

IMPACTS OF TROPICAL SYSTEMS ON THE SEDIMENTARY FABRIC OF THE MISSISSIPPI SOUND

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ABSTRACT

A geologic investigation was conducted in Mississippi Sound to determine patterns of estuarine sedimentation during the late Holocene. Major sources of sediment include the Pearl River, Mobile River, and transgressive barrier island sands. This sediment is delivered and reworked by episodic tropical systems and winter storms. Below fair-weather wave base, major storm events are recorded as sandy event layers in a muddy matrix.

Gravity and box cores were analyzed using radioisotope geochronology (²¹⁰Pb, ⁷Be, and ¹³⁷Cs), x-radiography, granulometry, and a multi-sensor core logger. Gravity core analysis reveals 5-8 event layers in ~3 m gravity cores. Our ²¹⁰Pb/¹³⁷Cs observations indicate accumulation rates of 0.3-0.5 cm y⁻¹. Wave data collected from Tropical Storm Isidore and Hurricane Lili indicate intense reworking of sediment on the shelf and moderate reworking of sediment in the Sound. Higher near-bottom orbital velocities were calculated for Tropical Storm Isidore than Hurricane Lili. Box cores collected after the storms contained a variable muddy event layer up to ~10 cm thick on the shelf and < 5 cm thick within the Sound. In contrast, event layers produced by major hurricanes (such as Camille, 1969), reach thicknesses exceeding 10 cm. Because of post depositional mixing, only event layers thicker than 5 cm in the Sound and ~10 cm on the shelf have significant preservation potential. Thus, data indicate that only major hurricanes create preservable event layers in the Mississippi Sound and represent 8-26% of the sediment column deposited in the last 600-1000 years.

INTRODUCTION

Mississippi Sound (Fig.1) is a bar-built estuary located in the Northern Gulf of Mexico along the Mississippi Gulf Coast. The Sound has an area of approximately 2100 km², bounded by Mobile Bay to the east and the St. Bernard lobe of the Mississippi Delta to the west. The northern boundary is defined by the Mississippi coast and southern boundary by a chain of barrier islands between 10-20

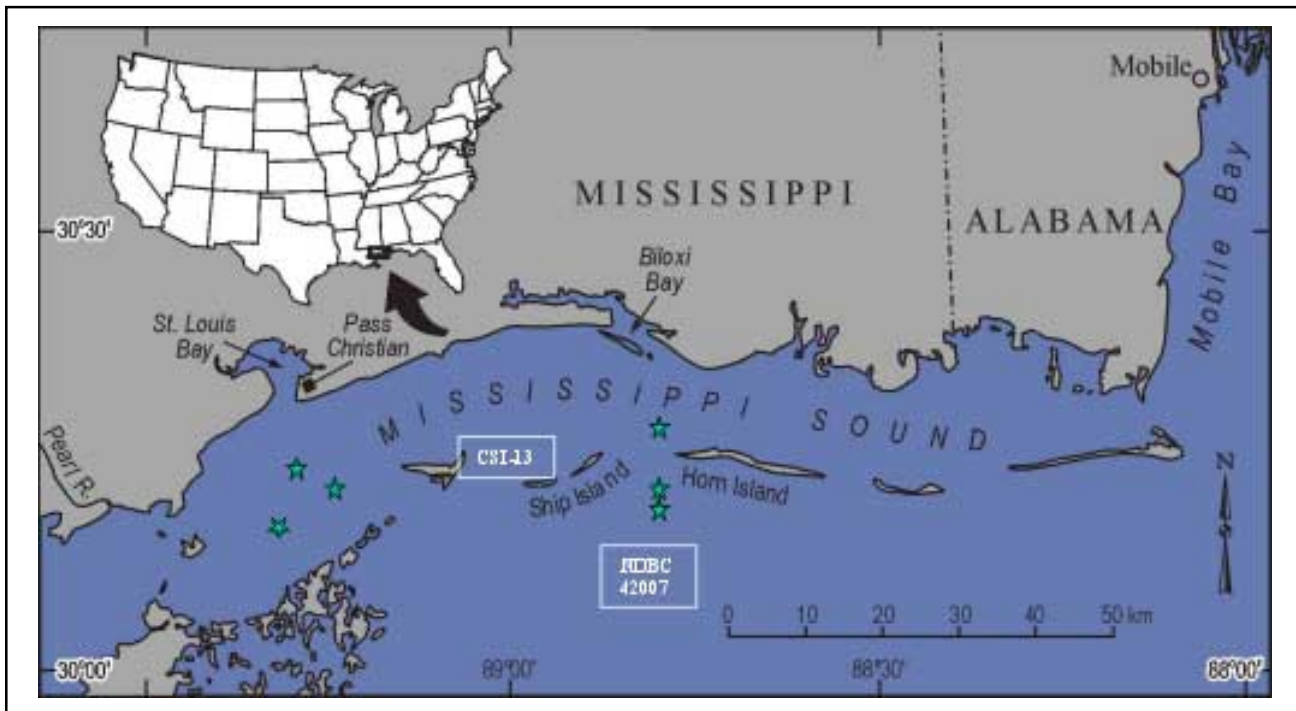


Figure 1. Map of the Mississippi Sound, core locations, CSI-13, and NDBC 42007.

km south of the mainland. Primary sources of sediment include the Mobile River, Pascagoula River, Pearl River, and transgressive barrier island sands.

