Assessment of Sand and Gravel Resources Along the Inner Continental Shelf of Maine: Years 1, 2, Outer Saco Bay: A Multi-Year Cooperative Between The U.S. Minerals Management Service, Maine Geological Survey and University of Maine

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Introduction

Beach erosion is arising as a critical and growing issue in southern Maine (Kelley and Anderson, 2000). State law precludes additional protective engineering structures along eroding beaches, leaving beach replenishment as the preferred method to cope with beach loss. Sand and gravel resources on land exist in this area, but transportation to the coast and road repair can add significantly to the expense of replenishment. Inland gravel pits are increasingly regulated in this growing suburban region. Thus, offshore borrow sites of aggregate are the most likely long-term sources of sand and gravel to replenish beaches. Herein we describe the results from Years 1 and 2 from a multi-year cooperative investigation between the Minerals Management Service and the University of Maine and Maine Geological Survey. The overall purpose of the Cooperative is to explore for and better define sand and gravel resources in federal waters offshore of the Maine coast. Years 1 and 2 focus on the sand and gravel resources in outer Saco Bay (Figure 1).

PREVIOUS STUDIES AND GEOLOGIC FRAMEWORK

Sand and gravel are found in several geological settings on the northern New England inner shelf: shorefaces, lowstand shorelines, stratified moraines, and paleodeltas. (Table 1)(Kelley et al., 2003). Seaward of major beaches, shoreface-sand deposits represent a significant repository of material. Off Saco Bay, for example, 56 million m^3 of sand line the shoreline (Kelley et al., 2003; 2005). This sand is geologically linked to the adjacent beaches, however, and is not an appropriate source for replenishment.

Lowstand shorelines (shorelines from a lower-than-present stand of sea level) exist in many places in this region (Table 1), but constructional beach deposits are widely recognized only off Cape Small, Saco Bay, Wells Embayment and the Merrimack River mouth (Kelley et al., 2003). The drowned shorelines extend from the lowstand position, around 50-70 m depth, into shallower water, where pinning points of bedrock or glacial deposits allowed spits to prograde and littoral landforms to develop. The amount of sand in these features is unknown, but likely to be variable.

TABLE 1

Deposit	Knowledge*	Volume (m^3)	Depth (m)	Proximity (km)
Wells				
Lowstand	1	10^7-10^8	30-70	<25
Moraines	1	10^7	30-70	<25
Saco				
Lowstand	1-4	10^7-10^8	30-70	<25
Paleodelta	None	10^7	50-60	<25
Cape Small				
Lowstand	3	>10^8	30-6	25-50
Paleodelta	3	10^8	30-60	25-50
Merrimack River				
Lowstand	2	10^8	30-60	>50
Paleodelta	2	10^8	30-60	>50

* 1 = preliminary seismic and side scan only; 2 = seismic and cores; 3 = side scan, seismic and cores; 4 = multibeam

A considerable body of geologic literature exists for Saco Bay, in part because it contains the largest beach in Maine (Kelley et al., 1986a, 1989a). Beginning in the late 1980's, cooperative work with the MMS led to several publications that define outer bay sand bodies with seismic reflection and bottom sample observations (Kelley et al., 1986b, 1989b) Vibracores added ground truth to the remotely sensed data and led to revisions on sand abundance (Kelley et al., 1990, 1992, 1995). Insight gained from this work on inner shelf sand bodies led to some more general discussions on offshore sand in Maine (Kelley et al., 1989b, 1998, 2003) and specifically sand offshore Saco Bay (Kelley et al., 2005).

Several problems became apparent during early investigations. Although lowstand deltas are known from other large rivers in the region (Barnhardt et al., 1997; Belknap et al., 2005), none has yet been found off the Saco River in outer Saco Bay

(Kelley et al., 2003). In addition, sand deposits observed in seismic records and vibracores from the outer bay are all relatively thin (< 2 m), and many shorelines are erosional features (Shipp et al., 1991, Kelley et al., 2003). During the Years 1 and 2 Cooperative projects described herein, our focus was directed at locating a lowstand delta and thicker lowstand shoreline deposits in an area of the outer bay that had received little prior work.

Geological Setting

Paleozoic bedrock crops on the headlands framing Saco Bay and is recognized as acoustic basement in seismic reflection profiles (Kelley et al., 1998). Rocky islands exist in the central part of the bay and an extensive shallow area surrounds the islands and is supported by near-surface bedrock. The bedrock consists mostly of metamorphic rocks that trend in a northeast direction (Osberg et al., 1985). A Carboniferous granite crops out just south of Saco Bay.

Bedrock locally exhibits several meters of relief over tens of horizontal meters. Numerous fractures exist in bedrock on land and are distinctive features on side scan sonar records (Kelley et al., 1998).

Till and glacial-marine muddy sediment locally bury bedrock. Glacial sediment was deposited by melting ice approximately 14,000 radiocarbon years ago (Borns et al., 2004) when local, relative sea level was approximately 75 m above present level (Barnhardt et al., 1997). Till represents a strong acoustic reflector that often resembles bedrock (Barnhardt et al., 1997). Glacial-marine sediment possesses strong and coherent acoustic reflectors that extend for hundreds of meters or more. The reflectors are draped over the underlying topographic elements. In water depths less than about 65 m, the glacial sediment is often eroded where it was apparently exposed to wave action at the sea-level lowstand between approximately 11,000 radiocarbon years ago and present. It was during the time of the lowstand of the sea that large rivers deposited significant bodies of sand in present water depths up to 70 m (Kelley et al., 2003). As sea level rose to the present time, sand has continued to be added to the inner shelf even as older deposits are reworked. The present seafloor sediment is, thus, modern close to shore, and palimpsest or relict in depths between about 30 m and 70 m.

METHODS

In the summer of 2003, we collected multibeam, and side scan sonar data simultaneously in outer Saco Bay (Figures 2, 3). Owing to budget constraints, we could not afford to extend the multibeam coverage to all areas evaluated with side scan sonar and seismic reflection profiles.

We used a digital Edgetech side scan sonar towfish with a topside Triton-Elics data processor. The range imaged varied between 100 m and 200 m. Multibeam bathymetric data were gathered with a Simrad SM 2000 system. Water profiles were evaluated every hour, and all data was processed with the Triton-Elics data processor. In all, 115 km of seismic reflection tracklines were gathered, and 180 km of side scan sonar tracklines, ensonifying an area of 45 km^2. .

Seventeen vibracores were gathered between 36 m and 78.5 m depth in the summer of 2004 with a Rossfelder Underwater P3 Vibracorer (16 cores were between 54 m and 78.5 m depth) (Figure 3). All cores were brought back to the sedimentology lab at the University of Maine for description and analyses.

Results

a. Multibeam Bathymetry

The study area is in southern and outermost Saco Bay, centered about 5.6 km (3 nautical miles) from the nearest land at Biddeford Pool (Figures 1, 2). This area is due south of areas previously investigated in the outer Bay. The depth ranges from about –25 m to –80 m, and focused on the presumed lowstand depth of –60 m (Kelley et al., 2003).

Multibeam coverage is conveniently broken into three regions (Figure 4). Area A forms the western edge of the multibeam study area, and appears as an 'island" to the south. Area A ranges from –25 m to –35 m depth. The large, almost rectangular and shallow regions in area A are separated by a crude grid of linear depressions averaging –40 m. Area A is bordered by Area B on most of its seaward side, where the seafloor abruptly descends to -65 m (Figure 4). Isolated regions within Area B project upward as relative shoals in a generally seaward sloping area. Two "islands", also mapped as Area B, exist to the southeast. These are each centered on a shallow area approximately –35 m deep, around which the seafloor deepens on all sides. Most of the eastern side of the study area, mapped as Area C (Figure 4), is deeper than 60 m and generally flat. Deep "channels" of Area C surround the three small "islands" of Area A and B.

Area C possesses the least bathymetric relief, and Area B possesses the greatest change in depth (Fig 4). Area A extends in a landward (northwest) direction out of the region of multibeam coverage, while Area B trends northeast-southwest out of the area of multibeam observations along the border of Areas A and C. Area C extends seaward of the region of multibeam coverage. It is apparent from close examination of the multibeam data that the depth range of the presumed lowstand, -50m to –60 m, is relatively flat compared to other depths, and could be a drowned wave-cut platform veneered with littoral deposits.

b. Side Scan Sonar

The bathymetry imaged by multibeam is mirrored by a similar pattern of changing acoustic reflectivity on the side scan sonar mosaic (Figure 5). The shallow, western Area A from the multibeam mapping is defined by high acoustic reflectivity uniformly over its surface. Some of the shallowest locations are the most reflective. The grid of linear depressions evident in the multibeam is not nearly so marked in the side scan mosaic, and most of the shallow regions are "hard". A more detailed examination of the data (Figures 6 and 7) reveals that the hard reflector in Area A is bedrock. The fractured nature of the rock resembles outcrops on land (Kelley et al., 1998) with steep edges to the rock bodies. In the fractures and between bedrock outcrops, strong reflections emanate from low-relief gravel occurrences (Figures 6 and 7). The intermediate Area B of the multibeam map is represented by a complex mix of acoustically reflective and non-reflective areas on the side scan images. Areas of bedrock are apparent as in Area A, but they are relatively small “islands” of rock surrounded by sediment. The sediment directly observed in cores and bottom samples (Figures 6 and 7) correlates well with acoustic reflectivity. The areas of acoustically stronger reflections, as seen in the mosaic in Figures 6 and 7, contained fine or medium sand in the upper part of the core or bottom samples. Areas of even stronger reflectivity are probably marked by concentrations of shells or pebbles such as those found in many samples. Areas of low reflectivity regions contained muddy surficial material. Area C, the deepest, most uniform and gentle area on the multibeam imagery is the most uniform and least acoustically reflective area. Some parts of the “channels” of Area C separating the “islands” of Area B are more acoustically reflective than the eastern edge of the study area, and are floored by sand.

The surficial sediment map (Figure 8), which synthesizes the side scan sonar, multibeam and core and bottom samples, reveals the overall area as one dominated by rock and mud. The rock areas are shallow, extensive and mostly bordered by mud. The bathymetric depression to the southwest, labeled a Shelf Valley by Kelley et al (1998), transitions from sand to mud between 30 and 70 m depth, with abrupt bedrock borders on its margins (Figure 8). Areas dominated by gravel and sand are relatively smaller and flank the rock in the northeast part of the study area. Gravel and sand-floored depressions also occur in the southern-most part of the study area.

There are many smaller gravel and sand areas that cannot be depicted on the scale of the map (Figure 8). The fractures between rock outcrops and the margins of the rock are places where shell fragments and gravel exist as lag deposits or are recent deposits derived from contemporary erosion of the bedrock and associated attached fauna.

c. Seismic Reflection Profiles

The subbottom geology of the study area is similar to other places studied in the region (Kelley et al., 1998). Bedrock, with up to 25 m of local relief, forms acoustic basement (Figure 9). Glacigenic sediment fills in basins in the bedrock. Till is not widespread as moraines in the study area, but appears to occur as smaller deposits only a few meters thick. Glacial-marine sediment is the thickest deposit in the region, with up to 30 m of material in some places (Figure 9). Numerous coherent reflectors are observed in the glacial-marine sediment, and may be sand deposits, but all are located beneath a thick, muddy cover.

