Prepared in cooperation with the Bureau of Ocean Energy Management and National Oceanic and Atmospheric Administration

Preliminary Sand and Gravel Reservoirs Assessment for Federal Waters: Midcoast Maine

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Disclaimer
This report is preliminary, but data and information published herein are accurate to the best of our knowledge. Data synthesis, summaries and related conclusions may be subject to change as additional data are collected and evaluated. While the Maine Coastal Program makes every effort to provide useful and accurate information, investigations are site-specific and applicability of results to other regions in the state is not yet warranted. The Maine Coastal program does not endorse conclusions based on subsequent use of the data by individuals not under their employment. The Maine Coastal Program disclaims any liability, incurred as a consequence, directly or indirectly, resulting from the use and application of any of the data and reports produced by staff. Any use of trade names is for descriptive purposes only and does not imply endorsement by The State of Maine.

For an overview of the Maine Coastal Mapping Initiative (MCMI) information products, including maps, data, imagery, and reports visit http://www.maine.gov/dacf/mcp/planning/mcmi/index.htm.

Acknowledgements

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ABSTRACT

Recently, the Bureau of Ocean Energy Management (BOEM) has recognized the need to identify additional outer continental shelf (OCS) sand resources for beach nourishment and coastal restoration projects because sand resources in state waters are either diminishing or are of poor quality, or otherwise unavailable (U.S. Department of the Interior, 2014). Quantitative assessments for many of these resources have only been conducted in nearshore waters within state jurisdiction (e.g. waters landward of 3-nautical mile line) (Kelley et al., 1997, 1998; 2003). However, much of the seafloor sediment and subsurface data (e.g. cores and seismic reflection profiles) used to perform these assessments does extend into waters of federal jurisdiction. As part of a multi-year, multi-agency cooperative, the Maine Coastal Mapping Initiative (MCMI) has been addressing the need for comprehensive resource assessment through high-resolution seafloor mapping using a multibeam echosounder (MBES) and by collecting additional seafloor substrate data. In this investigation, the MCMI combined new and pre-existing geological and geophysical data to characterize and estimate volume for potential sediment resources in waters of federal jurisdiction within Maine's mid-coast region.

Results identified 6 distinct zones containing potential sand and gravel resources within federal waters, with a combined total volume of approximately 32 million cubic meters (42 million cubic yards); approximately one order of magnitude smaller than estimated by Kelley et al. (1997) for the nearshore/shoreface reservoirs in the vicinity. Although considerable error exists for calculated volumes due to the lack of vertical resolution in many areas, these are considered best estimates using the available data. Despite the total volume, these deposits are somewhat unattractive as potential sand and/or gravel resources due to low overall quality and depths (30 m – 70 m) prohibitive to traditional dredging operations. The overall average sand, gravel, and mud content in all zones were approximately 60%, 19%, and 36%, respectively. Overall, this investigation highlights the need for more comprehensive assessment and management of additional potential resources (e.g. shoreface/nearshore deposits) for beach nourishment and coastal restoration efforts within the region.

Introduction

Sustainable management and exploitation of Maine's coastal and marine resources are necessary to ensure effective coastal resiliency and conservation efforts. The collection and analysis of geophysical and seafloor sediment data allow state and federal agencies to proactively identify the resources available to enhance resiliency, improve management of resources within their jurisdiction, and develop a more comprehensive understanding of potential resources. A key component of coastal resiliency and conservation efforts is access to quality near-shore and off-shore sand and gravel resources. Recently, the Bureau of Ocean Energy Management (BOEM) has recognized the need to identify additional outer continental shelf (OCS) sand resources for beach nourishment and coastal restoration projects because sand resources in state waters are either diminishing or are of poor quality, or otherwise unavailable (U.S. Department of the Interior, 2014). Although quantitative assessments for many of these resources have only been conducted in nearshore waters within state jurisdiction (e.g. waters landward of 3-nautical mile line) (Kelley et al., 1997, 1998; 2003), seafloor sediment and subsurface data (e.g. cores and seismic reflection profiles) does extend into waters of federal jurisdiction, albeit very poor vertical and horizontal resolution. However, when supplemented with high-resolution multibeam echosounder (MBES) bathymetry and backscatter intensity data and additional sediment samples, these data can be used to perform reasonable estimates of the volume and quality of the sand and gravel reservoirs in waters of federal jurisdiction. These MBES data can also be utilized to better understand coastal processes and sediment dynamics in nearshore areas.

Purpose

The purpose of this investigation is to describe, characterize, and estimate volumes for potential sediment resources for beach nourishment as outlined by BOEM. This report focuses on potential resources that solely exist within waters of federal jurisdiction and within the extent of the Maine Coastal Mapping Initiative's (MCMI) MBES coverage in mid-coast Maine.

Focus Area and Previous Work

The focus area (Figure 1) is located in Maine's mid-coast region in federal waters (seaward of the 3-nautical mile line) just offshore of the Kennebec River mouth, and was selected due to the high probability of being able to identify sand resources at this location. Previous work related to Quaternary geomorphology in the region is extensive and identifies it as one of the major sand repositories along Maine's inner continental shelf, as it contains a gently-sloping nearshore ramp containing reworked sediment of the submerged Kennebec River paleodelta (Barnhardt, 1994; Kelley et al., 1987; 1997; 1998; 2003; 2007). The lobate submarine expression of this feature is abruptly terminated to the east and south around the 55-meter isobath (Figure 2), which has been interpreted as the late Quaternary lowstand sea-level (Schnitker, 1974). Beyond the 65-meter isobaths the seabed consists of muddy shelf valleys bound by steep, rocky outcrops. The full extent of the paleodelta sediments were mapped (Kelley et al., 1987) using seismic reflection profiles, bottom samples, and side-scan sonar. However, the lack of full bottom sonar coverage and limited core data in the focus area have yielded poor resolution overall, and volume estimates for resources in federal waters do not exist. The addition of seafloor sediment samples and high-resolution multibeam data collected by the MCMI will supplement existing geophysical and geological data and enable considerable refinement of sediment distribution and (sand and gravel reservoir) volume estimates for this region.

Methods

Field methods used during this investigation consisted of collecting high-resolution bathymetry and backscatter data using a multibeam echosounder and bottom sampling. Methods used for sediment mapping and spatial analyses consisted of GIS mapping techniques and the synthesis of pre-existing sediment data, vibracores, and seismic profile data.

Multibeam surveys/bathymetry and backscatter collection

Multibeam sonar data (e.g. bathymetry and backscatter) were acquired aboard the R/V Amy Gale with a Kongsberg EM2040c set to a survey frequency of 300 kHz, high-density beam forming, with 400 beams per ping. Parallel lines with consistent spacing (based on depth) were run at 6 – 6.5 knots throughout the survey area. Data acquisition was performed using the Quality Positioning Services (QPS) QINSy (Quality Integrated Navigation System; v.8.12) acquisition software. The modules within QINSy integrated all systems and were used for real-time navigation, survey line planning, data time tagging, data logging, and visualization. Bathymetry data were processed using Qimera (v.1.3.6) and time-series backscatter data were processed using QPS' Fledermaus Geocoder Tool (FMGT; v.7.7.0) software. For complete details pertaining to the multibeam data collection and processing refer to Dobbs (2016a; 2017a).

Although a variety of environmental, geometric, and other external factors must be considered when interpreting backscatter data, the signal has been shown to directly relate to unconsolidated sediment grain size and seafloor roughness (Lurton and Lamarche, 2015), which makes this technique desirable for the purposes of this investigation. Manual interpretations of MBES data and 1st-order derivatives (e.g. bathymetric slope and rugosity) allowed for further refinement of the focus area (Figure 4).

