Naval Research Laboratory

Stennis Space Center, MS 39529-5004

NRL/MR/7430--06-8975

Geological Characterization of Select Mississippi Shelf Sites

Yoko Furukawa
Jan Watkins
Erin O'Reilly
Chad Vaughan
Tabitha Erman
Kristen Carbrey
Dale Bibee

Seafloor Sciences Branch
Marine Geosciences Division

December 15, 2006

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
15-12-2006

2. REPORT TYPE
Memorandum Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

Geological Characterization of Select Mississippi Shelf Sites

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
0602782N

6. AUTHOR(S)

Yoko Furukawa, Jan Watkins, Erin O"Reilly, Chad Vaughn,
Tabitha Erman, Kristen Carbrey, and Dale Bibee

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Seafloor Sciences Branch
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/7430--06-8975

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
One Liberty Center
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR / MONITOR'S ACRONYM(S)

ONR

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report documents results of a seabed survey in the Mississippi Bight conducted 16-22 December 2005 from the R/V Pelican. The objective of the survey was to find a site in proximity to the NRL Stennis in about 27 meters water depth with uniform soft clayey silt to silty clay sediments over the upper two meters of seabed profile for testing of an acoustic sediment classification system. This report documents the physical and geotechnical properties of the upper 2 meters of the sediments at the locations investigated. The top 10 ~ 50 cm of the sediments exhibits characteristics of storm deposits that can be readily interpreted as the results of Hurricane Katrina that passed through the study area on August 29, 2006. As a result of the storm, the study area is no longer composed of uniform soft sediments, but is covered with a 10 ~ 50-cm-thick deposit of thinly laminated sandy layers. In addition, the sediment cores contain records of historic catastrophic storms in the Mississippi Bight area.

15. SUBJECT TERMS

Mississippi Bight	Soft clayey silt
Acoustic sediment classification	Silty clay sediments

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Yoko Furukawa
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UL	32	**19b. TELEPHONE NUMBER** *(include area code)*
Unclassified	Unclassified	Unclassified			(228) 688-5474

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

CONTENTS

Geological Characterization of select Mississippi Shelf sites

Yoko Furukawa, Jan Watkins, Erin O'Reilly, Chad Vaughan, Tabitha Erman, Kristin Carbrey, and Dale Bibee

July 20, 2006

ABSTRACT:

This report documents results of a seabed survey in the Mississippi Bight conducted 16 – 22 December 2005 from the R/V Pelican. The objective of the survey was to find a site in proximity to the NRL Stennis in about 27 meters water depth with uniform soft clayey silt to silty clay sediments over the upper two meters of seabed profile for testing of an acoustic sediment classification system. This report documents the physical and geotechnical properties of the upper two meters of the sediments at the locations investigated. The top 10 ~ 50 cm of the sediments exhibits characteristics of storm deposits, that can be readily interpreted as the results of Hurricane Katrina that passed through the study area in August 29, 2006. As a result of the storm, the study area is no longer composed of uniform soft sediments, but is covered with a 10 ~ 50 cm-thick deposit of thinly laminated sandy layers. In addition, the sediment cores contain records of historic catastrophic storms in the Mississippi Bight area.

1.0 Introduction

This report documents results of a seabed survey in the Mississippi Bight conducted 16 – 22 December 2005 from the R/V Pelican. The objective of the survey was to find a site in proximity to the Naval Research Laboratory, Stennis Space Center in about 27 meters water depth with uniform soft clayey silt to silty clay sediments over the upper two meters of seabed profile for testing of an acoustic sediment classification system. This report documents the physical and geotechnical properties of the upper two meters of the sediments at the locations investigated.

2.0 Background

The study area (see Appendix I for coordinates) is within the Mississippi-Alabama shelf province (Kindinger et al., 2004) which encompasses the eastern Louisiana barrier islands, the Mississippi-Alabama and Florida western panhandle barrier islands and shelf, Mississippi Sound, and Mobile Bay. Specifically, in the western part of this shelf province in which the study area is located, the stratigraphy is dominated by multiple layers of fine silts, sands and clays being deposited by the Mississippi River (i.e., old St. Bernard Delta). This contrasts the layer of relict sand deposit in the eastern portion that was deposited during Pleistocene and early Holocene.

Hummocky cross-stratified sandstones in rock records have been regarded as the indicators of ancient severe storms (Duke et al., 1991; Keen and Slingerland, 1993). Their Holocene equivalence, occurrences of high-energy (i.e., coarse-grained) deposits within a sequence of low-energy (i.e., fine-grained) deposits, has been used as an indicator of severe storms in recent years. For example, sandy layers in Shelby Lake, a coastal lagoon in Alabama, were interpreted to have resulted from coastal dune overwash events due to extreme (i.e., Category 4 and 5) tropical cyclones (Liu and Fearn, 1993). The authors dated these sandy layers to determine that Shelby

Manuscript approved July 21, 2006.

Lake area has been struck by an extreme hurricane every ~600 years. However, their interpretation is not without controversy due to uncertainties in the history of Northern Gulf of Mexico sea level stand and coastal geomorphology of Lake Shelby area (Otvos, 1999; Liu and Fearn, 2002; Otvos, 2002). Based on the notion that present-day Shelby Lake was formed very recently, possibly after late Holocene, Otvos (1999) suggests that sand layers observed by Liu and Fearn (1993) may have originated due to normal estuarine valley filling processes rather than extreme storms.

River-dominated continental shelves typically receive a large amount of sediments carried down-river from the upland watersheds, resulting in a rapid (i.e., ~ cm/year) sediment accumulation rate (Nittrouer and Wright, 1994; McKee et al., 2004). In addition, siliciclastic sediment particles deposited by large rivers are typically fine-grained mud. These features make river-dominated shelves to be ideal sites for storm-bed preservation, because (i) high-energy, coarse grained layers are easily distinguished from the ambient fine-grained deposits; and (ii) coarse-grained storm beds are buried rapidly well below the maximum depth of bioturbation, protecting them from biological reworking and mixing with ambient fine-grained muds. In addition to these advantages, interpretation of sandy layers in continental shelf sediments is much more straightforward than that of coastal sediments due to lack of drastic transitions in depositional environment. Unlike the coastal areas of Northern Gulf of Mexico where barrier islands, estuarine valleys, and lagoonal lakes were under constant dynamic transformation, Mississippi-Alabama continental shelf has been under a constant depositional environment related to gradual Holocene transgression since early Holocene (Kindinger et al., 2004). As a result, occasional sandy layers within predominantly muddy strata could only be interpreted as storm layers in the study area.

3.0 Results from Gravity Core Samples

3.1. Visual Observations

Site One:

Two gravity cores (Paradise05GC1 and Paradise05GC2) were collected at Site One. Both cores indicate the presence of a thick (11 – 16 cm) storm deposit at the surface likely due to Hurricane Katrina: there is an abrupt transition horizon at 11 cmbsf (Paradise05GC2) or 16 cmbsf (Paradise05GC1). Below this horizon is a cohesive, homogeneous mud, whereas above the horizon is a mixture of small shells, sand, silt, and mud. In addition, sediment above this horizon exhibits the typical "fining upward sequence" which points to a significant storm deposition scenario in which the upper 11 – 16 cm of the sediment was deposited as a result of a rapid entrainment, suspension, and subsequent re-deposition according to the Stokes' law. It is likely that the currents and tides from Katrina were strong enough to produce a storm layer of this magnitude even at the depth of 27 m. Storm beds thicker than 50 cm have been hindcasted in the Mississippi Shelf to have been caused by Hurricane Camille (Bentley et al., 2002).

Below the storm layer, the cores are composed of cohesive soft mud. There is very little variability in terms of appearances (by visual observations) or mechanical properties (by handling the samples in order to obtain grain size and density subsamples).

Site Two:

Two cores (Paradise05GC3 and Paradise05GC4) were collected at Site Two. They both indicate the presence of a massive (16 – 58 cm) storm deposit at the surface likely due to sediment reworking by Hurricane Katrina. Unlike the cores from Site One, however, these cores exhibit more complex and less abrupt transition between the massive shelly/sandy horizon above and cohesive mud below. The massiveness of the shelly/sandy layer suggests that this site may have been functioning as a depocenter since Katrina entrained a large quantity of sediments in the region (i.e., the amount of sediments being deposited at Site Two may be much greater than the amount of sediments entrained and eroded from this location). The gradual, rather than abrupt, transition between the sand/shell horizon and cohesive mud sediments below indicates that either: (i) the erosion event at this site occurred in stages; or (ii) sediments from different locations with different grain size characteristics were deposited at this site in stages, perhaps as the directions and strengths of bottom currents shifted during Katrina's passage. In addition, the lack of fining-upward signature indicates either: (i) the bulk of fine-grained sediments are still in suspension at the time of coring (i.e., December 2005); or (ii) this site is not a depocenter under normal, non-storm conditions.

Below the storm layer, the cores are composed of cohesive soft mud. Unlike the cores from Site One, however, these cores contain isolated thin layers containing shell fragments (i.e., at 160 cmbsf, and between168 cmbsf and bottom of core in GC3, and several layers between 78 cmbsf and 183 cmbsf in GC4).

Site Three:

Two cores (Paradise05GC5 and Paradise05GC6) were collected at Site Three. They both indicate the presence of a thick (18 – 22 cm) storm deposit at the surface likely due to the sediment reworking by Hurricane Katrina.

Below the storm layer, the cores are composed of cohesive soft mud. These cores contain isolated thin layers containing shells and/or calcareous remnants of sea urchin (i.e., at 101 cmbsf, 119 cmbsf, 150 cmbsf, and 172 cmbsf in GC5, and 136 cmbsf, and 190 cmbsf in GC6).

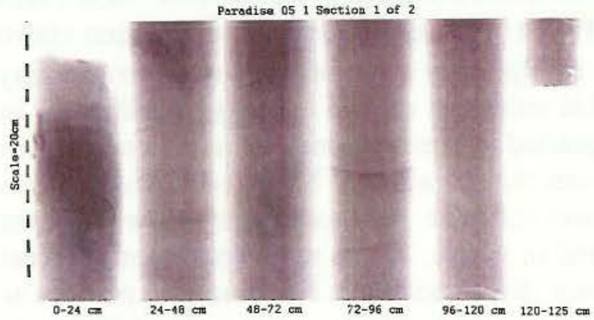
Site Four:

One core (Paradise05GC7) was collected at Site Four. It indicates the presence of a thick (12 cm) storm deposit at the surface likely due to the sediment reworking by Hurricane Katrina.

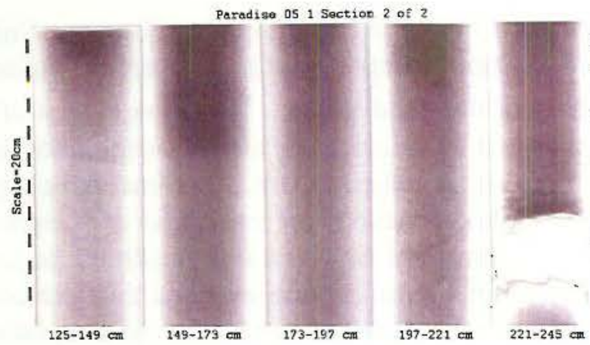
Below the storm layer down to 141 cmbsf, the core is composed of cohesive soft mud. At 141 cmbsf, there is a sharp contact below which is a very shelly bed.

3.2. Core X-radiography

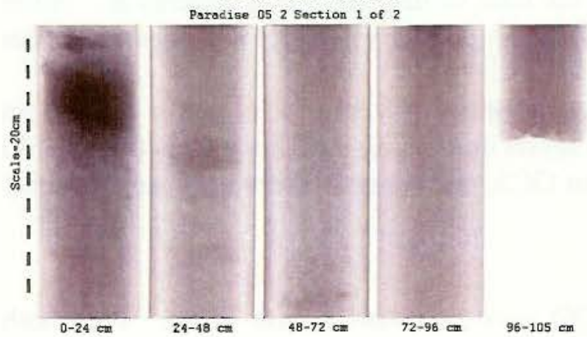
X-radiography images from the gravity cores (Figure 3.2.1) show that the top 5 – 30 cm of each core to be composed of higher density materials (e.g., sand) compared to the low density materials in sections below (e.g., fine muds). Occasional sandy layers in deeper parts are also visible, indicating paleostorm layers.