Reflectors in the upper glacial-marine sediment are truncated in depths shallower than 65 m. Seismic observations are obscured in the uppermost few meters of sediment overlying truncated reflectors, but core observations described below reveal that sand often caps the sedimentary section. In many places sand deposits possess a sigmoidal shape where sand is banked up against a bedrock cliff (Figure 9), and in other locations sand deposits form moderate-relief swells.

d. Cores

Vibracores provided essential ground truth regarding the surficial sediment texture over the study area and the nature of the uppermost few meters of the sedimentary section. Most cores met refusal in glacial-marine muddy sediment (Figure 10). This distinctive stiff muddy sediment is gray to blue in color when first exposed to air and has been recognized in many cores collected from the region (Barnhardt et al., 1997; Kelley et al., 2003). Sand either gradually increases in abundance above the mud or as in core SCVC04-22, for example, the sand rests with a sharp contact over the glacial-marine mud. The sharp contact between sand and mud coincides with truncated acoustic reflectors interpreted in the seismic record (Figure 10). The overlying sand is typically fine to medium in size (Appendix A), with a mud content ranging from 0 to more than 25%.

e. Sand Volume

Bedrock punctuates the study area, breaking it up into eight, generally unconnected basins containing sand deposits (Figure 11). Between these basins, bedrock or mud are the major surficial materials, with the possible exception of some of the area of multibeam coverage where no seismic data were collected. To evaluate sand thickness, side scan sonar data were used to delineate areas of surficial sand. Cores and seismic data were then used to evaluate the thickness of sand across an area. Because of the relatively large number of geologically unique, no extrapolation from basin to basin was possible. Within basins, however, extrapolation across a relatively large area was required by the relatively few cores. Because sand thickness varied across individual basins, maximum and minimum estimates were made for many basins. The true volume of sand is a value between these estimates.

<u>Basin 1</u>

Basin 1 is located in the Shelf Valley (Kelley et al., 1998) on the southwestern edge of the study area (Figures 3, 11). The Shelf Valley contains the largest volume of sediment in the study area, but most of the sediment is interpreted as glacial-marine, muddy material (Figure 9). The prominent reflectors in the glacial-marine sediment are probably sand or gravel layers, but most are buried beneath more than 10 m of muddy sediment and are not considered in this report.

Clean sand is restricted to the upper 20 cm of this basin, although sandy mud continues to greater than a meter’s depth in core SCVC04-05 (Figure 9). This core was collected from the center of the basin. Although more sand may exist higher up on this bank, sand thickness is not likely to exceed 20 cm across the remainder of the Shelf Valley. Sand probably increases in thickness in a landward direction, and decreases to seaward (Kelley et al., 1998). The sand volume estimate of $7.96*10^5$ m^3 assumes a uniformly thin sandy deposit across the basin (Table 2). Based on an interpretation of the seismic line (Figure 9), channels were possibly incised into the glacial-marine sediment at the time of sea-level lowstand. These may have been filled with valley fill material during transgression. The limited core data did not encounter sandy material at depth, however, so we are constrained to report a relatively small deposit here.

<u>Basin 2</u>

Basin 2 is on the northern edge of the study area, and borders the region of extensive investigation in the 1990’s (Kelley et al., 2003). Seismic lines depict a transition from the rocky, shallow area (labeled A, Figure 4) across the lowstand shoreline complex (labeled B, Figure 4) and into deep water (labeled C, Figure 4). The deepest feature, approximately –65 m, interpreted as a shoreline borders the extensive muddy region (labeled C, Figure 4) (Figure 12). Rock and till separate this landform from a more extensive and thicker sand deposit that was cored in 1992 (Core SCVC92-01). Almost 3 m of coarse and medium-size sand and some gravel were recovered in the core from an apparently widespread deposit that is banked up against a shallow bedrock outcrop. Between $3.8*10^5$ m^3 and $5.7*10^5$ m^3 (Table 2) of clean sand are interpreted to exist within this lowstand shoreline complex inside the study area. The shoreline complex trends out of the study area to the northeast; so this estimate is a minimum for the bay as a whole.

<u>Basin 3</u>

On the eastern edge of the study area, Basin 3 borders the muddy plain to the north and fits between two rocky “islands” to the northeast and southwest (Figures 3, 11). The core sample, VC04-01, (Figure 13) penetrated about 60 cm of clean sand over sandy mud and then mud. Medium and fine sand layers were encountered below 3.5 m depth in the core. These layers appear to be strong acoustic reflectors recognized in the seismic line and are not lowstand sand deposits. They are not included in the sand volume estimation since the reflectors do not have spatial continuity as the shoreline deposits do. The volume estimate for this basin assumes 0.6 m of sand across the basin and totals $1.11*10^6$ m^3 (Table 2).

<u>Basin 4</u>

Located near the center of the study area, Basin 4 borders the extensive muddy area to the northeast (Figures 3, 11). It is a relatively flat feature with somewhat stronger surface acoustic reflectivity than the muddy area (Figure 5). Core SCVC04-09 was gathered from a ridge that trends across Basin 4 (Figure 14). The ridge appears to be a constructional landform, possibly a beach, but Core SCVC04-09 contained less than 0.5 m of clean sand overlying sandy mud and glacial-marine mud. Owing to its relatively small area and apparently thin deposit of sand, Basin 4 is estimated to contain only $3.28*10^5$ m^3 (Table 2).

<u>Basin 5</u>

Basin 5 abuts Basin 4, but is separated from that Basin by a shallow, rocky ridge (Figures 3, 11). Seismic and core data (Figure 15) suggest that this basin may contain more sand than any other part of the study area. Core SCVC04-10 penetrated more than 3 m of coarse-grained sediment (Figure 15), including some pebble layers. Finer sediment accumulated near the bottom of the core, but the glacial-marine mud, inferred on the basis of the seismic data, was apparently not reached by the core.

The substantial sand body here, $1.6*10^7$ m^3 equals maximum value, $3.25*10^5$ m^3 equals minimum value (Table 2), appears to be a shoreline complex partly eroded into glacial-marine mud and overlying valley fill material (Figure 15).

<u>Basin 6</u>

Basin 6 lies along a narrow Shelf Valley in the central part of the study area (Figures 3, 11). Side scan sonar reveals that the core location is in a narrow portion of this valley, and up against the western side (Figure 4). Seismic data show that the core, SCVC04-20, was located in the middle of a bathymetric high (Figure 16). The core penetrated about 2 m of medium sand an muddy sand overlying glacial-marine mud. This suggests that the bathymetric high represents a sandy littoral remnant drowned when sea level rose past 65 m depth. The maximum sand volume estimate is based on a sand thickness of 2.0 m across the area of Basin 6, yielding $3.4*10^6$ m^3; the minimum estimate, $6.8*10^4$ m^3, assumes that the sand thickness is only 0.4 m thick (Table 2). The latter, minimum value corresponds to the thickness of sand inferred in the deeper part of the valley away from the bathymetric high.

Basin 7

Basin 7 is on the southeast border of the study area and is divided into two parts (Figures 3, 11). In the eastern region a ridge containing a substantial sand deposit was cored (Figure 17). The core was all medium-coarse sand, and refusal was met before the core reached the glacial-marine mud interpreted below the sand. The deposit, at 54 m depth, is above the inferred lowstand depth and is thicker than the thin veneer of sand at greater depths nearby. Though small in area, Basin 7 appears to have between $3.8*10^6$ m^3 and $1.52*10^6$ m^3, one of the largest deposits in the study area (Table 2). More sand exists in the western part of Basin 7, but no cores were gathered from that area and so it is not considered in the volume characterization.

Basin 8

The sand deposit in Basin 8 resembles the deposit in Basin 1, the Shelf Valley (Figures 3, 11). Basin 8 is also a bedrock-framed valley-like feature that is largely filled with glacial-marine mud (Figure 18). A core from the center of the basin recovered about 1 m of slightly muddy sand overlying dense mud interpreted as glacial-marine material. Although the volume of the deposit, $4.8*10^3$ m^3 of sand (Table 2), is the smallest evaluated for this study, the basin extends outside of the area of study.

Discussion

Large rivers that enter the Gulf of Maine, such as the Merrimack, Kennebec, and Penobscot, are all associated with deltas built at times of lower-than-present sea level (Belknap et al., 2004; Kelley et al., 2003). These rivers gathered their sand as new rivers that formed in the post-glacial period and eroded down into glacial sediment as local, relative sea level fell. The Merrimack and Kennebec actively contribute sand to the inner shelf today (FitzGerald et al., 2004), as does the Saco (Kelley et al., 2004). The Penobscot River does not carry sand to sea today and its paleodelta is buried under 10 m of mud in Penobscot Bay apparently due to drainage derangement in the early Holocene (Belknap et al., 2005).

Even though the Saco River actively contributes sand to the shelf today, it possesses a discharge that is an order of magnitude smaller than the Kennebec or Merrimack Rivers. This may account for its lack of a lowstand paleodelta. In its upper reaches, the Saco also passes through extensive wetlands and a pond (Kezar Pond, Fryberg, ME) where it may have deposited much of its early sand load before reaching the sea.

Table 2: SAND VOLUME IN LOSTAND SHORELINE BASINS, OUTER SACO BAY

Basin	Basin Area (km^2)	Sand Thickness (m)	Sand Volume (m^3)
1	3.98	0.2	$7.96*10^5$
2	1.91	3.0 (max)	$5.73*10^6$
		2.0 (min)	$3.82*10^6$
3	1.83	0.6	$1.11*10^6$
4	0.82	0.4	$3.28*10^5$
5	0.65	5.0 (max)	$1.6*10^7$
		0.5 (min)	$3.25*10^5$
6	0.17	2.0 (max)	$3.4*10^6$
		0.4 (min)	$6.8*10^4$
7	1.9	2.0 (max)	$3.8*10^6$
		0.8 (min)	$1.52*10^6$
8	0.16	0.3	$4.8*10^3$

Although it lacks a deltaic landform, the shoreline complex in outer Saco Bay still contains an abundance of sand (Table 2). In assessing the sand volumes in the eight basins of outer Saco Bay, seismic coverage was not dense enough in any one basin to construct an isopach map because of the highly irregular basement bathymetry. Maximum and minimum values were attached to the sand volumes in the basins based on extrapolations from the thickness of sand collected in the cores (Table 2). A maximum volume of sand was estimated at $3.1*10^7$ m^3, with a minimum volume of about $8*10^6$ m^3. The deposits extend beyond the study area into shoreline deposits to the northeast cored in earlier years (Kelley et al., 2003) and landward, up the Shelf Valley (Basin 1). Since no deltaic landform was recognized in these areas, it is unlikely that more than an additional $1*10^7$ m^3 could be found in these areas.

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Figure Captions

Figure 1. Location map and generalized surficial geology and bathymetry of the study area in Saco Bay Inset may shows study area in relation to the Gulf of Maine. Boxed area shown in greater detail as Figure 2.

Figure 2. Area mapped with multibeam and sidescan sonar. Side scan sonar lines used in report are indicated.

Figure 3. Seismic reflection track lines and vibracore sites. Seismic lines used in report are indicated.

Figure 4. Detailed multibeam bathymetric map of the study area. Areas labeled A, B, and C are discussed in the text.

Figure 5. Side scan sonar mosaic of study area. Filled circles represent vibracore sites; open squares represent bottom samples collected earlier (Kelley et al., 1986b).

Figure 6. Detailed side scan sonar image of rock and gravel. The linear acoustic noise to either side of the center trackline was caused by ship heave in rough seas. Lighter tones represent ‘soft” returns from mud; darker tones are “harder” returns from rock, sand and gravel. Side scan image is located in Figure 2.

Figure 7. Detailed side scan sonar image of sand and mud. Figure is located in figure 4. The linear acoustic noise to either side of the center trackline was caused by ship heave in rough seas. Side scan image is located in Figure 2.

Figure 8. Surficial material map interpreted from side scan sonar, and bottom and core samples.

Figure 9. SRP and core from Basin 1. BR is bedrock, T is till, GM is glacial-marine mid, Vf is valley fill, S is sand.

Figure 10. Vibracore SCVC04-22 collected along seismic line SC-04-98.

Figure 11. Map of basins within the study area containing sand on the surface.

Figure 12. Core SCVC92-01 was collected just south of this seismic line in Basin 2. All interpreted seismic units are the same as described in Figure 9.

Figure 13. Core SCVC04-01 from Basin 3. All interpreted seismic units are the same as described in Figure 9.

Figure 14. Core SCVC04-09 was collected in Basin 4 at about 65 m depth. All interpreted seismic units are the same as described in Figure 9.

Figure 15. Core SCVC04-10 from Basin 5. All interpreted seismic units are the same as described in Figure 9.

Figure 16. SCVC04-20 from Basin 6. All interpreted seismic units are the same as described in Figure 9.

Figure 17. Core SCVC04-02 from Basin 7. All interpreted seismic units are the same as described in Figure 9.