Bottom sampling

During the 2015 and 2016 survey seasons the MCMI collected grab samples to satisfy multiple objectives using was a single platform rig (Figure 3) outfitted with a clamshell style Ponar grab sampler, GoPro Hero 3+ digital video camera in a deepwater dive housing, Keldan underwater dive light, dive lasers spaced at 10 cm for scale, and a Xylem Exo 1 to collect water column data (e.g salinity, temperature, pH, dissolved oxygen, and chlorophyll concentrations; see Ozmon, 2017 for details). The 23 x 23 cm Ponar grab was capable of collecting a maximum volume of 8.2 liters of unconsolidated sediment per sampling attempt. Immediately upon retrieval, the sediment surface was photographed and partitioned into two subsamples; a minimum of 1000 cm^3 was set aside for grain-size analysis and the remainder was used for infaunal analysis. Sediment subsamples were then bagged, labeled, and stored in coolers until reaching the sedimentology laboratory at the University of Maine (UMaine).

Sediment samples were analyzed using standard laboratory techniques for the textural analyses of marine sediments (Poppe et al., 2005) by the sedimentology laboratory at the UMaine. The Wentworth (1922) grain-size scale for major textural splits, and in instances where the silt/clay ratio could not be determined accurately (e.g. mud-sized (silt + clay) portion was less than 5% of total weight) total mud was divided evenly between silt (phi size 4 - 8) and clay (phi size 8 - 12) fractions. The proportion of gravel-, sand-, silt-, and clay-sized particles were used to classify the overall sample using Folk (1974). The remainder of each bulk sample was preserved for archiving at the MCP headquarters in Augusta, ME.

The only samples considered in this analysis were those who fell within the refined focus area shown in Figure 4, yielding a total of 32 sediment samples after combining samples collected by MCMI and those from other agencies. Grain-size data for these samples are provided in Appendix A.

Additional details related to the collection and processing of all sediment samples collected by MCMI during the 2015 and 2016 field seasons are outlined in in separate reports (see Dobbs, 2016b; 2017b).

Sand and gravel volume estimates

MBES data were used to define the areal extent of surficial sand and gravel units within the refined focus area. Estimates of sediment thickness and depositional environment in these areas were based on previous interpretations of representative seismic profiles and limited core data from previous studies (e.g. Belknap et al., 1989; Barnhardt, W. A., 1994; Kelley et al., 1987; 1997; 1998; 2003). Vibracore data are presented in Appendix A. The simple procedure used to develop quantitative estimates of sand and gravel reservoir volume is described below.

First, the refined focus area was was divided into 6 lithologically and physically (above and below the seabed) distinct zones that were manually delineated based on MBES (bathymetry and backscatter) data. The estimated volume of unconsolidated sediment within each zone was calculated by multiplying the areal extent (square planar area) of each zone by the estimated mean thickness of the uppermost unit (e.g. Holocene sand and/or late Pleistocene deltaic sand and gravel) in representative seismic profiles. This method was chosen because there were too few seismic lines to isopach sediment thickness and core data was absent in 5 of the 6 zones. Each zone was then described in more detail based on the existing grain-size data. Although considerable error exists for calculated volumes due to the lack of vertical resolution, these are considered best estimates using the available data.

Geological and geophysical data corresponding to each zone are listed in Appendix A and B. Representative seismic profiles used to estimate the mean thickness for each zone are presented in Appendix C.

Results

This investigation identified 6 distinct zones (Figure 5) containing potential sand and gravel resources within federal waters, with a combined total volume of approximately 32 million cubic meters (42 million cubic yards). Although these deposits are of much lower quality, this estimate is approximately one order of magnitude smaller than estimated by Kelley et al. (1997) for the nearshore/shoreface reservoirs in the vicinity. Each zone varied considerably in size, quality, and volume. Overall depths ranged from 30 to 70 m. The depth, areal extent, and approximate volume calculated for each zone are summarized in Table 1. A breakdown of total area based on 10-meter depth intervals is presented in Table 2.

Table 1. Summary of sand and gravel reservoir volumes and water depths

Zone ID	Area (km^2)	Mean thickness (m)	Mean volume (10^6*m^3)	Mean volume (10^6*yd^3)	Depth range (m)	Mean depth (m)
A	0.54	3	1.63	2.13	52.2 - 71.6	63.3
B	1.04	5	5.18	6.78	35.8 - 71.7	53.1
C	1.41	1	1.41	1.84	31.0 - 70.0	42.2
D	3.22	5	16.1	21.0	32.6 - 68.0	42.9
E	1.74	1	1.74	2.28	30.4 - 67.8	50.3
F	3.07	2	6.13	8.02	30.4 - 66.3	55.0
Total	11		32	42		

Table 2. Percentage of total area at 10-meter depth intervals within sand and gravel zones

	Approximate percentage of total zone area based on depth					
Depth (m)	**A**	**B**	**C**	**D**	**E**	**F**
< 40	-	2	25	25	23	4
40 - 50	-	38	65	67	16	25
50 - 60	20	39	8	6	48	35
> 60	80	21	2	2	13	36

Zone A was the smallest, eastern-most, and had the deepest mean depth (63 m). This zone did not contain seismic or core data. Thus, mean thickness was estimated based on the interpreted morphology and seismic profiles in adjacent areas. Sediment samples in this zone contained muddy (>30%) mixtures of medium to coarse sand and gravel. The depths and backscatter data within this zone suggest these sediment mixtures are common throughout the entire zone but contain an even larger proportion of fine sediment and become thinner with increasing depth.

Zone B was of limited areal extent but seismic profile and core data suggest deltaic sand and gravel deposits are of considerable thickness (>5 m) at depths less than 50 m (Appendix B and C). Sediment samples in this zone were mainly muddy (8 – 25%), coarse sand and gravel mixtures. Grain-size and backscatter suggest that sediment in this zone is predominantly gravel at depths less than 50 m, which accounts for approximately 40% of the total area. Backscatter data also suggest the respective proportion of mud increases considerably beyond 60 m depth.

Zone C consisted of a relatively narrow, northeast-southwest trending zone of presumably thin (~1 m) unconsolidated sediment between bedrock outcrops. Backscatter and bathymetric data suggest the majority of sediment (depth <50 m) is coarse sand and gravelly mixtures but becomes considerably muddy at depths beyond 50 m. Sediment type was inferred from backscatter data because no grain size data were available for this zone.

Zone D was the largest zone by every metric and may have the highest resource potential out of all six zones identified in this investigation. Seaward-dipping, planar clinoforms and foresets in seismic profile data indicate that deltaic sand and gravel in this zone is thickest in the north-central and south-western portions and generally thins to the east with close proximity to bedrock. The area between the 40 m and 50 m isobaths made of the bulk (67%) of this zone, with 25% of total area at depths less than 40 m. Although grain-size data was very limited, backscatter data was fairly uniform and indicated two lithologically distinct areas in the south-eastern and north-western portions. Homogeneity within backscatter in the north-western portion suggests this is coarse to very coarse sand in predominantly gravel mixtures, and accounts for approximately 60% of the surficial sediment within this zone. Backscatter data in the south-eastern portion indicate medium to coarse sand with a much smaller gravel component than that inferred to the northwest.

Zone E was very similar to zone C in that it was laterally confined to narrow valleys between rocky outcrops and also lacked observed grain-size data throughout. Backscatter intensity data in this zone suggest sediment is mostly medium to coarse grained sand and gravel mixtures, with increases proportions of mud at depths greater than 60 m.

Zone F was the second largest zone by square area and estimated volume. However, seismic profile and grain-size data suggest this zone does not contain the coarse deltaic sediment found in the five zones to the east. All sediment samples in this zone were predominantly fine muddy sand. Samples collected from depths less than 50 m contained less than 20% mud. Grain size data also indicate the proportion of mud generally increases by 10% with each 10 m increase in depth beyond 50 m.