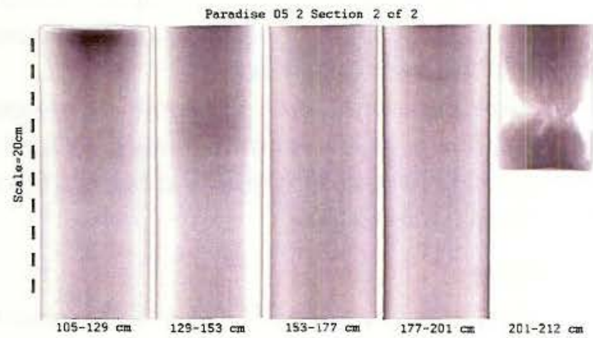
GC1 Section1



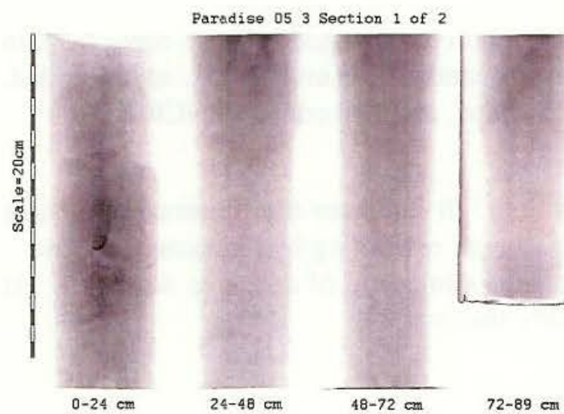
GC1 Section 2



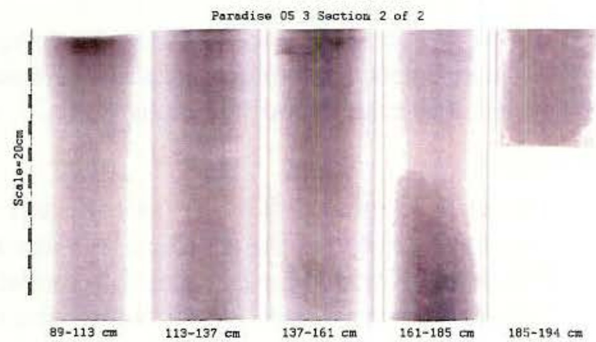
GC2 Section 1



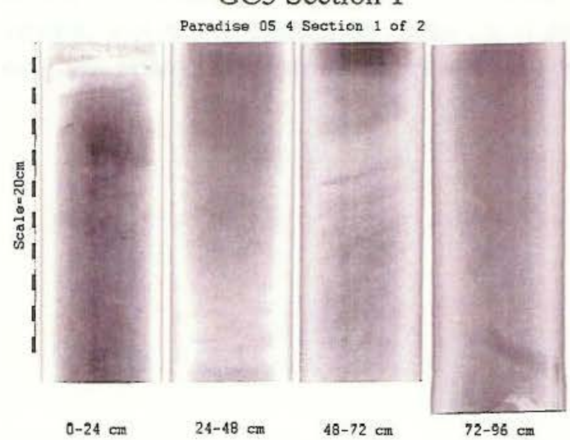
GC2 Section 2



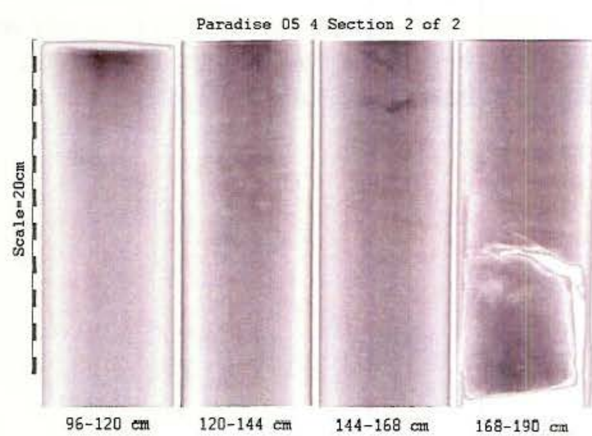
GC3 Section 1



GC3 Section 2



GC4 Section 1



GC4 Section 2

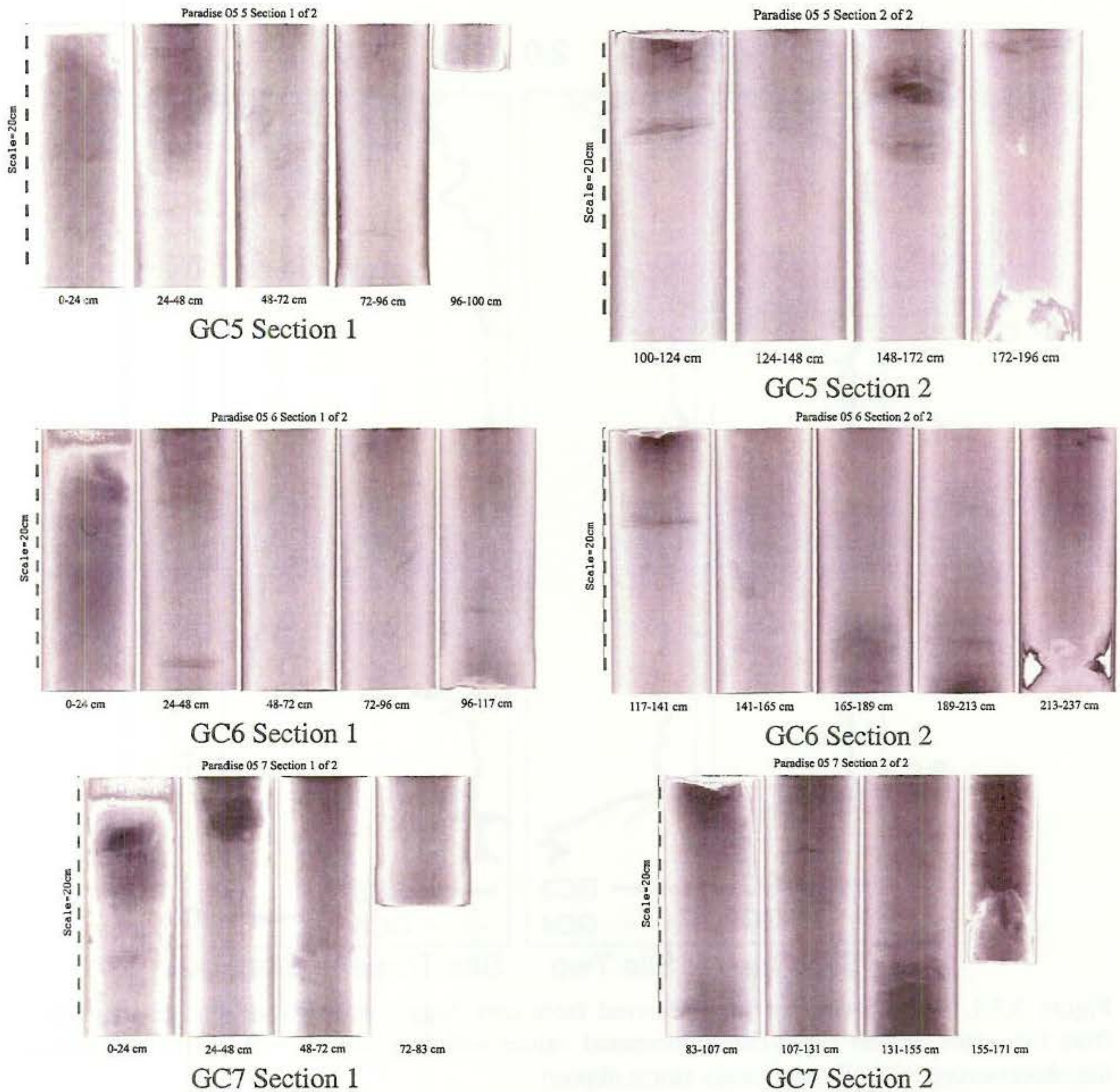


Figure 3.2.1. X-radiography images of the gravity cores. High density regions appear dark/black, and low density regions appear light/white.

3.3. Gamma Ray and Acoustic Impedance Logs

The core logger data (Figures 3.3.1 and 3.3.2) corroborate the observations noted above: all cores exhibit high gamma density and high impedance in the top 11 – 58 cmbsf indicative of sandy/shelly sediments, and low gamma density and low impedance in the middle parts indicative of fine-grained muds. The elevated impedance and gamma density near the bottoms of GC3 and GC7 reflect the presence of shelly bottoms in these cores. The presence of coarse-grained surface sediments over a subsurface fine-grained layer indicate a recent high energy depositional event (i.e., Katrina) at the location that has been usually subjected to low energy depositional environment.

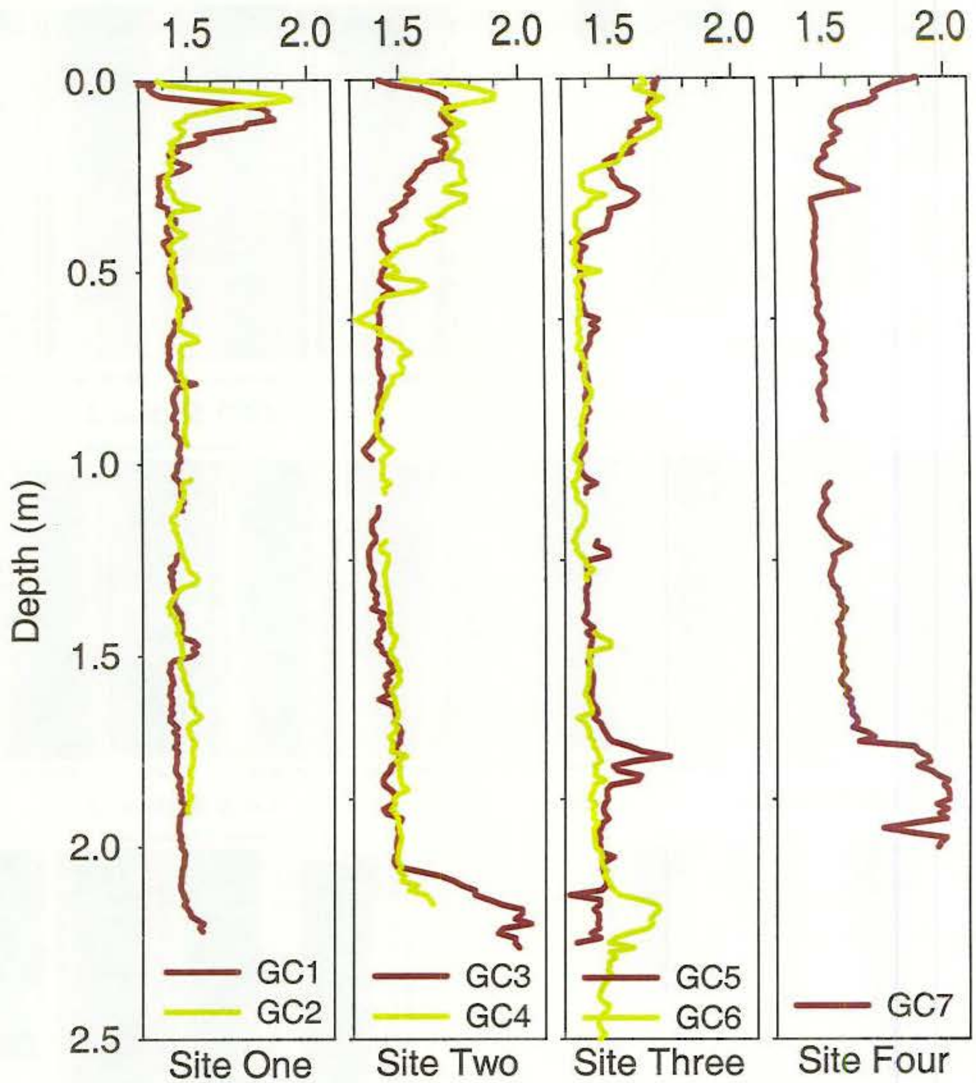


Figure 3.3.1. Gamma density (g/cc) derived from core logger data. Note that gamma density from this study exhibit significantly increased values within upper 10 – 40 cmbsf corroborating the observations of shelly and sandy storm deposit.

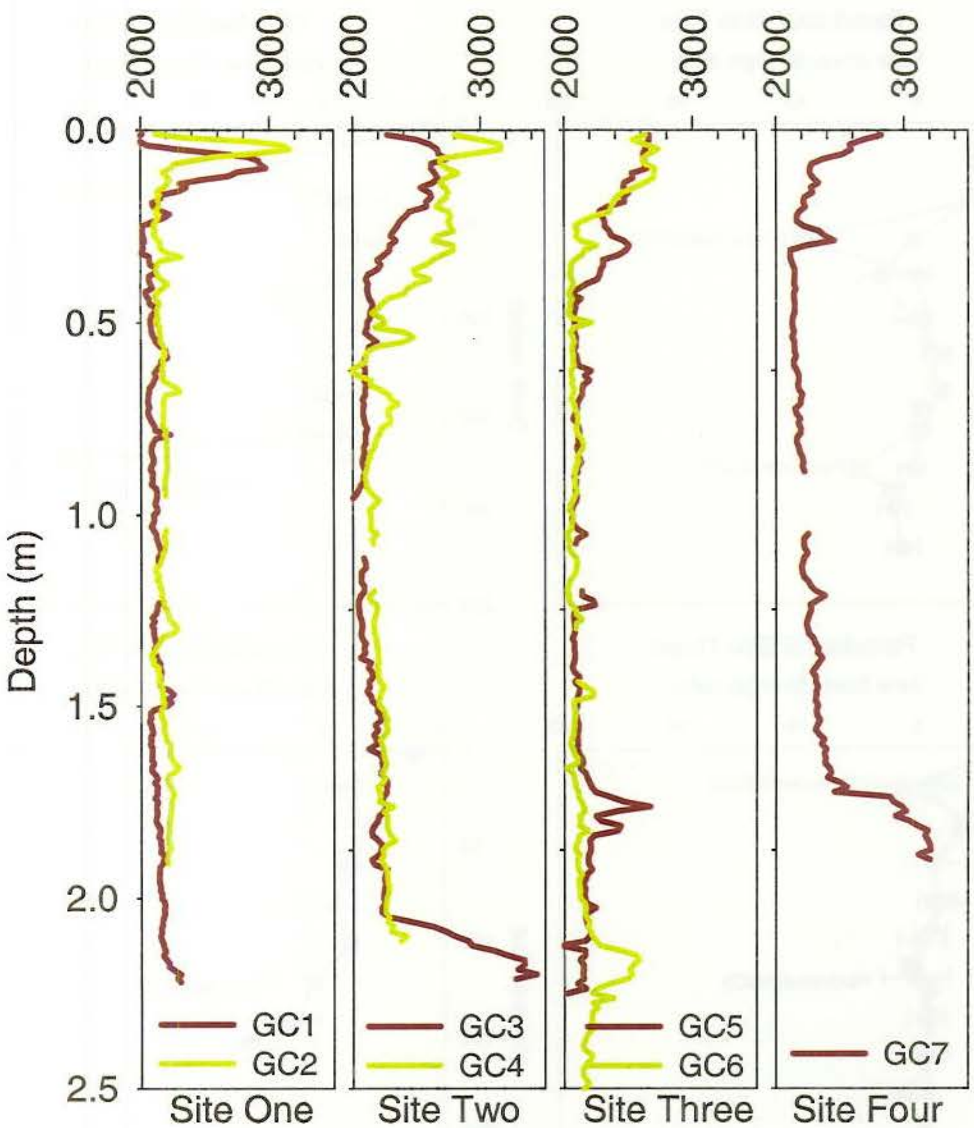


Figure 3.3.2. Acoustic impedance (g/m^2/s) derived from core logger data. Note that acoustic impedance from this study exhibit significantly increased values within upper 10 – 40 cmbsf corroborating the observations of shelly and sandy storm deposit.