The seabed of Mississippi Sound is predominantly sandy mud, but sandy regions occur near the passes and between the islands (Ludwick, 1964). Early estimates of sediment thickness indicate a Holocene isopach of 1-4 m, from which Ludwick (1964) estimated Holocene accumulation rates of $\sim 24 \text{ cm ky}^{-1}$. However, more recent data indicate a much more variable thickness, up to 10 m (G.Stone, J. Anderson, Pers. com to S. Bentley), implying the existence of a higher-resolution stratigraphic record.

The northern Gulf of Mexico is impacted by episodic tropical systems. These systems vary in strength and duration. Evidence of these storms is recorded in the sedimentary fabric as sandy event layers in a muddy matrix (e.g., tempestites of Aigner and Reineck, 1982). Such event layers are then subject to degradation by post-depositional physical and biological mixing, after which only the basal portions of the thickest layers remain recognizable as discrete storm beds. We know that major hurricanes produce event layers that are preservable (Bentley et. al., 2002). What is not known is 1) the minimum strength of the system required to create a preservable event layer, and 2) how often the Northern Gulf of Mexico is impacted by such events. To address these two questions, we investigated the sedimentary record to determine the return frequency of storms capable of creating preservable event layers. We will also study the deposits created by Tropical Storm Isidore and Hurricane Lili and predict the likelihood that these deposits will be preserved in the sediment record. Tropical Storm Isidore was a very broad storm that impacted most of the Northern Gulf of Mexico. Before Isidore made landfall on the Louisiana and Mississippi coasts, it struck Cuba as a category-two hurricane and then struck the Yucatan Peninsula as a category-three hurricane. Weakened, Isidore turned north and traveled over the Gulf of Mexico until it made landfall just west of Grand Isle as a 55-knot tropical storm on September 26, 2002. There was extensive damage to portions of both the Louisiana and Mississippi Gulf Coasts (NOAA, 2003; Stone et. al., 2003).

Hurricane Lili was first recognized on September 21, 2003, as a tropical depression in the Atlantic Ocean. It moved through the Caribbean while fluctuating between tropical storm and tropical wave status. Lili impacted Cuba on October 1 as a category-two hurricane. It then turned north where it rapidly gained strength and became a powerful category-four hurricane with sustained

winds up to 145 mph. However, Lili then lost much of its strength and made landfall south of Intracoastal City, LA as a category-one hurricane (NOAA, 2003; Stone et. al., 2003).

METHODS

Gravity cores and box cores were collected in the western Mississippi Sound in June of 2001. Box cores were also collected along two transects on October 11, 2002, one week after Hurricane Lili impacted the western Louisiana coastline. The first transect was north of Horn Island within Mississippi Sound, the second transect was south of Horn Island (Figure 1).

Box Cores

Box cores were sub-sampled for radioisotopes and physical properties. A 10-cm internal diameter PVC pipe was inserted into the sediment and extruded in 2-cm intervals for grain size and radiochemistry analysis. Grain size analysis of wet sediment was conducted using a Micromeritics ET-5100 Sedigraph following standard procedures (Coakley and Syvitski, 1991).

X-radiography slabs were collected by inserting 3-sided Plexiglas trays into the sediment, then siding the fourth side into place in order to minimize sediment disturbance. The trays are sealed with neoprene plugs to prevent slumping and desiccation before they were brought back to the laboratory where they were x-rayed in the days following the cruise using a portable veterinary X-ray unit. X-rays were then digitized for analysis of sedimentary structures.

Gravity Cores

Gravity cores were analyzed using a GEOTEK Multi-Sensing Core Logger (MSCL). Gamma density was measured with a narrow beam of gamma rays emitted from a 10 milli-curie ^{137}Cs source with energies principally at 661 KeV. An ultrasonic P-wave system measured P-Wave speed at 500 kHz. Magnetic susceptibility was measured through a Bartington Magnetic Loop Sensor. Electrical resistivity was measured through a Non-Contacting Resistivity (NCR) sensor developed by GEOTEK. Cores were then split for x-radiography and sub-sampled in 2 cm intervals for grain size, porosity, and radiochemistry.