Figure 18. Core SCVC04-12, from Basin 8 was gathered from sediment banked up against the wall of the basin. All interpreted seismic units are the same as described in Figure 9.

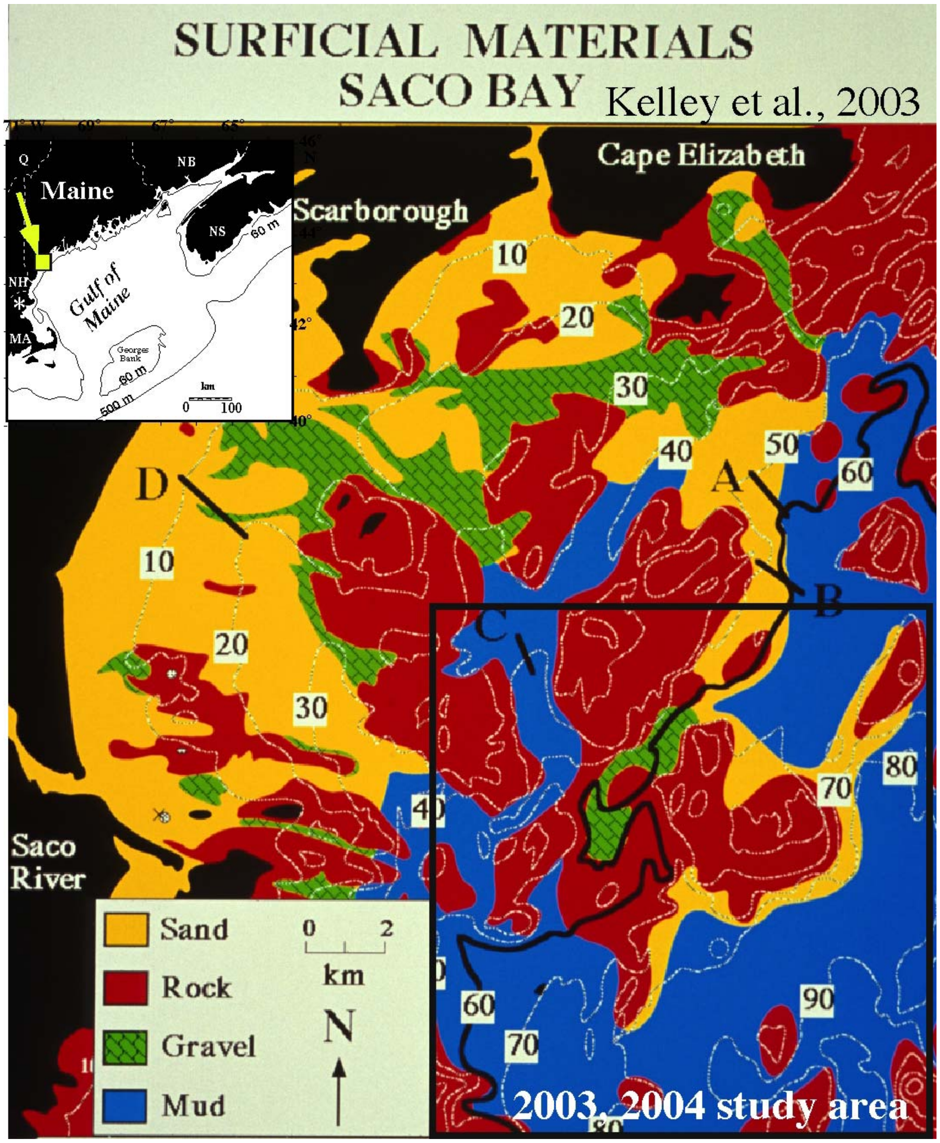


Figure 1. Location map and generalized surficial geology and bathymetry of the study area in Saco Bay Inset may shows study area in relation to the Gulf of Maine. Boxed area shown in greater detail as Figure 2.

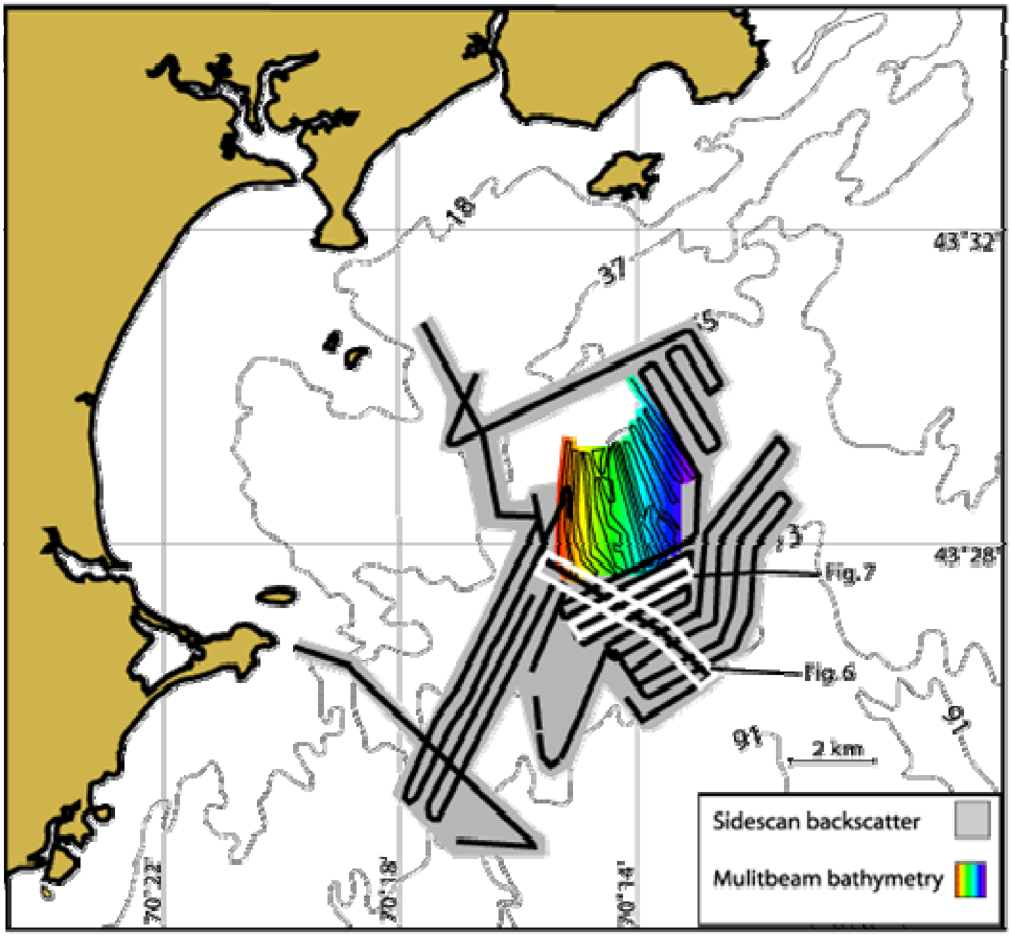


Figure 2. Area mapped with multibeam and sidescan sonar. Side scan sonar lines used in report are indicated.

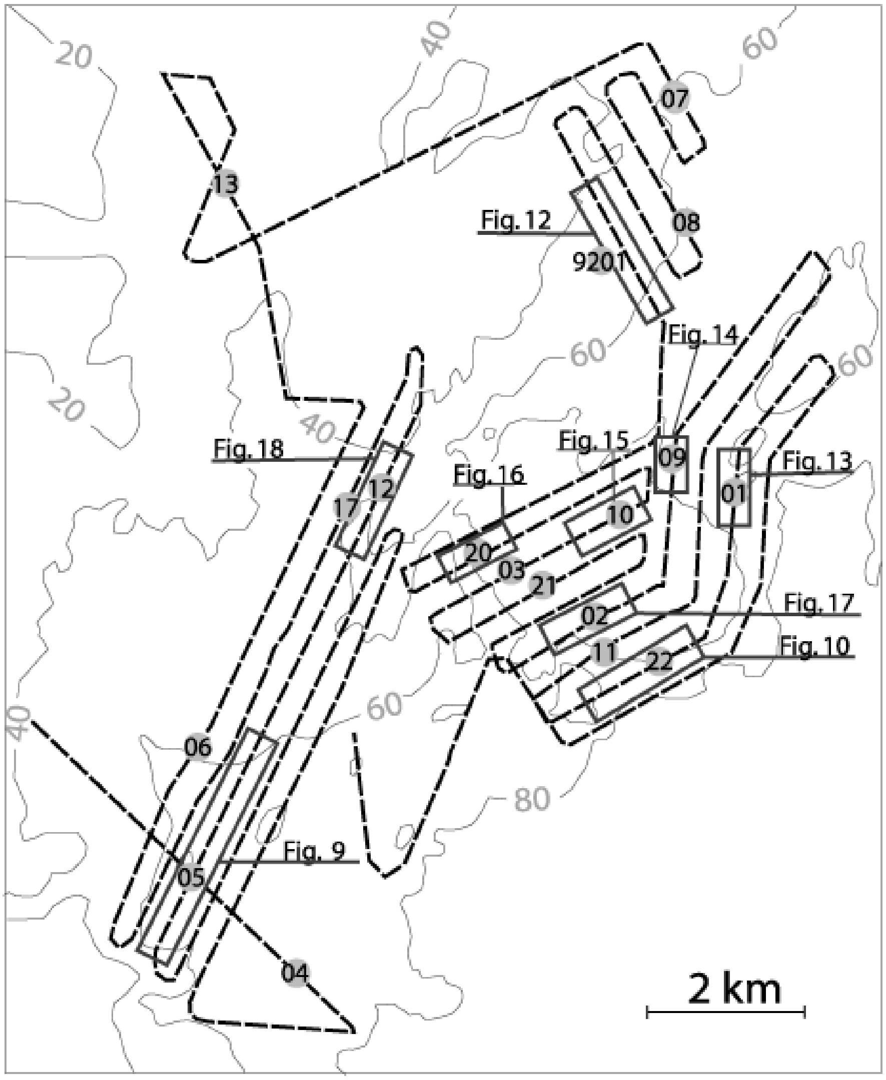


Figure 3. Seismic reflection track lines and vibracore sites. Seismic lines used in report are indicated.