3.4. Undrained Vane Shear Strength

Undrained vane shear strength was measured on extruded intact gravity cores. The vane shear blade was inserted with vane axis perpendicular to the sediment horizontal plane in situ. Vane shear strength values range from < 1 kPa to > 15 kPa (Figure 4.4.1). Most samples fall in 5 ± 1 kPa. The elevated vane shear strength values in the bottoms of cores GC3 and GC7 coincide with the presence of shelly beds in these cores. The elevated vane shear values at 20 cmbsf at Site Two result from the presence of massive storm bed at that site, rather than the presence of compacted mud. It must be noted that those vane shear strengths above 6 kPa reported herein are not true undrained shear strengths, but rather are indicating regions of non-cohesive, highly permeable sandy sediments which undergo partial drainage during shearing.

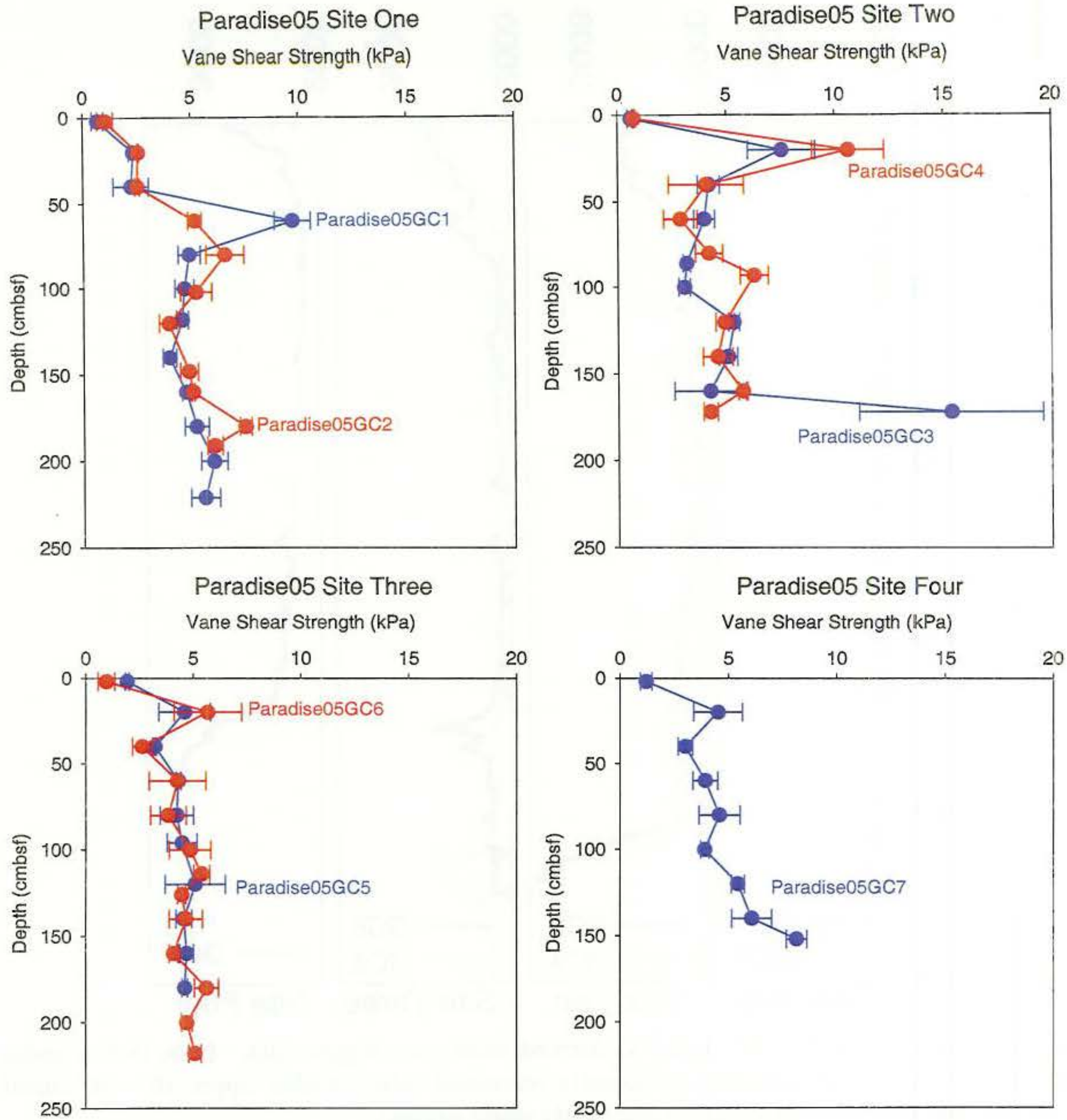


Figure 3.4.1. Undrained vane shear strength analyzed using extruded intact sections of the gravity cores.

3.5. Porosity, Grain Density, and Wet Bulk Density

Porosity (Figure 3.5.1), grain density (Figure 3.5.2), and wet bulk density (Figure 3.5.3, plotted together with the logger-derived gamma density for comparison) analyses were conducted following the widely used methods detailed elsewhere (Briggs, 1994; Briggs and Richardson, 1997).

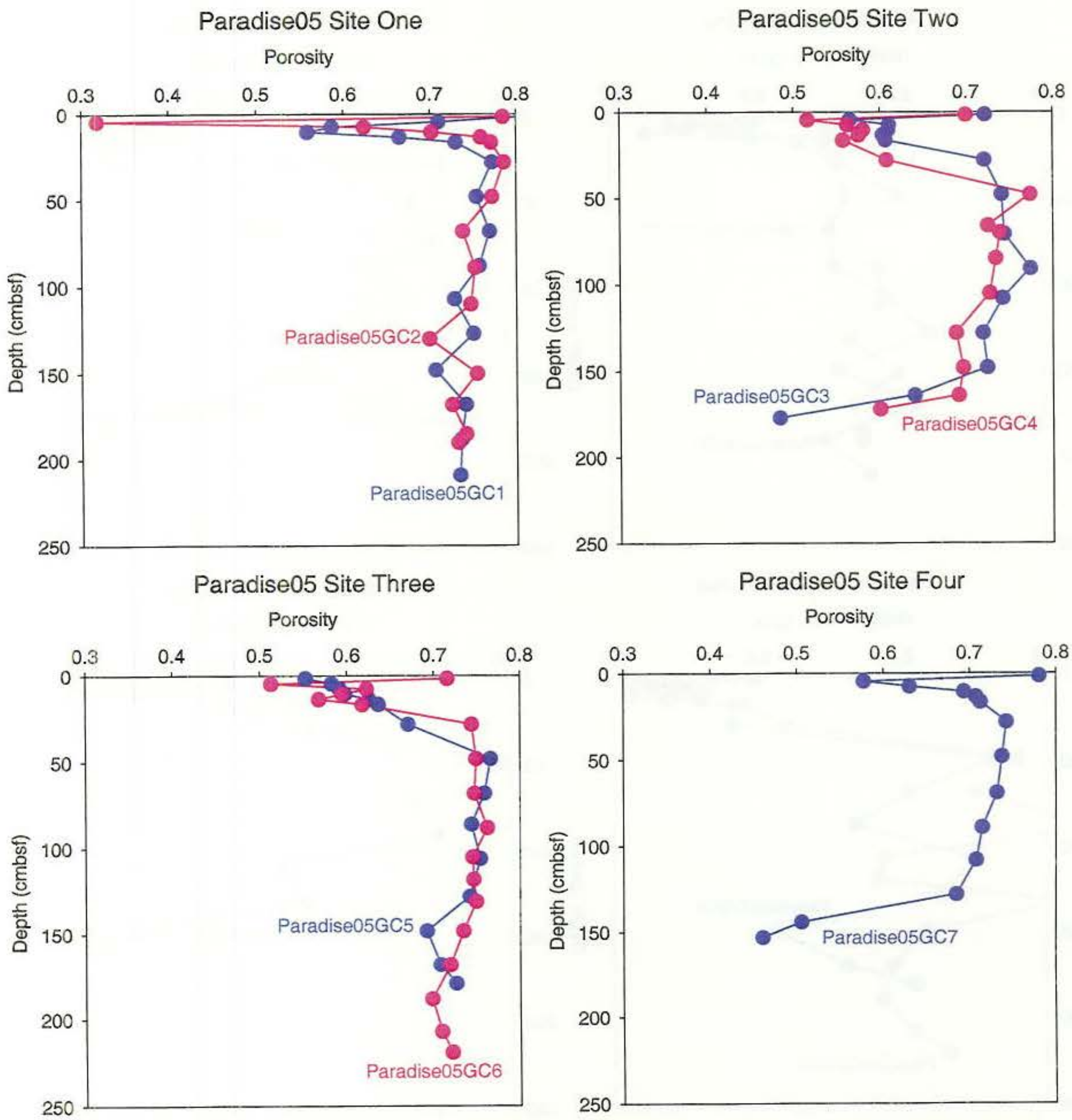


Figure 3.5.1. Porosity as determined by the weight difference of sediment aliquots before and after drying. Salt correction was made.

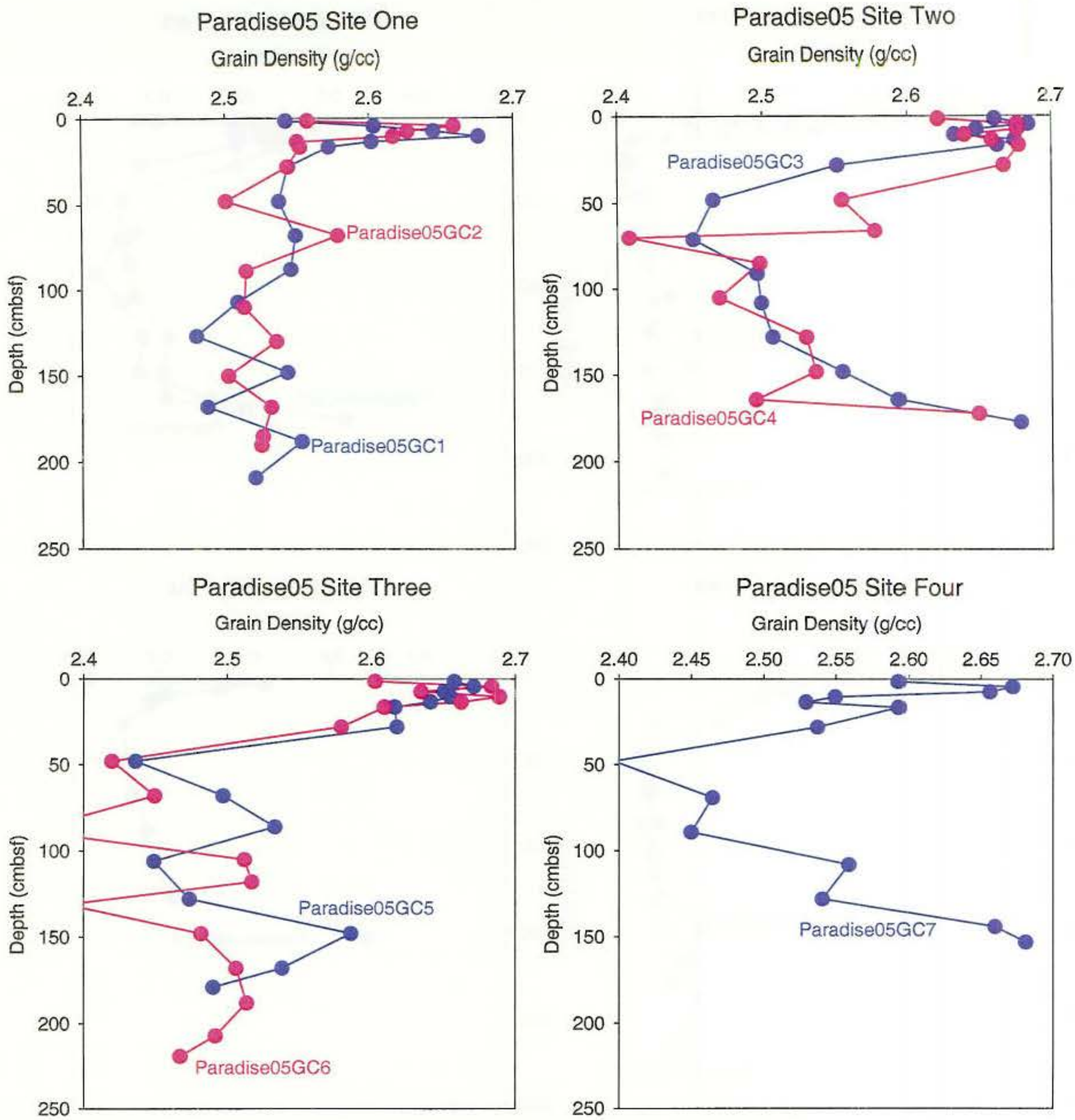


Figure 3.5.2. Grain density as determined by Quantachrome Pentapycnometer after sample aliquots were dried at 105°C.