Radiochemistry

Activities of ^{210}Pb (natural product of U-series decay, $t_{1/2} = 22$ years), ^{137}Cs (product of nuclear fission in nuclear reactors and bombs, $t_{1/2} = 30.7$ years), and ^7Be (a cosmogenic radionuclide, $t_{1/2} = 53.3$ days) were determined through gamma spectroscopy analysis of dried sediment (46.5 KeV peak for ^{210}Pb and 661 KeV peak for ^{137}Cs and 477.7 KeV peak for ^7Be). The sediment was weighed before and after drying to determine porosity. A known mass of ground sediment was placed in a 6 cm petri dish and sealed. The sealed samples were analyzed on a Canberra gamma detector for ^7Be , ^{210}Pb , and ^{137}Cs . ^7Be and ^{210}Pb were used to determine the accumulation rates by assuming that accumulation is the dominant process controlling the radioisotope distributions, using the equation:

$$S = \lambda z / \ln (A_z / A_0) \quad (1)$$

where, S (cm/yr) = accumulation rate, λ (1/t) is the decay constant ($0.693 / t_{1/2}$), z is the depth in the seabed (cm), A_0 is the excess activity at the surface (dpm/g) and A_z is the excess activity at depth z (dpm/g). Supported ^{210}Pb activity was also measured through decay counting of ^{210}Po , assuming secular equilibrium between ^{210}Pb and its granddaughter ^{210}Po . ^{210}Po decays by alpha emission to ^{206}Pb ; this emission was detected using a Canberra Alpha Analyst detector (Noller, 2000). ^{137}Cs was first released by the atmospheric testing of nuclear bombs in 1954. It is used as a time marker in the sediment and can also be used to estimate accumulation rate. Minimum detectable activities for ^7Be and ^{137}Cs are 0.05 dpm/g for a 24-h count of a 15-g sample.

Real-time Wave Data

Data from WAVCIS station CSI-13 and the National Data Buoy Centers NDBC 42007 (Fig.1) were collected during the dates that Tropical Isidore and Hurricane Lili impacted the Northern Gulf of Mexico. CSI-13 is located in the Mississippi Sound at 89° 00'46"N, 30° 15'967"W in ~7 m of water. NDBC 42007 is located 40 km South-Southeast of Biloxi, MS at 30°05'24"N 88°46'12"W in ~13.5 m of water. Data collected from these two stations included: water level, significant wave height H_s , and wave period T_s . Peak bottom wave orbital velocities u_b were computed using linear wave theory.

RESULTS

X-radiographs

The x-radiographs of box cores from western Mississippi Sound (BC1 and BC3, Fig.2) show regions of highly bioturbated muds and muddy sands as well as regions of stratified mud and sand. Gravity core x-radiographs (GC10) display surficial high porosity muds overlying stratified mud and sand, interbedded with bioturbated intervals of sandy mud.

X-ray radiographs from the second cruise (Est-1, Shelf-2, and Shelf-3, Fig.3) are variable and record unique sedimentary features. Est-1 reveals two distinct zones separated by an undulating contact at ~5 cm. Above this feature, a fining-upward sequence is recorded. Below the contact is bioturbated muddy-sand. Shelf-2 sedimentary fabric is bioturbated silty-mud with shell fragments. Shelf-3 is characterized by a mud layer ~10 cm thick, interbedded by two zones of coarse high-density material, overlying bioturbated muddy-sand.

Multi-Sensor Core Logger

Gravity core profiles of wet bulk density are characterized by a series of density maxima separated by regions of low density (1.5–1.65 gm/cc). KJ0601 GC10 (Fig.4) has five prominent spikes with densities at or above 1.7 gm/cc. There are three spikes that have maximum peaks at approximately 1.65 gm/cc. High bulk density values are attributed to an increase in sand/shell content, confirmed by granulometric analysis.

Radiochemistry

^{210}Pb profiles from the western Mississippi Sound are shown for BC3 and GC10 (Fig. 5). The upper portions (5-10 cm) of each graph display relatively constant activity. Below this interval, the profiles display a depth-dependent gradient. The constant activity in the top 5-10 cm is attributed to bioturbation and physical sediment mixing. Below this zone, the gradient is interpreted to be controlled by radioactive decay and sediment burial (Eq.1). The estimated sediment accumulation rates, (Eq.1) for BC3 is 0.29 cm yr⁻¹, while the sediment accumulation rate for GC 10 is much higher, 0.82 cm yr⁻¹. ^{137}Cs penetrates to a depth of 25 cm in GC10. Assuming a bioturbation depth of ~10 cm (Nittrouer et al, 1984; Bentley and Nittrouer, 1999), this ^{137}Cs penetration translates to an accumulation rate of 0.31 cm yr⁻¹, significantly lower than the ^{210}Pb rate, which integrates sedimentation rates over ~100 yr, or five half-lives of ^{210}Pb . ^{137}Cs penetrated to the base of both box cores; therefore, no accumulation rate can be calculated.