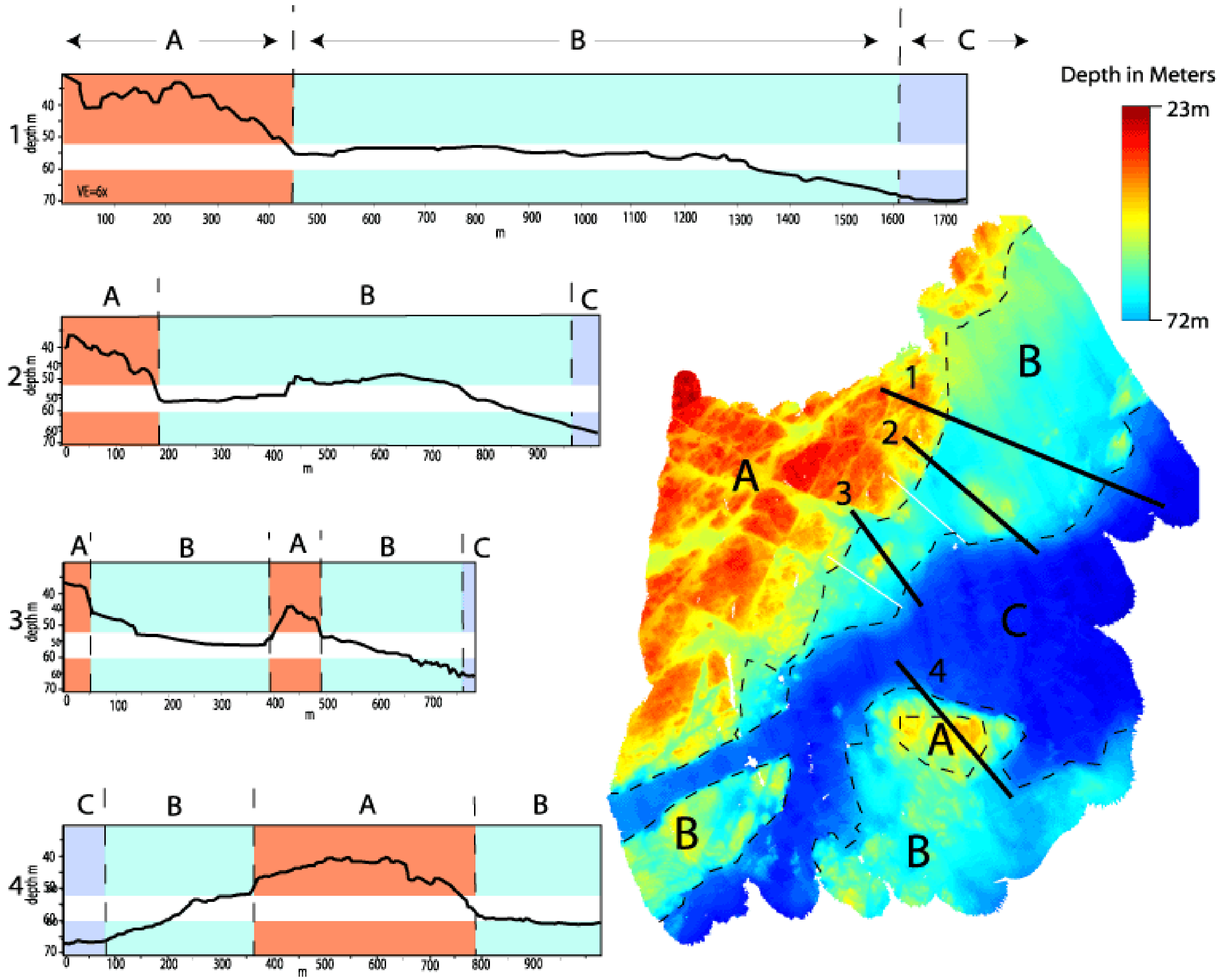


Figure 4. Detailed multibeam bathymetric map of the study area. Areas labeled A, B, and C are discussed in the text.

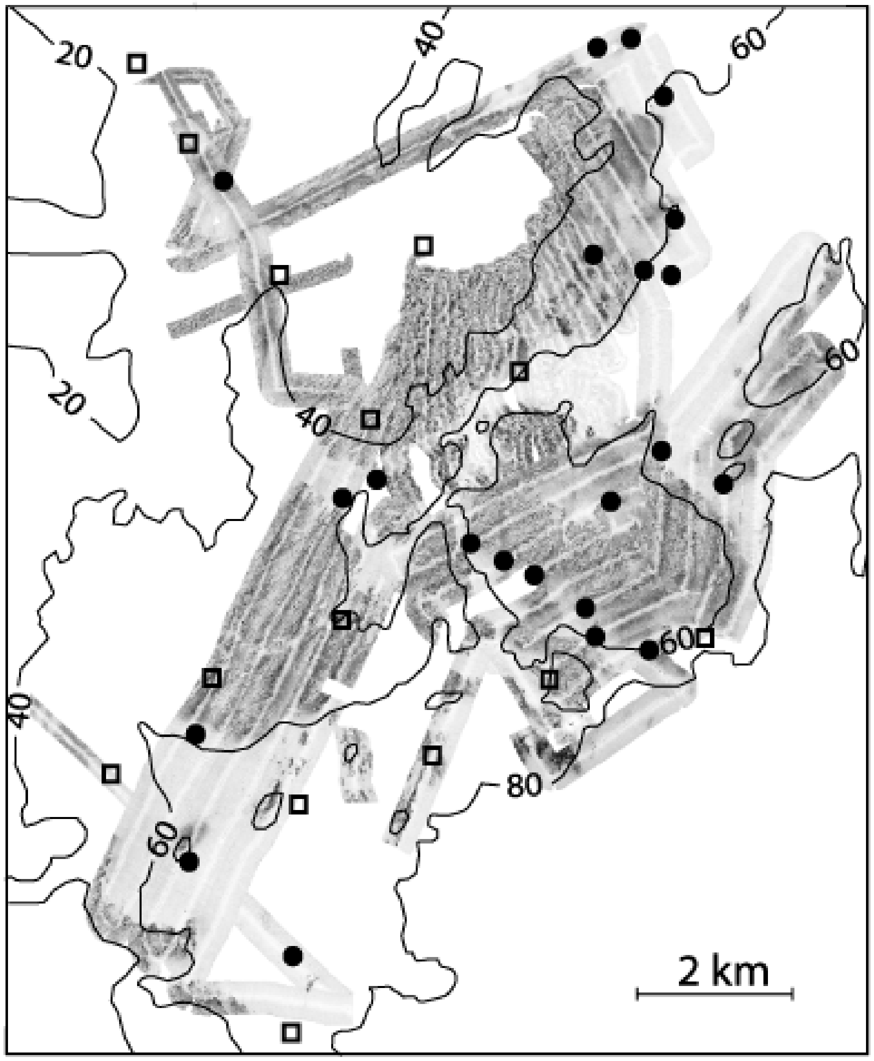
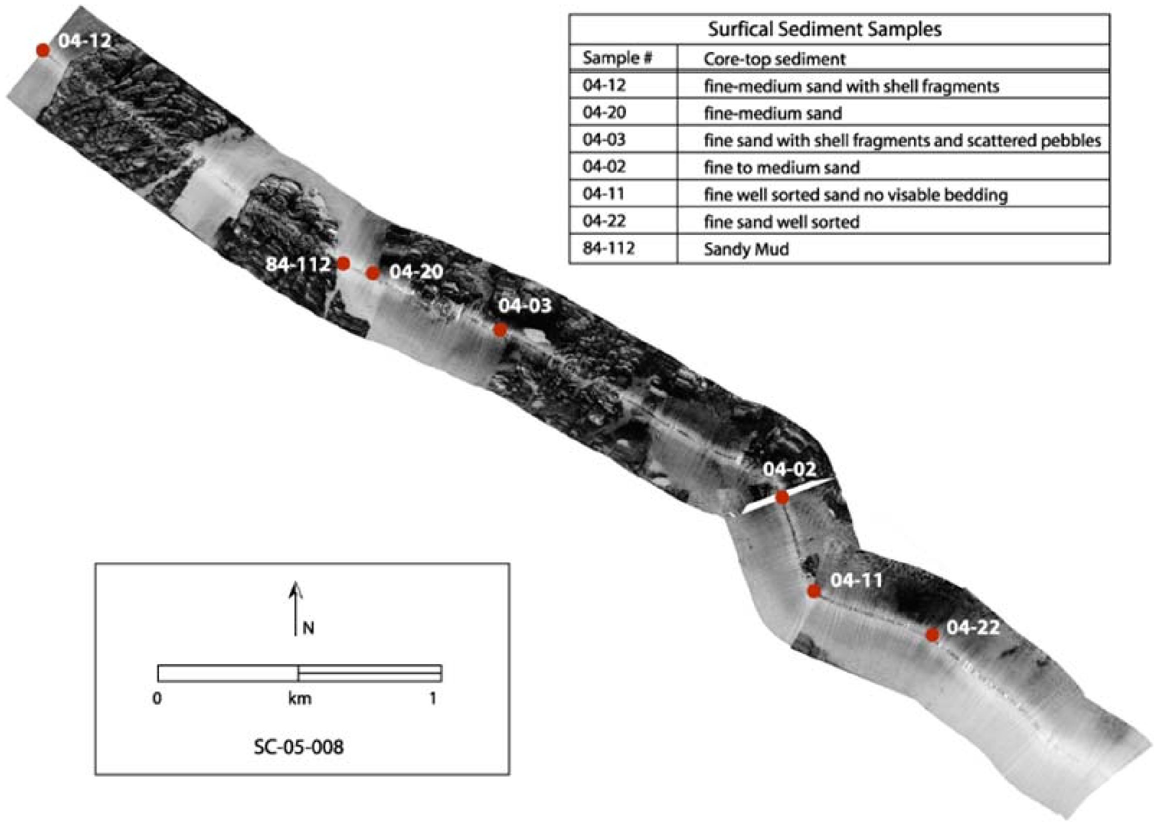
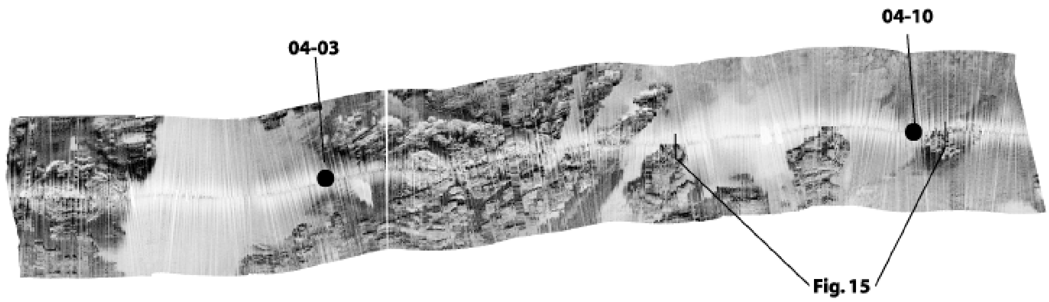


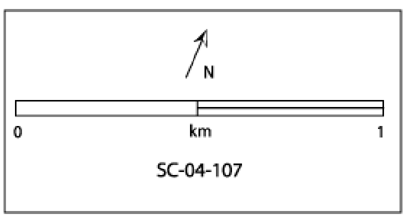
Figure 5. Side scan sonar mosaic of study area. Filled circles represent vibracore sites; open squares represent bottom samples collected earlier (Kelley et al., 1986b).



Surfical Sediment Samples	
Sample #	Core-top sediment
04-12	fine-medium sand with shell fragments
04-20	fine-medium sand
04-03	fine sand with shell fragments and scattered pebbles
04-02	fine to medium sand
04-11	fine well sorted sand no visable bedding
04-22	fine sand well sorted
84-112	Sandy Mud

Figure 6. Detailed side scan sonar image of rock and gravel. The linear acoustic noise to either side of the center trackline was caused by ship heave in rough seas. Lighter tones represent ‘soft” returns from mud; darker tones are “harder” returns from rock, sand and gravel. Side scan image is located in Figure 2.





Surfical Sediment Samples	
Sample #	Core-top sediment
04-10	fine-medium sand with shell fragments
04-03	fine-medium sand

Figure 7. Detailed side scan sonar image of sand and mud. Figure is located in figure 4. The linear acoustic noise to either side of the center trackline was caused by ship heave in rough seas. Side scan image is located in Figure 2.

