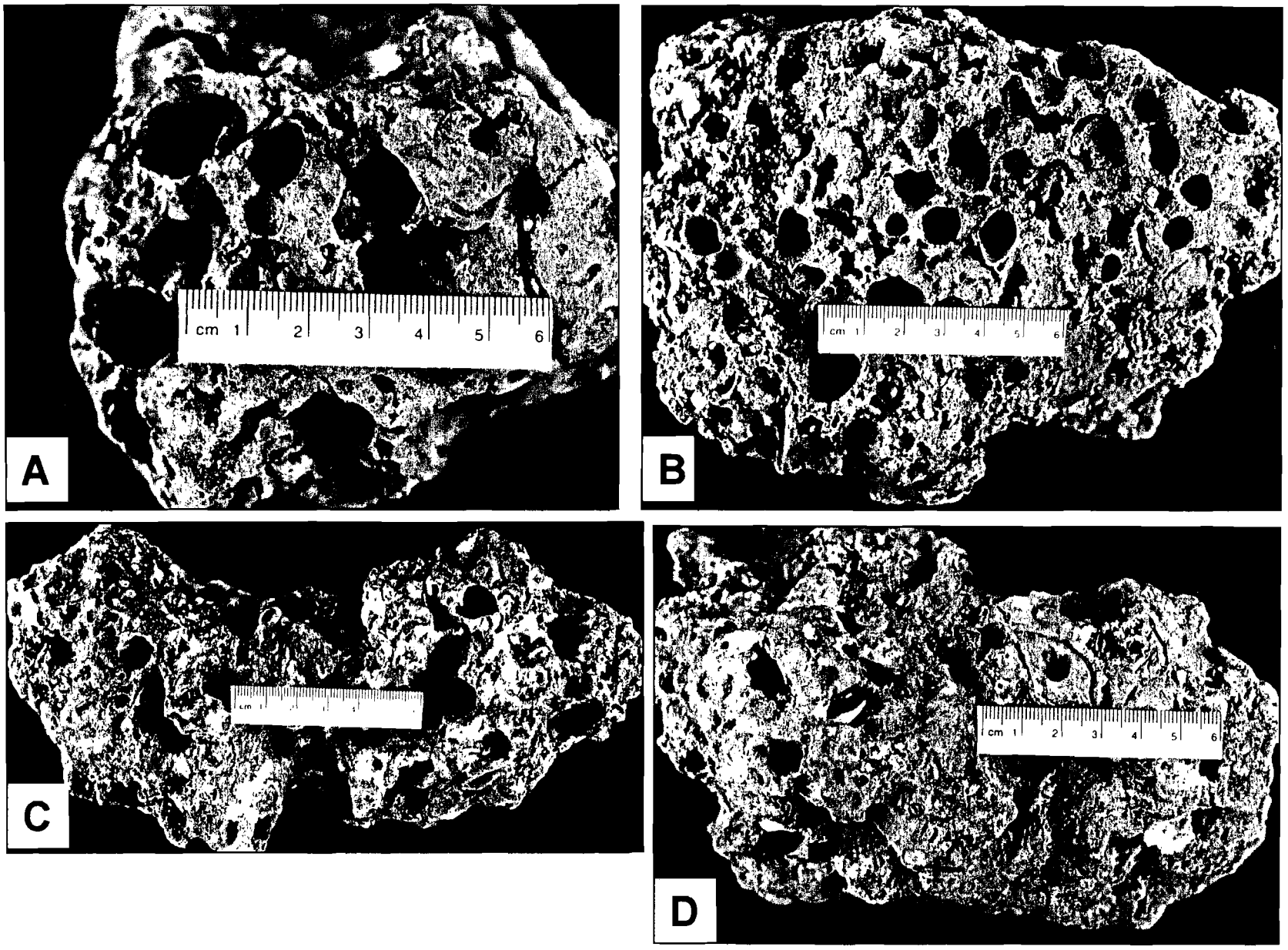


Figure 27. Cobble sized clasts of bored limestone from gravel-rich areas of the shoreface in the southern part of the study area. Cobbles are derived from various units of the Trent Formation (?) **A**. Rounded cobble of bored, quartz sand-rich limestone (SC 16 [4]). **B**. Highly bored limestone. Note 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).

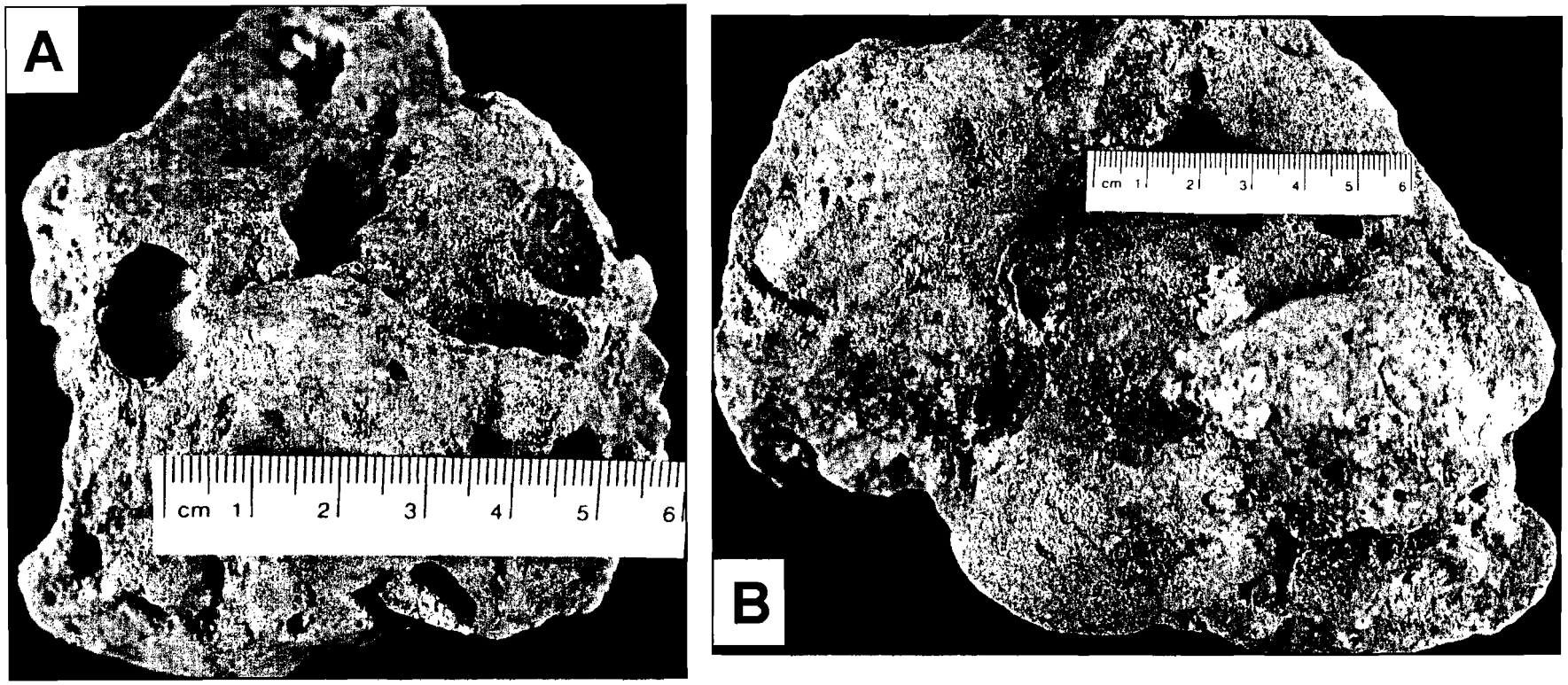


Figure 28. Rounded cobble size clasts from the dominant stratigraphic units that underlie the shoreface in the southern part of the study area. **A**. Bored clast of the Oligocene River Bend Fm. The olive green dolosilt clast is very friable and easily disaggregated with transport (SD 7 19). Most of 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).

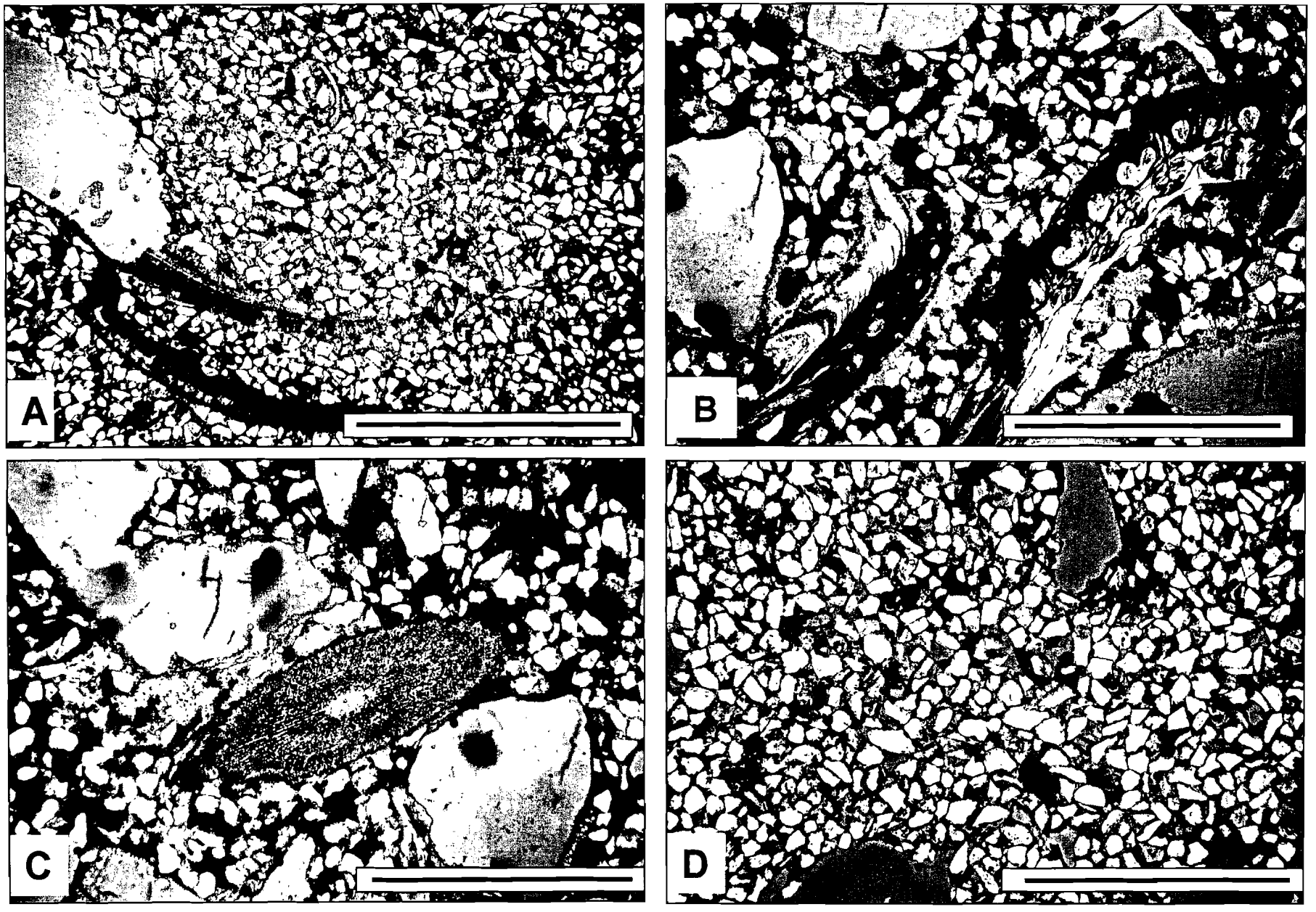


Figure 29. Thin-section photomicrographs of rocks from the southern segment of the shoreface. Scale bar =2.25mm. **A**. Sandy moldic Ls showing molds of dissolved shell material (Site SDA) in recrystallized micrite. **B**. Hollow wall barnacle in microcrystalline calcite cement (Top 15). **C**. Biomoldic 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).

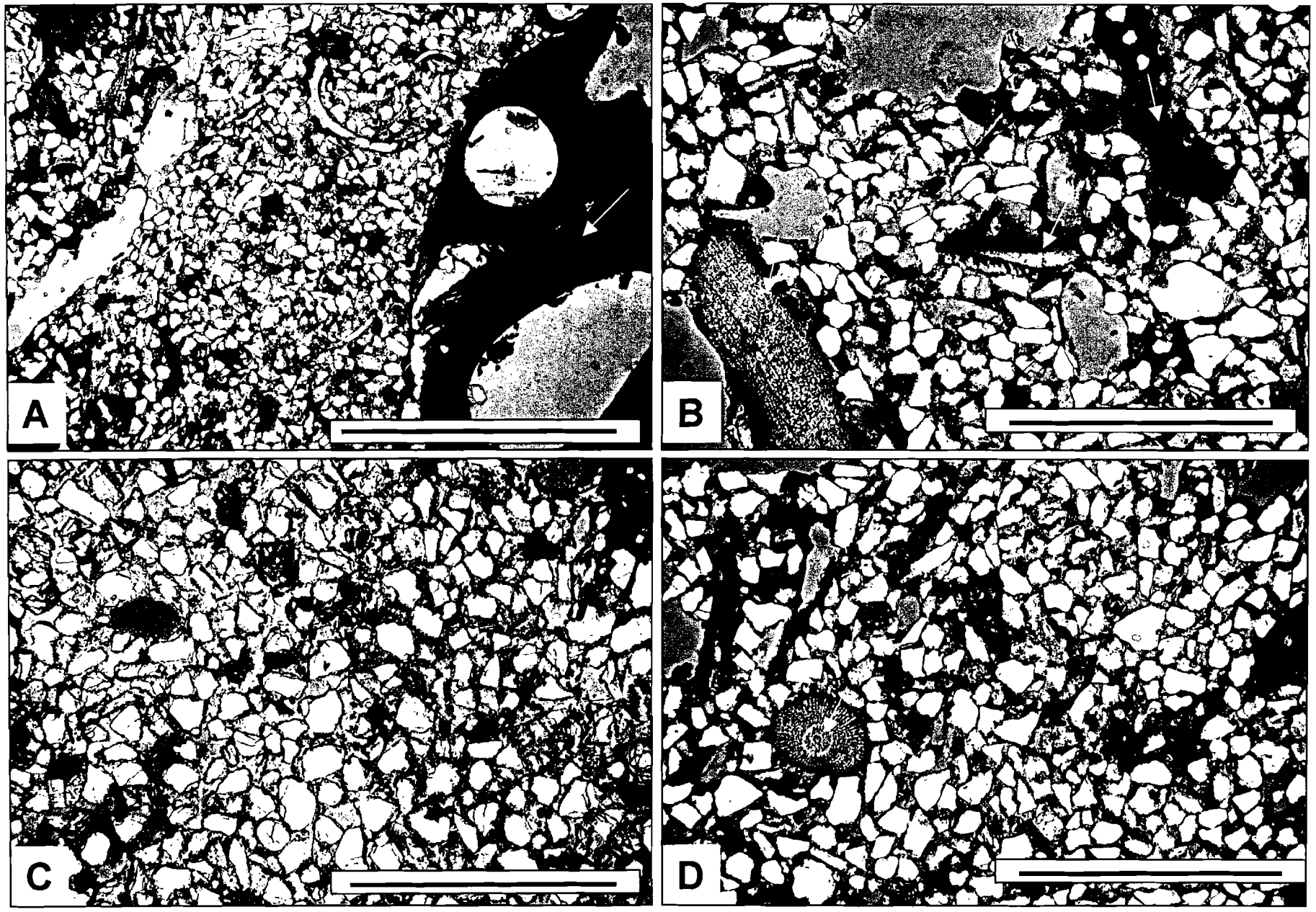


Figure30. Thin-section photomicrographs of rocks from the southern segment of the shoreface. Scale bar = 2.25mm. **A**. Sand- silt rich biomoldic Ls. Quartz and allochems set in recrystallized micrite cement, a variety of calcite cement has filled molds and pores. Opaque grains are mixture of micritized 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).

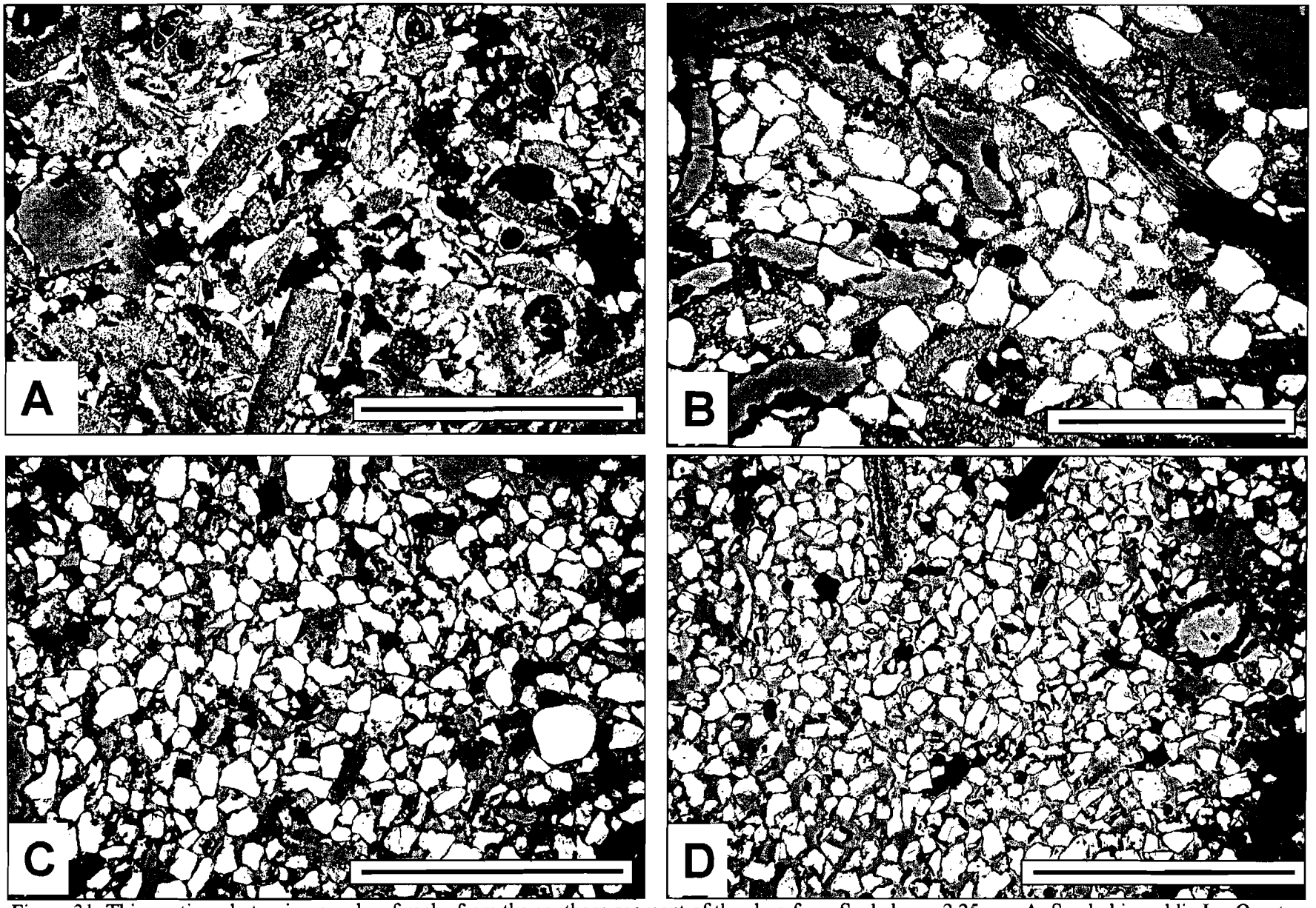


Figure 31. Thin-section photomicrographs of rocks from the southern segment of the shoreface. Scale bar = 2.25mm. **A**. Sandy biomoldic Ls. Quartz and allochems (echinoid plates and molluscan fragments) set in sparry calcite cement, clusters of calcite overgrowths on original grains are abundant (SC 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).