Summary and Conclusions

This investigation identified 6 distinct zones containing potential sand and gravel resources within federal waters, with a combined total volume of approximately 32 million cubic meters (42 million cubic yards). Although considerable error exists for calculated volumes due to the lack of vertical resolution, these are considered best estimates using the available data. Despite the total volume, these deposits are somewhat unattractive as potential sand and/or gravel resources due to low overall quality and depths prohibitive to traditional dredging operations. The overall average sand, gravel, and mud content in all zones were approximately 60%, 19%, and 36%, respectively. The spatial heterogeneity of most zones would also make it difficult to consistently predict the quality of a given resource without additional sampling in targeted areas. BOEM was most interested in sand deposits at depths < 30 m for this investigation. However, average depths in these zones are greater than 40 m.

Through this investigation the MCMI has provided the first ever volumetric assessment of potential sand and gravel resources in waters of federal jurisdiction for this region. The limited quality and spatial extent of these deposits limits their potential for beach nourishment and coastal restoration projects, which highlights the need for more comprehensive assessment and management of potential resources within the region (e.g. shoreface/nearshore deposits).

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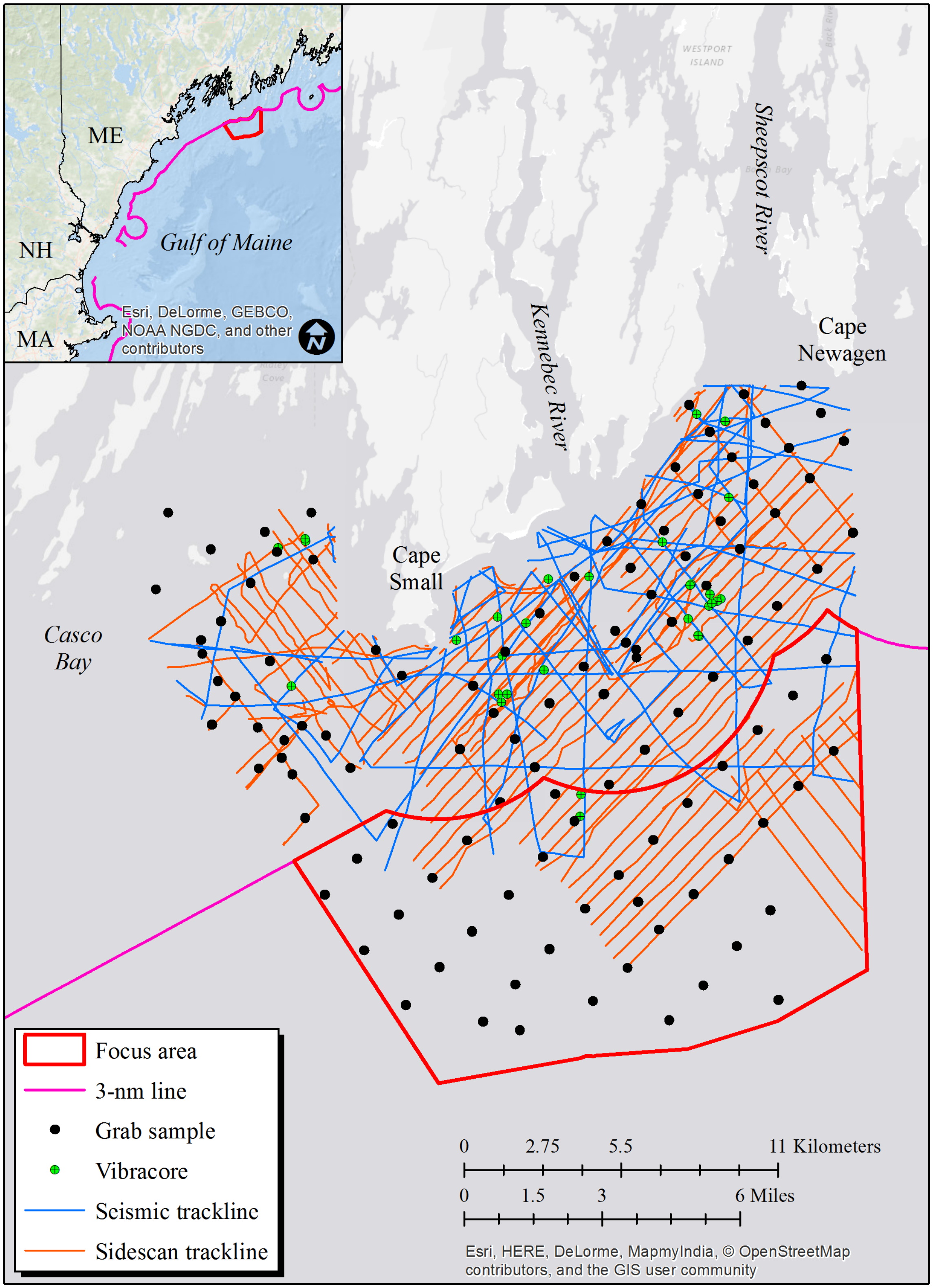

Figure 1. Focus area (red outline) and previous geological and geophysical data collected by other agencies in the vicinity.