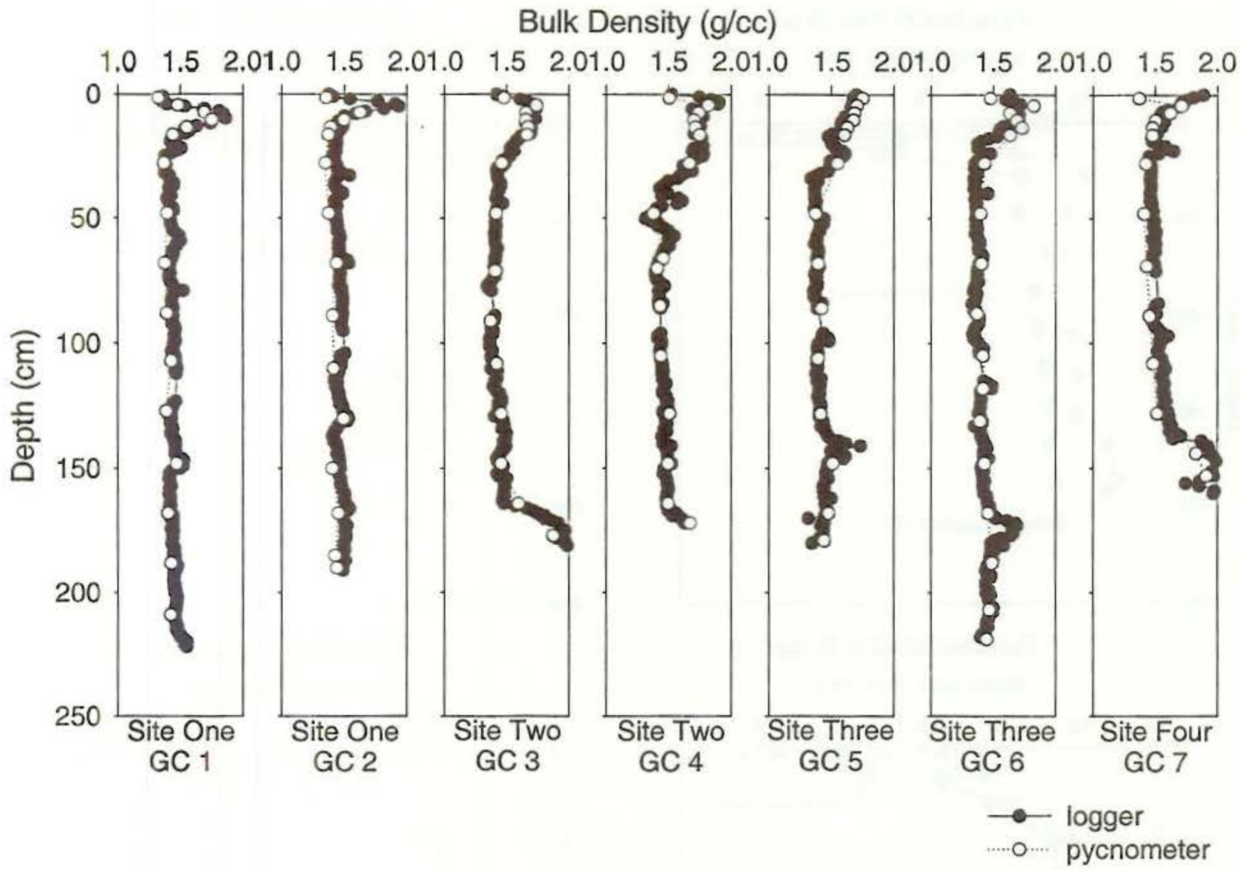


Figure 3.5.3. Bulk density was back-calculated by using the porosity data (Figure 3.5.1) and pycnometer-determined grain density data (Figure 3.5.2). Bulk density determined by the gamma ray logger is plotted together for comparison. In general, there is an agreement between pycnometer-derived bulk density and gamma density.

3.6. Grain Size

Grain size distribution was analyzed using the standard method involving wet sieving, dry sieving, and micromeritics (Briggs, 1994; Briggs and Richardson, 1997). Grain size data are shown in terms of the Folk (Phi) mean grain size (Figure 3.6.1) (Folk, 1968), percent gravel plus sand (Figure 3.6.2), and Phi histograms (Figure 3.6.3). Each core has a coarse-grained portion near the top (i.e., uppermost 20 – 50 cm), and the lower part of the core is homogeneous mud. The Phi histograms (Figure 3.6.3) reveal that the coarser-grained near surface sediments are bimodal, composed of significant fractions of both colloidal clays (around 0.001 mm) and fine to medium silt (0.008 mm < ϕ < 0.03 mm). In addition, there is a fining-upward trend within the surface bed. The bimodality and fining-upward are common signatures of storm deposits (Liu and Greyling, 1996).

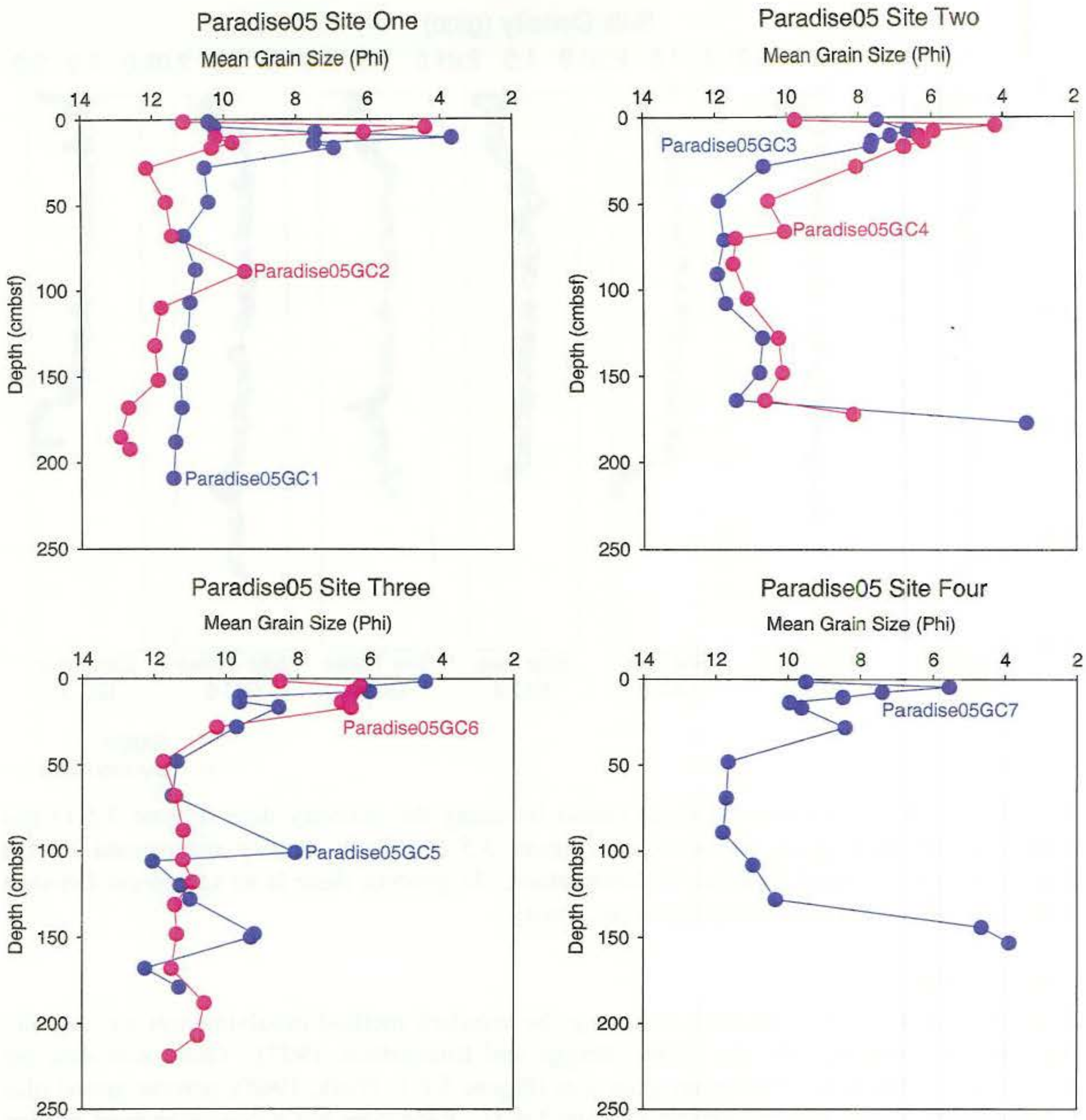


Figure 3.6.1. Mean grain size in Phi.

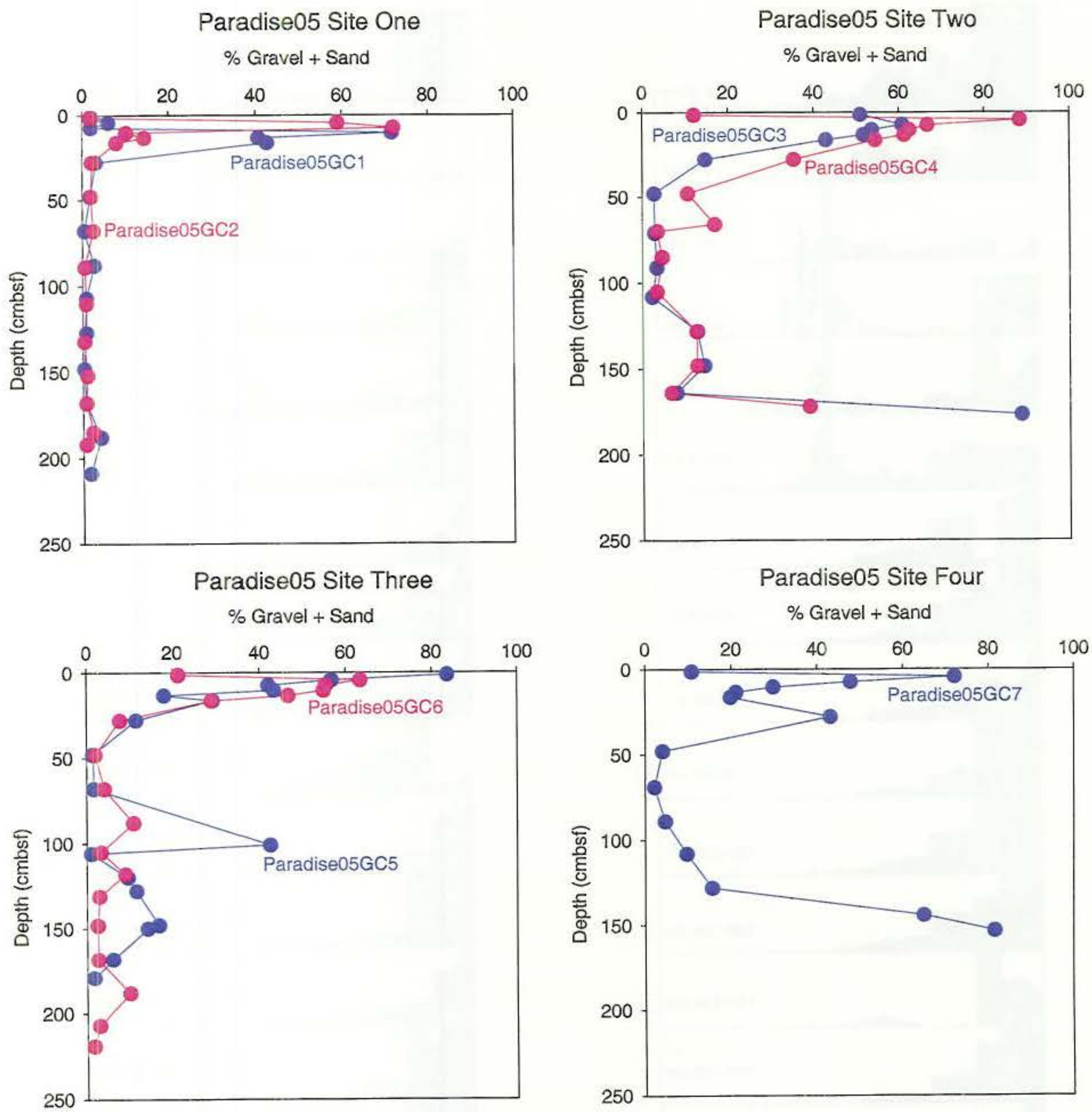


Figure 3.6.2. Gravel plus sand (weight %)