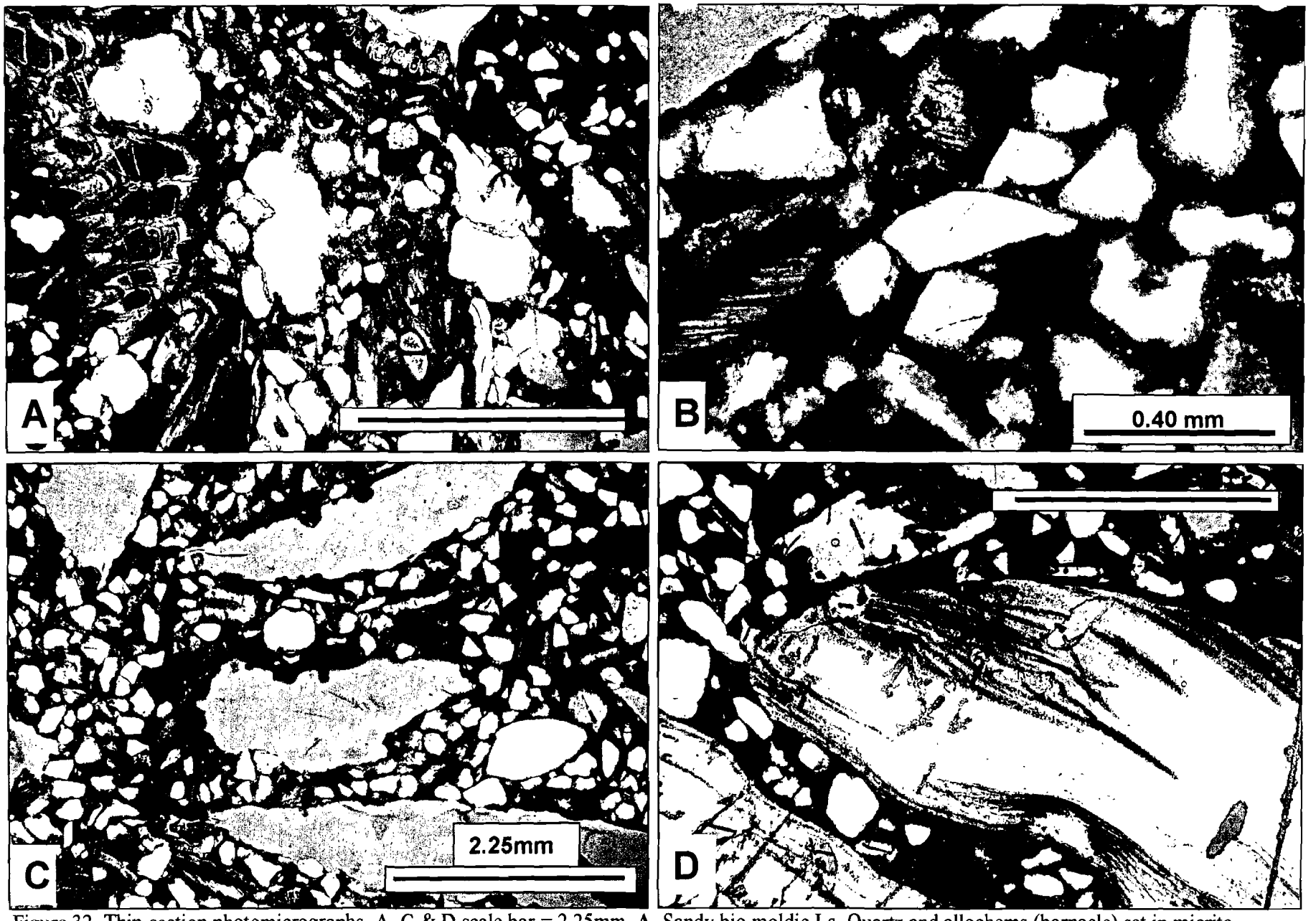


Figure 32. Thin-section photomicrographs. A, C & D scale bar = 2.25mm. **A**. Sandy bio moldic Ls. Quartz and allochems (barnacle) set in micrite cement (SC 79). **B**. Sandy biomoldic Ls. Angular fine quartz sand and recrystallized allochems are set in partially recrystallized micrite cement (SC 81). **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).

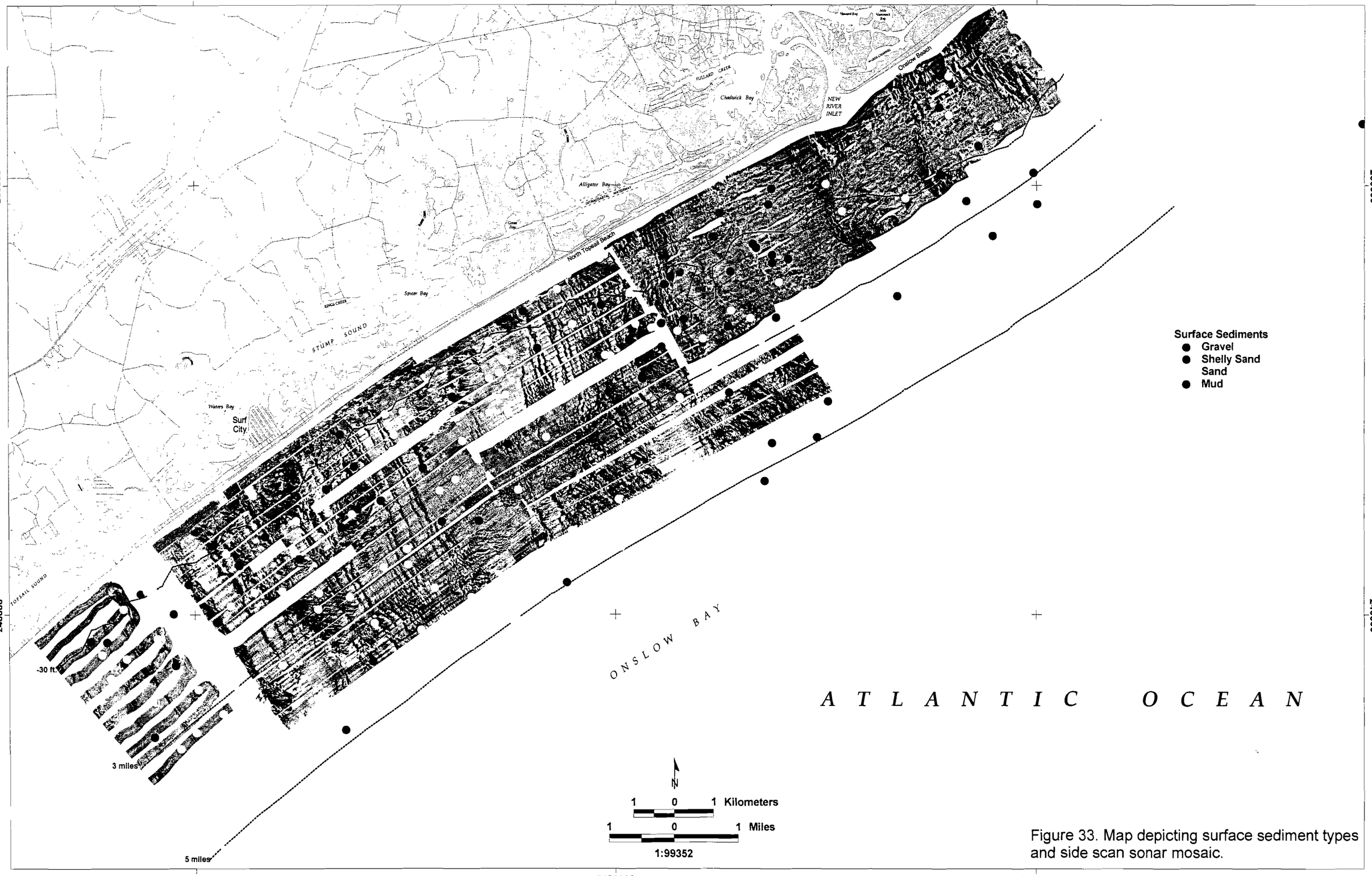
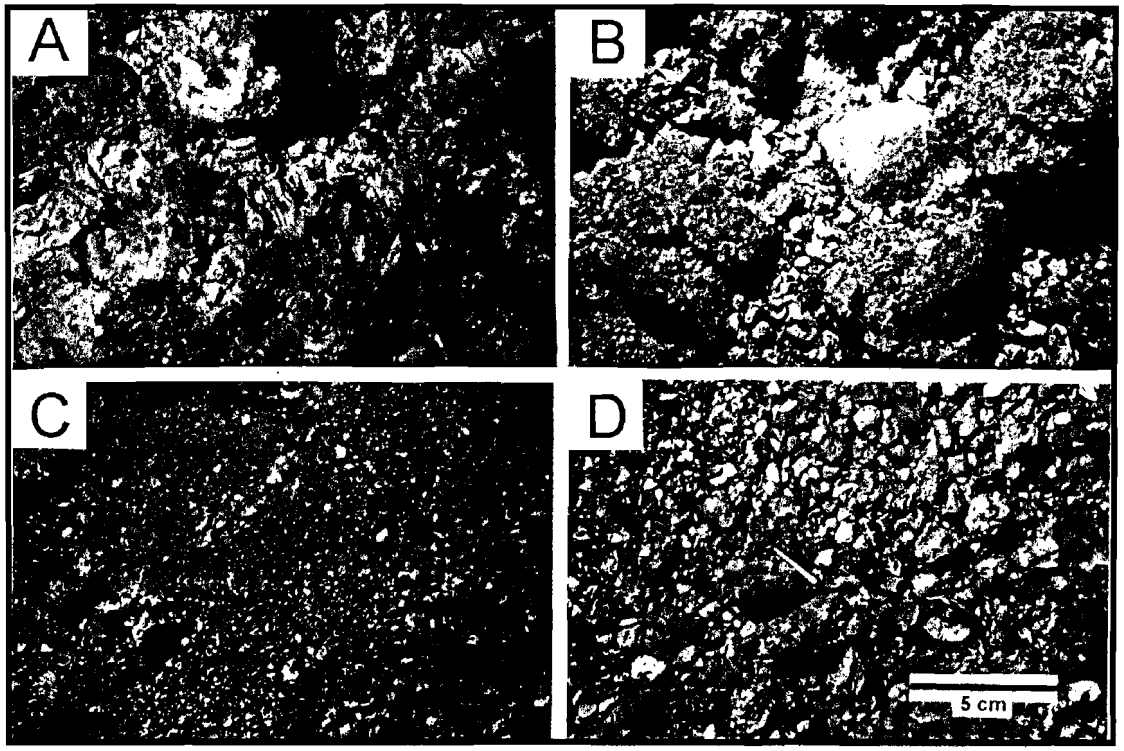


Figure 33. Map depicting surface sediment types and side scan sonar mosaic.



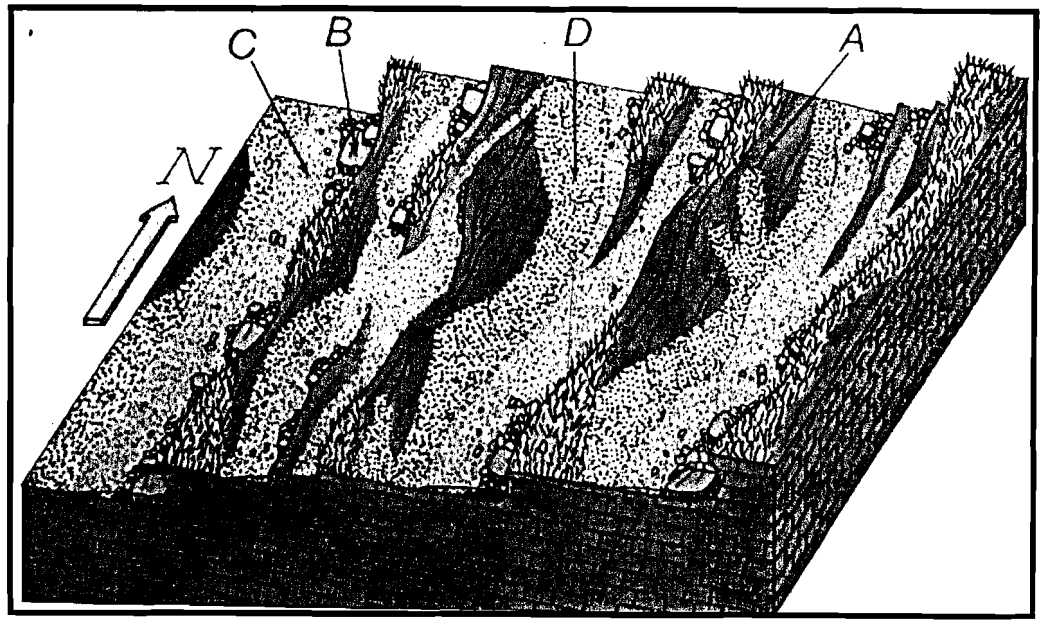


Figure 34. Bottom photographs of sediments and cartoon illustrating the general nature of step-like hardbottom features of shoreface off North Topsail Beach - Onslow Beach. **A**. East sloping scarp backs are generally barren of sediment near scarp edge. **B**. Poorly sorted rubble at base of scarp (talus 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).

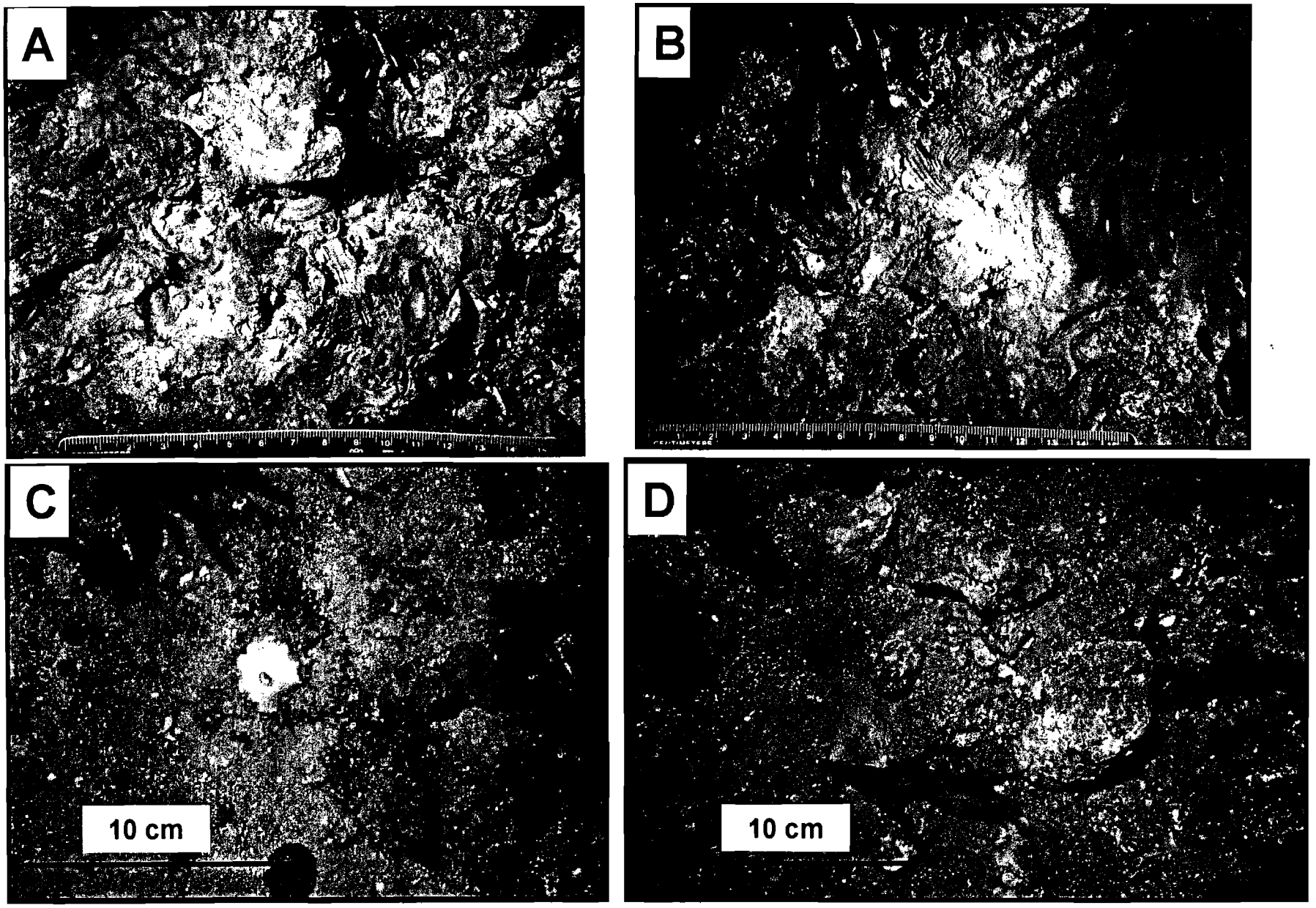


Figure 35. Bottom photographs of Dive Site 516 on high relief (>6 ft) hardbottom scarp on North Topsail Beach shoreface. **A**. Algal encrusted surface of bio moldic limestone in a sheltered area. **B**. Macro algae on lower portion of encrusted scarp face. **C**. Sand covered basal portion of scarp. 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.