^{210}Pb and ^7Be profiles were also plotted for Est-3 and Shelf-1,2 (Fig.6). The upper ~5 cm of Est-3 displays a zone of constant ^{210}Pb activity. Below this zone, the profile can be attributed to sediment accumulation and radioactive decay. The ^7Be profile displays activity in the upper 6-8 cm, below which ^7Be is non-detectable. The ^{210}Pb profile for Shelf-2 displays an unusual increase in activity with depth. There was also no ^7Be detected at this site. Shelf-3 displays two different trends in the profile. The top 8-10 cm displays constant ^{210}Pb activity. Below this zone the profile displays exponential decay associated with sediment accumulation and radioactive decay. ^7Be penetrates the core to a depth of ~7-10 cm.

Real-time Wave Data

Within the Mississippi Sound, CSI-13 recorded a maximum significant wave height (H_s) detected for Tropical Storm Isidore of ~ 1.7 m, the maximum wave period (T_s) of ~ 6.4 s, and the maximum water level recorded of ~ 8 m. During Hurricane Lili, H_s was ~ 1.2 m, T_s was ~ 4.5 s, and the maximum water level recorded was ~ 7.7 m. NDBC 42007 recorded H_s for Tropical Storm Isidore and Hurricane Lili to be 4.9 m and 3.8 m respectively. Peak wave period for the two storms was 13 s for both storms. Water level was not recorded by NDBC 42007. Orbital velocities within Mississippi Sound reached a maximum of 0.5 m/s during Tropical Storm Isidore and 0.3 m/s during Hurricane Lili. Peak orbital velocities on the shelf were 1 m/s for both Tropical Storm Isidore and Hurricane Lili.

DISCUSSION

Bulk density data collected on the MSCL for GC 10 reveals eight peaks that exceeded ~ 1.6 g cm⁻³ (Fig. 2). An increase in bulk density is attributed to an increase in sand content in the sediment. Therefore, these peaks are possible sandy basal portions of event layers recorded in the sedimentary fabric. Using both the historic accumulation rates calculated by Ludwick ($.024$ cm yr⁻¹) and the accumulation rates from BC1, BC3, and GC10 (~ 0.3 cm yr⁻¹) possible ages range from 12,000 years old to 1,000 years old. Since much of the Sound did not begin infilling until $\sim 6,000$ years ago (6-8 at 1 mm/yr), this represents a maximum age, not 12,000 years. Assuming that at least 6 of the peaks observed in the MSCL data are in fact event layers, this yields a return frequency of one recordable storm event every ~ 150 -1000 years. Thus, using the bulk density profile, we estimate that at least 8-26% of the sediment column was deposited by recordable storm events in Mississippi Sound.