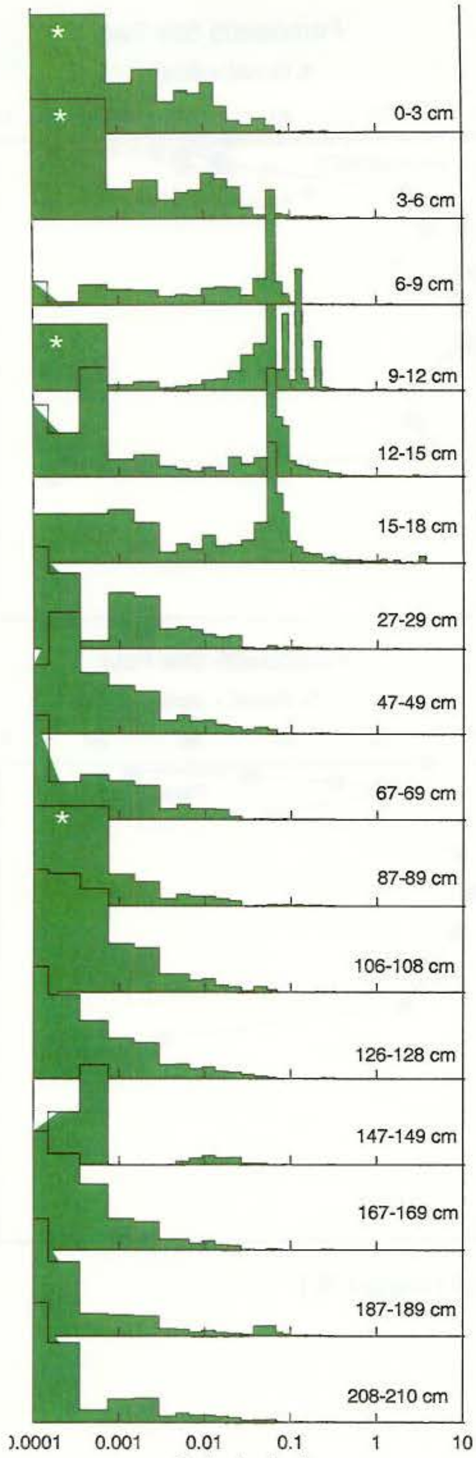


Figure 3.6.3.1. Site One, GC1 downcore grain size distribution. For samples indicated by *, distribution for particles smaller than 0.5 μm was grouped together, and not subdivided into conventional four bins (i.e., 10, 11, 12, and 13 phi) due to insufficient sample quantities.

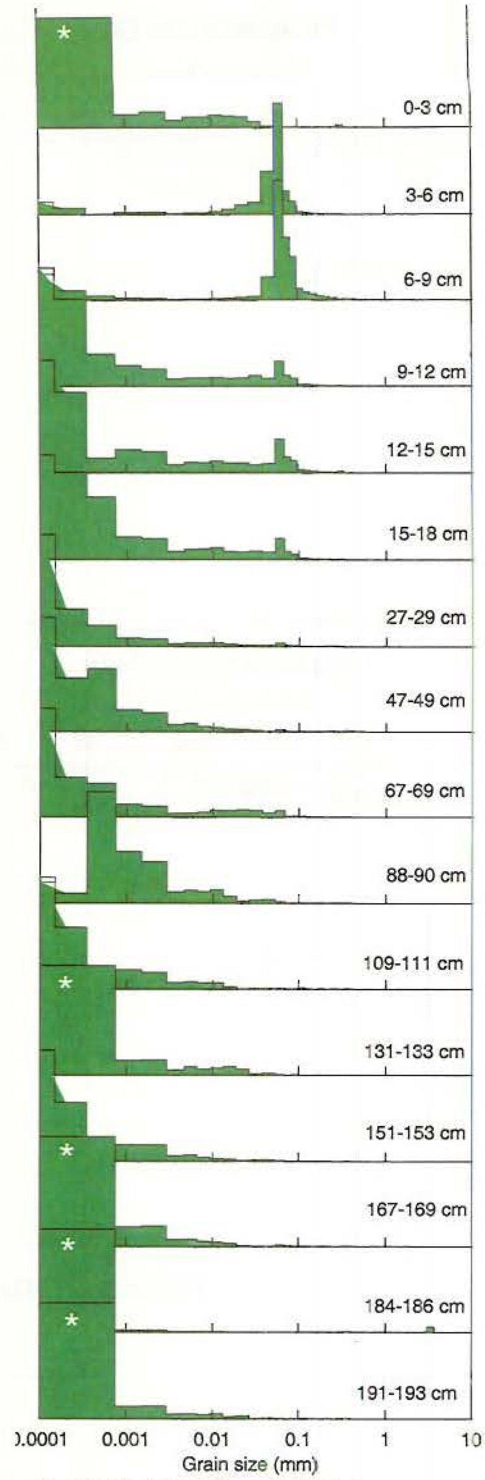


Figure 3.6.3.2. Site One, GC2 downcore grain size distribution. For samples indicated by *, distribution for particles smaller than 0.5 μm was grouped together, and not subdivided into conventional four bins (i.e., 10, 11, 12, and 13 phi) due to insufficient sample quantities.

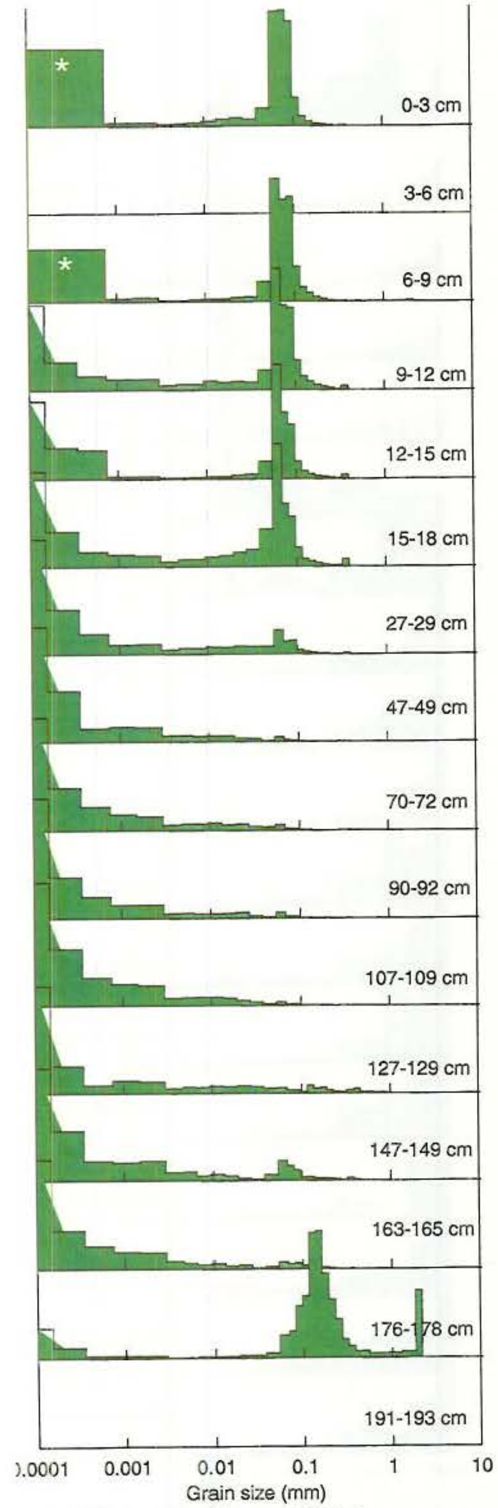


Figure 3.6.3.3. Site Two,GC3 downcore grain size distribution. For samples indicated by *, distribution for particles smaller than 0.5 µm was grouped together, and not subdivided into conventional four bins (i.e., 10, 11, 12, and 13 phi) due to insufficient sample quantities.

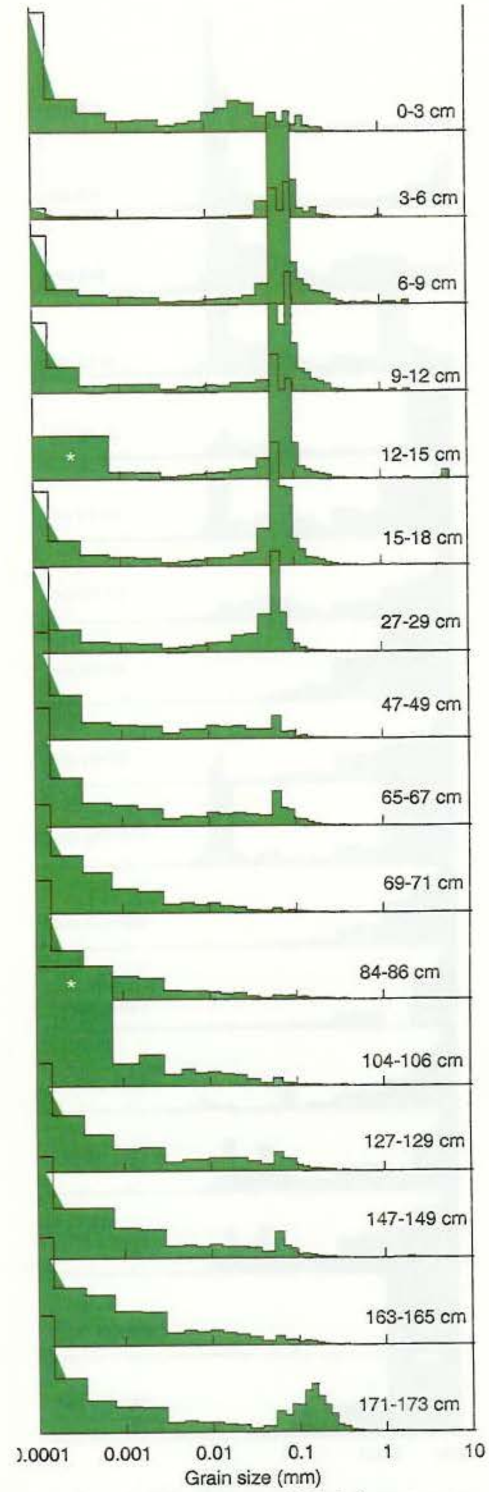


Figure 3.6.3.4. Site Two, GC4 downcore grain size distribution. For samples indicated by *, distribution for particles smaller than 0.5 µm was grouped together, and not subdivided into conventional four bins (i.e., 10, 11, 12, and 13 phi) due to insufficient sample quantities.

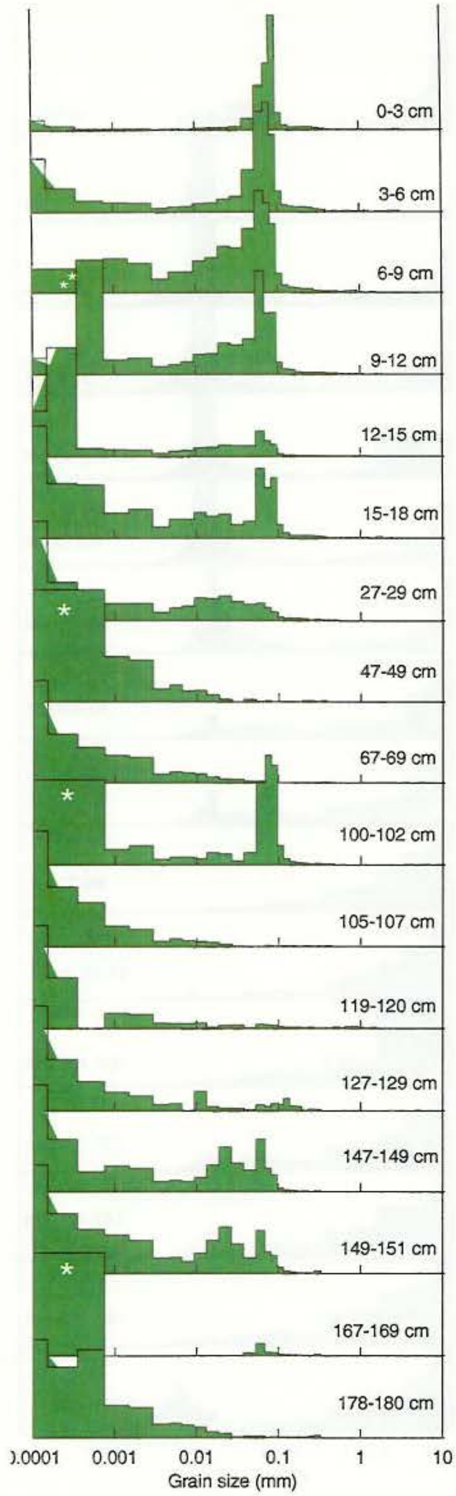


Figure 3.6.3.5. Site Three,GC5 downcore grain size distribution. For samples indicated by *, distribution for particles smaller than 0.5 μm was grouped together, and not subdivided into conventional four bins (i.e., 10, 11, 12, and 13 phi) due to insufficient sample quantities.