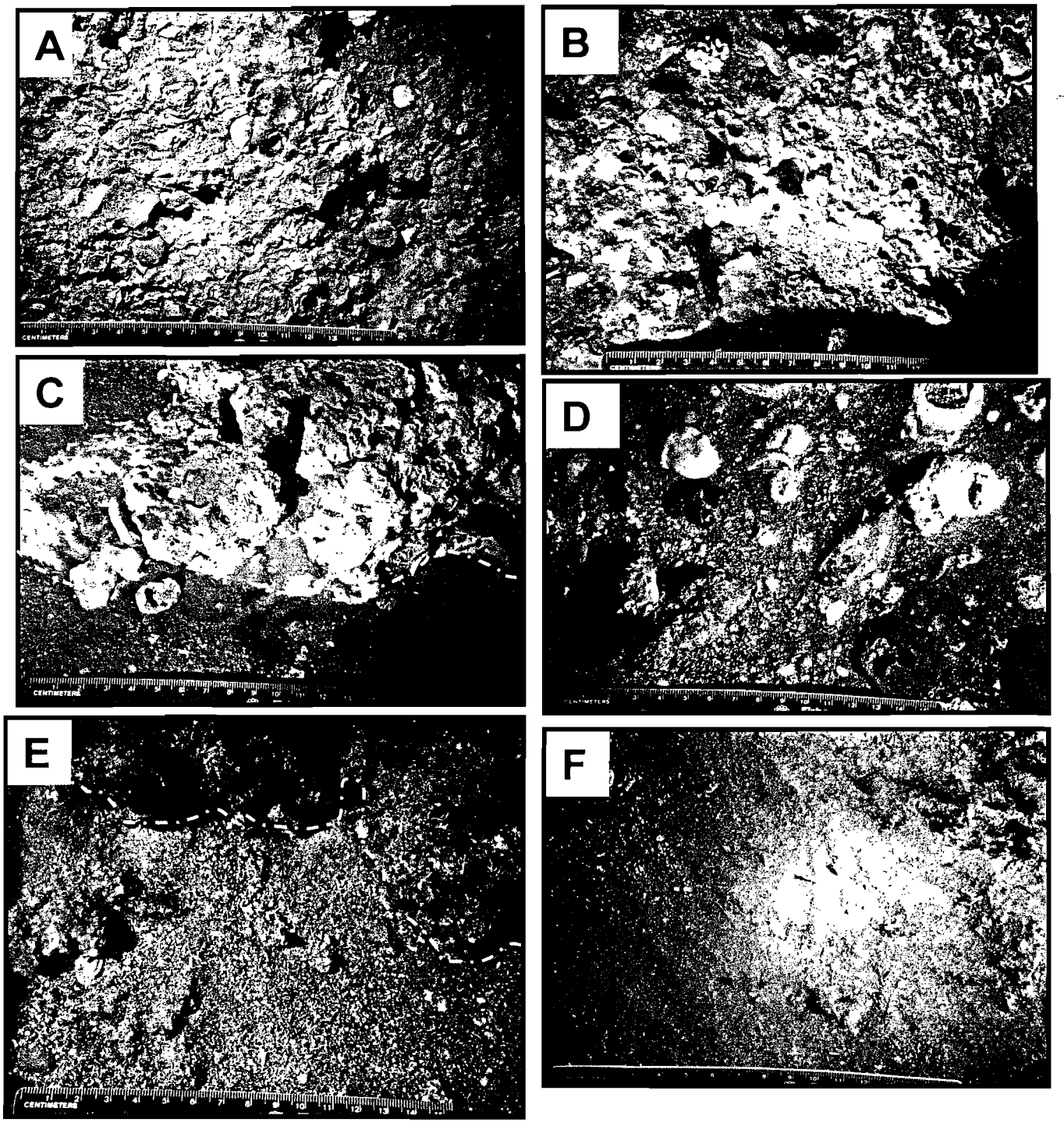


Figure 36. Bottom photographs of Dive Site 505 on North Topsail Beach shoreface in area of moderate relief hardbottom ledges. **A**. Irregular barren surface of moldic limestone ledge. **B**. Bored and encrusted limestone surface. **C**. Contact of mobile fine sand and irregular hardbottom **D**. Poorly 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.

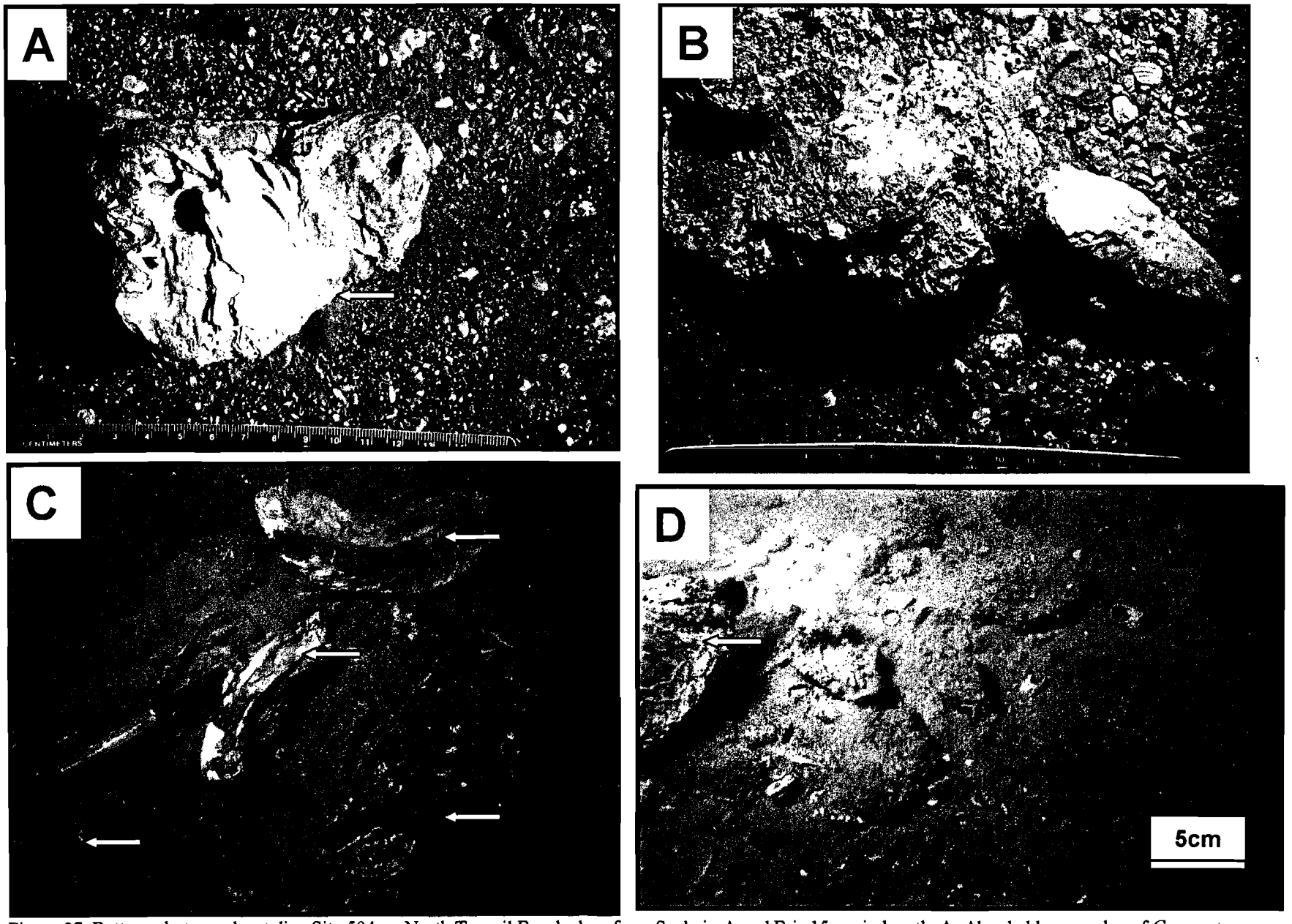
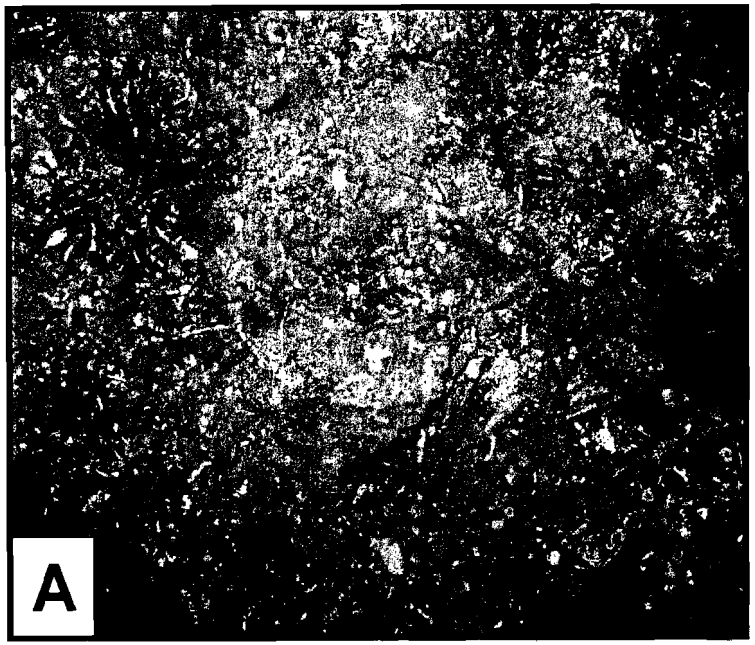


Figure 37. Bottom photographs at dive Site 504 on North Topsail Beach shoreface. Scale in A and B is 15 cm in length. **A.** Abraded lower valve of *Crassostrea gigantissima* (Oyster) and sand/ gravel mixture on limestone platform. **B.** Contact between limestone exposure (hardbottom) and silty fine 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.



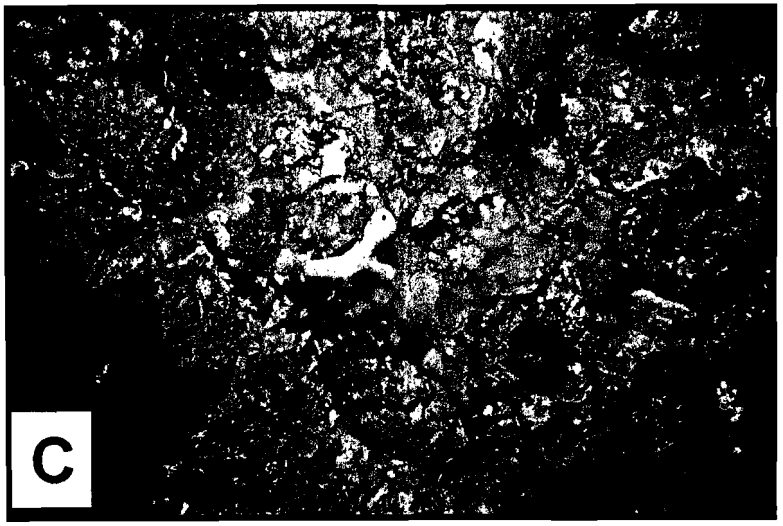


Figure 38. Bottom photographs of various dive sites on the Onslow Beach shoreface. Sites cluster around high relief hardbottom and karstic platform updrift of New River Inlet. Strong currents characterize this irregular platform. **A**. Thin veneer of sand and gravel mantles the irregular limestone surface 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.

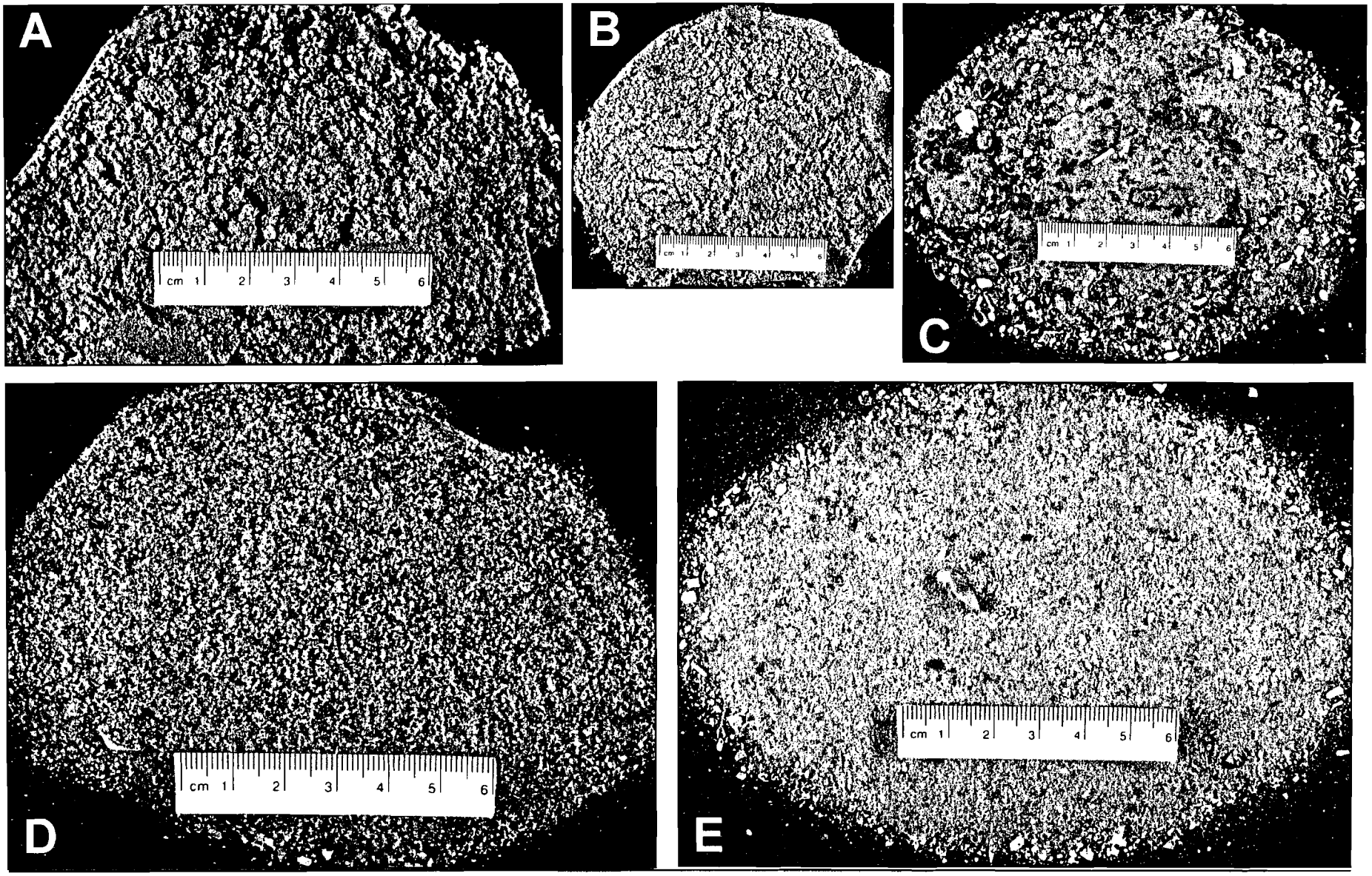


Figure 39. Silt and very fine shelly quartz sand surface sediments. **A**. Calcareous quartz silt offshore Alligator Bay inner shoreface (Site 835). **B**. Very fine quartz sand and silt withjin linear depression off shore Alligator Bay (Site 812). **C**. Black shell rich fine quartz sand offshore Alligator 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).