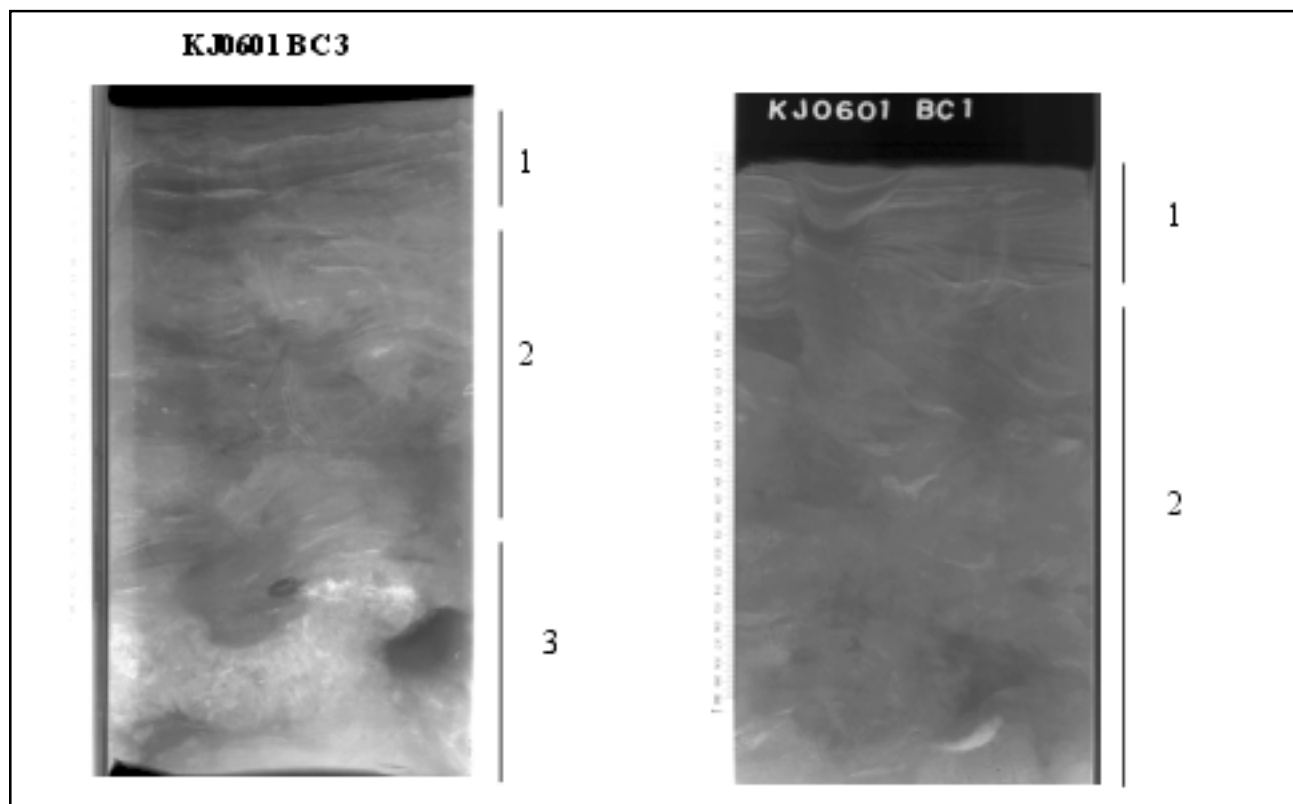


Figure 2. X-radiographs of KJ0601 BC 1 and BC 3. Bright zones correlate to sediment with high bulk density and dark zones are low bulk density. BC 3 displays three zones. 1) Stratified mud and sand 2) bioturbated sandy/mud 3) bioturbated muddy/sand. BC 1 displays two zones. 1) Stratified mud/sand and 2) bioturbated muddy/sand.