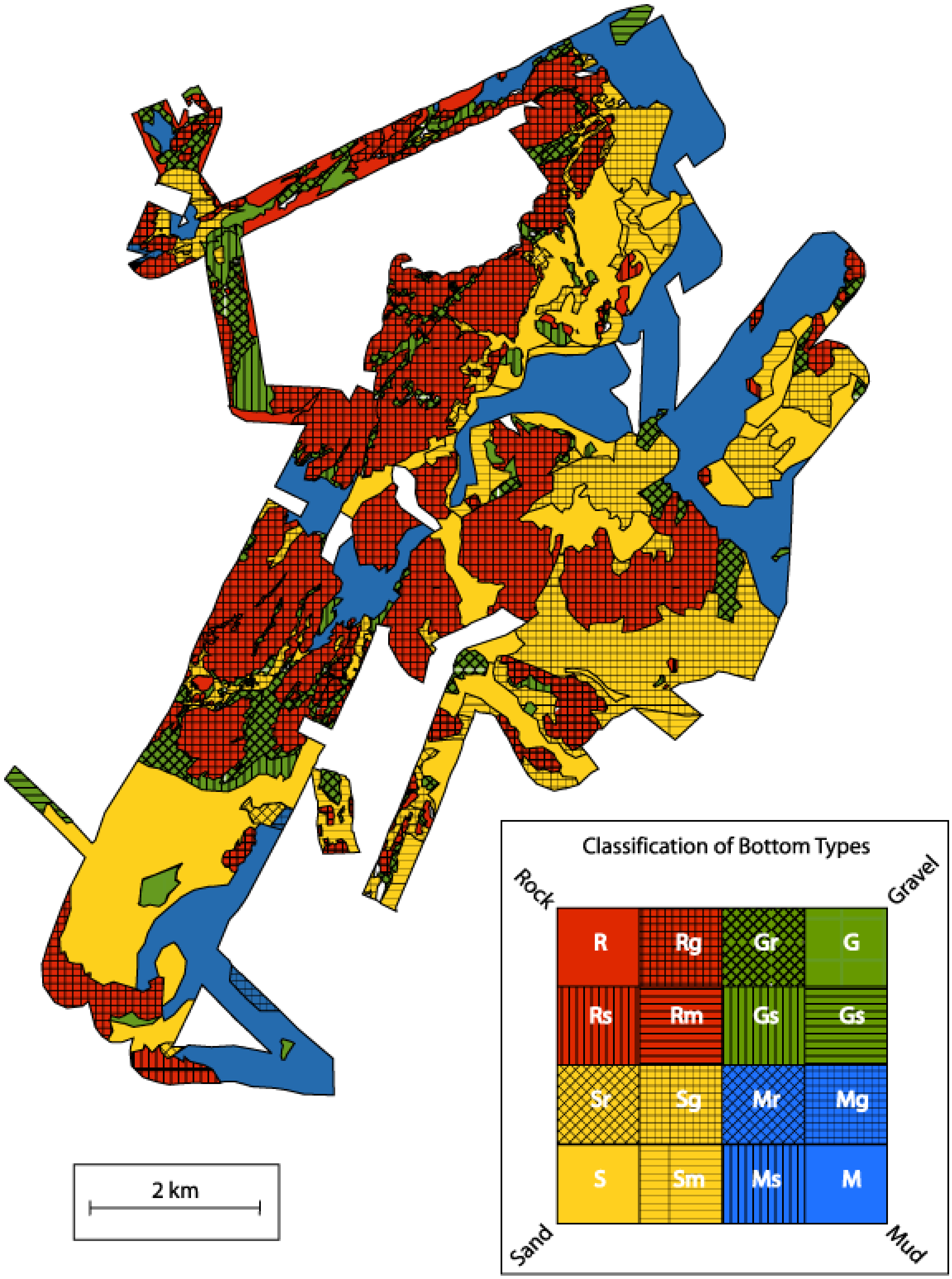


Figure 8. Surficial material map interpreted from side scan sonar, and bottom and core samples.

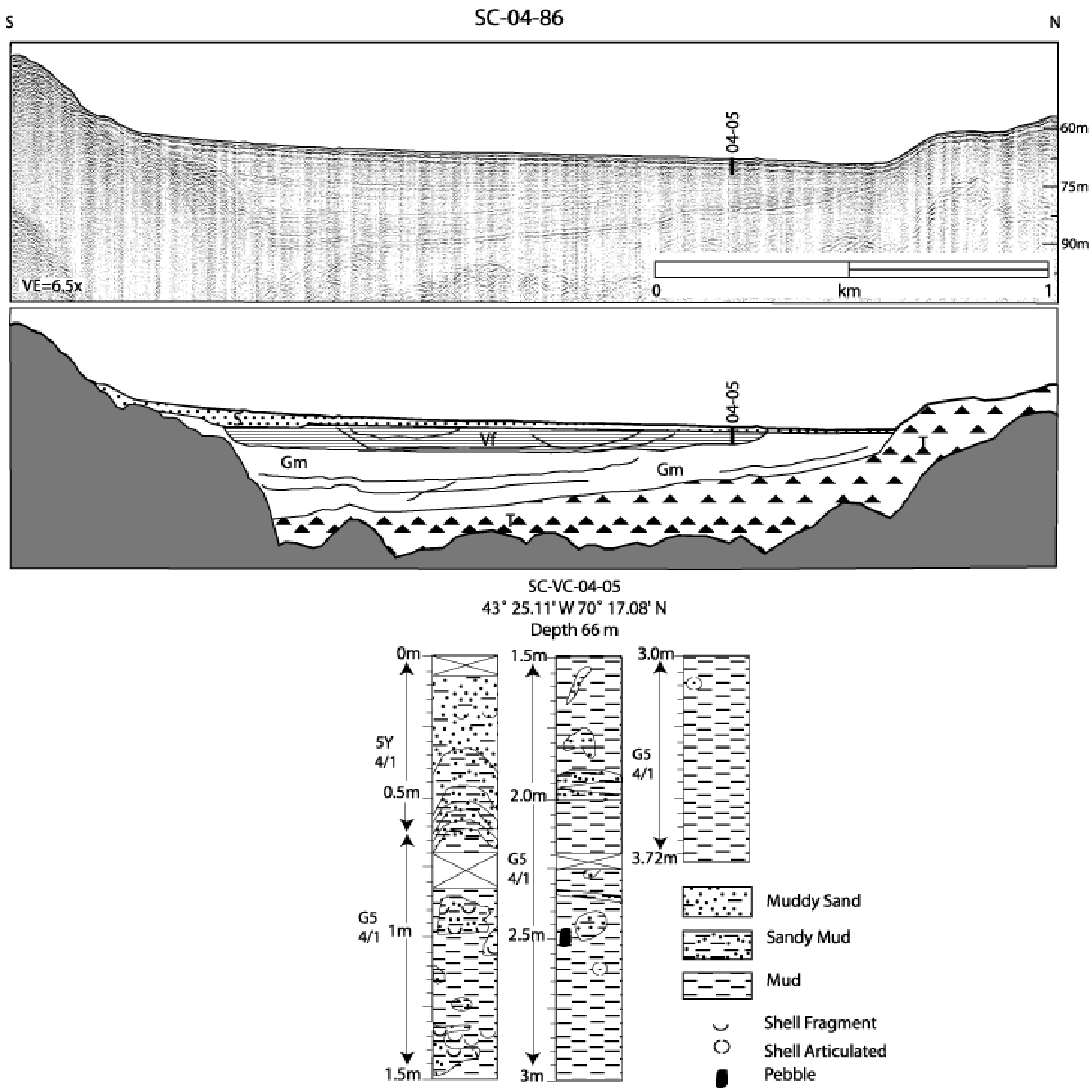


Figure 9. SRP and core from Basin 1. BR is bedrock, T is till, GM is glacial-marine mud, Vf is valley fill, S is sand.

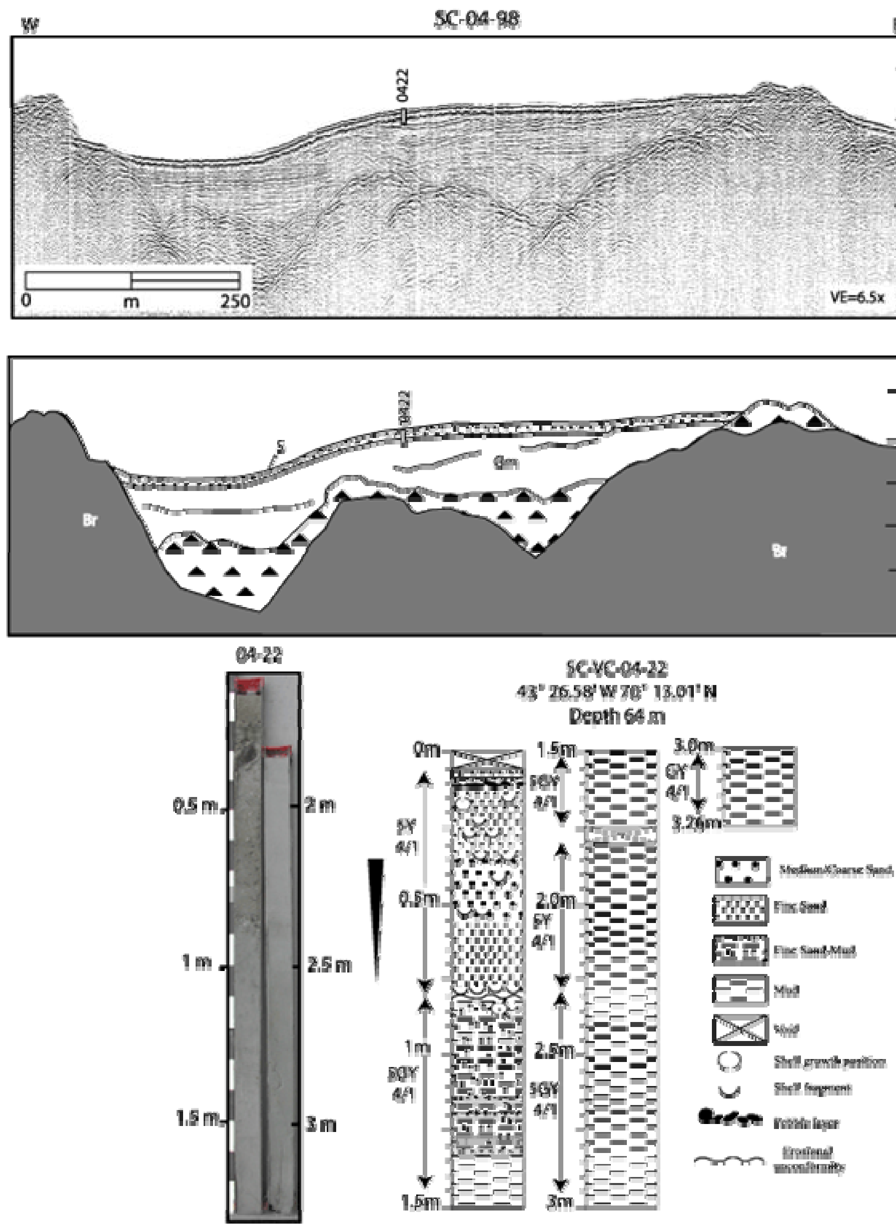


Figure 10. Vibracore SCVC04-22 collected along seismic line SC-04-98.

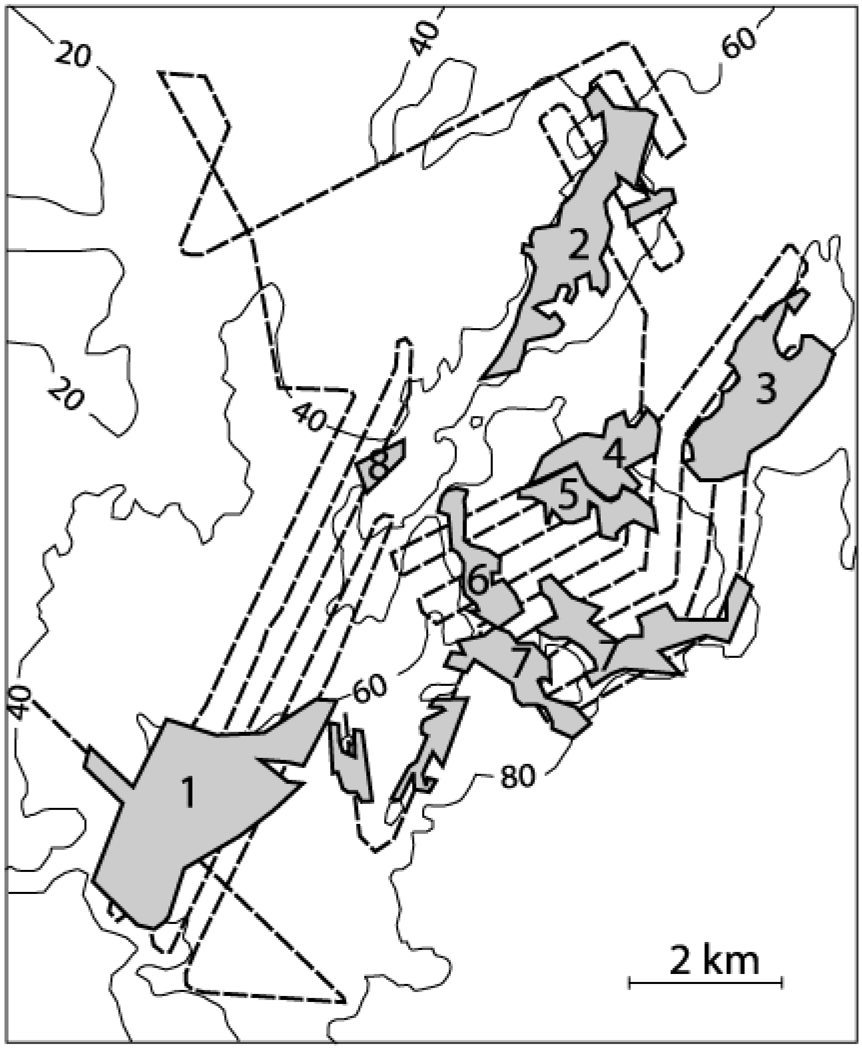


Figure 11. Map of basins within the study area containing sand on the surface.