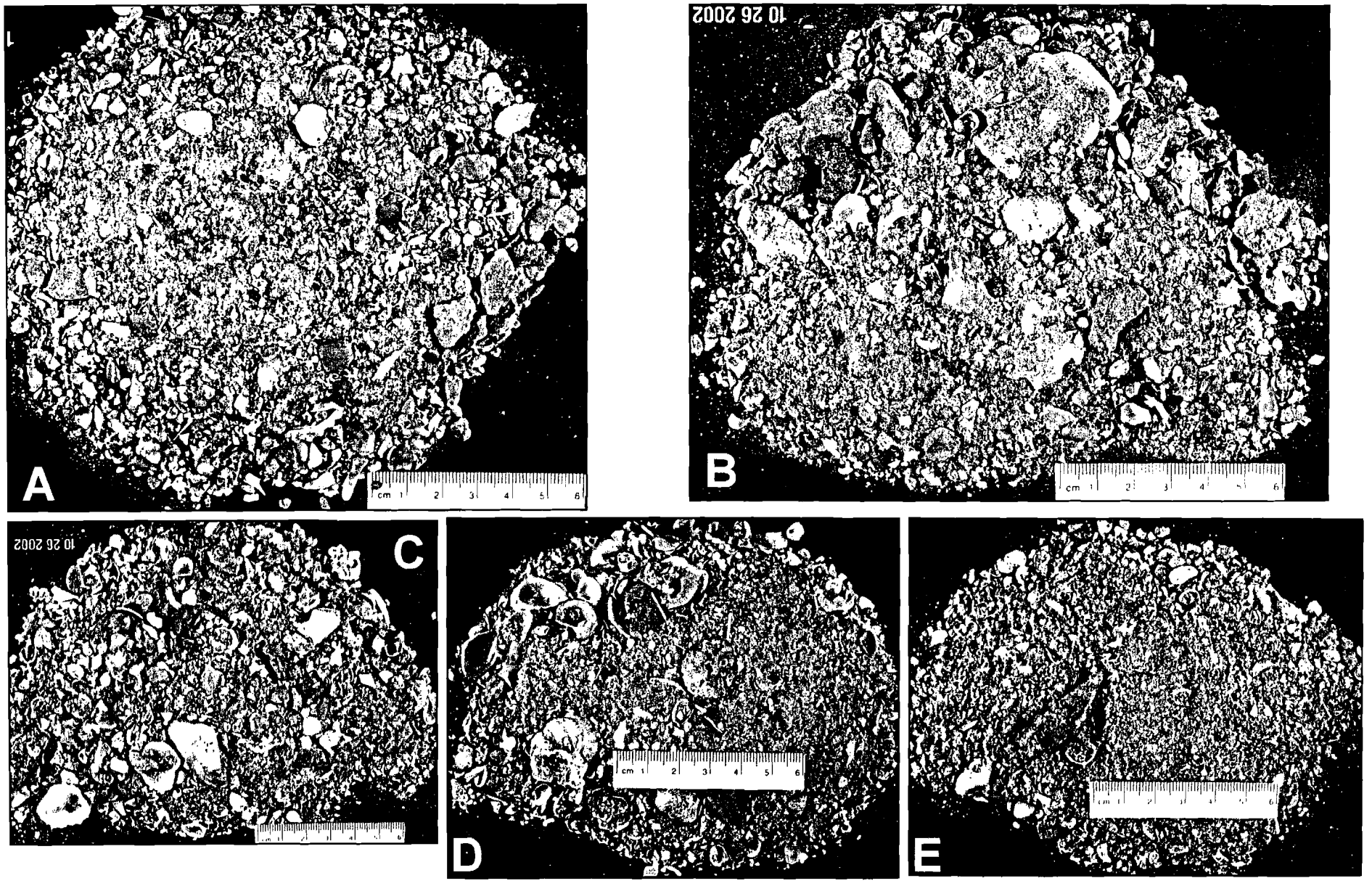


Figure 40. Sandy gravel and gravelly sand surface sediments. **A**. Sandy, lithic and shell gravel near high relief hardbottom (Site 509). **B**. Poorly sorted sandy lithic gravel offshore Alligator Bay (Site 602). **C**. Sandy algal, shell-rich lithic gravel on limestone platform off New River Inlet (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).

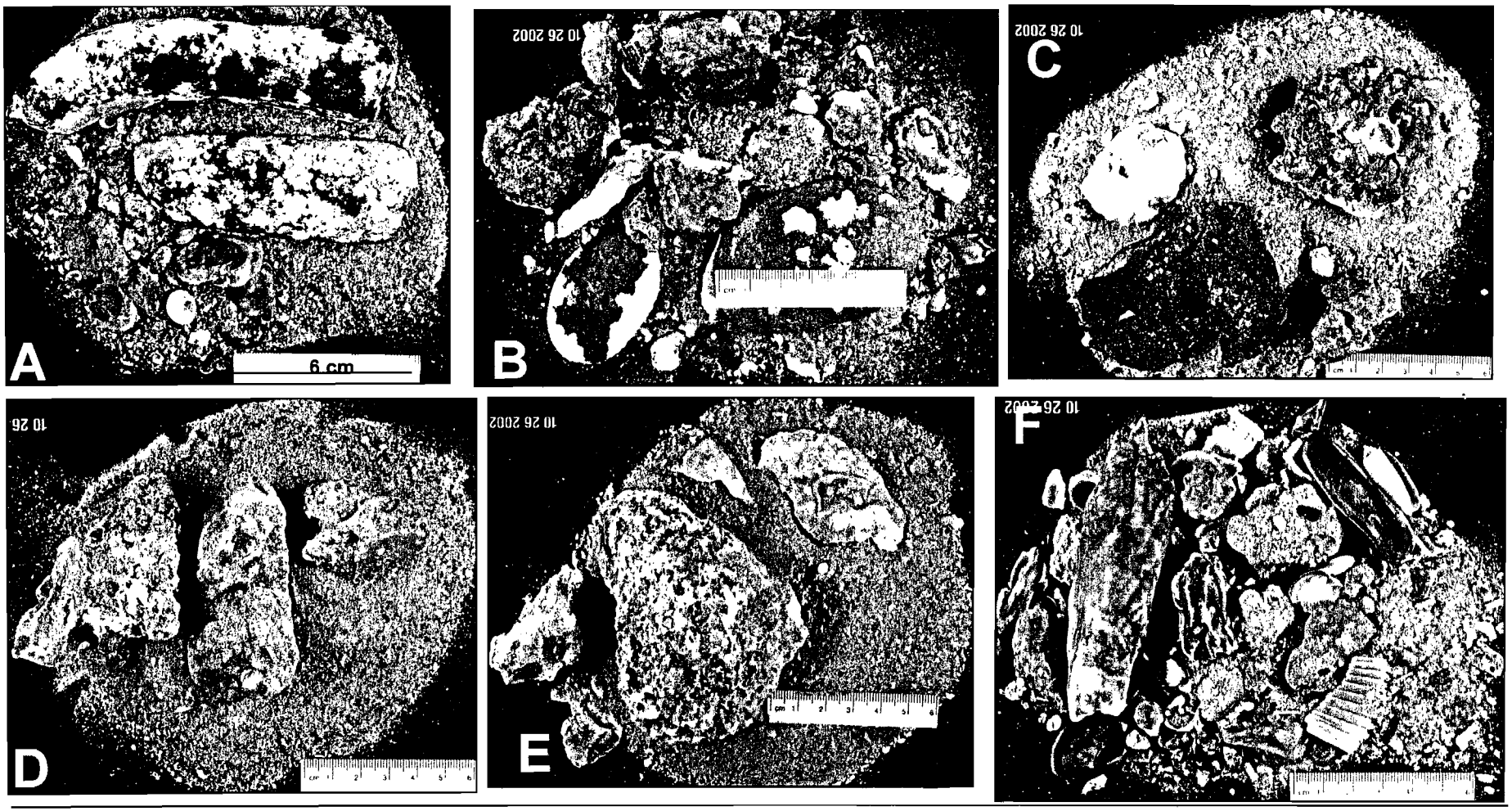


Figure 41. Gravelly sand and sand gravel mixtures. A. Orange brown quartz sand with lithic and shell gravel material. Large brown black fragments are encrusted bones from Site 701 offshore Onslow Beach (Site701). B. Poorly sorted sand/gravel mixture from Site 718 near outer platform offshore Onslow Beach. 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.

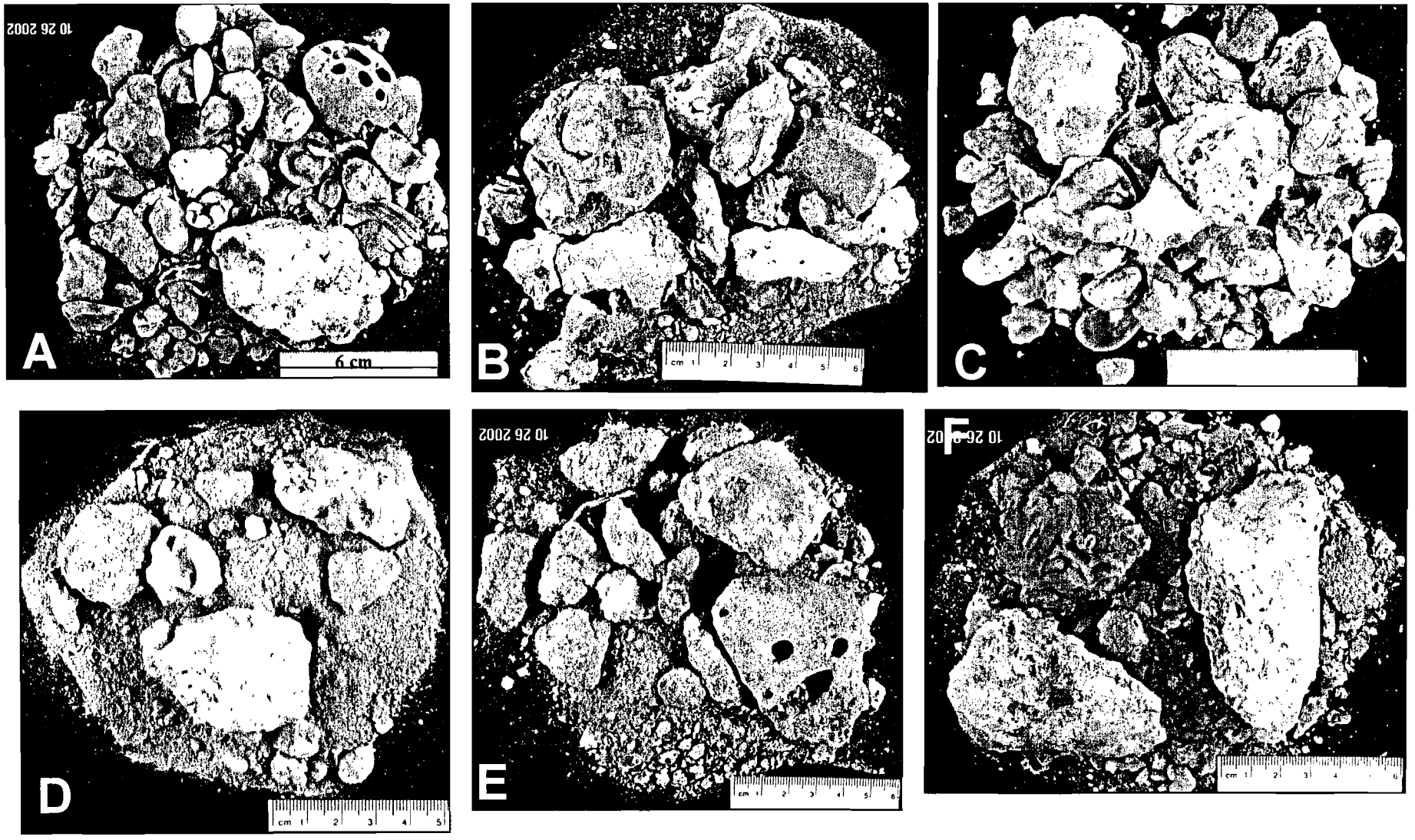


Figure 42. Lithic gravels, silt and sand rich gravel. **A**. Sandy subrounded to rounded limestone gravel (Site 511). **B**. Poorly sorted silt/sand rich angular lithic gravel near scarp (Site 515) offshore North Topsail Beach. **C**. Lithic and shell gravel on inner shoreface offshore North Topsail 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.

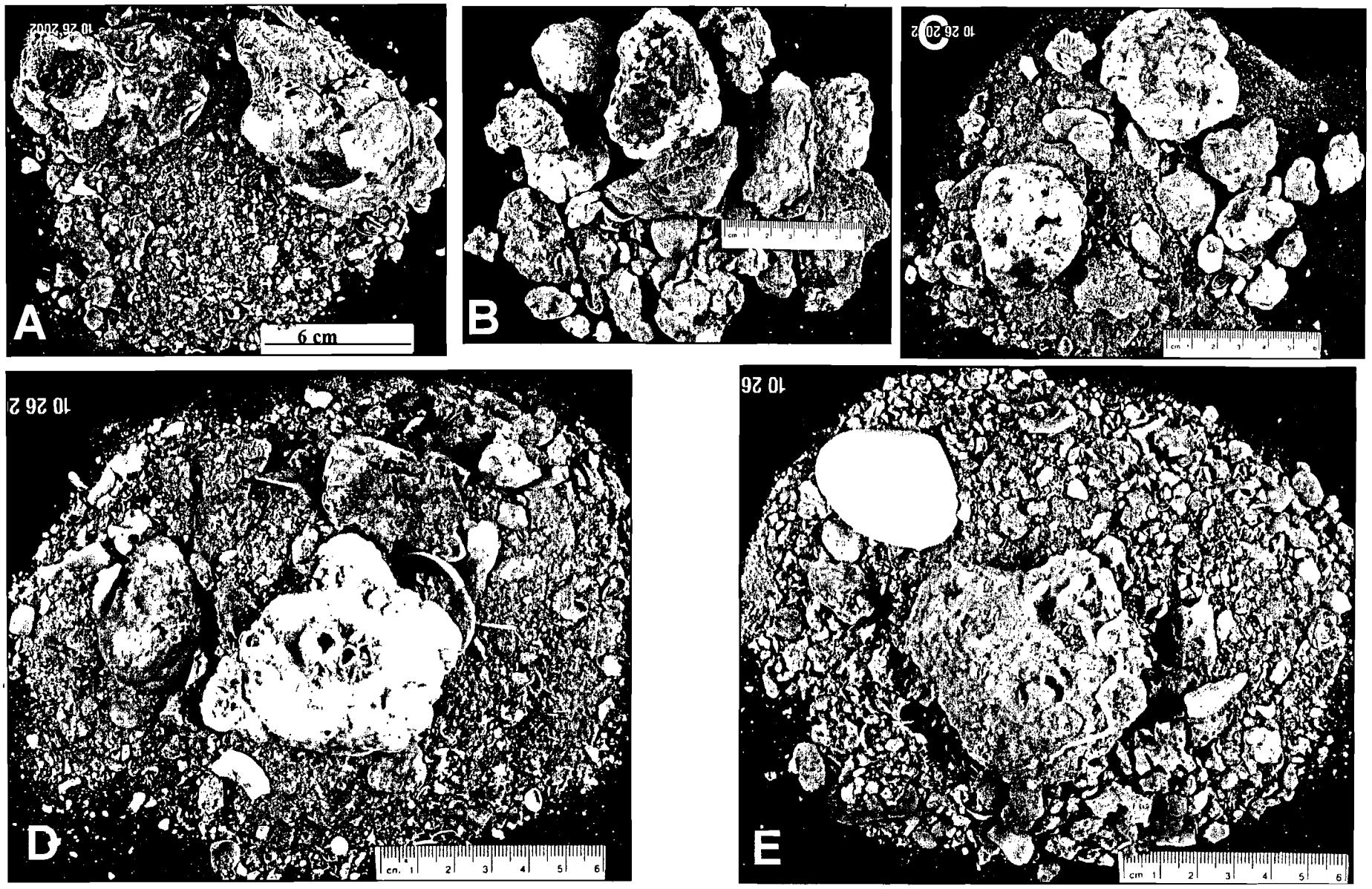


Figure 43. Lithic gravel and sandy gravel. A. Poorly sorted limestone gravel from platform near high relief scarp offshore Onslow Beach (Site 703). B. Subrounded lithic gravel on scarp back offshore North Topsail Beach (Site 720). C. Poorly sorted gravel/sand mixture. Some clasts are encrusted with calcareous 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.

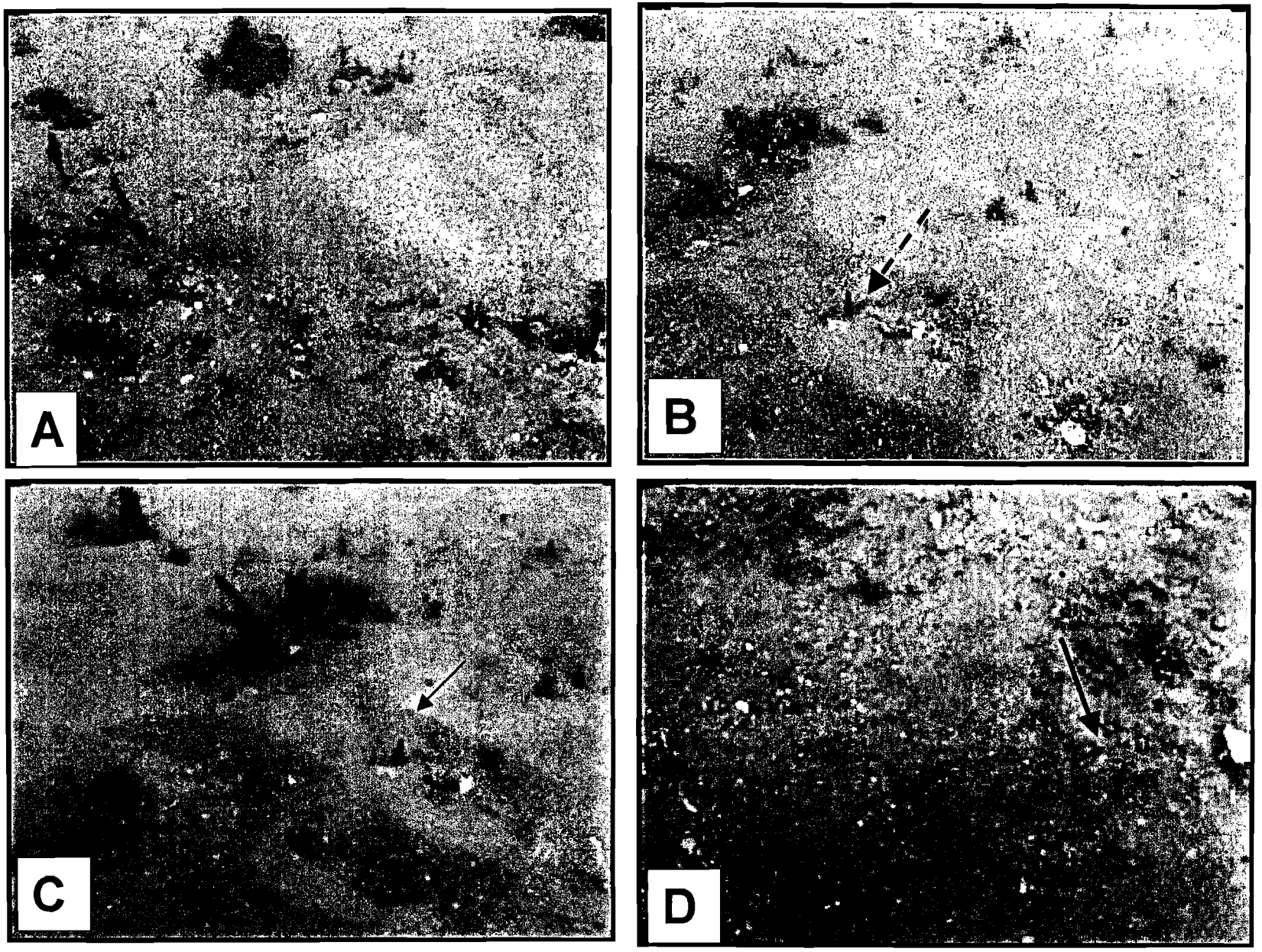


Figure 44. Bottom photos of hardbottom area with thin sand veneer off Surf City (Site SC 78). **A. - C**. Thin rippled sand veneer overlying limestone exposure. Gorgonians and epifauna are partially buried by mobile sand cover. **D**. Thin sand veneer with bored limestone protruding above sediment cover.