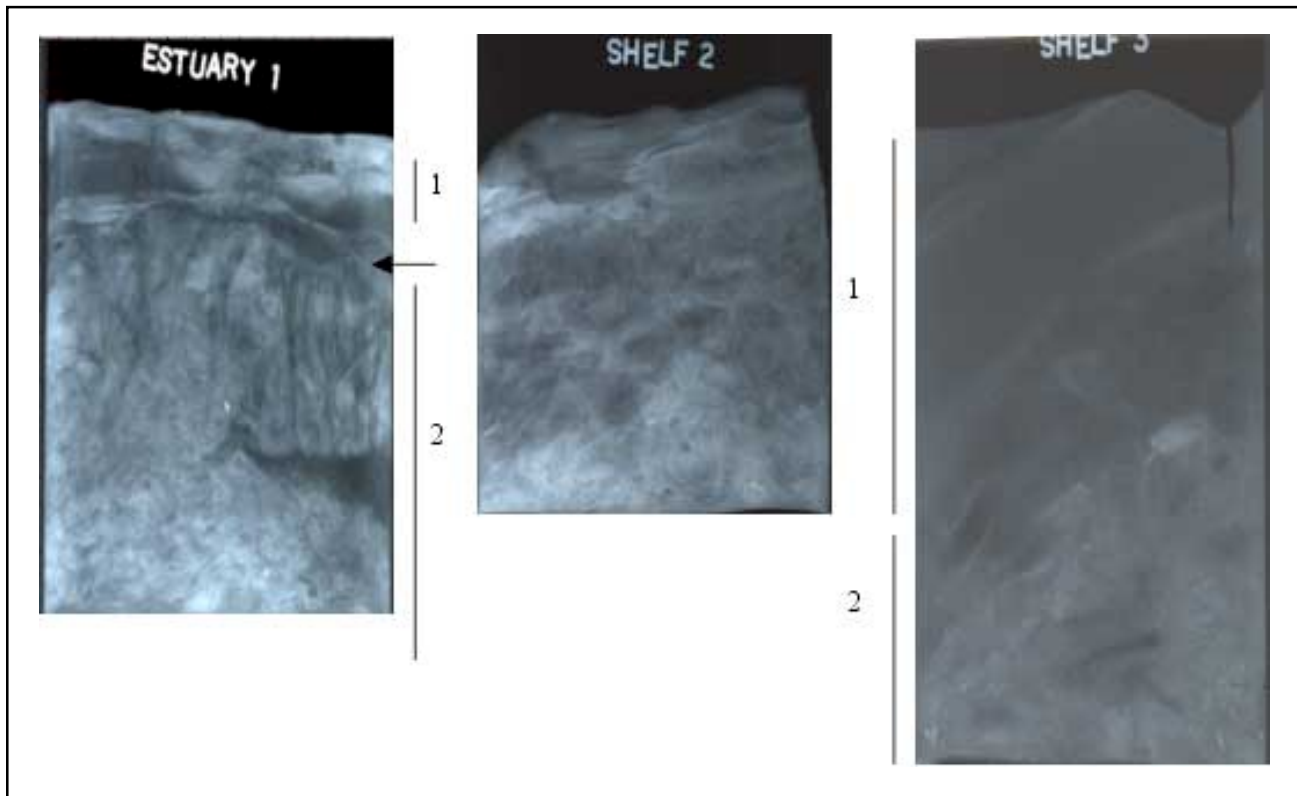


Figure 3. X-radiographs of Est-1, Shelf-2, and Shelf-3. Est-1 displays 2 zones separated by an erosional feature. 1) fining-upward sequence 2) bioturbated muddy-sand. Shelf-2 has an undulating surface. The fabric is bioturbated silty-mud. Shelf-3 has two distinct zones. 1) fine-grained mud layer with two zones of higher density coarse material 2) bioturbated muddy-sand.

Smaller storm events and typical estuarine processes deposited the other 74 – 92% of the sediment column. However, this raises the question: what defines a recordable storm event?

Wave data indicate that Tropical Storm Isidore created a more intense environment for sediment resuspension than Hurricane Lili. Orbital velocities were also much higher south of the barrier islands on the inner shelf than within Mississippi Sound.

Radioisotope and x-radiography data indicate the formation of a variable event layer ~ 1-4 cm thick within Mississippi Sound. South of the barrier islands there is very little deposition on the inner shelf; however, further offshore data indicate deposition of a 10 cm thick event layer. This indicates that the shelf experienced intense erosion nearshore and rapid deposition further offshore. Thus, Tropical Storm Isidore had a greater impact on the region than Hurricane Lili. This impact was greater south of the barrier islands on the inner shelf. However, the event layers left behind are not sufficient to survive the typical estuarine and biological conditions that are active today.

CONCLUSION

The Mississippi Sound is regularly impacted by tropical systems that vary in intensity, size, and duration. These storms can impact the sedimentary fabric in such a way that they are recorded as sandy event beds in a muddy matrix. The preservation potential of a storm layer is determined by three factors: 1) the initial thickness of the depositional layer, 2) the intensity and depth of subsequent physical and biological reworking, and 3) the burial rate of the layer. Only a powerful category -4 or 5 hurricane has the energy to produce preservable event layers. The recurrence interval for such events appears to be 150-1000 years.