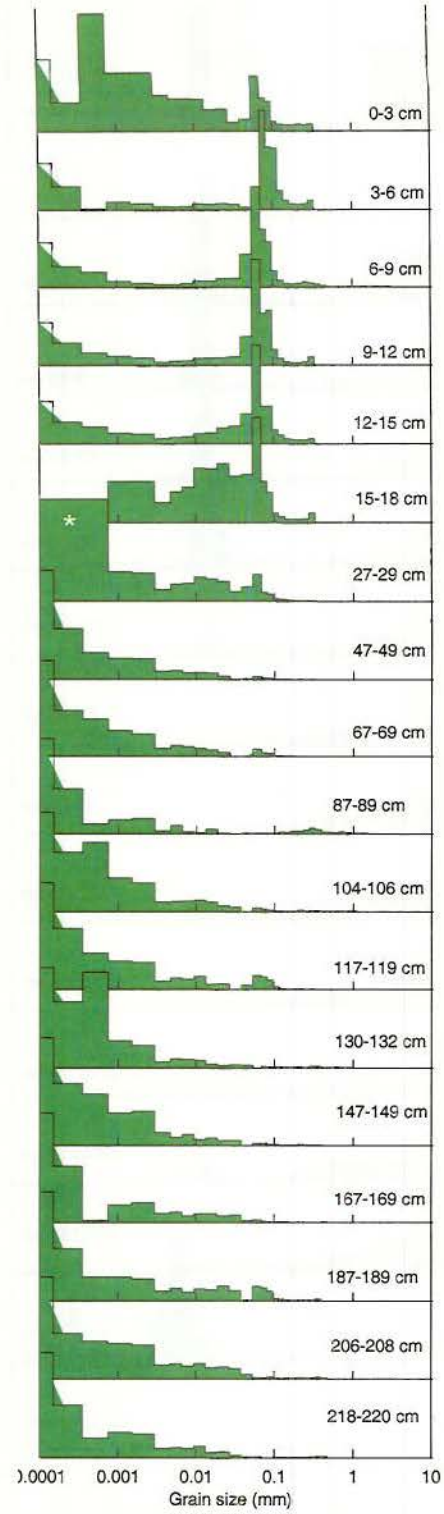


Figure 3.6.3.6. Site Three,GC6 downcore grain size distribution. For samples indicated by *, distribution for particles smaller than 0.5 μm was grouped together, and not subdivided into conventional four bins (i.e., 10, 11, 12, and 13 phi) due to insufficient sample quantities.

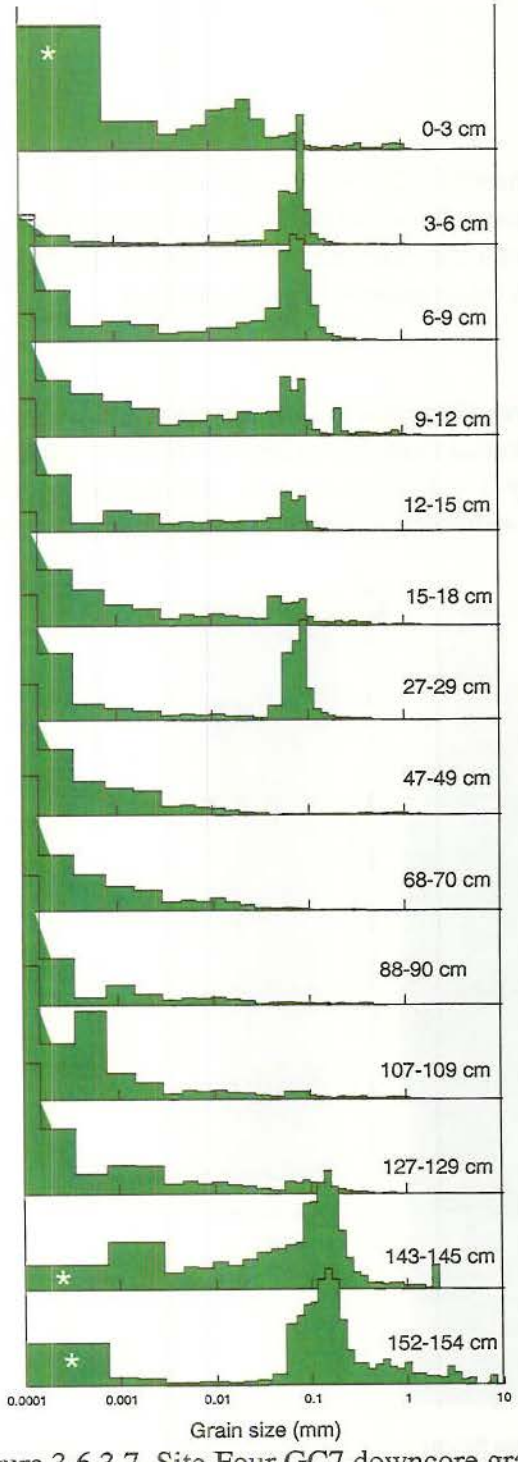


Figure 3.6.3.7. Site Four,GC7 downcore grain size distribution. For samples indicated by *, distribution for particles smaller than 0.5 µm was grouped together, and not subdivided into conventional four bins (i.e., 10, 11, 12, and 13 phi) due to insufficient sample quantities.

4.0 Results from Box Core Analysis

4.1. Visual Observations

Two box cores (Paradise05BC1 and Paradise05BC2) were collected at Site One. Paradise05BC1 has one subsample (BC1A), whereas Paradise05BC2 has three subsamples (BC2A, BC2B, and BC2C). Visual inspection reveals the presence of 7 – 15 cm sandy/shelly bed on top. Below the sandy/shelly layer is a visually homogeneous muddy stratum.

4.2. Core X-radiography

X-radiography images from the box core subcores (Figure 4.2.1) show the top 6 – 10 cm at Site One to be composed of much higher density material than the sediments below ~ 10 cmbsf. In addition, fine, mm-scale lamination within the top 2 – 3 cm is visible. These fine layers are likely due to the gradual settling of storm-suspended sediment particles in cyclical tide periods.

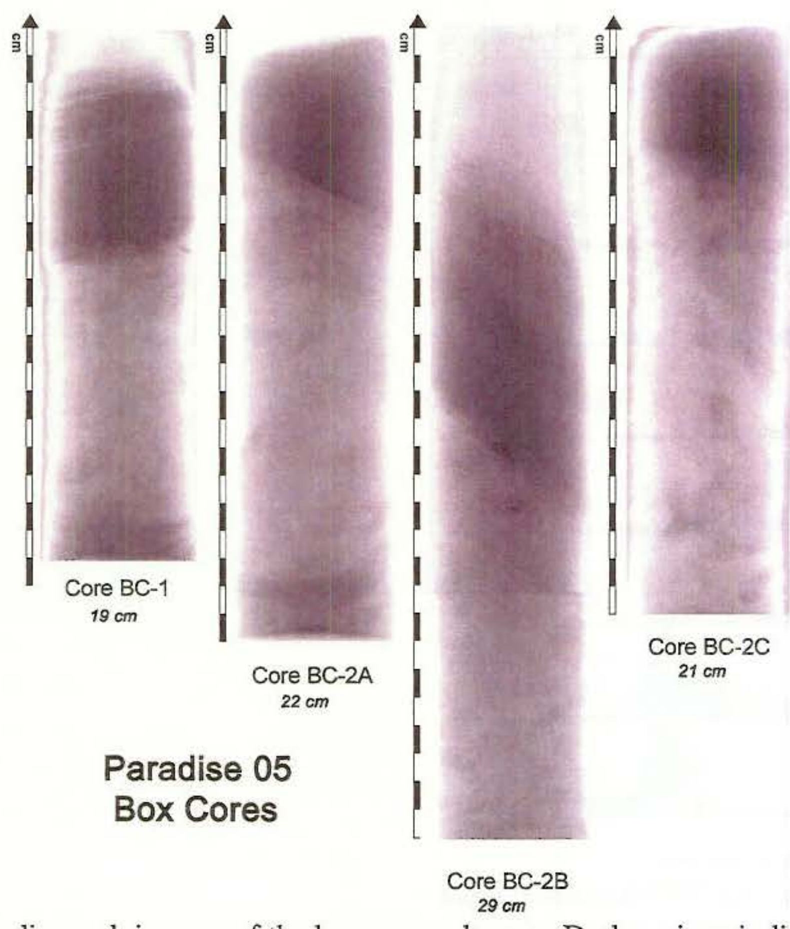


Figure 4.2.1. X-radiograph images of the box core subcores. Dark regions indicate high density materials (i.e., coarse grained sediments), and light regions indicate low density materials (i.e., water and soft mud).

4.3. Gamma Ray and Acoustic Impedance Logs

The gamma ray and acoustic impedance logs (Figure 4.3.1) both show the same trend observed for the gravity cores: a surface high-energy layer overlying a subsurface low-energy sediment.

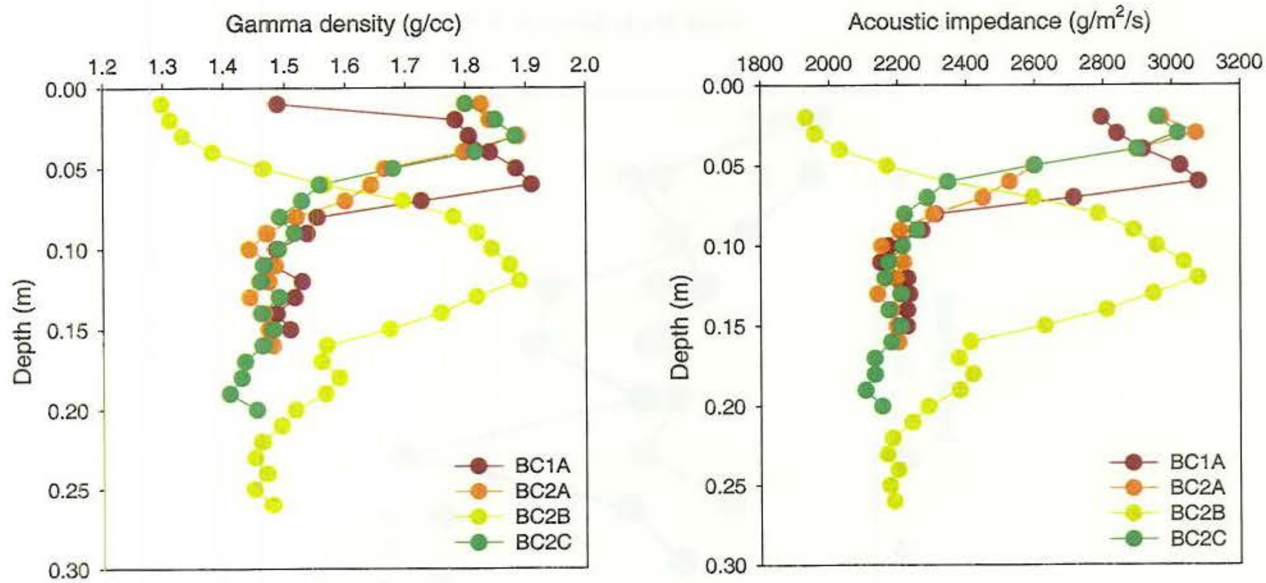


Figure 4.3.1. Gamma density and acoustic impedance for the box core subsamples

4.4. P-wave velocity and attenuation ("Earmuffs")

The p-wave velocity and attenuation were determined using the earmuff system (Figure 4.4.1). The top 6 – 20 cm is significantly more coarse-grained than the layers below.

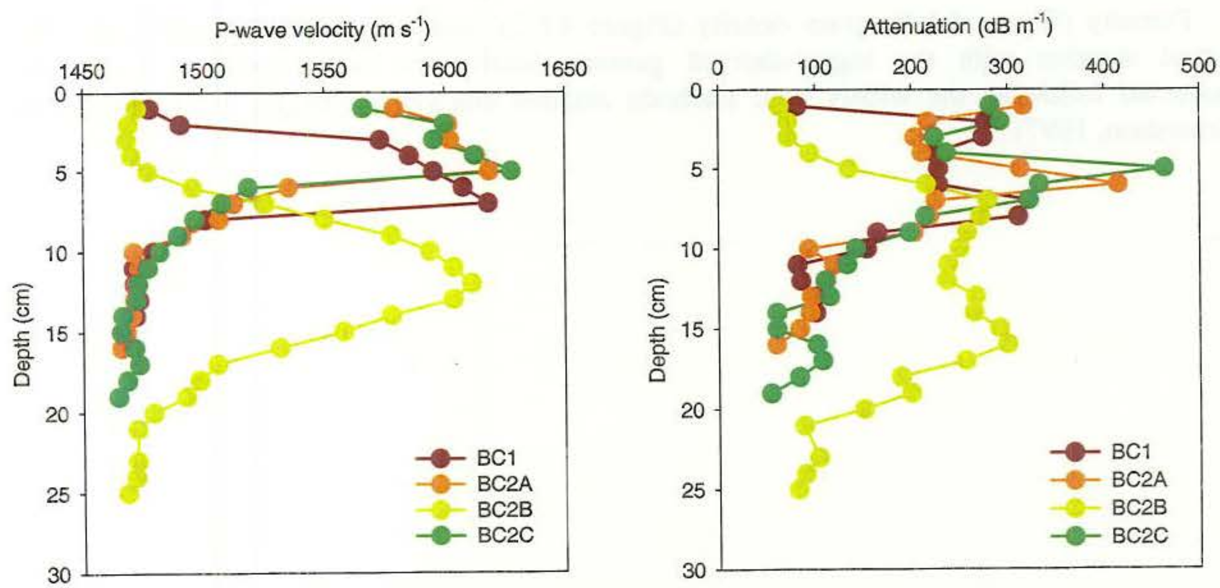


Figure 4.4.1. P-wave velocity and attenuation for the box core subsamples

4.5. Undrained Vane Shear Strength

Undrained vane shear strength was measured on extruded box core subcores. The vane shear blade was inserted with vane axis perpendicular to the sediment horizontal plane in situ. Vane shear strength values range from < 1 kPa to ~7 kPa (Figure 4.4.1).