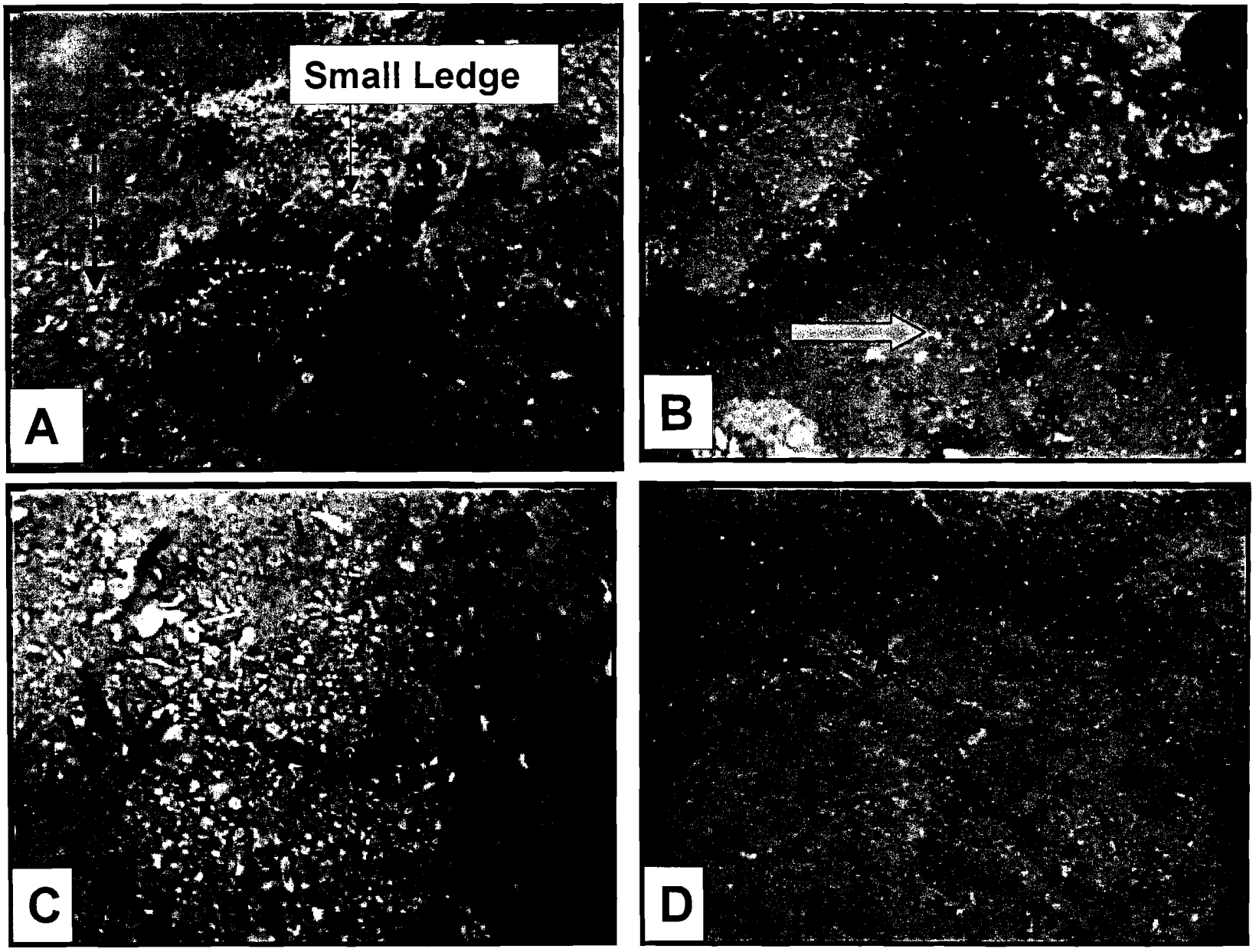


Figure 45. Small encrusted limestone scarp offshore Surf City (Site SDA). **A**. Macro algae and silt layer mantle ledge with poorly sorted gravel/sand mixture at base. **B**. Gravel/sand mixture at base of step like scarp. **C**. Buried macro algae at base of scarp. **D**. Rubble ramp at base of scarp.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

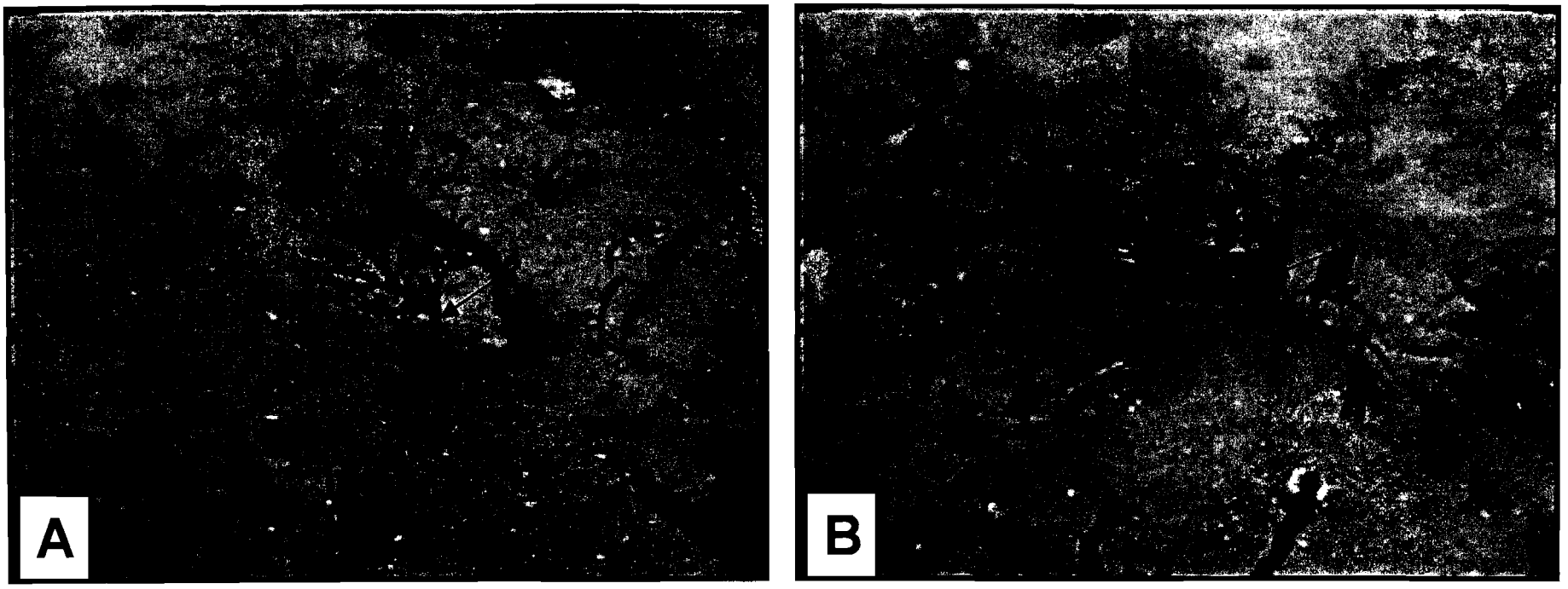


Figure 46. Thin sediment cover overlying limestone hardbottom at Site SC 83 offshore Surf City. **A**. Epifauna and macro algae meadows on limestone scarp back mantled with thin rippled sand veneer. **B**. Macro algae partially buried by a mobile silty fine-medium sand veneer.

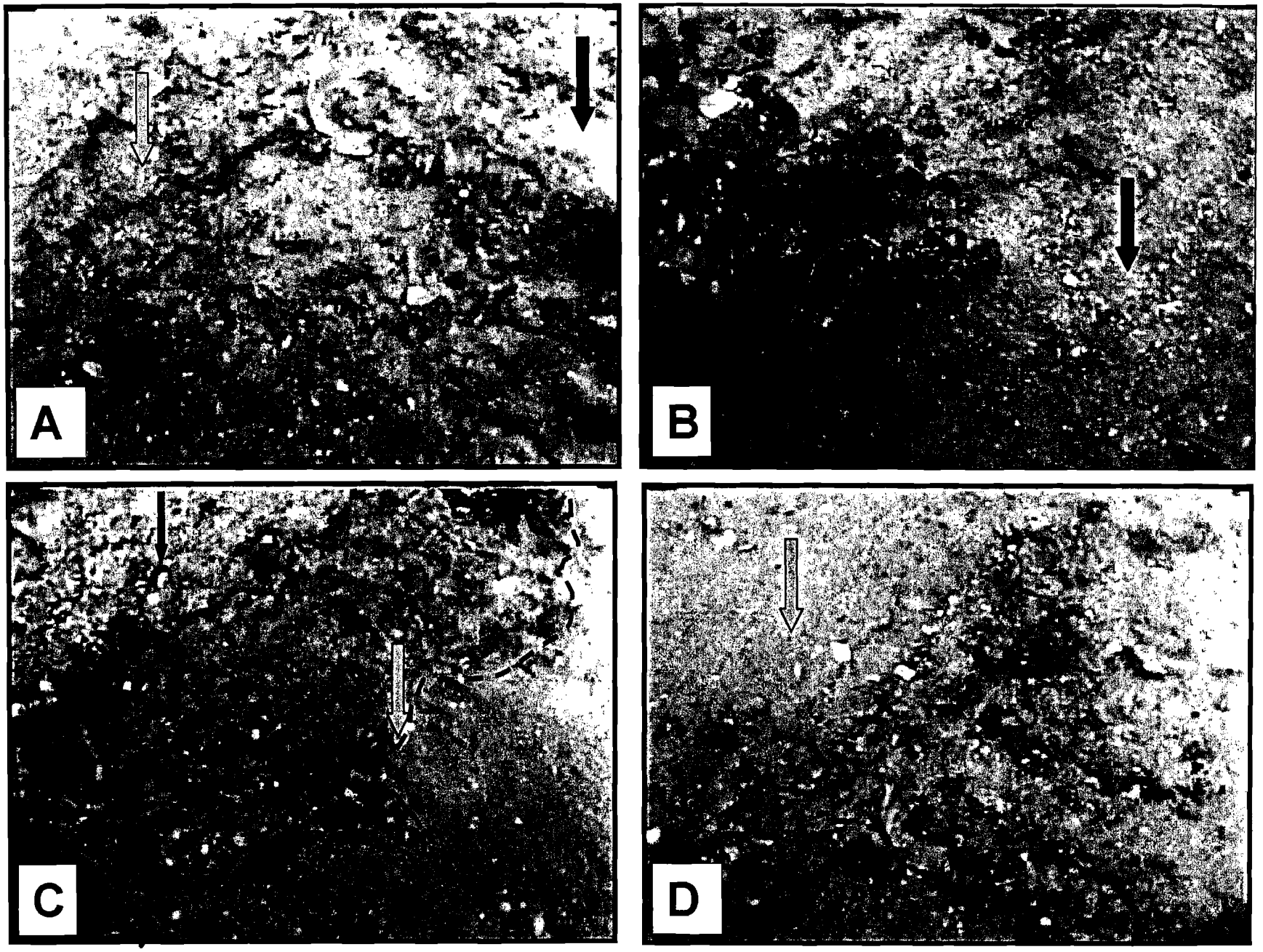


Figure 47. Hardbottom area offshore Surf City (Site 78). **A**. Thin layer of very fine sand (black arrow) overlying corroded limestone surface (white arrow). **B**. Gravel rich sand mixture overlying limestone. **C**. Bored (arrow) low relief limestone exposure and contact of surficial sand unit. **D**.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

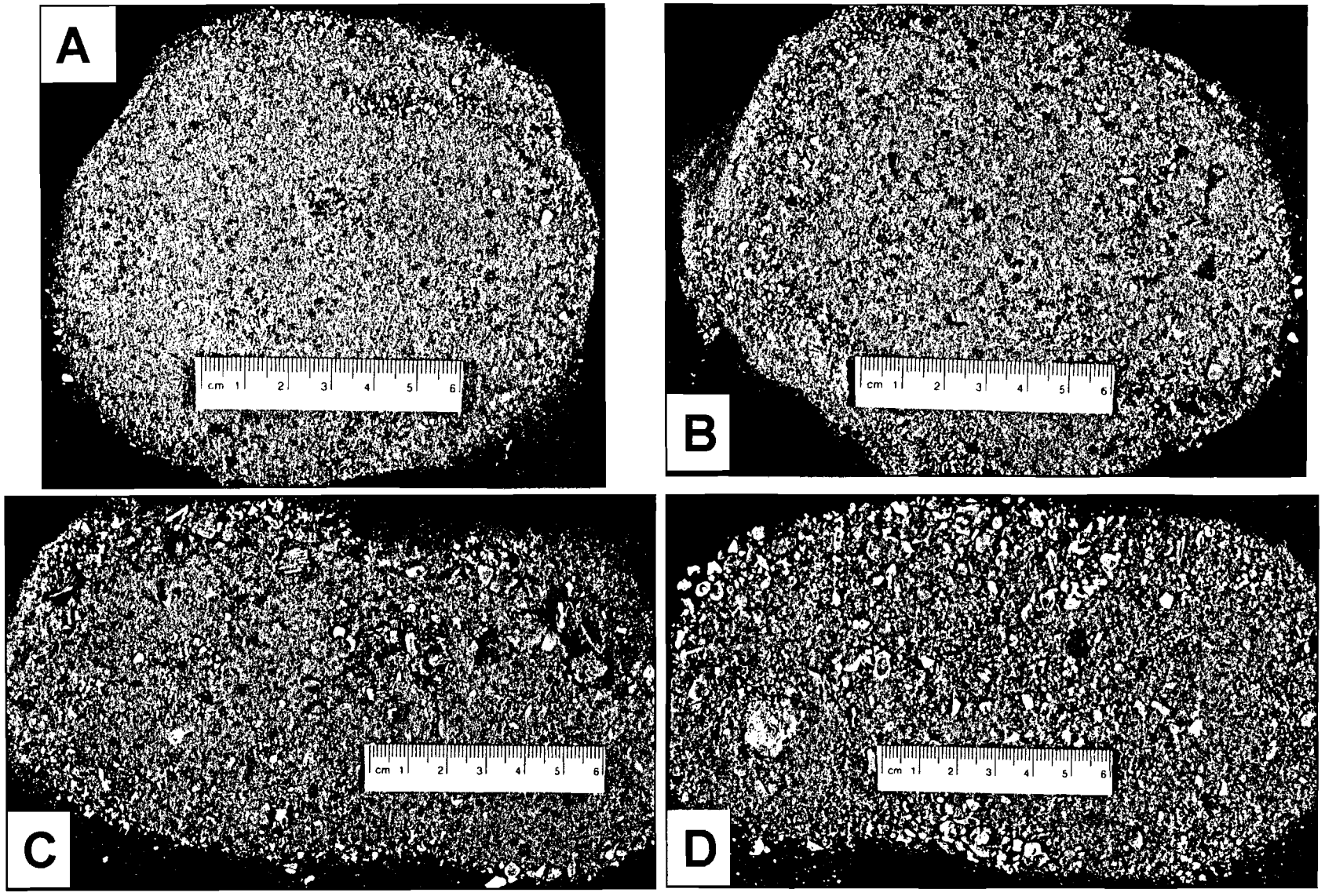


Figure 48. Shelly, fine to medium quartz sands from the shoreface in the southern part of the study area. The carbonate content is usually less than 15 % but can be higher near hardbottoms **A**. (SC3). **B**. (SC 104). **C**. (SC 40). **D**. (SC 80).