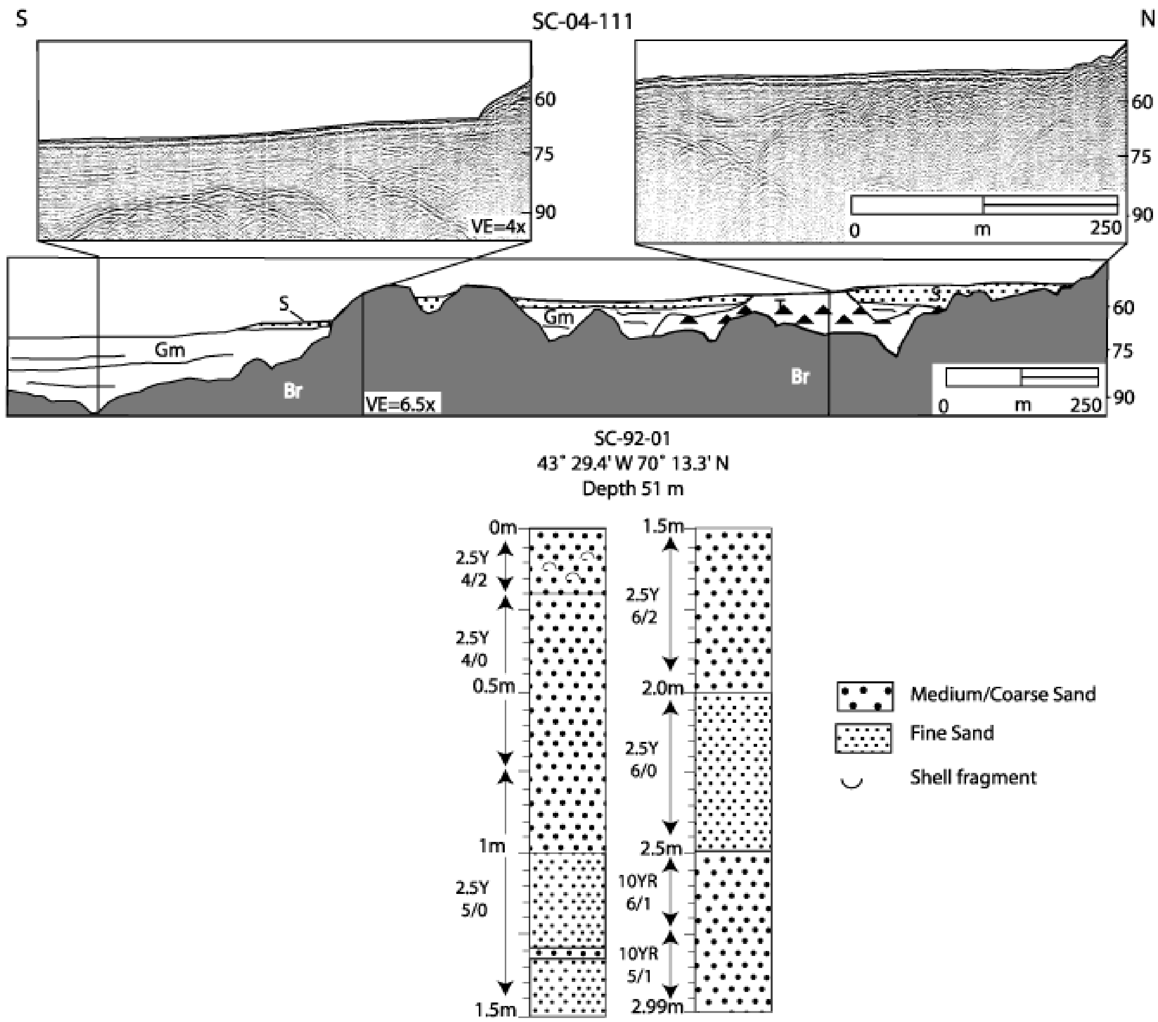


Figure 12. Core SCVC92-01 was collected just south of this seismic line in Basin 2. All interpreted seismic units are the same as described in Figure 9.

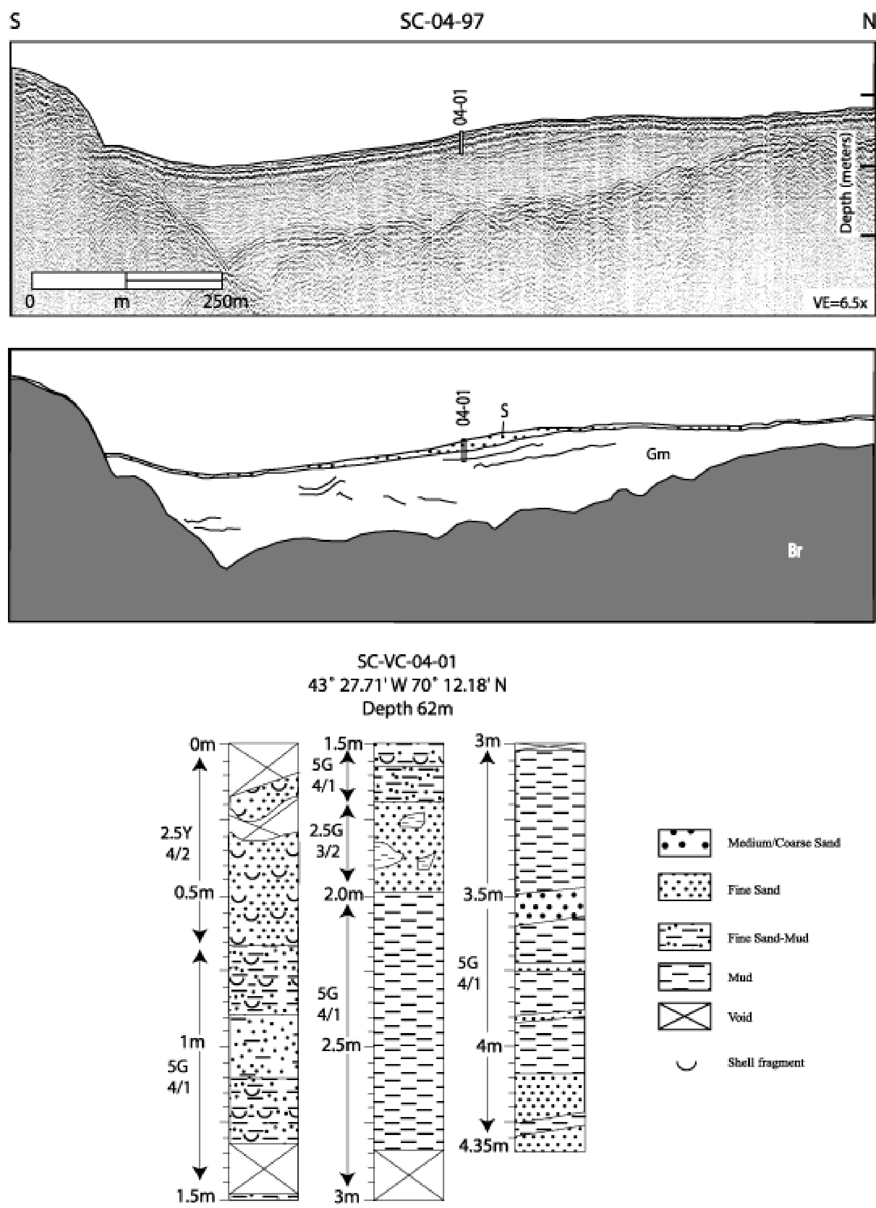


Figure 13. Core SCVC04-01 from Basin 3. All interpreted seismic units are the same as described in Figure 9.

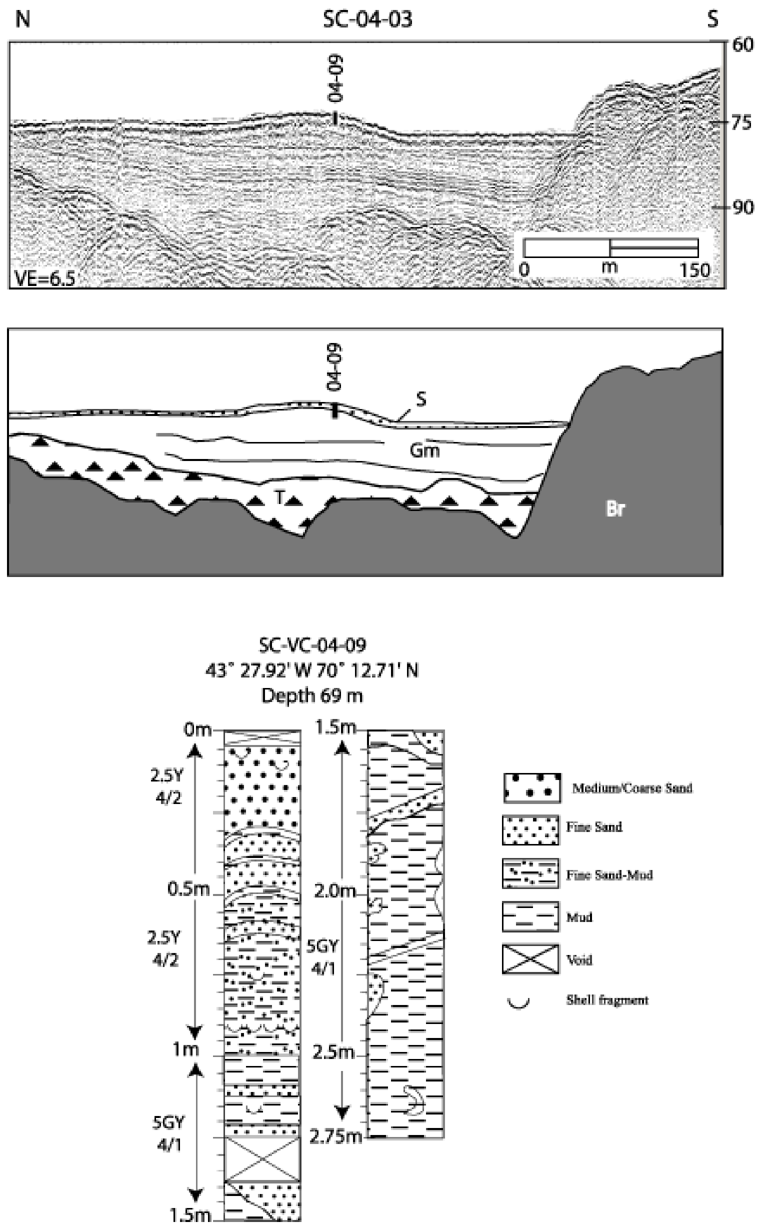


Figure 14. Core SCVC04-09 was collected in Basin 4 at about 65 m depth. All interpreted seismic units are the same as described in Figure 9.