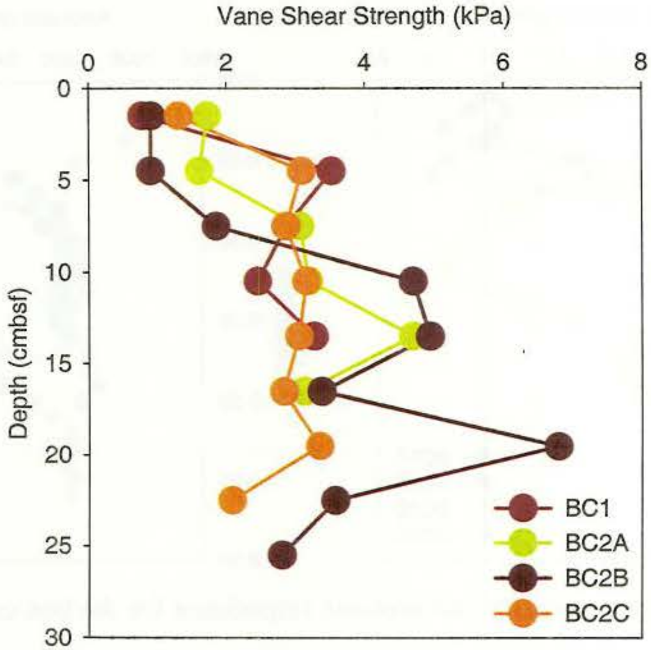


Figure 4.5.1. Undrained vane shear strength analyzed using extruded intact sections of the box core subcores.

4.6. Porosity, Grain Density, and Wet Bulk Density

Porosity (Figure 4.6.1), grain density (Figure 4.6.2), and wet bulk density (Figure 4.6.3, plotted together with the logger-derived gamma density for comparison) analyses were conducted following the widely used methods detailed elsewhere (Briggs, 1994; Briggs and Richardson, 1997).

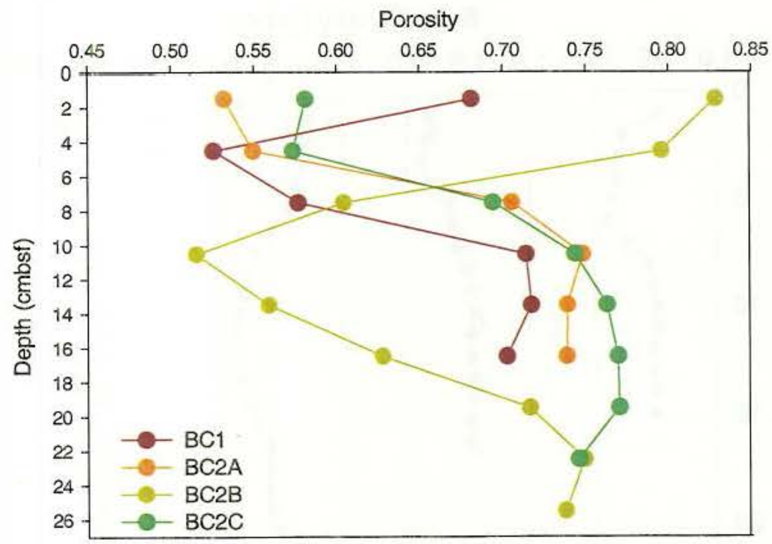


Figure 4.6.1. Porosity as determined by the weight difference of sediment aliquots before and after drying. Salt correction was made.

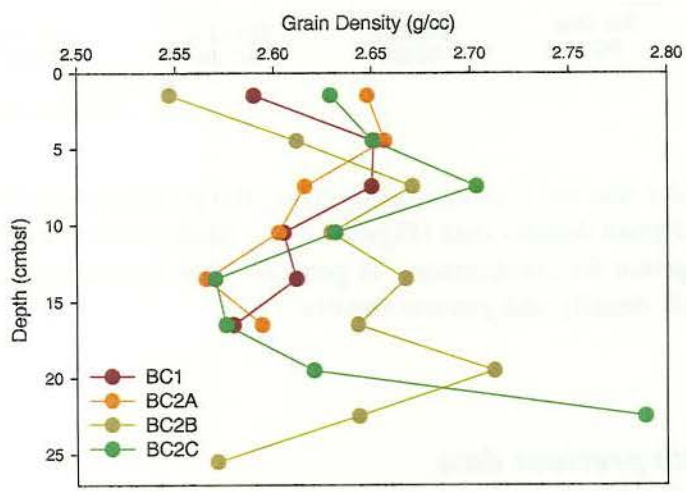


Figure 4.6.2. Grain density as determined by Quantachrome Pentapycnometer after sample aliquots were dried at 105°C.

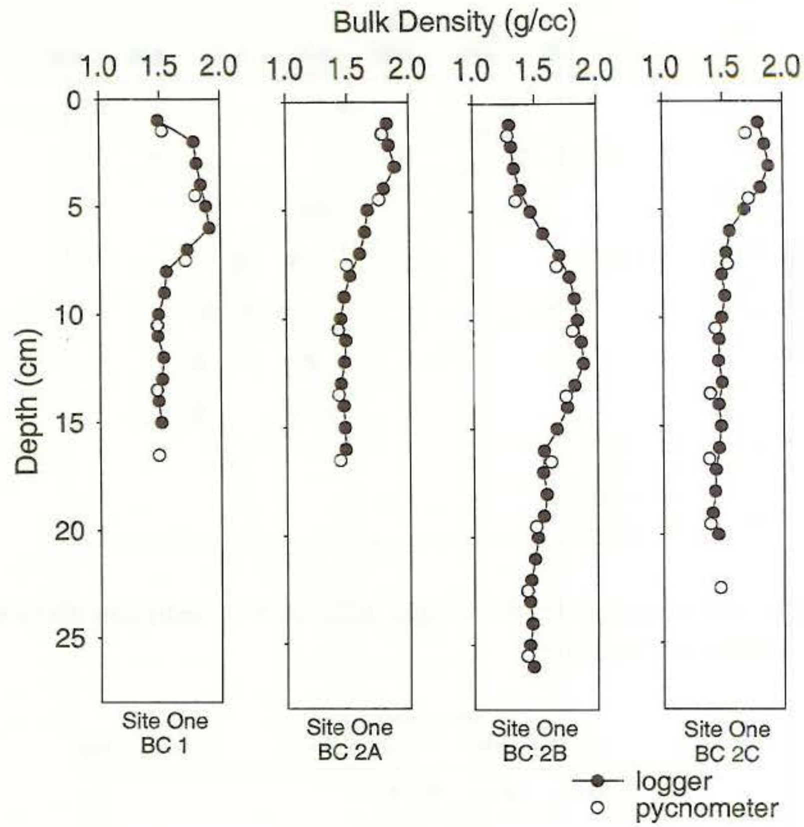


Figure 4.6.3. Bulk density was back-calculated by using the porosity data (Figure 4.5.1) and pycnometer-determined grain density data (Figure4.5.2). Bulk density determined by the gamma ray logger is plotted together for comparison. In general, there is an agreement between pycnometer-derived bulk density and gamma density.

5.0 Discussion

5.1. Comparison with previous data

The study area has been previously investigated by NRL as a part of the NAVOCEANO-funded Northern Gulf of Mexico Littoral Initiative (NGLI) program (Sawyer et al., 2001). The NGLI cores presented here were taken in May 1999. Core logger data and grain size data are available for comparison.

5.1.1. Sample locations

Figure 5.1.1 shows the locations of NGLI cores and cores from this study. NGLI's 599C6 and Site #4 from this study are the same location.

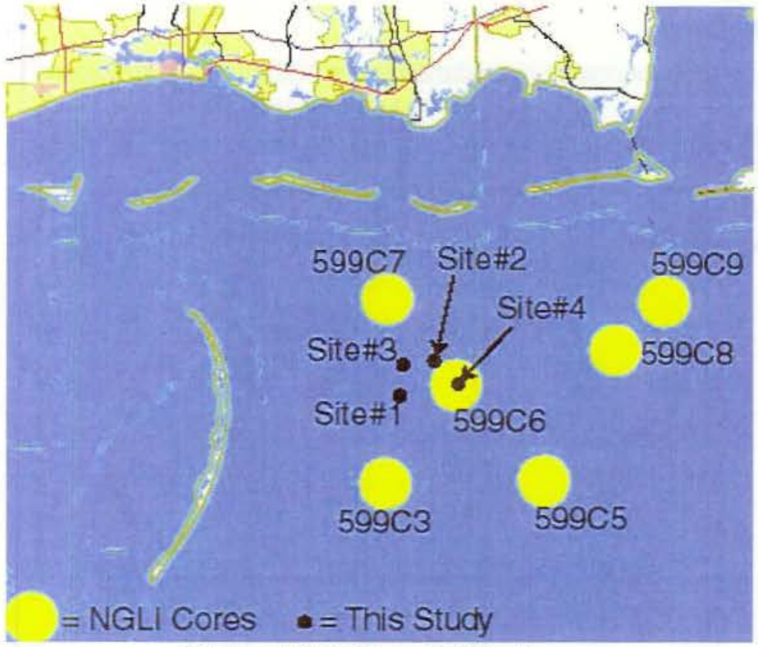


Figure 5.1.1. Sample locations

5.1.2. Gamma density

Figure 5.1.2 shows the gamma density from NGLI cores and cores from this study. The high density materials found in the upper ~ 20 cm of the post-Katrina sample from Site #4 was not present in the pre-Katrina sample taken at the same location (i.e., 599C6).

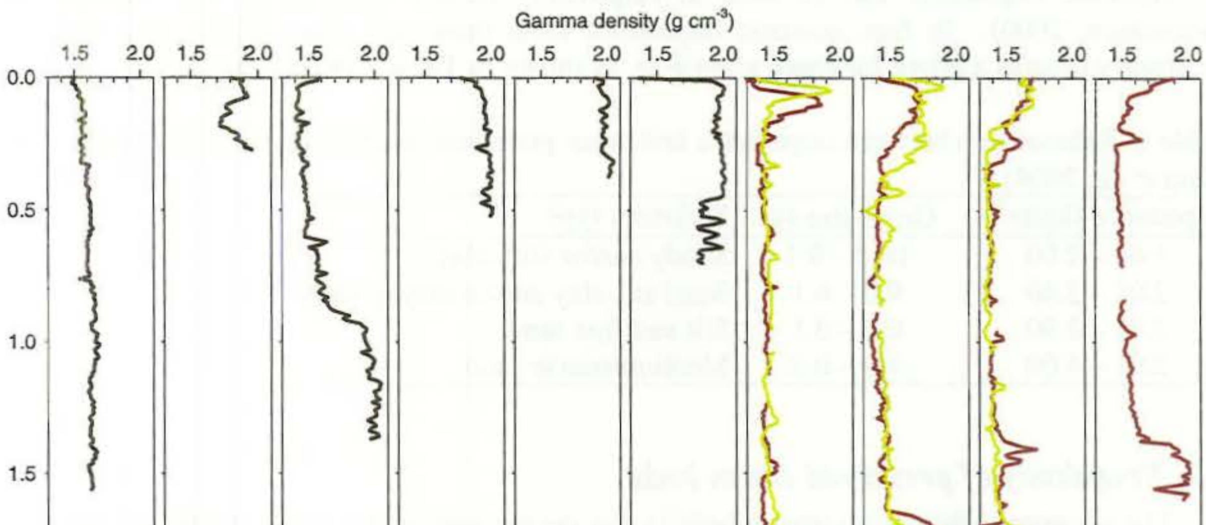


Figure 5.1.2. Gamma density of NGLI cores and gravity cores from this study are shown together for comparison. Note the lack of thick coarse-grained bed immediately below the WSI for NGLI cores which were taken before Hurricane Katrina.

5.1.3. Acoustic impedance

Figure 5.1.3 shows the acoustic impedance from NGLI cores and cores from this study.