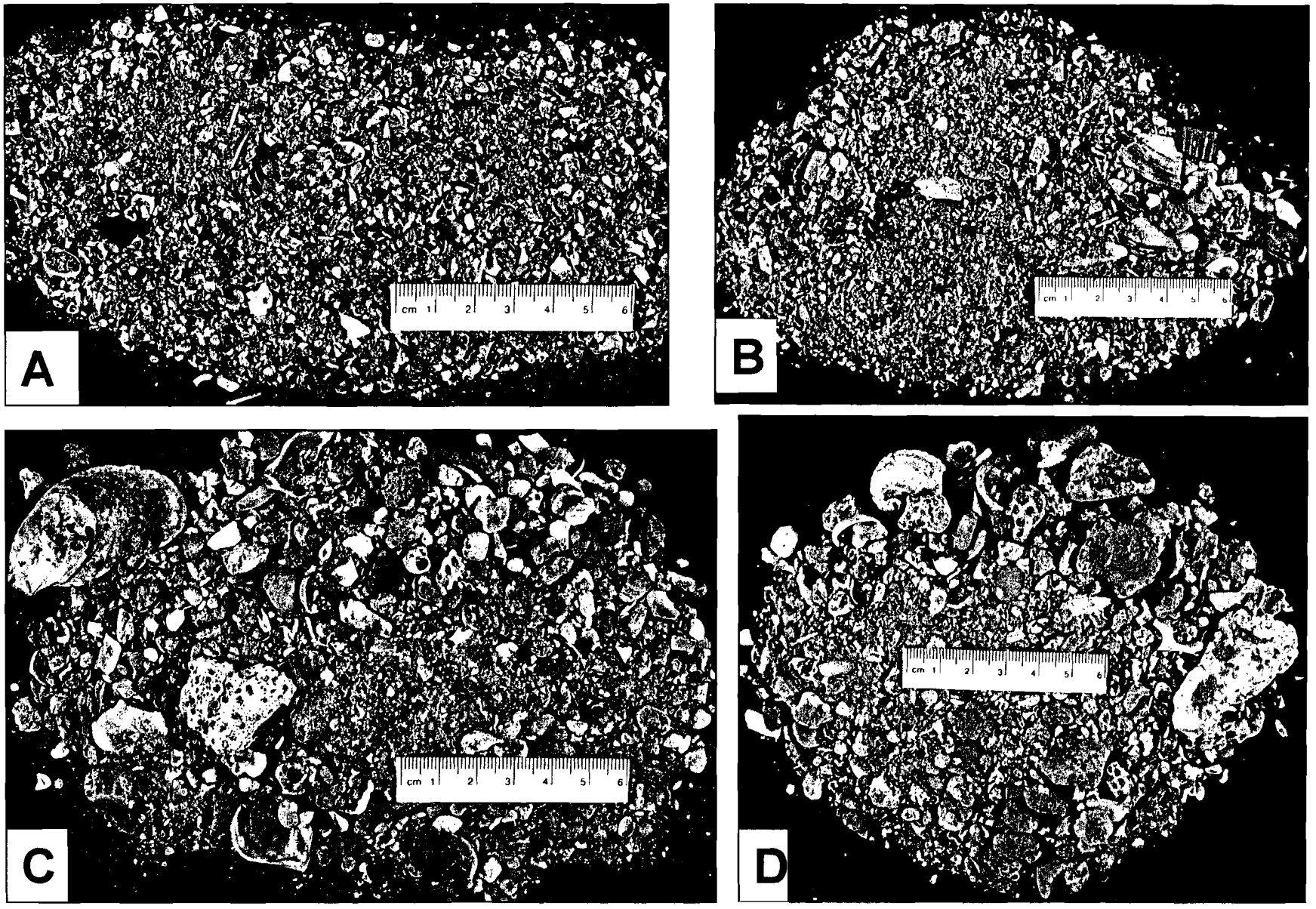


Figure 49. Sandy gravel and gravelly sand from the southern segment of the shoreface. **A**. (SC 82) and **B**. (SC113) are typical of the patches of rippled coarse sand and gravelly sand found near hardbottoms **C**. (TP 4) and **D**. (SC 22) are typical coarse sand and fine gravel. **C.** and **D.**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

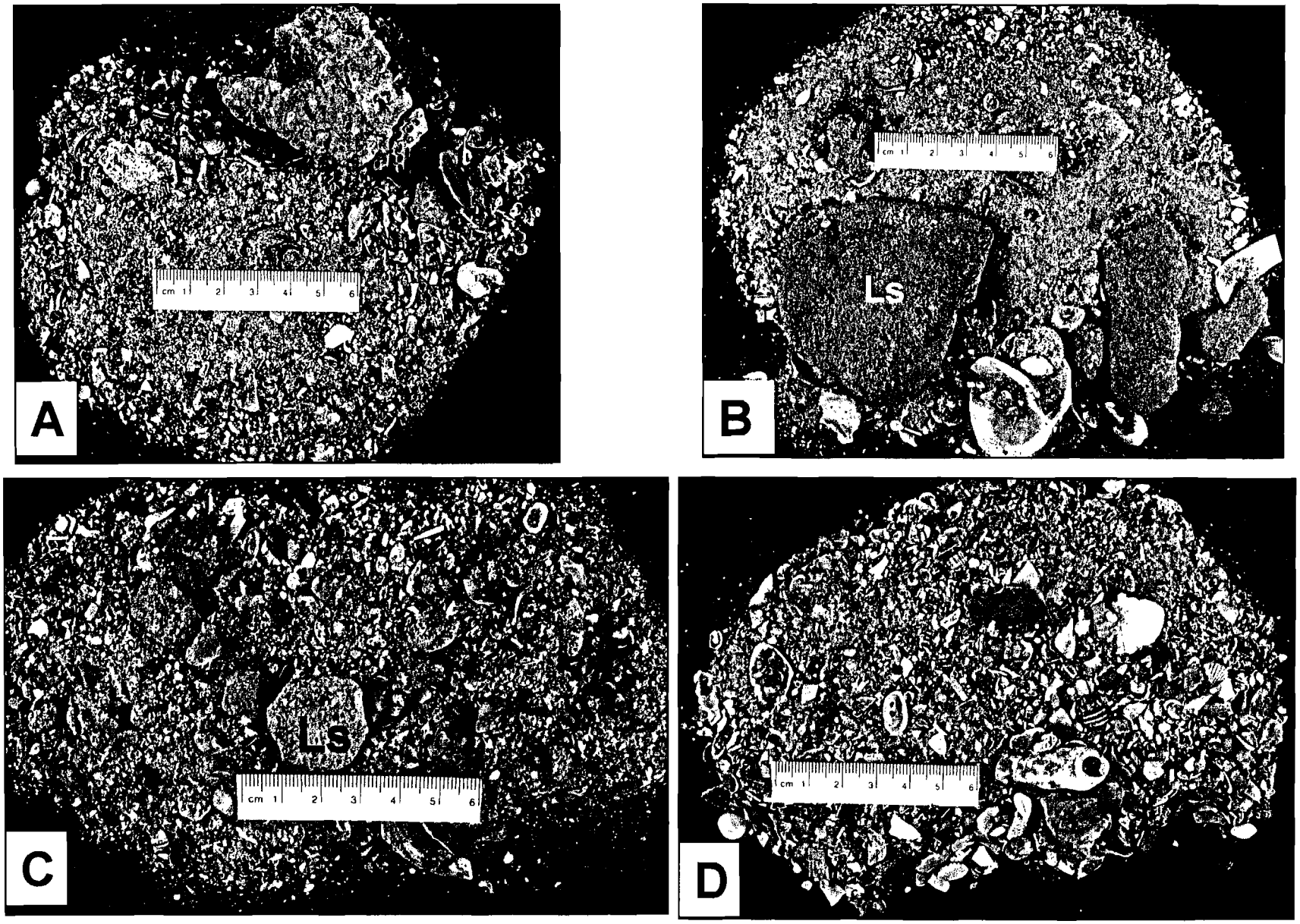


Figure 50. Gravel rich sand from the southern segment of the shoreface. **A. – D.** The composition of the gravel fraction varies from site to site depending upon the nature of the underlying substrate. Arenaceous and moldic limestone lithic fragments constitute a range of sizes. The black and gray shell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

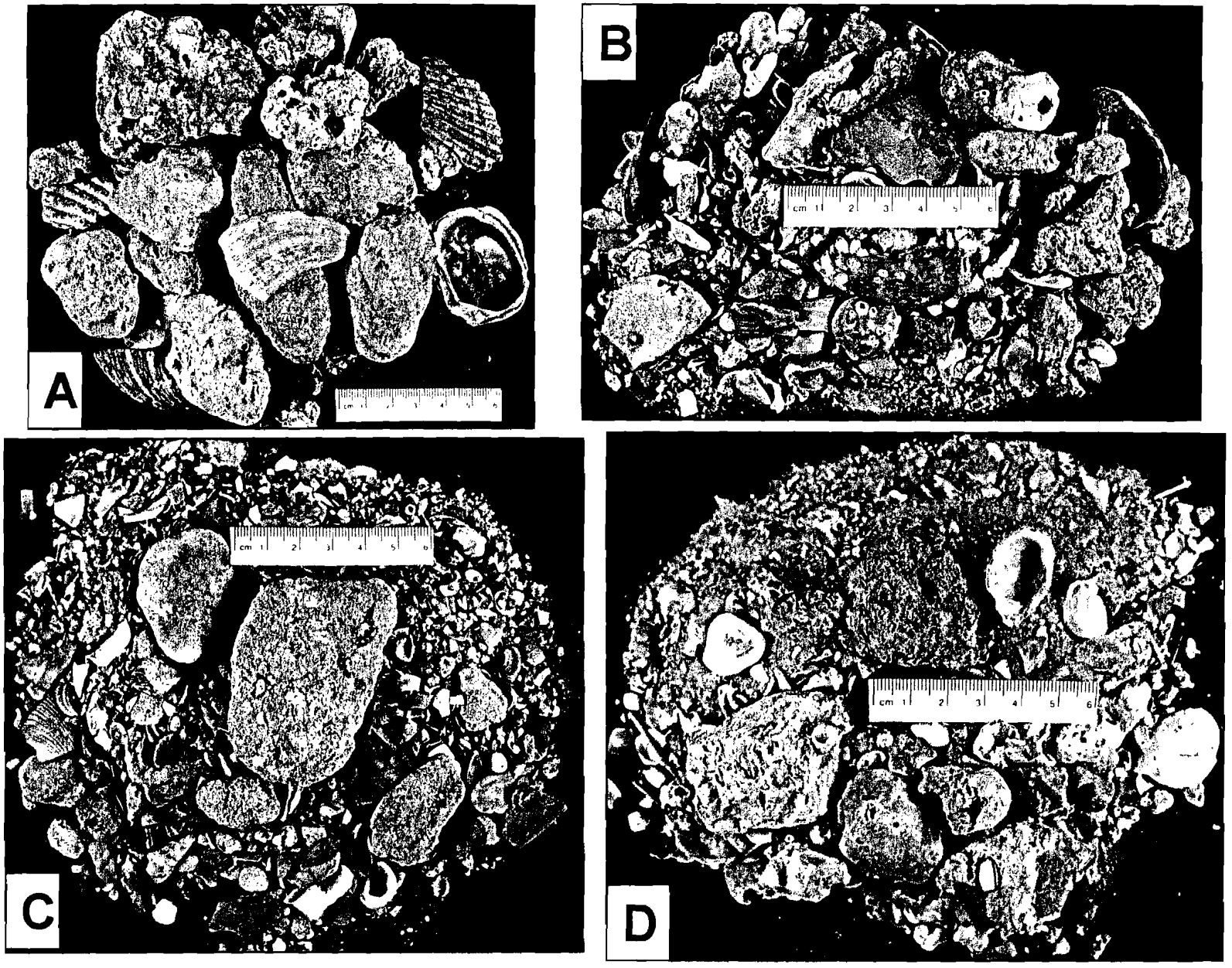


Figure 51. Gravel and sand/gravel mixtures from the shoreface surface sediment veneer in the southern part of the study area. **A**. Cobble size rounded fragments of Tertiary limestone and blackened shells. Shell material is derived from reworked backbarrier units (SC 40). **B**. Mixture of sandy shell 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).

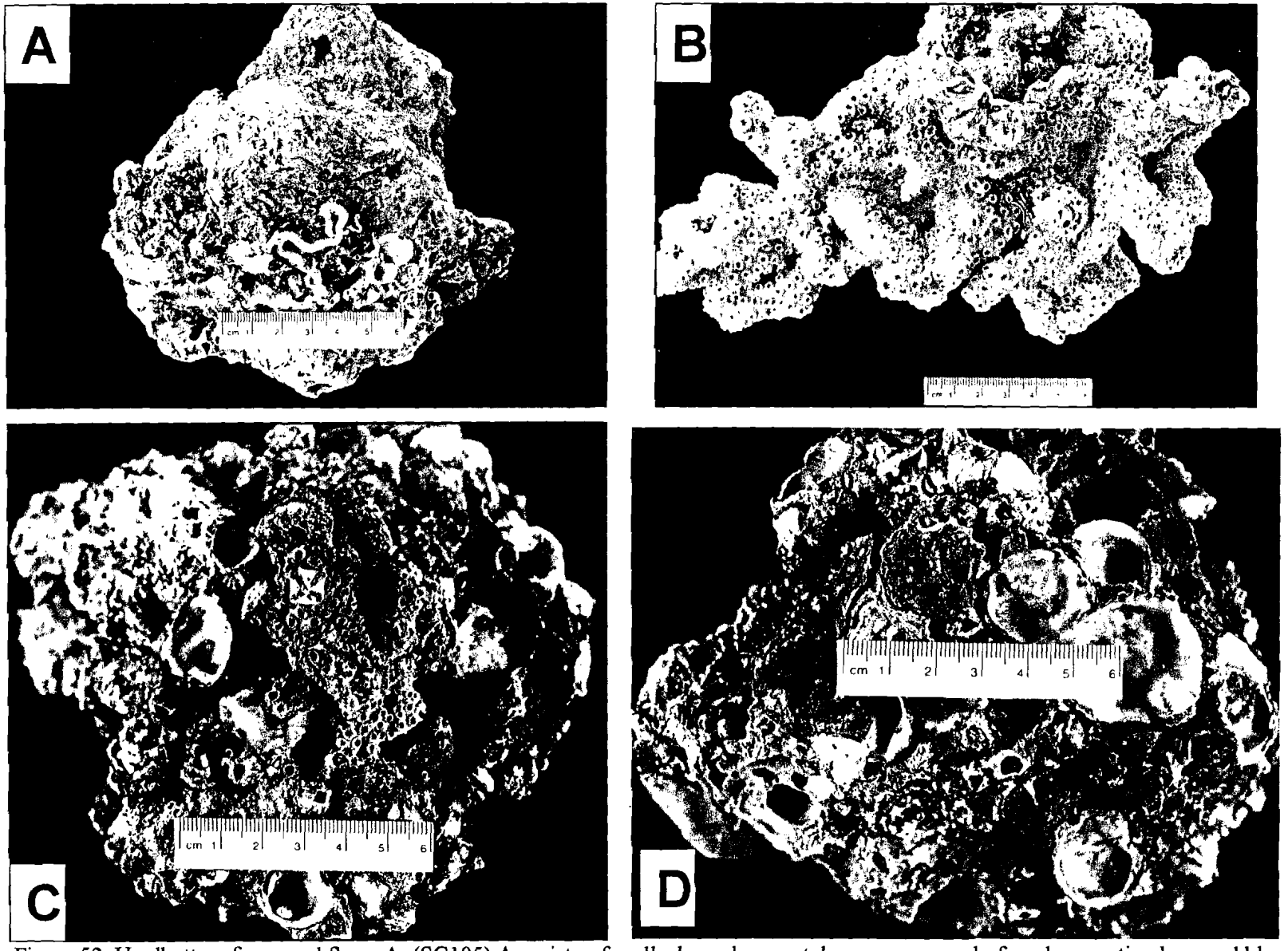


Figure 52. Hardbottom fauna and flora. **A**. (SC105) A variety of mollusks and worm tubes are commonly found encrusting large cobbles and surfaces. **B**. (SC 9 [29]) A variety of species of corals are typically found on the higher relief hardbottoms and on some cobbles in areas were sedimentation rates 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.

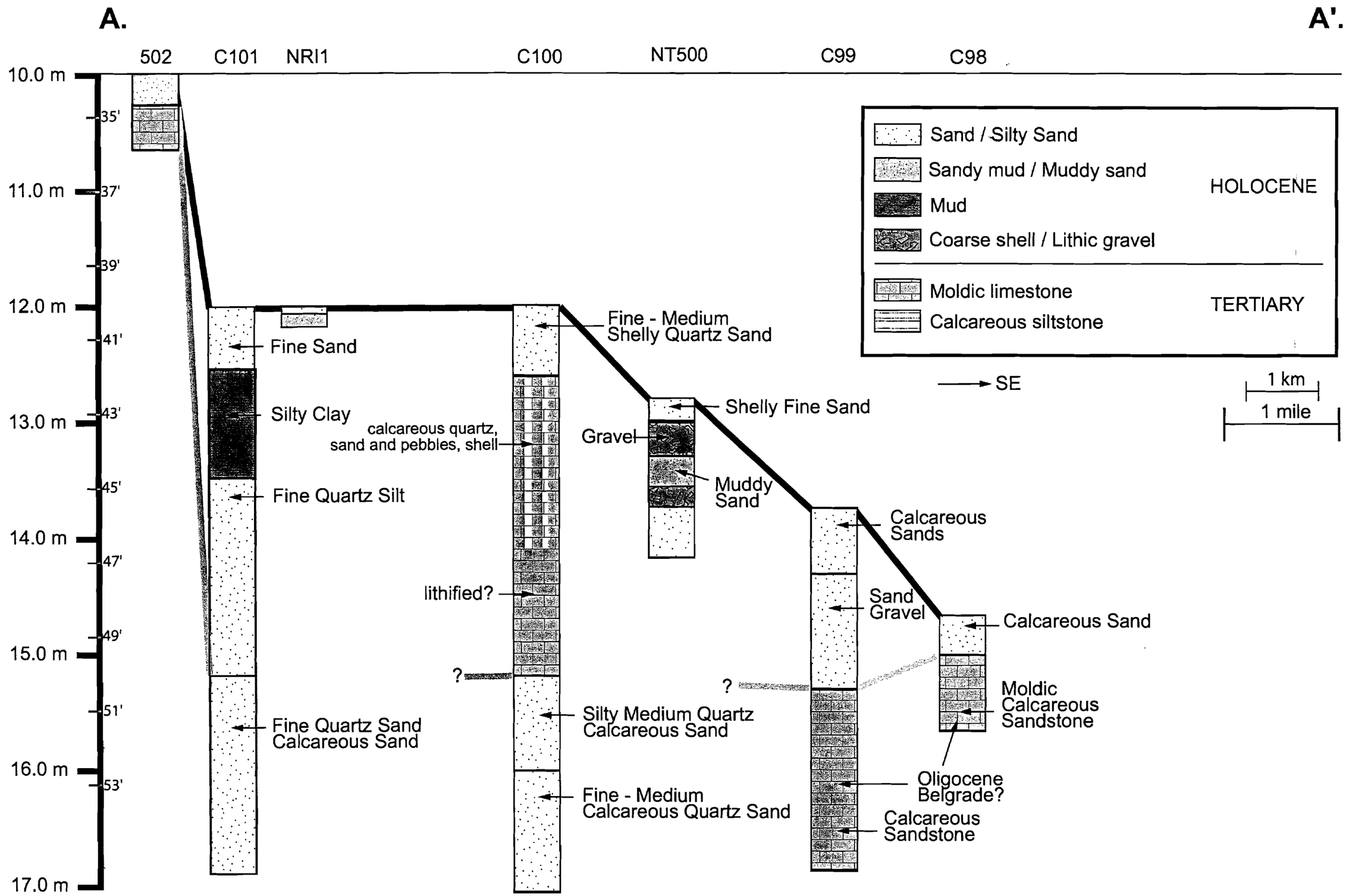


Figure 53. Shore-normal vibracore cross-section A-A'.