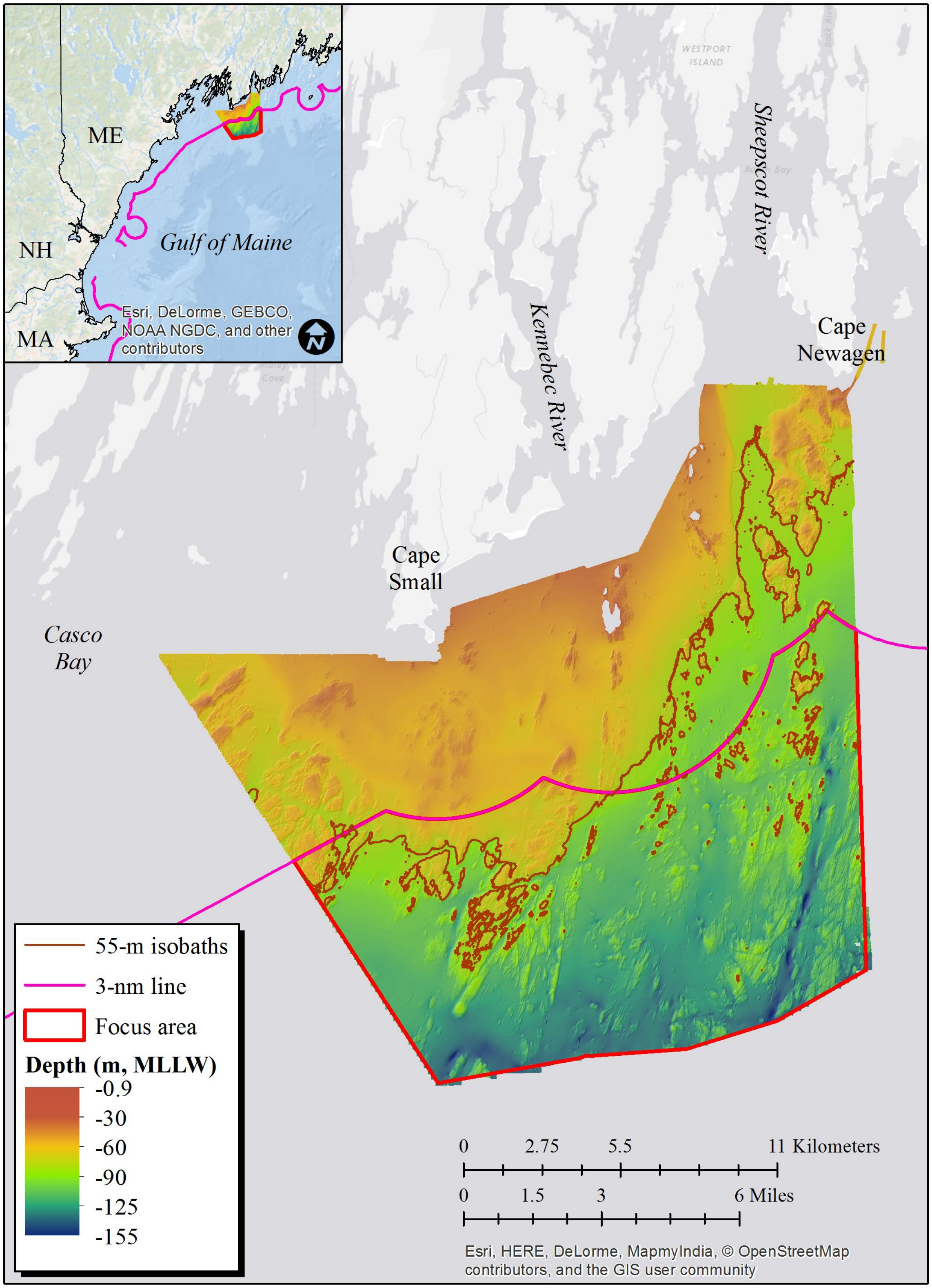

Figure 2. Focus area bathymetry showing Kennebec River nearshore ramp/paleodelta and 55-meter isobaths (dark red/maroon contours).

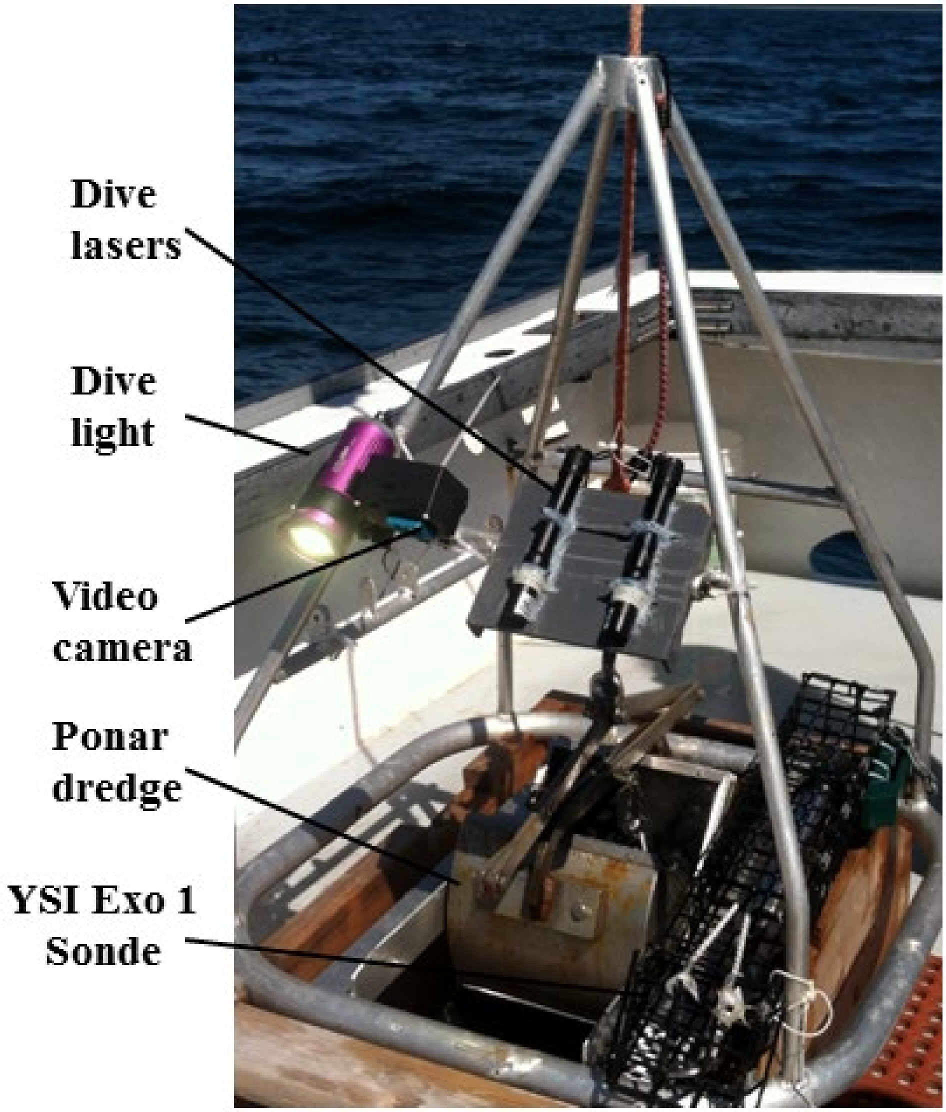

Figure 3. MCMI grab sampling platform.

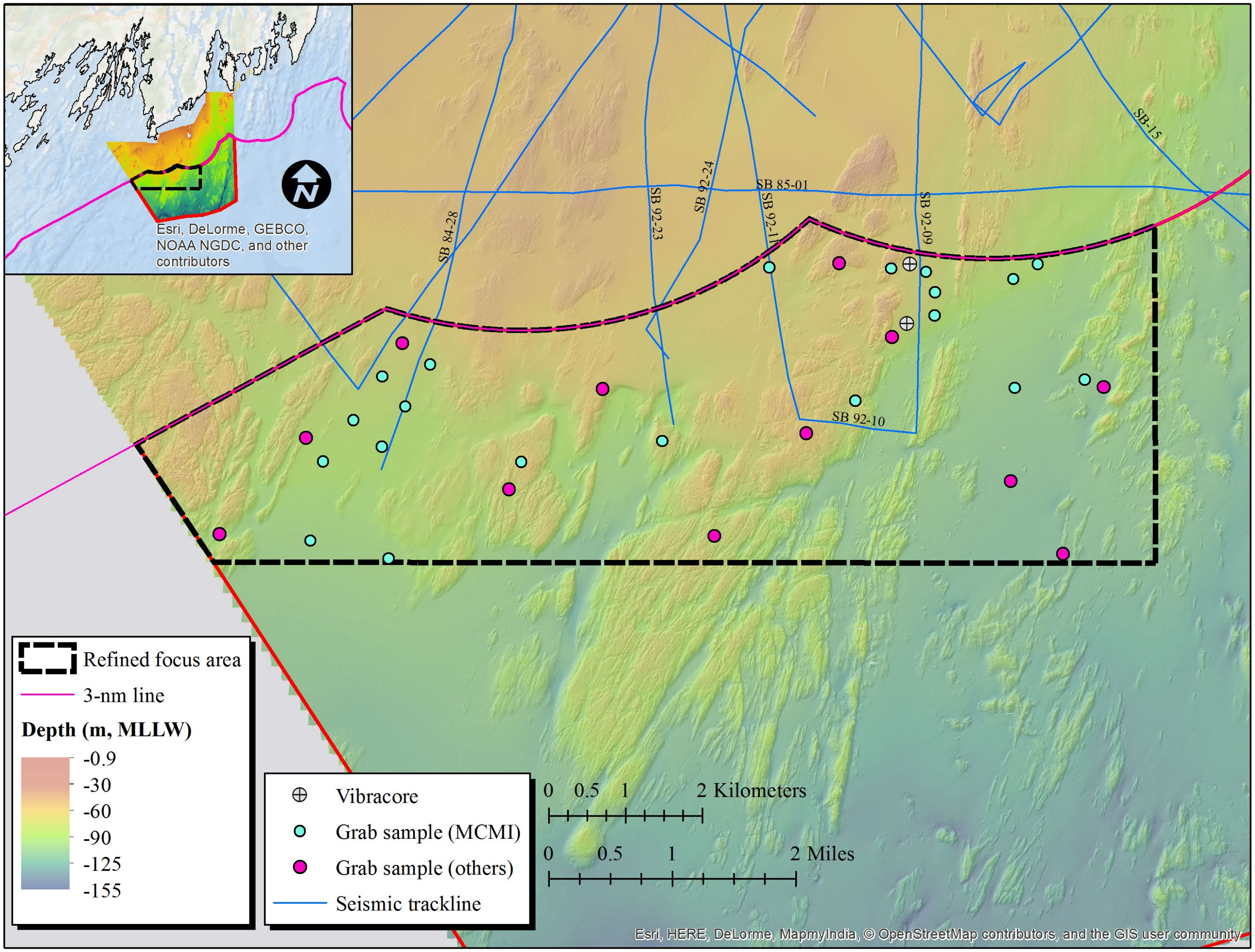

Figure 4. Geological and geophysical data used for sand and gravel assessment in refined focus area. Seismic lines (blue with label) were used to estimate mean thickness for each zone shown in Figure 5.