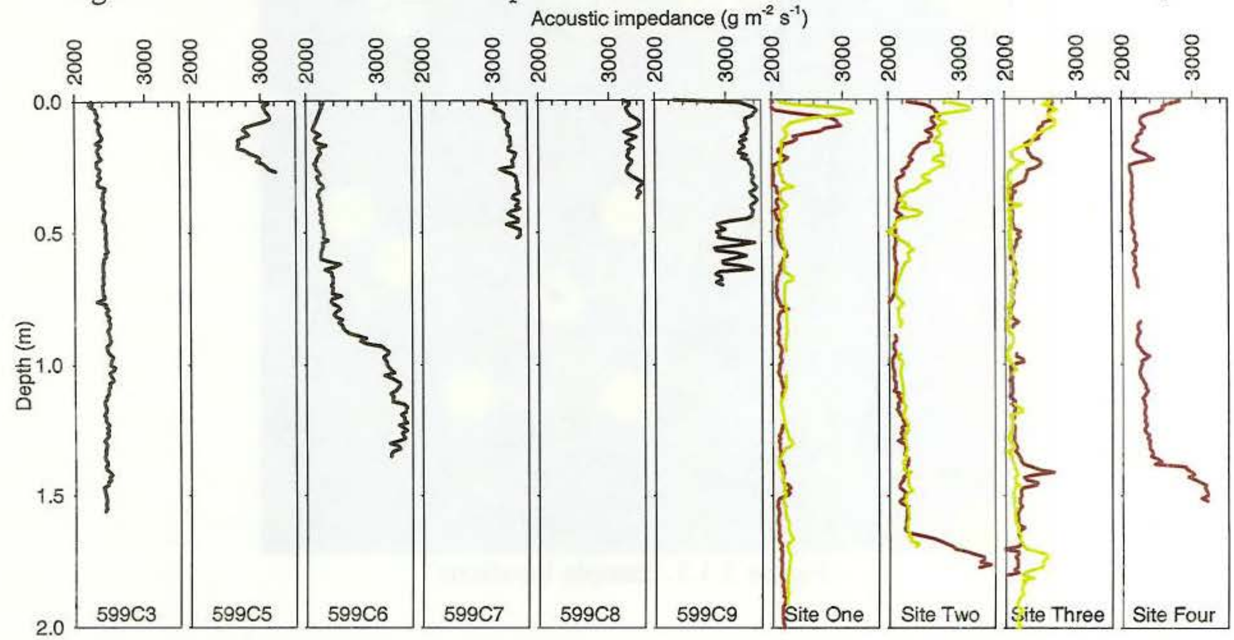


Figure 5.1.3. Acoustic impedance of NGLI cores and gravity cores from this study are shown together for comparison. Note the lack of thick coarse-grained bed immediately below the WSI for NGLI cores which were taken before Hurricane Katrina.

Acoustic impedance can be used to empirically predict mean grain size (Jackson and Richardson, 2006). In fact, acoustic impedance from these and other NGLI cores has been previously used as a proxy for mean grain size, as shown in Table 1 (Kim et al., 2004).

Table 1. Relationship between impedance and mean grain size determined from five NGLI cores (Kim et al., 2004).

Impedance (kg/m^2/s)	Grain size (ϕ)	Sediment type
1.60 – 2.00	10.0 – 9.1	Sandy and/or silty clay
2.01 – 2.40	9.0 – 6.1	Sand-silt-clay and/or clayey sand
2.41 – 2.90	6.0 – 3.1	Silt and fine sand
2.91 – 4.00	3.0 – 0.2	Medium/coarse sand

5.2. Frequency of preserved storm beds

The occasional thin sandy/shelly beds in the deeper part of the cores can be interpreted as ancient storm beds. This should be distinguished from the presence of massive sandy/shelly beds toward the bottoms of 599C6, Site Two, and Site Four which indicate the transition from previous high energy depositional environments to recent low energy depositional environments at these sites.

The study site is potentially an ideal site to investigate the frequency of severe tropical storms as the significant thickness of fine-grained sediments are deposited under low-energy conditions between each storm event. (It would be difficult to distinguish storm beds in cores from sandy, high-energy sedimentary environments such as 599C5, 599C7, and 599C9.) Whereas bioturbation usually obscures or completely erases signatures from less severe storms, it cannot do so if the storm is strong enough to erode and re-deposit a significant amount of sediment so that the initial thickness of the storm bed immediately following the re-deposition becomes thicker than the depth of bioturbation (i.e., > 13 cm). The depth of bioturbation is 10 – 12 cm in most cases (Boudreau, 1998).

In order to determine the temporal frequency of storm beds, the estimate of sedimentation rate at the study site is required. The maximum rate of sediment accumulation over the past 40 years in the inner shelf of the Mississippi Shelf at the water depth of 10 m is estimated to be 0.29 – 0.47 cm/year, and in the middle shelf at the water depth of 34 m is estimated to be 0.11 cm/year (Keen et al., 2004).

The occurrences of thin, isolated sandy/shelly horizons are identified using the logger impedance data, combined with visual and textual observations, as summarized in Table 2. Storm beds that are suspected to have originated from the same storm are color coded in the same color. The storm beds from core pairs from Site Two and Site Three could not be matched because the patterns of shelly/sandy bed occurrences were not corresponding at these sites.

Table 2. Vertical locations of sandy/shelly beds

	Site One		Site Two		Site Three		Site Four
599C6	GC1	GC2	GC3	GC4	GC5	GC6	GC7
62 cmbsf	22 cmbsf 59 cmbsf 76 cmbsf 149 cmbsf	33 cmbsf 40 cmbsf 68 cmbsf 130 cmbsf 166 cmbsf	44 cmbsf	43 cmbsf 60 cmbsf 77 cmbsf	52 cmbsf 84 cmbsf 99 cmbsf 146 cmbsf	40 cmbsf 66 cmbsf 92 cmbsf 102 cmbsf 118 cmbsf 132 cmbsf 146 cmbsf 176 cmbsf	23 cmbsf 97 cmbsf 110 cmbsf

A recent numerical modeling study has estimated that the deposition of storm beds thicker than 13 cm was limited to the immediate vicinity of the pass between Ship and Horn Islands following the unnamed hurricane of 1947. However, the same study estimated that, after Hurricane Camille in 1996, the storm bed thicker than 13 cm was widespread well into the middle Mississippi Shelf (Keen et al., 2004). If we use the middle-shelf estimate of 0.11 cm/year for the sedimentation rate, we can estimate the age of each preserved storm bed (i.e., a storm bed that was initially > 13 cm) for each core (Table 3). Storm beds that are suspected to have originated from the same storm are color coded in the same color. Note that it is incorrect to assume that a storm bed preserved in one location can be found in another location nearby because resuspension, erosion, deposition, and post-storm modification by physical and biological processes are laterally variable. Consequently, these preserved storm beds cannot be linked laterally in a fence diagram. In addition, because of the error in sedimentation rate estimate, a set of beds suspected to be originated by the same storm could yield significantly different age estimates (i.e., 536 years versus 364 years). Nevertheless, these estimates indicate that the study area has experienced a significant storm (i.e., initial storm bed thickness > 13 cm) every 200 - 600 years.

Table 3. Estimated ages of preserved storm beds

	Site One		Site Two		Site Three		Site Four
599C6	GC1	GC2	GC3	GC4	GC5	GC6	GC7
563 yrs	200 yrs 536 yrs 690 yrs 1354 yrs	300 yrs 364 yrs 618 yrs 1182 yrs 1509 yrs	400 yrs	391 yrs 545 yrs 700 yrs	473 yrs 764 yrs 900 yrs 1327 yrs	364 yrs 600 yrs 836 yrs 927 yrs 1072 yrs 291 yrs 1327 yrs 1600 yrs	209 yrs 882 yrs 1000 yrs

6.0. Summary

Physical and geotechnical properties of the upper two meters of the sediments at several locations in the Mississippi Bight display results of a significant sediment remobilization by the Hurricane Katrina that passed through the study area in August 29, 2006. The top 10 ~ 50 cm of the sediments exhibits characteristics of storm deposits, that include thinly alternating laminations of coarse-grained and fine-grained layers, fining-upward sequence, and bimodal grain size distribution.

In addition, the sediment cores analyzed for this study contain records of historic catastrophic storms in the Mississippi Bight area. Using the core records, it can be estimated that a severe storm, capable of depositing a storm bed with an adequate preservation potential (i.e., those with the initial thickness of > 13 cm), has passed through the study area every 200 – 600 years.

Acknowledgment

This work was funded by the NRL 6.2 Core program. The authors thank LCDR Clay Green, USNR, Bill Sanders, Edward Braithwaite, and the captain and crew of the R/V Pelican for field assistance.

7.0 References:

Bentley S. J., Keen T. R., Blain C. A., and Vaughan W. C. (2002) The origin and preservation of a major hurricane event bed in the northern Gulf of Mexico: Hurricane Camille, 1969. *Marine Geology* **186**(3-4), 423-446.

Boudreau B. P. (1998) Mean mixed depth of sediments: The wherefore and the why. *Limnology and Oceanography* **43**(3), 524-526.

Briggs K. B. (1994) High-frequency acoustic scattering from sediment interface roughness and volume inhomogeneities. Ph.D. dissertation, University of Miami.

Briggs K. B. and Richardson M. D. (1997) Small-scale fluctuations in acoustic and physical properties in surficial carbonate sediments and their relationship to bioturbation. *Geo-Marine Letters* **17**(4), 306-315.

Duke W. L., Arnott R. W. C., and Cheel R. J. (1991) Shelf Sandstones and Hummocky Cross-Stratification - New Insights on a Stormy Debate. *Geology* **19**(6), 625-628.

Folk R. L. (1968) *Petrology of Sedimentary Rocks*. University of Texas Publication.

Jackson D. and Richardson M. D. (2006) *(Jackson & Richardson Book)*.

Keen T. R., Bentley S. J., Vaughan W. C., and Blain C. A. (2004) The generation and preservation of multiple hurricane beds in the northern Gulf of Mexico. *Marine Geology* **210**(1-4), 79-105.

Keen T. R. and Slingerland R. L. (1993) 4 Storm-Event Beds and the Tropical Cyclones That Produced Them - a Numerical Hindcast. *Journal of Sedimentary Petrology* **63**(2), 218-232.

Kim G. Y., Richardson M. D., Bibee D. L., Kim D. C., Wilkens R. H., Shin S. R., and Song S. T. (2004) Sediment types determination using acoustic techniques in the Northeastern Gulf of Mexico. *Geosciences Journal* **8**(1), 95-103.

Kindinger J. L., Flocks J. G., and Ferina N. F. (2004) Late Pleistocene-Holocene geologic history and framework of the Mississippi-Alabama coasts and shelf, northern Gulf of Mexico. *Geological Society of America, 2004 annual meeting Abstracts with Programs - Geological Society of America* **36**(5), 302.

Liu K. B. and Fearn M. L. (1993) Lake-Sediment Record of Late Holocene Hurricane Activities from Coastal Alabama. *Geology* **21**(9), 793-796.

Liu K. B. and Fearn M. L. (2002) Lake sediment evidence of coastal geologic evolution and hurricane history from Western Lake, Florida: Reply to Otvos. *Quaternary Research* **57**(3), 429-431.

Liu K. W. and Greyling E. H. (1996) Grain-size distribution and cementation of the Cretaceous Mzamba Formation of Eastern Cape, South Africa: A case study of a storm-influenced offshore sequence. *Sedimentary Geology* **107**(1-2), 83-97.

McKee B. A., Aller R. C., Allison M. A., Bianchi T. S., and Kineke G. C. (2004) Transport and transformation of dissolved and particulate materials on continental margins influenced by major rivers: benthic boundary layer and seabed processes. *Continental Shelf Research* **24**(7-8), 899-926.

Nittrouer C. A. and Wright L. D. (1994) Transport of Particles across Continental Shelves. *Reviews of Geophysics* **32**(1), 85-113.

Otvos E. G. (1999) Quaternary coastal history, basin geometry and assumed evidence for hurricane activity, northeastern Gulf of Mexico coastal plain. *Journal of Coastal Research* **15**(2), 438-443.

Otvos E. G. (2002) Discussion of "Prehistoric landfall frequencies of catastrophic hurricanes..." (Liu and Fearn, 2000). *Quaternary Research* **57**(3), 425-428.

Sawyer W. B., Vaughan W. C., Lavoie D., Furukawa Y., Carnaggio N., Maclean J., and Populis E. (2001) Northern Gulf Littoral Initiative (NGLI), Geology and physical properties of marine sediments in the N. E. Gulf of Mexico: Data report. Naval Research Laboratory.

Appendix I: Core locations

Site One:

GC1 @ 29 55.575 N 88 31.702 W
GC2 @ 29 55.551 N 88 31.674 W
BC1 @ 29 55.0 N 88 31.2 W (approximate)
BC2 @ 29 55.491 N 88 31.712 W

Site Two:

GC3 @ 29 58.475 N 88 28.193 W
GC4 @ 29 58.395 N 88 28.281 W

Site Three:

GC5 @ 29 58.300 N 88 31.389 W
GC6 @ 29 58.037 N 88 31.404 W

Site Four (near NGLI 599-C6)

GC7 @ 29 56.427 N 88 25.921 W

Appendix II. Data that accompany this report

The data can be found at NRL's anonymous FTP site:
ftp://ftp.nrlssc.navy.mil/pub/yokof/Paradise05/