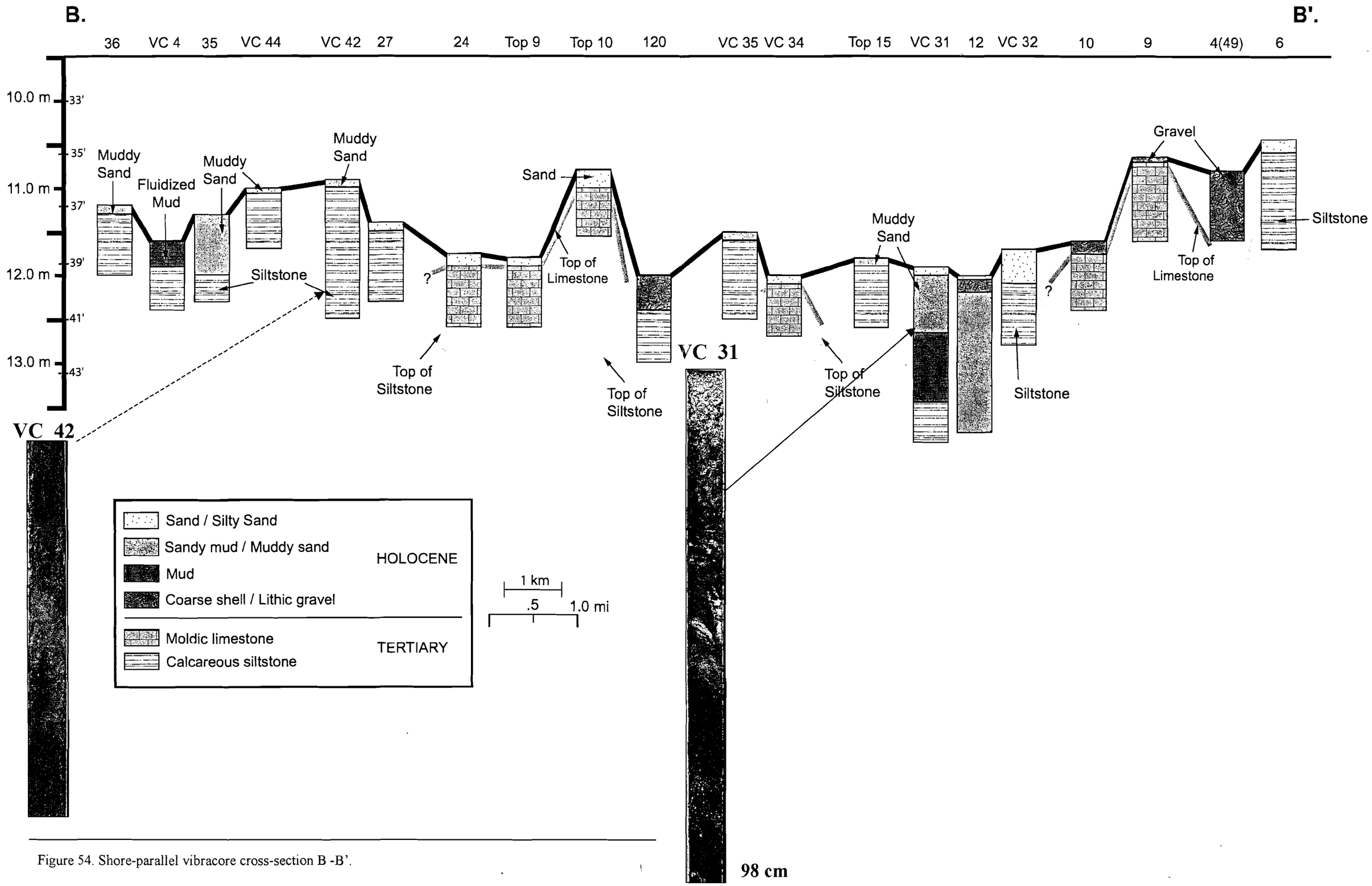


Figure 54. Shore-parallel vibracore cross-section B -B'.

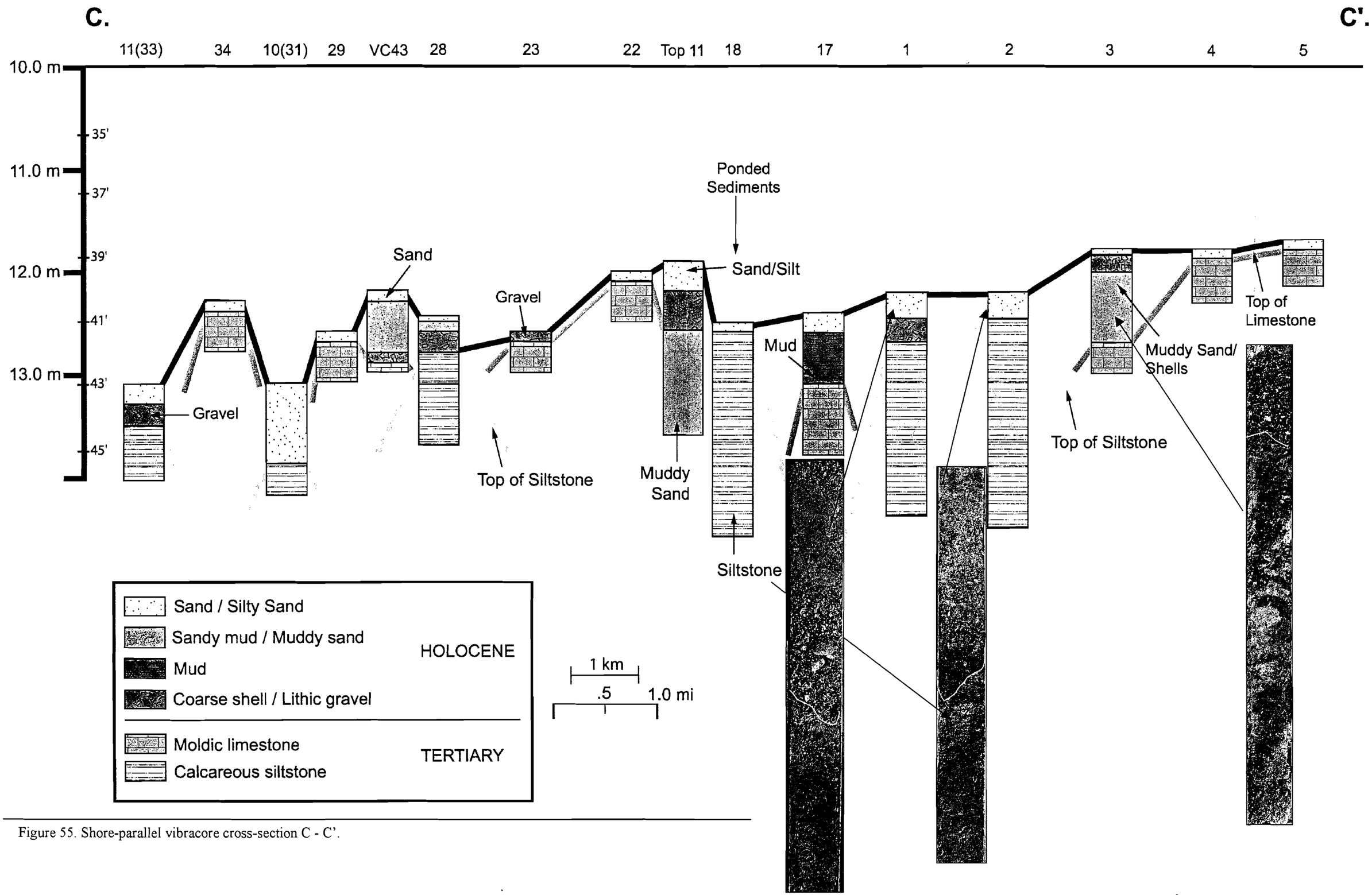


Figure 55. Shore-parallel vibracore cross-section C - C'.

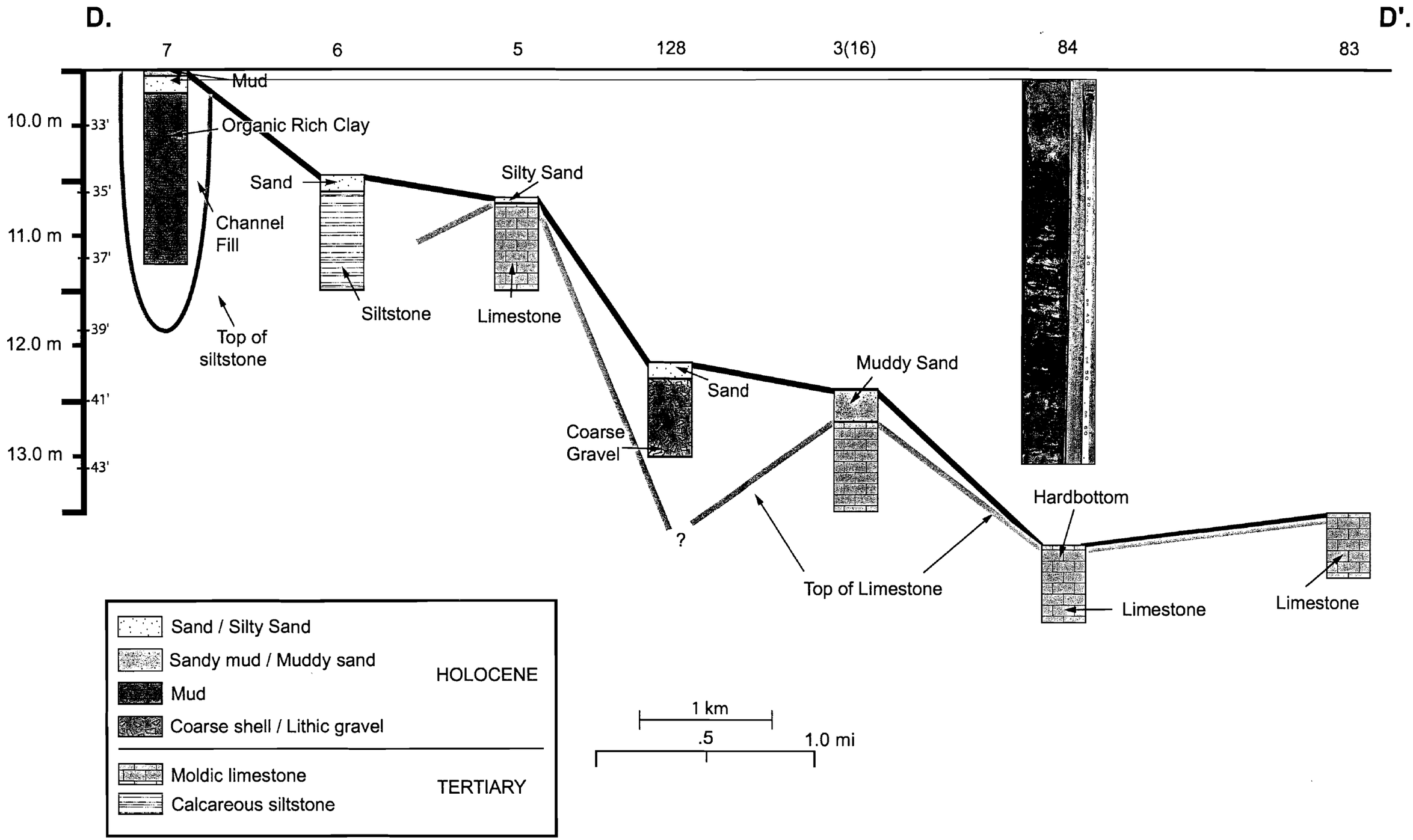


Figure 56. Shore-normal vibracore cross-section D - D'.

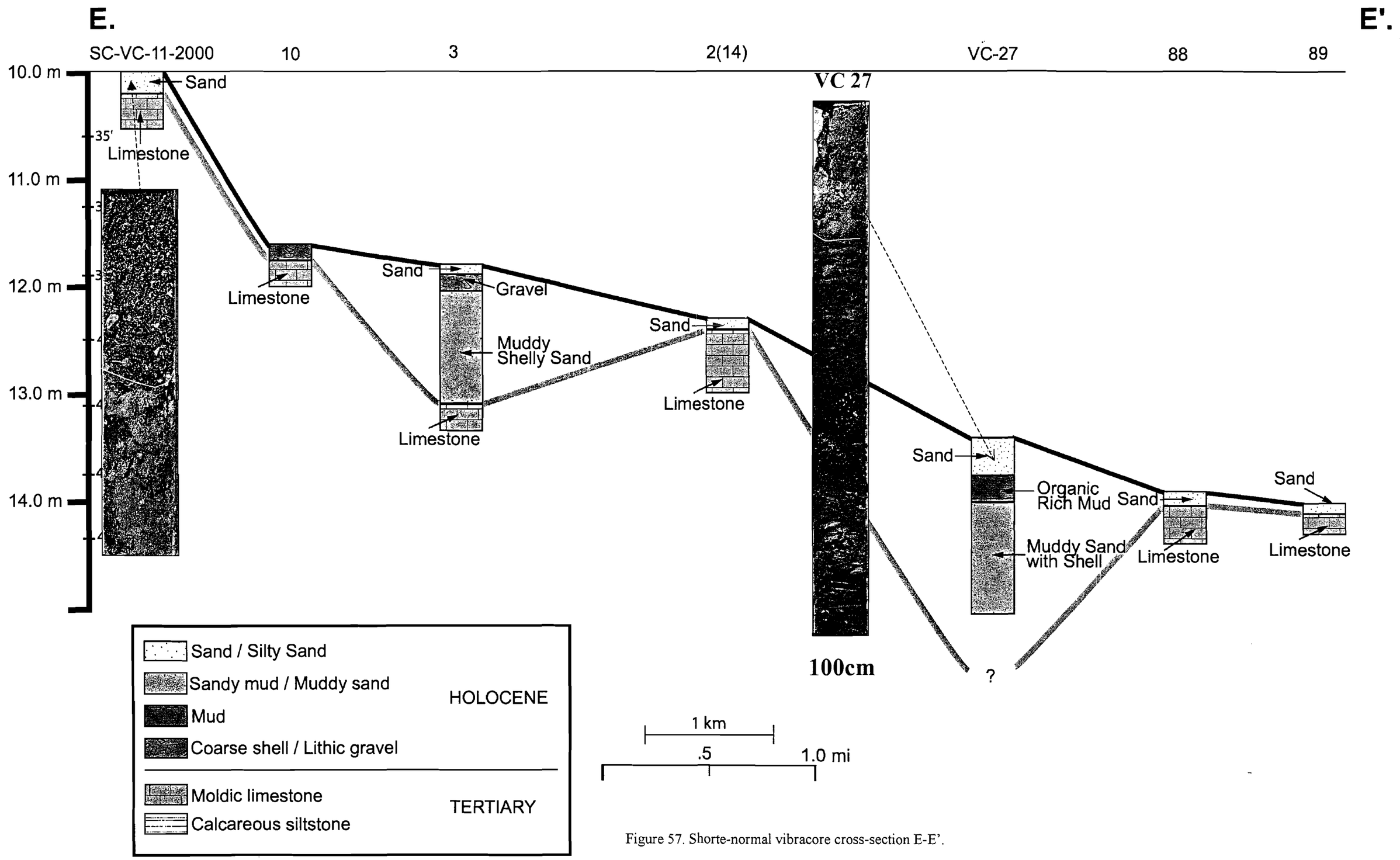


Figure 57. Shorte-normal vibracore cross-section E-E'.