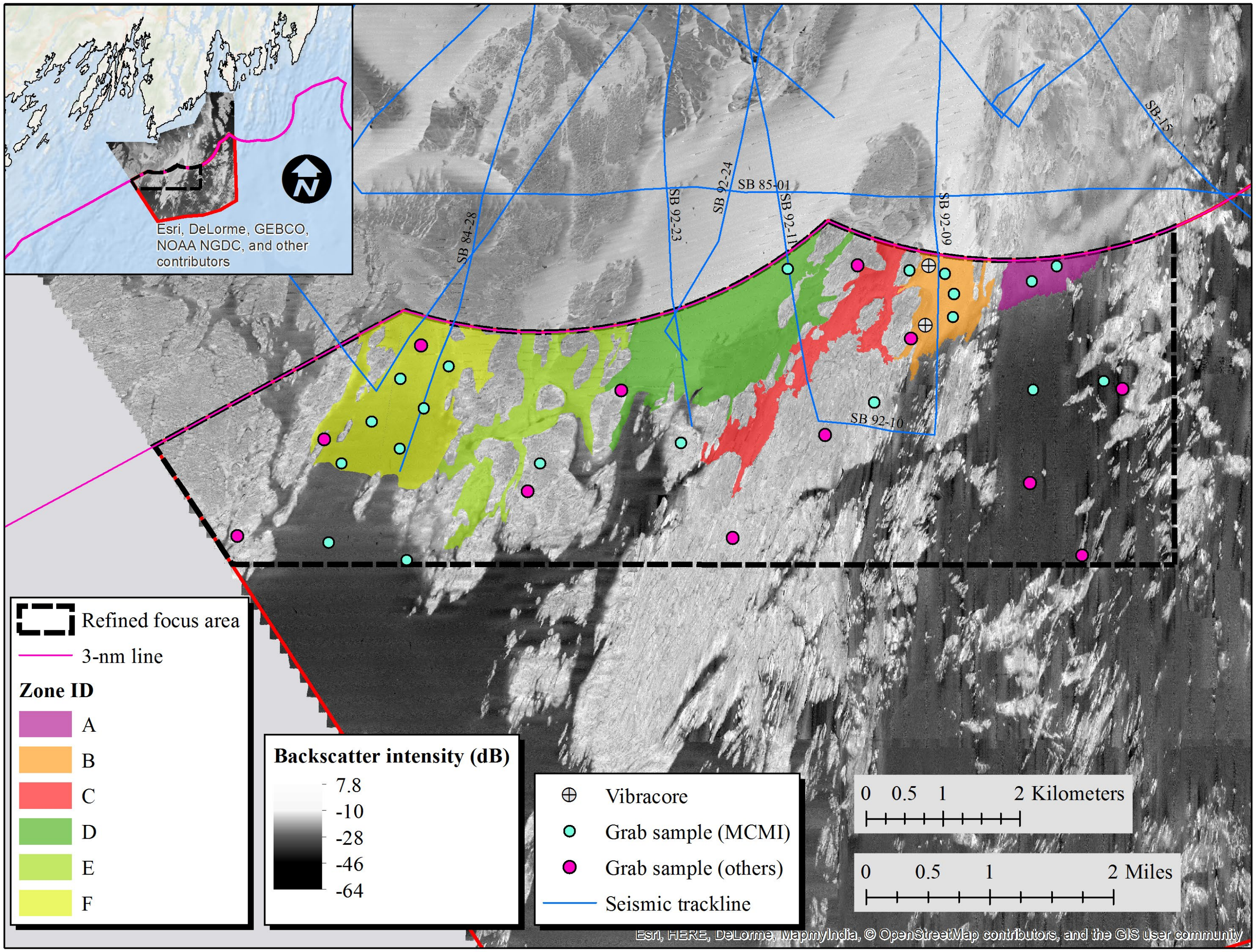

Figure 5. Sand and gravel zones shown with representative seismic lines (blue lines with label) were used to estimate mean thickness for each zone and geological data (vibracores and grab samples) used to characterize them. Lighter tones in backscatter intensity represent coarser sediment and darker tones represent fine sediment. Irregular-shaped areas with intermediate to light tones represent rock.