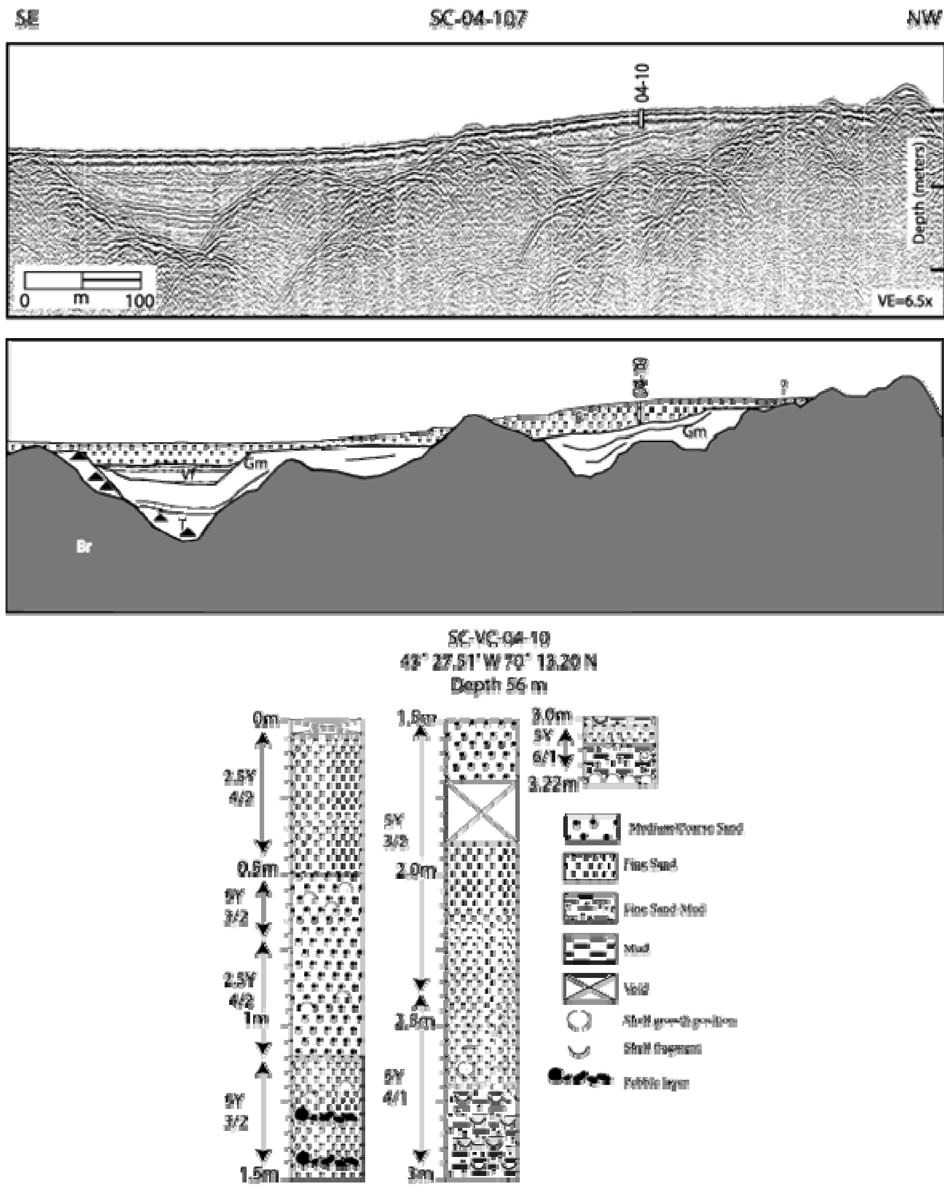


Figure 15. Core SCVC04-10 from Basin 5. All interpreted seismic units are the same as described in Figure 9.

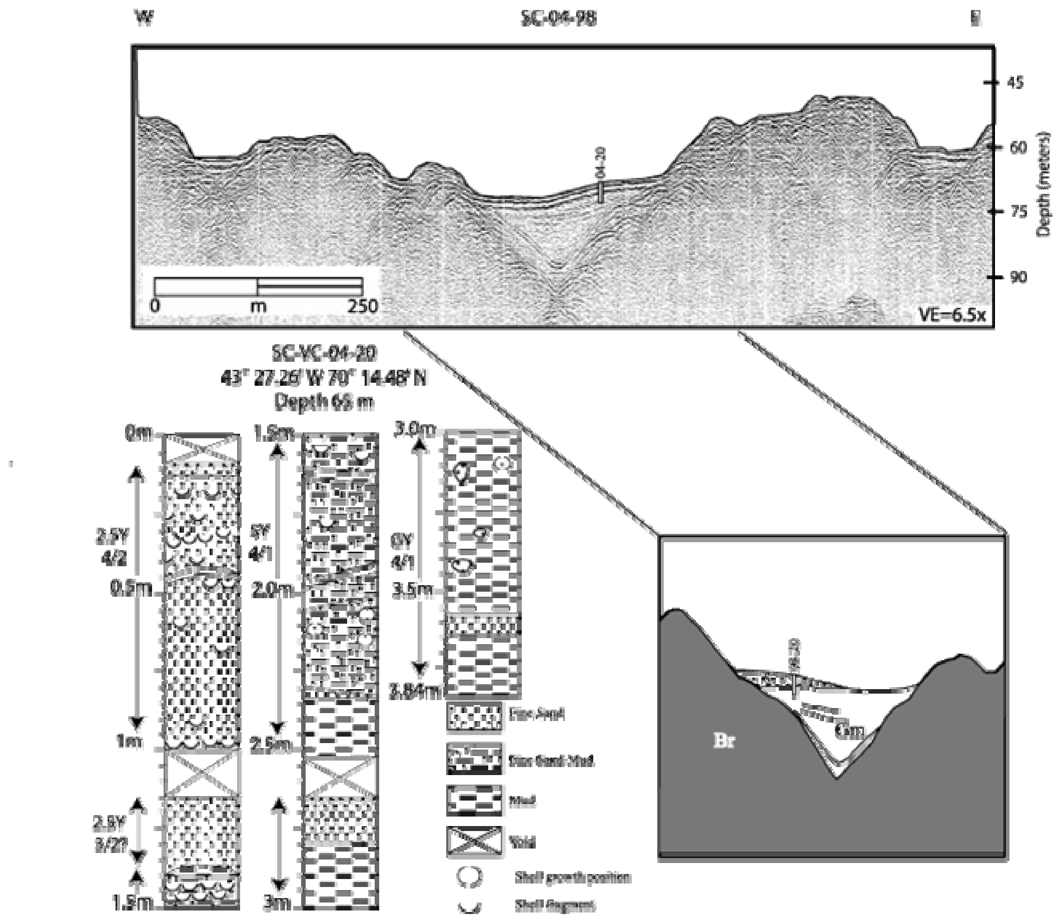


Figure 16. SCVC04-20 from Basin 6. All interpreted seismic units are the same as described in Figure 9.

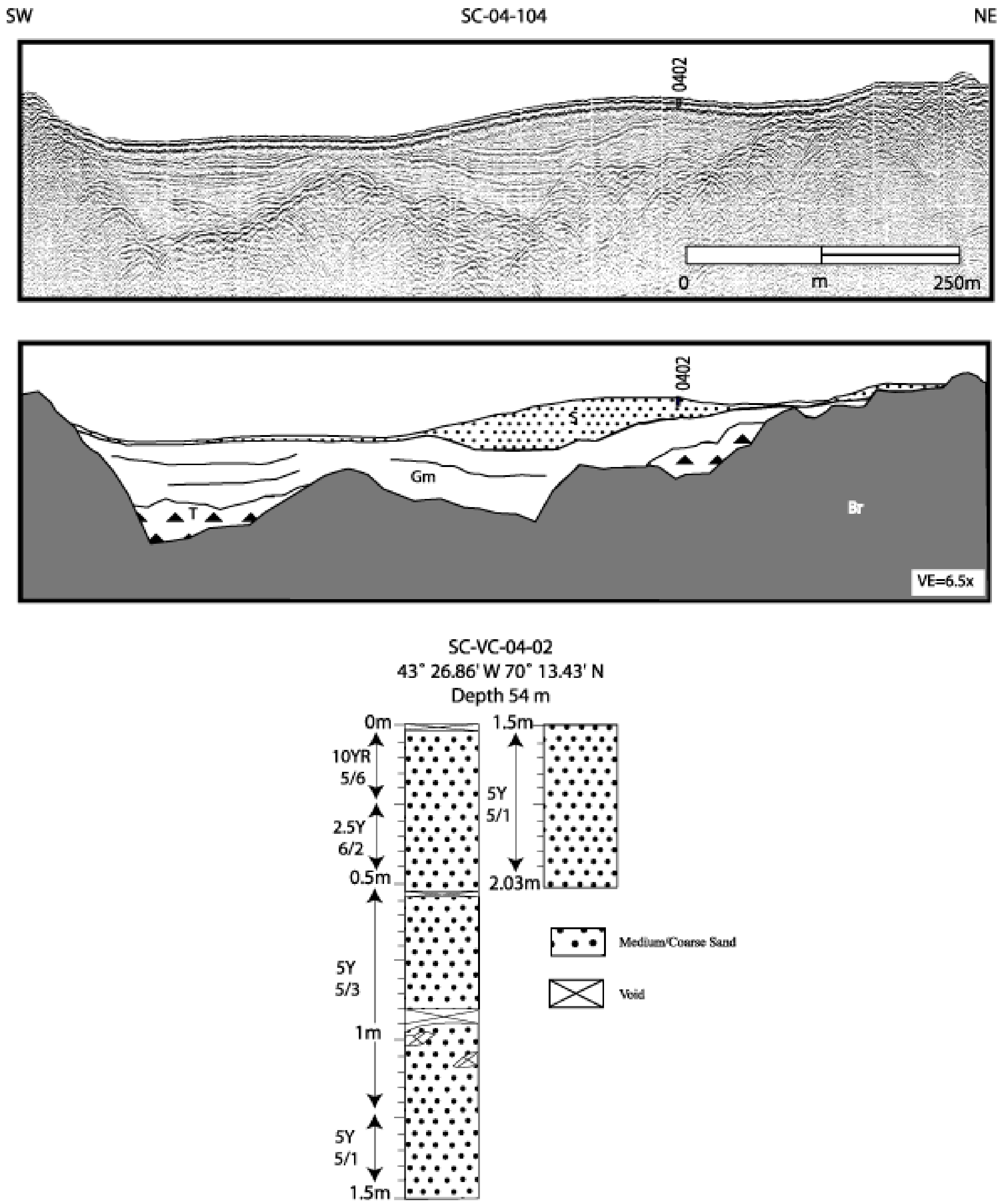
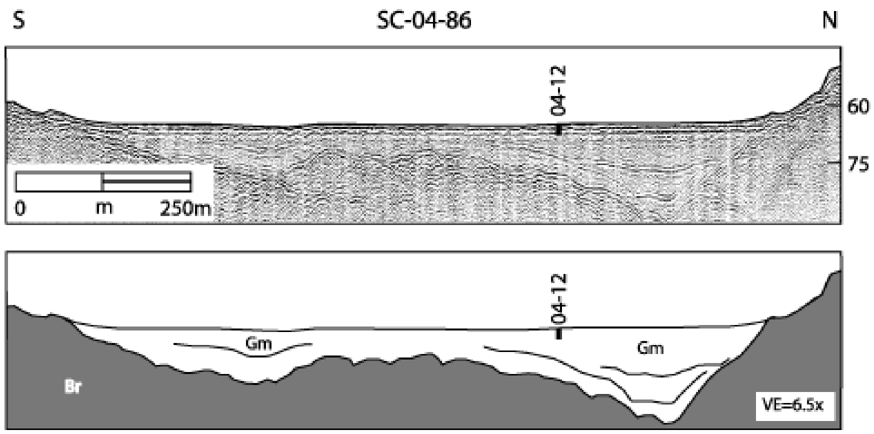


Figure 17. Core SCVC04-02 from Basin 7. All interpreted seismic units are the same as described in Figure 9.