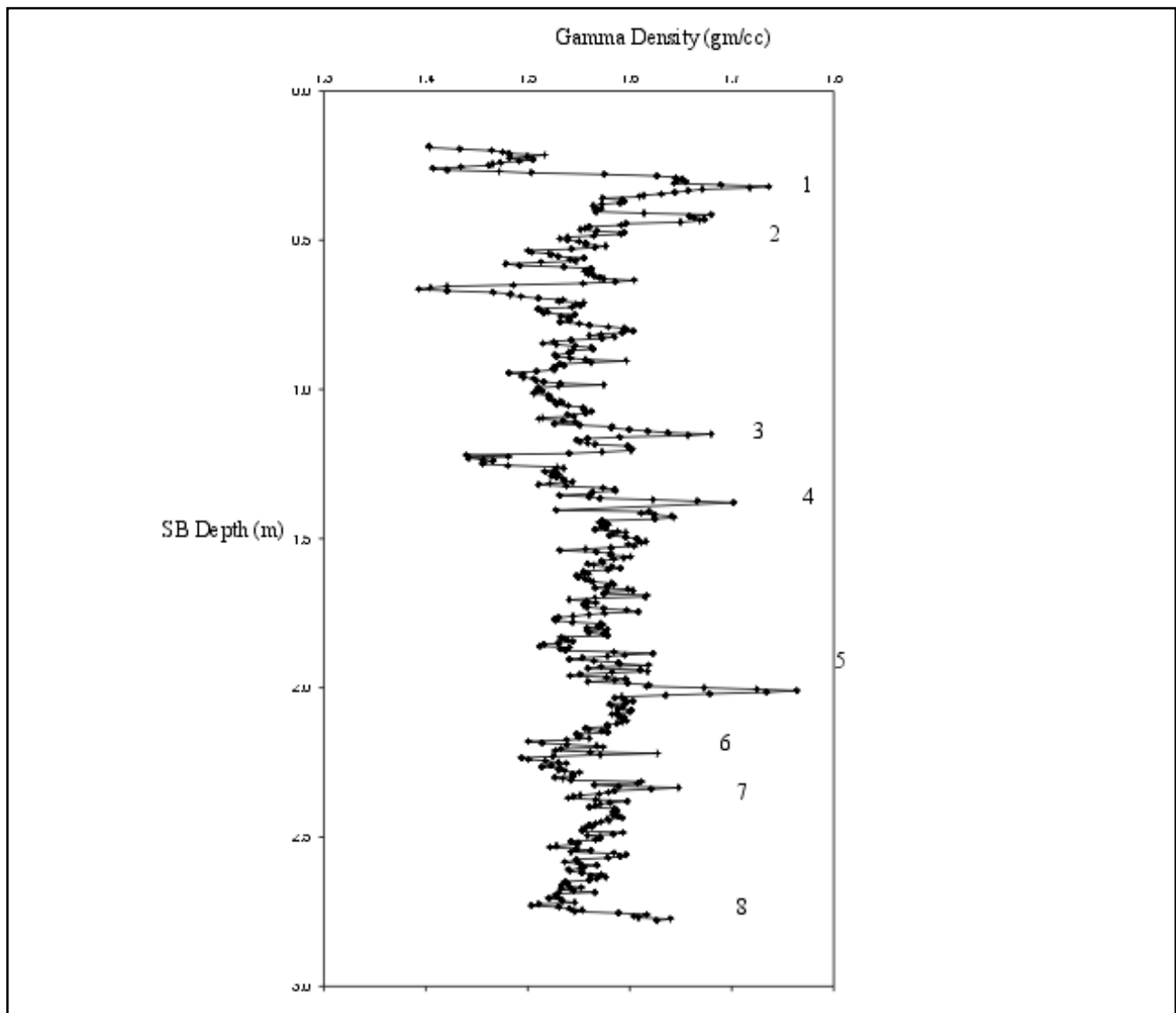


Figure 4. Profile of wet-bulk density in KJ0601 GC10, measured by MSCL. Peaks 1, 2, 3, 4, and 5 indicate maximum peaks approximately at or above 1.7 gm/cc. Peaks 6, 7, and 8 indicate maximum peaks at appx. 1.65 gm/cc. High bulk densities are attributed to an increase in the sand/silt content.

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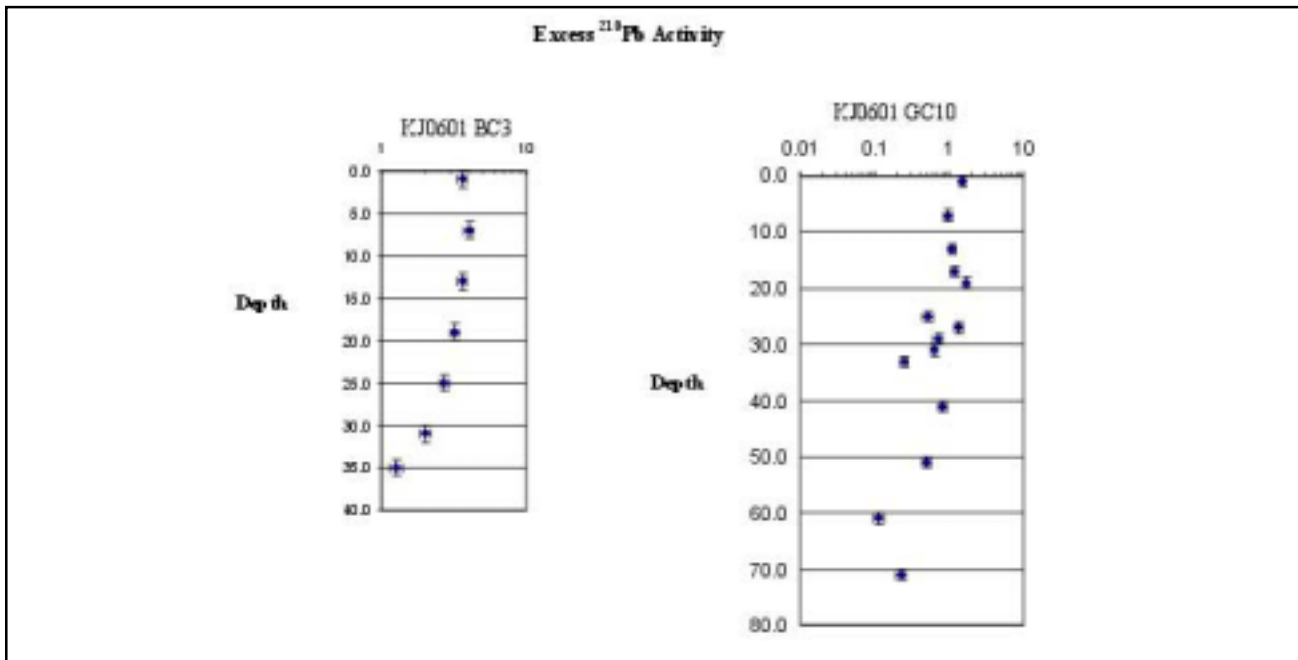


Figure 5. Excess ²¹⁰Pb profiles of KJ0601 BC 3 and KJ0601 GC10.