Appendix A – Grab sample and vibracore data

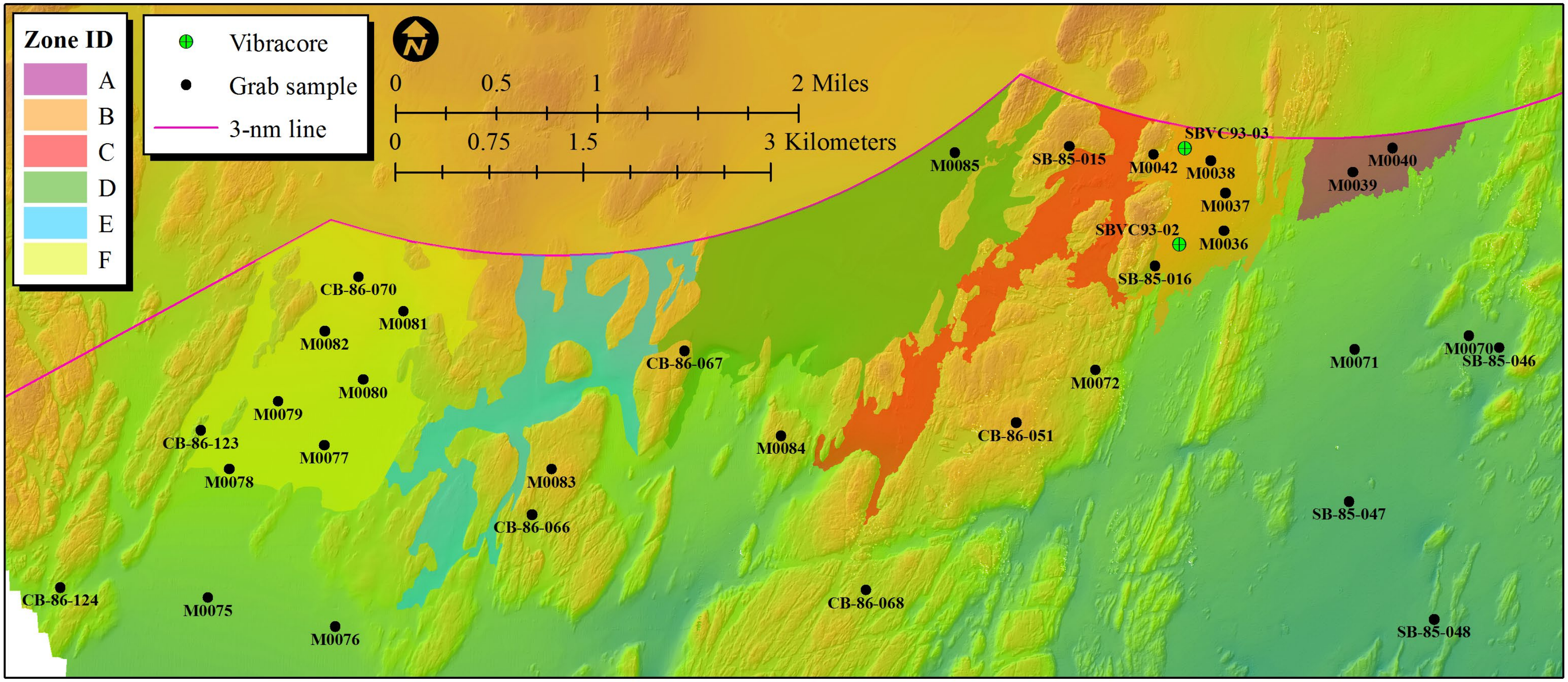

Figure A1. Overview map showing sand gravel zones, vibracores locations, and grab sample sites. Grab sample attributes are listed in table on next page. Grab sample sites with an 'M' prefix indicate samples collected by MCMI; all others were collected by other agencies.

Table A1. Grab sample site attributes, grain-size summary data, and zone ID

Sample ID[1]	Easting[2] (m)	Northing[2] (m)	Depth[3] (m)	Folk[4] (1974)	Gravel %	Sand %	Silt %	Clay %	Mud %	Phi Mean	Phi SD	Zone ID[5]
M0036	438265	4832944	56.7	msG	43.7	31.0			25.3	0.2	1.1	B
M0037	438274	4833246	51.1	msG	41.1	41.4			17.5	0.5	0.5	B
M0038	438158	4833508	46.4	msG	56.0	29.0			15.0	0.6	0.5	B
M0039	439292	4833412	61.8	(g)mS	4.0	54.3			41.7	1.0	1.1	A
M0040	439615	4833609	63.2	(g)mS	4.8	61.6			33.6	1.6	0.9	A
M0042	437700	4833553	35.3	R								
M0070	440224	4832106	78.7	M*								
M0071	439309	4831998	79.2	M*								
M0072	437235	4831833	48.6	R								
M0075	430138	4830012	72.4	sM	0.0	34.2	27.4	38.4	65.8	7.8	3.8	
M0076	431155	4829781	71.7	sM	0.0	26.4	29.9	43.7	73.6	8.4	3.7	
M0077	431066	4831232	62.6	mS	0.0	62.4	13.0	24.7	37.6	5.8	3.9	F
M0078	430307	4831040	64.0	mS	0.2	65.1	13.9	20.8	34.7	5.7	3.7	F
M0079	430700	4831580	58.9	mS	0.0	78.1	7.1	14.8	21.9	4.7	3.4	F
M0080	431378	4831756	59.8	mS	0.1	68.7	13.4	17.8	31.2	5.1	3.7	F
M0081	431700	4832303	52.9	mS	0.2	75.6	8.8	15.4	24.2	4.4	3.6	F
M0082	431072	4832143	52.8	cS	0.4	86.4	3.4	9.8	13.2	3.9	2.9	F
M0083	432886	4831039	39.6	R								
M0084	434721	4831308	44.9	R								
M0085	436113	4833569	38.7	gS	56.9	39.0	0.2	4.0	4.2	0.5	2.7	D
CB-86-051	436600	4831411	62	R								
CB-86-066	432728	4830677	48	R								
CB-86-067	433948	4831987	43	S	0.0	96.0	2.0	2.0	4.0	1.4	0.4	D
CB-86-068	435401	4830072	53	R								
CB-86-070	431340	4832577	44	S	0.0	92.0	2.0	6.0	8.0	2.3	1.3	F
CB-86-123	430081	4831352	58	gmS	18.0	64.0	7.0	12.0	19.0	2.1	4	F
CB-86-124	430047	4830078	62	gsM*								
SB-85-015	437020	4833618	35	S*								
SB-85-016	437713	4832664	52	gS	5.0	87.0	4.0	4.0	8.0	0.2	0.4	B
SB-85-046	440467	4832010	82	C	0.0	4.0	22.0	74.0	96.0	0	0	
SB-85-047	439264	4830783	87	M	0.0	5.0	30.0	66.0	95.0	0	0	
SB-85-048	439943	4829841	87	sC	0.0	10.0	22.0	69.0	90.0	0	0	

[1]Sample ID M0036 through M0072 collected/visited by MCMI during the 2015 field season. M0075 through M0085 collected/visited by MCMI during the 2016 field season. All other sites are from other angencies.

[2]WGS84 UTM Zone 19N meters

[3]Depths listed from sites M0001 through M0126 are referenced to mean lower low water in meters. Depths listed for other sites are not referenced to a vertical datum (estimated error ±3m).

[4]Samples denoted with an asterisk represent sites for which a grain-size analysis was not performed and/or were classified based on video observations and by field description.

[5]No grab samples collected within zones C or E.

Table A2. Vibracore coordinates

Vibracore ID[1]	Easting[2] (m)	Northing[2] (m)
SBVC93-02	437908	4832834
SBVC93-03	437951	4833605

[1]Vibracores not collected by MCMI (see Kelley et al., 1997).

[2]WGS84 UTM Zone 19N meters

Table A3. Vibracore textural properties

SBVC93-02 (Length = 0.86 m)						
Sample (cm)	Gravel %	Sand %	Mud %	Phi Mean	Phi SD	Comments (Seismic facies)
10	61	36	3	-0.1	0.6	mod. well sorted, v. coarse sand (d)
58	35	65	0	0	0.4	well sorted, v. coarse sand (d)

SBVC93-03 (Length = 0.73 m)						
Sample (cm)	Gravel %	Sand %	Mud %	Phi Mean	Phi SD	Comments (Seismic facies)
10	12	88	0	0.4	0.6	mod. well sorted, coarse sand (d)
70	19	77	4	0.7	0.8	well sorted, coarse sand (d)

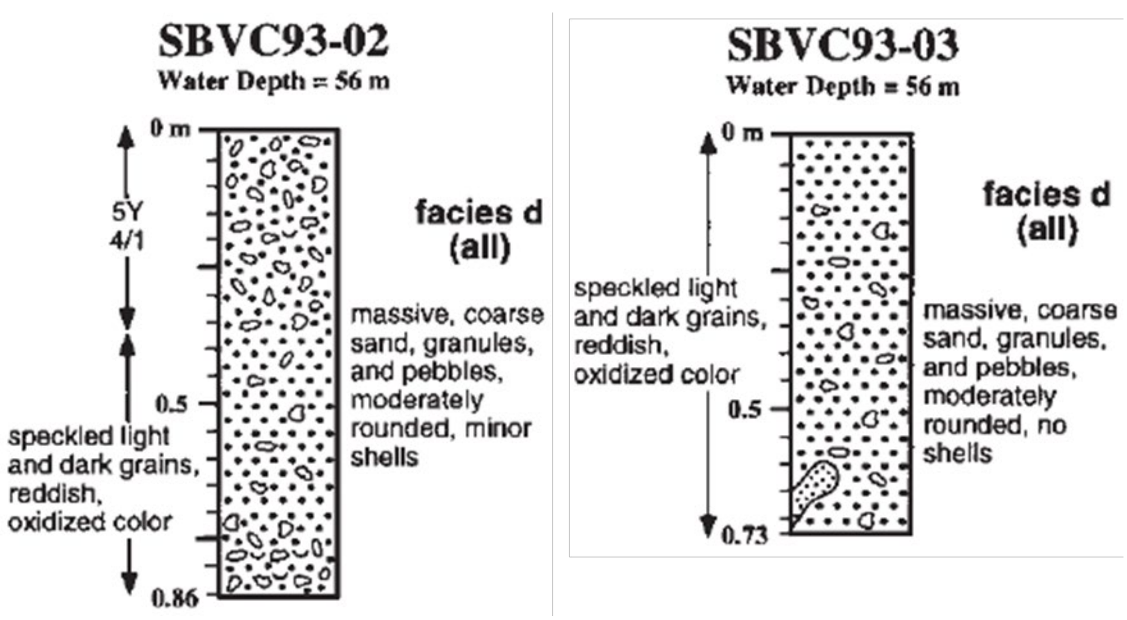

Figure A2. Vibracore data from Kelley et al., 1997. Facies 'd' represents deltaic sand and gravel.