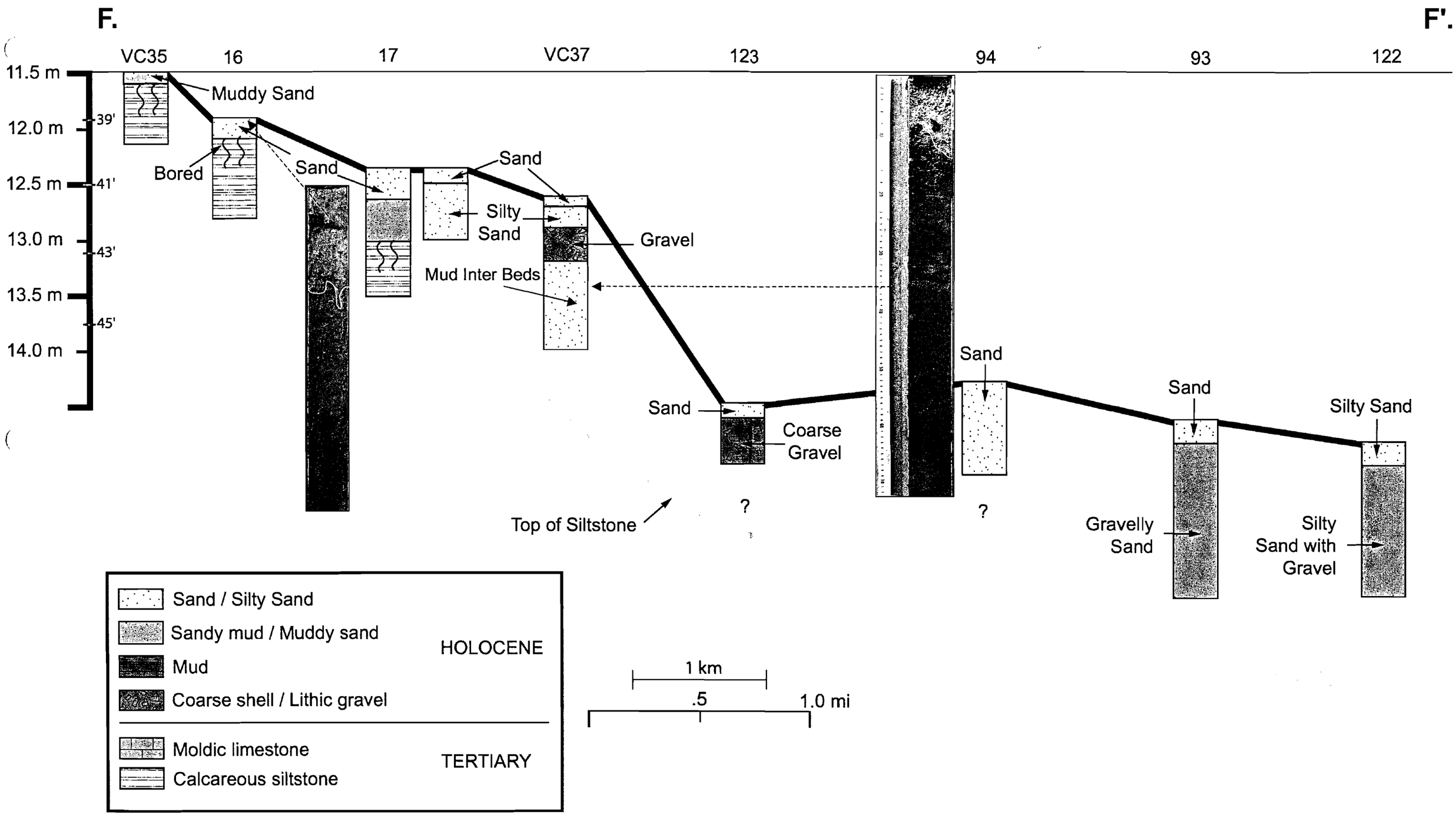
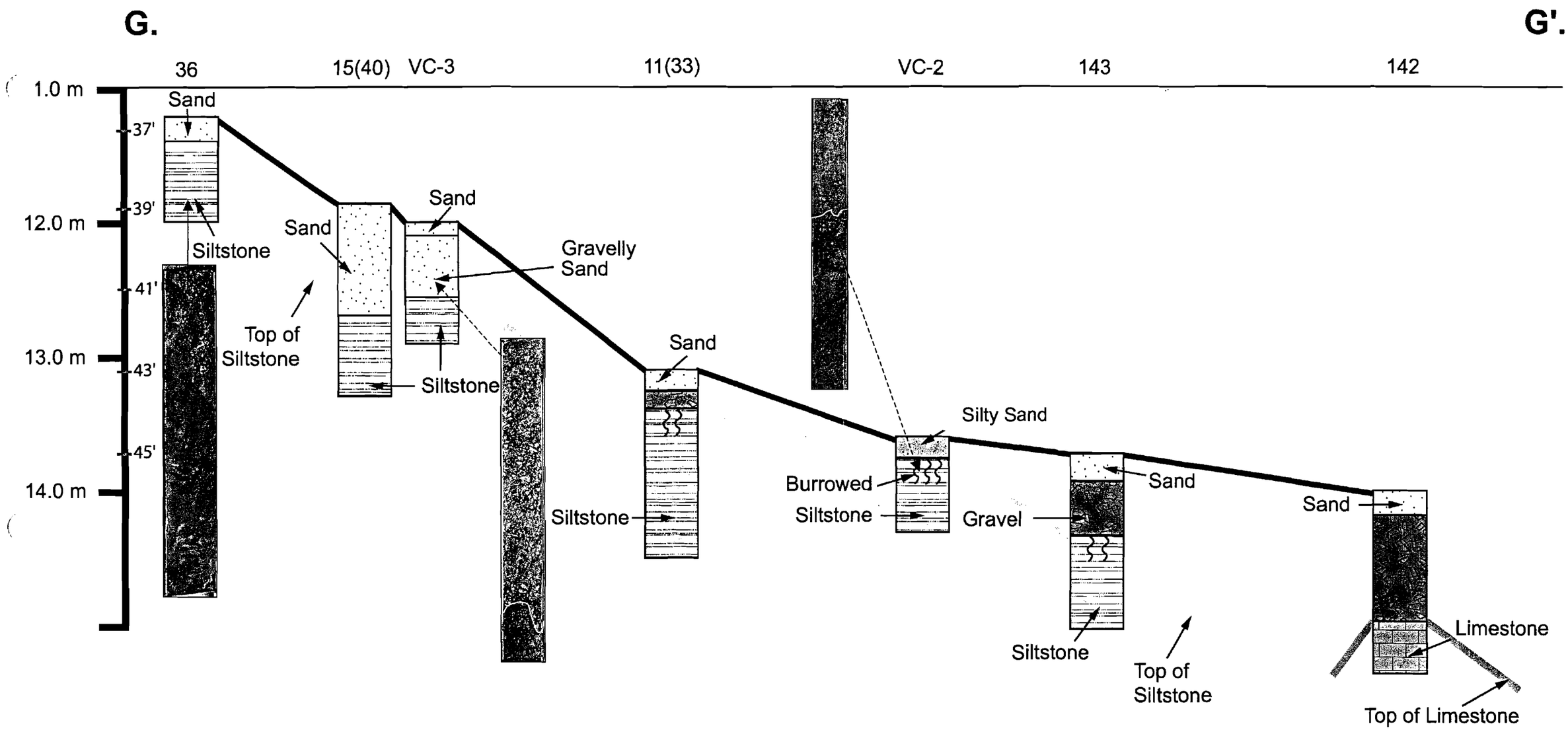
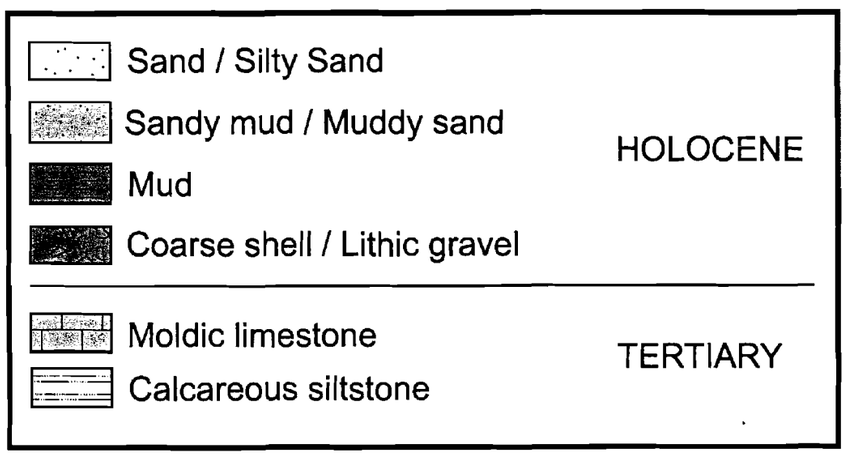


Figure 58. Shore-normal vibracore cross-section F-F'.





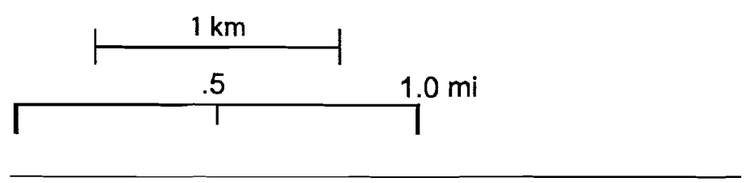


Figure 59. Shore-normal vibracore cross-section G-G'.

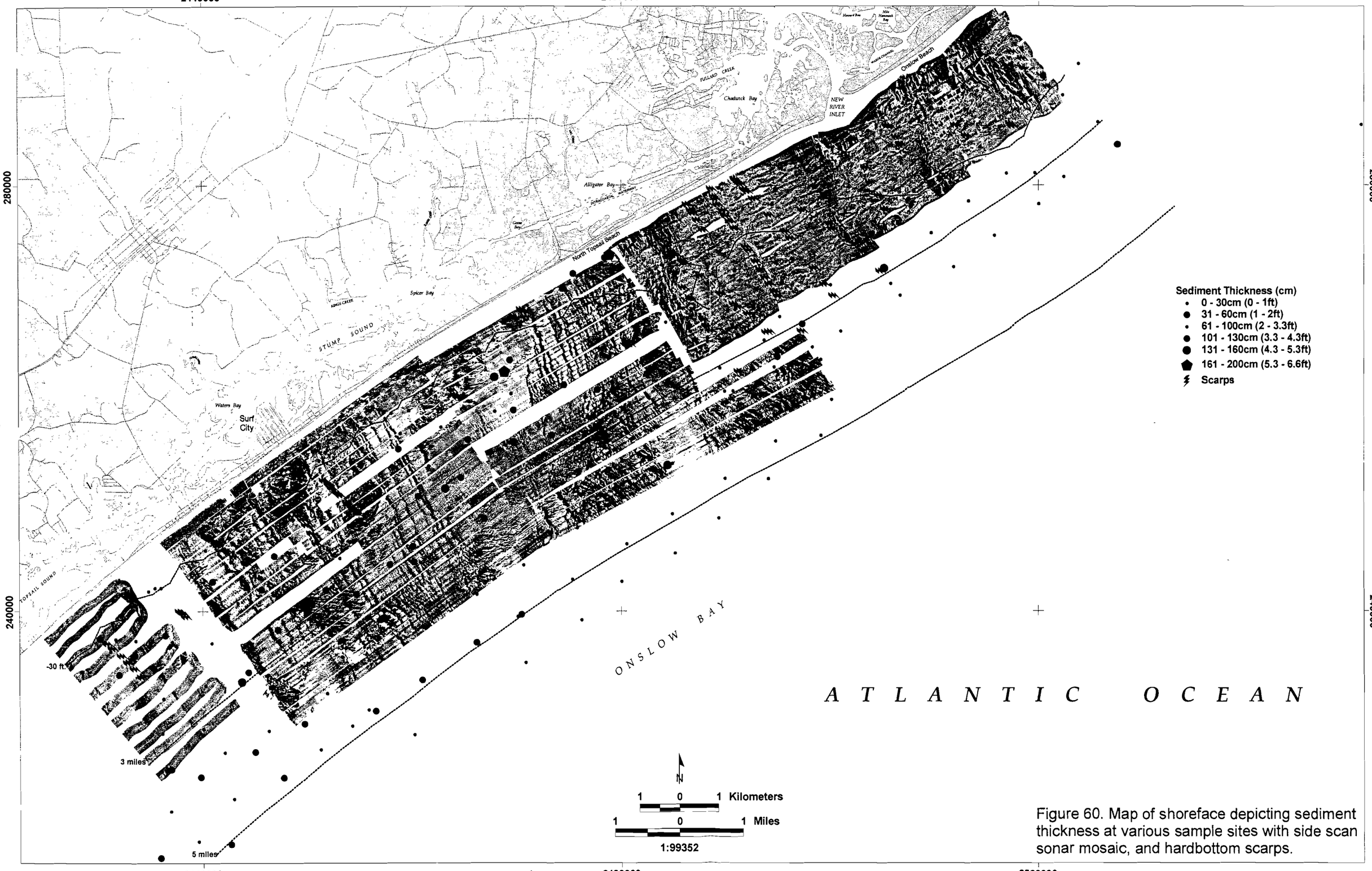


Figure 60. Map of shoreface depicting sediment thickness at various sample sites with side scan sonar mosaic, and hardbottom scarps.

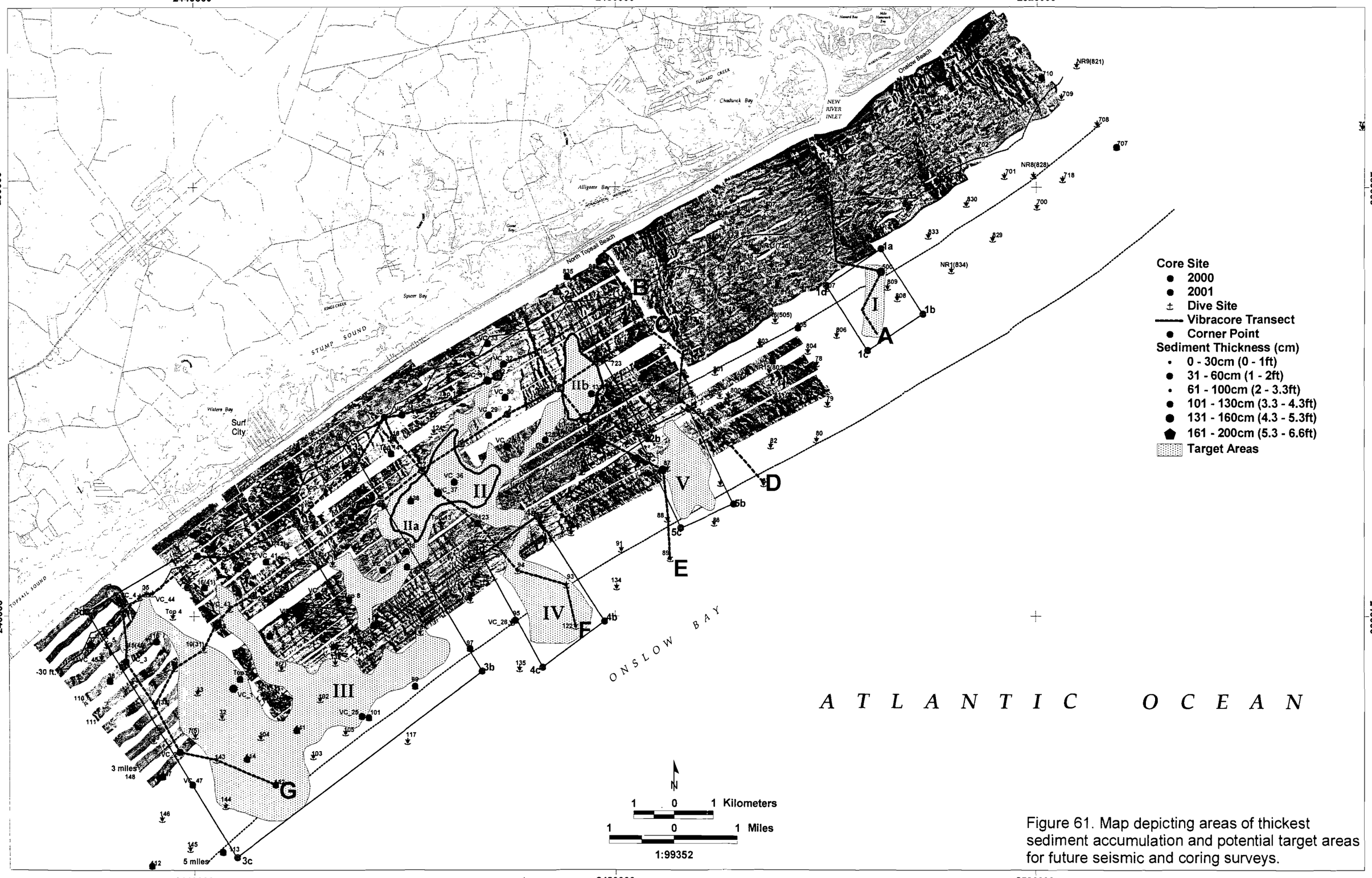


Figure 61. Map depicting areas of thickest sediment accumulation and potential target areas for future seismic and coring surveys.

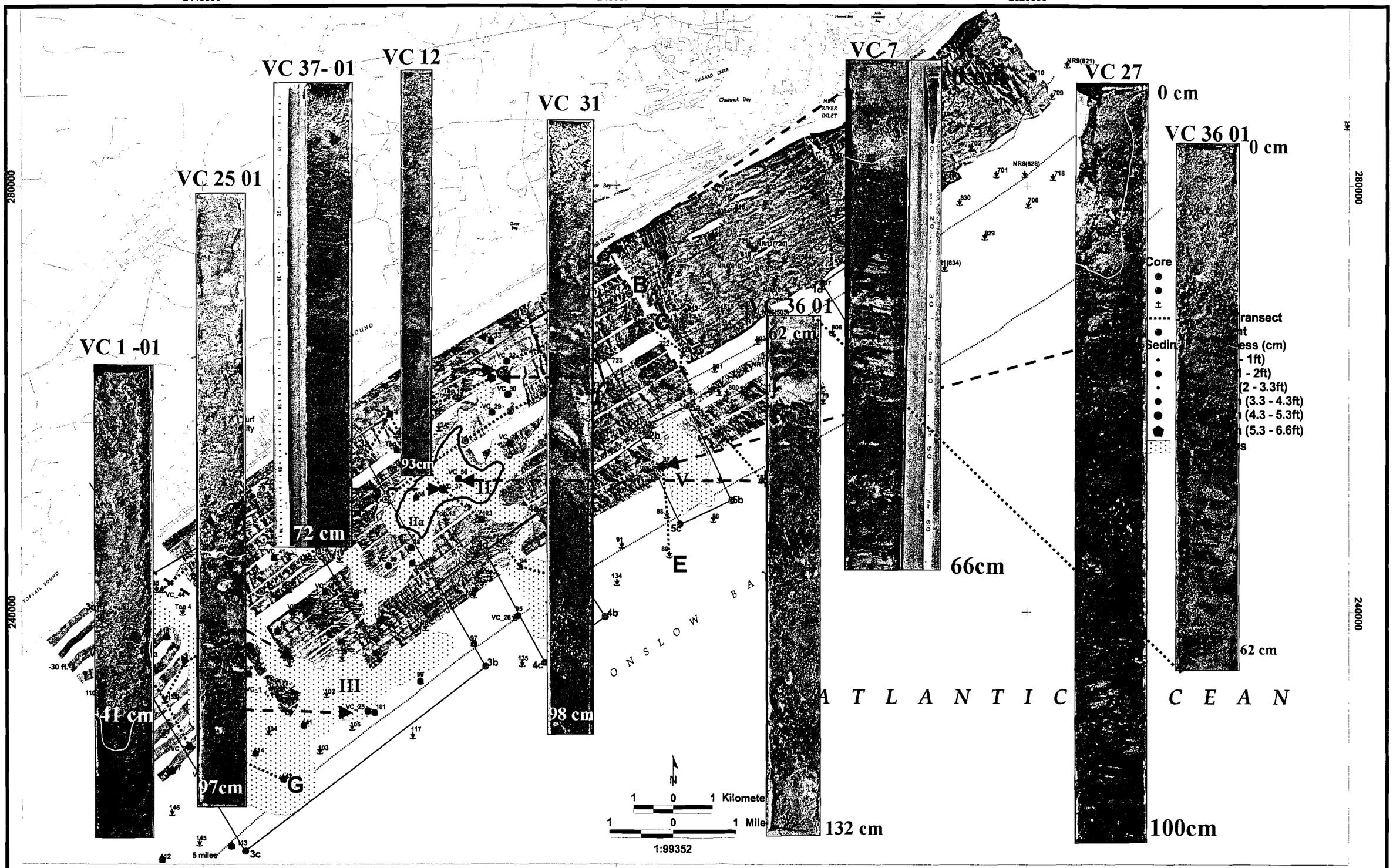


Figure 62. Map depicting areas of thickest sediment accumulation, potential target areas and photographs of representative vibracores.

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

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.