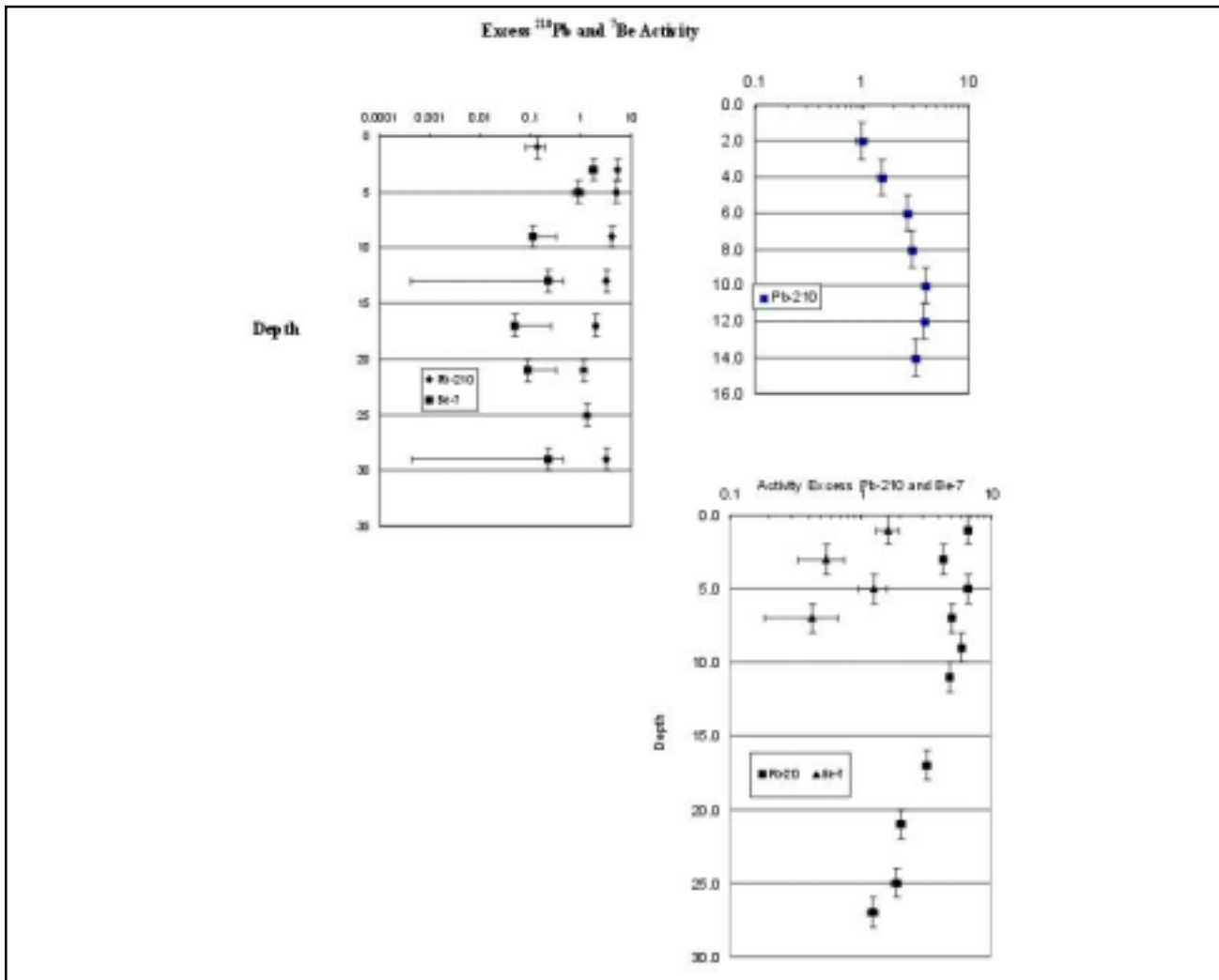


Figure 6. Profiles of the activity of excess ²¹⁰Pb and ⁷Be for Est-1, Shelf-2, and Shelf-3 on and 1n scale. ⁷Be was not detectable in Shelf-2.

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