Appendix B – Summary of seismic profiles and vibracores within sand and gravel zones

Zone ID	Seismic Profile ID	Vibracore ID
A	-	-
B	SB-92-09	SBVC93-03, SBVC93-02
C	SB-92-11	-
D	SB-92-11, SB-92-23	-
E	-	-
F	SB-84-28, SB-89-05	-

Appendix C – Seismic profiles

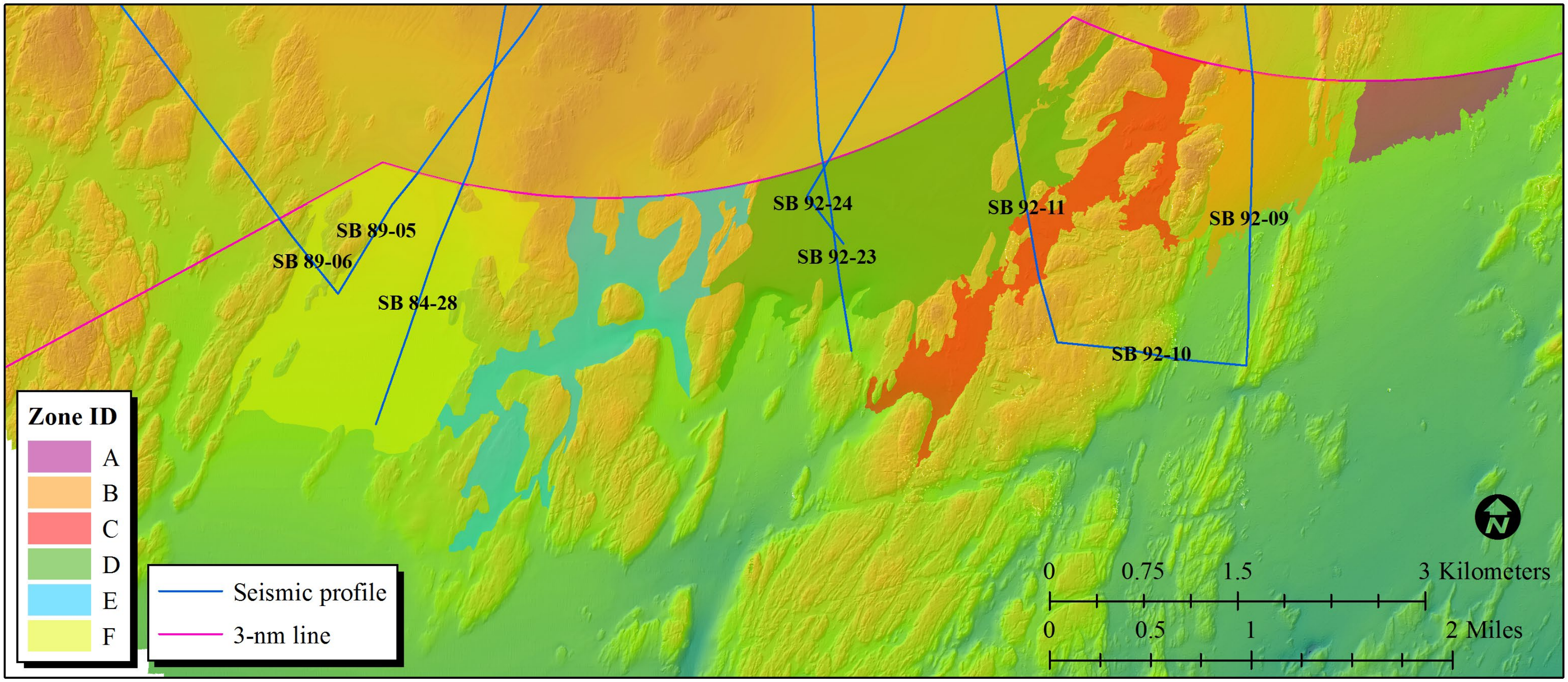

Figure C1. Overview map showing sand gravel zones and seismic profiles. Only representative seismic profiles used to estimate the mean thickness for the uppermost stratigraphic unit in each zone are presented in this report.

<u>Key to seismic profile units (from Kelley et al., 1998)</u>
s/g – Holocene sand and gravel
d – late Pleistocene/early Holocene deltaic sand and gravel
TGL – thin gravel layers
gm – glacial marine
br – bedrock

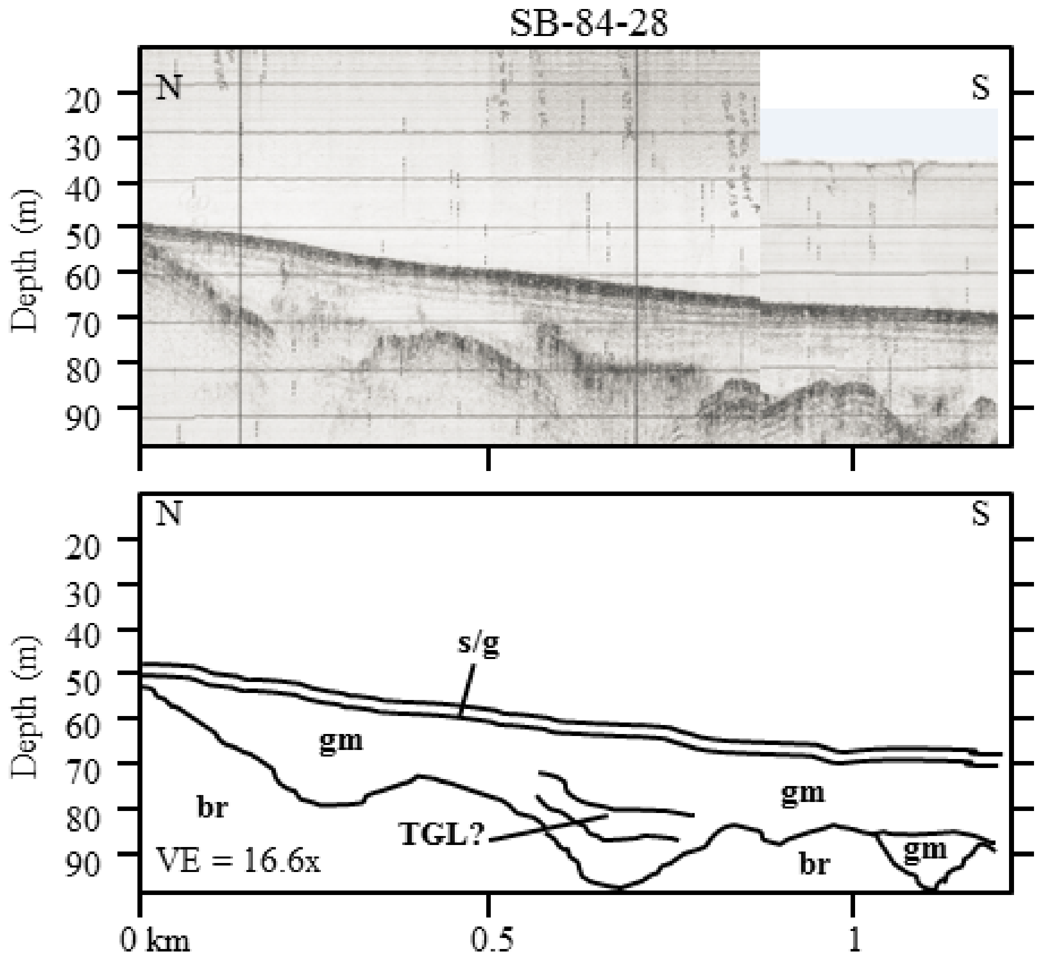

Figure C2. Seismic profile SB-84-28. Representative profile for zone F. Estimated mean thickness for uppermost Holocene sand was 2 m. Samples collected in this unit contained 62% to 92% fine sand with considerable proportions of mud.