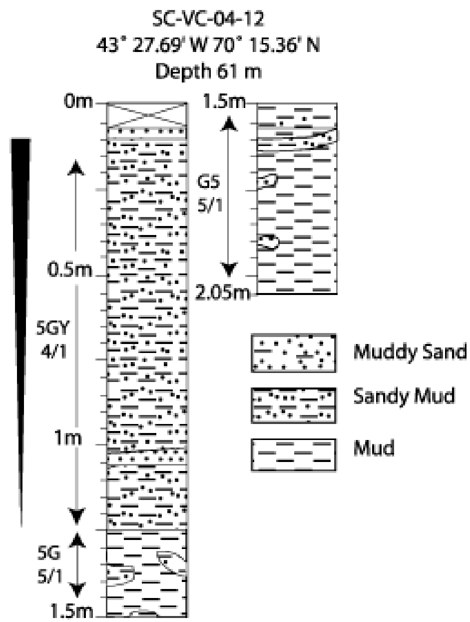
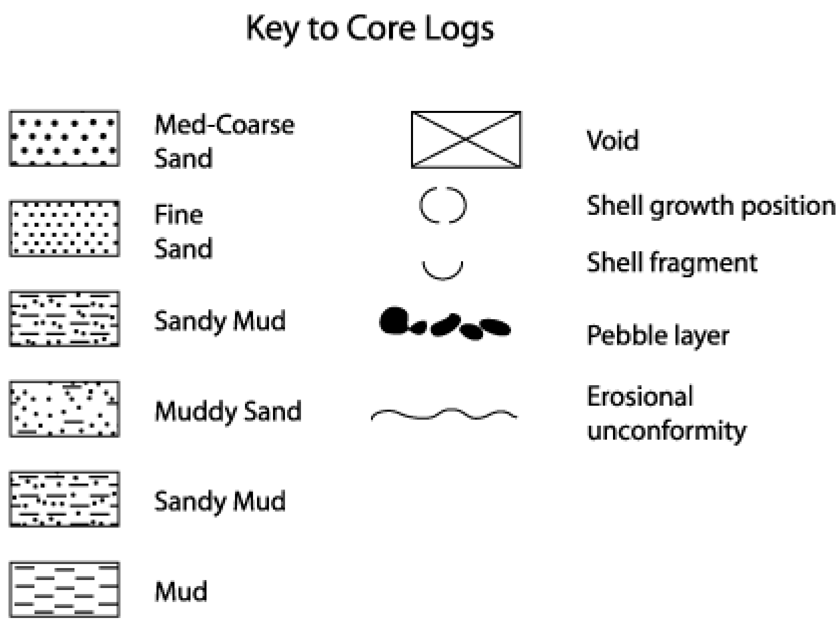
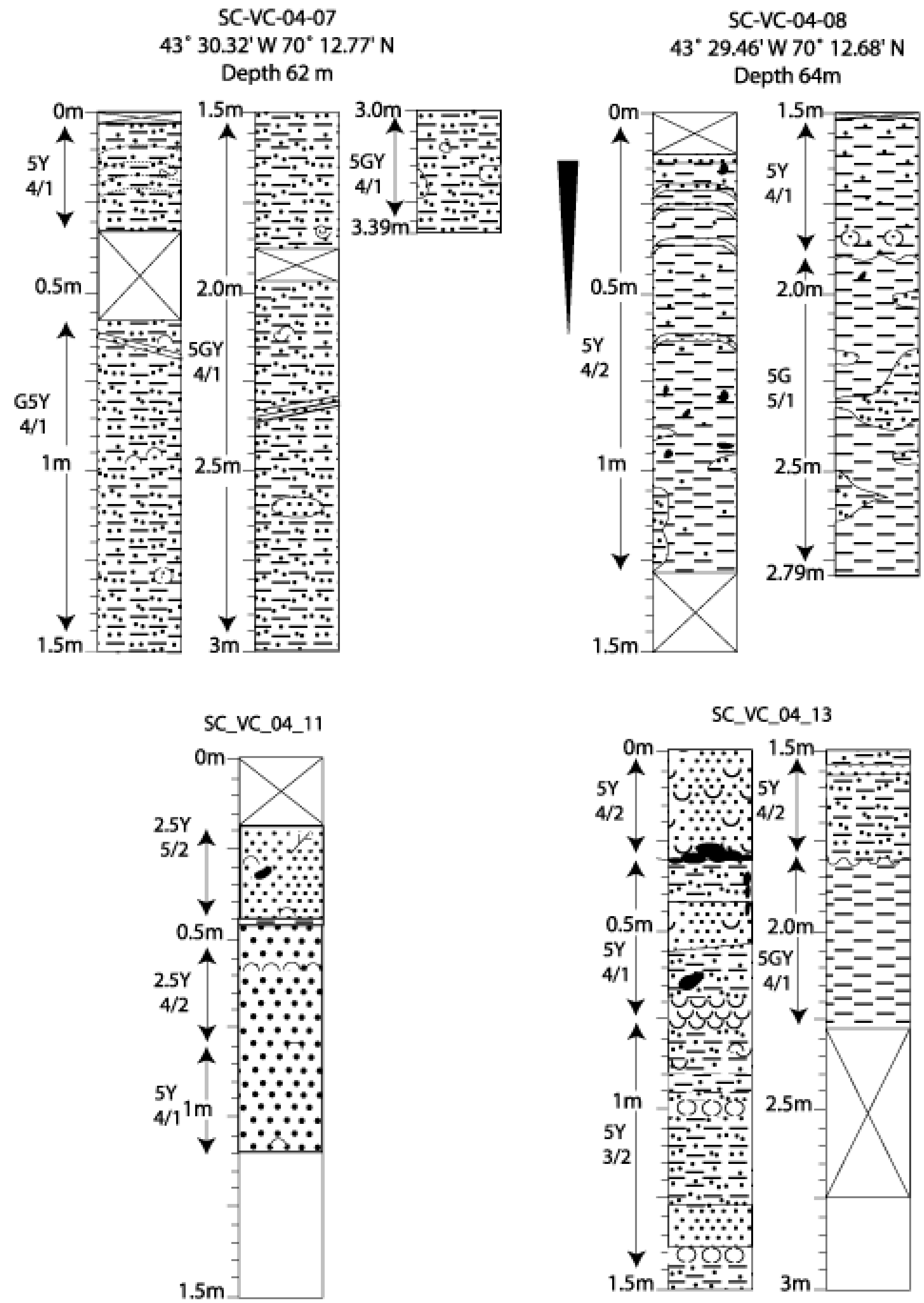
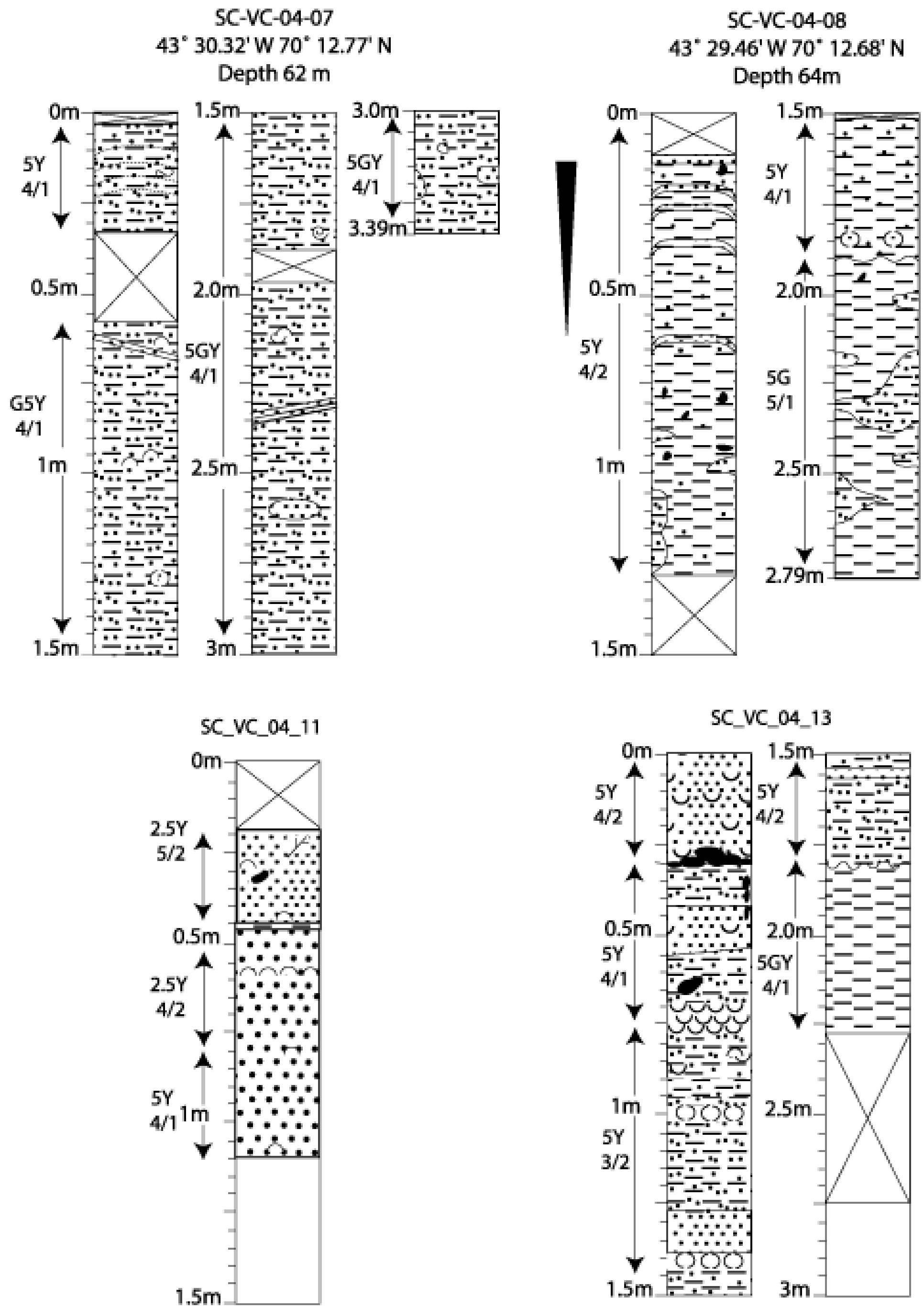


Figure 18. Core SCVC04-12, from Basin 8 was gathered from sediment banked up against the wall of the basin. All interpreted seismic units are the same as described in Figure 9.

Appendix A: Description of Vibracores

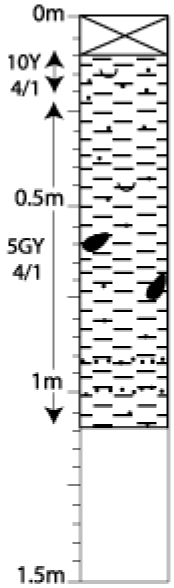



SC-VC-04-07
43° 30.32' W 70° 12.77' N
Depth 62 m
0m
5Y
4/1
0.5m
G5Y
4/1
1m
1.5m
1.5m
5GY
4/1
2.0m
2.5m
3m
3.0m
5GY
4/1
3.39m
SC-VC-04-08
43° 29.46' W 70° 12.68' N
Depth 64m
0m
0.5m
5Y
4/2
1m
1.5m
1.5m
5Y
4/1
2.0m
5G
5/1
2.5m
2.79m
SC_VC_04_11
0m
2.5Y
5/2
0.5m
2.5Y
4/2
5Y
4/1
1m
1.5m
SC_VC_04_13
0m
5Y
4/2
0.5m
5Y
4/1
1m
5Y
3/2
1.5m
1.5m
5Y
4/2
2.0m
5GY
4/1
2.5m
3m



SC-VC-04-07
43° 30.32' W 70° 12.77' N
Depth 62 m
0m
0.5m
1m
1.5m
2.0m
2.5m
3m
3.0m
3.39m
5Y 4/1
G5Y 4/1
5GY 4/1
5GY 4/1
SC-VC-04-08
43° 29.46' W 70° 12.68' N
Depth 64m
0m
0.5m
1m
1.5m
2.0m
2.5m
2.79m
5Y 4/2
5Y 4/1
5G 5/1
SC_VC_04_11
0m
0.5m
1m
1.5m
2.5Y 5/2
2.5Y 4/2
5Y 4/1
SC_VC_04_13
0m
0.5m
1m
1.5m
2.0m
2.5m
3m
5Y 4/2
5Y 4/1
5Y 3/2
5Y 4/2
5GY 4/1

SC-VC-04-17
43° 27.55' W 70° 15.70' N
Depth 58 m



SC-VC-04-21
43° 29.90' W 70° 14.27' N
Depth 71 m