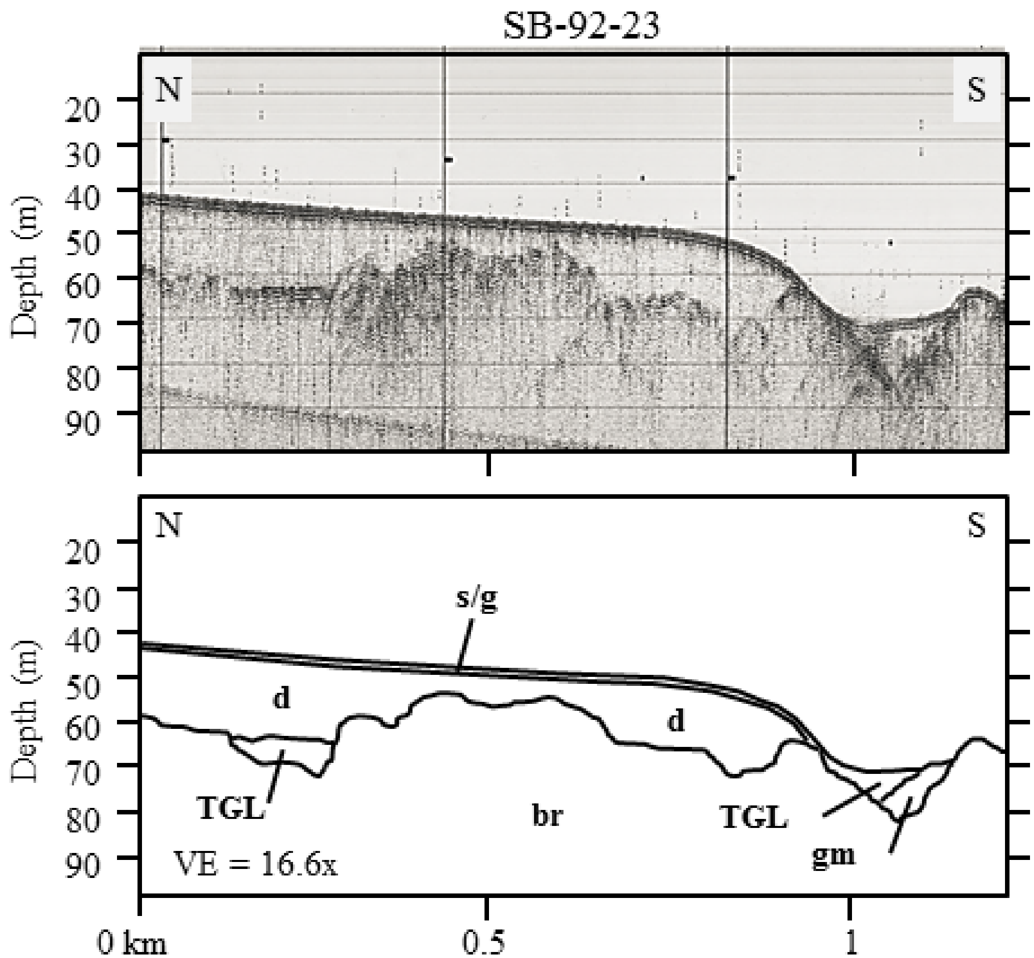

Figure C3. Seismic profile SB-92-23. Representative profile for zone D. Estimated mean thickness for deltaic material and overlying Holocene sand and gravel was 5 m. Samples collected in this unit contained very little mud (~4%) and were predominantly medium to coarse sand and gravel.

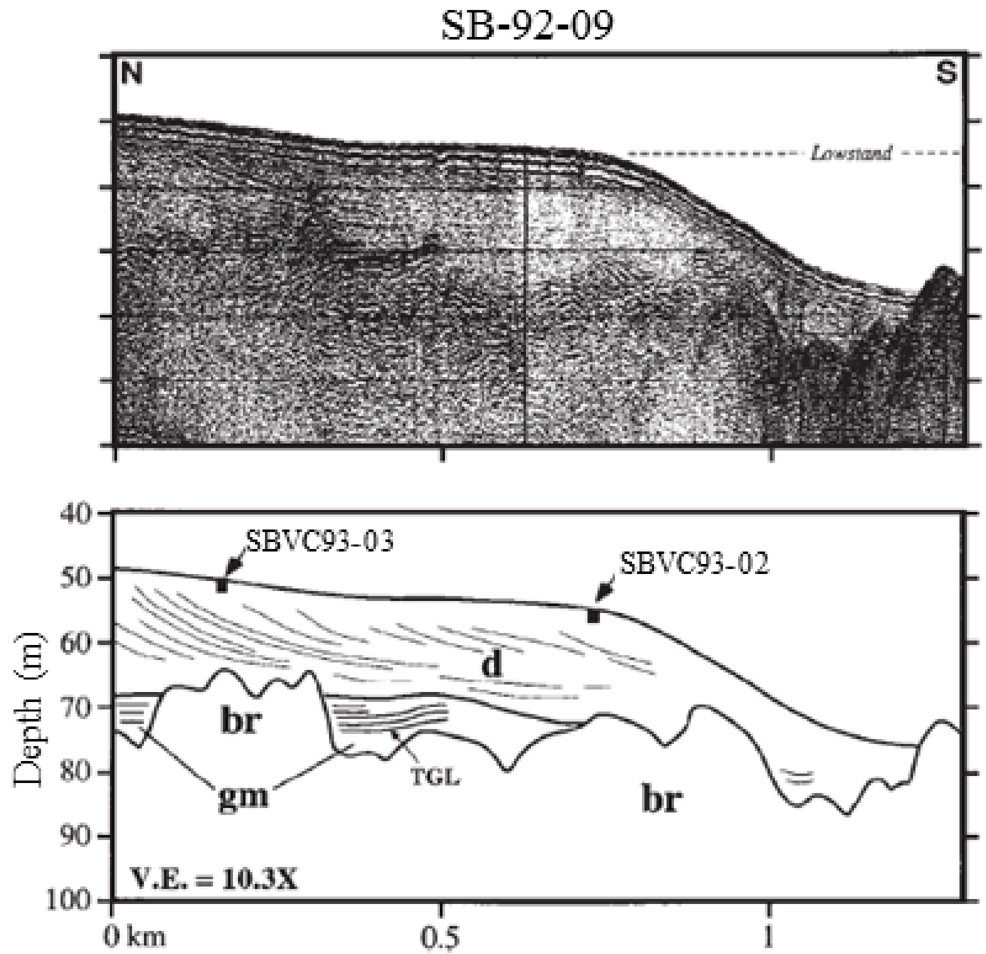

Figure C4. Seismic profile SB-92-09 (modified from Kelley et al., 1998). Representative profile for zone B. Estimated mean thickness for deltaic material and overlying Holocene sand and gravel was 5 m, which was very conservative. Samples collected in this unit contained up to 25% mud and approximately equal portions of medium to coarse sand and gravel.